Protocol for monitoring *air quality in school* environments using NO_2 diffusion tubes

ISGlobal Barcelona Institute for Global Health

CleanCities

STREETS FOR KIDS

4sfera INNOVA

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Quick overview

This Overview serves as a quick reference guide, but careful review of the full protocol should be done before any measurement campaign.

High levels of air pollution, including nitrogen dioxide (NO_2) in urban areas, are linked to increased disease and mortality, particularly impacting children. Therefore, protecting environments where children spend much of their time, like schools, is important.

This protocol outlines the best practice for citizen monitoring of NO_2 levels to measure air quality in school environments. It is designed for anyone interested, including school and community groups. The protocol establishes a standardised process for monitoring and interpreting NO_2 levels, and can be adapted for other citizen science projects.

In urban and suburban environments, measuring NO_2 levels is a way to measure traffic-related air pollution (TRAP). NO_2 Palmes diffusion tubes are affordable passive samplers suitable for citizen science projects. These low-cost sensors can complement existing networks, and can provide different measurement points around schools. Trends in NO_2 concentrations can be used to assess air pollution exposure and the effectiveness of policies and interventions to reduce air pollution.

Equipment required and key considerations

- [x] NO_2 diffusion tubes
- [x] QR sticker codes to identify each tube (2 stickers per tube are provided)
- [x] Supports for holding the tubes and cable ties
- [x] Airtight bag/box
- [x] Scissors/pliers
- [x] Exposure sheet provided by the laboratory: to be completed when installing tubes
- [x] A measuring tape (minimum 3 m) (optional)
- [x] Small ladder or stool (tubes should be installed at a minimum of 2.5 m)
- [x] A map of the study area
- [x] Camera, smartphone, or tablet to take pictures of the installed tubes locations

Tubes have a shelf-life of 12 weeks, so they must be used and returned for analysis within this period. They must be refrigerated when they are not being used; however, refrigeration is not necessary during shipping to and from the laboratory.

The measurement period for each NO_2 tube is between 2 and 4 weeks. The time required to install and remove the tubes will depend largely on the number of tubes and their locations, but as a guideline, half a day is required for a measuring campaign around schools to place the sensors and half a day for removal.

Ways to map the tube locations

The selection and recording of the tube locations can be undertaken in three ways:

- A paper map where you select and record the locations and information.
- CleanAir: A web interface by 4sfera Innova. This protocol includes information on how to use this website and transfer information to a mobile application.
- My Maps - Google: On your computer, follow the steps explained in this protocol. It can also be done with a smartphone or a tablet.

Installing the tubes

1. Select the desired location for each tube.
2. Install the tube holder support at the location.
3. Attach the QR code sticker to each tube before installing.
4. Fill in the exposure sheet with the other QR code sticker; in case you have another name associated with each point you can also register it here.
5. Remove the WHITE cap. Keep the cap in a safe place (put it inside a plastic bag or a plastic container). This cap is needed again after the measurement period ends to collect and seal the tubes.
6. With the coloured end cap of the tube facing UPWARD (the top), clip/place the tube into the support. Ensure the tube is positioned vertically with its open (uncapped) end downward.
7. Record the starting date and time of the measurement period on the exposure sheet.

Install the tubes at least 2.5 m above the ground, in outdoor locations around the school where people stay or pass by such as street lights or signposts (i.e. walking, cycling, etc.).

Avoid installing tubes at street intersections, bus stops or near building vents.

It is highly recommended to install a set of tubes (2 tubes, 3 if possible) next to the reference equipment of a nearby government environmental control station that also measures NO_2. This will allow the comparison of your results with reference data. This is an important part of quality control.

Collecting the tubes

After the measurement period, close the tube by putting the WHITE cap back on the tube and write down the time and the date of collection on the exposure sheet. Tubes should be returned to the lab for analysis with a copy of the exposure sheet as soon as possible after the measurement period ends. It is very important that you send an email to the lab, or your local distributor to notify them about sending the tubes.

Interpreting the results

The results are calculated and provided in parts per billion (ppb) and micrograms per cubic metre ($\mu g/m^3$). When interpreting the results from the laboratory analysis, it is important to be aware that they represent the average NO_2 concentrations during the exposure period (2-4 weeks). Therefore, results from NO_2 tubes cannot be directly compared with hourly or daily limit levels from other sensors, or with the annual mean limits from WHO or EU guidelines, because the timeframes are different. Results from NO_2 tubes can help detect changes over time, for example as a result of a policy or intervention. They can also help expand the number of measurement points within a city and give more specific information about sites like school areas, which can then be used to help prioritise and monitor air quality improvement actions.

De initions and abbreviations

AAQD: Ambient Air Quality Directives

AQGs: Air Quality Guidelines

Diffusion tube: Palmes-type diffusion tubes are passive samplers, open at one end whilst measuring, with an absorbent at the other (closed) end for absorption of a specific pollutant from the surrounding air

Grid: Used here to refer to the small mesh grids used inside the diffusion tube, which are coated with the absorbent TEA

End cap: The plastic cap fixed on the closed end of a diffusion tube, which holds the absorbent-coated grids

EU: European Union

NO_2: Nitrogen dioxide (NO_2) is a gas present in cities mainly produced by combustion associated with motorised traffic. NO_2 exposure can have negative impacts on health

PM: Particulate matter is a term used to describe a combination of solid particles and liquid droplets that vary in size and composition. It includes PM with a diameter less than or equal to 10 µg (PM10) and PM with a diameter less than or equal to 2.5 µg (PM2.5)

TEA: Triethanolamine. The reagent used in Palmes-type diffusion tubes as an absorbent for NO_2

TRAP: Traffic-related air pollution

QR code: A QR code sticker to identify each tube, comes in duplicate, one for the tube and the other for the exposure sheet

WHO: World Health Organization

Purpose of the protocol and who can use it

This protocol outlines the best practice for citizen monitoring of nitrogen dioxide (NO_2) levels to measure air quality in school environments. It is designed for anyone interested from school or community groups. The goal is to establish standardised procedures for monitoring and interpreting NO_2 levels and give citizens greater access to local data about air pollution exposures related to motorised traffic. This protocol can be adapted for other citizen science projects.

1. Background

High levels of air pollution, including NO_2 concentrations in urban areas, are linked to increased disease and mortality. NO_2 is mainly human-made, and in most major cities motorised vehicle traffic is the main source, known as traffic related air pollution (TRAP). Other sources can include shipping and aviation, power plants, industrial activities, and agriculture [1]. NO_2 exposure can cause asthma and decreased lung and cognitive function in children, and there is evidence that NO_2 exposure is linked to metabolic disorders and childhood cancer. A summary of health impacts on child health can be found on the ISGlobal Blog.

Since children are especially vulnerable to the short and long-term effects of air pollution, it is important to minimise their exposure in environments where they spend a lot of time, such as schools. Trends in NO_2 concentrations can be used to assess children's exposure and the effectiveness of air pollution policies and interventions.

Measuring NO_2: Understanding air quality guidelines and monitoring techniques

Because of the important links between air pollution and health, the **World Health Or-ganization (WHO)** has developed **Air Quality Guidelines (AQG)** that describe the risks asso-ciated with 37 of the most common air pollut-ants. The AQG are based on a review of the latest scientific evidence (Figure 1). They offer specific recommendations to reduce exposure to these key pollutants, and recommend limits; however, these limits are not legally binding. In 2024, the European Union proposed new **Ambient Air Quality Directives (AAQD)**, that are legally binding for EU members, Although they do not completely align with WHO recommendations, they significantly reduce the limits of pollutants that are most harmful to human health (*Figure 1*).

There is an increasing interest in air quality monitoring in local environments, including schools. Low-cost sensors are valuable tools which can be used by communities to enhance existing air quality fixed monitoring networks [2]. While there are many types of sensors available for citizens, there is some consensus that for understanding TRAP locally and within school environments, the use of Palmes diffusion tubes, as described in this protocol, are the best practice.

Passive diffusion tubes are a cheap, simple method that provide concentrations that in most circumstancesgive an indicative measure to assess NO_2 exposure during a defined time period. Tubes can be used to complement government monitoring networks that measure compliance with Air Quality criteria at the local level. [3,4] However, NO_2 diffusion tubes use an average exposure depending on the number of weeks exposed, while the WHO AQG and EU AAQD use average annual exposure. So these measures cannot be directly compared. To know more about the effects of NO_2 exposure and about the WHO guidelines and EU directives please refer to Annex C.

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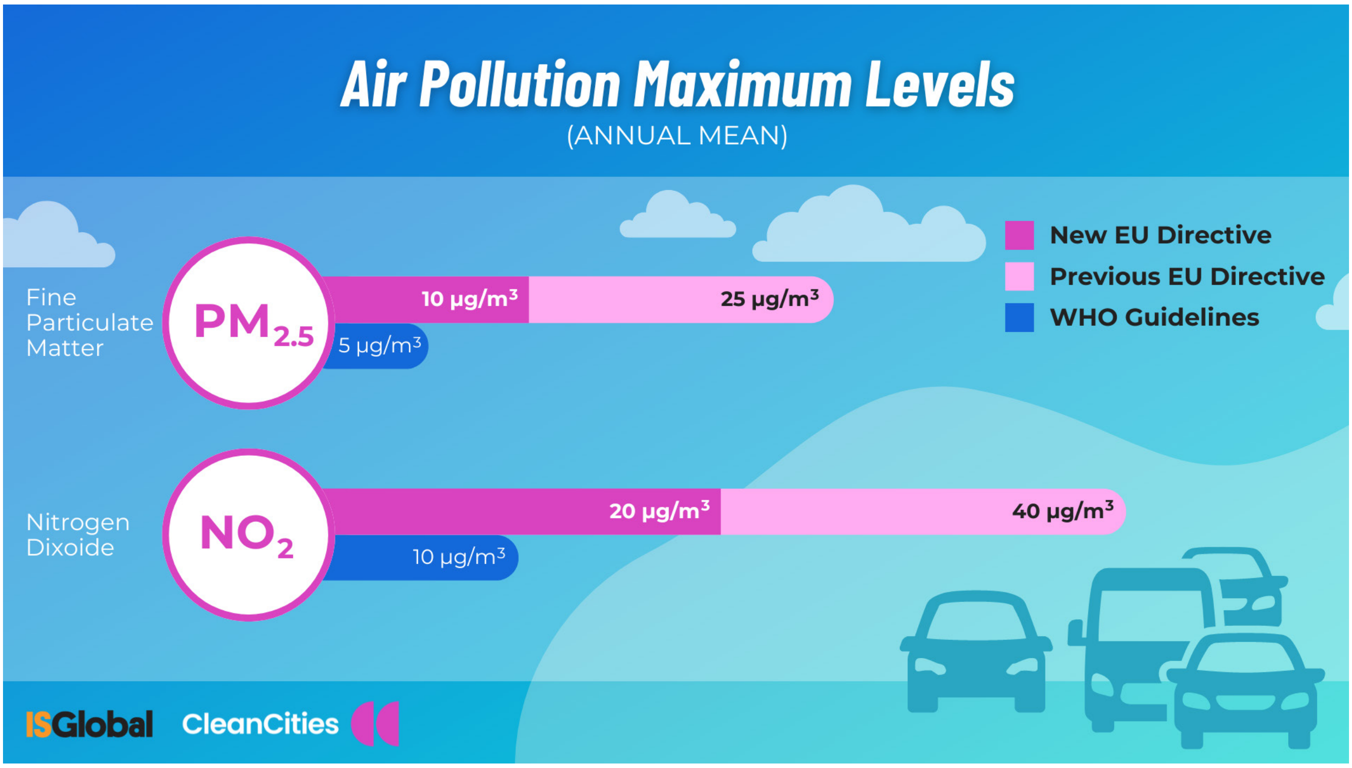
[1] Anenberg, S. C., Mohegh, A., Goldberg, D. L., Kerr, G. H., Brauer, M., Burkart, K., ... and Lamsal, L. (2022). Long-term trends in urban NO_2 concentrations and associated paediatric asthma incidence: estimates from global datasets. *The Lancet Planetary Health*, 6(1),e49-e58.

[2] World Meteorological Organization. (2024). Low-cost sensors can improve air quality monitoring and people's health. Press Release.

[3] Cape, J. N. (2009). The use of passive diffusion tubes for measuring concentrations of nitrogen dioxide in air. Critical Reviews in Analytical Chemistry, 39(4), 289-310.

[4] Heal, M. R., Laxen, D. P., and Marner, B. B. (2019). Biases in the measurement of ambient nitrogen dioxide (NO_2) by Palmes passive diffusion tube: a review of current understanding. Atmosphere, 10(7), 357.

Figure 1. Most recent Air Quality Guidelines for PM2.5 and NO_2.



2. Key considerations and equipment

In this section we present the materials and equipment needed, how the tubes work, and how to store them properly when not in use.

2.1. Equipment and Materials

- **NO_2 diffusion tubes** (Figure 2). Tubes come with two caps; a grey and a white one (see Annex D). The white one is the one you will need to remove when starting the exposure period. Do NOT remove the grey cap as the measurement grid will come out.
- **Support to hold the tubes in place**. There are different supports available, each suitable to a specific surface or type of exposure measurement. For example, in Figure 3, the left side support is suitable for installing tubes in windows. Others require use of cable ties.
- **Airtight bag/box** to store the tubes
- **Scissors/pliers**
- **QR code stickers** to identify the tubes. Two stickers for each tube are supplied along with the tubes.
- **Exposure sheet:** This form is provided by the laboratory and is to be completed when installing and uninstalling the tubes if the activity is carried out manually. Otherwise the CleanAir@School mobile application can be used.
- **A measuring tape** (min 3 m) (optional)
- **Small ladder or small stool** (tubes should be installed at minimum 2.5 m height)
- **A map of the study area** (or My Maps - Google or tablet/mobile with the CleanAir@School mobile application installed)
- **Camera, smartphone or tablet** to take pictures of the locations of the installed tubes or to use the CleanAir@School mobile application.

Figure 2. Diffusion tube components

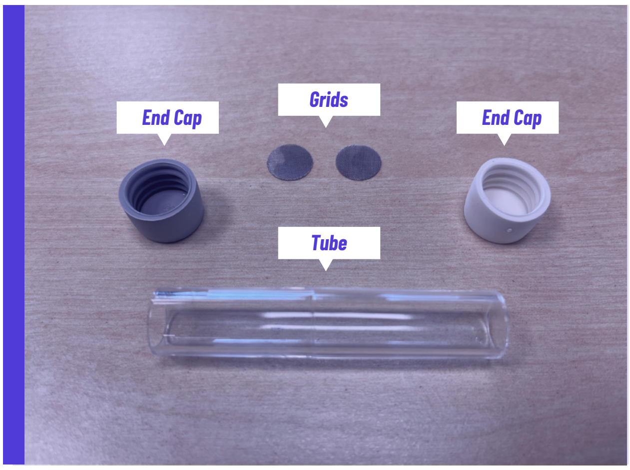


Figure 3. ***Types of NO_2 tube supports***

2.2. Acquiring the tubes

The authors of this protocol have carried out many tube measurement campaigns in different contexts using the Gradko laboratories tubes, and therefore have more experience with the quality and functioning of this provider. We have found them to be efficient with consistent quality. However, there are several laboratories that sell passive samplers to measure NO_2. They are all similar in how they function, though availability, price and other aspects such as shipping may vary, so please check the details carefully with the provider you select. Below are some options:

- Gradko (UK): gradko.com/environmental/nitrogen-dioxide-diffusion-tubes
- Passam ag (Switzerland): passam.ch/products
- Ormantine (USA): ormantineusa.com/nitrogen-oxides-diffusion-tubes

Prior to buying the tubes, consult with the laboratory provider to find the main distributor of Palmes diffusion tubes in your country through their website. They may refer you to your local distributor. The price of the tubes usually includes the laboratory analysis, but price may vary depending on your local distributor. Shipment is paid separately. Support holders for the tubes can often be purchased on the same website, and prices will vary depending on the type. These can also be ordered through your local distributor along with the tubes.

2.3. Tube shelf life

Tubes have a shelf-life of 12 weeks before they expire, so they must be used and returned for analysis within this period. The date of reception and the expiry date should be clearly identified on the package for each batch of tubes.

2.4. Tube storage

Tubes should be kept refrigerated before and after use, and should not be subjected to large changes in temperature. The use of plastic containers and/or sealable clean plastic bags is essential in order to avoid contamination for unused tubes whilst in the fridge, and during transportation.

2.5. Quality control: Blank Tubes

We recommend using two of the tubes from each batch as Blank Tubes to detect whether the tubes are working properly. They should be labelled with a QR code sticker (a different QR code for each tube) and kept in their original plastic bag, and taken with you during installation and collection of the study tubes. Store the Blank Tubes in the fridge while the other installed tubes are measuring. If a refrigerator is not available, they should be stored in a cool, dark place with stable temperature. Blank Tubes do not need an opening/closing date and time; write 'Blank' on the exposure sheet next to its QR code.

2.6. Labelling the tubes with a QR code

Tubes come with an exposure sheet and a strip of QR code stickers; these codes are in duplicate (2 QR stickers for each tube): 1 label is to be placed on the tube, and the other label is to stick it to the exposure sheet (Figure 4). If you are using the app instead of the exposure sheet, then, scan the code for each tube. Label the tubes and sheets right away at the measurement point to minimise errors. Please make sure the label is securely fixed to the tube (the labels are designed to endure poor weather conditions).

Figure 4. ***Palmes diffusion tube with the QR code attached (with both end caps)***

3. Installing and collecting the tubes

The following section details the installation and collection of the NO_2 tubes for analysis. We present the general criteria for selecting measurement points and a step-by-step guide on installing, collecting and sending for analysis. The number of tubes and distance from each other should be based on the objectives of the monitoring campaign.

> **Note**
> The measurement period for tubes is between minimum 2 weeks and maximum 4 weeks.

3.1. General criteria to install NO_2 outdoors

For outdoor monitoring, it is important to place diffusion tubes where there is open circulation of air around the tube. At the same time, street crossings and intersections should be avoided, as well as places that are focal points or localised sources of NO_2. For example, avoid points with close proximity (less than 10 m) to:

- Bushes or vegetation overhanging or surrounding the tube
- Air conditioning outlets
- Extractor vents
- Underground ventilation shafts
- Underground parking
- Parking exits, air outlets or fans
- Traffic lights
- Taxi or bus stops

Certain surfaces may act as pollutant absorbers, leading to reduced air concentrations immediately next to the tube. For this reason, ideally, tubes should NOT be mounted directly onto a surface i.e. the facade of a building.

To measure children's exposure to air pollution, install the tubes in locations where children stay or pass by (i.e. walking, cycling, etc.). For school settings:

- A measurement point should be at the main entrance of the educational centre. If there is another entrance on another street, a point could also be located there.
- The rest of the points can be located in places where you want to determine the NO_2 levels. Examples:
  - Streets or paths going to school
  - School drop-off and/or pick-up points
  - Streets connecting the school to the most central part of your neighbourhood or city
  - Streets for walking or sitting
  - Spaces where children go to play
- These points can be classified in two types: *traffic* and *urban background* (this allows better interpretation of the results):
  - Traffic points are located within the streets where motorised vehicles pass. The tubes should be placed within less than 10 metres from the road. The tubes may be located, if possible, on lamppost/street lights and traffic signs.
  - The urban background points are those located more than 25 metres from traffic, such as parks, squares, green areas or pedestrian streets.

Choose sites to place tubes in each of these two types of locations. Install at least 10% of tubes in urban background points. Place one tube at each point of interest.

The time required to install and collect the tubes will depend largely on the number of tubes and their location, but as a guideline, it can be assumed that half a day will be required to install the tubes and another half a day to collect them.

For quality control purposes, it is highly recommended to install two tubes (three, if possible) next to the NO_2 monitoring reference equipment of the nearby government environmental control station during the sampling period, if possible the exact same days. This will allow the comparison of the tube results with reference data.

> **Note**
> If your campaign is being done in collaboration with a school, install tubes inside the classroom and on the patio or playground. The tube on the playground should be installed away from the street; if there is more than one playground, you can install a tube in each. For the tube located inside a classroom or a communal space, install it preferably facing the busiest street around the school.

3.2. Options to register the tube locations

For every monitoring campaign, it is important to register the installation location of each tube. There are three mapping methods to register the measurement points you have previously selected: one is a paper map and two are digital. In all three methods, the map can be shared with other relevant stakeholders or school communities.

The ways to generate a map are:

- Paper printed map
- CleanAir@School mobile application
- My Maps - Google

3.2.1. Paper map

It is not necessary to use digital platforms to locate the points correctly, you can use a printed paper map to mark the points where you want to place the tubes. During installation, take the map to go to the previously selected measuring points that are marked on the map. If there are any changes during installation, these should be noted on the paper map and exposure sheets.

3.2.2. CleanAir@School Mobile Application

This mobile app is a tool that allows recording of geolocation data, time of installation/collection, tube QR code, etc. A small fee is required to use the web and mobile application in order to set up the individual activities in the platform. This price can vary depending on the size of the campaign, and the number of schools involved (if any), among other factors. To obtain more information on how much this can cost for your campaign, contact 4sfera Innova (info@4sfera.com).

Download the app

Android
https://play.google.com/store/apps/details?id=com.i4sfera.greenscent&pli=1

iOS
https://apps.apple.com/es/app/cleanair-school/id6466443487

To use the web and app, you can find a detailed step-by-step on how to use them in the following formats:

- **Youtube video** with all the steps you will need to follow to use the web. See Video.
- **Annex A** details the steps on how to register the measurement points previously selected, and how to install and collect them. See Annex A.

3.2.3. My Maps - Google

My Maps - Google is a tool that allows you to create maps with the places that are of your interest, add points, shapes, and share them with others. This tool, however, does not give any information about the tubes other than their location. To use My Maps, sign in to My Maps with your Google account. For a detailed step-by-step guide on how to create a map, locate the measurement points, etc. See Annex B.

3.3. Blank Tubes (Control Tubes)

For quality control, two Blank Tubes should be used for each batch of tubes to ensure that no quality control problems have occurred (see Section 2.5).

3.4. Attaching the tube supports

It is important to always use a strongly attached support to hold each tube. Supports should be at a sufficient height —at least 2.5m above the ground— to avoid theft and vandalism. The support ensures that the tube is slightly separate from the surface where the tube is attached to (Figure 5). Using a stool or ladder, the support should be fixed to a lamp p ost/street lights, traffic sign, or similar using cable ties. Safety is essential, so never install holders or tubes if it is not safe to do so.

Figure 5 NO_2 diffusion tubes with a support

3.5. Installing the tubes

A minimum of two people is recommended to install the tubes, as this makes the process easier and faster, and reduces errors. For collaborative projects with schools, the best way to install the tubes is to organise teams of 5-6 people, with each group placing tubes in a separate area. Each person/student can do one task so the activity becomes more dynamic.

Once all the locations have been chosen and the working groups have been defined, the installation of the supports and the tubes can start.

There are two different methods for recording installation, digital or paper. Steps 1 through 5 are the same for both. However, the method of registering the measurement points is different.

- **Digitally**, using the CleanAir@School mobile application.
- Or using the paper copy exposure sheet.

(Note: this process is different from registering the tube location, which has three options as described in the previous section).

Before installing the tubes, ensure that you have all the necessary materials with you (specified in Section 2.1). Depending on whether you carry out the registry digitally / on paper or both, ensure that each group has:

- **Digitally**, an electronic device (tablet or smartphone) - with the mobile application downloaded and all locations visible (via the CleanAir@School app). Beforehand, you will have to log in with the username and password obtained for each group (you will need an internet connection for this step) so you can see the points allocated to you and your team.
- Or using the **exposure sheet** and an electronic device to take pictures.

For measurements done in groups, we recommend that each group plan their route in advance. This will ensure that each group has the number of tubes required for the agreed locations and that points are installed the correct distance from each other.

Remove the tubes from the refrigerator on the same day that they are to be installed. Take the tubes to the study area in a sealed plastic bag or plastic container. Remember to also take the Blank Tubes (if you create groups, one group can take them).

Figure 6 ***NO_2 diffusion tubes installed on lampposts***

To install the tubes:

1. When you arrive **at a selected measurement point, assemble the tube support in a safe place**. The support has to be fixed to a lamppost, traffic sign, or similar, using cable ties (see Section 3.4) (Figure 6, above).
2. **Label each tube with its QR code sticker** (this task can also be done beforehand, see Section 2.6).
3. **Remove the white cap** and place it inside the bag/box, you will need it for the tube collection afterwards. It is advisable to have extra caps in case they get lost (you can buy a few extra caps when ordering the tubes).
4. **Place the tube vertically on the support**, leaving the lower end of the tube opened (uncapped) to allow the air to enter. The grey cap should be at the top end and must always be left on.
5. **Take a photograph of the tube in place**. This step is mandatory for the mobile application and highly advisable for the paper method. The picture should include the surroundings of the site, including the specific location the tube has been installed. This is very useful for future reference when collecting the tubes and when interpreting the results. If you are using the app, you can take up to a maximum of 5 photos (one from each side plus a very close one where you can see the QR code number).

If you are using the CleanAir@School mobile application, see Annex A to find a more detailed step-by-step process.

Installation using the paper exposure sheet

A paper copy of the exposure sheet should always be filled in to record the time and date of installation and collection, location, QR code and any other relevant information for each tube (Figure 7). The laboratory needs this information in order to calculate the mean NO_2 concentrations during the exposure time. The exposure sheet is provided along with the tubes when these are purchased, and can usually also be downloaded online through the provider's website.

Figure 7 Exposure Sheet with the main information required.

Exposure Sheet NO_2

Institution Name	
Contact Person	
SOR Number	
Type of Tube	
Job Reference	

Tube Code / Number	Barcode / QR Code	Location (location where the tube is deployed)	Date on (dd/mm/yy)	Time on (hh:mm)	Date off (dd/mm/yy)	Time off (hh:mm)	Comments
SM-01-Aribau1	1003039	Arribau Street 37	07/02/24	09:45	06/03/24	09:20	

Once each tube is identified with its QR code, the installation and registration process is as follows:

1. Fill in the **exposure monitoring sheet** clearly with the supplied QR code stickers. In case you have another code associated with each point you can also note it here.
2. **Record the date and time** of the start of the measuring period on the exposure sheet once installed.
3. Any **relevant comments** associated with the measurement point can be added, for example additional information about the location or conditions.

Note

It is advisable to check the condition of the tubes and report any incidents during the measurement period. This can be done periodically by those participating.

3.5. Removing the tubes

After the measurement period is finished, return to the locations where you installed the tubes and collect them. Bring the exposure sheet that was used for the tube installation.

To collect the tubes:

1. **Review and validate** all the information at each tube location.
2. **Close the tube** by putting the **WHITE cap** back on the tube. If you do not have a cap you can cover it with cellotape, well wrapped to prevent any contamination which could impact the results.
3. **Write the time and date** down on the exposure sheet.
4. **Make a note of any site irregularities** (e.g., building/road works, traffic diversions), also anything that might affect, or even invalidate, the tube's results (e.g., tube found on the ground, dirt, insects, or liquid inside the tube). If you find spiders or any other insects, leave them inside and record it on the exposure sheet.
5. Once the collection of the tubes finishes, **store the tubes** inside the plastic bag and keep them in the fridge until they are sent to the lab.

3.6. Sending the tubes for analysis

Tubes should be returned to the lab for analysis as soon as possible after they are collected. However, if you store them in a refrigerator, you can collect more tubes for a few weeks and send a larger number of tubes to the lab before the expiry date. The exposure sheet, including the opening and closing date and time, should also be sent along with the tubes in a paper copy, and also online through the email (ie. a scanned copy or Excel spreadsheet.) Please keep a copy of the exposure sheet for your re-cords. The tubes should be returned in a sealed container, such as the plastic bag that they are sent in. They do not need to be sent refrigerated.

Please contact your local distributor in case you need further information regarding the mailing process, as customs and regulations may vary by country. For example, the UK charges entry fees to send the tubes, and they also may need some extra information. Your local distributor will also inform you about the need to have a non dangerous content letter and a proforma invoice when sending the tubes.

4. Interpreting the results & case studies

The lab will send an analysis report through email with the results (see Figure 8 for an example), including the NO_2 concentrations of each tube. The time to receive the results is usually several weeks but may vary depending on external factors, such as airport customs and regulations. Results are reported in micrograms per metre cubed (µg/m3), and also in parts per billion (ppb).

Figure 8 Example of a laboratory analysis report. *1) Internal Code assigned to each tube installed; 2) This is the QR Code assigned to each tube; 3) This is the number of hours that the tube has been exposed for this specific campaign.*

Laboratory Analysis Report

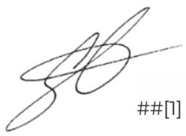
Institution Name: Q06891R
Job Reference: character (0)
Date of Report: 2022-09-06

Site	Sample Number	Exposure Data		Time (h)	$\mu g/m^3$*	ppb*	µg NO_2	Lab Comments
		Date On	Date Off					
Barcelona_street_point_1	2024780	2022-06-30	2022-07-14	336	32.44	16.93	0.79	
Barcelona_street_point_2	1875643	2022-06-30	2022-07-14	337	34.44	17.77	0.83	
Girona_street_point_1	187644	2022-06-30	2022-07-14	336	27.69	14.45	0.68	
Girona_street_point_2	187645	2022-06-30	2022-07-14	337	29.01	15.14	0.71	
Laboratory Blank	NA	NA	NA	336	0.16	0.09	0.00	

Note:
(*) Results have been corrected to a temperature of 293 K (20°C).
Comments: Results are not blank substracted.

- Overall M.U.: ±9.7%
- Detection Limit: 0.030 mg NO_2
- Date of Analysis: 2022-08-30

Analysis carried out in accordance with documented in-house Laboratory Method GLM7.
This signature confirms the authenticity of these results.



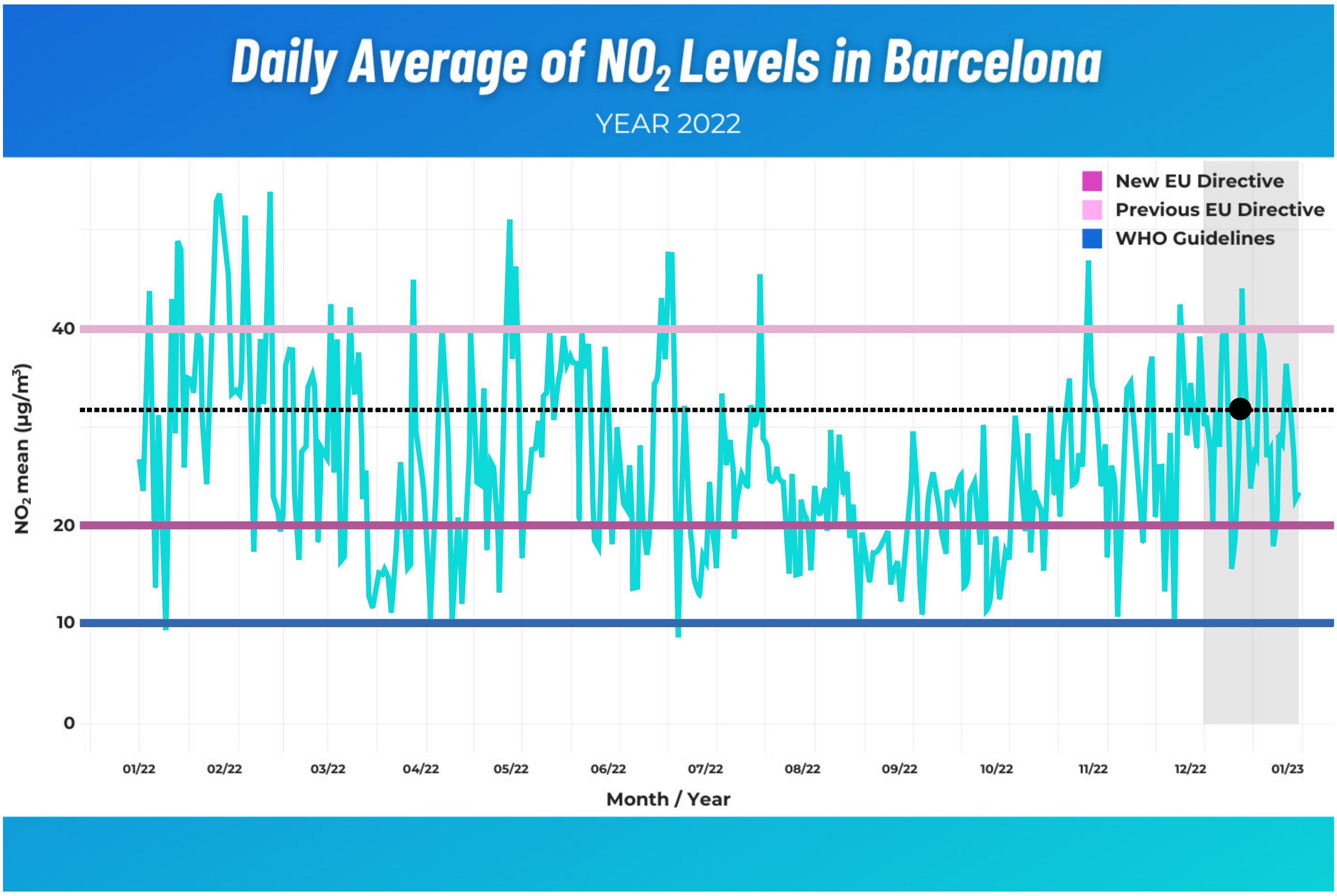
##[1] "Signed: ___name___, Data Analysis Manager"

The Palmes-diffusion NO_2 tube method for air quality monitoring is an affordable way to increase the number of air pollution measurement points and target specific areas. This can be useful to measure trends over time and indicate impact trends of policies or interventions.

The tubes provide an NO_2 exposure average for a period of 2-4 weeks, depending on the length of the campaign. Thus, when interpreting the laboratory analysis report, it is important to note that the concentration is averaged over weeks, while the WHO AQG and the EU AAQD use yearly averages. Because air pollution levels can vary across weeks and months of the year, the levels obtained from measuring 2-4 weeks do not represent the variations and the average across a longer time period. For example, there could be an air pollution peak that happens outside the tube measurement period. Or conversely, the tube measurement could be during a pollution peak that is not present in other times of the year. Therefore, direct comparisons between these methods are not feasible, and this should be taken into account and acknowledged when interpreting and presenting the results.

Often, contextualising the results of a measurement period makes it easier to interpret and communicate them. For example, in the following graph (Figure 9), the red line shows the daily mean fluctuations of NO in Barcelona throughout 2022. As expected, pollution levels vary throughout the year. Having this information allows us to know the levels of pollution of the area/city when the measurement campaign was done. The black dot represents the mean NO_2 concentration for a tube that was exposed for 4 weeks. In this case it was 31.74 µg/m³. The 4-week measurement period is indicated by the vertical grey band. For reference, the light pink line indicates the annual legal limit set by the previous European Union AAQD (40 µg/m³) and the dark pink line indicates the new EU AAQD (20 µg/m³); the blue line indicates the current WHO recommendation (10 µg/m³). This graphic presentation of the results allows easier interpretation and helps show the results of a specific tube within the more general air pollution context of the city.

Figure 9 **Daily average NO_2 levels in Barcelona during the year 2022**



Occasionally, you may find a result that seems abnormal for a particular location, such as unexpected very low or high levels, compared to the rest of the measurement tubes in a similar area. In these cases, we may have to consider if: a) the tube is/was defective, b) something out of the ordinary happened during the measurement period; or c) the information was recorded incorrectly on the exposure sheet. In these cases the result should be disregarded from the analysis and reporting.

In cases where NO_2 diffusion tube measurement campaigns need to be more compatible with other air pollution measurements, it is advisable to conduct NO_2 measurements with diffusion tubes repeatedly over an extended period of time (which would require multiple measuring campaigns throughout the year). This systematic approach increases accuracy and reliability in assessing air quality trends and making informed decisions based on the data collected.

Communicating results – case studies

Measurement campaigns can be useful for raising awareness and advocacy about air pollution around school environments by engaging citizens and providing data. Regardless of the results obtained, it is essential to present the results objectively and be clear about the limitations.

Usually, in order for the information from the laboratory analysis to be communicated to diverse audiences, it is useful to transform the data into more visual formats such as maps or graphs. A web search for your city or region might provide examples of how other projects have communicated results. Or you can look for examples on the EU Citizen Science Portal (https://eu-citizen.science/).

Below are examples of previous citizen science projects using tube measurements and how they communicated their results and interpretation:

- **Case study 1**: xAire study, Barcelona, Spain
- **Case study 2**: Breathe London, London, UK
- **Case study 3**: CleanAir@School, Girona, Spain

Case Study 1
***xAire Study**, Barcelona, Spain*

The xAire project carried out in 2018 aimed to increase the local air quality data available by installing 800 NO_2 diffusion tubes distributed in each neighbourhood around schools. These measurements complemented the data gathered by the existing government fixed measuring stations in Barcelona. Additionally, the project sought to raise awareness about air quality and empower approximately 1,650 participants, including schools and families.

To effectively communicate the results, they created an interactive map, where the air quality levels were summarised in three categories to give a general overview of how "good" or "bad" the air quality was for each measurement location (Figures 10 and 11). The air quality rating system was on a scale of:

- for values **0 µg/m³** to **10 µg/m³**: **very good**
- for values between **10 µg/m³** and **20 µg/m³**: **fair**
- and anything above **20 µg/m³**: **bad**, considered poor air quality and considered unhealthy.

This rating system was based on the EU AAQD at the time (these have now changed and are lower) and allowed the identification of pollution hotspots and safer areas for health in a way that is easier for interpretation. These results were indicative for the measurement period, and were not presented as an official or legal description of the air pollution levels in that area. However, they were powerful for communication and awareness raising and covered a much more diverse and local number of points than the official monitoring stations. Participating school children presented the map and results to the mayor and city council officials, and the results were publicly available.

***Figure 10** xAire interactive map of Barcelona*

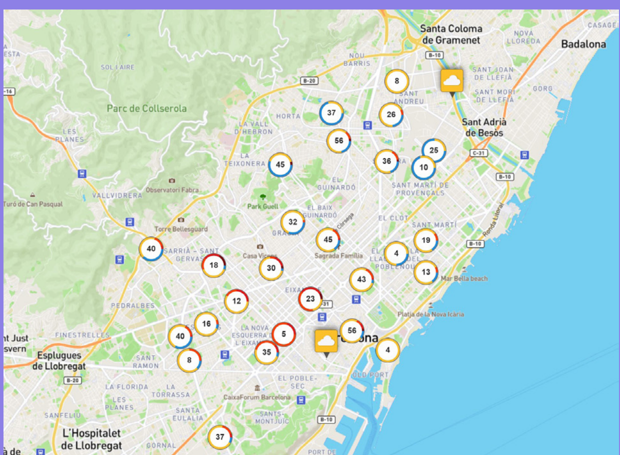
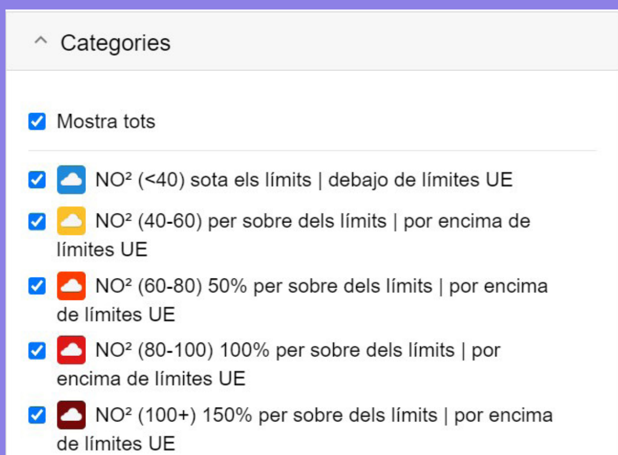


***Figure 11** Legend of the interactive map from the project xAire*



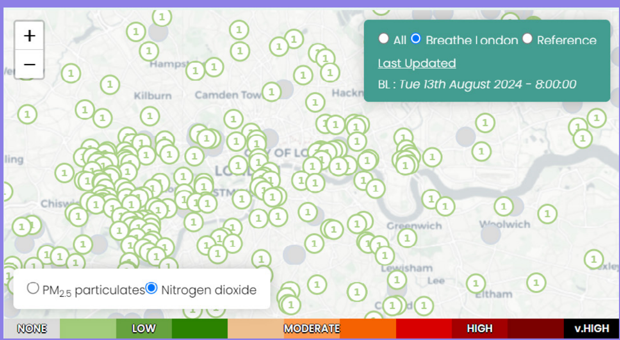
Case Study 2
Breathe London, London, UK

The aim of this study was to characterise London's school children's exposure to air pollution and to present this information in a way that the school community could directly relate to.

During spring 2019, five London primary schools from the boroughs of Richmond, Greenwich, Haringey, Hammersmith and Fulham, and Royal Borough of Kensington and Chelsea took part in the project. Over 250 children and 33 teachers across the five schools were given wearable NO_2 tubes to carry to and from school for a period of five school days.

To communicate the campaign results, Breathe London developed an innovative online platform to share and visualise air pollution data. Several important steps were taken to promote public access and simplify the process for others to access the data and replicate the platform. Aimed at advancing the understanding of spatial and temporal patterns of air pollution in London, the data presented highlighted the variability of pollution levels at different times and locations across the city, accessible for diverse users, including the general public, citizen scientists, and academics (Figure 11).

***Figure 12** This map shows the average pollution levels in London from monitoring data collected during the Breathe London pilot project. The colour of the points depend on the concentration of pollution*



Case Study 3
CleanAir@School, Girona, Spain

In November 2023, primary school students participated in the CleanAir@School activity monitoring at 20 locations in and around each of the 10 schools, in Girona, Spain.

Teachers and students from each school planned their 20 locations using the CleanAir@ School platform. The majority of locations were traffic points (locations within the streets where motorised vehicles pass, as explained in Section 3.1). Urban background points were chosen in nearby parks.

Two groups of students accompanied by a teacher installed the NO_2 tubes and collected them after 4 weeks. The activity was done using mobile phones with the CleanAir@School mobile application to facilitate data collection (Figure 12). The tube supports were attached to lamp posts and traffic lights (Figure 13).

Figure 13 Student scanning a tube before installing it

Figure 14 Student placing a NO_2 tube in a specific location

After 4 weeks, the tubes were collected and sent for analysis. All tubes were analysed together. The results were validated by air quality experts from 4sfera Innova who prepared short reports with the results. These were distributed to all participant schools and technicians from Girona's Municipality.

The results were presented to all the schools together at the Girona City Hall, using maps with more than 200 locations (Figure 14). At each school, the results were analysed and presented by students in their classroom.

Results show great variation of NO_2 levels across the city (Figure 15). As anticipated by students, concentrations were higher at traffic points compared to the background locations. Lower pollution levels were found at schools at the outskirts of the city. These schools are located in less built up areas and closer to larger parks and forests.

Figure 15 NO_2 levels in November 2023 in Girona from 10 schools

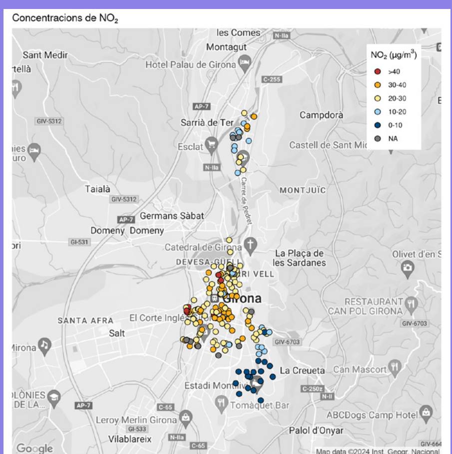
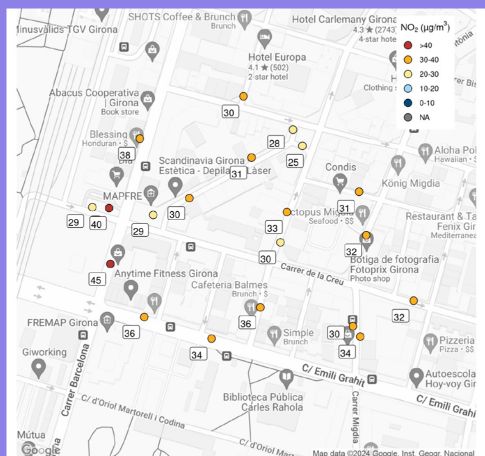


Figure 16 NO_2 levels in November 2023 around Dr Masmitjà school



Conclusion

NO_2 air quality monitoring campaigns using diffusion tubes are an effective and efficient way to help urban residents identify and understand local air quality conditions related to TRAP. By following a standardised protocol, results are more reliable and can be compared with other campaigns or campaigns repeated in the same location at different times. Since air quality can have significant short and long term impacts on health, especially for children, it is important that communities can use these tools to gather, analyse and use data. Improving air quality around schools and monitoring the impact of policies and interventions are important and achievable public health goals.

Acknowledgements

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Annex A. CleanAir@School App Cheatsheet

CleanAir@School App Cheatsheet

This web app is designed to be used with NO2 tube measurements. It allows you to locate each point, assign an identifying name and also differentiate points by each group.

1 Locating the tubes

Full explanation in video: youtu.be/yE0Fji-bn0Y

- Go to **greenscent.4sfera.eu** and sign in with your username and password (provided by 4sfera).
- Once inside, on the left hand side, you will a list of tubes you have available for the measurement area, numbered with a generic code.
- **Click on the tube you want to locate** from the list and click on the point on the map where you want to place it.
- Once the tube has been placed on the map, you can click on the location symbol to add a descriptive name to differentiate it from the others.
- Whether the installation and collection of the tubes is **organised into different groups**, or in one large group, it is mandatory to **assign all tube locations to a group** using the web interface. Any point that is not assigned to a group will be discarded.
- Click on the "**Finalise the placement**" button so that the data is sent to the mobile application: the status will change to "Tubes to be installed".
- If you want to download the data for printing, you can do it either in Excel or a map by clicking on "Export table" or "Export map".

2 Installing the tubes

Make sure you have all the necessary equipment and the mobile app with you before going to the locations.

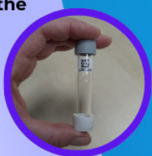
- **Select** in the app the **measurement point** where you are and **scan the QR code** of the tube to record the time and date of installation (the QR code should already be attached to the tube).
- **Take a photo** of the tube installed including the surroundings; this will help contextualizse the location of the tube. Take a maximum of 5 photos.
- If you do not install exactly where you originally planned, click where you are on the map and click on "**Save New Location**".
- When all the tubes of your group have been installed, click on "**Finish Placement**" (status will change to "Tubes to collected")

Note

It is advisable to check the condition of the tubes and report any incidents during the measurement period. This can be done periodically by those involved.

After a few weeks... Time to collect!

3 Collection of the tubes



- Go back to the installation points to **collect the tubes**. Select in the app the **measurement point** where you are.
- **Scan the QR code** of the tube to record the time and date of collection.
- Any relevant comments can be added, such as how busy the road is, the status of the tube or in case anything unusual is happening.
- When all tubes of your group are collected, click on **Finish Collection** (status will change "All groups collected")

Note

If the tube is not at the location, for whatever reason, click on the "Missing" button.

4 Return the tubes for analysis and wait for your results!

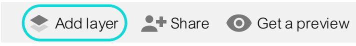
4sfera ISGlobal Barcelona Institute for Global Health CleanCities

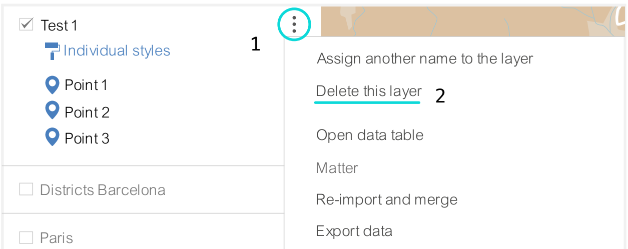
Annex B. Mapping with My Maps - Google

My Maps - Google allows you to create maps with the places of interest, add points, shapes, photos and videos, and share them.

How to create a map

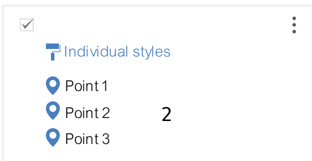
1. To use My Maps, **sign in to My Maps** with a Google account. If you're having problems using My Maps, try updating your browser.
2. **Create a map**. On a computer, sign in to My Maps. Click "Create a new map". At the top left, click "Untitled map" and give your map a name and description.
3. **Add map layers**. Maps are created with one layer, but you can have up to 10 layers. In your map you'll see your layers in the box on the left. To add a layer, just click "Add layer", then click the title and add a name.

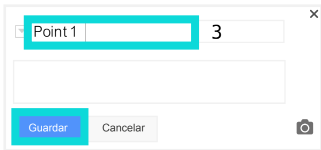




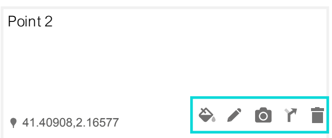
Actions you can perform on a map

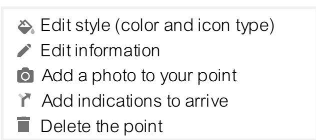
1. **Add places to your map**. You can add important places by searching for locations or drawing them directly on the map. To add a place, first click on the "Add marker". Then select a layer and click where to put the place. Finally, give your place a name and click save.





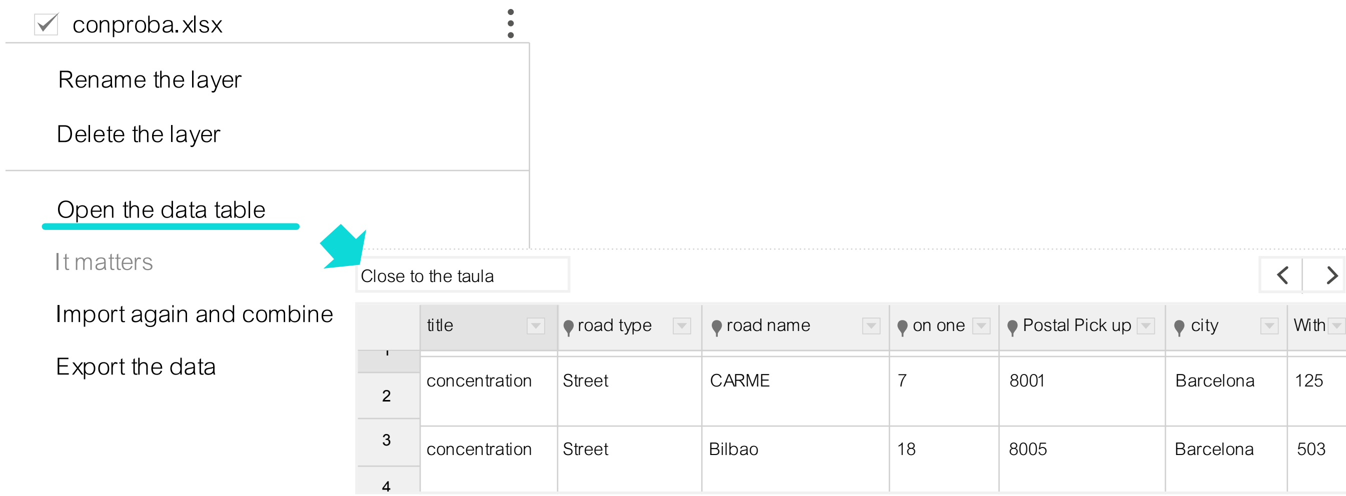
2. **Edit a place**. Click an existing place on the map. In the bottom right of the box that appears, use the icons to make changes.





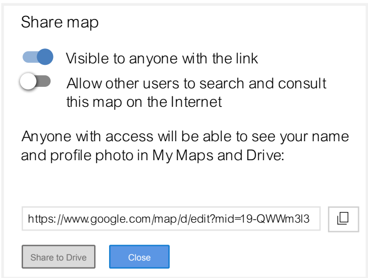
3. **Hide or show everything on a layer**. To do this, you need to uncheck or check the layer.
4. **Move places**. Drag the feature on the map.
5. **Import map features from a file**. You can import map features like lines, shapes, and places to your map from KML files, spreadsheets and other files.

6. **Import files or images into the map**. Make sure the information you want to import is one of these file types: **CSV, TSV, KML, KMZ, GPX, XLSX** or **Google Sheet**. In the map legend, click "Add layer". Under the new layer, click Import, upload the file or photos that have your info. Then click "Select". By clicking on "Open the data table", you can modify the values of the imported file on My maps.



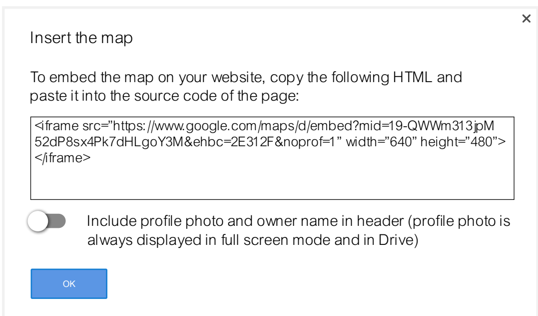
	title	road type	road name	on one	Postal Pick up	city	With
2	concentration	Street	CARME	7	8001	Barcelona	125
3	concentration	Street	Bilbao	18	8005	Barcelona	503

7. **Share, download, or print your map**. You can share your maps with others online, download their info for other apps, or print them out. At the top of the thumbnail, on the right, click Share map and select how you want to share your map. Follow the onscreen instructions. Also, you can edit access to your map in the left panel, clicking on Add collaborator.



8. **Download map info**. In the left panel, click Menu More and then Export to KML/KMZ. Download layer info. You can export individual layers to CSV, but not Maps. In the left layer panel, click Menu More and then Export data and then CSV.

9. **Add your map to a website**. In the left panel, click Share or Menu More and then Embed on my site. Make sure the map is public.



Annex C. NO_2 air quality guidelines and references

Air pollution is a global problem with local consequences, as it affects ecosystems and people's health, especially of those most vulnerable. Effective actions to reduce air pollution, and its impacts, require knowledge of its causes and sources. High levels of NO_2 concentrations in urban areas have been linked to increases in disease and mortality. NO_2 pollution is a child health challenge in cities given that many schools are located in areas that do not meet air quality guidelines.[5]

C1. Sources of nitrogen dioxide

NO_2 is a component of nitrogen oxides, and the primary human-made sources of NO_2 include emissions from transportation (such as motorised vehicles of different sizes, shipping, and aviation), power plants, industrial activities, and agriculture.[6] NO_2 is particularly useful as a marker for human-made fuel combustion, especially from traffic, and in urban areas. It is a widespread air pollutant that serves as a precursor to ground-level ozone and PM2.5, both of which are major contributors to air pollution-related deaths. Trends in NO_2 concentrations can be used to assess the effectiveness of air pollution regulations and to understand the impacts of sudden changes in emissions, such as those seen during COVID-19 lockdowns. NO_2 is considered the main traffic-related air pollutant (TRAP) and is used as a toxicity indicator in motor vehicle exhaust.[7]

C2. Nitrogen dioxide and its health effects

NO_2 is a highly reactive gas that can irritate the human respiratory system. Evidence shows significant associations between NO_2 exposure and increased asthma development in children, increased risk of asthma-related exacerbations, and asthma-related emergency department visits. NO_2 exposure is also associated with the development of atopy, wheezing, and airflow obstruction in children with asthma attending schools with high NO_2 concentrations. In a 9-year study based in Spain, while the NO_2 levels were below 30 µg/m³ during the nine years, they found associations between increased NO_2 concentrations and increased emergency department visits for asthma.[8] Short and long-term childhood exposure to NO_2 is associated with high blood pressure, and increased prevalence or risk of hypertension in children and adolescents, and it is significantly associated with risk of childhood obesity and higher BMI. Currently, air pollution is one of the main threats to child health worldwide.

A summary of health impacts on child health can be found on the ISGlobal Blog.

C3. Air quality monitoring and WHO air quality guidelines

The initial release of the **World Health Organization (WHO) Air Quality Guidelines (AQG)** for Europe occurred in 1987 and was revised in 2005 (referred to as the second edition) and most recently in 2021. The AQG describe the health risks associated with 37 of the most common air pollutants (Figure 1).

While the AQG are not legally binding, they are formulated based on expert assessment of current scientific knowledge to provide recommendations for reducing the health effects of air pollution. These guidelines serve as a valuable resource for governmental authorities as they develop health-based national air quality management strategies.[9] The implementation of ambient air quality standards globally has greatly improved air quality in many regions compared to levels before they were established, and prompted improvements in air monitoring, technological advancements in

[5] Anenberg, S. C., Mohegh, A., Goldberg, D. L., Kerr, G. H., Brauer, M., Burkart, K., ... and Lamsal, L. (2022). Long-term trends in urban NO_2 concentrations and associated paediatric asthma incidence: estimates from global datasets. *The Lancet Planetary Health*, 6(1), e49-e58.

[6] Anenberg, S. C., Mohegh, A., Goldberg, D. L., Kerr, G. H., Brauer, M., Burkart, K., ... and Lamsal, L. (2022). Long-term trends in urban NO_2 concentrations and associated paediatric asthma incidence: estimates from global datasets. The Lancet Planetary Health, 6(1), e49-e58.

[7] Favarato, G., Anderson, H. R., Atkinson, R., Fuller, G., Mills, I., and Walton, H. (2014). Traffic-related pollution and asthma prevalence in children. Quantification of associations with nitrogen dioxide. *Air Quality, Atmosphere and Health*, 7, 459-466.

[8] Albi, T. R., Izquierdo, R. L., Hernández, A. C., Torrero, F. M., Díez, P. B., Álvarez, D., and del Campo Matías, F. (2021). Influencia del dióxido de nitrógeno ambiental en las consultas a urgencias por asma en un entorno con baja contaminación: análisis de series temporales y casos cruzados. *Emergencias: Revista de la Sociedad Española de Medicina de Urgencias y Emergencias*, 33(6), 421-426.

[9] Krzyzanowski, M., and Cohen, A. (2008). Update of WHO air quality guidelines. Air Quality, Atmosphere and Health, 1, 7-13.

emissions control technology, and the adoption of environmentally sustainable practices in various industries. This in turn, has led to health benefits.

Figure 18 ***Environmental station in Barcelona***

Urban air quality can be assessed using different scales of exposure measurements at the local level and are useful to compare the current state with WHO guidelines and EU Directives. Environmental stations give city-level measurements and are usually a good way to have annual averages (Figure 17). However, the number of stations in each city may be limited, and therefore might not capture local variations or identify hotspots in pollution levels. Other types of sensors can provide air quality values at the local level, available for the general population, such as the Palmes diffusion NO_2 tubes. The new EU AAQD also revises the air pollution monitoring and reporting systems for member states and should improve the data available as well as comparison among different regions.

Annex D. Palmes Diffusion NO_2 Tubes

D1. Components of the tubes

- **Tubes**: These are 7 cm tall and 1.4 cm wide (Figure 2).
- **Grids**: Two grids are used per tube, located at the coloured end cap (usually grey colour). .
- **End caps**: The coloured cap contains the absorbent. Coloured end caps may be re-used, but must be discarded when the colour begins to fade.

Note

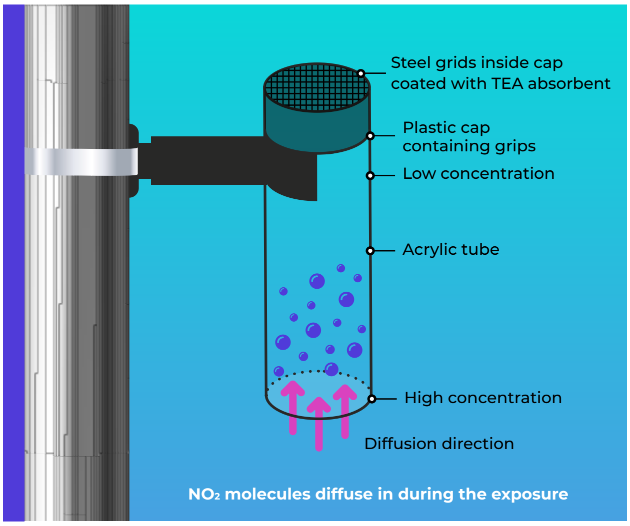
Diffusion tubes are ready-made from a supplier, so reject any that arrive with split or damaged end caps.

D2. How Palmes diffusion tubes work

The Palmes diffusion tubes operate based on the principle of molecular diffusion of NO_2, where NO_2 molecules naturally move from areas of high to low concentration (Figure 18). These tubes are passive samplers, meaning they do not require any external power source to operate.

The tubes are small glass tubes containing a chemical reagent, in this case, triethanolamine (TEA), which acts as an absorbent agent to trap NO_2 directly from the air. The TEA is coated onto stainless-steel mesh grids located at the closed end of the tube, typically using a water-based or acetone-based solution. When exposed to air, NO_2 molecules diffuse into the tube and are absorbed by the TEA. Over time, the concentration of NO_2 trapped by the absorbent increases, allowing for precise measurement and analysis. These tubes are especially effective for detecting high NO_2 levels from stable sources like traffic emissions.

Figure 19 Molecular diffusion process in the NO_2 tube



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