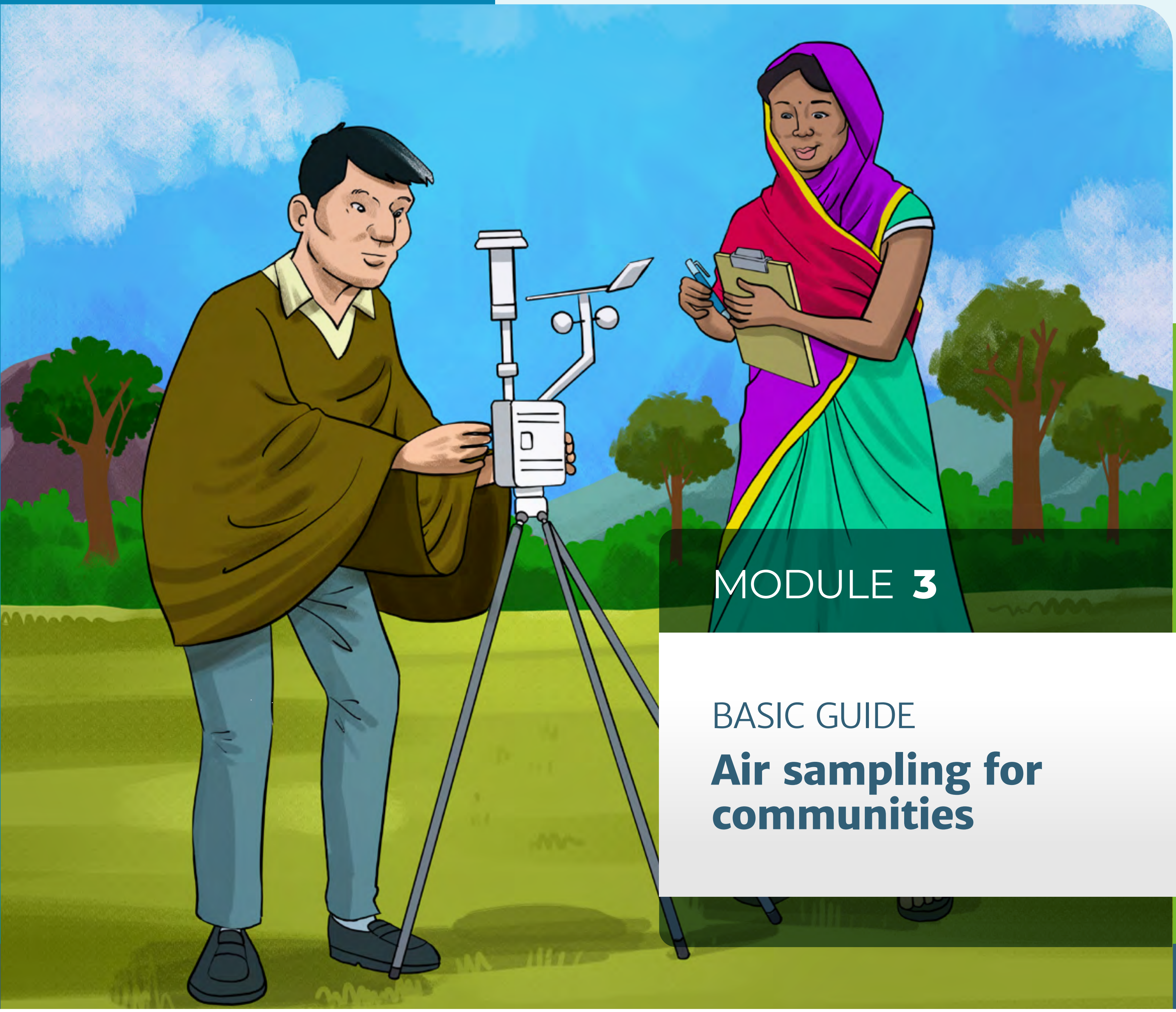
GUIDE

ENVIRONMENTAL
SAMPLING
GUIDE

MODULE 3



MODULE 3

BASIC GUIDE

Air sampling for communities

ELAW
Environmental Law Alliance Worldwide

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Acknowledgements

This Guide is part of the ***Guide to Environmental Sampling for Communities (ELAW),*** which is composed of four modules:

- **Module 1**. Introduction: How to Organize Community Environmental Sampling
- **Module 2.** Water Sampling – Basic Guide for Communities
- **Module 3.** Air Sampling – A Basic Guide for Communities
- **Module 4.** Soil Sampling – A Basic Guide for Communities

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The Environmental Law Alliance Worldwide (ELAW) supports environmental and public interest advocates in their efforts to defend the right to a healthy environment. ELAW supports environmental advocates and the communities they represent with legal and scientific information to protect the air, water, soil, and ecosystems in their countries .

Additional information on ELAW and the other three modules of the **Basic Guide to Environmental Sampling for Communities** are available free of charge on the ELAW website: www.elaw.org.

GUIDE TO TAKING ENVIRONMENTAL SAMPLES

MODULE 3

BASIC GUIDE

Air sampling for communities

Content

1. Basic concepts:

1.1. AIR POLLUTION AND HUMAN HEALTH

Indoor and outdoor air pollution are some of the world's major causes of death and disease. Chemical, physical, and/or biological agents can dramatically reduce the air quality. Smog over cities, dust, smoke inside the home, particulate matter, and pollutants from industrial sources pose a major threat to people, wildlife, and the environment globally. Air pollution increases the risk for cardiovascular diseases, stroke, chronic lung diseases, cancer, asthma, and pneumonia. In 2016, the World Health Organization (WHO) estimated that approximately 7 million people die prematurely globally due to air pollution (4.2 million outdoor and 3.8 million due to indoor air pollution). Nine out of ten of these premature deaths are in low- and medium-income countries[1]. The elderly, children, and people with pre-existing health conditions are more sensitive to the effects of air pollution. Therefore, clean air is critical to the health and well-being of both people and ecosystems.

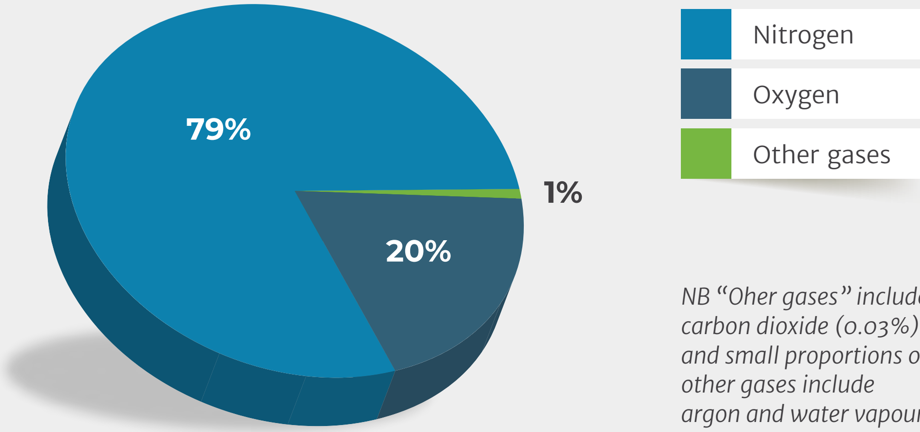
Dirty air, like dirty water, can affect many people across a large area at the same time. It is important that communities be aware of, and protect, the quality of the air they breathe. Dirty air has been a concern for centuries, but specific toxic effects of polluted air were not clearly identified until the middle of the twentieth century, when several major air contamination events occurred. The heavy toxic "smog" that blanketed the small town of Donora, Pennsylvania, USA for four days in October 1948 caused respiratory problems for about half the town's residents and killed 20 people. Four years later, a similar smog episode in London, England killed 4,000 people, injuring hundreds of thousands more. After these episodes, interest grew in identifying, and mitigating, the specific air pollutants involved.

1.2. ATMOSPHERIC BASICS

Composition of Air

Air is a mixture of approximately 79 percent nitrogen, 20 percent oxygen, and 1 percent other gases such as hydrogen, carbon dioxide, neon, and others in small amounts.

1. https://www.who.int/health-topics/air-pollution#tab=tab_1



NB "Oher gases" includes carbon dioxide (0.03%) and small proportions of other gases include argon and water vapour.

1.3. SOURCES OF AIR POLLUTION

There are very many diverse sources of air pollution, and they have different impacts on indoor versus outdoor air. Here we give some examples:

Outdoor Sources

- ***Mobile fossil fuel sources:*** Buses, trains, trucks, cars, airplanes, and other motorized vehicles. In addition to pollutants resulting from fossil fuel combustion, these also contribute fine airborne particles from tire wear, brake wear, etc.
- ***Stationary fossil fuel and industrial sources:*** Coal-, gas-, or diesel-fired power plants producing electricity and/or heat are a major source. Industrial facilities also contribute pollution from fossil fuel burning, as well as other air pollutants resulting from manufacturing.
- ***Area sources:*** Forest fires, agricultural areas, cities, stacks from wood burning fireplaces, etc.
- ***Natural sources:*** Forest fires, volcanoes, wind-blown dust and sand, etc.

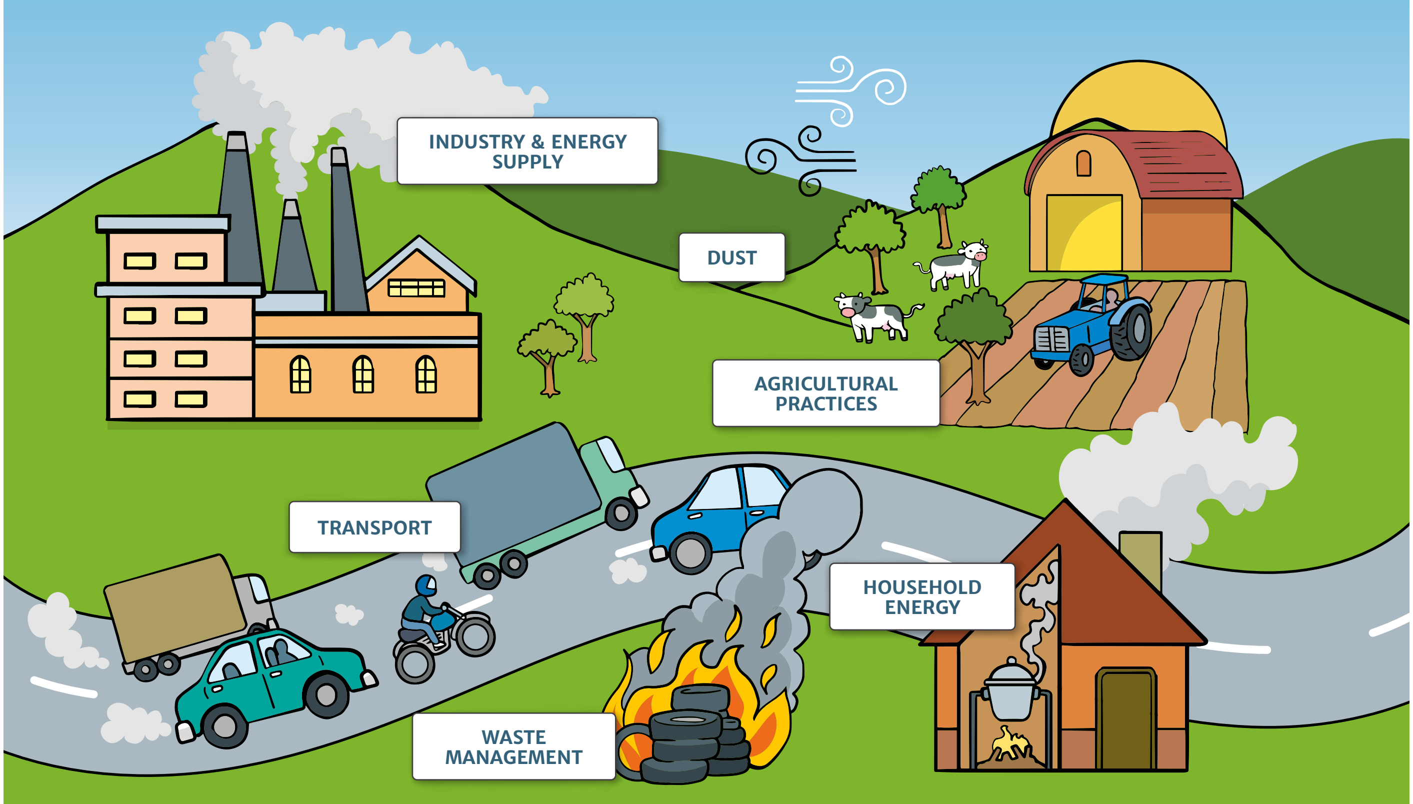
Indoor Sources

- A cook stove burning wood, other "biomass", or fossil fuels can produce extremely high levels of indoor air pollution. Any other heating unit also produces air pollution.

- Tobacco smoke.
- Mold and mold spores.
- Pet hair and dander.
- Radon, a carcinogenic radioactive gas, is released from rocks in some areas, and can infiltrate into the home, especially when ventilation is inadequate.
- Paints, stains, glues, carpets, and many other common materials emit small amounts of volatile organic compounds into the indoor air. Some buildings contain asbestos or formaldehyde.
- Many consumer products emit small amounts of various chemicals into the air, including electronics, cleaning products, fragrances, etc.
- Mold releases large quantities of tiny mold spores into the air.
- ... in addition to the above, indoor air pollution contains most or all of the outdoor air pollutants, when they enter the building.

WHAT ARE THE SOURCES OF AIR POLLUTION?

Outdoor air pollution affects urban and rural areas and is caused by multiple factors:



Countries cannot tackle air pollution alone.
It is a global challenge we must all combat together.

2. Types of Air Pollution

It is important to recognize that air pollution can be composed of many different types, each of which has specific health and environmental effects. It is critically important, when analyzing air pollution, that we are looking at the right types of pollutants. We review the major air pollutants here.

- The term **"smog"** (derived from "smoke" and "fog") was widely used in the 20th century to refer to visible air pollution. A related name, "photochemical smog", helps us identify one of the major air pollutants: **Ozone**, or **O_3**, which results when certain other air pollutants are struck by sunlight. Ozone remains one of the most important and most dangerous air pollutants. Ozone causes many respiratory problems, including asthma.

  Ozone near the surface, which can be inhaled and is quite hazardous, should not be confused with ozone high up in the stratosphere. Stratospheric ozone is the result of natural processes and helps protect life on the surface from intense ionizing radiation from the sun. You may find it helpful to distinguish between the two types of ozone with the mnemonic, "good up high, bad nearby."

- When fossil fuels are burned, the nitrogen present is transformed into various acidic nitrogen oxides, especially **nitrogen dioxide (NO_2).** Sometimes oxides of nitrogen are referred to collectively as **"NOx."** NOx molecules cause important health problems but are also an important precursor of ozone formation. Similarly, sulfur liberated from fossil fuels results in various acidic sulfur oxides, especially **sulfur dioxide (SO_2)**, which are sometimes collectively called **"SOx."** Both NOx and SOx have serious impacts on health. In addition, when rains wash NOx and SOx out of the air onto land and waters, the resulting "acid rain" can be devastating for forests and trees. Acid rain caused widespread destruction of forests in the USA and Canada through the 20th century, until the NOx and SOx emissions were brought under control.

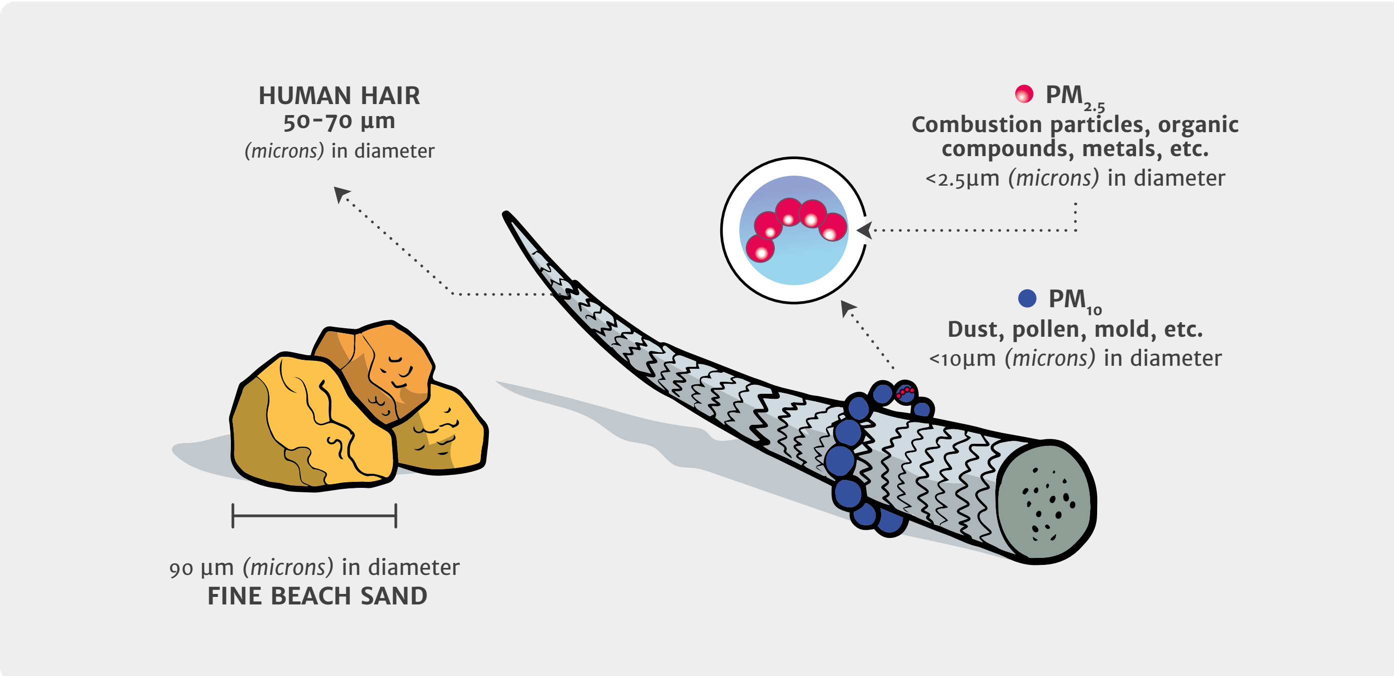
- Another important byproduct of burning fossil fuels is **carbon monoxide (CO)**, which forms when there is not enough oxygen to completely burn a fuel. CO should not be confused with CO2, which is the most common result of any fossil fuel burning, and which is largely responsible for global warming. When inhaled, CO prevents oxygen from traveling through the blood, and can result in death.

- The smoke that results from burning is composed of many small particles that together make up **particulate matter (PM)** air pollution. PM is usually separated into different categories by size: total PM includes all particulates, while PM_{10} is made of coarse particles. $PM_{2.5}$, or fine particulate matter, is smaller still, and is more dangerous because its small size allows it to be breathed deep into the lungs. Research now is turning to "ultrafine" PM, or $PM_{0.1}$, which is so small that it can enter the bloodstream and is linked to several neurological and cardiovascular problems in addition to obvious respiratory concerns.

The pollutants described above, all of which result from fossil fuel burning, are the "criteria pollutants" on which most air quality monitoring is based. (The last of the "criteria pollutants" is **lead (Pb)**, which was formerly added to gasoline, and constituted a very serious neurological threat until it was finally removed in recent years.) These pollutants are extremely common, being found wherever burning takes place. Each has specific and important impacts on human health and the environment; many cities and other locations around the globe regularly monitor for the presence of the criteria pollutants.

In addition, almost any chemical that can evaporate can be found in air, and some of these can be very toxic. A small sample of these toxic air pollutants includes.

- Many factories emit chemicals used in production into the air, for example, solvents like **benzene** (a proven carcinogen, which also evaporates from gasoline). In 1984, the Union Carbide factory in Bhopal, India released a large cloud of **methyl isocyanate**, a chemical used in the manufacture of pesticides. By the next morning, an unknown thousands of people had died, and hundreds of thousands were injured.
- Products like glues and paints can emit **volatile organic chemicals (VOCs)** which directly contribute to ozone formation and can be toxic in themselves.
- Inefficient burning results in the emissions of a variety of **dioxins and furans**, many of which are potent carcinogens. Backyard burning of trash, especially plastics, is a major global source of dioxins and furans. These toxic chemicals almost never break down, and eventually make their way into the food chain, through which people around the world are exposed.
- Solvents like **trichlorethylene (TCE)** and **perchloroethylene (PCE)** can evaporate during use or disposal and are linked with cancer and neurological impairments. These solvents can contaminate both air and water.
- Finally, it is worth mentioning **carbon dioxide (CO2)**, which is responsible for most human-caused global warming. Despite its tremendous importance on the global scale, CO2 is not usually toxic to humans or animals, and there is rarely any reason to test for it. (Be careful not to confuse carbon dioxide, CO2, with carbon monoxide, CO, which is one of the "criteria" pollutants.)



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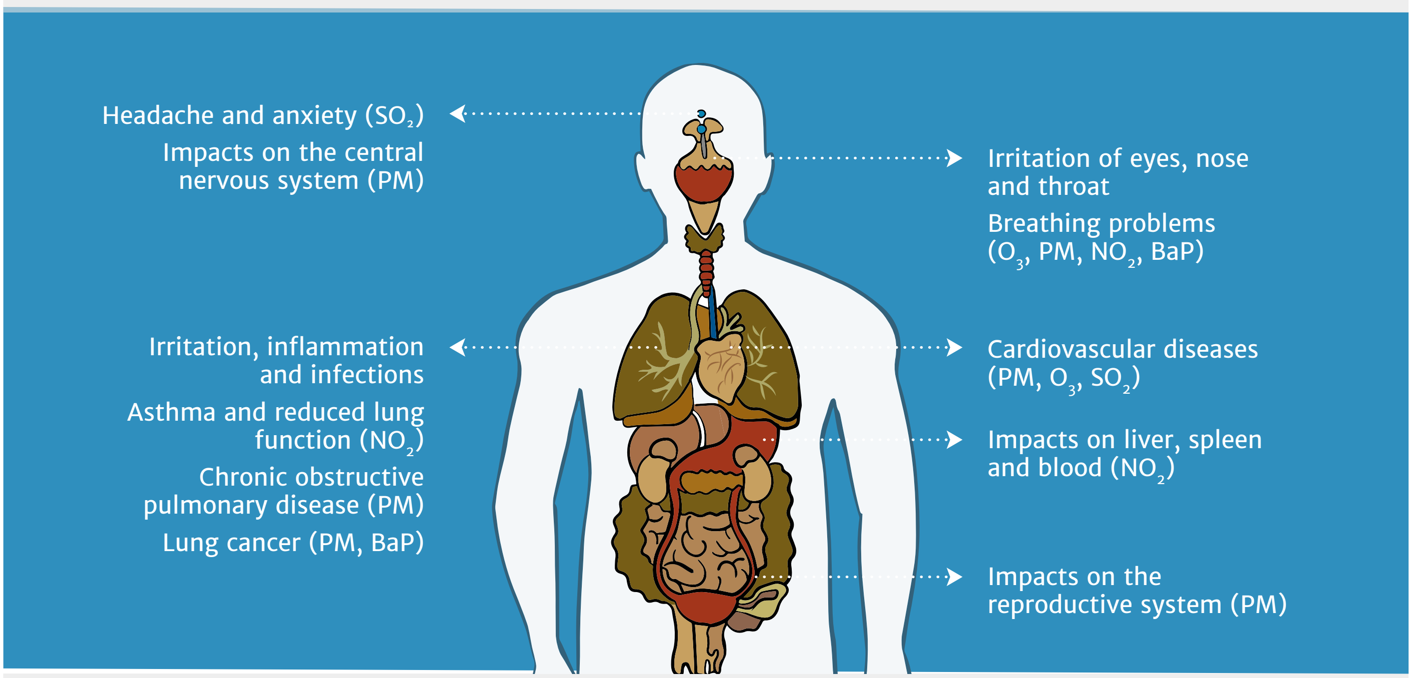
HEALTH IMPACTS OF AIR POLLUTION



Note: Particulate matter with a diameter of 2.5 µm or less ($PM_{2.5}$), particulate matter with a diameter of 10 µm or less (PM_{10}), ozone (O_3), nitrogen dioxide (NO_2), benzo [a]pyrene (BaP) and sulphur dioxide (SO_2).

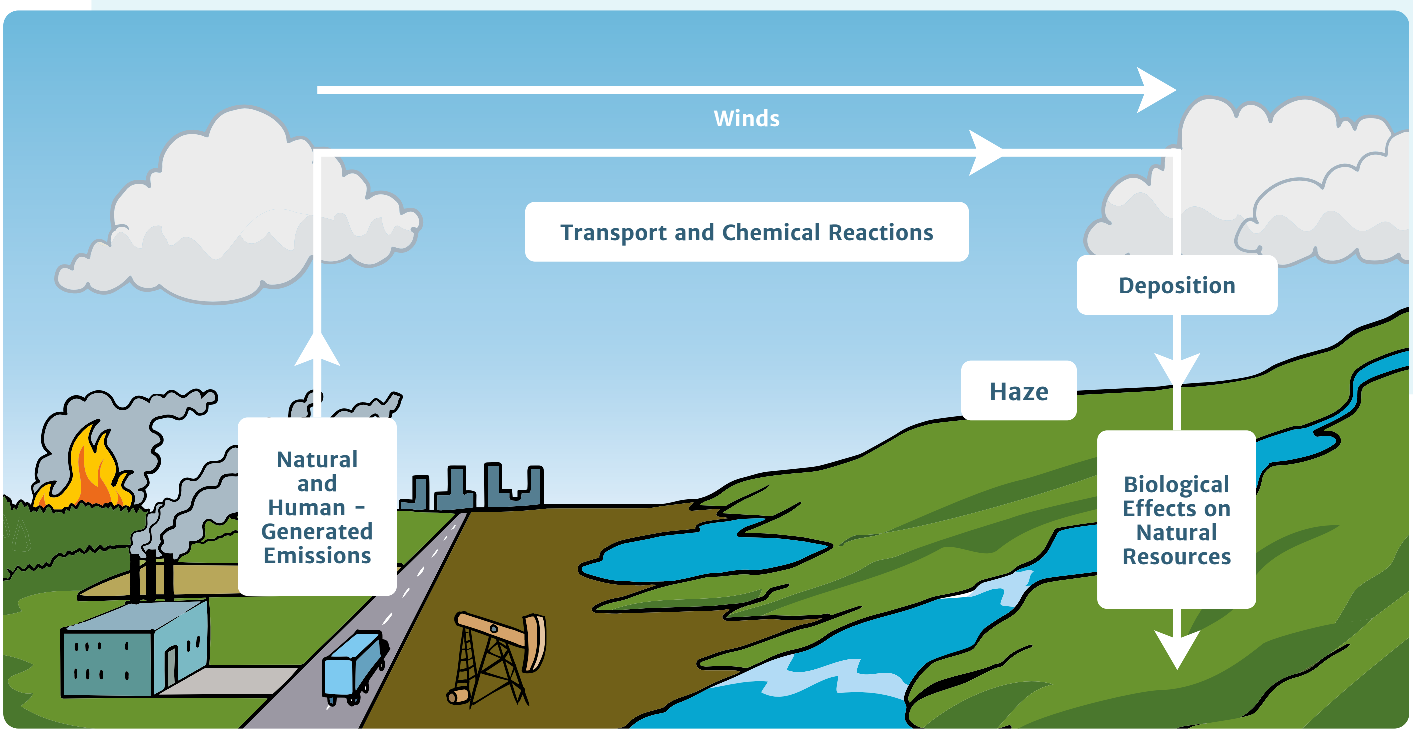
https://www.epa.gov/sites/default/files/2016-09/pm2.5_scale_graphic-color_2.jpg

3. Transport of Air Pollutants

3.1. LONG-RANGE TRANSPORT

Air pollution is often seen as a local or regional problem; but air masses can transport air pollutants for hundreds of kilometers, affecting the environment and public health over a large area. When pollutants are carried across state or national boundaries, regulation becomes much more difficult. (For example, much of the air pollution in the eastern part of the United States comes from power plant emissions in the Midwest, a thousand km to the west, that are carried east by prevailing winds. Pollutants from large-scale seasonal agricultural burning, industrial and/or urban air emissions, pesticides, organochlorine, and highly persistent and toxic substances such as polychlorinated biphenyls (PCBs) can also be transported very long distances, especially towards the poles. This can lead to large toxic exposures among Northern peoples (Inuit, Faroese, etc) as a result of pollution emitted in industrial regions around the world.

The importance of transboundary air pollution has prompted initiatives and treaties such as the 1979 Convention on Long-Range Transboundary Air Pollution (LRTAP) between Europe, North America, and Eurasia to address the atmospheric transport of hazardous air pollutants.



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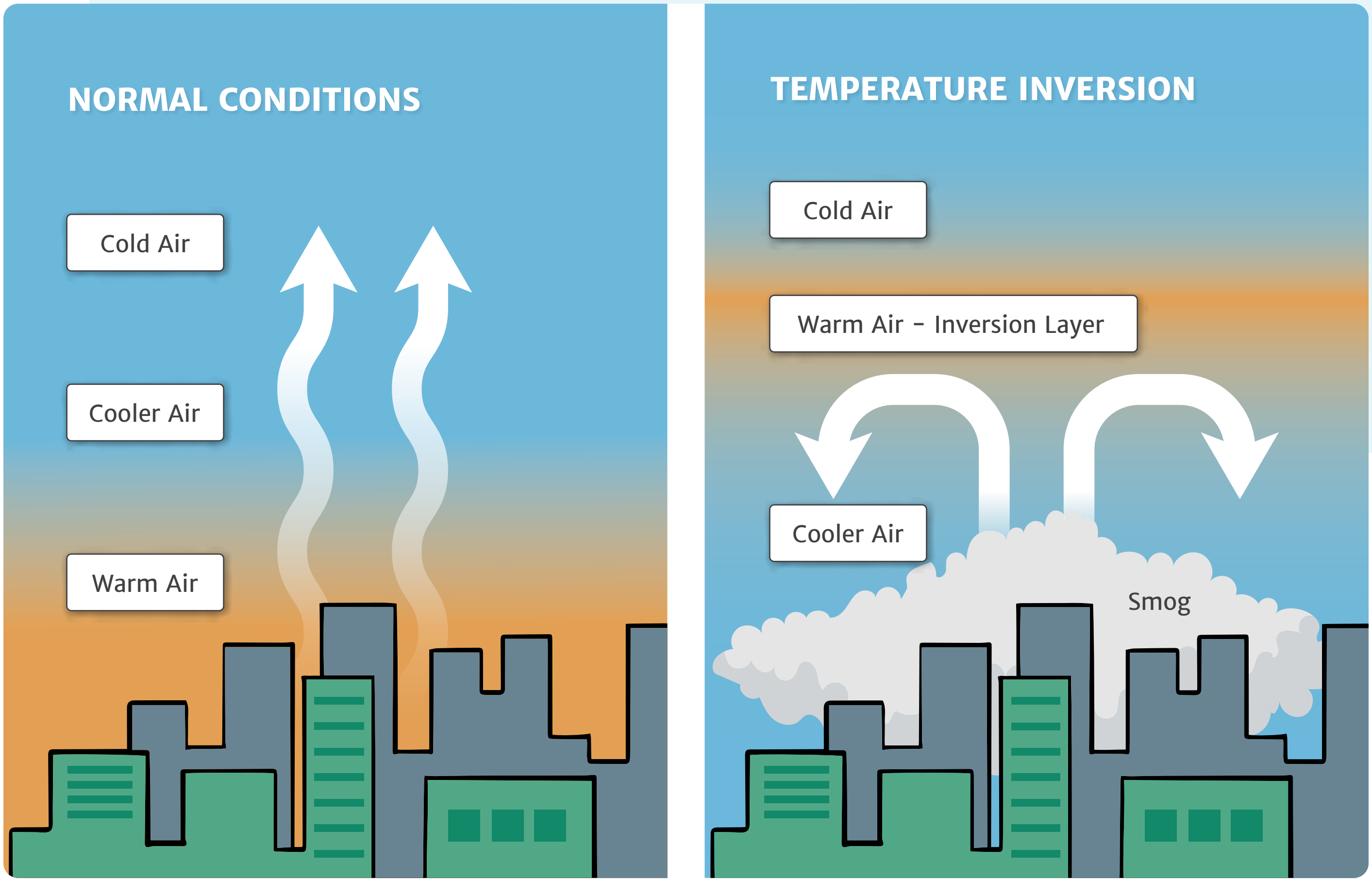
3.2. THERMAL INVERSIONS

Some regions, especially in valleys, suffer bad air quality during a "thermal inversion". Under normal conditions, the air temperature decreases with altitude. But sometimes the opposite happens: lower altitudes of the atmosphere are at colder temperatures, and warm air (the "inversion layer") is above the cooler air. Since cold air sinks, and hot air raises, this thermal imbalance traps pollutants near the ground, concentrating them in the lower layer of air. A thermal inversion can trap pollutants for days, sometimes turning mild air pollution into a dramatic and dangerous situation with dramatic consequences for public health and the environment.



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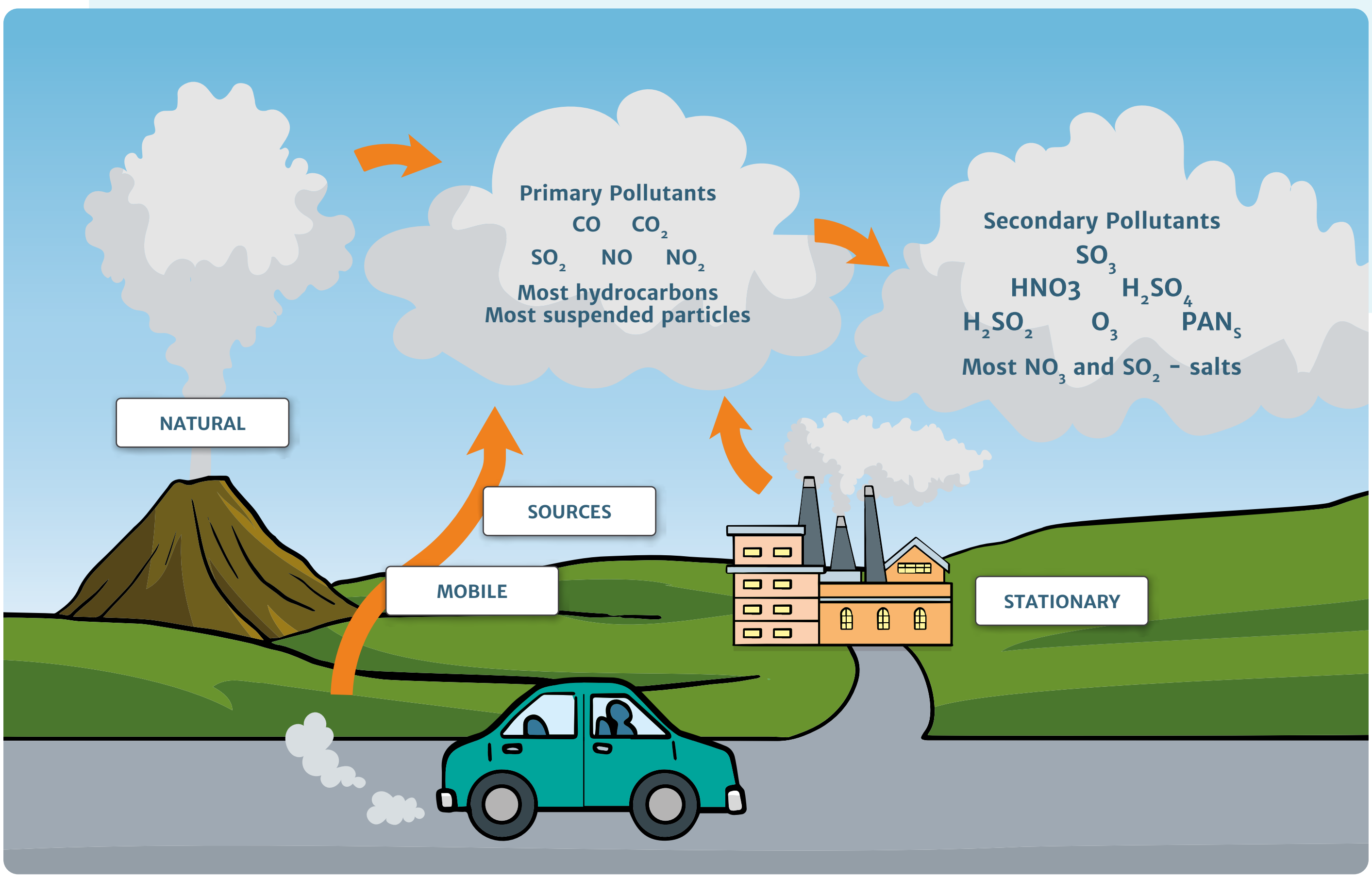
4. Air Quality and Regulation?

4.1. PRIMARY AND SECONDARY AIR POLLUTANTS

Regulators generally divide air pollutants into two broad types. Those air pollutants that are emitted directly from a particular source are called **primary air pollutants** – such as carbon monoxide from engine combustion. By contrast, **secondary pollutants** are formed in the atmosphere as a result of chemical reactions. The most common example of a secondary air pollutant is ozone, O_3, which forms from nitrogen oxides and volatile organic compounds in the presence of sunlight, is a major component of "photochemical smog". Secondary air pollutants like ozone are challenging to manage because they cannot be regulated directly, but must be managed indirectly by reducing emissions of their precursors.



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4.2. CONTROLLING AND ASSESSING AIR POLLUTION

In principle, there are two ways to monitor air pollution: first, by taking **ambient samples** of the air around you; second, taking emissions samples directly from a chimney, tailpipe, stack, or other source of pollutants.

In the case of a factory, power plant, or other stationary source, regulators can set **emissions standards** for the amount of pollution that can be released – for example, the amount of benzene that can be released into the atmosphere from factory. These emissions standards tend to be very technical, and depend on the specific kinds of emissions control technology available. An emissions sample taken from the point source (for example, a chimney) gives us direct information about whether the emissions standards are being met.

But the air we breathe includes stationary pollution sources as well as mobile sources (like cars and trucks) and distant sources (via long-trange transport). Protecting the health of people and environments therefore requires us to consider the total amount of pollution in the air around us – the **ambient pollution**. Many governments set standards for a small number of ambient pollutants, and require local governments to meet those standards. This can be extremely challenging when pollutants come from distant sources – like PM pollution from distant coal plants, or dust blown in from outside the city. Moreover, it is usually not clear exactly what sources have contributed to any particular pollutant: It can be difficult to determine whether high levels of sulfur oxide come from trucks in the city, or industry near the city, or coal plants far away.

Because ambient standards refer to pollution in the air around us, and therefore to the air that we breathe, these are usually the most important for protection of public health. Ambient samples can be easy to take, for example by capturing a liter of air in a plastic bag and sending it to a laboratory, whereas monitoring emissions directly usually requires access to the emissions source (the chimney, exhaust pipe, outflow, etc). In most cases, if you take ambient air samples, you will be able to compare the concentrations you find in your sample with the safe levels identified by your government, or by some other body like the World Health Organization (WHO).[2] Notice that most ambient standards refer to averages over time, which we discuss in the next sections.

2. The World Health Organization's guidelines for the most important fossil-fuel-related ambient pollutants can be found at https://www.who.int/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health

5. Low-Cost Air Sampling Methods for Communities

A wide range of methods and equipment are available to collect air samples. Each has pros and cons depending on the parameters to analyze, the location conditions, the sampling site, and the project budget.

5.1. PLANNING

Before any sampling is done, it is very important to develop a good sample plan. Your plan should address the components below.

Defining Your Objectives

This may be the most important question of all, and you should consider it carefully and strategically.

First, we can distinguish between **sampling** (once or a limited number of times) and **monitoring** (an ongoing process of tracking pollution). You may simply want to find out if a toxic air pollutant is present, in which case a few short-term "grab" samples may be enough. Or you may want to learn whether the air pollution in your community is above the WHO guidelines, in which case you will need many days, or even a year, of data. Perhaps you want to see whether the installation of a public transportation system lowers the amounts of ambient air pollution in your city: in this case, you may need years of data to see long-term trends.

If the purpose of your sampling is to compare your region's air with standards from the WHO or your national government, be careful that the methods you are using are acceptable. A low-cost air pollution monitor may be perfect for identifying good and bad air days, but if you bring these numbers to the government or to a court, they may not trust your results. Before you sample, make sure your samples and your laboratory's analytical methods are acceptable for comparison with the standards.

Finally, consider how you will use the results you obtain. If you are convinced that air quality is very bad, or that a factory is emitting a particular toxic chemical, consider: What will happen if you take a single sample on a clear day, or when the factory is closed, and your results do not support your case? Your air pollution results may not provide as much evidence as you hope; therefore, your air pollution sampling should be just one part of your larger plan.

Selecting Your Parameters

This is a critically important question, but it is not always easy to answer. The type of pollutant you sample for depends on the pollution source, as well as on the impacts on human health and environment that you are most concerned with.

Many people assume that a laboratory will test for everything in an air sample. Unfortunately, that is not the case. Methods of analysis are usually designed to look for only one pollutant – PM, O_3, or CO. When looking for a specific toxic chemical in air (for example, trichlorethylene), it is likely that the analytical method will also turn up closely related compounds (like perchloroethylene). But a chemical analysis can almost never find a chemical it was not specifically told to look for. (Looking for more chemicals, of course, also raises the price of the analysis.) Therefore, you will need to choose both your laboratory and your method of analysis to best suit the pollutant types you are interested in. When in doubt, discuss these issues with experts at your laboratory, or talk to a Staff Scientist at ELAW. Here are a few suggestions:

- Are you concerned about urban air pollution from vehicles? Look for O_3 and $PM_{2.5}$.
- Are you concerned about pollution from diesel vehicles? Look for $PM_{2.5}$.
- Are you concerned about pollution from a plant burning coal, gas, or oil? Look for the criteria pollutants: $PM_{2.5}$, NOx, SOx, and O_3.
- Are you concerned with gasoline or other fossil fuels evaporating from a storage facility? You will want to test for benzene and other small g asoline-related hydrocarbons.
- Are you concerned about a specific type of air pollution coming from a factory? You may need to consult an expert to decide which pollutants are most appropriate, and how you can sample them.

Finally, be careful that you are sampling for something that will be found in the air! Many toxic chemicals are "non-volatile" or "semi-volatile" and will not stay in the air for long; for example, pesticides are typically semi-volatile, and will rapidly settle out of the air. In this case, even if you are concerned about aerial spraying of pesticides, it may be wiser to sample on the ground rather than in the air.

Choosing Your Sample Location(s)

Choosing a sampling location is your next challenge. If you want to find out if a particular factory is emitting methyl isocyanate, you will want to sample near the factory (be sure to consider wind direction). If you're interested in the impacts of pollution on a community, you may want to sample a central place in the community, like near a school or in a park. Be careful that your sample location is at a reasonable height above ground (where people or animals might breathe) and that it is not surrounded by tall buildings or numerous trees, and that it is not directly exposed to strong winds.

5.2. AIR SAMPLE COLLECTION METHODS

There is a wide range of air sampling collection methods available with different levels of precision and price.. This guide does not describe all the air sampling methods available, but focuses on basic, low-cost sample collecting methods accessible for communities and NGOs.

During the planning stage, it is important to compare not only the sampling methods but also consider their cost, operation, and logistic needs based on the overall sampling project's objectives.

We often want to take samples to compare them to a standard set by a government or another body like the WHO. For official use in setting standards and assessing violations, governments typically rely on a specific set of sampling equipment and methods called a **"reference method"**. Data collected with a reference method is generally considered reliable, while data collected by other methods may not be acceptable to a government or a court. Most reference method samplers are extremely sophisticated and expensive, and are not usually available to community organizations. If you want to compare your data to a standard for some official reason – as in a lawsuit – you should discuss with your laboratory the methods that you propose to use, how closely they follow the reference standard, and whether the result will meet your goal.

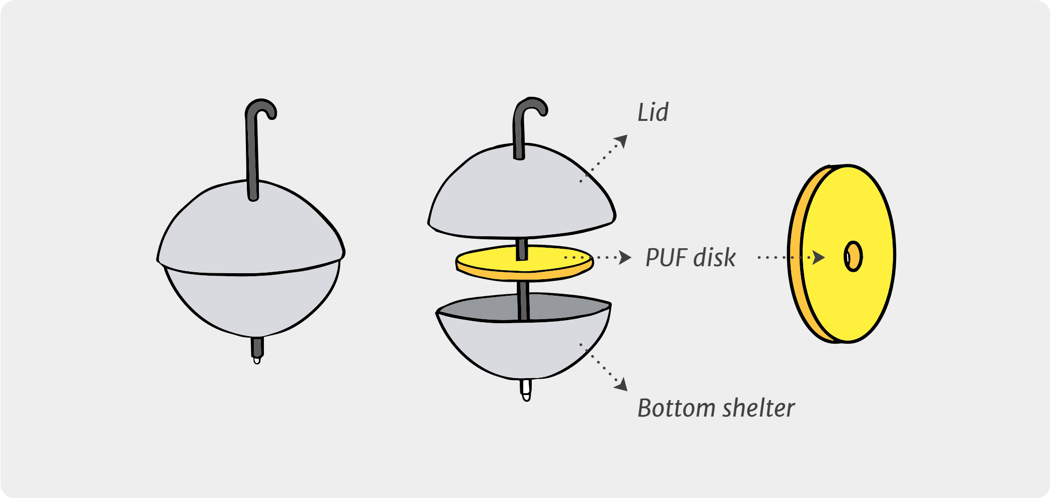
METHOD	PROS	CONS
Passive Sampling	Low-cost for area studies. Easy to use	Not useful for all pollutants. Requires a laboratory for analysis. Good for long-term (weeks/months) averages.
Active Sampling	Depending on the equipment, it could be low-cost and easy to use. Reliable and can provide daily averages	Less user-friendly and more costly. Requires laboratory analysis, adds to the costs.
Low-Cost Real-Time Sensor	Can be portable, and low or moderate cost	Accuracy and reliability varies depending on the equipment.

Passive Air Samplers

Passive air samplers collect air in a sorbent medium without the need of additional mechanical equipment. Passive samplers are frequently used indoors and outdoors. They can be used to sample for nitrogen dioxide, benzene, toluene, xylene, 1,3-butadiene, sulfur dioxide, and many other compounds.

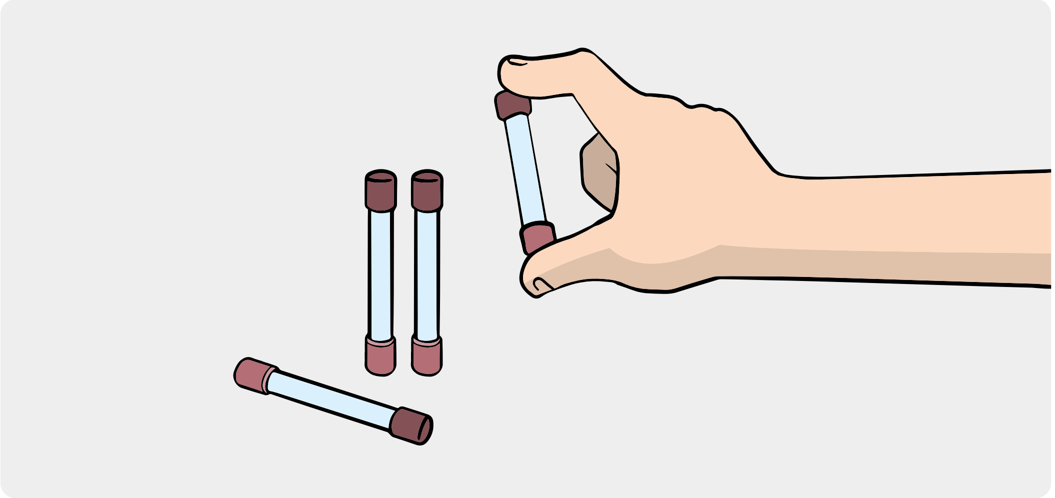
POLYURETHANE FILTERS (PUF)

Can be used to absorb air for a period of days. After being analyzed at a laboratory, these passive samplers will provide qualitative and quantitative data about contaminates in the sample.



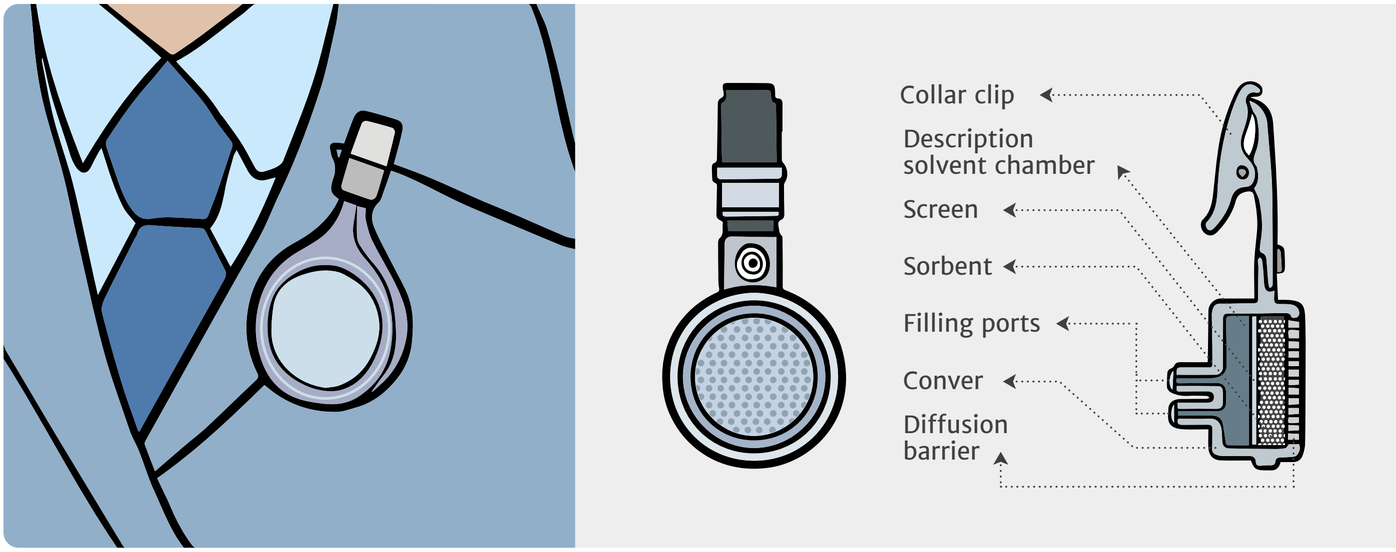
DIFFUSION TUBES

Are another type of passive sampler. These are more commonly used for shorter-term samples (hours), and therefore are common when sampling in highly contaminated areas, like within a factory.



PERSONAL MONITOR / BADGE-STYLE DEVICE

A passive sampling device in the form of a clip-on badge can provide excellent data about exposures to a particular person (for example, a factory worker). Therefore, these devices are most commonly used in occupational settings.



Low-Cost Active Air Samplers

Active air sampling requires a pump to collect the sample and a container of some sort. The simplest active samplers collect a sample of air in a sealed container, which can then be sent to a laboratory for testing. Other active sampling devices use a sample collection medium to absorb the air contaminants. There is a wide range of models, which may use silica or another sorbent medium in a tube or may use preloaded cassettes ready to insert in the sampling equipment.

THE BUCKET BRIGADE

Organized groups of citizens concerned about air quality have used low-cost air quality sampling equipment to analyze environmental pollutants. One example is the Bucket Brigade[3] in the community of Mossville in Calcasieu Parish, Louisiana. The Bucket Brigade began taking air samples using a bucket in September 1998 and was able to detect air quality violations for vinyl chloride, EDC, benzene (a carcinogen) that exceeded more than 200 times the state's standard.

The Louisiana Bucket Brigade[4] describes the equipment:

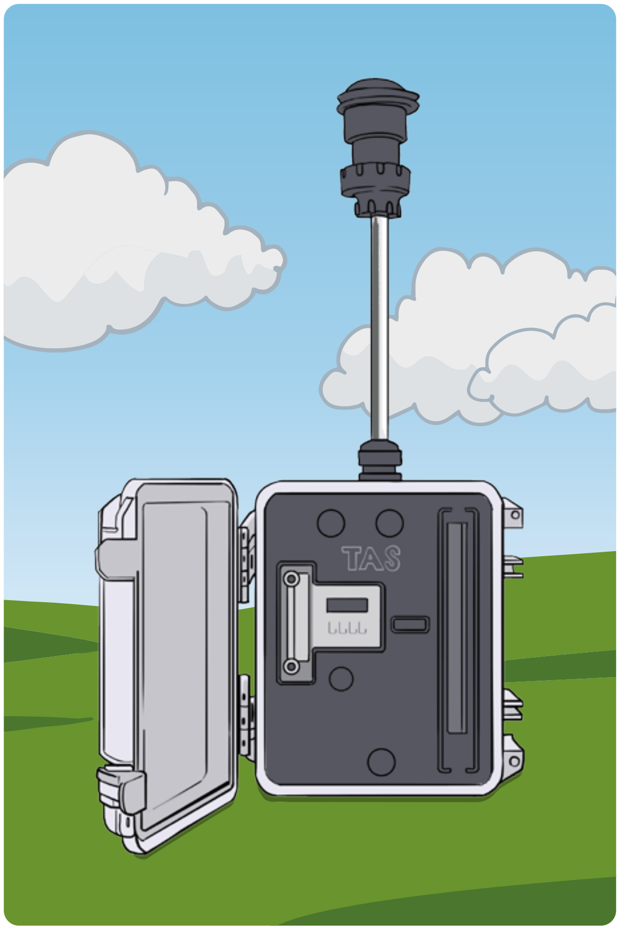
> *"The bucket is a $75 version of a much more expensive device, a $2,000 summa canister. Air is drawn into a Tedlar bag ($15), a non-reactive plastic, inside the bucket. The valve on the bag is then closed, and the bag is shipped overnight to a laboratory for analysis."*

Communities for a Better Environment (CBE) and the National Oil Refinery Action Network (NORAN) published the "Bucket Brigade Manual" (1998)[5] with the steps to build a bucket and how to organize a bucket brigade.

3. https://labucketbrigade.org/pollution-tools-resources/the-bucket/#
4. Ibid
5. Gradow, K. (2020). How the Bucket Works: https://publiclab.org/notes/kgradow1/06-09-2020/how-the-bucket-works

MINIVOL

A common and reliable active sampler is the MiniVol. Often available for rent, this device pumps an air sample through a filter for a defined period (for example, 24 hours). The filter is then sent to a laboratory for analysis. Although not as precise as a reference method, this approach yields very high-quality and reliable data.



5.3. REAL-TIME ACTIVE SAMPLERS

In some cases, samplers are available that can generate results in real time, without the need to send samples to a laboratory. These devices are often more expensive than other sampling types; but new and lower-cost active samplers are becoming available every year. If you want to use a real-time sampler, be sure to check how it compares to data generated by a more official, laboratory-based approach. In many cases, violations of standards can only be shown with standard laboratory-based samples. Real-time samplers may, however, provide you with critical data.

MODERATE-COST, PUMP-BASED MONITOR

A small, battery-powered aerosol monitor can be worn (to assess personal exposure to PM_{10} or $PM_{2.5}$), or can be placed in a living area to assess indoor air quality (for example, to compare emissions from different types of cookstoves). Such monitors are less accurate than those used by regulatory agencies or governments, and may not be accepted as evidence by a regulatory body or a court; but there is a long history of useful scientific data generated with such tools.

LOW-COST AND PORTABLE "PURPLE" STYLE MONITOR

The falling cost of small-scale computing technology has resulted in a number of new sampling methods. Numerous companies like Purple (in the USA) and Prana Air (in India) sell very low-cost, portable monitors for home use, usually limited to measuring $PM_{2.5}$, CO, and O_3. These devices are affordable and provide extensive data. While they are increasingly being used by scientists in field studies, it is unlikely that a government or a court would accept data generated by such a simple device.

6. Planning Your Sampling Process

6.1. GENERAL CONSIDERATIONS

We advise you to speak with your laboratory experts and scientist allies to help you plan and choose the best air sampling methods for your needs.

A few important considerations are:

- For a **general air sample**, you may need to capture a specific volume of air—perhaps a few liters—and send that to a laboratory for analysis. This can be done with a canister (like the traditional stainless steel Summa canister) or sometimes with a plastic bag. The sample container may be calibrated to fill over a specific time-period, such as 2 hours or 24 hours. The specific sampling methods and requirements will be specified by your laboratory. For an overview of a canister/bag sampling, see *https://www.eurofinsus.com/media/161448/guide-to-air-sampling-analysis-2014-06-27_revised-logos.pdf.*
- For **some air pollutants—especially for common pollutants like O_3**—a continuous monitor may be available, though it may be expensive. This might be handheld or mounted on a tripod for a day to a week. In some cases, you can rent the air pollution monitor you need for a week or so. Speak with your laboratory expert or the scientists at ELAW about specific monitors.
- For **analysis of particulate matter, toxic metals**, and **forms of carbon**, the most common sampling method is to pull air across a small filter for 24 hours (or some other period) at a predefined rate using an air pump, such as a MiniVol, which is often available for rent. An "impinger" attached to the nozzle of the sampler determines the size of particles collected by the filters, with PM_{10} and $PM_{2.5}$-sized impingers available to collect samples of those specific sizes. After filtered air samples are collected, the filters are sent to a special laboratory for analysis. Since the weights of the filters are premeasured (tared), the weights of the filters after sample collection can be directly converted into the concentration of particulate matter (PM_{10} and $PM_{2.5}$) in the air. Furthermore, if Teflon or quartz filters are used, then additional analytical methods can be employed at the laboratory to measure the concentrations in the air samples of toxic metals and other elements (using X-ray fluorescence), and elemental carbon (EC) associated with diesel smoke (using a Thermal/Optical Carbon Analyzer).
- For some pollutants, like $\mathbf{PM_{2.5}}$ and $\mathbf{O_3}$, there can be small, battery-powered samplers available (such as "AirNow" or "PurpleAir" monitors, or the low-cost "Airveda" monitors made in India). These monitors are likely to be much less accurate than other methods, but they may be enough to give you a sense of pollution levels.

6.2. SAMPLE SIZE AND DURATION

The sample size and duration will be determined by the sample method and by your goals. This may be a brief **grab sample** of a few liters of air, a **10-minute average** with a handheld $PM_{2.5}$ monitor, or a **24-hour sample** with a calibrated canister. In many cases, a 10-minute sample is adequate to get a good picture of air pollution at the time the sample was taken.

In other cases, you may want to engage in **monitoring:** taking several samples over an ongoing period to check for changes in pollutant levels, or to identify the occasional presence of specific contaminants (as with a leak from a factory). Monitoring generally requires an ongoing effort, including staff time and funding, to take samples on a regular basis, analyze them, and report them regularly.

For some pollutants, especially $PM_{2.5}$ and O_3, there may be different regulations or guidelines for 1-hour, 24-hour, or even 1-year samples. For example, according to the World Health Organization, average $PM_{2.5}$ concentration over a whole year should not exceed 5 ug/m_3; it is not unusual to have some bad air days that are well above this level. Thus, the WHO guidance for a single 24-hour average is 15 ug/m_3. For O_3, however, the WHO specifies 8-hour averages and 8-hour maxima. Consider sample length carefully to ensure that you can compare your samples with an appropriate standard.

6.3. WHEN TO COLLECT THE SAMPLES

Deciding when to take samples is an important part of the puzzle. Will you take samples just once, several times, or over many months or years? (See the discussion of sampling vs monitoring, below.) Are you attempting to measure an average pollution level, or are you trying to catch a sudden release from a factory? Knowing the purpose of your sampling project will help you to decide when, and how often, you will take samples.

In many cases, the health outcomes from air pollution can be divided into short-term (acute) and long-term (chronic) types of pollution. A single, sudden release of a toxic vapor from a factory is an acute exposure, and your sample may help prove that it happened. By contrast, the background air pollution from cars and trucks in a city is a chronic exposure, impacting residents over months and years. In this case, you are not interested in a sudden peak of air pollution, but in a long-term average.

Finally, be aware and cautious of the weather and wind patterns during your sampling. A strong wind may blow pollution out of an area, or a thermal inversion (see above) may trap air in a valley leading to high levels of pollution for a brief time. You should notice and document the weather patterns on the days you sample, to aid in the interpretation of your results.

7. Sample of Chain of Custody Form

Whenever you take an environmental sample, you must be careful to record the sample details (location, time, duration, sampling method, etc.). You must also carefully track the progress of the sample from the target site to the laboratory, then to the resulting dataset, so you can demonstrate to yourself and others that your data corresponds to the correct sample. The process used to track this information is generally called chain of custody (COC). It is useful to have a COC form accompanying every sample and for the form to be fil led out along every step of the way.

CHAIN OF CUSTODY								
1. SAMPLE COLLECTIONS							2. MANAGEMENT AND STORAGE	
			COORDINATES				Sample Storing Place	
Sample Number	Date	Time	Latitude	Longitude	Label	Notes	Temperature	
							Date and time of storage	
							Date and time of transportation	
							Name of Person in Charge	
							Signature	
							Notes:	
Person in charge								
Signature								
3. SHIPPING OF SAMPLES (IF NECESSARY)								
Sent by:							4. LABORATORY – SAMPLES RECEIVED	
Date							Received by:	
Time							Date:	
Shipment company							Time:	
Notes								

Air Quality Guidelines: WHO, EU, Australia, USA, and Canada

Pollutant	World Health Organization Guidelines (a)	European Union (b)	Australia (c)	United States (d)	Canada (e)
Ozone (1 hr.)			0.1 ppm		--
Ozone (8 hours)	100 µg/m³	120 (not to be exceeded more than 25 days/year)	--	0.070 ppb	62 ppb
Particulate Matter 2.5, (24 hr.)	15 µg/m³	--	25 µg/m³	35 µg/m³	27 µg/m³
Particulate Matter 2.5 (annual)	5 µg/m³	25 µg/m³	8 µg/m³	12 µg/m³	8.8 µg/m³
Particulate Matter 10, (24 hrs)	45 µg/m³	50 µg/m³	50 µg/m³	150 µg/m³	--
Particulate Matter 10 (annual)	15 µg/m³	40 µg/m³	--	--	--
Sulfur dioxide (1 hr.)		350 µg/m³			70 ppb
Sulfur dioxide (24 hrs.)	40 µg/m³	125 µg/m³ not to be exceeded more than 3 days/year)	80 ppb	75 ppb	
Sulfur dioxide (annual)		--			5 ppb
Nitrogen dioxide (1 hr.)	200 µg/m³	200 µg/m³			
Nitrogen dioxide (24 hrs.)	25 µg/m³	--	--		--
Nitrogen dioxide (annual)	10 µg/m³	40 µg/m³	0.03ppm	53 ppb	17 ppb
Carbon Monoxide 1 hr.	35 mg/m³	--	--	35 ppm	--
Carbon Monoxide (8 hrs.)	10 mg/m³	10 µg/m³	9 ppm	9 ppm	--
Carbon Monoxide (24 hrs.)	4 µg/m³	--	--		--

Pollutant	World Health Organization Guidelines (a)	European Union (b)	Australia (c)	United States (d)	Canada (e)
Lead	--	0.5 µg/m³ (annual)	0.5 µg/m³	1.5 µg/m³	--
				Not to be exceeded	

(a) WHO (2021) Global air quality guidelines. https://apps.who.int/iris/handle/10665/345329

(b) European Environmental Agency. Air Quality Standards. https://www.eea.europa.eu/themes/air/air-quality-concentrations/AirQlimitvalues.png

(c) Australia: Air Quality Standards. https://www.transportpolicy.net/standard/australia-air-quality-standards

(d) EPA NAAQS. https://www.epa.gov/criteria-air-pollutants/naaqs-table

(e) CCME Canadian Ambient Air Quality Standards (CAAQS). https://ccme.ca/en/air-quality-report

European Union Air Quality Directives and World Health Organization - WHO Guidelines

8. Analysis and Interpretation of Results

8.1. UNITS OF ANALYSIS

National air quality standards and international guidelines units are given in parts per million (ppm) by volume, parts per billion (ppb) by volume[6], and micrograms per cubic meter of air (µg/m_3).

The six most frequently used parameters for air quality (called "criteria" air pollutants) include carbon monoxide, lead, ground level ozone, particulate matter, nitrogen dioxide, and sulfur dioxide.

6. One part per million (1 ppm) corresponds to one gram of a contaminant in 1,000,000 grams of soil, or 1 cubic centimeter of air in 1,000,000 cubic centimeters

8.2. SIMPLE RESULTS: AVERAGES AND TIME SERIES

Once you have collected your data, or received your results from the laboratory, you will need to be able to describe these results in a way that other users of the data will find compelling. In most cases, this means using the appropriate statistical tools to demonstrate that your data is of good quality, and not a simple fluke result.

If you have a single result, or only a few results, you may be able to compare these directly to reference or regulatory standards. For example, a single sample reporting the presence of trichloroethylene (TCE) in the air in your building may be compelling on its own, if TCE is not permitted to be present at any level.

To compare many samples, or a number of samples taken over a period of time, it will usually be helpful to take an average (or mean) of the data. You can calculate this in Excel or Google Sheets by using the 'AVERAGE' formula.

8.3. COMPARISON AND STATISTICAL TESTING

When you compare your data against another number (data from another sample or a regulatory limit) you should also present some measure of the quality of your data. For example, if you take ten air samples in one hour, you may want to publish the average value, along with the standard deviation (which you can calculate in Excel with the 'STDEV' formula). The standard deviation is a measure of the variability of your data. If you report your air pollution measurements as 50 with a standard deviation of 20, this means that it is not uncommon for your data to be as low as 30 (= 50-20) or as high as 70 (= 50 + 20). By contrast, 50 with a standard deviation of 2 means that most of the data falls between 48 and 52 – implying that your measurements are extremely consistent.

There are many other ways to describe the variability in your data (90% ranges, confidence intervals, sample variance, etc.). You will need to use the measure that is most appropriate for your data set. In general, however, it is useful to present such a measure along with your data.

9. Next Steps in Statistical Analysis and Presentation

There are an endless number of ways to present your data, and we cannot review them all here. If you are using your data to get a sense of the pollution level, or for your own information, a simple average value may be enough. The more impact you hope to make with your data, the more pressure there will be to make sure it has been sampled and analyzed in the most accurate way. If you hope to use your data in court, or in a regulatory case, you may be limited to using a government-approved reference method. Any less accurate method could be dismissed by the government or the court as inadequate.

For assistance choosing sampling and analysis methods, consider finding a local expert (perhaps in the Chemistry or Statistics department of your local university). They may be willing to advise you informally, or even to help your analyze your data in the most accurate way.

If you are having trouble getting started, or would like to discuss a range of sampling methods and goals, consider speaking with an ELAW Staff Scientist.

A few common ways of analyzing and presenting air pollution data are given here.

Time series

If you have a lot of data over time – for example, weeks of air pollution, measured every 10 seconds – you may want to "smooth" your data to reduce the variability. Excel will let you plot a "moving average," which is often a good (although simple) way to see the smoothed data. Be sure to select 'Trendline' in your graph.

Data cleaning

If you have data points that don't make sense, you may need to "clean" your data. For example, if your hourly air pollution measurements average around 50, but suddenly shoot up to 1000 or down to -50, you may have had a glitch in your equipment or in the analysis. Removing points that are truly incorrect is good, and your results will be more consistent. However, manipulating data in this way is dangerous, and you may be biasing your results. In general, if you need to remove data, it is best to explain what you removed and why.

Statistical testing

In most practical cases, your audience will want to know whether your data is "statistically significantly different" from someone else's data. If you measured air pollution at 50 but the government measured it at 40, are your results truly different? If your measurements averaged 50 with a standard deviation of 2 – that is, most of your data fell between 48 and 52 – , then yes, they appear to be different. If your measurements averaged 50 with a standard deviation of 20 – where most of your data fell between 30 and 70 – then it is not clear that your results are very different than the government's.

Statistical testing is a complex, nuanced, and contentious field. If you don't need to present a statistical test, don't – let the data speak for itself. If, on the other hand, you are told that your data is meaningless because it is not statistically significant, you may want to find an expert who can help you understand whether that is really the case, or whether there is some other interpretation.

Glossary

ACID RAIN	Acid rain or acid deposition, refers to precipitation with acidic components, such as sulfuric or nitric acid that fall to the ground from the air. Some forms include rain, snow, fog, hail or even dust that is acidic. Acid rain results when sulfur dioxide (SO_2) and nitrogen oxides (NOx) react with water and/or other chemicals, including oxygen, form sulfuric and nitric acids before falling to the ground.
AIR BASIN	An area surrounded totally or partially by mountains that in the absence of wind holds air and smog within the area.
AIR SAMPLING	The collection of air samples for the identification and quantification of airborne pollutants with instruments and/or laboratory equipment.
AIR QUALITY INDEZ (AQI)	In an index to inform the public about how air pollution could affect human health within a short time-period. The U.S. Environmental Protection Agency (EPA) estimates the AQI based on five priority pollutants: ground level ozone; particulate matter ($PM_{2.5}$ and PM_{10}), carbon monoxide, sulfur dioxide, and nitrogen oxide.
AMBIENT AIR QUALITY	The quality of outdoor air in our surrounding environment. It is typically measured near ground level, away from direct sources of pollution[7].
ATMOSPHERE	The mixture of gases that surrounds Earth or some celestial body. It is held by the force of gravity and forms various layers at different altitudes. It could also refer to a unit of pressure equivalent to the pressure of air at sea level, about 14.7 pounds per square inch or 1.01 Bar.
BENZENE	A colorless volatile liquid hydrocarbon present in fossil fuels, such as petroleum and coal tar, and used in chemical synthesis of some industrial processes. It is a known carcinogenic.

7. www.eionet.europa.eu

CARBON DIOXIDE (CO_2)	A colorless, odorless, and non-poisonous gas formed by combustion of carbon and in the respiration of living organisms and is a greenhouse gas. Burning of fossil fuels, the consumption of solid, liquid and gas fuels, as well as gas flaring, are important sources of CO_2[8].
CARBON MONOXIDE (CO)	A colorless, odorless, and very toxic gas formed during the incomplete combustion of fuel or carbon compounds. It is emitted from the exhaust of cars, household heaters, tobacco products, kerosene, wood stoves, fireplaces, generators, and other gasoline powered equipment. At high concentrations, CO exposure can be fatal[9].
CONTAMINANT	See pollutant.
EMISSIONS (GAS)	The release of gas or vapor into the atmosphere.
FUGITIVE EMISSIONS	Emissions gases due to leaks and other unintended or irregular releases of gases, mostly from industrial activities.
GREENHOUSE GASES	Gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of thermal infrared radiation emitted by the Earth's surface, atmosphere, and clouds. This property causes the greenhouse effect. Water vapor (H_2O), carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4), and ozone (O_3) are the primary greenhouse gases in the Earth's atmosphere[10].

8. www.epa.gov
9. www.epa.gov
10. https://www.ipcc-data.org

HAZARDOUS AIR POLLUTANTS	Pollutants known to cause cancer and other serious health impacts. The Clean Air Act of the U.S.A. requires the environmental authority (Environmental Protection Agency - EPA) to regulate toxic air pollutants such as benzene (found in gasoline), perchloroethylene (emitted in some dry-cleaning facilities), methylene chloride (used as solvent and paint stripper), dioxin, asbestos, toluene, and metals such as cadmium, chromium, lead and mercury, among others[11].
HYDROCARBON	A compound containing hydrogen and carbon. The term is frequently used to refer to the main components of petroleum, natural gas, coal, and bitumen.
HYDROGEN SULFIDE	A colorless, flammable, extremely hazardous gas with a "rotten egg" smell. It is also known as sewer gas, swamp gas, or manure gas. It occurs naturally in crude petroleum, natural gas, and hot springs. Hydrogen sulfide is also produced by bacterial action on organic matter, so it may be found in human and animal waste and sewers. Some industrial processes such as fishmeal processing plants, tanneries, and paper mills can also emit hydrogen sulfide[12].
INVERSION (THERMAL)	See this guide's section: Types of Air Pollution.
METHANE	A colorless, odorless, flammable gas which is the main constituent of natural gas. Methane consists of one atom of carbon and 4 atoms of hydrogen (CH_4). It can be found in coal mines and marshes and is known as marsh gas. Commercially it is obtained from natural gas. Methane is the second most abundant anthropogenic greenhouse gas after carbon dioxide (CO_2), accounting for about 20 percent of global emissions. Methane is more than 25 times as potent as carbon dioxide at trapping heat in the atmosphere[13].
MOBILE AIR POLLUTION SOURCE	Includes any air pollution emitted from motor vehicles that can be moved such as automobiles, trucks, airplanes, engines, boats, recreational motor vehicles, etc.

11. www.epa.gov
12. OSHA Fact Sheet. Hydrogen sulfide (H2S). DSG 10/2005
13. https://www.epa.gov/gmi/importance-methane

NITROGEN OXIDES	A group of highly reactive gases that include nitrogen dioxides, nitrous acid, and nitric acid. Nitrogen dioxide (NO_2) is used as the indicator for the larger group of nitrogen oxides. NO_2 primarily gets in the air from the burning of fuel from motor cars, trucks, buses, power plants, and off-road equipment. Breathing air with high concentrations of NO_2 can irritate the airways of the human respiratory system, aggravate respiratory diseases, exacerbate asthma, and potentially increase susceptibility to respiratory infections[14].
OZONE	A gas composed of three atoms of oxygen. Ozone occurs naturally in the Earth's upper atmosphere and at ground level. Ozone could be good or bad depending on where it is found[15].
OZONE (GROUND LEVEL)	Ground level ozone, also known as tropospheric ozone, is a colorless and very irritating gas that forms just above ground level. It is a secondary air pollutant because it is formed when two primary air pollutants react in the presence of sunlight, in this case nitrogen oxides (NOx) and volatile organic compounds (VOCs). Ground level ozone can cause irritation of the respiratory system. It should not be confused with stratospheric ozone.
OZONE (STRATOSPHERIC)	A gas that occurs naturally in the upper atmosphere, where it forms a protective layer that shields us from the Sun's harmful ultraviolet rays. This beneficial ozone has been partially destroyed by human-made chemicals, causing what is sometimes called a "hole in the ozone"[16].
PARTICULATE MATTER (PM)	A mixture of extremely small airborne particles and liquid droplets of numerous components including organic and inorganic substances.
$PM_{2.5}$	An airborne particulate matter of 2.5 micrometers or less in diameter.

14. www.epa.gov
15. www.epa.gov
16. www.epa.gov

PM_{10}	An airborne particulate matter of 10 micrometers or less in diameter.
PARTS PER BILLION (ppb)	The number of units of mass of a contaminant per billion units of its total mass.
PARTS PER MILLION (ppm)	The number of units of mass of a contaminant per million units of the total mass.
POLLUTANT	A pollutant is a substance that is present in concentrations that may harm organisms (humans, plants and animals) or exceed an environmental quality standard. The term is frequently used synonymously with contaminant.
SMOG	Fog or haze composed by a mixture of gases, smoke, and chemicals that negatively affect the air quality and pose risks to public health.
STATIONARY SOURCE	A source of air pollution whose location is fixed, such as fossil fuel power plants, oil/gas refineries, mining smelters, or other industrial or domestic sources.
SULFUR OXIDES	A group of air pollutants formed by gaseous and particulates of sulfur dioxide, sulfur monoxide, sulfur trioxide, and disulfur monoxide.
VOLATILE ORGANIC COMPOUNDS	A group of organic compounds that evaporate easily at ordinary room temperature.

Information Resources

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https://labucketbrigade.org/pollution-tools-resources/the-bucket/#

U.S. Environmental Protection Agency - EPA.
An Introduction to Indoor Air Quality (IAQ)
http://www.epa.gov/iaq-intro.html

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http://www.epa.gov/iaq/

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https://www.epa.gov/criteria-air-pollutants/naaqs-table

World Health Organization - WHO. Air Quality Guidelines
https://www.who.int/news-room/feature-stories/detail/what-are-the-who-air-quality-guidelines

Environmental Law Alliance Worldwide – ELAW

www.elaw.org

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