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Risk communication of ambient air pollution in the WHO European Region

Review of air quality indexes and lessons learned

Kevin Cromar, Noussair Lazrak

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Abstract

This report provides an overview of air quality indexes used in 37 Member States of the WHO European Region and some observations/suggestions for future developments to improve risk communication on air pollution. In the Region, air quality information is widely available to the public, both online and through official mobile apps. Forecasted air pollution information is often reported alongside near real-time air pollution monitoring data. Most countries use a national Air Quality Index instead of a uniform index, such as that provided by the European Environment Agency, and some use several different indexes. A wide range of approaches are used to calculate index values, but the general structure of indexes is similar. Many indexes lack rigorous validation to ensure that index values correspond to population-level health risks. Quality of the accompanying health messaging varies widely, but good examples were found throughout the Region. The best examples provide information on the affected subpopulations, describe likely symptoms and make specific recommendations to reduce exposures and health risks. Given the wide range of pollutant concentrations, mixtures and risk preferences observed, it is critical to provide tailored health messaging to accompany index levels. In addition to health-based validation studies, research should focus on understanding how the public uses air quality indexes (including special alerts): how many people are aware of the index, whether they consult it regularly, whether they modify behaviour in response to the information, and what specific actions they take in response to index values and associated health messages.

Keywords

AIR POLLUTION, AIR POLLUTANTS, HEALTH COMMUNICATION, ENVIRONMENT AND PUBLIC HEALTH, EUROPE

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Abbreviations

CO	carbon monoxide
EAQI	European Air Quality Index
EEA	European Environment Agency
NO_2	nitrogen dioxide
O_3	ozone
PM	particulate matter
$PM_{2.5}$	particulate matter, where particles have an aerodynamic diameter equal to or less than 2.5 µm
PM_{10}	particulate matter, where particles have an aerodynamic diameter equal to or less than 10 µm
SO_2	sulfur dioxide

Background

There is ample evidence of the adverse health effects of air pollution. According to WHO, exposure to ambient air pollution is estimated to cause about 4.2 million deaths annually worldwide *(1)*. In the European Union, despite a significant decrease in emissions for many air pollutants over the last two decades, air pollutant concentrations are still too high. According to the European Environment Agency (EEA), in 2020 96% of city residents were exposed to harmful concentrations of particulate matter (PM), where particles have an aerodynamic diameter equal to or less than 2.5 µm ($PM_{2.5}$) *(2)*. To help mitigate the negative health impacts of exposure to high levels of ambient air pollution, people must be aware of the air quality in their area and have clear, detailed information on what health risks they face and what actions they need to take to protect their health.

The importance of risk communication on the adverse health effects from air pollution is recognized in several key WHO and United Nations documents. Resolution WHA68.8, Health and the Environment: addressing the Health Impacts from Air Pollution *(3)*, identifies the following key activity: providing information to policymakers and the public about the health impacts of air pollution and actions to reduce them.

In the *WHO Global Strategy on Health, Environment and Climate Change*, the role of the health community is expanded and is identified as a key objective *(4)*. The Global Strategy highlights the need for enhanced communication, awareness raising and public participation to achieve the transformational change. It also emphasizes the potential of increasing public awareness for promoting adaptive actions and pro-environment behaviours.

Likewise, the Ostrava Declaration of the Sixth Ministerial Conference on Environment and Health emphasizes the leading role of authorities in raising public awareness of issues related to air quality and health, including through appropriate communication, in its compendium of possible actions for implementation *(5)*.

At a broader level, raising awareness of the risks from air pollution is aligned with and supports the United Nations' strategic priorities for the prevention and control of non-communicable diseases *(6)*, as well as those established in the 2030 Agenda for Sustainable Development *(7)*.

Building upon WHO's ongoing effort to enhance and promote evidence-informed risk communication *(8–10)*, a review of the air quality indexes and general risk communication practices from 37 countries in the WHO European Region[1] was completed under the umbrella of the Sharing Knowledge on Air Pollution and Health in Europe (SKAPHIE) project. The work was conducted by a team of 21 researchers with a wide range of collective language capabilities. Official authorities were contacted in each

[1] Austria, Belarus, Belgium, Bulgaria, Croatia, Czechia, Cyprus, Denmark, Estonia, Finland, France, Georgia, Germany, Greece, Hungary, Iceland, Ireland, Italy, Kazakhstan, Latvia, Lithuania, Luxembourg, Malta, Monaco, Netherlands, Norway, Poland, Portugal, Russian Federation, San Marino, Spain, Sweden, Switzerland, Türkiye, Ukraine, United Kingdom and Uzbekistan. Azerbaijan and Slovenia were also reviewed, but the information from the official websites/mobile applications could not be validated against official responses. However, the case of Azerbaijan is highlighted in the "Accounting for the combined health impacts of multiple pollutants" section, based on the available literature.

country to identify national policies on air pollution and health risk communication practices. A grey literature review was also completed to identify any studies focused on the development, use or validation of the air quality indexes.

The results of the review are presented through examples from individual countries that illustrate key conclusions rather than by attempting to report all of the information collected from every country. This report intends to highlight how countries across the Region are communicating air quality health risks and makes suggestions for decision-makers to drive local risk communication policy.

Key findings at a glance

Air quality information is widely available to the public both online and commonly through official mobile apps. Forecasted air pollution information is often reported alongside real-time air pollution monitoring data. Forecasted pollution values have been shown to be sufficiently reliable because day-to-day variations in air quality are often driven by meteorological conditions, which are easier to model than changes in local emissions.

Most countries in the WHO European Region use a country-specific air quality index instead of the uniform index provided by the EEA. In some cases, different indexes are used within the same country. A wide range of approaches are used to calculate index values (e.g. variations in the pollutants included, different number of categories and different cut-points) but the general structure of the indexes is largely similar for all countries that use an air quality index. However, validation studies using local health data to evaluate the efficacy of the air quality indexes currently used in Europe are notably lacking. Examples of validation efforts in other WHO regions, particularly in North America, can be emulated in Europe in order to provide a more rigorous evidence base for decision-making on the verification and potential reformulation of air quality indexes.

The quality of health messaging (discussed in depth in the section "Health messaging") accompanying the index values varied widely across the study area, but good examples of health messaging were found throughout the WHO European Region. The best examples provide information on the affected subpopulations, a description of symptoms likely to be experienced, and specific recommendations on how to reduce exposures and health risks. Given the wide range of pollutant concentrations and mixtures and of risk preferences observed across Europe, it is critical that tailored health messaging is provided to accompany index levels. The effectiveness of health messaging should be evaluated through follow-up research studies.

The key findings are as follows.

1. There is tremendous variation in how air quality risks are reported to the general public across the WHO European Region.
2. Most Member States of the Region use a country-specific index instead of the European Air Quality Index (EAQI).
3. There is a critical need to validate air quality indexes using local health data to ensure that index values effectively reflect health risks.
4. Risk communication approaches need to be flexible enough to account for differences in air pollution mixtures, baseline concentrations, cultural differences with regards to outdoor activities, and health risk preferences.

EAQI

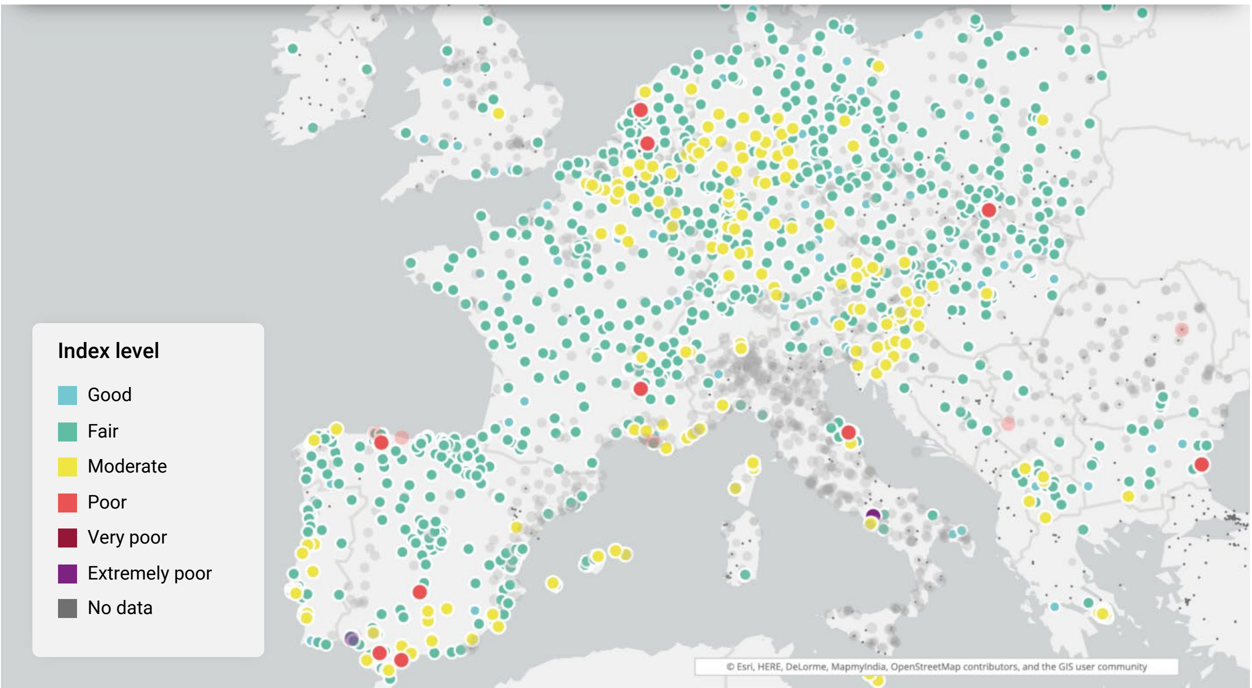
The EEA has provided an online geographical information system-based tool for visualizing air quality conditions throughout Europe, available both on the internet and as a smartphone application *(11)*. The data are reported using the EAQI, which was jointly developed by the EEA and the European Commission's Directorate-General for the Environment. Information for each available monitoring station is easily accessible and includes the location of the monitor, the current EAQI level of the pollutant driving the index level, information about index levels over the last several days, forecasted values, a breakdown of the percentage of days classified within each index level over the last year and health messaging based on current index levels.

The EAQI levels are reported as categories that correspond to a range of pollutant concentrations (i.e. a numerical index value is not specified) that were developed based on epidemiological studies into associations of short-term pollutant exposure with mortality risk *(12)*. The increased risk of mortality per 10 µg/m³ daily mean fine PM ($PM_{2.5}$) is the primary basis of the index, with cut-points for other pollutants determined by estimating the equivalent relative risk compared with $PM_{2.5}$.

Using equivalent risks for mortality across different pollutants within the same index level is a much more rigorous approach compared with the United States Air Quality Index, which anchors the primary cut-point for each pollutant within the index to national ambient air quality standards (these are reviewed one pollutant at a time on a rolling 5-year cycle). Notably, the decision to base the index on mortality risks may result in selecting different cut-points as would potentially be used if the index was based on respiratory morbidity health outcomes, which have been shown to be the most responsive to air quality alerts *(13)*. Although the approach used in the EAQI avoids the problem of inconsistent changes in risk when comparing individual pollutants, as observed in the United States *(14)*, it still cannot fully account for the differences in health risks based on the combined impacts of multiple pollutants.

Although the current literature does not provide evidence to establish clear cut-points for health risks, the EAQI has been divided into six generic index levels: good, fair, moderate, poor, very poor and extremely poor (Fig. 1). This provides a quick and easy way to compare overall air quality conditions across Europe. Generic health messaging is also provided for each index level for both the general population and sensitive populations (e.g. people with heart or lung disease, people with diabetes, elderly people and children). Similar to many other indexes used around the world, the pollutant with the highest index level is the one generally reported to the public, although details for the non-driver pollutants are also available.

Fig. 1. EAQI map



Source: reference *11*. Reproduced under CC BY 2.5 DK licence (https://creativecommons.org/licenses/by/2.5/dk/deed.en_GB).
Disclaimer: this map does not represent all the Member States of the WHO European Region. It is used for illustrative purposes only.

Potential challenges with using a uniform index

There are clear advantages of having a uniform index across Europe or even across the world. A uniform index has the potential to easily compare air quality conditions between geographical locations (within or between countries), as well as allowing users to become familiar with and understand the index across regions. However, there are also important weaknesses related to use of a uniform index across geographical areas with very different baseline levels of ambient air pollution. The generic characterization of air quality conditions as good, moderate or poor in indexes such as the EAQI emphasizes the relative quality of air pollution conditions between geographical locations. However, it may provide less useful information on temporal changes in relative air quality conditions at a single location, which is the general public's primary use of air quality indexes.

Potential problems associated with a lack of detailed index information for a given location over time occur in areas with relatively good air quality as well as those with relatively poor air quality. There is ample evidence for the adverse health effects of ambient air pollution in areas with relatively good air quality. In some cases, most health impacts related to air pollution have occurred on days in which the air quality was reported as good or very good *(15,16)*. In such circumstances, the index values do not provide enough information to protect vulnerable populations that may experience differing levels of risk across days that are uniformly described as having good air quality.

Likewise, if a geographical area has relatively poor air quality virtually every day of the year, it is not useful to have daily health messaging that recommends reducing outdoor physical activity. Health messaging that involves potential behaviour modification should also take into account the likely number of days when this may be necessary. For example, in Ireland the air quality is rated as fair, poor or very poor (as defined by the Irish Air Quality Index for Health; Table 1) for 20–30 days per year *(17)*. This may be a reasonable number of days to change the timing or location of outdoor exercise, turn on air filtration without extra energy expenditure, or modify commuting or leisure behaviour. Given the large variation in air quality conditions across Europe, it is essential to improve health messaging and recommendations for behaviour modification by taking into account the local air quality conditions. This will maximize the potential health benefits by promoting public awareness and use of an air quality index *(18)*.

If an air quality index is intended to broadly compare qualitatively and quantitatively determined levels of pollution between geographical areas, then a uniform index with a generalized characterization of the overall air quality is appropriate. However, if the goal is to inform the public about temporal variations in air quality within a geographical area, then it is more important to report deviations from the typical air quality for the area to promote health protection for the most vulnerable population. If a uniform index is to be used, potential solutions to this problem include removing generic characterizations in favour of either broader categories (e.g. meets WHO guidelines/does not meet WHO guidelines) or adopting numeric scaling without qualitative characterization.

Examples of country-specific air quality indexes

Not all countries make use of an air quality index. For example, Cyprus *(19)* and Denmark *(20)* have chosen to simply report the concentrations of each pollutant, without calculating a combined index. This straightforward approach allows the public to clearly see the monitored concentrations of each pollutant without having to learn how these concentrations are converted into a complex index value. However, these countries are exceptions because most countries use some form of an air quality index (Table 1).

Table 1. Examples of national air quality indexes in the WHO European Region

Country	Index	Website
Austria	*Luftqualitätsindex*	https://luft.umweltbundesamt.at/pub/gmap/start.html
Belarus	Atmospheric Air Quality Index	https://rad.org.by/monitoring/air.html
Belgium	BelAQI index	https://www.irceline.be/en/air-quality/measurements/belaqi-air-quality-index/information
Bulgaria	Air Quality Index	http://pdbase.government.bg/airq/alarm-en.jsp
Croatia	*Indeks kvaliteta zraka*	http://iszz.azo.hr/iskzl/
Czechia	Air Quality Index	https://www.chmi.cz/files/portal/docs/uoco/web_generator/actual_3hour_data_GB.html
Estonia	Ambient Air Indicators	http://airviro.klab.ee/
Finland	Air Quality Index	https://en.ilmatieteenlaitos.fi/air-quality
France	Indice ATMO	https://atmo-france.org/
Georgia	Air Quality Index	https://air.gov.ge/
Germany	*Luftqualitätsindex*	https://www.umweltbundesamt.de/daten/luft/luftdaten/luftqualitaet/eJzrWJSSuMrIwMhQ18BS19B0UUnmIiCZl7pgUXHJgsUpbkVwSQOLxSkh-chqc6vYF-UmNy3OSSw57eCx4My0Aoazi3Py0k87qPyo_3uAgREASoMkSg==
Greece	Air Quality Index	http://mapsportal.ypen.gr/layers/geonode:stations
Hungary	Hungarian Air Quality Index	https://legszennyezettseg.met.hu/
Iceland	*Loftgæði á Íslandi*	https://loftgaedi.is
Ireland	Air Quality Index for health	https://airquality.ie/
Italy	*Indice di Qualità dell'Aria*	https://moniqa.dii.unipi.it/

Table 1 contd

Country	Index	Website
Kazakhstan	Air Pollution Index	https://www.kazhydromet.kz/vc/silam/
Latvia	*Gaisa kvalitātes indekss*	http://gmsd.riga.lv
Lithuania	*Oro užterštumo lygio indeksas*	http://193.219.53.11/ap3/
Luxembourg	Air Quality Index	https://environnement.public.lu/fr/loft/air/mesures/mesures-actuelles.html
Malta	Air Quality Index	https://era.org.mt/air-quality-widget/
Monaco	Air Quality Index	https://www.atmosud.org/
Netherlands	Air Quality Index	https://www.atlasleefomgeving.nl/kaarten
Norway	Air Quality Index	https://luftkvalitet.miljodirektoratet.no/
Poland	*Polski Indeks Jakości Powietrza*	https://powietrze.gios.gov.pl/pjp/current
Portugal	Air Quality Index	https://qualar.apambiente.pt/indices
Russia Federation (Moscow)	Air Pollution Index	https://web.archive.org/web/20211011074753/https://mosecom.mos.ru/karta/
San Marino	*Indice di Qualità dell'Aria*	https://www.iss.sm/on-line/home/dipartimento-prevenzione/sanita-pubblica/tutela-dellambiente-naturale-e-costruito/dati-ambientali/monitoraggi.html
Spain	*Índice Nacional de Calidad del Aire*	http://www.ica.miteco.es
Sweden	National Air Quality Index	https://www.smhi.se/data/miljo/luftwebb/
Switzerland	*L'indice Suisse de pollution de l'air à court terme*	https://www.bfs.admin.ch/bfs/fr/home/statistiques/themes-transversaux/city-statistics/indicateurs-qualite-vie/qualite-environment/qualite-air.html; https://www.ge.ch/connaitre-qualite-air-geneve/dernier-bulletin-qualite-air-geneve
Türkiye	Air Quality Index	https://sim.csb.gov.tr/Services/AirQuality
Ukraine	*Індекс якості повітря*	https://web.archive.org/web/20210625035644/https://air.kyivsmartcity.com/
United Kingdom	Daily Air Quality Index	https://uk-air.defra.gov.uk/latest/currentlevels
Uzbekistan	Air Pollution Index	https://monitoring.meteo.uz/en/

In many cases, countries use more than one index. For example, Hungary has an Air Quality Index that is reported by the Hungarian Meteorological Service and also the Air Hygiene Index that was developed by the National Public Health Centre and is based on air quality data provided by the Hungarian Air Quality Network. There are also many instances of individual states and cities adopting their own index (which is reported to local populations) that is distinct from the national index.

Some countries, such as Latvia *(21)*, have directly adopted the EAQI as the basis of their official air quality index. Other countries, such as Hungary *(22)*, have based their index (as reported by the

Hungarian Meteorological Service) almost entirely on the EAQI. The Hungarian Air Quality Index has no modifications other than also reporting the 24-hour running means for benzene and the hourly concentrations for carbon monoxide (CO), which form part of the online communication of pollutant values at monitoring stations. Even in countries that have developed their own air pollution limits, the health messaging and number of index levels are clearly influenced by those provided by the EEA.

Many processes have been used to develop a country-specific air quality index that is distinct from the EAQI, but the development often involves both environmental and health agencies and, in many cases, relies on additional expertise from the broader scientific community. A typical example is Poland, where the Chief Inspectorate for Environmental Protection relied on the results of work commissioned by independent experts. The specified ranges of air quality index values and the health information prepared for individual thresholds were finalized after consulting the Polish Ministry of Health, the National Institute of Public Health – National Institute of Hygiene, and the Institute of Occupational Medicine and Environmental Health *(23)*. This is an ongoing process and at any given time multiple European countries are likely to be making changes to their index, for example, the recent changes in France *(24)*.

Air quality information is made available to the public through official websites and mobile apps (Table 2; some examples are shown in Box 1).

Table 2. Examples of mobile apps used to report air quality in Europe[2]

Country	Mobile app
Belgium	BelAir
Cyprus	Air Quality Cyprus
Czechia	Smogalarm
Finland	Ilmanlaatu
France (Paris)	Airparif
Germany	Luftqualität (air quality)
Italy	MonIQA, whatsAiR
Kazakhstan	AirKz
Luxembourg	Meng Loft
Netherlands	RIVM LCI-richtlijnen
Norway	Luftkvalitet
Poland	Air Quality in Poland
Portugal	QualAr
Sweden	Luft Stockholm
Switzerland	Air2G2
Uzbekistan	AirUz

[2] All of the mobile apps can be found on digital distribution platforms.

Box 1. Air quality tools from selected countries

Georgia: Air Quality Portal
The website was launched in 2019 to report the national Air Quality Index. It provides air quality data obtained from stationary stations and detailed health advice based on pollutant cut-points *(25)*.

Poland: Air Quality in Poland app[3]
The app gives current air quality data from automatic measuring stations, as provided by the Chief Inspectorate for Environmental Protection, along with health messaging based on the index value and a 2-day forecast.

Uzbekistan: AirUz app[3]
The app provides the Current Air Pollution Index, along with information on emissions and pollutants and their health effects. Health advice is also given, along with recommendations for outdoor activities.

[3] This mobile app can be found on digital distribution platforms.

Air pollution forecasting

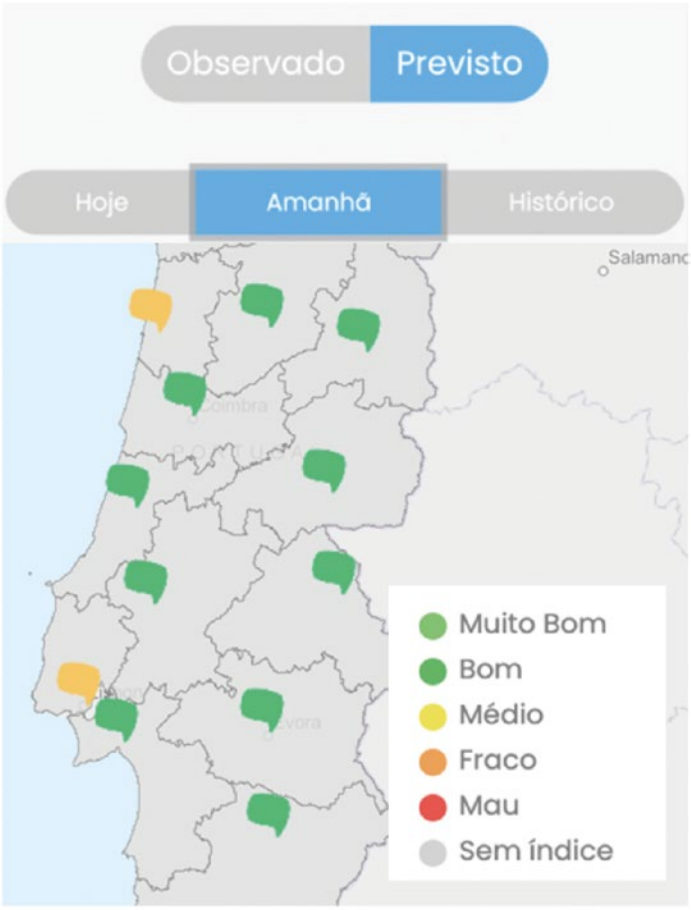
In addition to the EAQI from the EEA, many countries provide forecasted pollution values alongside monitored pollutant concentrations (e.g. Kazakhstan *(26)* and Portugal *(27)*), and the forecasted values are sufficiently reliable for reporting next-day pollutant concentrations. The next-day forecasts are accurate because day-to-day variations in air quality are primarily driven by changes in meteorological conditions, which can be effectively modelled, and secondarily by changes in local emission activity, which cannot be effectively included in a daily forecast. This was convincingly demonstrated in a Turkish study into the relationship between air pollution and atmospheric conditions *(28)*. The study established that ambient air quality was largely determined by meteorological conditions rather than by emissions at all monitoring stations, except those close to heavy traffic.

Forecasted pollution values are often shown alongside real-time monitoring of pollutant values For example, in Portugal the daily air quality index values, the values forecast for the next day and the historical values at central monitoring locations are shown (Fig. 2) *(27)*. In contrast, in Kazakhstan the 2-day forecasted pollution values are shown as a continuous spatiotemporal surface *(26)*. Uniquely, the website shows which pollutant is driving the index value alongside the index value itself. The examples from Kazakhstan and Portugal show how forecasted air pollution levels can be depicted using static next-day values for central monitoring sites or as continuous 2-day spatiotemporal surfaces.

Even the most sophisticated air pollution forecasts can be wrong if meteorological conditions or emission activity changes unexpectedly. Rapid changes in air quality conditions are particularly difficult to forecast if the averaging time of the pollutant used to calculate index values is based on 8-hour or 24-hour average concentrations.

The United Kingdom previously recommended the use of trigger concentrations to warn the public to expect a period of higher pollution *(29)*. Monitoring data that exceeded predetermined thresholds for two consecutive hours would trigger the immediate reporting of the next higher index value. Use of this time frame was demonstrated to greatly reduced false warnings. Although this approach is not recommended for widespread utilization, it provides an example of how rapidly changing air quality conditions can be considered in reporting air pollution index values.

Fig. 2. Forecasted air quality information from Portugal



Source: reference 27. Reproduced with permission from Agência Portuguesa do Ambiente.

Note: The website provides the observed (*observado*) and forecast (*previsto*) air quality – today (*hoje*), tomorrow (*amanhá*) and historical (*histórico*) – classified as very good (*muito bom*), good (*bom*), average (*médio*), poor (*fraco*), bad (*mau*) or no index (*sem indice*).

Table 3 shows examples of recommended trigger pollutant concentrations to alert the public to worsening air quality conditions in the United Kingdom. The trigger levels must be reached for two consecutive hours to reduce false warnings. The Gilbert skill score (GSS) assesses the likelihood of a false warning based on trigger warnings. The score is the total number of correct event forecasts (hits) divided by the total number of event forecasts plus the number of misses (hits ÷ (false warnings + misses)).

Table 3. Recommended trigger concentrations to alert the public to worsening air quality conditions, United Kingdom

Pollutant	Band	Trigger value (µg/m³)	GSS
PM_{10}	Moderate or above	68	0.533
	High or above	107	0.348
	Very high or above	117	0.188
$PM_{2.5}$	Moderate or above	50	0.591
	High or above	74	0.422
	Very high or above	101	0.260
O_3	Moderate or above	105	0.791
	High or above	170	0.726
	Very high or above	ND	NA

Source: reference *29*. Contains public sector information licensed under the Open Government Licence v3.0 (https://www.nationalarchives.gov.uk/doc/open-government-licence/version/3/).

GSS: Gilbert skill score; NA: not applicable; ND: not determined; O_3: ozone; PM_{10}: particulate matter, where particles have an aerodynamic diameter equal to or less than 10 µm.

Box 2 shows examples of air quality forecasting tools from Germany, Kazakhstan and Portugal.

Box 2. Air quality forecasting tools from selected countries

Germany: Current Air Data Portal

The portal provides measured and forecasted values with the help of Germany-wide map and graphs with historical data *(30)*. It also provides health tips and recommendations for different population groups.

Kazakhstan: SILAM AQ Model

Launched in September 2020, SILAM AQ is a predictive model of atmospheric air quality based on the Integrated Atmospheric Composition Modelling System *(26)*. Based on this model, Kazhydromet (the Kazakh hydrometeorological service) added pollutant concentration forecasts to the interactive atmospheric air quality map, with a 24–48-hour forecast for each observation post.

Portugal: QualAr app[4]

The app provides information on daily air quality, along with forecasting at selected locations. It provides health warnings via a notification system according to the expected QualAr index.

[4] This mobile app can be found on digital distribution platforms.

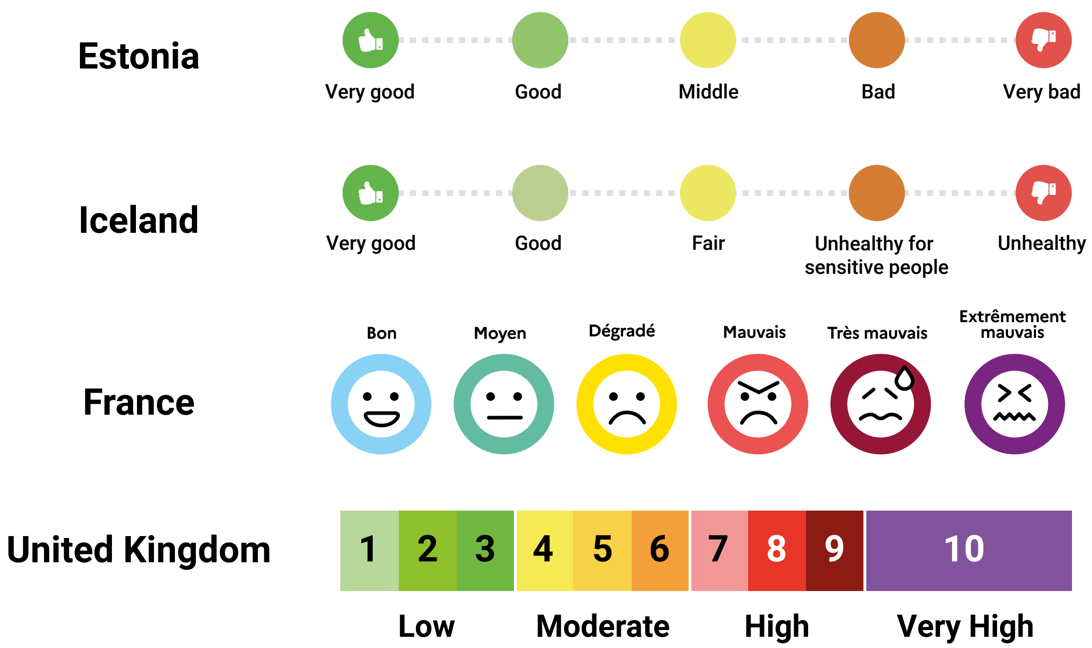
Differences in the number of index levels and cut-points

Three primary differences were observed between the formulation and presentation of air quality index values in different countries: (i) the pollutants considered in the index, (ii) the cut-points for each individual pollutant and (iii) the number of index levels.

In nearly all countries, indexes use PM, nitrogen dioxide (NO_2) and ozone (O_3). Some countries also incorporate CO, sulfur dioxide (SO_2) or other monitored pollutants. The precise pollutant cut-points (or limits) used are commonly based on the levels used in the EEA EAQI or the WHO guidelines or in established regulatory limits. Despite the different numbers of pollutants considered and very different limits used, PM appears to be the most important pollutant across the WHO European Region.

The number of index levels varies across the Region, but five, six, and 10 levels were most common. In some cases, numerical index levels are grouped into fewer messaging categories (e.g. the United Kingdom). Fig. 3 shows examples from Estonia, France, Iceland and the United Kingdom.

Fig. 3. Examples of different numbers of index levels in use across the WHO European Region



Sources: references *31–34*. Contains public sector information licensed under the Open Government Licence v3.0 (https://www.nationalarchives.gov.uk/doc/open-government-licence/version/3/).

Some countries report concentrations of various pollutants for several different averaging times (e.g. 1, 3, 8 and 24 hours), even when the same pollutants are included in an index. The rationale for using a short (1 hour) rather than a substantially longer (24 hour) averaging time is that shorter averaging times may allow a more immediate response to changing conditions and also align more directly with measurements taken outside the official monitoring network. In contrast, epidemiological studies *(35,36)* have clearly shown that the adverse health effects of some ambient air pollutants are associated with longer averaging times and even with lag structures *(37)* over multiple days. When balancing these potential trade-offs in decisions on which averaging times should be used, it is important to validate the final index values to ensure that they accurately reflect population-level health risks (discussed in the section "Critical need to evaluate and validate air quality indexes").

Accounting for the combined health impact of multiple pollutants

Air pollutants do not exist in isolation in the ambient environment. One structural limitation of air quality indexes that report the index level of the pollutant with the highest concentration relative to predetermined cut-points is that they ignore the concentrations of other pollutants in health messaging and in calculating index levels. Depending on the concentrations of the other pollutants, this can result in higher index values actually corresponding to lower health risks.

However, some geographical areas whose air quality index does not include a mechanism to account for the combined health risks of multiple pollutants have made supplementary efforts. For example, in Germany reports of air quality specifically mention the potential health impacts of exposure to multiple pollutants even if not all are reflected in the index level *(38)*. Even during days with an index level of good, the report states that "effects from combinations of air pollutants and from long-term exposure to the individual substance cannot be ruled out".

The Netherlands developed a unique system to try to account for the possibility of all reported pollutants (NO_2, PM, where particles have an aerodynamic diameter equal to or less than 10 µm (PM_{10}), $PM_{2.5}$, O_3) having high index values. When all four have numerical index values at the top end of a band (A, B, C or D), this triggers the reporting of the next highest band (Table 4). Although this method can account for the combined health risks of multiple pollutants given the low probability of having this combination of index levels, it is unlikely to be generally useful.

Notably, some countries in eastern Europe and central Asia have multiple indexes that serve different purposes. For example, the Azerbaijan Air Pollution Index provides an index value based on the sum of index levels for multiple pollutants that are scaled against the regulatory concentration limits *(40)*. The overall index value is reported to the public both as a number and as one of four index categories. However, approaches based on regulatory limits are extremely sensitive to policy changes, such as the 2005 change in the regulatory limits for formaldehyde. In Belarus, the 2005 change in the formaldehyde limit resulted in index values that could not be compared with values from previous years *(41)*. Therefore, there was a substantial reduction in the application of the index by the national air monitoring system.

Table 4. The Dutch Air Quality Index captures the combined health risks of multiple pollutants

Pollutant	Individual index	Air quality index	Category (index range)
NO_2	2	3	A (1–3)
PM_{10}	3		
$PM_{2.5}$	3		
O_3	3		
NO_2	3	4	B (4–6)
PM_{10}	3		
$PM_{2.5}$	3		
O_3	3		
NO_2	6	7	C (7–9)
PM_{10}	6		
$PM_{2.5}$	6		
O_3	6		
NO_2	9	10	D (10)
PM_{10}	9		
$PM_{2.5}$	9		
O_3	9		

Source: reference *39*. Reproduced with permission from Rijksinstituut voor Volksgezondheid en Milieu.

Note: Each pollutant has an index. The total air quality index is equal to the highest value among the pollutant indexes. For example, if the pollutant index for NO_2, PM_{10}, $PM_{2.5}$ and O_3 are 2, 3, 3 and 3, respectively, then the total air quality index takes the highest value of the pollutant indexes, which is 3. However, when all pollutant indexes have the same value, then the total index is equal to the next index class. For example, if the pollutant indexes for NO_2, PM_{10}, $PM_{2.5}$ and O_3 are 3, 3, 3 and 3, respectively, then the total air quality index would be 4. The overall air quality index is then categorized as A, B, C or D.

Alternative structures of air quality indexes explicitly incorporate the combined influence of multiple pollutants in the index calculation. An exploratory study in Sweden demonstrated that from a policy perspective two important factors can be developed by incorporating a multipollutant air quality index *(42)*. This is particularly relevant for sensitive individuals, who may respond very differently to air pollution reported as good or fair using the existing index levels. Ideally, an index would allow users to identify the index level at which they begin to experience symptoms and start taking protective action at that level. However, this will not be possible if the index values are not well associated with adverse health risks owing to use of a single driver pollutant.

Incorporating the 2021 WHO global air quality guidelines

Many countries calculate their air quality index based on WHO-recommended pollutant levels *(9)*. In Czechia index values are calculated based on the number of pollutants for which the 3-hour moving average is above or below WHO reference values (Table 5) *(43)*. Since the revised WHO global air quality guidelines were published in 2021, each country that relies on WHO-recommended pollutant levels will now have to decide whether and how to update their air quality index. most countries are likely to make these changes after the revision of EU air quality standards, which is currently being considered. As an example, an official from an EU member state commented:

> The air quality index was developed 10 years ago. The bands were selected according to the limits set out in Directive 2008/50/EC) [(44)] and the health advice was finalized after consultation with health protection institutions. Index values were established according to the limits set out by European Union directives, and more or less correspond to the values used in the EAQI.
>
> The index provides simplified information about air quality to the public, along with general recommendations. It is difficult to provide specific recommendations because each person reacts differently to the levels of air pollution. Recent scientific evidence on the adverse effects of air pollution on human health and the recently published *WHO Global Air Quality Guidelines* indicate that European Union limits are not strict enough to preserve the health of all people in society (9). The European Union is revising its air quality standards to align them more closely with WHO recommendations. Therefore, in the near future the index values will have to become stricter.

Table 5. Index levels used in Czechia

Level	Index range	Air quality
1A	≥ 0.00 and < 0.34	very good to good
1B	≥ 0.34 and < 0.67	
2A	≥ 0.67 and < 1.00	acceptable
2B	≥ 1.00 and < 1.50	
3A	≥ 1.50 and < 2.00	aggravated to bad
3B	≥ 2.00	
	Component is not measured, index not determined	
	Incomplete data	

Source: reference *43*. Reproduced under CC BY NC ND 3.0 CZ licence (https://creativecommons.org/licenses/by-nc-nd/3.0/cz/deed.en).

Critical need to evaluate and validate air quality indexes

Focused research is needed to understand how the public uses air quality indexes, including any special alerts: Important questions to consider include how many people are aware of the index and, for those who are aware of it, whether they consult the index regularly, whether they modify their behaviour in response to information from the index, and what specific actions they take in response to the index values and associated health messages *(45–47)*. Some studies have had unexpected findings, such as increased health-care utilization among a treatment group receiving air quality alerts compared with the control group *(48)*. This was attributed not to worsening health conditions but instead to an increased awareness of the need to see a doctor, in line with guidance provided in the alerts.

Of the limited number of studies that included this type of evaluation *(49)*, a consistent finding was the importance of health-care providers in raising public awareness and interpreting air quality information. Therefore, air quality information materials could be specifically developed for health-care providers (e.g. such efforts are currently under way at WHO *(50)*) so that they, in turn, can better educate their patients. Ireland has already incorporated this type of messaging into its air quality index, which states: "Health professionals can help at-risk patients use the Air Quality Index for Health to increase their own awareness of how sensitive they are to air pollution and to take preventive action when air quality is fair, poor or very poor".

Even the most rigorous processes to develop an air quality index, including efforts made over several years to develop the EAQI *(11)* or the United Kingdom Air Quality Index *(51)*, are incomplete until the index values are validated using local health data (Box 3 shows examples from North America). Decisions about, for example, which health end-points to use to scale the index, which cut-points (if any) to use for each pollutant and whether to account for the combined health risks of multiple pollutants are academic until the index has been evaluated using real-world health data to ensure that it is associated with key health outcomes of interest.

Box 3. Validation of air quality indexes: examples from North America

Air Quality Index values and respiratory morbidity in the United States
Air Quality Index values were shown to be associated with only respiratory morbidity in California (United States) when index values were largely driven by a single pollutant. Index values performed poorly during times of the year and in locations with health-relevant variations in more than one pollutant *(52)*. This finding confirms the findings of a previous study in New York *(35)*.

Air Quality Health Index and AQHI+ in Canada
Since the launch of the Air Quality Health Index in 2004, Health Canada and other researchers have continued to evaluate the effectiveness of index values in representing population-level health risks *(53)*. Recently, the index was modified (AQHI+) for use during the wildland fire season based on studies that showed that index did not fully capture the health risks from elevated $PM_{2.5}$ values caused by wildland fires *(54)*.

Development of a health-based Air Quality Index in Mexico City, Mexico
The social media campaign, *Conoce tu número* (know your number), accompanies the health-based air quality index that was developed for Mexico City *(55)*. This index was developed and validated using local health data and focuses on providing information for individual behaviour modification.

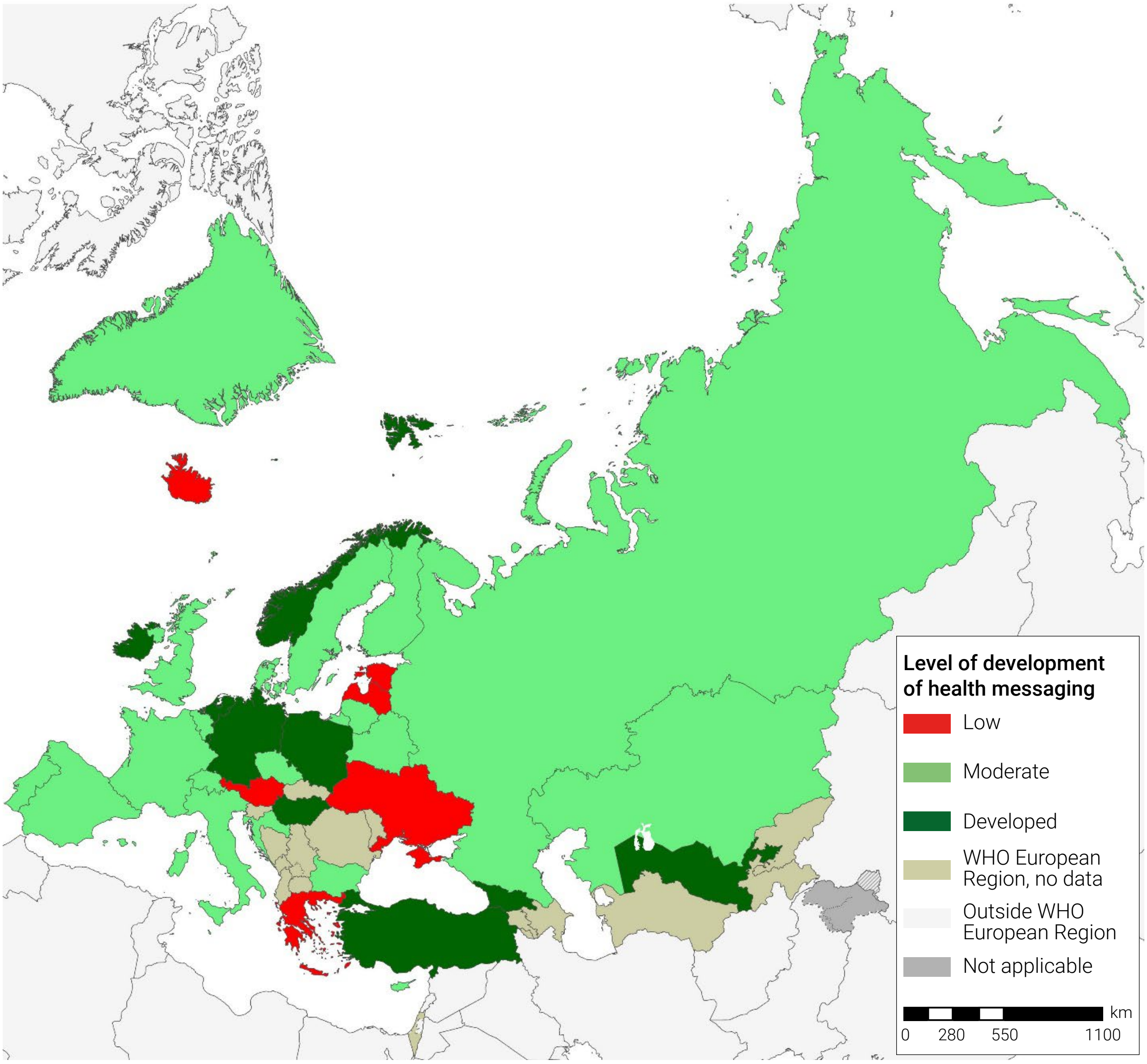
European studies that evaluate air quality indexes are lacking, but North America provides good examples of evaluations of currently used indexes *(52,56,57)*. They show that a positive association between index values and adverse health outcomes is of key importance; however, they also show that the precise magnitude of the association is unimportant and should not be used to compare the potential effectiveness of two different indexes. Importantly, air quality indexes must be evaluated by season owing to changes in ambient pollution mixtures over the course of the year. In general, at times of the year and in locations with relatively simple air quality mixtures (e.g. in which variations in the concentration of only one pollutant are relevant to health), index values will usually be associated with adverse health outcomes. However, when more than one pollutant has health-relevant variations in ambient concentrations, an index based on the single highest pollutant is much less likely to adequately capture the day-to-day changes in health risk.

Lastly, if index values are not associated with adverse health outcomes, then it is important to verify that the underlying pollutants are individually associated with adverse health events. If they are not, then it may be necessary to improve the exposure monitoring of these pollutants before an index can be successfully validated *(58,59)*.

Health messaging

The detail and specification of health messaging that accompanies air quality indexes vary widely in the WHO European Region (Fig. 4). The best examples of health messages combine the following three factors: detailed information of the populations at-risk, information on symptoms that may be experienced, and specific examples of behaviour modification that should be considered to reduce exposures and health risks. Ideally, these messages would be based on empirical evidence obtained through consultation with patients, health experts and clinicians, and not on common sense alone.

Fig. 4. Level of development of health messaging across the WHO European Region[5]



[5] The visualization of the qualitative scoring of health messaging for each country is meant to illustrate the wide range of development levels of health messaging across the Region, with the specific score for any single country being less important.

Germany

The *Umweltbundesamt* (Federal Environment Agency) portal provides measured values and forecasts alongside health tips and recommendations for sensitive groups *(30)*.

Poland

Powietrze.gios provides health advice based on seven index levels *(60)*. The health messages identify sensitive groups and suggests behaviour modifications for each group based on the air quality index level.

Georgian health messaging is a good example of informing sensitive populations (Fig. 5) *(25)*. The country provides recommendations for specific population groups to change their behaviour based on both the index level and the specific pollutant. For example, moderate O_3 levels may trigger a health recommendation for people with asthma, but the same index level for PM or NO_2 may trigger a recommendation for another population group. In Monaco, susceptible people include "people who know they are sensitive to pollution peaks or whose symptoms appear to worsen during pollution peaks" *(61)*.

Fig. 5. Georgian health messaging

INDEX RANGE	GOOD	FAIR	MODERATE	BAD	VERY BAD
LEVELS OF HEALTH CONCERN	GOOD	MODERATE	UNHEALTHY FOR SENSITIVE GROUPS	UNHEALTHY	VERY UNHEALTHY
	Air quality is considered satisfactory, and air pollution poses little or no risk for health.	Air quality is acceptable; however, for some pollutants there may be a moderate health concern for a very small number of people who are unusually sensitive to air pollution.	Members of sensitive groups may experience health effects. The general public is not likely to be affected.	Everyone may begin to experience health effects; members of sensitive groups may experience more serious healt effects.	Health alert: everyone may experince more serious health effects
Recomendations to Protect Your Health					
PM Particles less than 2.5 and 10 µm	None	Unusually sensitive people shold consider reducing prolonged or heavy exertion.	The following groups should reduce prolonged or heavy exertion: • People with hearth or lung disease • Children and older adults.	The following groups should avoid prolonged or heavy exertion: • People with hearth or lung disease • Children and older adults. Everyone else should reduce prolonged or heavy exertion.	The following groups should avoid all physical activity outdoors: • People with hearth or lung disease • Children and older adults. Everyone else should avoid prolonged or heavy exertion.

Source: reference *25*.

Notes: sensitive populations are clearly defined by both the index level and pollutant. Health messaging is shown for PM only; it differs for other pollutants.

Health messaging that describes potential health side-effects can help users to react specifically to elevated levels of ambient air pollution *(62)*. In Luxembourg, warnings specify that as air quality worsens, sensitive populations can experience negative effects on health, including irritation of the nose, eyes or throat; breathlessness; or more frequent or stronger asthma exacerbations *(63)*. In Uzbekistan, the health messaging warns that at certain pollution levels anyone who feels uncomfortable or has eye pain, a sore throat or a cough should take protective action *(64)*.

It is also useful for health messaging to provide more detailed recommendations for potential behaviour modifications beyond limiting outdoor activity. For example, in Norway reducing outdoor activity is recommended not only during periods of elevated air pollution but also in areas that are more likely to have higher air pollution *(65)*. Monaco similarly suggests limiting travel on or near major roads when air pollution is elevated but also recommends avoiding peak periods during the day, for example, avoiding outdoor activity in the early afternoon (e.g. when O_3 is elevated). The Netherlands is one of the few countries in which health messaging specifically recommends consulting your doctor about whether medication levels need to be adjusted *(66)*, and Uzbekistan provides guidance on mask-wearing outdoors when PM levels are very high (i.e. > 0.15 mg/m^3) *(64)*.

In Iceland, health messaging is highly developed but is restricted to SO_2 exposure, which is mainly due to volcanic activity *(32)*. It provides combined recommendations for three groups of sensitive individuals (children, individuals with underlying disease and vulnerable individuals), along with information on likely symptoms and specific guidance on behaviour, including when to turn off ventilation systems. It includes exposure levels at which people should try to only breathe through their nose or stay indoors with closed windows, and even when no outdoor work should be carried out without suitable gas masks and gas meters. This level of detail is probably not appropriate for every ambient pollutant, but is an example of what can be achieved in terms of detailed health messaging.

Georgia provides health risk messages based on index categories and organized by pollutants *(25)*. Sensitive groups are specifically mentioned (e.g. for O_3, people with asthma) and recommendations made for behaviour modification.

Conclusions

Although the underlying principles of risk communication are similar, countries in the WHO European Region vary tremendously how they report air quality risks to the general public. The typical concentrations of ambient air pollution and of relevant pollutants vary too greatly to enable the use of a uniform index and health messaging across the Region.

Risk communication approaches should be flexible enough to account for differences in air pollution mixtures, baseline concentrations, and cultural differences regarding outdoor activities and risk preferences. Country-specific health messaging reflecting the national context and preferences should be continued.

No matter which approach is used to develop an air quality index, there is a critical need to validate air quality indexes using local health data. Without such validation, behaviour modification in response to information reported through an index may not result in the desired reductions in personal exposure or improvements in public health. Although this report focuses on air quality indexes in the WHO European Region, the principles are broadly relevant to air quality indexes in use around the world.

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