

Air Quality Monitoring and Data Management Guidebook for the States of the Gulf Cooperation Council



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FOREWORD

Every year, an estimated seven million early deaths are recorded as a result of exposure to air pollution. Hence, air pollution is considered to be the leading threat to environmental health globally, and the countries of the GCC are no exception in this regard, in fact, air pollution is of greater magnitude in the region due to geographic and meteorologic conditions such as sand, dust, and sea salt coupled with industrial air pollution.

To combat this threat and set frameworks for action to reduce the effects of air pollution on human health, the Ministers of Environment of the GCC countries approved to launch the Green Gulf Initiative in 2017 which includes four projects, namely a project to develop an "Air Quality Monitoring and Data Management Guide" for the GCC states. An agreement was reached with the United Nations Environment Programme (UNEP) – West Asia Office to cooperate on the Initiative and its projects.

As part of this project, the GCC and UNEP conducted a comprehensive analysis of sources of air pollution, their different types, and options for addressing them. One of the project's objectives was to develop a guide for collecting data on air quality specifically tailored for the Gulf region.

The "Air Quality Monitoring and Data Management Guidebook" provides comprehensive guidance for monitoring air pollution that aligns with implementing global best practices.

- First, this guide contains guidelines for ambient air quality monitoring to determine the causes of air pollution.
- Second, strategies to manage air quality data are presented, namely proper collection, classification, protection, and storage.
- Third, pollutants that require monitoring are identified.

It is worth noting that the guidelines in this Guidebook are not legally binding but are intended to assist governments, academic institutions, and other institutions involved in air quality monitoring to enhance current practices of air quality monitoring and data collection. Accordingly, this guidebook aims to standardize monitoring in the GCC countries and provide local and national authorities with a powerful toolkit to mitigate air pollution. To support compliance with and implementation of these guidelines, countries must consider capacity building programmes on the national and regional levels.

The Secretariat General of the Gulf Cooperation Council

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1. What This Guidebook Covers

This guide includes the steps required to establish an air quality monitoring process, from the selection of pollutants to monitor, the monitoring equipment, and monitoring site, to the collection, storage, acceptance, reporting, and interpretation of the data. The presented recommendations and procedures are heavily based on international practices with modifications to best fit the Gulf Cooperation Council (GCC). The structure of the guide is as follows.

Chapter 1	Introduction	describes the purpose of the guide
Chapter 2	What to Monitor	contains information on the standards and guidelines for the pollutants that harm human health and public welfare identified by the GCC countries and World Health Organization (WHO) and includes a brief discussion on meteorological monitoring
Chapter 3	How to Monitor	discusses the methods used to monitor air quality, including those recommended for monitoring criteria pollutants
Chapter 4	Where to Monitor	provides guiding principles on how to choose a monitorin site
Chapter 5	Data Management Guidelines	provides guidelines to ensure data quality in instrument calibration, data acquisition, data and sample storage, and data acceptance data reporting formats
Chapter 6	Air Quality Data Assessments and Analysis	discusses the methods used to analyze and interpret data
Appendix A	Monitoring Unit and Conversion Calculations	contains recommendations on what monitoring units to use and on how to convert between monitoring units
Appendix B	Negative and Missing Data	contains guidelines on how to deal with negative and missing data

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2. What to Monitor? - Choosing Contaminants

2.1. Monitoring for standards

All GCC countries have set national ambient air monitoring standards which are mostly based on international guidelines and local conditions. Noted below is the difference between a guideline and a standard.

A **guideline** is a recommendation or guidance set to protect human health and the environment from the harmful effects of air pollution. Ambient air quality guidelines are concentration limits that can be incorporated as objectives into national or regional plans. They do not specify permitted exceedances.

A **standard** is the concentration level or limit of an air pollutant. It differs from a recommendation or a guideline in that it has mandated monitoring methods and reporting requirements. The effect-based level, averaging time, measurement strategy, data handling procedures and statistics used to derive the value to be compared with the standard must be specified in the formulation of a standard. According to the World Health Organization (WHO) *air quality standards are levels of air pollution, in terms of potential impacts on public health and the environment, that are considered acceptable and adopted as enforceable by a regulatory authority (World Health Organization, 1997). Some ambient air quality standards include the number of exceedances allowed in any 12 month period (i.e the number of occasions when the contaminant level may exceed the standard in a year).*

2.1.1. WHO air quality guidelines and GCC national air quality standards

The WHO air quality quidelines (AQGs) are based on extensive scientific evidence relating the main criteria pollutants to adverse impacts on public health. These pollutants include particulate matter (PM_{10} and $PM_{2.5}$), ozone (O_3), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), carbon monoxide (CO) and lead (Pb). WHO AQG values, as updated in 2021, as well as interim targets proposed as incremental stages in the gradual reduction of air pollution are summarized in Table 1. The air monitoring standards established by each GCC country are contained in Tables 2-7. Note that the major difference in the limit values for particulate matter (PM_{2.5} and PM₁₀) in the WHO guidelines and those in national ambient air quality standards in GCC countries is because the region's arid climate and exposure to particulate matter originating from the Arabian Desert present a natural barrier to stay within WHO AQG value. In fact, the arid climate of the GCC is positively correlated with the elevated levels of particular matter (Al Jallad, Al Katheeri, & Al Omar, 2013). Whether or not the WHO guidelines need to take this natural barrier into consideration is contingent on the evaluation of the health effects of desert dust. Efforts to answer this question are still ongoing. What has been established thus far based on a recent systematic review is that the potential health impacts of desert dust particles may be associated with high mineral dust concentration in PM₁₀ with levels extending from 400 µg/m³ to more than 1000 µg/m³ (Querol et al., 2019). Acute exposure to such high concentrations has been associated with silicosis, also known as "desert lung" syndrome (Derbyshire, 2007). At receptor sites away from the sources of desert particles, airborne dust becomes increasingly loaded with anthropogeic dust, enriching it with PM_{2.5} and PM₁ in concentrations that can surpass 35 per cent share of biogenic dust.

Particles mixed or coated with anthropogenic emissions that could also be loaded with biological and microbiological organisms have been shown to cause asthma as well as viral, bacterial and other types of infection (Watanabe et al., 2011, Griffin, 2007). In addition, Polymenakou et al. (2008) concluded that pathogens in desert dusts might have significant concerns for human health (Cassee et al., 2013), and several other epidemiological studies conducted by Mallone et al., 2011, Neophytou et al., 2013, Perez et al., 2008 and Tobias et al., 2011 showed that particulate matter has stronger effects on mortality rates during dust days than during non-dust days. On the other hand, studies conducted by)Al-Taiar and Thalib, 2014 (did not find any substantial increase in mortality rate in Kuwait due to dust storms (Shahsavani et al., 2020). Park et al. (2018) inferred that the effect of toxicity score of desert dust particulate matter is 10,000 times lower than diesel engine exhaust particles (Park et al., 2018). In conclusion, the direct health effect of desert dust is best correlated with the chemical content of mineral and anthropogenic loads (metals, organic and inorganic pollutants and biological), mainly determined by the origin of emission sources and transport pathways (Querol et al. 2019 and references therein).

Table 1: 2021 WHO air quality guidelines (source: WHO (2021);	
https://apps.who.int/iris/bitstream/handle/10665/345329/9789240034228-eng.pdf?sequence=1&isAllowed=	y)

Contaminant	WHO AQGs value (µg/m³)	WHO Interim target (IT) (µg/m³)	Time average
PM	15	IT-1: 70 IT-2: 50 IT-3: 30 IT-4: 20	Annual mean
PM ₁₀	45	IT-1: 150 IT-2: 100 IT-3: 75 IT-4: 50	24-hour mean
DM	5	IT-1: 35 IT-2: 25 IT-3: 15 IT-4: 10	Annual mean
PM _{2.5}	15	IT-1: 75 IT-2: 50 IT-3: 37.5 IT-4: 25	24-hour mean

O ₃ NO ₂	100	IT-1: 160 IT-2: 120	8-hour mean
	60	IT1: 100 IT-2: 70	Peak season
	10	IT-1: 40 IT-2: 30 IT-3: 20	Annual mean
	25	IT-1: 120 IT-2: 50	24-hour mean
SO ₂	40	IT-1: 125 IT-2: 50	24-hour mean
CO	4 mg/m₃	IT-1: 7	24-hour mean

Table 1: 2021 WHO air quality guidelines (source: WHO (2021);https://apps.who.int/iris/bitstream/handle/10665/345329/9789240034228-eng.pdf?sequence=1&isAllowed=y)
(continued)

The air quality standards in United Arab Emirates (UAE), Saudi Arabia, Bahrain, Kuwait, Oman, and Qatar are shown in **Tables 2-7**.

Parameter	Limit	Avg. period*
	350 μg/m³ (131 ppb)	1 h
SO ₂	150 μg/m³ (56 ppb)	24 h
	60 μg/m³ (23 ppb)	Annual
	400 μg/m³ (209 ppb)	1 h
NO ₂	150 μg/m³ (78 ppb)	24 h
со	30 mg/m ³ (26 ppm)	1 h
	10 mg/m³ (9 ppm)	8 h
0-	200 µg/m³ (100 ppb)	1 h
U3	120 μg/m³ (60 ppb)	8 h
PM ₁₀	150 μg/m³	24 h
Total	230 μg/m³	24 h
suspended particles	90 μg/m³	Annual
Lead	1 μg/m³	Annual

Table 2: Ambient air quality	/ standards in LIAF	(source · https://www.adairguality.ae/)
		(bour co : https:// mmaaan quanty.uo/)	/

Parameter	Limit	Avg. period	Number of exceedances
	10 mg/m ³ (9 ppm)	8 h	2 times per month
со	40 mg/m ³ (34 ppm)	1 h	1 time per year
Pb	0.15 µg/m³	3 months	none
NO	200 µg/m³ (105 ppb)	1 h	24 times per year
NU ₂	100 µg/m³ (52 ppb)	Annual	N/A
	441 µg/m³ (165 ppb)	1 h	24 times per year
SO ₂	217 µg/m³ (81 ppb)	24 h	3 times per year
	65 μg/m³ (24 ppb)	Annual	N/A
Benzene	5 µg/m³ (1.5 ppb)	Annual	N/A
DM	340 µg/m³	24 h	12 times per year
P IVI ₁₀	50 μg/m³	Annual	N/A
DM	35 µg/m³	24 h	12 times per year
PIM2.5	15 µg/m³	Annual	N/A
03	157 µg/m³ (79 ppb)	8 h	25 times a year (average over 3 years)
Hvdrogen sulphide	150 μg/m³ (100 ppb)	24 h	10 times per year
(H₂S)	40 µg/m³ (30 ppb)	Annual	N/A

 Table 3: Ambient air quality standards in Saudi Arabia

 (source: https://www.mewa.gov.sa/ar/InformationCenter/DocsCenter/RulesLibrary/Pages/default.aspx)

Pollutant	Limit		Avg. period
	ppb	µg/m³	
	115	300	1 h
SO ₂	48	125	24 h
	19	50	Annual
	106	200	1 h
NO ₂	80	150	24 h
	21	40	Annual
PM	-	340	24 h
1 10110		80	Annual
DM.	-	50	24 h
F 1V12.5		25	Annual
	17 ppm	20,000	1 h
60	9 ppm	10,000	8 h
Dawrana	4	13	24 h
Benzene	1.56	5	Annual
Taluana	300	1,130	24 h
Toluene	106	400	Annual
Xylene	100	434	24 h
Aylone	23	100	Annual
Total non-methane hydrocarbons (NMHC)	0.240 ppm	160	3 h
Hydrogen	30	42	1h
sulfide (H ₂ S)	11	15	24 h
	604	420	1h
1113	144	100	24 h

 Table 4: Ambient air quality standards in Bahrain (source: sce.gov.bh)

Parameter	Limit	Avg. period
50.	200 µg/m³ (75 ppb)	1 h
302	51 µg/m³ (19 ppb)	24 h
	191 µg/m³ (100 ppb)	1 h
NO ₂	40 µg/m³ (21 ppb)	Annual
со	41 mg/m³ (35 ppm)	1 h
03	140 µg/m³ (70 ppb)	8 h
PM ₁₀	350 µg/m³	24 h
PM _{2.5}	75 μg/m³	24 h

 Table 5: Ambient air quality standards in Kuwait

 (source: https://enterprise.emisk.org/eMISKAirQuality/#/KAQI)

Pollutant	Limit		Avg. period
	ppb	µg/m³	
60	131	350	1 h
302	56	150	24 h
H₂S	20	30	1 h
NO	131	250	1 h
NO ₂	68	130	24 h
03	60	120	8 h
NH₃		200	24 h
<u> </u>	25,773	30 mg/m ³	1 h
0	8,591	10 mg/m³	8 h
PM ₁₀	-	150	24 h
PM _{2•5}	-	65	24 h
NMHC	0.24	160	3 h
Pb		1.5	3 months

 Table 6: Ambient air quality standards in Oman
 (source: https://www.duqm.gov.om/upload/files/air-quality-protection.pdf).

Parameter	Limit	Avg. period
	365 µg/m³ (137 ppb)	24 h
SO ₂	80 µg/m³ (30 ppb)	Annual
	400 µg/m³ (209 ppb)	1 h
NO ₂	150 µg/m³ (78 ppb)	24 h
	100 µg/m³ (52 ppb)	Annual
0	235 µg/m³ (118 ppb)	1 h
03	120 µg/m³ (60 ppb)	8 h
00	40 mg/m³ (34 ppm)	1 h
CO	10 mg/m³ (9 ppm)	8 h
	150 µg/m³	24 h
PM ₁₀	50 µg/m³	Annual
514	_	24 h
PM _{2.5}	-	Annual

Table 7: Ambient air quality standards in Qatar (source: https://www.psa.gov.qa/en/knowledge/Publications/Environment /Env_Environmental_Statistic_Report_En_2013.pdf)

2.2. Meteorological monitoring

The In situ meteorological monitoring includes primary meteorological variables such as wind direction, wind speed, temperature, humidity, pressure, and radiation. Wind speed, direction and variability affect the travel time from pollutant source to the receptor site and the overall movements of pollutants in the atmosphere (U.S. Environmental Protection Agency, 2000b). Therefore, meteorology should be considered when determining the location, height, direction and extensions of sampling probes. Additionally, meteorological data are a prerequisite for dispersion modeling. In order to account for variations between, good quality monitoring of meteorological data may require a number of stations depending on the site topography.

Wind speeds is usually measured using light weight three-cup anemometers equipped with sensors with high accuracy at low wind speeds and a low starting threshold. Wind direction is measured directly using a wind vane and temperature and temperature difference are measured using resistance temperature devices. Thermocouples are not recommended because of their limited accuracy and complex circuitry. Humidity is usually measured using a dew point, lithium chloride, or thin-film capacitor hygrometer and precipitation is measured with a weighing or tipping bucket rain gauge. Atmospheric pressure is measured with an aneroid barometer and pyranometers are normally used for measuring global solar radiation.

Sensors for wind speed and wind direction should be located over level, open terrain at a height of 10 m above ground level and at a distance at least ten times the height of nearby obstructions. For elevated releases, additional measurements should be made at stack top or 100 m, whichever is lower. Temperature sensors should be located at 2 m. Temperature sensors should be shielded to protect them from thermal radiation and any significant heat sources or sinks. Pyranometers used for measuring incoming (solar) radiation should be located with an unrestricted view of the sky in all directions during all seasons. Sensor height is not critical for pyranometers; a tall platform or rooftop is an acceptable location. Net radiometers should be mounted about 1 m above ground level.

A microprocessor-based digital data acquisition system should be used as the primary data recording system; analog data recording systems may be used as a backup. Estimates of means should be based on at least 60 samples (one sample per minute for an hourly mean). Estimates of the variance should be based on at least 360 samples (six samples per minute for an hourly variance).

Procedures for compliance with reporting and archiving requirements should be documented in the monitoring protocol prior to the commencement of monitoring. Meteorological data provided to regulatory agencies for use in modeling should be reduced to hourly averages. The data should be recorded in chronological order; records should be labeled according to the observation time (defined as the time at the end of the averaging period, i.e. the hour ending).

Quality assurance/quality control (QA/QC) procedures should be documented in a quality assurance project plan (QAPP) and approved by the appropriate project or organizational authority. These procedures should provide quantitative documentation to support claims of accuracy. Procurement documents for meteorological monitoring systems should include the specifications for instrument systems and should identify the test method by which conformance with the specification will be determined. All acceptance-testing activities should be documented in the station log. Routine system calibrations and system audits should be performed at the initiation of a monitoring programme (within 30 days of start-up) and at least every six months thereafter. More frequent calibrations and audits may be needed in the early stages of the programme if problems are encountered, or if valid data retrieval rates are unacceptably low.

What to monitor

Monitor levels of the main criteria pollutants set by each GCC country as well as local meteorological conditions, such as wind speed, wind direction, wind variability, temperature, dust load, and humidity at each monitoring station.

03

3. How to monitor? - monitoring methods

This chapter describes the methods, equipment, and technologies best suited for monitoring air quality, and discusses mandatory ambient air quality methods.

3.1. Using appropriate monitoring methods

Numerous methods can be used to monitor air quality. When choosing specific and appropriate methods care must be taken to account for the objective, and purpose of the monitoring (Environment Agency, 2011), the type of contaminants being monitored, the availability of reference standards, the appropriate time average, and the budget. The time average defines whether the monitoring method needs to be continuous. Some regulations require recurring 8-hour averages of certain pollutants, for example O_3 in this case, analyzers must be continuous. In cases where initial screening surveys are needed, lower resolution instruments can be used.

Such methods precede long-term monitoring and are useful for prioritizing sites among those already selected for possible inclusion in the monitoring programmes. It is not recommended to use screening methods to determine compliance with national standards or guidelines as they usually lack the level of accuracy required for ambient air quality monitoring.

A variety of measurement programmes support air quality assessments. These include:

- 1. routine regulatory and deposition networks
- 2. intensive aircraft and ground-based field studies
- 3. satellite measurements
- 4. focused, fixed-site, special purpose networks

Points 1, **2** and **4** are described below. **Point 3** is detailed in the companion guidebook on air quality modelling and forecasting for the GCC region (see **Preface**).

Routine surface-based ambient air quality and deposition networks are usually set up to measure concentrations the six criteria air pollutants (O_3 , NO_2 , CO, SO_2 , Pb, and PM (PM_{10} and $PM_{2\cdot5}$). How sites in these networks are to be located is described in the sections below. Monitoring devices commonly report pollutant concentrations continuously (e.g. hourly). Pollutant concentrations can also be reported discretely as a 24-hour sample average using filter or solution collection methods. Filter collection methods are commonly used for determining the mass concentrations of PM_{10} , $PM_{2\cdot5}$ and $PM_{10-2\cdot5}$ (Where $PM_{10-2\cdot5}$ is the difference between the PM_{10} and $PM_{2\cdot5}$ concentrations). Filter samples are typically taken every third or sixth day for 24 hours.

In the case of the GCC countries where dust storms are frequent, there is a need to assess the contribution of dust particles to the total particle mass. It is therefore recommended that, in addition to monitoring PM concentrations, a sub network to measure chemical speciation should be established. Speciation data on sulfate, carbon (organic and elemental splits), nitrate and crustal elements enables insights into diurnal speciation patterns, which can be helpful in diagnosing various cause-effect phenomena related to emissions characterization, source attribution analysis, and model evaluation.

In the case of episodic events associated with dust storms, a harmonization between continuous $PM_{2.5}$ mass samplers and gravimetric methods for PM mass remains a challenge. Measurement artefacts associated with filter-based, gravimetric techniques creates significant ambiguity in PM data, such as loss of mass of semi-volatile constituents. Correlation techniques between the two methods could avoid this problem. Harmonization of these measurements could address both temporal and spatial gaps in PM_{2.5} monitoring.

In addition to routine long term monitoring networks, intensive field campaigns of relatively short duration are necessary to measure the spatial, temporal, and compositional distribution of pollutants and precursors. These studies are designed to investigate the emission and physical and chemical processing of precursors and pollutants to understand their source, fate, transport, and removal. Typically, field campaigns use some combination of aircraft- and/or ship-based studies, satellite- and ground-based remote sensing, research-grade instrumentation, and advanced analytical methods. These efforts complement routine ground-based measurements, which usually do not address reactive gaseous species, aerosol size distributions, organic chemistry characterization, and vertically stratified data.

3.2. Monitoring methodology types

Monitoring methods can be classified into two main types: continuous and discontinuous. These two types are described below.

3.2.1. Continuous monitoring methods

Continuous monitoring methods are usually high-resolution methods that continuously measure pollutant levels and can operate over weeks or months with regular maintenance approximately every two weeks. These methods often overcome many of the limitations associated with measuring atmospheric pollutant mass concentrations by daily filter-based methods (e.g., potential positive or negative sampling artefacts, including GCC in countries with extreme weather conditions such as high temperature and humidity as well as high dust load persists). Continuous monitoring methods require high standards of maintenance, calibration, and QA/QC procedures to ensure good data quality (see Section 5.1). Continuous monitoring methods are extremely convenient when ambient air quality measurements are needed at high temporal resolutions. However, the accuracy of continuous monitoring methods for measuring mass concentrations of particulate matter greatly depends on the instrument used (Wang, 2016). Regardless of the type of instrument that is used, it is recommended that in extreme weather conditions, such as those in GCC countries, calibration models should be tested at the operational scale of locally developed high and low-cost networks for an extended period to demonstrate the monitoring network's capabilities in ambient conditions, including during episodic events. The large-scale deployment of such calibrated devices can represent integrated solutions for effective and hi-resolution spatiotemporal monitoring and prediction centered on ground-based measurements.

3.2.2. Discontinuous monitoring methods

Passive or diffusive samplers (diffusion tubes) are cheap and simple methods able to generate a spatial distribution of contaminants over large areas. However, passive sampling is only available for certain contaminants. They are especially useful during the initial stages of air monitoring and in screening surveys. They can only provide average concentrations over a long period of time (usually some weeks).

For example, using diffusion tubes is a simple way to measure NO_2 , SO_2 or NH_3 . They operate based on the diffusion of the pollutant into a tube containing reactive material. The tubes are then analyzed after a known exposure time, providing a time-averaged pollutant concentration. The relatively low cost allows sampling at numerous points across the region of interest, which is useful in identifying hot spots with high contaminant concentrations (Wales Government, 2018). After collection, laboratory analysis must be carried out with high standards of quality assurance and quality control to ensure accurate and consistent results. Some diffusive sample manufacturers provide analysis in an accredited laboratory along with their products.

Gravimetric analysis is one of the most established analytical methods and is defined as the determination of PM concentrations on a filter based on differences in mass before and after sampling (Greene, 2008). Monitoring begins with a measured volume of air drawn and pumped through a pre-weighed filter for a known length of time. Gravimetric monitoring might be associated with errors, so precaution must be taken to ensure accurate results including:

- proper temperature and humidity control during weighing
- minimal weight losses due to vaporization by keeping the filters cool during transport
- avoiding electrostatic charge buildup on the filter

PM is commonly collection on filters every third or sixth day for 24 hours and 24-hour averages for a whole year are used to calculate annual averages. For a dust episode, a shorter averaging period can be selected depending on the site and the dust load during the episode. This avoids the oversaturation of the filter and the spillover of collected particles, especially when using a cascade impactor.

Methodology types

Continuous and discrete PM monitoring are used to monitor pollutants with each method presenting advantages and disadvantages. Filter collection methods present potential sampling artefacts, especially in countries such as GCC Member States with extreme weather conditions, including high temperature and humidity, as well as high dust loads.

3.3. Ambient air monitoring methods

This section describes the ambient air monitoring methods that can be used to monitor the pollutants PM_{10} , $PM_{2\cdot5}$, CO, NO_2 , O_3 , SO_2 , and Pb that the focus of air quality standards in GCC countries. The section draws on methods described for use in the United States of America (U.S. Environmental Protection Agency, 2021), the United Kingdom (Department for Environment Food & Rural Affairs, 2019) and the European Union (EU) (Directive 2008/50/EC). In **Tables 8-14**, contain further detailed references, including to relevant U.S regulations including **40 CFR Part 53** and **40 CFR Part 50**.

3.3.1. Particulate matter (PM₁₀ and PM_{2.5})

Method	Reference	Description
In-Stack Particulate Filtration (gravimetric measurement method)	CFR 40, Part 50, App. J, L EN12341: 2014	An air sampler draws ambient air at a constant flow rate over a specified sampling period. The suspended PM is separated into size fractions in the PM size range that are collected on a separate filter. The filters are weighed prior to and after sampling to determine the net weight gained due to PM. The mass concentration of PM ₁₀ is calculated by dividing the total mass of the collected particles in the PM ₁₀ size range by the volume of air sampled. Because this method depends on weight, any moisture accumulation due to humidity (which is high in the GCC region) will interfere with the measurements, so precautions as described in Section 3.2.2. must be taken when using this method.
Dichotomous Air Sampler	EQPS-031 1-198 EQPS-031 1-197	Air is drawn to the inlet of the dichotomous air sampler where it is separated by size. These samplers can measure mass particles of different sizes.

Table 8: Monitoring methods for PM (PM_{10} and $PM_{2\cdot 5}$)

Table 8: Monitoring m (ethods for PM (PM10 and PM2.5) continued)

Beta-Attenuation Monitoring	EQPM-0391-081 EN 16450:2017	Measurement of mass concentration on a continuous basis should be conducted using the beta gauge method. This method is based on the attenuation of beta particles as they pass through PM collected on a filter over a specified time period.
Tapered Element Oscillating Microbalance (TEOM®)	EQPM-1090-079 EQPM-1013-208 EN 16450:2017	An air sample is drawn through a filter mounted on a tapered oscillating element. Particles collected on the filter change the oscillation frequency. The particle mass is calculated according to the correlation between mass and frequency. Note that interferences may occur due to mechanical noise, and that significant temperature fluctuations might cause errors in the calculations so frequent calibration is especially recommended in the GCC region.
Light Scattering Methods	EN 16450:2017	Particles in an air sample are measured by the principle of light scattering. Every particle is lit up by a laser light and its scattering signal is detected by a photo diode. Each measured height is proportional to the particle size. Particle volume is calculated from the particle size. The volumes are then converted to mass distribution.
Laser Aerosol Spectrometry	EQPM-0311-195	This method uses lasers to measure both PM ₁₀ and PM _{2.5} . An air sample is drawn to a thin inlet. A laser curtain perpendicular to the inlet stream is generated by a collimator. The quantity of particles is detected when the particles pass through the curtain. The concentration can be calculated using the inlet volume.

A review of literature addressing the various methods that can be used to measure PM, including during dust storms, shows that the selection of the best instruments and equipment for particulate matter monitoring objective depends on their specificity, sensitivity, accuracy, precision, ease of calibration, and response time. Operational parameters to consider include the availability of the sensors, the spatial resolution, maintenance requirements and downtime, additional equipment required, and the availability of skilled labor for operations and maintenance.

For methods relying on filter collection to measure PM concentrations, for the risk of passive deposition of windblown dust on the filter prior to and following sampling should be considered because storing filters in the sampler can positively bias PM measurements (Bruckman and Rubino, 1976; Chahal and Romano, 1976; Blanchard and Romano, 1978; Swinford, 1980). This bias can be minimized by more frequent sampling (i.e., reduce the passive deposition period), pre-loading filters in the laboratory, and transporting unexposed and exposed filter cassettes in covered cassette holders.

All PM measurement methods described in **Table 8** are able to differentiate between PM sizes but not between particulate matter originating from natural dust and other anthropogenic sources or secondary aerosols. Speciation between these particle types can be done at a secondary step by conducting PM characterization chemically. Quick methods that can be applied to collected filters include sampling substrates for further chemical exploration using scanning electron microscopy equipped with energy dispersive X-ray systems (SEM-EDX). Based on the morphology and elemental composition, conclusions on the origin of the particles can be drawn. Another method that is commonly used is Fourier transform infrared (FTIR) spectroscopy. This method identifies the different types of functional groups and bonds found in the samples at molecular levels. Abundance of carbon associated materials is associated with anthropogenic sources whereas the presence of silicon, quartz, aluminosilicates, calcium, and chloride can be correlated to combinations of wind-blown sand particles, dust, and sea salt particles.

3.3.2. Carbon Monoxide (CO)

Table 9: Monitoring method for CO

Method	Reference	Description
Non- dispersive infrared photometry	CFR 40, Part 50, App. C EN14626:2012	Non-dispersive infrared photometry (NDIR) is the recommended method for determining CO concentrations. The method's simplicity and accuracy makes it a reliable technique. CO infrared absorption is calibrated against a standard gas and converted into CO concentration in the measurement cell. Other gases that also absorb infrared radiation, such as carbon dioxide and water, may cause interference.

3.3.3. Nitrogen oxide (NO) and dioxide (NO₂)

Table 10: Monitoring methods for NO and NO_2

Method	Reference	Overview of Method of Operation
Gas Phase Chemiluminescence	CFR 40, Part 50, App. F EN14211 :2012	Gas phase chemiluminescence is used to measure total nitrogen oxides (NO ₂ and NO, or together NO _x). It is the most commonly used method for measuring NO _x concentrations due to its accuracy and reliability. By means of a converter, NO _x is first reduced to NO and the latter is measured photometrically at 600 nm after reacting with O ₃ . When by-passing the converter, NO is measured and by subtracting it from total NO _x , NO ₂ concentration is determined. Interferences may occur due to other nitrogen compounds. Interferences originate from: 1. Since the resulting emission signal is measured using a photomultiplier tube (PMT), other chemiluminescence processes can also be detected. Contributions to the measured emission from other species are minimized by using a red filter on the detector to block emission wavelengths below ca. 600 nm, and by employing a background subtraction cycle 2. Chemiluminescent instruments typically alternate between two operation modes: one that directly measures NO and one that measures $\Sigma(NO + NO_2)$, by first converting NO ₂ to NO with the help of a catalyst such as molybdenum (Mo) heated to 300 – 350°C. Interferences from other contaminants like HNO ₃ , HONO, N ₂ O ₅ , HO ₂ NO ₂ , PAN, NO ₃ and organic nitrates) could also be converted to NO. One solution would be to use an instrument equipped with a photolytic NO ₂ conversion stages where a blue light LED converting NO ₂ to NO. However, this has also been shown to present artefacts from the generation of HO _x radicals through photolysis of photolabile carbonyl species such as glyoxal, forming peroxy radicals promoting NO-to-NO ₂ conversion within the instrument (Villena G., 2012) .

3.3.4. Ozone (O₃)

Table 11: Monitoring methods for O_3

Method	Reference	Description
Chemiluminescence	CFR 40, Part 50, App. D	Ambient air containing ozone is mixed with ethylene. In the mixing zone, ethylene or NO ₂ reacts with ozone, emitting light. The light is detected by a photomultiplier tube (PMT) that converts the light to a flow of electrons proportional to the intensity of the light. The resulting photo current is amplified and displayed. Water vapor is the only potential source of interference, so proper adjustments will ensure accurate results.
U.V. photometry	EQOA-0410-190 EQOA-0514-215 EQOA-0895-105 EQOA-0206-148 EQOA-0881-053 EQOA-0407-165 EN14625:2012	An air sample is drawn into a mixing chamber in the device and exposed to ultraviolet (UV) light at a 254 nm wavelength. Ozone absorbs UV light in proportion to its concentration (and other parameters) and is compared to an air sample without ozone. To reduce interferences, most UV O ₃ monitors use conventional manganese dioxide (MnO ₂) scrubbers. Because O ₃ molecule is almost unique in its absorption of the mercury (Hg) emission line at 254 nm, only few potential compounds such as water vapor will interfere with this method. But water vapor interference means that the change in relative humidity like it is the case in the GCC countries plays a major role in affecting the transmission of the UV light. Recent studies have also reported interferences with fine particles.

3.3.5. Sulphur dioxide (SO₂)

Table 12: Monitoring methods for SO₂

Method	Reference	Description	
Pararosaniline Method	CFR 40, Part 50, App. A	A known volume of air is bubbled through a 0.04M potassium tetrachloromercurate (TCM) solution. SO ₂ in the sample reacts with this solution and forms a stable monochlorosulfonatomercurate complex. This complex is then reacted with formaldehyde and acid-leached pararosaniline dye to form a colored pararosaniline methyl sulfonic acid during analysis. The optical density and the amount of SO ₂ collected is established using a spectrophotometer at 548 nm. The total volume of air sampled is found from the measured flow rate and sampling time.	
U.V. fluorescence	EQSA-0990-077 EQSA-0809-188 EQSA-0580-046 EQSA-0779-039 EN14212:2012	SO ₂ releases a characteristic fluorescence when it is irradiated by ultraviolet light of 190-230 nm. The molecule absorbs this region of light, while most other pollutants in air do not. A beam of radiation is passed through a sample. The decay radiation is passed through a filter and photomultiplier tube, which allows a concentration to be measured. Because water vapor and oxygen may cause interferences at certain wavelengths, it is recommended to remove water vapor using a dryer or by selecting particular wavelengths to minimize error. It is also recommended to dilute an air sample with nitrogen to reduce the oxygen concentration, and thus the potential error. This is the most widely used method because of its cost effectiveness, accuracy, and simplicity. It is capable of measuring very particular samples, and with the help of additional UV lasers, any interferences or potential overlapping can be eliminated.	

3.3.6. Lead (Pb)

Table 13: Monitoring methods for Pb

Method	Reference	Description
Inductively-Coupled Plasma Mass Spectroscopy (ICP-MS)	CFR 40, Part 50, App. G	Ambient air PM is collected on a filter. Lead in PM is solubilized by extraction with nitric acid aided by heat, ultrasonication, and a mixture or nitric acid and hydrochloric acid. The liquid sample is converted to aerosols with the help of a nebulizer. Aerosols are atomized when passed through a plasma chamber and then atoms are separated and identified using a mass spectrometer.
X-ray fluorescence spectrometry	EQL-0783-058 EQL-0589-072	X-ray radiation is passed through the sample which causes the particle to emit a fluorescence unique to the chemical composition of lead. The concentration of lead is directly proportional to the intensity of the emitted fluorescence.
Flame/flameless atomic absorption spectroscopy	EQL-0380-044 EQL-0895-107	A liquid sample is introduced to a flame or furnace which breaks down the molecule into gaseous atoms. Light passing through the burning sample is directed to a photomultiplier tube to detect the lead concentration.

Method	Reference	Description
Differential Optical Absorption Spectroscopy (DOAS)	EQOA-0495-103 EQOA-0400-137 EQNA-0400-139	DOAS is a spectroscopic system based on light absorption of the gases at different wavelengths. The system has three main components: a light source, a detector and an analyzer. The light source sends a beam of light at different wavelengths over a selected path to the detector. The distance between the light source and the detector is the pathlength which, for ambient air quality applications, are in the order of several hundred metres. DOAS systems require high levels of maintenance and calibration especially in areas like GCC region where high relative humidity and temperatures can interfere with the peaks being measured.
Low-cost monitors		Low-cost monitors provide an opportunity to gather information on air quality for objectives such as public health or the extent of air quality problems affecting communities. These monitors require constant calibration and maintenance as their sensitivities are affected by environmental factors such as humidity, temperature, and pressure (Clements Andrea L et al, 2017). Note that the performance of low-cost monitors might also be affected by the aerosol loads. It is recommended that a correction curve established against a stable PM monitor in the vicinity of the sites is developed and frequently checked for every device before installation.

 Table 14: Methods for monitoring multiple gases simultaneously

Special care in mounting the air sampling manifold on the monitoring station needs to be taken in areas where desert storms are frequent (see also **Section 3.4**). The purpose is to make sure the glow of air is not restricted and excess moisture, pressure drops, and dust entrainment are minimized. The shelter housing the monitoring system needs to be closed tight, reflective of sun radiation and cooled at all times in order to protect the instrumentation from excessive dust and reduce electronic drift due to high temperature and intense radiation. If using DOAS dust and humidity may attenuate or obstruct the UV or IR beam while also causing high interference from the water signals. DOAS might not be the best instrument in this case.

Mandatory ambient air monitoring methods

To monitor the criteria	a pollutants, it is recommended to use:
(PM ₁₀ & PM _{2·5})	In-stack particulate filtration, gravimetric measurement methods, dichotomous air sampling, beta-attenuation monitoring, tapered element oscillating microbalance, light scattering methods, and laser aerosol spectroscopy
CO:	Non-dispersive infrared photometry
NO ₂ :	Gas phase chemiluminescence, differential optical absorption spectrometry and ultra violet photolytic conversion
O ₃ :	Ethylene chemiluminescence, differential optical absorption spectroscopy and ultra violet photometry
SO ₂ :	Pararosaniline method and UV fluorescence
Pb:	Inductively-coupled plasma mass spectroscopy, X-ray fluorescence spectrometry and flame/flameless atomic absorption spectroscopy

3.4. Choosing appropriate monitoring equipment

The choice of the most appropriate monitoring equipment is usually based on several factors. The purpose of establishing a monitoring network defines the instrument's sensitivity and resolution. Compliance with a country's air quality standards, for instance, may require a higher level of sensitivity and resolution than needed for screening purposes. The required range of measurements dictates the detection limit and precision of the instrument, while the duration and method of deployment influence decision on the size, weight, robustness, connectivity, and maintenance frequency of the equipment selected. The location of the sampling site and the installation of the instrument will require consideration of temperature, humidity control, dust events, snow, fog and other meteorological conditions. The local human capacity and resources also need to be taken into account when deciding on instruments that will require frequent calibration and elaborate QA/QC procedures. All these factors must be incorporated into the budget in order to make the final decision (New Zealand Ministry of the Environment, 2009).

In areas subject to frequent periods of dust like the GCC countries, a special air sampling manifold can be mounted on the monitoring station housing with multiple gas analyzers to reduce excess moisture, pressure drops, and dust entrainment. Manifold designs commonly used include either a conventional borosilicate glass (Pyrex) or quartz manifold with a blower motor. The monitoring station can further be improved by checking frequently that air flow is unrestricted, installing a water trap at the manifold, and making sure the gas analyzers are configured with an existing internal filter. The shelter housing the monitoring system needs to protect the instrumentation from excessive dust and dirt, intense light, or radiation. If using an optical instrument like the DOAS, a shortened monitoring pathlength should be considered to minimize the loss of data due to temporary optical obstructions from dust.

Choosing appropriate monitoring equipment

Factors to be taken in consideration when choosing appropriate monitoring equipment are: the purpose of monitoring, detection limit and precision range, ability to conform to relevant monitoring standards, duration and method of deployment, frequency of calibration, ability to interface remotely, environmental requirements, ease of use, location, meteorological conditions, and cost.

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4. Where to monitor? - selecting monitoring sites

4.1. Representativeness of monitoring sites

Choosing appropriate monitoring sites requires the specification of the desired spatial and temporal scales of representativeness.

4.1.1. Spatial representativeness

EU (Directive 2008/50/EC, amended by Directive (EU) 2015/1480) and US regulations (**40 CFR Appendix D to Part 58**) both set macroscale criteria to ensure the representativeness of sampling sites. Both stipulate that a site:

- 1. captures the highest exposure of the population
- 2. reflects the typical concentrations of highly populated areas
- 3. represents the impact of surrounding sources
- 4. is also exposed to regional pollutant transport
- 5. well represents weather fluctuations

Spatial representativeness is translated into spatial scales that are defined in terms of the physical dimensions of air parcels located near the site. The spatial scales of representativeness are described in **Section 4.2**.

4.1.2. Temporal representativeness

Temporal scales vary among pollutants, and usually reflect weather fluctuations and changes in emission levels. Temporal analysis provides insight into the cycles of production and dispersion of contaminants and takes into consideration the temporal representativeness of the monitoring site. Temporal analysis techniques include diurnal, weekly and seasonal analyses. The diurnal analysis method shows the temporal distribution of contaminant concentration for each hour of the day. This provides information on the variation of emission levels in a day. The weekly analysis technique determines the temporal distribution of contaminant levels for each day of the week (Environment Agency, 2011). Finally, the seasonal analysis method shows the temporal distribution of pollutants for each month of the year. To determine how air quality compares to previous years and how contaminant levels are changing over time, it is suggested to perform a regression analysis on the annual mean and other statistics.

4.2. Site classifications

Monitoring site location is determined taking into consideration the monitoring objectives and the type of the desired monitoring site. The classification of the site by its type and spatial scale of representativeness is important in the interpretation of the monitoring data. For example, to determine the concentration of CO in areas having high CO levels, a microscale and a middle scale site will be appropriate (U.S. Environmental Protection Agency, n.d.). Areas that include CO maxima are usually areas with high traffic density and poor atmospheric ventilation. The different spatial scales used by the US EPA are described in **Table 15**. **Table 16** shows the different site types and their relationship to the siting scales. The approach in the EU is described in **Tables 17** and **18**.

Spatial Scales	Description	
Microscale	Concentrations in air volumes related to areas ranging from several meters to about 100 meters.	
Middle Scale	Concentration in areas with dimensions ranging from about 100 meters to 0.5 kilometer.	
Neighborhood Scale	Concentrations within extended area of the city with air volumes related to area dimensions ranging from 0.5 to 4.0 kilometers	
Urban Scale	Concentrations in an area of city-like dimensions ranging from 4 to 50 kilometers.	
Regional Scale	Concentrations in a rural area of relatively homogeneous geography with no large sources, with volumes of air associated with dimensions ranging from 10 to 100 of kilometers.	
National and global scales	Measurement scales representing the concentrations at the national or global scale.	

 Table 15: Site classification (US approach)

 (source: https://www.law.cornell.edu/cfr/text/40/appendix-D_to_part_58)

Site Type Description		Spatial Scale of representativeness
Highest Concentration	Determine the highest expected concentrations in the area	Microscale Middle scale Neighborhood scale (sometimes regional or urban for secondarily formed pollutants).
Population Oriented	Determine typical concentrations in populated areas	Neighborhood Urban
Source Impact	Determine the impact of significant sources on air quality	Micro Middle Neighborhood
General/background/ regional transport Determine general background concentration levels		Urban Regional
Welfare-related impacts	Determine the effects of contaminants on welfare	Urban Regional

Table 16: Relationship between site type and spatial scale of representativeness (US approach)

Table 17: Site classifications (EU approach)

Spatial Scales	Description	
Urban	Areas of high residential population and traffic densities in "old" city centers	
Suburban	Areas of lower residential population and traffic density compared to urban areas	
Rural	Areas of very low residential population and traffic density	

Table 18: Relationship between type of site and type of area (EU approach)

Type of Site	Description	Type of Area
Traffic	Located near a major road	Urban
Industrial	Located near an industrial source or area (thermal power generation, heating plants, refineries, waste incinerators, airports, ports, mining sites)	Suburban
Background	Neither classified as "traffic" nor "industrial." Located such that the average pollution exposure of the general population is represented. Pollution level is not dominated by a single source type (eg. traffic, industry) unless that source type is typical within the area under monitoring Representative of a wider area (several km ²)	Rural

4.3. Considerations for site selection

Depending on the sampling objectives, the criteria summarized in **Table 19** should be considered for site selection, either independently or in combination.

Factors	Description	
Long-term viability of sites	High consideration must be given to the duration of the monitoring plan. If the purpose of monitoring is to obtain long-term data, a site that would be available long-term must be chosen. It is recommended to have at least one year of data recording in each site.	
Security	A particular site may not be appropriate for the installation of an ambient monitoring station because of problems with the security of the equipment. Sample inlets are the most vulnerable since they should be at breathing height. If space is available, putting up a security fence can be an option.	
Logistics	Logistics refers to the process of obtaining, transporting and maintaining of material and personnel for a monitoring operation. Sites must have easy access for the transport of calibration cylinders and other bulky equipment to and from the site. With roadside sites, it can be difficult to locate a power supply, but it is sometimes possible to use the power supply from streetlights by running armored cable under the pavement.	
Topography	Topological features affect the transportation of air contaminants. It is recommended to review the topography of the area to ensure that the purpose of monitoring at that site will not be adversely affected.	
Restricted air flows around sample inlet	Sites should not be close to walls, buildings, trees, or under overhanging greenery that can affect the air flow	
Physical and chemical interferences	Interferences might come from physical temporal variations and from chemical reactions of some contaminants with the gas being sampled	
Local emissions	Sites need to be away from neighboring sources	
Economic	It is recommended to take into consideration the resources required for the entire data collection activity, including human resources, instrumentation, installation, safety equipment, maintenance, data retrieval/data transfer, data analysis, quality assurance and data interpretation.	

Selecting a monitoring site

When selecting a monitoring site, consideration should be given to the representativeness and type of the monitoring site as well as the long-term viability of the site, including security, logistics, topography, meteorological conditions, pollutant considerations, air flow in inlet, interferences, local emissions and economic factors.

05 5. Data management guidelines

The gathered data must serve to achieve the data quality objectives and enable the quantitative assessment of air quality and its compliance with relevant national and regional standards, limit values, guidelines and other rules. Tools used for air quality data acquisition, processing, and evaluation have to generate data which is acceptable to the national authority, GCC bodies and under international standards in terms of quantity and quality as well as how it is stored, presented and transmitted. General data management guidelines that can be applied universally to comply with data quality objectives are described below. Some of the parameters described can be adjusted on a state-by-state or regional basis after data quality objectives have been defined.

The main purpose of the data management guidelines is to ensure that the collected data is of high enough quality to allow its interpretation and the consequent development of strategies to mitigate air pollution. Ensuring data quality is therefore of utmost importance.

The data management guidelines also aim to ensure the safekeeping of information and systematic data reporting. The key dimensions of data quality are:

Consistency	Consistency represents if the same calibration information produced at multiple instances matches. This dimension does not apply to measured values of ambient air pollution since there is intrinsic variation in the measurements.
Accuracy	The level to which data represents the real value and confirms with a reference source.
Validity	All data in a database can be traced and connected to other data.
Completeness	The data set covers more than 75 per cent of the hour, day, season or year (see Section 5.1.5)
Timeliness	Data is published and shared in a timely manner

Quality assurance and quality control (QA/QC) is generally associated with the entire air quality monitoring process including the choice of instrumentation, site selection, calibration and maintenance processes, data collection and storage, as well as staff expertise and technical proficiency (New Zealand Ministry of the Environment, 2009). QA is the integrated system that involves the determination of monitoring and data quality objectives, network design, site selection, equipment evaluation and training to ensure measurements meet defined standards of quality. QC is the operational procedures and checks used to assess equipment performance relative to desirable or specified criteria. QC is also includes checks or comparisons performed during data validation for the purpose of identifying data that may be invalid, suspect or in need of adjustment (American Society for Quality, 2021).

The following sections provide procedures for implementing QA/QC, starting with instrument calibration and maintenance, followed by data acquisition, then sample and data storage, and finally in data acceptance. Details on what should be documented as part of the QA/QC procedures are then described. The challenges the GCC countries related to data collection (especially for PM), evaluation, and reporting will be addressed at the end of the section.

Considerations that should be taken when dealing with the monitoring units and conversion factors as well as with negative and missing data are detailed in **Appendices A** and **B**, respectively.

5.1. Principle elements of QA/QC

This section highlights the key principles of QA/QC and how to prevent poor quality data and errors. Focusing on obtaining high quality data is more valuable than focusing on the amount of data collected. To avoid poor data quality that prevents data from being used for its intended purpose and imposes avoidable challenges in data analysis, QA/QC procedures have to be implemented as soon as the monitoring site is established and all through the monitoring process. To start with, QA/QC procedures should be carried out in instrument calibration and maintenance. Then, the procedures should be implemented during data acquisition, sampling and data storage, and finally in the process of data acceptance which consists of data verification, data adjustment, and data validation. This is important to ensure data quality before analyzing and interpreting the data.

5.1.1. Instrument calibration and maintenance

Instrument calibration is an indispensable element of QA/QC and a vital part of managing an ambient air monitoring site. Without proper calibration, data quality cannot be ensured, making subsequent data analyses unreliable, especially in the GCC where relative humidity and temperature fluctuations interfere with monitors.

Calibration is defined as the process of testing and adjusting an instrument's measurements by comparing the response of the instrument to a known reference value (U.S. Environmental Protection Agency, 2014). Instruments and equipment are exposed to different influences that might affect the measured value over the course of time, and inaccurate measurements, errors and biases will disrupt data quality (U.S. Environmental Protection Agency, 2008). Calibration is therefore recommended to be done regularly and it should be carried out at the monitoring site. Different instruments require different calibration and maintenance frequencies. In principle, instrument calibration and maintenance should follow the recommendations and requirements of the appropriate standard method, such as those of the USEPA, the EU, British Standards, or the International Organization for Standardization (ISO), and the manufacturer's instructions (New Zealand Ministry of the Environment, 2009). Calibration of air quality monitoring instruments are generally followed by detailed calibration instructions produced by the instrument manufacturers. Analyzer being calibrated should be tested with samples having known pollutant concentrations to detect deviations. An analyzer is recommended to be in operation in its normal sampling mode for several hours to stabilize its operation before being calibrated. To elaborate, instrument calibration is ideally carried out under the same meteorological conditions, background air and concentration ranges as those in which the analyzer will collect data.

Calibration should be done at a routine interval, and when:

- A new instrument is being used and after repair of an instrument
- An instrument has been put out of calibration due to shock or vibrations
- o Observations have become questionable
- The instrument is being relocated
- o Instrument operation has been interrupted for more than a few days

Instrument calibration

Instrument calibration should be done regularly at the monitoring site and when an instrument has been newly installed, repaired, put out of calibration due to shock or is being relocated. Calibration should also be done when instrument has been non-operative for more than a few days and when observations become questionable.

The stages of calibration are as follows:

1. Compare the response of the analyzer against the concentration of a reference

Gas analyzers are tested against "zero" air, or air containing none of the relevant pollutants to determine the precision of the instrument. The instrument is then tested multiple times with a gas source having a known concentration of the pollutant. The requirements for the calibrating of gas analyzers are therefore the calibration or reference gas of known concentration and the 'zero' air supply. Calibration gas mixtures should be traceable back to the standard reference material. The true concentration of the calibration gas can be determined by a reference monitor located near the gas analyzer being calibrated.

2. Plot a calibration curve

A calibration curve establishes the relationship between the output of the data logger and the reference concentration of the contaminant. In other words, the data logger response curve relates the analyzer readings to known concentrations of unit gases. After a set of standards containing a known pollutant concentration is prepared, the instrument response is measured for each standard to develop a relationship between the response and the concentration. The curve can be either linear or nonlinear. The relationship is used to transform measurements made on test samples into estimates of the contaminant concentration.

Multi-point calibrations are used to verify the linearity of analyzers after major maintenance at specified frequencies upon installation (Barwick, 2003). The analyzer readings are plotted against reference concentrations, along with a curve that best fits the points. Least squares regression analysis is a form of mathematical analysis used to determine the slope and intercept for the best fit calibration line form: (instrument response) = (calibration slope) * (actual pollutant concentration) + (calibration intercept) where:



Figure 1 shows an example of a typical calibration curve.

Figure 1: Typical calibration curve

Calibration curve

It is recommended that a calibration curve be built before monitoring. To do so, prepare samples of the criteria pollutants of known concentrations and record the instrument reading. The calibration curve is built by plotting the curve of the instrument reading against the known concentrations of the contaminants.

3. Carry out zero and span adjustments

Zero and span adjustment checks are the stages of calibration that establish the instrument's drift performance and reliability over time. Sometimes, an instrument does not read **"0"** for zero pollutant input. In other words, the y-intercept of the calibration curve is not zero, as shown in the **Figure 2.** The adjustment related to the y-intercept is called "the zero", so its adjustment shifts the curve vertically. The adjustment that relates to the slope of the curve is called the span.

Zero/span checks must be implemented when a monitoring instrument is first installed since there is little to no information available on its drift performance. When there is sufficient information on the analyzer's drift performance, the frequency of the calibration can be changed based on the previously mentioned considerations. Zero/span checks are done by recording the instrument response at zero and span concentrations. The routine zero and span calibrations are made using an appropriate "zero source" which can be "zero grade" air.



Figure 2: Zero and span on an instrument response curve

The analyzer is then calibrated by physically altering the instrument setting to read the known concentration of the supplied gas, and for the instrument responses to read "zero" when fed with "zero" air. Control charts are necessary to represent and monitor zero/span. These charts can show if the drift becomes excessive, so that corrections can be applied. Control charts, which can be built in different ways, are important to visually represent monitor drift and detect when it becomes excessive so that corrective action can be taken. When drift becomes excessive, data should be invalidated. Note that some analyzers have an "auto-zeroing" function. It is not recommended to have automatic or manual adjustments to the span unless drift becomes excessive and justify calibration.

Analyzer responses tend to drift unpredictably with time. Different factors that cause data bias and can develop gradually. However, due to technological advancements, ambient air monitors are very stable, and adjustments are not as necessary as they previously were (U.S. Environmental Protection Agency, 2008). Moreover, it may not be always possible to make precise adjustments of the zero and span controls because of the interaction between the zero and span controls, the limited resolution of the controls and the potential delayed stabilization period or reaction to the adjustments. For this reason, it is not recommended that frequent adjustments be made.

4. Equipment maintenance

Preventive maintenance of monitoring stations and monitoring instruments is important for the smooth operation of the station and the assurance of good data quality. Preventive maintenance is defined as the systematic maintenance of equipment to provide optimum operating conditions and prevents downtime failure (Brammer and Mills, 2007). Preventive maintenance plans can include the following instructions (New Zealand Ministry of the Environment, 2009):

- **1.** Run regular monitoring site inspections
- **2.** Check instrument diagnostics for normal operation
- 3. Check sample inlets and filters and repair or alter as needed
- 4. Check pumps (vacuum and filters) and repair as needed
- 5. Check that the data logger and instrument times are correct

Maintenance is a continuous process that is generally incorporated into daily routines and includes monthly, quarterly, bi-annually, and annually scheduled activities. Maintenance requirements are specific to each type of air monitoring equipment because of differences in the physical and chemical properties that they measure in order to determine pollutant concentrations. For this reason, maintenance routines must be determined by the instrument manufacturer. It is important that these routines be incorporated into detailed schedules that allocate time accordingly (New Zealand Ministry of the Environment, 2009).

Zero and span

It is recommended that zero and span checks be done when an instrument is first installed using certified "zero grade" air as the zero source. Building control charts is recommended in order to detect when there is excessive drift. Frequent adjustments are not recommended.

5. QA/QC for the measurement of particles

A QA/QC programme can be designed for the measurement of PM under the conditions prevalent in the GCC countries. The first step is to adopt the general procedures of QA/QC to make sure that instruments are installed and operated so as to yield representative PM data. If the PM collection is manual, the sampler is usually located outdoors whereas automatic samplers such as β -absorption and TEOM monitors (and BS samplers) are generally placed inside special shelters, and sample the air from outside through a sampling tube. Air conditioning is required in the shelters.

Water condensation and observable deposition must not occur in the sample line, so in GCC countries where high humidity is often measured, frequent site visits should be conducted and clear flow inside the sample line must be ensured at all times. Since it is impossible to calibrate a particle sampler by passing a known ambient particle mixture into the inlet and comparing to a measured value. QA/QC procedures focus on flow rate measurement and inter-instrument and intra-location comparability. Periodic co-location of samplers is in fact a useful method of evaluating instrument performance. If chemical analysis of the filters (commonly collected during manual sampling) is to be conducted for speciation and source apportionment, QA/QC procedures need to be established for the laboratory weighing and analysis. Decisions on chemical speciation are tied to the overall objectives of the air quality monitoring programme. Objectives may include but are not restricted to assessing the natural dust contribution to PM levels, reporting on ambient air quality, assessing the harmful effect of PMs on health and the environment, evaluating a polluted area and estimating the improvements in air quality.

5.1.2. Data acquisition

After calibrating the instruments and starting the monitoring process, the next step is to protect the integrity of the collected data. For this, it is important to follow good practice guidance during data acquisition. Data acquisition is the process of capturing the data generated by the monitoring instruments, storing it for an appropriate interval and transferring it for final storage in a local database. Data acquisition technology is constantly improving and evolving. Most modern air monitoring systems have their own data acquisition systems that provide data in an instantaneous digital format from the instrument to external data loggers. It is possible to use an instrument's data acquisition system to transfer, collect, and store the monitoring data on a laptop, and these systems can increase data capture and reporting. However, if there are several different instruments and monitoring sites, data management can become burdensome. For this reason, the following practices are recommended:

- Digital signals are favored and recommended over analog signals by bodies including USEPA because analog voltages can vary with time, and digital data acquisition systems decrease noise, improving sensitivity as a result. Digital data acquisition systems are superior to analog systems as they can track calibration data, thereby directing the performance of instrument calibrations and recording calibration settings (U. S. Environmental Protection Agency, 2008).
- 2. Use a purpose-built or PC-based external data logger for all instruments to ensure that all parameters have the same date and time stamps for future comparisons and analyses. Configure continuous monitors in a way that their own data acquisition system is recording in parallel to the external data loggers. Synchronize instruments' internal clock with the external data loggers to avoid time mismatches.
- **3.** Use external data loggers that provide, and store 10-minute averages calculated from finer-resolution instantaneous measurements. Two sets of data could be used to make sure that the external data logger's averaging and programming algorithms match with the instrument's output.
- **4.** Many data loggers sample the instrument output at frequent time intervals specified by the operator, and then compress the data into the specified time-averaged intervals. Considerable thought should be given to choosing these time intervals. They should be chosen according to the storage capacity of the data loggers, the temporal representativeness of the contaminant concentration and the response time of the instrument.
- 5. Use a telemetry system, or other means of transferring data such as telephone lines, the internet or satellite to download data loggers periodically to a central archive. Manual downloads are acceptable but require frequent visits to the monitoring site depending on the data logger's storage capacity, but this can run the risk of missing instrument faults taking place between sites.

Data acquisition

When choosing the data loggers' sampling time intervals, the data logger's storage capacity, the response time of the instrument and the temporal representativeness of the contaminant concentration should be taken into consideration. When monitoring large number of sites, it is recommended to use purpose-built or PC-based data loggers for all instruments and to configure continuous monitors in a way that their own data acquisition system is recording in parallel to the external data loggers. It is also suggested that instruments' internal clock be synchronized with the data loggers, and that external data loggers provide 10-minute averages calculated from finer-resolution instantaneous measurements and have high resolution raw data files. The use of digital systems for data transfer is also highly recommended.

5.1.3. Sample storage

In parallel to data acquisition systems, special care must be given to the storage of samples that are taken for analysis. When samples are taken and the measurement systems encompass the use of a sample line, there is a potential risk of sample loss due to various factors including adsorption, deposition, diffusion, and chemical reaction.

These losses could result in some systematic uncertainties. To avoid this, it is recommended that consideration be given to the length and composition of the sample line. For example, for reactive contaminants, the material of the sample line should be inert, sampling systems must be tested to guarantee sample integrity, and samples must be identifiable during sampling, sample preparation and analysis.

For this reason, it is important that samples be given an identification or reference number. It is recommended to keep a log that provides the reference number of each sample as well as details of the date, time and location where the sample was acquired, purpose of the sample and method of sample treatment. Note that measures to protect sample integrity depends on the type of sample (Environment Agency, 2011). For example, for PM, it is highly recommended that samples collected on a filter be stored individually in closed containers. For other samples, storage is best in dark and cool environments and under conditions where there are no risks of contamination.

Sample storage

To avoid sample losses in sampling systems, sample lines should be tested to ensure sample integrity. It is recommended that samples be given identification numbers and that a log be held that provides all the details of each sample. Moreover, samples should be stored away from contaminations and in a cool and dark environment.

5.1.4. Data storage

When transferring data for final storage in a data base, it is important to ensure proper and systematic data storage that protects against the loss of data files and eases the location and reconstruction of the details of studies long after they have been conducted. It is thus necessary to have a robust system for data storage and long-term preservation to guarantee that the data is available, complete, and accurate throughout the project life cycle.

There are a variety of electronic database systems and software packages available to efficiently store air quality data, and provide for data manipulation, such as graphical analysis, the calculation of fixed and moving averages, and exceedance percentiles. Acceptable data content and ease of use are important considerations for choosing field data storage systems. To ensure that data is organized for easy retrieval and use, and that the data are in a single, secure location, the following practices are recommended:

- Store data in a central database that is frequently backed up and assign each monitoring site and parameter a unique identifier that enables easy retrieval.
- Store data in a way that incoming data is appended to the archive file so it can be viewed as a continuous data set.
- Preserve two parallel data sets:
 - o A data set that preserves raw data in its original form
 - o A data set that has been quality assured and is available for further analysis

This ensures that the data can be revisited and re-analyzed in case issues arise with the original quality assurance process.

Data storage

It is recommended that data be stored in a frequently backed up central database and that identifiers be assigned to every parameter. Incoming data should be appended to an archive file. It is also suggested to maintain one data set that preserves raw data and another that contains quality assured data.

5.1.5. Data acceptance

It is vital to make sure that the data is acceptable before interpreting it. Data acceptance consists of:

- 1. Data and instrument verifications: data checks are made to assess the quality of the sample and the authenticity of the measurements
- 2. Data and instrument adjustments: made to correct data defects that will impact the quality of the data.
- **3. Data validation:** a documented process that assures that the instrument provides reliable results within the acceptance criteria. If the data is out of specification, system improvements must be made, and invalid data should be deleted from the final data set.

The process of data acceptance, which proceeds data analysis, is described in **Figure 3**. Details on data and instrument verification, data and instrument adjustments, and data validation are presented in the following sections.



Figure 3: Process of data acceptance

5.1.5.1. Data and instrument verification

To minimize data loss, data checks have to be conducted at regular intervals to identify and remedy errors such as system failures, human error, power failures, interferences, instrument faults, and data spikes. Telemetry ensures that data is checked at least once daily, so it is recommended to record data checks from telemetered sites. Telemetry systems should be periodically reviewed to guarantee the integrity of the checking function. Notes of occurrences that could affect results must be recorded. Because there is a large quantity of data that needs to be checked, automated checks are preferred where possible. A combination of manual and automated checks is the most effective way in checking large quantities of input data (Emmanuel et al., 2018).

Moreover, instruments must be frequently checked, calibrated and maintained. The frequency of these checks depends on the instrument being used. When performing instrument checks and calibrations, it is important to keep logs and technician notes describing the adjustments made and specifying the time of adjustment. These will be useful when validating and removing suspect data.

5.1.5.2. Data and instrument adjustments

As mentioned in **Section 5.1.1**, an instrument's response curve tends to drift unpredictably with time. Different factors can cause data bias and can emerge gradually over time. An example is given in **Figure 4**, which shows a change in the span of an instrument's response, illustrating the need for daily data and instrument checks.



Figure 4: Span in an instrument response curve can drift over time

Checks may show changes that require physical site visits to determine the cause. Solutions include deleting all the data after the last good zero/span check or adjusting the later readings to match the former batch.

5.1.5.3. Data validation

Preventing, identifying, correcting, and defining the factors that affect the precision, accuracy and validity of the measurements is a vital step before data analysis. Data validation is a process designed to detect and verify data values that are not representative of the actual air quality conditions at the monitoring site. Data validation must be done as soon as the data is collected to reduce effort and minimize data loss, and should be the last step before interpreting the data. Data validation should therefore be undertaken with extreme care.

Data validation can be performed manually or automatically.

With manual methods, data validation is based on results from the data checks that monitor the parameters in sampling, analysis, and data storage.

With automated methods, if zero and span checks exceed acceptance, measurements must be invalidated back to the most recent point where these measurements were valid, generally the previous check. Sometimes, other points in time such as instrument malfunctions or power failures can be associated with the cause of the drift or exceedance. Any data succeeding an instrument malfunction, or a period of non-operation, must be invalidated until the next acceptable check or calibration. Automated methods should also be done according to set screening criteria (Hafner, 2016). Screening criteria are made up of the following:

- Pollutant concentration range
- Diurnal consistency
- Rate of change or spike

The general approach (Hafner, 2016) to data validation is as follows:

- 1. Manipulate the data and sort it or graph it (e.g. scatter plots, summary statistics, box-whiskers plot).
- 2. Remove data corresponding to calibration, outliers and electronic offset.
- **3.** Prepare the screening criteria to help focus the validation efforts.
- 4. Verify that the criteria are met
- 5. Use flags to identify problems with the sample. The flags can indicate that the data may be suspect due to contamination or special events (e.g fireworks, desert storms). Flags can be used to determine if the data should be invalidated
- 6. Document changes.

Note that a sample is considered valid until proven invalid. When a measurement is found inconsistent with expectations, first assume that it is because of a measurement error. If nothing unusual is found after tracing the path of a measurement, then the sample can be assumed valid. Also note that **75 per cent of valid data must be considered valid, before averages can be calculated** and that any data calculations and assessments that used invalidated data should be redone with the justification for every data invalidation documented. For example, if the continuous monitoring data is collected as 15 minute averages, at least 3 of these averages are needed to determine an hourly average. If there was less than 75 per cent of the data is valid, averages should be calculated (**Figure 5**).



Figure 5: A flow chart describing data validation leading to calculated averages

Data validation should take place at the different monitoring and data generation steps and should comply with the data quality objectives set forth at the national and/or regional level.

One suggested mechanism is a feedback loop that includes data validation at the monitoring station, the measurement data centre (laboratory for manual measurement and monitoring station for automatic measurements), the monitoring data centre, the national data centre and, if required and available, the regional data centre as shown in **Figure 6**.





Data validation

It is advised to apply flags to suspect data until its validity is determined. Invalidate data following a period of instrument operation interruption or instrument malfunction. If zero and span checks exceed acceptance limits, invalidate the measurements back to the most recent point where these measurements were valid. To calculate unbiased averages, at least 75 per cent of valid data must be obtained. The validation process is repeated at the different stages that include the monitoring station and the measurement, monitoring, national and regional (if required and defined by the data quality objectives) data centres.

5.2. Documentation template

The different aspects of documentation that need to be considered for an operational air quality monitoring site are:

- 1. Routine site inspections, instrument calibrations, and routine maintenance
- 2. Detailed instrument calibration and servicing records
- 3. Documentation of instrument types, date of installation and serial numbers for all equipment
- 4. Data storage procedures, including file creation and archiving systems (see Section 5.1.4.)
- 5. Data handling and adjustment procedures to correct for calibrations, checks and baseline or span drift (Refer to **Section 5.1.5.2.**)
- 6. Any data adjustments and excluded or missing records
- 7. Monitoring methods used
- **8.** Monitoring site metadata i.e. an overall description of the site characteristics and any local sources of air pollution

Proper records of metadata help ensure appropriate interpretation of data. The metadata that has to be documented is summarized in **Table 20**:

Table 20: Metadata	documentation	template
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Monitoring Site Metadata
Monitoring objectives
Site name and identification number
Site location: street address, city, region, geographic coordinates
List of the contaminants being monitored
Spatial scale of representativeness
Site category
Site topography
Site height above sea level
Equipment housing and housing environment
Location and description of major emission sources including information of on the type, location, and distance from monitoring site
Photograph of the site
Contact details forequipment owner, land owner, electrician and air conditioning service
Meteorological site metadata
Meteorological variables being measured
Location of meteorological site, including if any industrial facility is located near the monitoring site
Regional and local characteristics

Table 20: Metadata documentation template (continued)

Contaminant metadata
Contaminant
Sampling and analysis methods and operating schedules for each monitor
Instruments used
Sampling period and period of operation
Sampling probe height
Calibration frequency
Percent valid data

Documentation

It is recommended to document the monitoring site metadata as well as routine site inspections, instrument calibrations, instrument information, data quality validation criteria, data storage procedures, data adjustments, missing records and monitoring methods used.

5.3. Reporting monitoring results

At the *monitoring station*, data may be made available to the public in real-time provided that this data has been validated and verified at the monitoring station.

Validated data is reported at the *measurement data center* in hourly-average format. For example, minute data collected between 01:01 and 02:00 are averaged and reported at 02:00 in local standard time. Invalid and missing data are noted with a flag as defined by the standard operating procedures for operating and reporting. Other data summaries can be reported for various averaging periods and statistical forms, including 1-hour, 8-hour, 24- hour, daily maximum 1-hour, daily maximum 8-hour and daily means. 8- hour means are running 8-hour averages for each hour of the year, with the result reported for the end hour. Daily maximum 8-hour values are the maximum 8-hour mean values for each day of the year. 24-hour means are running 24-hour averages for each hour of the year, with the result reported for the end hour. Daily means are based on the average hourly concentrations recorded from 01:00 to 00:00.

Also at the *measuring data centre*, sample site ID, sampling date, time and volume, information on the sampling media and equipment, all field and sampling lab information and qualifier codes are included. The laboratory reports include information about sample preparation, analytical method and equipment and qualifier codes associated with the analysis.

At the *monitoring data centre*, a second level of validation takes place, mostly done on a quarterly basis.

At the *national and regional data center*, data supports air management policies and is reported according to national and regional air quality agreements. Data are also used to track trends in ambient air quality in communities (urban and rural) across a country; support health and environmental research and analysis; conduct environmental assessments; verify emissions inventories; conduct source apportionment analysis; validate and calibrate air quality models, remote sensing and air quality forecasting; and develop and assess new monitoring technologies.

A systems audit could be established to review the entire monitoring system documentation and procedures for station siting, instrumentation calibration and maintenance, and data collection and validation. A performance audit focusses on station operations (e.g. instrument performance, inlet manifold, siting, maintenance, safety). These audits can be performed either independently or concurrently. It should be ensured that all site documentation is readily available and all sites, instruments and data collection systems are easily and safely accessible.

Finally, a data quality assessment which involves the statistical analysis of air quality data helps to determine if reported data meet the objectives of the air quality monitoring network. These assessments can help in the evaluation of overall systems performance and the revision of guidelines or objectives as necessary.

5.3.1. Summary statistics

A considerable amount of data can be generated by an air quality monitoring network. Assessments may include network data quality reports. These reports should be aggregated for all methods at each site and for the network as a whole. Summaries should also include maximum and minimum concentrations based on the relevant averaging period, arithmetic mean and median, number of exceedances, percentiles and proportion of results belonging to particular bands. More details are shown in **Table 21**.

Contaminant	Summary Statistics
со	 1-Hour values: Hourly average concentrations. Number of Measurements (8760 values per year would be produced with uninterrupted monitoring) Highest and second-highest 1-hour values in the year Number of Exceedances 8-Hour values: Calculated as a moving average of eight 1-hour values. Number of Measurements Highest and second-highest non-overlapping (not the same as 1-hour means) 8-hour values in the year Number of Exceedances
Pb	 24-Hour values: Daily average concentrations. Number of Pb measurements is contingent to PM measurements and the number of pooled samples thereafter. Required is at least one measurement every sixth day The maximum of all rolling 3-month averages in the year 1st Max, 2nd Max, 3rd Max, 4th Max: (the four highest 24-hour averages in the year) Annual Mean: Arithmetic mean of 1-hour values.

Table 21: Summary Statistics (source: https://www.epa.gov/outdoor-air-quality-data/about-air-data-reports#con)

Table 21: Summary Statistics(source: https://www.epa.gov/outdoor-air-quality-data/about-air-data-reports#con)(continued)

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NO₂	 Hour values: hourly average concentrations. Number of Measurements (8760 values per year would be produced with uninterrupted monitoring) Highest and second-highest daily max 1-hour values in the year (Take the highest 1-hour value of each day, and report the highest four of those values) 98th percentile of the daily max 1-hour values in the year Annual Mean: Arithmetic mean of 1-hour values.
O3	 1-Hour values: hourly average concentrations Number of Measurements 1st Max, 2nd Max, 3rd Max, 4th Max (Take the highest 1-hour value of each day, and report the highest Number of Exceedances Valid days (number of days when the requisite number of values were reported) 8-Hour values: calculated as a moving average of eight 1-hour values. Number of measurements 1st max, 2nd max, 3rd max, 4th max (take the highest 8-hour value of each day and report the highest four) Number of exceedances 24-Hour values: Calculated for each day as an average of 1-hour values
SO₂	 1-Hour values: hourly average concentrations Number of Measurements 1st Max, 2nd Max, (Take the highest 1-hour value of each day, and report the highest) Number of exceedances 99th percentile 24-Hour values: calculated for each day as an average of 1-hour values Number of 24-hour Highest and second-highest 24-hour average concentrations in the year Number of exceedances

Table 21: Summary Statistics(source: https://www.epa.gov/outdoor-air-quality-data/about-air-data-reports#con)(continued)

PM _{2·5}	 24-Hour values: Daily average Number of measurements 1st Max, 2nd Max, 3rd Max, 4th Max 98th Percentile Annual mean: computed from 24-hour values. Composition: Anthropogenic: X.X % Biogenic (mainly dust): X.X% 			
PM ₁₀	 24-Hour values: daily average concentrations Number of measurements The two highest 24-hour values of the year, in micrograms per cubic meter. Number of exceedances Annual mean: computed from 24-hour values. Composition: Anthropogenic: X.X % Biogenic (mainly dust): X.X% 			

06 6. Air quality data assessments and analysis

Once data has been collected and its quality established, it is ready to be interpreted and analyzed in order to assess air quality. This chapter provides three ways in which air quality can be assessed based on the monitoring results:

- 1. Comparing reported data to set standards,
- 2. Displaying data in concentration plots to identify trends
- 3. Using the reported data to calculate an air quality index (AQI)

6.1. Assessments against air quality standards

One of the ways to assess air quality is to determine whether the air in the area that is being monitored is compliant with air quality standards (such as national air quality standards). Continuous monitoring data is generally collected as hourly averaged data. However, to assess data against the standards for some contaminants, it must be converted to other averaging periods. Ambient air quality standards in GCC countries required 8-hour rolling averages for CO and O_3 , and hourly averages for SO₂ and NO₂. To determine long term trends at least 75 per cent of the data must be available so that the number of yearly exceedances and the annual averages to be reported (Environment Agency, 2011). If the monitoring period is shorter than a year, extrapolation is needed to produce the yearly number of exceedances, but consideration must be given to the representativeness of the monitoring period.

Assessments against standards

When determining averages air quality to assess against standards, it is recommended that the data used represents at least 75 per cent of the collected data within one year. It is possible to use extrapolation if the monitoring period is shorter than a year.

6.2. Air quality plots

To get more information about the source and dispersion of poor air quality from the monitoring data, different analysis techniques can be implemented. Three of the main analysis methods are temporal, concurrence, and directional analysis.

Temporal analysis provides insight on the cycles of production and dispersion of contaminants. It takes into consideration the temporal representativeness of the monitoring site to show how the concentration of the pollutants changes with time. Temporal analysis includes diurnal, weekly and seasonal analyses (Environment Agency, 2011). To determine how air quality compares to previous years and how contaminant levels are changing over time, it is suggested to perform a regression analysis on the annual mean, or to display the data in concentration plots to show air quality trends. Trend lines are especially useful to determine how the implementation of new policies affect contaminant concentrations. Increasing contaminant concentrations can indicate that more control is needed to reduce air pollution. Decreasing contaminant pollution can indicate that existing regulations are successful in reducing emissions.

Concurrence analysis examines the relationship between the concentration of a pollutant and other parameters measured at the same time to identify potential pollution sources. For example, it may be possible to identify an association between meteorological conditions and the rise in concentration of a particular pollutant (Environment Agency, 2011). This can be done by comparing the periods of highest concentrations of that pollutant to other pollutants and to the collected meteorological data during a given period.

Directional analysis provides useful information on the source and dispersion of contaminants relative to the monitoring site. To perform directional analysis, wind direction has to be recorded at the monitoring site. The data can be represented in charts and plots. For example, charts using polar coordinates represent the average concentration of a contaminant in different wind sectors and shows the wind direction contributing to high concentration levels of a pollutant at a monitoring site. (Environment Agency, 2011). It is also possible to compute the level of a pollutant at various percentiles for different wind sectors to visually examine the distribution of the pollutant concentrations at the monitoring location.

Data analysis techniques

To get more information on the source of poor air quality from the monitoring data, you can implement temporal, directional and concurrence analyses by establishing an inter-annual comparison, correlating contaminants to each other and to meteorological data, and linking contaminants to wind direction.

6.3. Air quality index (AQI)

An air quality index (AQI) is a scale used to indicate how polluted the air in a given region is and how badly it risks the health of certain groups of people. It is generally calculated based on the measurement of each of the criteria pollutants (PM_{10} and $PM_{2\cdot5}$, O_3 , NO_2 , SO_2 , and CO), though indices can be calculated based on a smaller number of pollutants. Measurements are usually based on hourly readings, meaning that an AQI reported at 10:00 indicates that the measurement was done from 09:00 to 10AM. Color-codes can be used to indicate the level of air quality in the monitored area and which groups of people may be affected. This is important in informing the population about the air quality in their region in an accessible and comprehensible manner, and aids in the development of policies for air pollution mitigation.

Countries may develop their own AQIs according to their national air quality standards. For example, the US EPA has developed a widely-used AQI with scale running from 0 to 500, where value over 300 represents the greatest health concern (unvalidated AQIs from around the world calculated using the US EPA scale can be viewed on www.waqi.info). For every criteria pollutant, an AQI of 100 generally corresponds to the ambient air concentration of the level of the short-term national ambient air quality standard set for the protection of public health. The AQI categories are shown in **Table 22** (AirNow, n.d.):

Color	AQI Category	AQI Value	Description	
Green	Good	0-50	Satisfactory, pollution poses little to no risks	
Yellow	Moderate	51-100	Acceptable, may be risk for some people, especially people who are unusually sensitive to air pollutior	
Orange	Unhealthy for sensitive groups	101-150	General public is not very likely to be affected but members of sensitive groups could encounter health effects	
Red	Unhealthy	151-200	Members of sensitive groups could encounter more serious health effects, and members of the general population could experience health effects	
Purple	Very Unhealthy	201-300	Health alert: everyone has an increased risk of health effects	
Maroon	Hazardous	301 and higher	Health warning of emergency conditions: everyone is more likely to be affected	

Table	22:	air	aualitv	index	categories
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The AQI is calculated using the following equation (AirNow, 2016):

$$AQI = \frac{AQI \ high - AQI \ low}{Conc \ high - Conc \ low} \times (Conc \ i - Conc \ low) + AQI \ low$$

where:

Conc i is the input concentration for a given pollutant Conc low is the concentration breakpoint that is less than or equal to Conc i Conc high is the concentration breakpoint that is greater than or equal to Conc i AQI low is the AQI value/breakpoint corresponding to Conc low AQI high is the AQI value/breakpoint corresponding to Conc high

Appendix A

Monitoring unit and conversion calculations

Monitoring units

When assessments are carried out with regard to compliance with guidelines and standards, it is vital to specify an appropriate temperature. Ambient air quality guidelines and standards are identified at wide ranges of temperature. However, there is some inconsistency on the temperature used. For example, USEPA uses 25°C. In the EU, the standard conditions are 293 K (20°C) and an atmospheric pressure of 101,3 kPa for gaseous pollutants. For PM and its constituents, sampling volume refers to ambient conditions in terms of temperature and atmospheric pressure at the date of measurements. Hence, it is important to understand an instrument's data reporting software conventions and alter as needed.

Concentrations of air pollutants can be measured by either volume or mass, but most analyzers measure by volume. Concentrations by mass, such as mg/m^3 or $\mu g/m^3$, depend on ambient temperature and pressure at the time when the sample was taken. They refer to the weight of a gas or particulate contaminant in a cubic metre of dry air.

It is recommended to use volume measurements, such as parts per billion (ppb) or parts per million (ppm), for recording and archiving gaseous air contaminant data because they are independent of temperature and pressure.

For monitoring and recording air quality data, the following units are commonly used:

Gas	ses	Pa	rticulate Matter	
Recorded and archived as ppm or ppb		Recorded and archived as $\mu g/m^3$		
Cor	nversions from mg/m³ or µg/m³	Со	nversions from mg/m³ or µg/m³	
ο	At 25°C following US standards	ο	At 25°C following US standards	
0	At 20°C following EU standards	0	At the ambient temperature at the date of measurement following EU standards	

Monitoring units

Gases should be recorded and archived as ppm or ppb but can be converted to mg/m³ or μ g/m³ if needed. Particulate matter should be recorded and archived as μ g/m³.

Conversion calculations

For gaseous pollutants, the conversion between ppb and $\mu g/m^3$ (or ppm and mg/m³) depends on the molecular weight, pressure and temperature of the gas.

Note that ppb represents the volume of the pollutant in the gas phase per 109 cubic metres of ambient air, and that $\mu g/m^3$ represents the mass of the gaseous pollutant per single cubic metres of ambient air.

Through substitutions and rearrangements, we arrive at the general equation used to convert from ppb to $\mu g/m^3$ is at 1 atm and 298K is (Boguski, 2006):

$$\mu g/m^3 = 0.0409 \times (ppb) \times M$$

where M is the molar mass of the substance in question. And the general equation used to convert from $\mu g/m^3$ to ppb to at 1 atm and 298K is:

The conversion constants 0.0409 and 24.45 are obtained after using the ideal gas law at 1 atm and 298K. Table below shows the conversion of gaseous criteria pollutants from ppb to μ g/m³. Note that the same equation is used to convert from ppb to μ g/m³ and ppm to mg/m³.

 Table 23:
 Conversion from ppb to μg/m³ at 298K (25°C)

 (source: https://uk-air.defra.gov.uk/assets/documents/reports/cat06/0502160851_

 Conversion_Factors_Between_ppb_and.pdf)

Criteria Pollutant	Molar Mass (g/mol)	ppb	µg/m³
СО	28.01	1	1.15
NO ₂	46.01	1	1.88
O ₃	48.00	1	1.96
SO ₂	64.1	1	2.62

Appendix B

Negative and missing data

This appendix discusses on how to deal with the common issues such as negative or missing data. It also provides insight on the monitoring units and conversion factors that should be used in data management.

Negative data

Measurement data can sometimes contain negative values. Given that there are no negative gas concentrations, it can be tempting to delete them. However, deleting negative values from a data set will artificially increase the ambient concentration. It is therefore recommended to keep these negative data in a set where the data is within the expected range of uncertainty.

As a reference, the following limits are recommended for the reporting of negative values for gaseous criteria pollutants (U.S. Environmental Protection Agency, 2016):

- SO₂: -4.0 ppb
- O₃: -4.0 ppb
- NO₂: -5.0 ppb
- CO: -0.4 ppm

Similarly, following EU standards, all values greater than or equal to the negative value of the detection limit are accepted for further calculations, whereas values less than the negative value of the detection limit must be discarded. For instance, for a detection limit of $-3 \ \mu g/m^3$, a value of $-2.8 \ \mu g/m^3$ should be accepted, but a value of $-3.5 \ \mu g/m^3$ is discarded (European Commission, 2013).

For repetitive values exceeding the acceptable negative limits, investigate cause(s) like zero drift and the need to adjust the monitor's calibration baseline and document. Determine if a site visit is warranted to perform corrective actions.

Negative data

It is recommended to keep negative values in the data set if they fall with acceptable limits determined according to the specifications of every instrument.

Missing data

Even in the most meticulously managed monitoring networks, it is not easy to reach 100 per cent data validity for long-term monitoring. Some data gaps are unavoidable, for instance during calibration periods. But missing data is mostly due to unexpected equipment failures, power outages, or bias drifts (Kang, 2013).

Down time for routine calibrations and maintenance is typically excluded from the calculation of data capture, but the percentage of valid data includes it. Calibration shifts, slight bias or drifts are often dealt with, however special consideration is required for complete power outages. The following measures can be applied if gaps (missing data) due to non-routine calibration practices are identified:

- Determine root cause of data loss and document it. For example, if a user-defined flag
 indicates a power failure occurred, the reviewer should look at the associated minute data
 to see precisely when the power failure occurred and how many minutes of data were lost.
 In addition, the operator can look at whether other instruments at the site experienced power
 loss during that same hour. Other than the power failure that affects all the equipment at the
 monitoring station, reasons for missing data includes impaired equipment, insufficient sampling
 frequency, hardware problems, and human error.
- Re-poll datalogger or instrument, if possible, to see if missing data can be restored
- Review all status flags applied by the data management system (datalogger, sampler, etc.)

Note that the imputation to fill in missing data should not be used; the missing data should be left as a gap if used to report air quality.

In case the data is used for specific statistical analyses, gaps may bias findings and reduce statistical power. Therefore, researchers have developed imputation models to substitute for the missing valuable information. The review of the different imputation approaches is beyond the scope of this guidebook (Alsaber, Pan, & Al-Hurban, 2021). https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7908071/

Missing Data

For air quality reporting, it is generally recommended to leave any gaps in a data set instead of using interpolation or extrapolation to replace missing data.

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