Integral Indicators as Tools for Air Quality Assessment

Over 50 years, air pollution and its impact on human health are a concern for the World Health Organization (WHO). A large number of studies have demonstrated relations between air pollution and a variety of health effects. The results of these studies have confirmed that air pollution is a serious threat to public health. By reducing air pollution levels, countries can reduce the burden of disease from stroke, heart disease, lung cancer, and both chronic and acute respiratory diseases, including asthma.

As a consequence, it is vital to notify the public about the levels of air pollution and related health risks so that people can take measures to keep their health [1]. Many countries are working to make information about outdoor air quality as available to the public as information about the weather. A key tool in this effort is the Air Quality Index or AQI. It informs the public of the local level of ambient air pollution, and the potential health risk it would [2].

The AQI made its debut in 1968, when the National Air Pollution Control Administration undertook an initiative to develop an air quality index and to apply the methodology to Metropolitan Statistical Areas. The impetus was to draw public attention to the issue of air pollution and indirectly push responsible local public officials to take action to control sources of pollution and enhance air quality within their jurisdictions. The initial iteration of the air quality index used standardized ambient pollutant concentrations to yield individual pollutant indices. These indices were then weighted and summed to form a single total air quality index. The overall methodology could use concentrations that are taken from ambient monitoring data or are predicted by means of a diffusion model. The concentrations were then converted into a standard statistical distribution with a preset mean and standard deviation [3].

The first air quality index was introduced by the United States Environmental Protection Agency (EPA) started to use an AQI in 1976 (the original name was Pollutant Standard Index – PSI) for use by States and local agencies on a voluntary basis. The aim was to create certain homogeneity among the 14 different indices used by more than 50 urban areas in USA and Canada at that time [2]. The Clean Air Act (the law that defines EPA's responsibilities for protecting and improving the nation’s air quality), which was last amended in 1990, requires EPA to set National Ambient Air Quality Standards (NAAQS) for widespread pollutants from numerous and diverse sources considered harmful to public health and environment. The Clean Air Act established two types of national air quality standards, Primary standards set limits to protect public health, including the health of «sensitive» populations such as asthmatics, children and elderly. Secondary standards set limits to protect public welfare, including protection against visibility impairment, damage to animals, crops, vegetation and buildings. The Clean Air Act requires periodic reviews of the science upon which the standards are based and the standards themselves. EPA AQI is

---

**Keywords:** Air, integral indicator, AQI, PM\(_{10}\), PM\(_{2.5}\).
The objective of this work was to analyze the integral indicators of the air quality assessment and approaches to the definition of the AQI for example PM$_{10}$, PM$_{2.5}$.

Materials and methods. The levels of the Air Quality Index are determined based on 24-hour concentrations of PM$_{10}$ and PM$_{2.5}$, using methods recommended by the United States Environmental Protection Agency and the European Environment Agency of the European Union. The study used concentrations PM$_{10}$ and PM$_{2.5}$, which were received during 10.2017-11.2018 at the fixed monitoring station, located at the address: 50, Popudrenko str., Kyiv.

Results. There is no unified indicator for air quality assessment, but in most countries the use of the Air Quality Index is a priority. AQI is a tool for informing the public about the quality of atmospheric air and the associated risks to the health of the population. The AQI levels for a specific pollutant, including PM$_{10}$ and PM$_{2.5}$, may vary significantly depending on the indexing approach used. This is due to the variability in the pollutants’ concentration ranges that correspond to a respective category of the index.

Keywords: air, integral indicator, AQI, PM$_{10}$, PM$_{2.5}$.
quality in European cities in real-time. At the same time the CAQI received an update. Since the CAQI was launched the air quality directives have been revised and a limit value for PM$_{2.5}$ was added in the new, so called, Directive 2008/50/EC [8]. PM$_{2.5}$ is a health relevant and regulated parameter so it had to be included in the CAQI calculation [9].

The CAQI is defined in both hourly and daily versions, and separately near roads (a «roadside» or «traffic» index) or away from roads (a «background» index). As of 2012, the CAQI had two mandatory components for the roadside index, NO$_2$ and PM$_{10}$, and three mandatory components for the background index, NO$_2$, PM$_{10}$ and O$_3$. It also included optional pollutants PM$_{2.5}$, CO and SO$_2$. A «sub-index» is calculated for each of the mandatory (and optional if available) components. The CAQI is defined as the sub-index that represents the worst quality among those components [2, 9]. The CAQI has a scale from 1 to 100 with lower rankings representing better air quality. Some of the higher class borders are linked to concentrations mentioned in the EU air quality directives (Directive 2008/50/EC) [8]. The large range of the scale assures changes, even at the lower end of the scale. Three different indices have been developed to enable the comparison of three different time scales: an hourly index; a daily index; an annual index.

In 2016, Ricardo Energy and the Environment prepared a final report for the Directorate-General for Environment prepared a final report for the Directorate-General for Environment (DG ENV) and presented the developed prototype AQI (EU-AQI). It harmonises existing Air Quality Indices for key air pollutants. Twenty air quality indices were identified, reviewed and assessed, plus the existing CAQI for Europe during the development of the AQI prototype. The review included 14 indices used in EU Member States, and seven from non-EU countries. The indices selected covered a mixture of region types: some were specific to a Member State or other country while others were specific to a region, state or city [10].

The main target group for an AQI is identified as ordinary citizens who are concerned about air pollution and its possible effects on their health. An EU AQI must be easy to use, clear, and based on well-informed health advice, based in turn on robust data. The four major pollutants to be included are: NO$_2$, ozone O$_3$, particulate matter as PM$_{10}$ and as PM$_{2.5}$, SO$_2$ is to be included as an optional pollutant where it is monitored and relevant. The AQI prototype database is populated using automated data flows for UTD measurement data and MACC AQ forecast data. In the prototype system every monitoring location has to present values for each of the four critical pollutants. Where values are missing because the pollutant is not measured or the equipment is off-line then the missing data are populated from the modelled (forecast) MACC data. This enables the most complete and up-to-date geographical picture of European AQI to be presented to the public end users of the system. In November 2017, the European Environment Agency announced the EU-AQI and started encouraging its use on websites and for other ways of informing the public about air quality. EU-AQI meant to complement existing national air quality indices, not replace them.

The air pollution index (API) is used to assess and analyze the atmospheric air pollution in Ukraine. API is used for comparison of the four main air pollutants: PM$_{10}$, PM$_{2.5}$, CO and SO$_2$. The API is calculated for each of the four pollutants for 24-hour and 1-hour periods. The API categories are eight: Excellent, Good, Moderate, Unhealthy for Sensitive Groups, Unhealthy, Hazardous, Very Unhealthy, Very Hazardous. The API categories are based on the limit values for each of the four pollutants: PM$_{10}$, PM$_{2.5}$, CO and SO$_2$. The API categories are defined as follows:

- Excellent: API ≤ 50
- Good: 51 ≤ API ≤ 100
- Moderate: 101 ≤ API ≤ 150
- Unhealthy for Sensitive Groups: 151 ≤ API ≤ 200
- Unhealthy: 201 ≤ API ≤ 300
- Hazardous: 301 ≤ API ≤ 400
- Very Unhealthy: 401 ≤ API ≤ 500
- Very Hazardous: API > 500

The API is used to assess and analyze the atmospheric air pollution in Ukraine. The API is used for comparison of the four main air pollutants: PM$_{10}$, PM$_{2.5}$, CO and SO$_2$. The API is calculated for each of the four pollutants for 24-hour and 1-hour periods. The API categories are eight: Excellent, Good, Moderate, Unhealthy for Sensitive Groups, Unhealthy, Hazardous, Very Unhealthy, Very Hazardous. The API categories are defined as follows:

- Excellent: API ≤ 50
- Good: 51 ≤ API ≤ 100
- Moderate: 101 ≤ API ≤ 150
- Unhealthy for Sensitive Groups: 151 ≤ API ≤ 200
- Unhealthy: 201 ≤ API ≤ 300
- Hazardous: 301 ≤ API ≤ 400
- Very Unhealthy: 401 ≤ API ≤ 500
- Very Hazardous: API > 500

The API categories are defined as follows:

- Excellent: API ≤ 50
- Good: 51 ≤ API ≤ 100
- Moderate: 101 ≤ API ≤ 150
- Unhealthy for Sensitive Groups: 151 ≤ API ≤ 200
- Unhealthy: 201 ≤ API ≤ 300
- Hazardous: 301 ≤ API ≤ 400
- Very Unhealthy: 401 ≤ API ≤ 500
- Very Hazardous: API > 500

The main target group for an AQI is identified as ordinary citizens who are concerned about air pollution and its possible effects on their health. An EU AQI must be easy to use, clear, and based on well-informed health advice, based in turn on robust data. The four major pollutants to be included are: NO$_2$, ozone O$_3$, particulate matter as PM$_{10}$ and as PM$_{2.5}$, SO$_2$ is to be included as an optional pollutant where it is monitored and relevant. The AQI prototype database is populated using automated data flows for UTD measurement data and MACC AQ forecast data. In the prototype system every monitoring location has to present values for each of the four critical pollutants. Where values are missing because the pollutant is not measured or the equipment is off-line then the missing data are populated from the modelled (forecast) MACC data. This enables the most complete and up-to-date geographical picture of European AQI to be presented to the public end users of the system. In November 2017, the European Environment Agency announced the EU-AQI and started encouraging its use on websites and for other ways of informing the public about air quality. EU-AQI meant to complement existing national air quality indices, not replace them.
evaluate pollution of certain areas, cities with the establishment of their priority on the level of pollution and trends of pollution. This indicator is relative and its value depends on the concentration of the substance in the analyzed point, the maximum permissible concentration (MPC) and the amount of substances that pollute the atmosphere. API calculation is based on the principle that the MPC at all harmful substances are characterized by the same effect on humans, and with further increase of concentration the degree of their harmfulness increases with different speed, depending on the hazard class of the substance. Considered that when API <1 air quality by separate pollutant meets sanitary and hygienic requirements [11].

Air Quality Index is not used as an official indicator of air quality in Ukraine. The most significant issues preventing scientists from development of the AQI in our country are: lack of continuous monitoring data on atmospheric air pollution with 1-hour or daily averaging periods; uneven distribution of monitoring sites; no monitoring for PM10 and PM2.5, as well as, absence of the official national guidelines for assessing safety of these pollutants; poor access to the most recent monitoring data.

The exposure to PM can have a detrimental health effect. Particle pollution is linked to a number of health problems, including coughing, wheezing, reduced lung function, asthma attacks, heart attacks and strokes. The exposure to PM is suspected of harming pregnant women and unborn children. PM can cause oxidative stress, leading to inflammation. Other effects of pregnancy include endocrine disruption and impaired oxygen transport to the placenta, leading to a lower birth weight, congenital disabilities (birth defects), premature delivery, or even premature death. There is a close, quantitative relationship between exposure to high concentrations of PM10 and PM2.5 and increased mortality or morbidity, both daily and over time. Conversely, when concentrations of small and fine particulates are reduced, related mortality will also go down [1]. According to the WHO ambient air pollution in both cities and rural areas was estimated to cause 4.2 million premature deaths worldwide per year in 2016. This mortality is due to exposure to PM2.5, which cause cardiovascular and respiratory disease, and cancers.

The objective of this work was to analyze the integral indicators of the air quality assessment and approaches to the definition of the AQI for example PM10, PM2.5.

Materials and methods. To calculate the AQI index we used the concentration data from the stationary monitoring station of PM10 and PM2.5 (based at the SI «O.M. Marziev Institute for public health» NAMSU) located in Kyiv, Popudrenko 50 str. Sampling location meets the requirement of representativeness of the measurement point(s): monitoring station is located far from the local sources of pollution (including the close proximity to carriageway) and in the place without aerodynamic perturbation, which may be present in the near-wall region, etc. Instrumental measurements of the concentration levels of PM2.5 and PM10 in ambient air were done using the APDA-371 (HORIBA) analyzer which automatically measures airborne particulate concentration levels (in milligrams or micrograms per cubic meter), using the industry-proven principle of beta ray attenuation. Each hour, a small carbon-14 element emits a constant source of high-energy electrons (known as beta rays) through a spot of clean filter tape. These beta rays are detected and counted by a sensitive scintillation detector to determine a zero reading. Then APDA-371 automatically advances this spot of tape to the sample nozzle, where a vacuum pump then pulls a measured and controlled amount of dust-loaded air (standard – 16.7 l/min) through the filter tape. Hourly this dirty spot is placed back between the data source and the detector thereby causing an attenuation of the beta ray signal which is used to determine the mass of the particulate matter on the filter tape. Standard measurement range of APDA-371 is 0-1,000 mg/m3 (0-1000 µg/m3). Measurement was conducted at the height of 2 m from the horizontal roof surface of the monitoring station using the vertical sampler with the protection of atmospheric aerosol. Stationary monitoring station provides the automatic continuous measurement of PM10 and PM2.5 concentration during 24-hour [12].

Duration of the measurements is one year from November 1, 2017 till October 31, 2018. The statistical processing of the results was analyzed using STATISTICS software. We computed AQI based on daily levels of PM10 and PM2.5 and we used the AQI tool provided by the Environmental Protection Agency and the European Environment Agency of the European Union [4, 9].

Results. The health risk associated with various levels of ambient PM10 and PM2.5 was categorized as per the specifications of US EPA and Europe (tables 1, 2). A total of 335 daily PM10 and 332 daily PM2.5 were collected over a period of November 1-st 2017 through October 31-st 2018. Based on figure 1 (a), in terms of PM10, US EPA AQI was less than standard limit (AQI<100) in 100% of cases of which 16% and 84% were in good and moderate quality. The US EPA AQI for PM2.5 there were 16% days of good air quality, 73% days of moderate air quality,
9% days of unhealthy air quality for sensitive groups, 3% days of unhealthy air quality during the entire study period (figure 1b).

EU-AQI was less than standard limit (AQI<50) in 78.5% of cases in terms of PM$_{10}$, of which 22% and 39% were in very good and good quality, 17.5% was in moderate quality. In addition, in 21.5% of cases, the concentration of PM$_{10}$ was higher than standard limit EU-AQI and which 20% and 1.5% of cases were in bad and very bad quality. Figure 2c. Meanwhile, based on figure 2 d, in terms of PM$_{2.5}$, EU-AQI was less than standard limit in 71%, of cases of which 11.5% and 46% were in very good and good quality, 13.5% was in moderate quality. In 26% and 3% of cases EU-AQI for PM$_{2.5}$ were in bad and very bad quality.

The findings of the study reveal a significant difference between the AQIs that were calculated using two different approaches proposed by the US EPA and EEA. This is explained by the fact that the AQI categories are developed taking into account different air quality standards and levels of their accidences. In most of the cases, the integral indicator is determined based on the level of air pollution formed by the substance that is responsible for the highest accidences of the air quality standards.

Air quality in the United States of America must comply with the National Ambient Air Quality Standards (NAAQS) established by the EPA [13]. European Union countries are guided by the limit values of pollutants as set out in Directive 2008/50/EC «On ambient air quality and cleaner air for Europe» [8]. It should be noted, that setting the limits of the AQI category for PM$_{10}$ and PM$_{2.5}$, European Union also consider concentrations limit recommended by WHO. As shown in table 3 EEA and WHO sets tougher standards for PM$_{10}$ and PM$_{2.5}$ than EPA [1, 8, 13].

Conclusions. There is no unified integrated indicator for air quality assessment, but in most countries the use of the Air Quality Index is a priority. AQI is a tool for informing the public about the quality of atmospheric air and the associated risks to the health of the population. The AQI levels for a specific pollutant, including PM$_{10}$ and PM$_{2.5}$, may vary significantly depending on the indexing approach used. This is due to the variability in the pollutants’ concentration ranges that correspond to a respective category of the index.