Aerosol and Air Quality Research, 20: 1026–1037, 2020

ISSN: 1680-8584 print / 2071-1409 online
doi: 10.4209/aaqr.2019.11.0605

Strengths and Weaknesses of the WHO Global Ambient Air Quality Database

Dietrich H. Schwela[*], **Gary Haq**

Stockholm Environment Institute, Department of Environment and Geography, University of York, York YO10 5DD, UK

ABSTRACT

The 2018 World Health Organization (WHO) global ambient air quality database is an impressive compilation of PM_{10} (particulate matter [PM] with an aerodynamic diameter ≤ 10 µm) monitoring data for 3,570 cities in 97 countries and $PM_{2.5}$ (PM with an aerodynamic diameter ≤ 2.5 µm) data for 2,628 cities in 81 countries. The database collects PM measurements and estimates from established public air quality monitoring systems. PM contain sulphates, nitrates, and black carbon that can penetrate deep into the lungs and the cardiovascular system, posing the greatest risk to human health. Unsurprisingly, the WHO database reports relatively low levels of urban PM pollution in high-income (HI) countries in Western Europe, the Americas, the Western Pacific, and Oceania. However, there are high PM levels in low- and middle-income (LMI) countries in Africa, Southeast Asia, and Latin America—where lack of funding and inadequate staffing are key barriers to effectively reducing the air pollution. Unfortunately, politicians, organizations, and the media have used the database to draw inaccurate and misleading conclusions based on comparisons between cities, such as occurred with the 2016 version. In this paper, we investigate the strengths and weaknesses of the 2018 database with respect to several criteria such as the selection of pollutants, completeness, spatial and temporal representativeness, and quality assurance and quality control, and offer recommendations for improvement.

Keywords: Air pollutants; Completeness; Comparability; Representativeness; Data coverage.

INTRODUCTION

The 2018 World Health Organization (WHO) global ambient air quality database contains monitoring data for coarse and fine particulate matter (PM). It has PM_{10} (coarse PM of 10 microns or less in diameter) monitoring data for 3,570 cities in 97 countries, and $PM_{2.5}$ (fine PM of 2.5 microns or less in diameter) data for 2,628 cities in 81 countries (WHO 2018a). The database is an update of the 2016 WHO global urban ambient air pollution database (WHO, 2016). The 2018 update uses PM data from established public air quality monitoring systems. PM_{10} and $PM_{2.5}$ include pollutants such as sulphates, nitrates and black carbon. These pollutants can penetrate deep into the lungs and into the cardiovascular system and pose a significant risk to human health.

Both the 2016 and 2018 WHO versions of the ambient air quality database resulted in the media, and international organisations awarding the “Most Polluted City” title to different cities around the world (WHO, 2016, 2018a).

Based on the 2018 WHO database, Wikipedia (2019) published a list of the 500 most polluted cities by $PM_{2.5}$ concentrations. CBS News (2019) similarly published a list of the 50 most polluted cities. Based on $PM_{2.5}$ data measured in 62 capital cities (2018), IQAir AirVisual (2019a) published an indicative ranking with New Delhi (India) at the top, followed by Dhaka (Bangladesh), Kabul (Afghanistan), Manama (Bahrain), Ulaanbaatar (Mongolia), Kuwait City (Kuwait), Kathmandu (Nepal), Beijing (China), Abu Dhabi (United Arab Emirates), and Jakarta (Indonesia). The World Economic Forum (WEF) used the IQAir data to state that 7 of the world’s 10 most polluted cities are in India (WEF, 2019).

Based on the 2016 WHO database, the WEF published a similar list of the 20 most polluted cities in the world with respect to PM_{10}. Onitsha (Nigeria) was identified as the most polluted city, followed by Peshawar and Rawalpindi (Pakistan), Zabol (Iran), Kaduna and Aba (Nigeria), Riyadh and Al Jubail (Saudi Arabia), Mazar-Sharif (Afghanistan), and Gwalior (India) (WEF, 2016). The other 10 cities on the WEF worst polluted cities list were Hamad Town and Ma’ameer (Bahrain), Allahabad and Raipur (India), Shijiazhuang (China), Karachi (Pakistan), Damman (Saudi Arabia), Umuahia (Nigeria), Kabul (Afghanistan), and Bosher (Iran).

The variation in these lists of most polluted cities within two years raises the question if it makes sense to award the “Most Polluted City” title to different cities around the world (see: CNN, 2016a, b; Guttikunda, 2016; HT, 2016; Legit, 2016; Livemint, 2016; Los Angeles Times, 2016; MWN, 2016; Tech Times, 2016; The Guardian, 2016; The Hindu, 2016; The Indian Express, 2016a, b; The Wall Street

---

[*] Corresponding author.
E-mail address: dietrich.schwela@york.ac.uk

Journal, 2016; The Washington Post, 2016; WEF, 2016).

On 30 October 2019, New Delhi Television (NDTV) used single-day air quality index (AQI) to state that New Delhi was the most polluted city, followed by Lahore (Pakistan); Hanoi (Vietnam); Dhaka (Bangladesh); Hangzhou, Beijing, and Shenyang (China); Sofia (Bulgaria); Ulaanbaatar (Mongolia); and Kolkata (India) (NDTV, 2019). In contrast, the 2018 IQAir Air Visual report ranked New Delhi eleventh in the 50 most polluted cities. Seven Indian cities (Gurugram, Ghaziabad, Faridabad, Bhiwadi, Noida, Patna, and Lucknow), two Pakistani cities (Faisalabad and Lahore); and one Chinese city (Hotan), ranked higher than New Delhi (IQAir Air Visual, 2018). In the following year, New Delhi was ranked fifth, after Ghaziabad, Hotan and two Pakistani cities (Gujranwala and Faisalabad) (IQAir Air Visual, 2019a). These different rankings based on different time durations of exposures demonstrate the arbitrariness of compiling a list of the most polluted cities.

While this "name and shame" approach may make eye-catching headlines, it can be inaccurate and misleading. Saying one city is more polluted than another is like comparing apples and pears, especially in the developing world. In addition, the pollutants that cause poor air quality in cities may be different. In the USA, the American Lung Association (ALA) characterized Los Angeles, California (CA), as the most polluted city with respect to ground-level ozone (O_3); Bakersfield, CA, was assessed to be the most polluted city, when it comes to short-term (24-hour) $PM_{2.5}$ concentrations while Fresno-Madera-Hanford, CA, was found to be the most polluted area with regard to long-term (annual) $PM_{2.5}$ averages (ALA, 2020a). Martin *et al.* (2019) tried to put an end to ranking speculation by stating that nobody can know "which city has the highest concentration of particulate matter".

This is not to say that we should not raise awareness of urban air pollution. It is a "silent killer" that can increase the risk of death and disease from chronic obstructive pulmonary disease (COPD) (43%), lung cancer (29%), ischaemic heart disease (25%), deaths from stroke (24%), and death and disease from acute lower respiratory diseases (17%) (WHO, 2019a). Often the poor and vulnerable groups such as children and the elderly suffer the most (Lipfert, 2004; Samet and White, 2004; WHO, 2010; Wright and Diab, 2011; Walker, 2012; PAHO, 2018; Patella *et al.*, 2018; Schröder *et al.*, 2018; UN Environment, 2018; UNICEF, 2018; WHO, 2018b).

The 2018 WHO ambient air quality database found relatively low levels of urban air pollution in high-income (HI) countries (e.g., in Western Europe, the Americas, the Western Pacific, and Oceania) and high levels in low- and middle-income (LMI) countries (e.g., in Africa, Latin America, and Southeast Asia) and in some high-income countries in Latin America. In LMI countries, lack of funding and inadequate staffing are key barriers to effective air pollution reduction. The relatively low levels of urban air pollution in HI countries does not mean that people think their air is clean, but the link between public perception of and public response to air pollution is still weak (Oltra and Sala, 2014; Kelly and Fussell, 2015; Oltra and Sala, 2015).

In this paper, we examine the challenges of comparing air pollution in different cities. We use several criteria to determine the strengths and weaknesses of the WHO 2016 and 2018 databases. Finally, we make recommendations to improve future WHO global ambient air quality databases.

METHODOLOGY

The rationale for this paper is to examine the 2018 WHO global ambient air quality database and assess certain database properties. In particular, we examine the comparability of ambient air quality data reported for different cities, the number of concentrations reported in the database versus the number of data existing at the time of WHO's compilation.

Most developed countries now have fully automated systems for urban air quality monitoring (UAQMon) with simultaneous visual display and an auto-transmission facility. In contrast, UAQMon programmes in developing countries have severe resource and infrastructure constraints. Often such constraints are the main factor that determines the configuration of an air quality monitoring network to meet minimum local data needs. While UAQMon systems have to be designed to meet the objectives with available resources, essential criteria applied for UAQMon in developed countries have also to be applied for UAQMon in developing countries if air quality monitoring results are to be comparable. This paper will assess the WHO global ambient air quality database on the following four essential criteria: (i) quality assurance and quality control (QA/QC); (ii) spatial representativeness; (iii) temporal representativeness; and (iv) meteorological conditions and topographic features.

Quality Assurance and Quality Control

Whatever the objectives—whether for health impact assessment, to meet local or national objectives, assessing traffic or industrial impacts, planning, policy development or providing public information—measurements will need to be accurate and reliable if they are to prove useful. Without QA/QC, measured data will not provide a sound basis for the assessment of population health effects of air pollution or for effective air quality management; as a result, any investment of money, time and effort made in monitoring will have been wasted. Proper QA/QC is essential in ensuring the comparability of measurements made at different monitoring sites. QA/QC is therefore a basic tool in ensuring that data within a network of sites are harmonised.

Spatial Representativeness

Spatial representativeness relates to the question of where UAQMon is to take place. In cities, monitoring is usually undertaken at selected sites, rather than at points on a grid. Sites should be representative of specific location types covering, for example, characteristic central urban, industrial, residential, commercial or roadside areas. UAQMon stations may differ from neighbouring urban sites affected by multiple sources. According to European Union (EU) Directive 2008/50/EC, at least 2 monitoring sites should be installed for a city with less than 250,000 inhabitants to measure the annual average of ambient PM and 1 more site for every 250,000 inhabitants up to 1.5 million inhabitants; for up to

6 million inhabitants the directive recommends 13 sites and for urban areas with more than 6 million inhabitants, 15 sites (EU, 2008).

Temporal Representativeness

The EC Directive 2008/50/EC suggests a minimum data capture of 90% (EU, 2008). WHO recommends that 50% of the valid data for the reported period should be available to obtain annual average values, and at least 75% of valid data should be available to obtain 1-hour average values from data with a smaller averaging time (WHO, 1999).

Meteorological Conditions and Topographic Features

Prevailing meteorological conditions and topographic features will influence the dispersion of air pollutants and the production of secondary pollutants in the atmosphere. A city will have higher pollutant concentrations in a dry year than in a wet year. Different seasons (i.e., summer/winter) have unique meteorological conditions and activities (e.g., burning of agricultural residues) may cause dips or spikes in air pollution. If data for one season are used to extrapolate an annual mean air pollution level, the results may be skewed.

In addition to the four key criteria, we examine the comparability of air pollutant concentration data taken in different years and at different seasons among cities. Some cities generate most of their own air pollution (e.g., from road traffic) and can address the sources, while others are downwind from industrial areas or other external sources they cannot control. We look at the comparability of cities with different transboundary pollution regimes.

Monitoring methods used for pollutants in one city may differ from those in other cities, requiring adjustments to make the data comparable. Analysis of the data may also vary; some cities may eliminate outliers (very high or low values), while others include all data readings. Finally, we address the issue of pollutant selection in the WHO database and the conversion of $PM_{2.5}$ to PM_{10} and vice versa, if only one of these particle ranges is monitored. Usually only a few air pollutants are chosen based on their potential impact on human health, animals, natural vegetation, agricultural crops or the ecosystem. In general, it is necessary to first focus on those pollutants, for which air quality standards/guidelines exist.

STRENGTHS OF THE WHO DATABASES

The main strength of the 2016 and 2018 WHO ambient air quality databases is that they attempt to provide a global overview of PM pollution. It compiles PM mass concentration data from over 4,300 cities globally, with most data from developed countries. Less than 28% (approximately 1,200) are from developing countries. The database provides quantitative data on PM_{10} concentrations, where measured, and estimates of $PM_{2.5}$ concentrations where not measured, and vice versa. PM estimates are produced using $PM_{2.5}/PM_{10}$ conversion factors.

From a health perspective, $PM_{2.5}$ and PM_{10} are the most hazardous air pollutants. WHO estimates that most of the global mortality caused by air pollution is due to exposure to $PM_{2.5}$, with 91% of 4.2 million premature deaths occurring in low- and middle-income countries (WHO, 2018c). The WHO review of evidence on the health aspects of air pollution demonstrated (WHO, 2013) that the annual mean concentrations of $PM_{2.5}$ and PM_{10} are indicative of long-term human exposure to particulate pollution. A Health Effects Institute (HEI) report on global air pollution reiterated this finding (HEI, 2019)

The data in the WHO 2016 and 2018 databases include measurements assessed for urban background, residential and commercial areas. Mixed areas are used for averaging over urban sites while "hot spot" data or data from exclusively industrial areas/roadside areas are excluded, except in a few exceptional cases. For data to be included in the WHO 2018 database, they needed to have a temporal coverage greater than six months and be representative of an annual measurement.

WEAKNESSES OF THE WHO DATABASES

In this section we consider limitations already noted by WHO as well as other general and specific limitations of the databases.

Limitations Noted by WHO

In the 2016 and 2018 databases, data from sites close to emission sources such as industries, power plants, highways, and urban roadside are not included. This is important for developing countries where many people live near such sites, and are therefore exposed to pollutant emissions. Cities of inhabitants less than 100,000 are also not included in the database although a population may be exposed to emissions from industrial facilities outside an urban area.

Data from different countries have only limited comparability due to different locations, different measurement methods, different percentages of coverage of the year (i.e., the part of the year covered by monitoring), and the fact that converted $PM_{2.5}/PM_{10}$ values are only indicative. These are substantial limitations why compiled urban air quality data should be interpreted and not directly compared. Different locations of air quality monitoring sites among cities or within a city will affect the spatial representativeness of data.

A city of a certain size will need a minimum number of monitoring stations in order to obtain spatially representative air pollutant concentrations. Monitoring stations need to be situated in such a way that they ensure coverage and are representative of urban air quality levels. However, the actual placement of stations can vary. They may be concentrated in (less polluted) residential areas in one city, and on busy roads (with high pollution) in another city.

Different measurement methods for PM concentrations include gravimetric, optical and oscillating microbalance methods (Amaral *et al.*, 2015). The gravimetric method is based on filters and cascade impactors and can collect particles and estimate their mass concentrations. Optical methods used for estimating particle mass concentrations, in real time, are based on the principles of light scattering, absorption, and extinction.

Oscillating microbalances measure changes in the oscillating frequency of a crystal or filter on which particles are sampled and translate the change of the frequency into the mass collected.

All these measurement methods have different specifications such as detection limit, particle size range, accuracy and precision (Amaral *et al.*, 2015). In particular, measurements from different instruments that do not measure particle mass directly are not always equivalent or comparable. This is demonstrated by the need for a correction formula between a light-scattering instrument such as the DustTrak and the Tapered Element Oscillating Microbalance (Morawska *et al.*, 2003). This fact makes comparisons of PM concentration among cities problematic.

In addition, background pollution related to transboundary movement of air pollutants also complicates the comparison of cities. Some cities generate most of their own air pollution (e.g., from road traffic) and can readily address the sources, while others are downwind from industrial areas or other external sources they cannot control. An example is Hong Kong, which suffers from transboundary pollution (e.g., PM and NO_2 from industrial and transport activities) emerging in the Pearl River Delta (Government of Hong Kong, 2015).

A city that does not monitor air quality may have higher air pollutant concentrations than a city that does—but because the former is not in the database, it will not make a "most polluted" list. For example, an analysis by the Russian Service for Hydrometeorology and Environmental Monitoring (RSHEM) of air quality in Russian cities estimated the grade of air pollution based on indicators (Klyuev, 2019). These indicators included hazardous emissions from stationary and mobile sources, the air pollution potential based on meteorological factors, and the frequency cities appeared on the RSHEM blacklist (Klyuev, 2019). Since indicators do not quantitatively represent air quality concentration levels, extremely high PM concentration may still occur in the Russian cities considered.

A city will have higher pollutant concentrations in a dry year than in a wet year. Therefore, data taken in different years in different cities are not comparable. A city labelled "the most polluted" based on 2013 data may not achieve the same ranking with 2015 data due to meteorological variation.

Limitations—General

WHO ambient air quality data are limited to annual averages of $PM_{2.5}$ and PM_{10} which are related to long-term health effects of PM pollution i.e., 4.2 million premature deaths per year globally (WHO, 2019b). Short-term health impacts of PM are not covered by annual averages of PM concentrations.

The Global Burden of Disease (GBD) study has attributed 233,638 premature deaths per year globally to long-term exposure to O_3 (Cohen *et al.*, 2017; Gakidou *et al.*, 2017). Although a global estimate of premature deaths due to exposure to nitrogen dioxide (NO_2) does not exist, some papers have estimated the premature deaths attributable to NO_2 (Walton *et al.*, 2015; Hadei *et al.*, 2017; Abdolahnejad *et al.*, 2018; EEA, 2019). The European Environment Agency (2014) estimated a total of 78,000 premature deaths from exposure to NO_2 in 41 European countries. In a study of $PM_{2.5}$- and NO_2-related premature deaths in London, 5,900 premature deaths (2010) across London was found to be associated with NO_2 long-term exposure, while the premature deaths associated with long-term exposure to $PM_{2.5}$ were 3,500 (Walton *et al.*, 2015).

As a consequence, the WHO ambient air quality databases should also include NO_2 and O_3 data. This was the case in the UNEP/WHO Global Environment Monitoring System for Air (GEMS/Air) database (1975–1996), and in the collection of the Healthy Cities Air Management Information System (AMIS) (1997–2003) (Schwela, 1999). In addition, the omission of short-term exposure data for PM and gaseous compounds is also a shortcoming of the WHO 2016 and 2018 databases when compared to the GEMS/Air and AMIS databases.

In some developing countries such as Azerbaijan (Baku), only total suspended particulate matter (TSP) concentrations are monitored. The inclusion of TSP data would give an indication of population exposure using a calculated annual mean. This was the case in the EC-supported National Pilot Project in Azerbaijan (EU, 2014). The project used a TSP/PM_{10} ratio of 1.35 for 2005–2013 in Baku to determine PM_{10} concentrations. Although exposure-response relationships have not been developed for TSP exposure, the WHO TSP guideline values (WHO, 1979, 1987, never repealed) can be used for a qualitative judgement on the health effects of TSP exposure.

The WHO databases are limited to concentrations only and do not assess the at-risk groups such as those under 18, those aged 65 and over, and those suffering from asthma, chronic obstructive lung disease, lung cancer, cardiovascular disease, and diabetes, and those having a low socio-economic status.

In contrast, the American Lung Association has considered people at-risk groups since 2012 (ALA, 2020b). The ALA estimates the number of people who live in areas that have unhealthy levels of O_3 or PM pollution, the number of people who suffer from unhealthy long-term (year-round) levels of PM pollution, and others with short-term exposure to PM and those with exposures to short-term, long-term PM and O_3.

A general limitation of the WHO ambient air quality databases is the uncertainty associated with how stakeholders (e.g., politicians, media) will use the data, in particular, misinterpretation of the data by the media, international organizations, and others that rank cities according to their pollution. This use of incomparable data is counterproductive, misleading and inept and does not give incentives to politicians and decision makers to develop good governance on air quality management.

Limitations—Specific

The following section addresses specific issues related to the WHO 2018 global ambient air quality database. These issues are the incompleteness of the database despite the availability of air quality measurements; the elimination of hot spot data, QA/QC; spatial and temporal representativeness; and the conversion of $PM_{2.5}$ and PM_{10} data if only one of the size distributions are monitored and the other is estimated using a $PM_{2.5}/PM_{10}$ ratio.

Firstly, a few examples for PM are given that could have been included in the WHO 2018 ambient air quality database because they were published before the time of its publication in May 2018. These include air quality data for Argentina, Brunei Darussalam, Egypt, Ghana, India, Kuwait, Malaysia, Nigeria, Kazakhstan, the Russian Federation, Ukraine, and Taiwan.

Argentina

For Argentina, the WHO 2018 database reports PM_{10} concentration data from only 3 monitoring stations in Buenos Aires (Parque Centenario, Córdoba and La Boca). It uses a $PM_{2.5}/PM_{10}$ ratio (0.44) to estimate $PM_{2.5}$ concentrations (BAC, 2019a, b, c). It should be noted that this ratio relies on educated guesswork (see below) since a study (Riojas-Rodriguez *et al.*, 2016) infers a range of $PM_{2.5}/PM_{10}$ ratios for 19 Latin American cities to lie between 0.23 and 0.89 for Jalisco (Mexico) and San José (Costa Rica), respectively.

Other monitoring stations exist in Argentinian cities and have produced PM_{10} data since the late 1990s. For example, since 1997 Bahia Blanca has monitored PM_{10} (and some gaseous compounds) (Allende *et al.*, 2010). This PM_{10} data has been validated up to 2013 and the Bahia Blanca government has published data for 2010–2012 (QPBB, 2019). Real-time air quality indices are published daily (see: https://aqicn.org/city/argentina/bahia-blanca/). 2 monitoring sites exist in Acumar (La Matanza and Dock Sud I) in the vicinity of Buenos Aires. These sites monitor PM_{10} and $PM_{2.5}$, and reports daily AQI (WAQI, 2019).

Brunei Darussalam

Brunei Darussalam has established 4 stations that are located throughout the 4 districts (Brunei Muara, Temburong, Tutong and Belait) that continuously monitor PM_{10} and $PM_{2.5}$ (UNEP, 2015; AP_Brunei, 2019). PM monitoring stations have been in operation in Brunei since the 1990s (Radojevic and Hassan, 1999; UNEP, 2019). However, the WHO database reports no PM data for Brunei.

Egypt

In 2016, Egypt had 88 fixed air quality monitoring stations countrywide and 2 mobile monitoring units, with 42 real-time continuous monitoring stations and 46 air pollutant sampling stations (Mourad, 2017; EEEA, 2018). Of the 88 monitoring and sampling stations, 49, 13, 8, 15, and 3 are located in Cairo, the Delta, Alexandria, Upper Egypt, and on the Sinai Peninsula, respectively. All monitoring stations measure PM_{10} and criteria gaseous pollutants. Data are reported monthly and compiled in annual reports. In the 2018 WHO database, there are only data from 18 urban stations in the Delta Region and Alexandria and 13 stations for Greater Cairo are aggregated. The Delta Region is a conglomerate of different urban areas of varying sizes. It is therefore inappropriate to compare a conglomerate of secondary cities and Alexandria with a megacity such as Cairo.

Ghana

In Ghana, the Environmental Protection Agency (EPA), operates an air quality monitoring network that collects PM_{10} and limited $PM_{2.5}$ data from up to 15 locations throughout the city of Accra and its surroundings (Ghana EPA, 2018). PM_{10} concentrations have been assessed since 2005 at 10 roadside monitoring sites, 2 in industrial and residential areas and 1 in a commercial area; $PM_{2.5}$ is measured at 1 station (Ghana EPA, 2017). This station has PM_{10} and $PM_{2.5}$ monitoring data for eleven years (Appoh, 2018). Data are missing for 2011–2013 but data up to the year 2017 were available at the time of the publication of the WHO 2018 database.

India

The WHO 2018 database for India presents $PM_{2.5}$ and PM_{10} concentration data for 2015/2016 for 34 cities. For 101 cities PM_{10} concentration values are reported for 2012 and a few for the years 2013–2015. Compared to the data reported by the Indian government on the internet, the WHO data are incomplete. The Indian Central Pollution Control Board (CPCB) manages the National Air Quality Monitoring Programme (NAMP), which manually collects, among other air pollutants, samples of PM_{10} and $PM_{2.5}$ twice a week for 8 hours within 24-hour periods (CPCB, 2019a, b, c; Pant *et al.*, 2019). The number of cities and sampling stations for each state are compiled in the Supplement as Table S1 for PM_{10} for 2013–2016 and Table S2 for $PM_{2.5}$ for 2014–2016.

According to Table S1, PM_{10} was monitored in 2013, 2014, 2015 and 2016 in 223, 234, 241 and 250 cities, respectively. $PM_{2.5}$ was monitored in 2014, 2015 and 2016 in 29, 59 and 71 cities, respectively. The high number of cities with recent monitoring data are a contrast to the 101 Indian cities reported in the WHO database. The challenges of the manual PM monitoring in India, especially the reduced monitoring duration and other methodological issues should also be kept in mind (Pant *et al.*, 2019; Verma, 2019).

In addition to the monitoring sites under the NAMP, several states (including Maharashtra, Gujarat, Kerala, Odisha, Karnataka, Telangana and Andhra Pradesh) conduct outdoor PM monitoring at additional sites under the State Ambient Air Quality Monitoring Programme (SAMP), the results of which do not appear to be included in the WHO database except for Karnataka. The CPCB has also set up a network of continuous automatic air quality monitoring stations (CAAQMS) for assessing PM_{10} and $PM_{2.5}$.

In September 2018, there were 65 cities monitored at more than 130 sites (Patna, 2019) and as of November 2019 the number of cities increased to 101 with 161 monitoring stations (https://app.cpcbccr.com/ccr_docs/caaqms_list_All_India.pdf). From the increase in the number of monitoring stations it is possible that in 2016 more cities in India had automatic stations than those listed in the WHO 2018 database.

Malaysia

Malaysia has established a national air quality monitoring network of 6 real-time PM_{10} monitoring stations (Continuous Air Quality Monitoring [CAQM]), which is supplemented by 19 sites of the Manual Air Quality Monitoring (MAQM) network. The MAQM network measures PM_{10} and TSP once every 6 days (DOE, 2019). The 2018 WHO database quotes PM_{10} data from only 6 cities, apparently from the CAQM network, and no data from the MAQM network, and does not include the capital, Kuala Lumpur.

Nigeria

Data from 12 cities in Nigeria were presented in the 2016 database and Onitsha was reported to have the extreme PM_{10} concentration of 594 µg m^{-3} (2009), a value which is neither spatially representative for the city (6 monitoring stations would be necessary instead of only 1 existing) nor temporally representative for a year (data coverage only 4%). None of them is in the 2018 database and no reason is provided for this omission of the Nigerian data. At least data from Port Harcourt should be included since they are available in the literature (Ede and Edokpa, 2015; Akinfolarin, 2017).

Kazakhstan

Kazakhstan has only 1 continuously monitoring site in Astana at the United States Embassy, which monitors $PM_{2.5}$ (AP_Kazakhstan, 2019; U.S. Embassy Kazakhstan, 2019). No data is reported in the WHO 2018 database.

Russian Federation

In 2013, 8 PM_{10} automatic monitoring stations and 2 $PM_{2.5}$ continuous monitoring stations were operating in Moscow (Kislova, 2013). PM_{10} annual average concentrations were reported for the period 2003–2012. The WHO 2018 database presents data for 2 urban background stations in Moscow for the year 2009.

Taiwan

17 cities in Taiwan perform air quality monitoring and measure $PM_{2.5}$ and PM_{10}, among other compounds (Taiwan EPA, 2019). These data are not quoted in WHO's databases. Although this omission is probably due to the controversial issue of the political status of Taiwan, it is the opinion of the authors that air quality data from Taiwanese cities have nothing to do with a recognition of Taiwan as a sovereign state and, therefore, should have been included in the WHO database.

Ukraine

Since the 1990s, the Ukraine has monitored only PM in terms of TSP. In 2020, Ukraine had 33 real-time PM_{10} and $PM_{2.5}$ urban monitoring stations, some of which were in operation in 2016 (Milinevski *et al.*, 2018; AP_Ukraine, 2019). IQAir AirVisual ranks 10 Ukrainian cities by U.S. AQI for $PM_{2.5}$ (IQAir AirVisual, 2019b). The WHO database does not report $PM_{2.5}$ and PM_{10} data for Ukraine.

Hot Spot Data

A second issue with respect to the WHO databases is the elimination of hot spot data or their consideration only in specific situations. In the Notes to the WHO database it is stated that monitors "are not unduly influenced by a single source of pollution (i.e., a power plant, factory or highway); rather the monitors should reflect exposures over a wide area". The omission of hotspot data is inappropriate in cities of developing countries where street vendors spend up to 12 hours at the roadside and are exposed to vehicle emissions and air pollutants from industrial and other sources (Kongtip *et al.*, 2008; Serya *et al.*, 2019).

This may also apply to people living close to highly polluted streets and roads in developed countries, who are exposed to traffic-related air pollution, which may cause the onset of childhood asthma, impaired lung function, premature death and death from cardiovascular diseases and cardiovascular morbidity (HEI, 2010; ALA, 2018). A Danish study found that long-term exposure to traffic air pollution may increase the risk of asthmatics and people suffering from diabetes or developing chronic obstructive pulmonary disease (Andersen *et al.*, 2011).

QA/QC

The third and most important issue refers to the quality of the data in the WHO database with regard to QA/QC. Whatever the objectives, reported measurements will need to be accurate and reliable if they are to prove useful. This is why QA/QC is a key component of any air quality monitoring programme. Proper QA/QC is also essential in ensuring the comparability of measurements made at different monitoring sites. QA/QC is therefore a basic tool to ensure data within a network of sites are harmonised.

A properly designed and implemented QA/QC programme should cover all aspects of network operation, ranging from system design and site selection through equipment selection, operation, calibration and maintenance to data management and validation. Essentially, QA refers to the overall management of the entire process leading to a defined quality of the data product; QC refers to the activities undertaken to obtain a specified accuracy and precision of the measurement. QA functions will cover directly measurement-related activities including network operation, calibration, data handling, review and training.

There is no indication in the Notes of the 2018 WHO database that issues of QA/QC were addressed in the compilation of data. While WHO certainly cannot check the validity of the collected data, questions following from the presentation of QA/QC requirements on the application of rigorous QA/QC procedures should be answered by the data providers.

The GAP Forum Air Pollution Monitoring Manual provides examples of the main questions that should be answered by data providers (Schwela, 2011). An example for data where QA/QC requirements were neglected is the case of data from Bosnia and Herzegovina where monitoring is performed in 17 (only 7 quoted in the WHO 2018 database) urban areas (FHMI, 2017; RHMI, 2018). As a result, such data are of unknown quality and not necessarily suited for city comparison.

Spatial Representativeness

Related to the issue of QA/QC is the need for spatial and temporal representativeness. Table 1 shows the number of monitoring stations needed for a given urban population of cities in a number of countries and compares them with the number of monitoring stations quoted in the WHO 2018 database. The table indicates that the number of monitoring stations in the WHO database is below the minimum number required by EU Directive 2008/50/EC according to population size. Therefore, the results reported in the WHO database cannot be considered as spatially representative for the cities. An exception appears to be Gyeonggi (South Korea). Gyeonggi, however, is not a city but a South Korean province, consisting of 24 cities of different population sizes (MoE, 2013). This makes a comparison of Gyeonggi with other cities problematic.

Temporal Representativeness

Temporal representativeness of values is also an important issue when estimating annual PM values. As discussed above, a minimum percentage of data collected throughout a year should be available for the estimation of annual mean PM concentration, for example, 75% or even 90%. Low percentage data coverage risk biased estimates of an annual mean. When investigating if any of these requirements are fulfilled in the WHO database, instances are found where this is not the case. For example, $PM_{2.5}$ monitoring in Bamenda (Cameroon) was performed 7 times per week for 24 hours during 2 weeks, corresponding to data coverage of 4% (Antonel and Chowdhury, 2014). Other examples lacking temporal representativeness include Peshawar (Pakistan), where monitoring was performed for half the week, corresponding to data coverage of 1% (Alam *et al.*, 2011), and Gwalior (India), where monitoring at 2 stations was performed during 15 and 19 days, corresponding to data coverage of between 4% and 5%, respectively (GoI-OGD, 2012). Such low data coverage should not be considered temporally representative for a year as claimed in the WHO database for Bamenda and Gwalior. Another example from the WHO 2016 database is Onitsha (Nigeria). PM_{10} monitoring was performed once per week for 12 hours during 36 weeks (Ngele and Onwu, 2015). This corresponds to data coverage of 5%, far below the 75% usually required. Again, such low data coverage is not temporally representative for a year.

$PM_{2.5}/PM_{10}$ Conversion Factors

A final issue of concern is the use of $PM_{2.5}/PM_{10}$ conversion factors if only one of the pollutants is monitored. If a local $PM_{2.5}/PM_{10}$ factor is unknown, the usual approach of WHO is to use a region-specific conversion factor. For developing countries, the selected conversion factor is often around 0.5 (WHO, 2008). In the WHO 2018 database, data from measured PM_{10} is used to estimate $PM_{2.5}$ when $PM_{2.5}$ measurements do not exist, and vice versa (e.g., in U.S. and Indian cities). As Table 2 shows estimated conversion $PM_{2.5}/PM_{10}$ ratios can differ from monitoring data.

CONCLUSION AND RECOMMENDATIONS

Clean air is a basic human right, and we urgently need to act to reduce air pollution—particularly in the cities of developing countries, where poor air quality poses a significant threat to human health and well-being. Rankings and comparisons that single out "the worst city" do not advance this cause; instead, they confuse people and politicise a public health issue. If we are to save lives now and protect future generations, we need to be more thoughtful and precise when we talk about urban air quality.

The WHO global ambient air quality databases attempt to provide an overview of air quality in cities around the world. This is crucial to raising awareness, measuring progress, and inspiring action. However, as demonstrated here, compiling a database of measurements and estimates from various cities that can be accurately compared is not without its challenges, including the presence (or lack) of monitoring stations, representativeness, data coverage, background pollution, meteorological conditions, seasonality of the pollution, differences in monitoring methodology, and QA/QC. Therefore, the WHO should explicitly advise users of its global ambient air quality databases—in particular, the

Table 1. Some examples of lack of spatial representativeness in the WHO 2018 global ambient air quality database.

Country	City	Year of monitoring or reporting	Number of monitoring stations (WHO, 2018)	Population [millions]	Minimum number of stations (EU, 2008)
Chile	Santiago	2016	1	4.657	11
Cameroon	Bamenda	2012	1	0.270	3
Chile	Puente Alto	2016	1	0.492	2
Saudi Arabia	Riyadh	2016	1	4.087	11
Pakistan	Peshawar	2010	1	2.983	10
Poland	Warsaw	2016	7	1.764	7
Macedonia	Tetovo	2013	1	0.053	2
India	Gwalior	2012	2	0.827	4
Korea	Gyeonggi	2014	71	12.340	15
China	Shijiazhuang	2015	1	10.702	15
China	Xingtai	2016	1	7.104	15
Iran	Zabol	2016	1	0.131	2
Brazil	Santos	2016	2	0.434	3
Peru	Lima	2016	3	8.852	15
Malaysia	Kuching	2014	1	509	3

Table 2. $PM_{2.5}/PM_{10}$ conversion factors for various cities in the USA and India.

City	$PM_{2.5}/PM_{10}$ measured	$PM_{2.5}/PM_{10}$ converted (WHO)
Bakersfield, CA, USA	0.34	0.49
Baton Rouge, LA, USA	0.46	0.45
Boston, MA, USA	0.55	0.50
Chicago, IL, USA	0.37	0.55
New York, NY, USA	0.59	0.50
Washington, D.C., USA	0.51	0.47
Surat, India	0.34	0.54
Vadodara, India	0.32	0.54
Vapi, India	0.31	0.54
Indore, India	0.57	0.53
Nagda, India	0.52	0.53
Rayagada, India	0.58	0.54
Rourkela, India	0.60	0.53
Sambalpur, India	0.65	0.53
Coimbatore, India	0.59	0.53
Nalgonda, India	0.56	0.54
Howrah, India	0.58	0.54
Singrauli, India	0.51	0.53
Ujjain, India	0.49	0.54

media—against ranking the listed cities, as such comparisons are misleading. Furthermore, the potential political consequences ought to be considered: if city officials fear being “named and shamed”, they have a strong incentive to conceal air quality data or to under-report pollution. The controversy over the spatial representativeness of air quality data measured at the Beijing U.S. Embassy compared to the data from Beijing’s air quality monitoring stations (The Guardian, 2014) and the removal of Nigerian data from the 2018 database highlights this risk.

To mitigate the issues described in this paper and improve future versions of the WHO’s global ambient air quality database in terms of comprehensiveness and comparability, we strongly recommend the following measures: a rigorous peer review to improve the reliability of data, data collection should be accompanied by an extensive literature review; the mean annual concentrations of NO_2 and O_3 should also be compiled, following the example of the WHO Healthy Cities AMIS database; and data providers should be required to answer a set of QA/QC questions about their data, e.g., whether they strictly followed a detailed QA/QC plan. These actions would ensure the comparability of the measurements, evaluate the accuracy and precision of the data, and confirm that the results fulfilled defined standards with a specified level of confidence. Finally, a strong warning should be issued to database users against abusing the data by naming and shaming the “most polluted city”.

ACKNOWLEDGEMENT

The authors wish to thank Dr. Bjarne Sivertsen for his fruitful discussions on the issues of this paper.

CONFLICTS OF INTEREST

The authors confirm that there are no conflicts of interest.

SUPPLEMENTARY MATERIAL

Supplementary data associated with this article can be found in the online version at http://www.aaqr.org.

REFERENCES

Abdolahnejad, A., Jafari, N., Mohammadi, A., Miri, M. and Hajizadeh, Y. (2018). Mortality and morbidity due to exposure to ambient NO_2, SO_2, and O_3 in Isfahan in 2013–2014. *Int. J. Preventative Med.* 9: 11. https://doi.org/10.4103/ijpvm.IJPVM_387_16

Akinfolarin, O.M., Boisa, N. and Obunwo, C.C. (2017). Assessment of particulate matter-based air quality index in Port Harcourt, Nigeria. *J. Environ. Anal. Chem.* 4: 224. https://doi.org/10.4172/2380-2391.1000224

Alam, K., Blaschke, T., Madl, P., Mukhtar, A., Hussain, M., Trautmann, T. and Rahman, S. (2011). Aerosol size distribution and mass concentration measurements in various cities of Pakistan. *J. Environ. Monit.* 13: 1944–1952.

Allende, D., Castro, F. and Puliafito, S.E. (2010). Air pollution characterisation and modelling of an industrial intermediate city. *Int. J. Appl. Environ. Sci.* 5: 275–296. https://www.researchgate.net/publication/265126443_Air_Pollution_Characterization_and_Modeling_of_an_Industrial_Intermediate_City

Amaral, S.S., de Carvalho, J., Martins Costa, M.A. and Pinheiro, C. (2015). An overview of particulate matter measurement instruments. *Atmosphere* 6: 1327–1345. https://doi.org/10.3390/atmos6091327

American Lung Association (ALA) (2018). Living near highways and air pollution. American Lung Association, Chicago, IL. https://www.lung.org/our-initiatives/healthy-air/outdoor/air-pollution/highways.html

American Lung Association (ALA) (2020a). State of the Air

- Most polluted cities. American Lung Association, Chicago, IL. http://www.stateoftheair.org/city-rankings/most-polluted-cities.html

American Lung Association (ALA) (2020b). People at Risk. American Lung Association, Chicago, IL. http://www.stateoftheair.org/key-findings/people-at-risk.html

Andersen, Z.J., Hvidberg, M., Jensen, S.S., Ketzel, M., Loft, S., Sorensen, M., Tjonneland, A., Overvad, K. and Raaschou-Nielsen, O. (2011). Chronic obstructive pulmonary disease and long-term exposure to traffic-related air pollution: A cohort study. *Am. J. Respir. Crit. Care Med.* 183: 455–461.

Antonel, J. and Chowdhury, Z. (2014). Measuring ambient particulate matter in three cities in Cameroon, Africa. *Atmos. Environ.* 95: 344–354.

AP_Brunei (2019). Air pollution in Brunei. World Air Quality Index team. https://aqicn.org/map/brunei/

AP_Kazakhstan (2019). Air pollution in Kazakhstan. World Air Quality Index team. https://aqicn.org/map/kazakhstan/

AP_Ukraine (2019). Air pollution in Ukraine. World Air Quality Index team. http://aqicn.org/map/ukraine/

Appoh, E.K.E. (2018). Overview of Air Quality Monitoring in Accra, Ghana-2. Environmental Quality Department, Environmental Protection Agency, Ghana. Presentation at the Air Sensors International Conference, Oakland, CA, September. 12-14, 2018. https://asic.aqrc.ucdavis.edu/sites/g/files/dgvnsk3466/files/inline-files/Emmanuel%20Appoh%20-%20Ghana%20%20International%20Plenary%20Presentation%20at%20%208am%20of%2014%20Sept%202018.pdf

Buenos Aires Ciudad (BAC) (2019a). Control ambiental. Estación Parque Centenario. Buenos Aires Ciudad. https://www.buenosaires.gob.ar/agenciaambiental/controlambiental/estacion-parque-centenario

Buenos Aires Ciudad (BAC) (2019b). Control ambiental. Estación Córdoba. Buenos Aires Ciudad. https://www.buenosaires.gob.ar/agenciaambiental/controlambiental/estacion-cordoba

Buenos Aires Ciudad (BAC) (2019c). Control ambiental. Estación La Boca. Buenos Aires Ciudad. https://www.buenosaires.gob.ar/agenciaambiental/controlambiental/estacion-la-boca

CBS News (2019). The most polluted cities in the world, ranked. CBS News, https://www.cbsnews.com/pictures/the-most-polluted-cities-in-the-world-ranked/51/

Central Pollution Control Board (CPCB) (2019a). AQI Bulletin (Archive). Central Pollution Control Board, Ministry of environment, forest and Climate change, Government of India. https://www.cpcb.nic.in/AQI_Bulletin.php

Central Pollution Control Board (CPCB) (2019b). Annual average AAQM data at 04 CPCB monitoring stations in Agra. Central Pollution Control Board, https://cpcb.nic.in/agradata/AAQM_data-Pjroject_Office_Agra-2002-2018.pdf

Central Pollution Control Board (CPCB) (2019c). National Ambient Air Quality Monitoring Programme data for the year 2016. Central Pollution Control Board, https://cpcb.nic.in/displaypdf.php?id=bWFudWFsLW1vbml0b3JpbmcvTG9jYXRpb25fZGF0YV8yMDE2LnBkZg==

CNN (2016a). Dirtied by success? Nigeria is home to city with worst PM_{10} levels. CNN Africa View – Insights and updates from across Africa, June 1, 2016. http://edition.cnn.com/2016/05/31/africa/nigeria-cities-pollution/

CNN (2016b). I live in the world's most polluted city. CNN Money, February 19, 2016. http://money.cnn.com/2016/02/17/news/economy/india-new-delhi-air-pollution-health/

Cohen, A.J., Brauer, M., Burnett, R., Anderson, H.R., Frostad, J., Estep, K., Balakrishnan, K., Brunekreef, B., Dandona, L., Dandona, R., Feigin, V., Freedman, G., Hubbell, B., Jobling, A., Kan, H., Knibbs, L., Liu, Y., Martin, R., Morawska, L., Pope, C.A., III, Shin, H., Straif, K., Shaddick, G., Thomas, M., van Dingenen, R., van Donkelaar, A., Vos, T., Murray, C.J.L. and Forouzanfar, M.H. (2017). Estimates and 25-year trends of the global burden of disease attributable to ambient air pollution: An analysis of data from the Global Burden of Diseases Study 2015. *Lancet* 389: 1907–1918. https://doi.org/10.1016/S0140-6736(17)30505-6

Department of Environment (DOE) (2019). Air pollution. Official Portal of Department of Environment, Ministry of Environment and Water. https://www.doe.gov.my/portalv1/en/info-umum/kuality-udara/114

Ede, P.N. and Edokpa, D.O. (2015). Regional air quality of the Nigeria's Niger Delta. *Open J. Air Pollut.* 4: 7–15. https://doi.org/10.4236/ojap.2015.41002

Egyptian Environmental Affairs Agency (EEEA) (2018) Air quality reports. Egyptian Environmental Affairs Agency. Ministry of Environment, Arab Republic of Egypt. http://www.eeaa.gov.eg/en-us/topics/air/airquality/airqualityreports.aspx

European Environmental Agency (EEA) (2019). Premature deaths attributable to $PM_{2.5}$, NO_2 and O_3 exposure in 41 European countries and the EU-28, 2014. European Environmental Agency, https://www.eea.europa.eu/highlights/improving-air-quality-in-european/premature-deaths-2014#tab-news-and-articles

European Union (EU) (2008). Directive 2008/50/EC of the European Parliament and the Council of 21 may 2008 on ambient air quality and cleaner air for Europe. OJ L 152, 11.6.2008, p. 1–44. https://eur-lex.europa.eu/legal-content/en/ALL/?uri=CELEX%3A32008L0050

European Union (EU) (2014). Air quality governance in the ENPI east countries. National Pilot Project - Azerbaijan. "Improvement of legislation on assessment and management of ambient air". Draft National Strategy on AQAM. Azerbaijan Branch office of Regional Environmental Center for Caucasus. https://europa.eu/capacity4dev/file/22147/download?token=DzJUlvLE

Federal Hydro-Meteorological Institute (FHMI) (2018). Annual report on the air quality in the Federation of Bosnia and Herzegovina for 2017. March 2018. Federal Hydro-Meteorological Institute. https://www.fhmzbih.gov.ba/PUBLIKACIJE/zrak/izvjestaj-2017.pdf

Gakidou, E., Afshin, A., Abajobir, A.A., Abate, K.H., Abbafati, C., Abbas, K.M., Abd-Allah, F., Abdulle, A.M., Abera, S.F., Aboyans, V., Abu-Raddad, L.J., Abu-Rmeileh, N.M.E., Abyu, G.Y., Adedeji, I.A., Adetokunboh, O., Afarideh, M., Agrawal, A., Agrawal, S., Ahmadieh, H., … Murray, C.J.L. (2017). Global, regional, and national comparative risk assessment of 84 behavioural, environmental and occupational, and metabolic risks or clusters of risks, 1990–2016: A systematic analysis for the Global Burden of Disease Study 2016. Lancet 390: 1345–1422. https://doi.org/10.1016/S0140-6736(17)32366-8

Ghana EPA (2017). Ghana state of the environment Report 2016. Environmental Protection Agency Ghana. http://www.epa.gov.gh/epa/publications/state-environment-report

Ghana EPA (2018). The Greater Accra Metropolitan Areas Air Quality Management Plan. Environmental Protection Agency Ghana. http://www.epa.gov.gh/epa/publications/environmental-quality

Government of India, Open Government Data (GoI-OGD) (2012). Ambient air quality with respect to particulate matter under National Air Quality Monitoring Programme (NAMP) in the year 2012. Government of India, Open Government Data (OGD) Platform India. https://data.gov.in/catalog/ambient-air-quality-respect-particulate-matter-under-national-air-quality-monitoring

Government of Hong Kong (2015). Pearl River Delta Air Quality. Government of the Hong Kong Special Administrative Region. http://www.gov.hk/en/residents/environment/air/raqi.htm

Guttikunda, S. (2016). Most polluted cities in the world (WHO, 2016) – Delhi not the most polluted city. http://urbanemissions.blogspot.de/2016/05/most-polluted-cities-in-world-who-2016.html

Hadei, M., Hopke, P.K., Hashemi Nazari, S.S., Yarahmadi, M., Shahsavani, A. and Alipour, M.R. (2017). Estimation of mortality and hospital admissions attributed to criteria air pollutants in Tehran metropolis, Iran (2013–2016). *Aerosol Air Qual. Res.* 17: 2474–2481. https://doi.org/10.4209/aaqr.2017.04.0128

Health Effects Institute (HEI) (2010). Traffic-related air pollution: A critical review of the literature on emissions, exposure, and health effects. A Special Report of the Institute's Panel on the Health Effects of Traffic-Related Air Pollution, Health Effects Institute, Boston, 2010. https://www.healtheffects.org/publication/traffic-related-air-pollution-critical-review-literature-emissions-exposure-and-health.

Health Effects Institute (HEI) (2019). State of Global Air 2019. Special Report. Health Effects Institute, Boston, MA. https://www.stateofglobalair.org/sites/default/files/soga_2019_report.pdf

Hindustan Times (HT) (2016). Half of the world's 20 most polluted cities in India, Delhi in 11th position. Hindustan Times. June 04, 2016. http://www.hindustantimes.com/del hi/four-out-of-top-five-polluted-cities-are-in-india-delhi-not-among-them/story-Gn2htcLbESB3BpeYJ4mY8K.html.

IQAir Visual (2018) 2018 World air quality report. Region & City $PM_{2.5}$ ranking, https://www.airvisual.com/world-most-polluted-cities/world-air-quality-report-2018-en.pdf

IQAir Air Visual (2019a). 2019 World air quality report. Region & City $PM_{2.5}$ ranking. https://www.airvisual.com/world-most-polluted-cities

IQAir Air Visual (2019b). Ukraine AQI ranking. https://www.airvisual.com/ukraine

Kelly, F.J. and Fussell, J.C. (2015). Air pollution and public health: Emerging hazards and improved understanding of risk. *Environ. Geochem. Health.* 37: 631-649. https://doi.org/10.1007/s10653-015-9720-1

Kislova, O. (2013). Air quality monitoring system in Moscow: Measurement methods and techniques. Presentation at the Special Session: Environmental Case studies from Mediterranean, Central and Eastern Europe of the European Network on New Sensing Technologies for Air Pollution Control and Environmental Sustainability - EuNetAir. COST Action TD 1105. Duisburg, Germany, 4–6 March 2013. https://www.airmontech.eu/fileadmin/airmontech/user/2013-presentations/34_Kislova.pdf

Klyuev, N.N. (2019). Air quality for Russian cities for 1991-2016. *Reg. Res. Russia* 9: 204–212. https://doi.org/10.1134/S2079970519020072

Kongtip, P., Thongsuk, W., Yoosook, W., Chantanakul, S. and Singhaniyom, S. (2008). Health effects of air pollution on street vendors: A comparative study in Bangkok. *Thai J. Toxicology*. 23: 5–14.

Legit (2016). See the most polluted cities in Nigeria. Legit. May, 2016. https://www.legit.ng/829345-shocking-four-nigerian-cities-included-top-worlds-polluted-cities-list.html.

Lipfert, F.W. (2004). Air pollution and poverty: Does the sword cut both ways? *J. Epidemiol. Community Health* 58: 2–3. https://doi.org/10.1136/jech.58.1.2

Livemint (2016). Delhi is no longer the world's most polluted city, says WHO. Livemint. May 13, 2016. http://www.livemint.com/Politics/mgVmRwZjpCzC41Vli0jgMI/80-of-worlds-city-dwellers-breathing-bad-air-says-UN.html

Los Angeles Times (2016). 22 of the world's most polluted cities are in India. Los Angeles Time. October 28, 2016. http://www.latimes.com/world/asia/la-fg-india-polluted-cities-20160512-snap-story.html

Martin, R.V., Brauer, M., van Donkelaar, A., Shaddick, G., Narain, U. and Dey, S. (2019). No one knows which city has the highest concentration of fine particulate matter. *Atmos. Environ. X* 3: 100040. https://doi.org/10.1016/j.aeaoa.2019.100040

Milinevsky, G., Danylevsky, V., Miatselskaya, N., Han, W., Shulga, V. and Simon, A. (2018). Evaluation of particulate matter $PM_{2.5}/PM_{10}$ air pollution in some of Ukraine and China cities. Geophysical Research Abstracts 20: EGU2018-3844. European Geoscience Union. https://meetingorganizer.copernicus.org/EGU2018/EGU2018-3844.pdf

Ministry of Environment (MoE) (2013). Metropolitan Air Quality Management Office. Ministry of Environment, Seoul, Korea. http://eng.me.go.kr/eng/web/index.do?menuId=41

Morawska, L., He, C., Hitchins, J., Gilbert, D., Parappukkaran, S. and Mengersen, K. (2003). Characteristics of particle number and mass concentrations in residential houses in Brisbane, Australia. *Atmos. Environ.* 37: 4195–4203. https://doi.org/10.1016/S1352-2310(03)00566-1

Morocco World News (MWN) (2016). Casablanca sixth most polluted city in the world. Morocco World News. September 07, 2016. https://www.moroccoworldnews.com/2016/09/196299/casablanca-sixth-polluted-city-world/

Mourad, M. (2017). Ambient air quality monitoring network in Egypt. Egyptian Environmental Affairs Agency, Cairo. In: International Workshop on Seamless Prediction of Air Pollution for Africa: From Regional to Urban. 4-6 December, Pretoria, South Africa. https://community.wmo.int/meetings/international-workshop-seamless-prediction-air-pollution-africa-regional-urban

NDTV (2019). Delhi is the most polluted city in the world today, says air quality report. NDTV https://www.ndtv.com/india-news/delhi-is-the-most-polluted-city-in-the-world-today-says-air-quality-report-2124800

Ngele, S.O. and Onwu, F.K. (2015). Measurements of ambient fine and coarse particulate matter in ten South-East Nigerian cities. *Re. J. Chem. Sci.* 5: 71–77.

Oltra, C. and Sala, R. (2014). A review of the social research on public perception and engagement practices in urban air pollution. Part of the project "New strategies for public engagement in urban air pollution control. CIEMAT/ Departamento de Medio Ambiente, Madrid.

Oltra, C. and Sala, R. (2015). Communicating the risks of urban air pollution to the public. A study of urban air pollution information services. *Rev. Int. Contam. Ambie.* 32: 361–375.

Pan American Health Organization (PAHO) (2018). Ambient and household air pollution and health: Frequently asked questions. Pan American Health Organization. https://www.paho.org/hq/index.php?option=com_content&view=article&id=14454:ambient-and-household-air-pollution-and-health-frequently-asked-questions&Itemid=72243&lang=en

Pant, P., Lal, R.M., Guttikunda, S.K., Russell, A.G., Nagpure, A.S., Ramaswami, A. and Peltier, R.E. (2019). Monitoring particulate matter in India: Recent trends and future outlook. *Air Qual. Atmos. Health* 12: 45–58. https://doi.org/10.1007/s11869-018-0629-6

Patella, V., Florio, G., Magliacane, D., Giuliano, A., Crivellaro, M.A., Di Bartolomeo, D., Genovese, A., Palmieri, M., Postiglione, A., Ridolo, E., Scaletti, C., Ventura, M.T., Zollo, A., Air, P., Climate Change Task Force of the Italian Society of Allergology, A. and Clinical, I. (2018). Urban air pollution and climate change: "The Decalogue: Allergy safe tree" for allergic and respiratory diseases care. *Clin. Mol. Allergy* 16: 20. https://doi.org/10.1186/s12948-018-0098-3

Qué Pasa Bahía Blanca (QPBB) (2019). Mediciones de calidad de aire - material articulado 24 hrs. Qué Pasa Bahía Blanca. http://www.quepasabahiablanca.gov.ar/sensores/calidad_de_aire/

Radovic, M. and Hassan, H. (1999). Air quality in Brunei Darussalam during the 1998 haze period. *Atmos. Environ.* 33: 3651–3658.

RHMI (2018). Air quality report for the Republika Srpska for 2016. Republic Hydrometeorological Institute of Republika Srpska, Ministry of Agriculture, Forestry and Water Management. Working Team: Zlatko Đajić, Ranka Radić, Nada Mijatović. 64 pp. In Serbian.

Riojas-Rodríguez, H., da Silva, A.S., Texcalac-Sangrador, J.L. and Moreno-Banda, G.L. (2016). Air pollution management and control in Latin America and the Caribbean: Implications for climate change. *Rev. Panam. Salud. Publica* 40: 150–159.

Samet, J.M. and White, R.H. (2004). Urban air pollution, health, and equity. *J. Epidemiol. Community Health* 58: 3–5. https://doi.org/10.1136/jech.58.1.3

Schröder, P., Shen, W. and Srivastava, S. (2018). Tackling the challenges of urban air pollution - why does air pollution impact inequality as well as health? Institute of Development Studies. https://www.ids.ac.uk/opinions/tackling-the-challenges-of-urban-air-pollution-why-does-air-pollution-impact-inequality-as-well-as-health/

Schwela, D.H. (1999). Public Health and the Air Management Information System (AMIS). *Epidemiology* 10: 647–655.

Schwela, D. (2011). GAP Forum Air Pollution Monitoring Manual. Second draft of guidance note on air pollution monitoring. Global Atmospheric Pollution Forum. https://www.sei.org/projects-and-tools/projects/global-atmospheric-pollution-forum-gap-forum/

Serya H., El Hadidi, S. and El Bestar, S. (2019). Respiratory health effects among female street food vendors in Mansoura City, Egypt. *Egypt. J. Occup. Med.* 43: 17–32. https://doi.org/10.21608/EJOM.2019.25104

Taiwan EPA (2019). Air quality monitoring. Environmental Protection Administration Executive Yuan ROC (Taiwan). https://taqm.epa.gov.tw/taqm/en/

Tech Times (2016). Here are the top most polluted cities in the worlds. Tech Times. May 14, 2016. http://www.techtimes.com/articles/158134/20160514/here-are-the-top-most-polluted-cities-in-the-world.htm

The Guardian (2014). Apec: China blocks access to US air pollution data for Beijing. The Guardian. 10 November 2014. https://www.theguardian.com/world/2014/nov/10/apec-china-blocks-access-us-air-pollution-data-beijing

The Guardian (2016). Which are the world's two most polluted cities – and why. The Guardian. May 12, 2016. https://www.theguardian.com/environment/2016/may/12/which-are-the-worlds-two-most-polluted-cities-and-why

The Hindu (2016). Delhi not 'most polluted', but dirty air fouls many cities. The Hindu. May 13, 2016. http://www.thehindu.com/news/cities/Delhi/delhi-is-not-the-most-polluted-city-in-the-world-who/article8589775.ece

The Indian Express (2016a). Gwalior is the most polluted Indian city, not Delhi: WHO report. The Indian Express. September 27, 2016. http://indianexpress.com/article/india/india-news-india/gwalior-is-the-most-polluted-indian-city-not-delhi-who-report-3052946/

The Indian Express (2016b). Delhi second-most polluted major city in the worlds, says WHO study. The Indian Express. September 27, 2016.http://indianexpress.com/article/india/india-news-india/delhi-pollution-traffic-air-quality-second-most-polluted-city-who-3053607/

The Telegraph (2019). Is Delhi the most polluted city on Earth? Not quite. The Telegraph. https://www.telegraph.co.uk/travel/destinations/asia/india/articles/delhi-most-polluted-city-in-the-world/

The Wall Street Journal (2016). Which cities in the world have the worst air pollution? The Wall Street Journal. May 12, 2016. http://blogs.wsj.com/indiarealtime/2016/05/12/which-cities-in-the-world-have-the-worst-air-pollution/

The Washington Post (2016). The most polluted city in the world isn't Beijing or Delhi. The Washington Post. May 13, 2016. https://www.washingtonpost.com/news/worldviews/wp/2016/05/13/the-most-polluted-city-in-the-world-isnt-beijing-or-delhi/

U.S. Embassy Kazakhstan (2019). Air quality monitor. https://kz.usembassy.gov/embassy-consulates/embassy/air-quality-monitor/

UN Environment (2018). Young and old, air pollution affects the most vulnerable. United Nations Environment Programme. https://www.unenvironment.org/news-and-stories/blogpost/young-and-old-air-pollution-affects-most-vulnerable

United Nations Environment Programme (UNEP) (2015). Air quality policies. https://wedocs.unep.org/bitstream/handle/20.500.11822/17155/BruneiDarussalam.pdf?sequence=1&isAllowed=y

United Nations Environment Programme (UNEP) (2019). Air pollution in Asia and the Pacific: Science-based solutions. United Nations Environment Programme, https://www.ccacoalition.org/en/resources/air-pollution-asia-and-pacific-science-based-solutions-summary-full-report

United Nations International Children's Emergency Fund (UNICEF) (2018). The toxic school run. UK children at daily risk from air pollution. UNICEF UK research briefing. United Nations Children's Fund. https://downloads.unicef.org.uk/wp-content/uploads/2018/09/UUK-research-briefing-The-toxic-school-run-September-2018.pdf?_ga=2.234006365.298981577.1537257494-289689197.1536231694

Verma, A. (2019). Basic difference between AAQMS and CAAQMS. OIZOM Redefining Resources. https://oizom.com/caaqms-vs-aaqms/

Walker, G. (2012). *Environmental justice: Concepts, evidence and politics*. Routledge, Abongton, Oxon, UK.

Walton, H., Dajnak, D., Beevers, S., Williams, M., Watkiss, P. and Hunt, A. (2015). Understanding the health impacts of air pollution in London. Environmental Research Group, School of Biomedical Sciences, King's College, London. https://www.london.gov.uk/sites/default/files/hiainlondon_kingsreport_14072015_final.pdf

Wikipedia (2019). List of most-polluted cities by particulate matter concentration. https://en.wikipedia.org/wiki/List_of_most-polluted_cities_by_particulate_matter_concentration

World Air Quality Index (WAQI) (2019). Buenos Aires air pollution: Real-time Air Quality Index (AQI). https://aqicn.org/city/buenos-aires/

World Economic Forum (WEF) (2016). Which are the world's most polluted cities? World Economic Forum, https://www.weforum.org/agenda/2016/05/which-are-the-world-s-most-polluted-cities/

World Economic Forum (WEF) (2019). 7 of the world's 10 most polluted cities are in India. World Economic Forum, https://www.weforum.org/agenda/2019/03/7-of-the-world-s-10-most-polluted-cities-are-in-india/

World Health Organization (WHO) (1979). Sulfur oxides and suspended particulate matter. Environmental Health Criteria No. 8. World Health Organization, Geneva. http://www.inchem.org/documents/ehc/ehc/ehc008.htm

World Health Organization (WHO) (1987). Air Quality Guidelines for Europe. WHO Regional Publications, European Series No. 23. Regional Office for Europe, World Health Organization, Copenhagen.

World Health Organization (WHO) (1999). Monitoring ambient air quality for health impact assessment. World Health Organization, Regional Office for Europe, Copenhagen. http://www.euro.who.int/__data/assets/pdf_file/0010/119674/E67902.pdf

World Health Organization (WHO) (2008). Burden of disease for urban outdoor air pollution for 2008. Description of method. World Health Organization, Geneva. https://www.who.int/airpollution/data/OAP_BoD_2011_.pdf?ua=1

World Health Organization (WHO) (2010). Environment and health risks: A review of the influence and effects of social inequalities. World Health Organization, Regional Office for Europe, Copenhagen. www.euro.who.int/

World Health Organization (WHO) (2013). Review of evidence of health aspects of air pollution - REVIHAAP project: Final technical report. World Health Organization, Regional Office for Europe, Copenhagen. https://www.who.int/en/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health

World Health Organization (WHO) (2016). WHO global urban ambient air pollution database (update 2016). World Health Organization, Geneva. https://www.who.int/phe/health_topics/outdoorair/databases/cities/en/

World Health Organization (WHO) (2018a). WHO global urban ambient air pollution database (update 2018, version 11). World Health Organization, Geneva. https://www.who.int/airpollution/data/cities/en/

World Health Organization (WHO) (2018b). Air pollution and child health. Prescribing clean air. Summary. World Health Organization, Geneva. https://apps.who.int/iris/rest/bitstreams/1157950/retrieve

World Health Organization (WHO) (2018c). Ambient (outdoor) air pollution. Key Facts. World Health Organization, Geneva. https://www.who.int/en/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health

World Health Organization (WHO) (2019a). Ambient air pollution: Health impacts. World Health Organization, Geneva. https://www.who.int/airpollution/ambient/health-impacts/en/

World Health Organization (WHO) (2019b). Air pollution. World Health Organization, Geneva. https://www.who.int/airpollution/en/

Wright, C.Y. and Diab, R. (2011). Air pollution and vulnerability: Solving the puzzle of prioritization. *J Environ. Health*. 73: 56–64.

Received for review, November 22, 2019
Revised, March 11, 2020
Accepted, March 11, 2020