Evaluation of Air Pollution Monitoring in Bogotá, Colombia

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Introduction

A wide variety of chemicals and substances contribute to air pollution. Pollutants can be gases, such as nitrogen dioxide (NO_2), harmful vapours or tiny particles of solid or liquid material that has become suspended in the air (called particulate matter). Box 1 briefly describes the air pollutants discussed in this report.

Box 1: Types or air pollution

Particulate Matter (PM_{10} and $PM_{2.5}$)
Pollution in the form of small liquid or solid particles suspended in the atmosphere. This type of pollution is described according to the size of the particle, rather than the chemicals within them. PM_{10} refers to particles that are less than 10 micrometres across, sometimes known as coarse particulate matter or respirable suspended particles (RSP) because they can be breathed into the lungs. $PM_{2.5}$ refers to particles that are less than 2.5 micrometres across, sometimes known as fine particulate matter or fine suspended particles (FSP). The particles are small enough to penetrate the lung barrier and enter the blood system.

Sulphur Dioxide (SO_2)
A gaseous air pollutant produced by the combustion of fuel that contains sulphur. This can include fossil fuels like coal and oil. Sulphur dioxide is toxic and has been linked to many health impacts. Sulphur dioxide can also react with moisture in the air causing acid rain.

Nitrogen Dioxide (NO_2)
A gaseous air pollutant produced by all combustion processes, including from fossil fuel use in vehicles and

power stations. Nitrogen dioxide is toxic and has been linked to many health impacts. Nitrogen dioxide can also react with moisture in the air causing acid rain, and in the presence of sunlight and VOCs (see below) it can contribute to the formation of ground level ozone, sometimes called photochemical smog.

Ozone (O_3)
Ground level ozone is a gaseous pollutant that forms in the atmosphere when other pollutants such as NO_2 and VOCs react. It contributes to damage from acid rain, can damage plants and crops and can cause respiratory problems in people. It is toxic to humans.

Volatile Organic Compounds (VOCs)
These are chemicals that contain carbon and which evaporate readily. An important source of VOCs leading to air pollution is evaporation from fossil fuel during use, storage and transportation. Many VOCs are toxic to humans.

The principal sources of atmospheric pollution within the study area are road transport emissions, the resuspension of particulate matter (dust), industry, and commercial activities such as restaurants and street vendors (Pachón et al., 2018). An inventory of emissions for Bogotá for the year 2012 found that mobile sources dominated emissions of CO_2 (80%), CO (99%), VOC (68%), NOx (95%), and SO_2 (85%). More recent emission studies continue to find that road emissions dominate; for example, it is estimated that approximately 80% of $PM_{2.5}$ particles are generated by mobile sources while the remaining 20% are provided by stationary sources (Ministry of Environment and Sustainable Development, No Date).

Colombian national regulations provide the policy framework for air quality management in Bogotá. These regulations set thresholds for the average daily concentrations of key air pollutants (Ministerio de Ambiente y Desarrollo Sostenible de Colombia [MADS], 2017) (Table 1). The World Health Organisation also publishes Air Quality Guidelines (Table 1), which are a widely used benchmark for assessing air quality, with regard to minimising health impacts. In most cases the WHO guidelines are stricter than those described in Colombia's local regulations.

Table 1: Maximum allowable levels for selected criterion contaminants in the Air, MADS Resolution 2254 (2017) and World Health Organisation Air Quality Guidelines (2005)

	MADS Resolution 2254		WHO Guidelines		Comparison with MADS Resolution
Pollutant	**Concentration (µg/m3)**	**Averaging period**	**Concentration (µg/m3)**	**Averaging period**	
PM_{10}	50	Annual	20	Calendar Year	WHO stronger
	100	24 hours	50	24 hours	WHO stronger
$PM_{2.5}$	25	Annual	10	Calendar Year	WHO stronger
	50	24 hours	25	24 hours	WHO stronger
SO_2	50	24 hours	20	24 hours	WHO stronger
	100	1 hour	500	10 minutes	No direct comparison
NO_2	60	Annual	40	Calendar Year	WHO stronger

	200	1-hour	200	1 hour	Equal
O_3	100	8-hours	100	8-hours	Equal

Source: District Secretariat of Environment[1]

Air pollution monitoring network overview

A network of air quality monitoring stations, the Bogotá Air Quality Monitoring Network (its Spanish acronym is RMCAB), is operated in Bogotá by the District Secretariat of Environment. It includes 13 fixed automatic monitoring stations and one mobile station. Since 1998, the monitoring network has measured levels of pollutants including PM_{10}, $PM_{2.5}$, CO, NO_x, NO_2, SO_2, and O_3 (Mura et al., 2020).

For the current study, measured hourly mean concentrations of NO_2 and $PM_{2.5}$ were obtained for all stationary monitoring sites operating as part of the Bogotá Air Quality Monitoring Network (RMCAB) reporting those pollutant species (Table 2, Figure 1).[2] The results from the official monitoring were downloaded from the website of the Bogotá District Secretariat of Environment.[3] Annual mean concentrations are shown in Table 3 and reveal that, while pollution monitors rarely record exceedances of the annual mean WHO guideline levels for NO_2, annual mean concentrations for both $PM_{2.5}$ and PM_{10} regularly exceed WHO guidelines. Exceedances of the standards described in MADS Resolution 2254 are less frequent because these standards are less strict.

Table 2: Bogotá Air Quality Monitoring Network (RMCAB) Stations

Station	**Latitude**	**Longitude**	**Altitude (m)**	**Sampling height from ground (m)**	**Station type**
Bolivia	4.74	-74.13	2574	4.6	Background
Carvajal - Sevillana	4.60	-74.15	2563	6	Traffic Industrial
Centro de Alto Rendimiento	4.66	-74.08	2577	4.6	Background
Fontibon	4.67	-74.14	2591	15	Industrial
Guaymaral	4.78	-74.04	2580	4	Background
Kennedy	4.63	-74.16	2580	7	Background
Las Ferias	4.69	-74.08	2552	4.6	Of traffic
Puente Aranda	4.63	-74.12	2590	13	Industrial

[1] District Secretariat of Environment. 2021. http://ambienteBogotá.gov.co/ (Accessed 10 March 2021)

[2] District Secretariat of Environment, Bogotá. http://ambienteBogotá.gov.co/estaciones-rmcab Accessed 09/04/2021

[3] District Secretariat of Environment, Bogotá. http://201.245.192.252:81/report/MonitorReport Accessed 11/03/2021

San Cristobal	4.57	-74.08	2688	4	Background
Suba	4.76	-74.09	2571	9	Background
Tunal	4.58	-74.13	2589	3	Background
Usaquen	4.71	-74.03	2570	13	Background
Sagrado Corazón	4.63	-74.07	2621	18	Traffic
	Sagrado Corazon data not available to download				

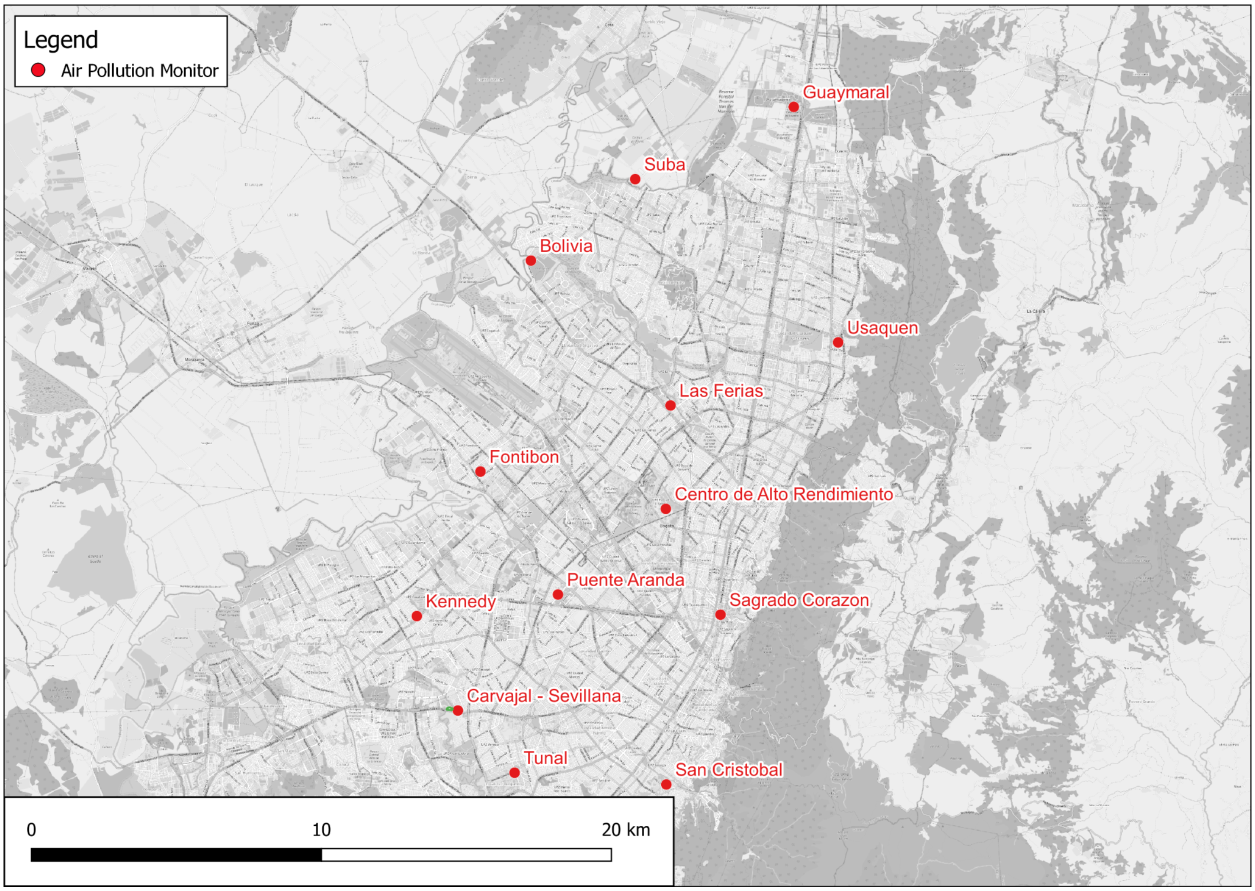

Figure 1. Bogotá Air Quality Monitoring Network (RMCAB)

Table 3: Bogotá Air Quality Monitoring Network (RMCAB) Annual Mean concentrations for 2020 and 2019*

	2020			**2019**		
Station	**NO_2**	**PM_{10}**	**$PM_{2.5}$**	**NO_2**	**PM_{10}**	**$PM_{2.5}$**
Bolivia	Missing Data	Missing Data	Missing Data	Missing Data	Missing Data	Missing Data
Centro de Alto Rendimiento	25.6	**21.5**	**13.3**	28.4	**27.1**	**14.9**
Guaymaral	20.4	**25.7**	**13.5**	29.0	**24.7**	**13.5**
Kennedy	35.1	**41.1**	**21.4**	Missing Data	**43.7**	**25.1**

San Cristobal	Missing Data	**23.5**	**11.9**	Missing Data	**24.9**	Missing Data
Suba	Missing Data	**34.2**	**14.7**	Missing Data	**45.8**	**16.1**
Tunal	28.9	**36.4**	**14.5**	27.2	**33.6**	**15.7**
Usaquen	Missing Data	Missing Data	**13.4**	Missing Data	**24.8**	**14.0**
Fontibon	30.9	**33.7**	**19.6**	40.8	**37.2**	**18.4**
Puente Aranda	33.2	**34.2**	**20.5**	35.9	**40.0**	Missing Data
Las Ferias	30.1	**23.6**	**13.6**	33.0	**28.3**	**12.8**
Carvajal - Sevillana	**48.4**	**63.7**	**29.1**	**44.3**	**57.7**	**36.2**
Units	ug/m^3	ug/m^3	ug/m^3	ug/m^3	ug/m^3	ug/m^3
WHO Guideline	40	20	10	40	20	10
MADS Resolution 2254	60	50	25	60	50	25

*Values excluded where data availability was less than 75%. Exceedances of WHO Guidelines are shown in **bold.** Exceedances of MADS Resolution 2254 are shown underlined.

Site locations and population exposure

Site Classification

Urban air quality can change significantly over short distances, meaning that the location of air quality monitors has the potential to significantly affect the concentrations measured. This effect is most pronounced for reactive gaseous pollutants such as NO_2. Once released into the atmosphere, nitrogen oxides react with other chemicals present in the air, especially in the presence of sunlight. This can lead to the formation of other pollutants such as ground-level ozone (See Box 1). As a result concentrations can be significantly higher close to emission sources such as roads and fall rapidly with increasing distance from the source. When pollution concentrations are dominated by a local source, large changes can be observed over distances of just a few meters. In some circumstances concentrations can fall by as much as 50% within the first 10 metres from a source, and then decline more slowly with increasing distance, following an exponential curve. The effect is less pronounced for particulate matter.

Interpretation of data from pollution monitors is aided by classifying the monitors according their location and the pollution sources that surround them. As an illustration, Table 4 describes the classification system used by the UK Department for Environment, Agriculture and Rural Affairs (DEFRA 2021) and the EU Air Quality Directive 2008/50/EC.

Table 4. Classification of air quality monitoring stations

Urban Traffic	Roadside or	Sites in an urban area at least 25 metres from the edge of major

	Kerbside	junctions and no more than 10 metres from the kerbside
Urban Background	Urban Background or Urban Centre	Sites in an urban area away from major roads that are representative of exposure of the general population. Urban background sites should not be dominated by single sources and should be representative of a wide area.
Suburban Background	Suburban	Sites in a suburban area away from major roads that are representative of exposure of the general population. A suburban area is defined as a location type situated in a residential area on the outskirts of a town or city. Suburban background sites should not be dominated by single sources and should be representative of a wide area
Rural Background	Rural	Sites in a rural area away from roads that are representative of exposure of the general population. Rural background sites should not be influenced by agglomerations or industrial sources and should be representative of a wide area
Urban Industrial	Industrial	Site in an urban residential area downwind of specific industrial source
Suburban Industrial	Industrial	Site in a suburban area downwind of a specific industrial source. A suburban area is defined as a location type situated in a residential area on the outskirts of a town or city

Distance to relevant exposure

Of the 13 monitoring stations operated by the Bogotá District Secretariat of Environment, eight are described as Background stations. These monitors are located away from major pollution sources and in some cases are at high elevations above ground level (Table 2).

The remaining monitors represent traffic or industrial settings; these are Carvajal - Sevillana (Traffic-Industrial), Fontibon (Industrial), Las Ferias (Traffic) and Puente Aranda (Industrial). However none of these monitors represent the worst-case locations in the city. Analysis of satellite imagery has been undertaken to estimate the distance between each monitor and the nearest major road. It has not been possible to determine the precise location of the monitor at Fontibon, although this monitor's elevation of 15 m discounts in from being in a worst-case location (See section 'Monitoring at Height'). All of the traffic or industry monitoring stations are located more than 35 m from the nearest significant road. With reference to the UK/EU criteria described in Table 4, these monitors are therefore unlikely to reflect the full impact of traffic on air quality in Bogotá.

The relationship between measured concentrations of NO_2 and distance from busy roads has been studied extensively in the United Kingdom (Air Quality Consultants, 2008). Measurements made at different distances from busy roads across multiple locations and studies follow a single defined relationship, described by a linear reduction in the influence of the road with the natural logarithm of distance from the kerb. Put simply, when a major road is the dominant source of NO_2 emissions, concentrations relatively large drops in concentration can be expected over short distances away from the road, with more gradual reductions continuing at greater distances away.

Taking the traffic monitoring location at Carvajal as examples, this relationship has been used to predict the likely NO_2 concentration at locations closer to nearby roads. This is of particular importance because, at both locations, the air pollution monitor is located at a greater distance from the road than other buildings, including businesses and residences where the occupants are therefore likely to be exposed to higher concentrations of NO_2 than are indicated by the monitoring data.

Using measured 2020 annual mean NO_2 concentrations at Carvajal, the annual mean concentration at nearby locations where the public may be exposed to roadside air pollution has been estimated (Table 5, Figure 2, 3 and 4). Carvajal is selected because it is the only traffic monitor in Bogotá that is within 50 m of a major road and where the sampler is located below 10 m above ground. The calculation requires an estimate of background NO_2. The result is sensitive to the choice of Background concentration and therefore the estimate is repeated using results from both of the two nearest Background monitoring stations, Tunal and Kennedy.

The estimates indicate that locations within Bogotá experience considerably poorer air quality than that measured by the cities monitoring network. Furthermore, many of these locations are places where the public are exposed to the polluted air. This is clearly illustrated near the Las Ferias monitor, where the Traffic monitoring station is located approximately 150 m from the nearest major road, but many residences and businesses are much closer (Figure 5).

Table 5. Estimated annual mean NO_2 concentration at a roadside location with relevant exposure

Traffic Monitor	**Traffic monitor distance to major road (m)**	**2020 Traffic Annual Mean NO_2 ($\mu g/m^3$)**	**Background Monitor**	**2020 Background Annual Mean NO_2 ($\mu g/m^3$)**	**Nearby exposure distance to major road (m)**	**Nearby exposure predicted NO_2 ($\mu g/m^3$)**
Carvajal	50	**48.4**	Tunal	28.9	10	78.3
			Kennedy	35.1		**68.8**
WHO Guideline						40

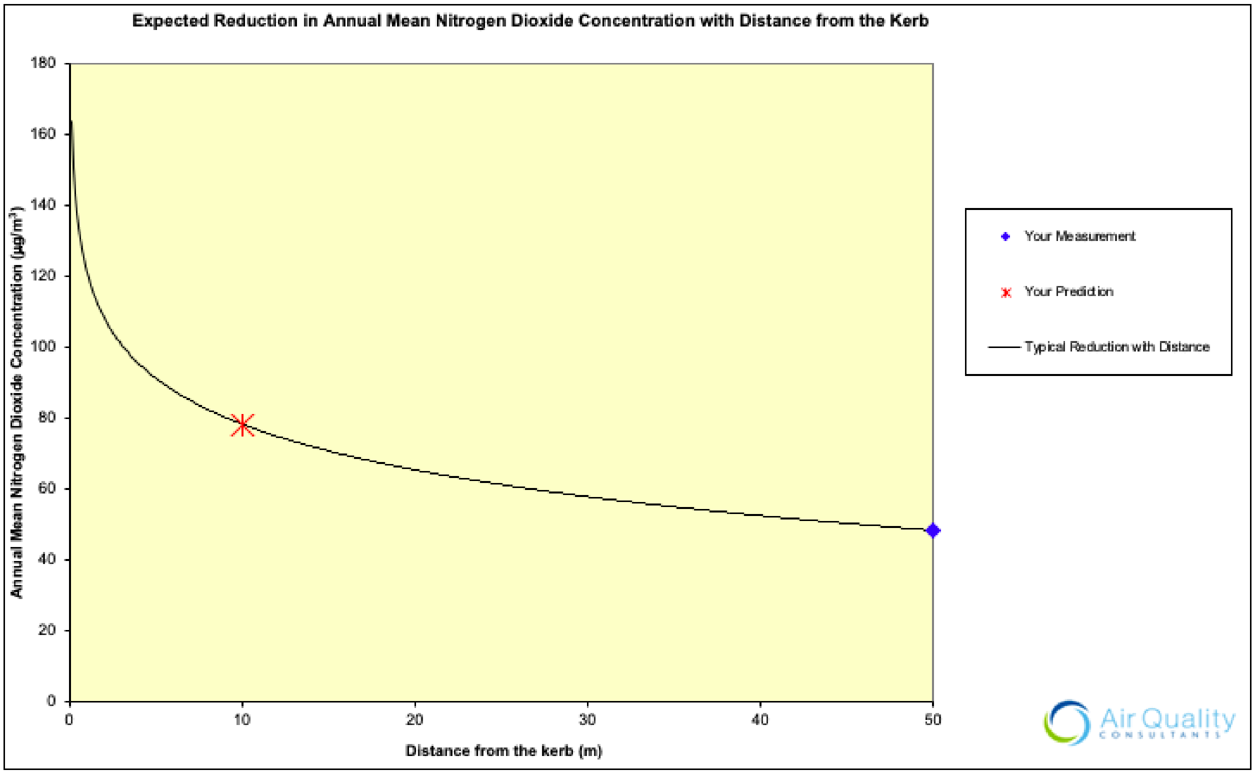

Figure 2. Measured 2020 annual mean NO_2 at Carvajal (Blue Diamond) and projected concentration at nearby local exposure (Red Star) using background concentrations at Tunal

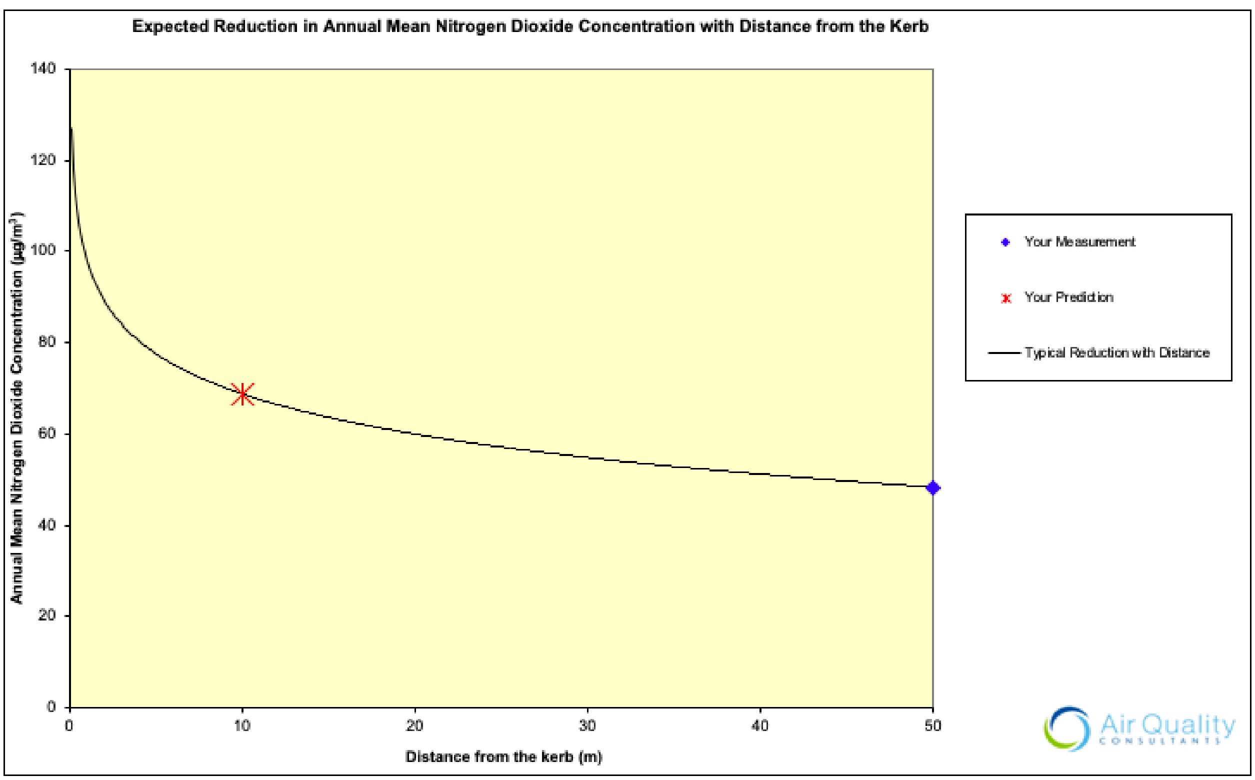

Figure 3. Measured 2020 annual mean NO_2 at Carvajal (Blue Diamond) and projected concentration at nearby local exposure (Red Star) using background concentrations at Kennedy

Figure 4. Carvajal air pollution monitor and surrounding area.
Map data: Bing Maps © 2021 Maxar, © 2021 TomTom

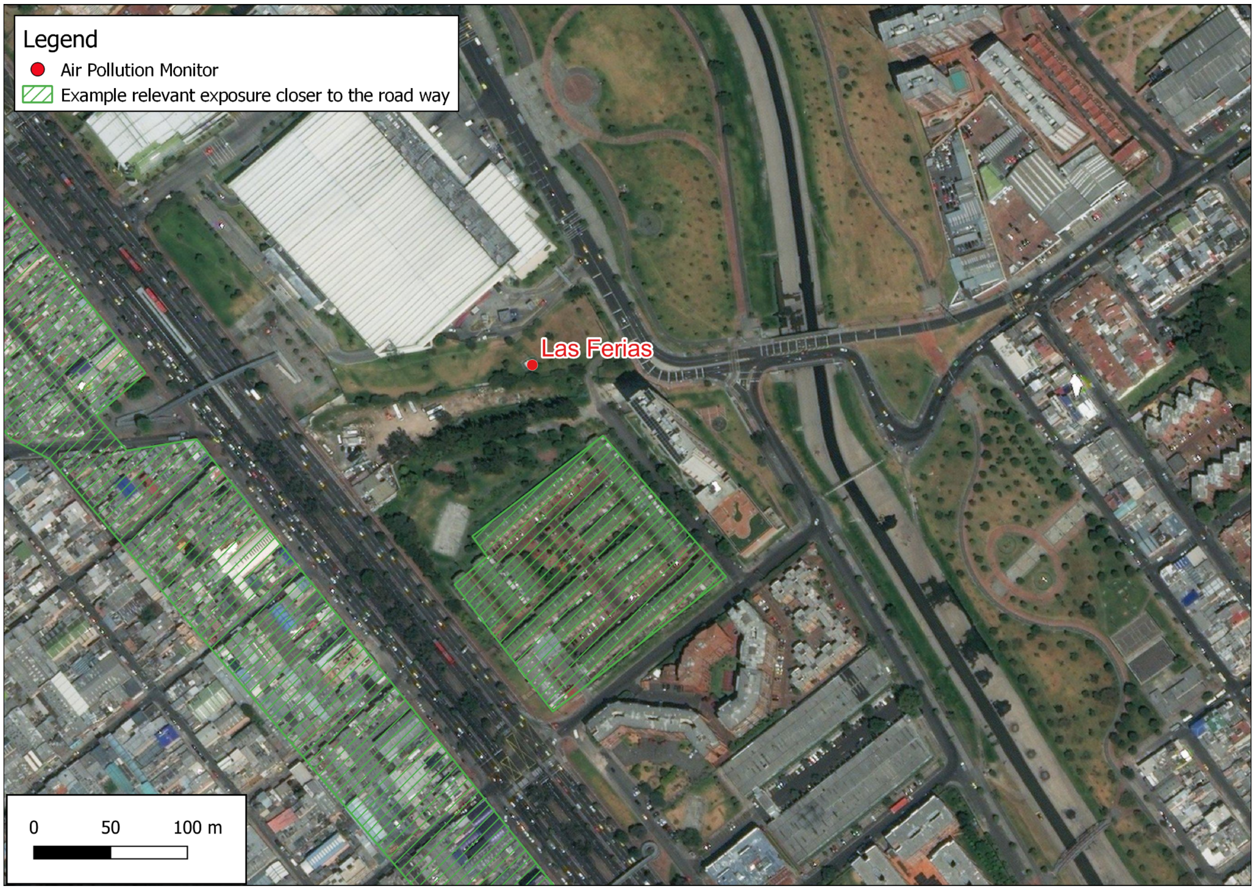

Figure 5. Las Ferias air pollution monitor and surrounding area.
Map data: Bing Maps © 2021 Maxar, © 2021 TomTom

Monitoring at height

Six of the 13 air pollution monitors in the RMCAB network are located on rooftops, with two of these being over 10 m above ground level.[4] Most RMCAB monitor inlets are significantly higher than the height at which people breathe (Figure 6).

Although there is considerable variation between locations, concentrations of pollutants can be expected to decrease with height away from pollution sources on the ground. This relationship is more pronounced at roadside sites with significant ground level emissions than at background sites. The rate at which concentrations fall depends on numerous factors including emission source characteristics, weather conditions and the geometry and layout of nearby buildings. A study of 26 locations in the UK found that average NO_2 concentrations at monitored 'roadside' locations reduced with height by approximately 50% to 60% between the ground and fourth floor. It is therefore likely that pollution monitors in Bogotá may underestimate ground level exposure because they are frequently located at rooftop locations.

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[4] District Secretariat of Environment, Bogotá. http://ambienteBogotá.gov.co/estaciones-rmcab Accessed 09/04/2021

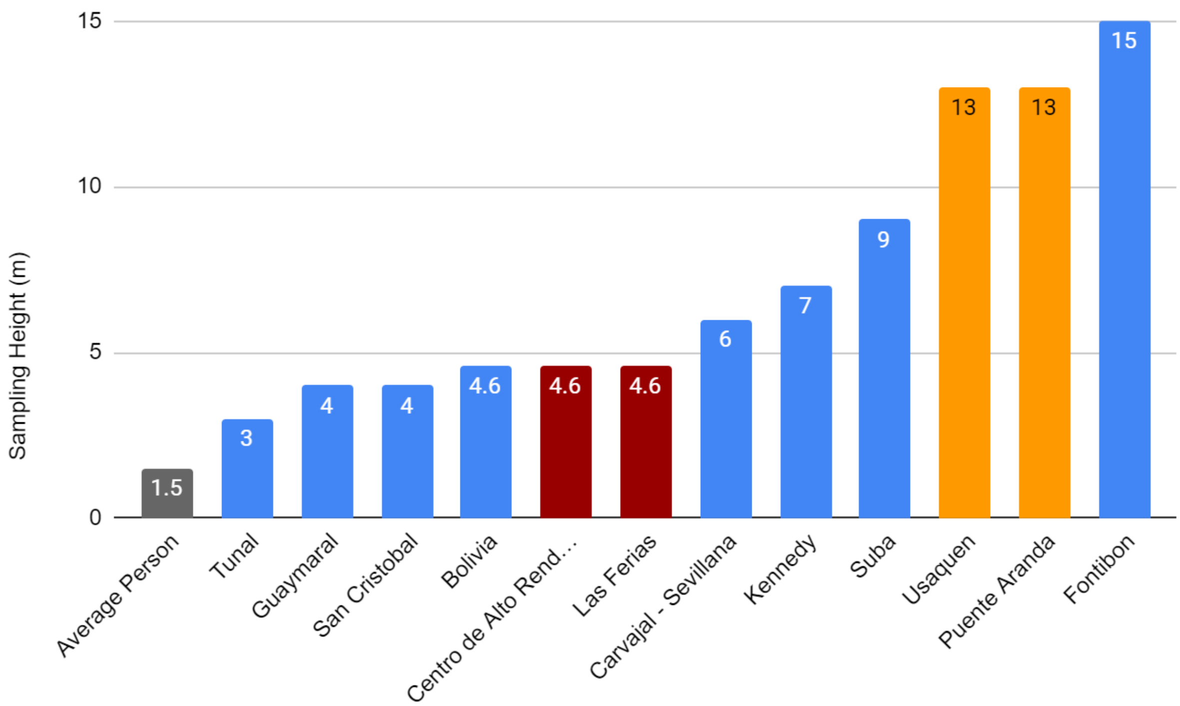

Figure 6. Sampling height (m) at Bogotá's Air Quality Monitoring Network (RMCAB) Stations compared to the breathing zone of an average person. Roadside sites are shown in red, background sites in blue and industrial sites in yellow.

Conclusions

Measured annual mean concentrations of PM_{10} and $PM_{2.5}$ in Bogotá frequently exceed WHO guidelines. This is of significant concern for public health in the city. In contrast, measured annual mean concentrations of NO_2 in Bogotá only rarely exceed WHO or national guidelines. Air pollution monitors in Bogotá are frequently located away from major roads and at elevated locations. There is significant evidence that, in these locations, pollution concentrations (especially of NO_2), are likely to be lower than at locations closer to major sources of traffic pollution, including the locations of many homes and businesses in Bogotá. This report presents evidence to suggest that, at these locations, WHO and national air quality guidelines may be exceeded. It is judged that the location of RMCAB monitors do not provide adequate illustration of pollution concentrations, especially with respect to population exposure to NO_2.

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