UDC 614.71 https://doi.org/10.32402/dovkil2019.01.051

ІНТЕГРАЛЬНІ ПОКАЗНИКИ ЯК ІНСТРУМЕНТИ ОЦІНКИ ЯКОСТІ АТМОСФЕРНОГО ПОВІТРЯ

Турос О.І., Маремуха Т.П., Петросян А.А., Міхіна Л.І., Моргульова В.В.

INTEGRAL INDICATORS AS TOOLS FOR AIR QUALITY ASSESSMENT

TUROS O., MAREMUKHA T., PETROSIAN A., MYKHINA L., MORHULOVA V.
State Institution «O.M. Marzeiev Institute for Public Health, NAMSU», Kyiv

Keywords: air, integral indicator, AQI, PM_{10}, $PM_{2.5}$.

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 verity 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 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

ІНТЕГРАЛЬНІ ПОКАЗНИКИ ЯК ІНСТРУМЕНТИ ОЦІНКИ ЯКОСТІ АТМОСФЕРНОГО ПОВІТРЯ
Турос О.І., Маремуха Т.П., Петросян А.А., Михіна Л.І., Моргульова В.В.
ДУ «Інститут громадського здоров'я ім. О.М. Марзєєва НАМН України», м. Київ

***Мета роботи** – проаналізувати інтегральні показники оцінки якості атмосферного повітря та підходи до визначення індексу якості повітря на прикладі PM_{10} та $PM_{2.5}$.*
***Матеріали та методи**. Визначено рівні Індексу якості повітря на основі 24-годинних концентрацій PM_{10} та $PM_{2.5}$ з застосуванням методик, рекомендованих Управлінням з охорони довкілля США та Європейською Агенцією Довкілля ЄС.*
Для дослідження використовувалися концентрації PM_{10} та $PM_{2.5}$, що були отримані протягом 10.2017-11.2018 року на стаціонарному пункті моніторингу, який розміщений за адресою: м. Київ, вул. Попудренка, 50.
***Результати**. Виявлено, що не існує уніфікованого інтегрального показника для оцінки якості повітря, але у більшості країн світу пріоритетним є використання Індексу якості повітря (AQI). Було показано, що AQI є інструментом для інформування громадськості щодо якості атмосферного повітря та пов'язаного з цим ризиком для здоров'я населення.*
Встановлено, що рівні AQI за окремим показником, у тому числі PM_{10} та $PM_{2.5}$, можуть суттєво відрізнятися залежно від використаного підходу визначення індексу у зв'язку з варіабельністю діапазонів концентрацій забруднюючих речовин, що відповідають певній категорії індексу.

Ключові слова: атмосферне повітря, інтегральний показник, AQI, PM_{10}, $PM_{2.5}$.

INTEGRAL INDICATORS AS TOOLS FOR AIR QUALITY ASSESSMENT

Turos O., Maremukha T., Petrosian A., Mykhina L., Morhulova V.
State Institution «O.M. Marzieiev Institute for Public Health, NAMSU», Kyiv

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 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.

Keywords: air, integral indicator, AQI, PM_{10}, $PM_{2,5}$.

an index for reporting daily air quality. It tells how clean or polluted air is, and what associated health effects might be a concern for you. The AQI focuses on health effects you may experience within a few hours or days after breathing polluted air. EPA has set NAAQS for five main common pollutants: carbon monoxide (CO), nitrogen dioxide (NO_2), ozone (O_3), particulate matter (PM_{10} and $PM_{2,5}$) and sulphur dioxide (SO_2). Six categories corresponding to different level of health concerns (and symbolized by different colors) are considered [4, 7].

Canadian government, through the Meteorological Service of Environment Canada, provides an AQI computed in the same way as EPA's one, but considering 4 categories only. Recently, a new Air Quality Health Index (AQHI) has been added to AQI. When developing the AQHI, Health Canada's original analysis of health effects included five major air pollutants: PM_{10} and $PM_{2,5}$, O_2 and NO_2, as well SO_2 and CO. The latter two pollutants provided little information in predicting health effects and were removed from the AQHI formulation. The AQHI is based on the relative risks of a combination of common air pollutants and is measured on a scale ranging from 1 to 10. The AQHI values are also grouped into 4 health risk categories helping to easily and quickly identify the actual level of risk as Low Health Risk (1-3), Moderate Health Risk (4-6), High Health Risk (7-10), or Very High Health Risk (10+) [5].

In a review of the UK Air Quality Index, Committee on the Medical Effects of Air Pollutants (COMEAP) developed and recommended a Daily Air Quality Index (DAQI) for the purpose of providing short-term health advise to the public regarding the air quality around them and possible recommendations such people can take. Following the recommendations from COMEAP, the Department for Environment, Food and Rural Affairs (Defra) together with responsible administrations implemented this index from January 2012. This Index was later updated with minor changes through Defra's update on the implementation of DAQI in April 2013 to conform with the EU limit values of pollutant concentrations. The update also emphasised that data rounding off should always be performed at the end of calculations before communicating results to avoid errors [2]. DAQI is defined on a scale of 1 to 10 with colour coding and categorised into four bands of Low (1-3), Moderate (4-6), High (7-9) and Very High (10). COMEAP report recommended the removal of CO from the AQI and the inclusion of $PM_{2.5}$. Currently the DAQI uses the pollutants of O_3, NO_2, SO_2, $PM_{2.5}$ and PM_{10} in calculation of the index. The Automatic Urban and Rural Network (AURN) measures these pollutant concentrations in near real-time and their values used in calculation of the index. The overall index is given by the highest pollutant concentration of the considered pollutants. To allow prediction of elevated air pollution episodes in real-time, DAQI uses trigger values to predict concentrations of pollutants [6].

The ATMO Index is the air quality index used in major cities in France that have a population of more than 100,000 inhabitants. The index is represented by a giraffe and is based on a scale of 1 to 10 ranging from very good to very bad and with three coloured bands of Green (1-4), Orange (5-7) and Red (8-10). ATMO Index considers the pollutants of SO_2, NO_2, O_3, $PM_{2.5}$ and PM_{10}. Sub-indices are calculated for the four pollutant concentrations and the final aggregated index is the highest sub index calculated from the pollutant concentrations. Each pollutant has defined limit values for the scale ranges upon which pollutant concentrations are compared to determine the pollutant sub index [7].

At European level, the last air quality directives came into force in June 2008 and will be transposed into national legislation by June 2010 (Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe). This directive lays down measures aiming at, among others, «assessing the ambient air quality in Member States on the basis of common methods and criteria». Actually this directive has not been applied yet, and each country follows (when it is done) its own method. The European Environment Agency (EEA) is the agency of the European Union (EU), that came into force in late 1993, whose task is to provide sound, independent information on the environment; it represents a major information source for who is involved in developing, adopting, implementing and evaluating environmental policies, and also for the general public [8].

The Common Air Quality Index (CAQI) is an air quality index used in Europe. It was developed in the course of the CITEAIR project [9] and has been around since 2006. The index was made for the purpose of easily comparing the air

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 scale: an hourly index; a daily index; an annual index.

In 2016, Ricardo Energy and the Environment prepared a final report for the Directorate-General The European Commission 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 compara-

Table 1

Pollutants and category grid for US EPA AQI

Index Values	AQI Categories	Particulate Matter (µg/m^3)	
		PM_{10} (24-hour)	$PM_{2.5}$ (24-hour)
Up to 50	Good	0-54	0-12.0
51-100	Moderate	55-154	12.1-35.4
101-150	Unhealthy for sensitive groups	155-254	35.5-55.4
151-200	Unhealthy	255-354	55.5-150.4
201-300	Very unhealthy	355-424	150.5-250.4
301-500	Hazardous	425-604	250.5-500.4

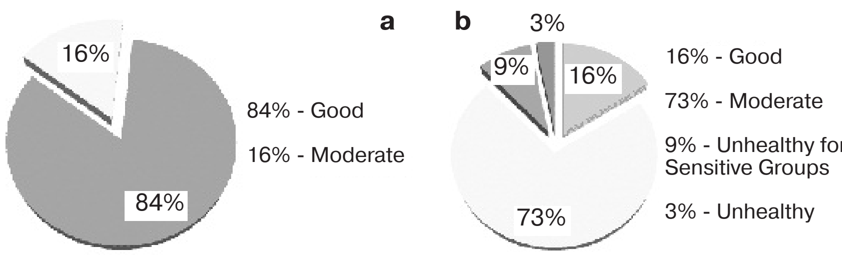
Table 2

Pollutants and category grid for EU AQI

AQI Categories	Particulate Matter (µg/m^3)	
	PM_{10} (24-hour)	$PM_{2.5}$ (24-hour)
Very Good	0-20	0–10
Good	21-35	11-20
Moderate	36-50	21-25
Bad	51-100	25-50
Very Bad	>100	>50

Figure 1

US EPA AQI categories for concentration PM_{10} (a) and $PM_{2.5}$ (b) during the study period



tive evaluation 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 PM_{10} and $PM_{2.5}$, 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 on 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 PM_{10} and $PM_{2.5}$ 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 $PM_{2.5}$, which cause cardiovascular and respiratory disease, and cancers.

The objective of this work was 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. To calculate the AQI index we used the concentration data from the stationary monitoring station of PM_{10} and $PM_{2.5}$ (based at the SI «O.M. Marzeiev 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 $PM_{2.5}$ i PM_{10} 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 beta 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/m^3 (0-1000 $\mu g/m^3$). 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 from atmospheric precipitations. Stationary monitoring station provide the automatic continuous measurement of PM_{10} and $PM_{2.5}$ 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 PM_{10} and $PM_{2.5}$ 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 PM_{10} and $PM_{2.5}$ was categorized as per the specifications of US EPA and Europe (tables 1, 2).

A total of 335 daily PM_{10} and 332 daily $PM_{2.5}$ were collected over a period of November 1-st 2017 through October 31-st 2018.

Based on figure 1 (a), in terms of PM_{10}, 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 $PM_{2.5}$ there were 16% days of good air quality, 73% days of moderate air quality,

Figure 2

EU-AQI categories for concentration PM_{10} (c) and $PM_{2.5}$ (d) during the study period

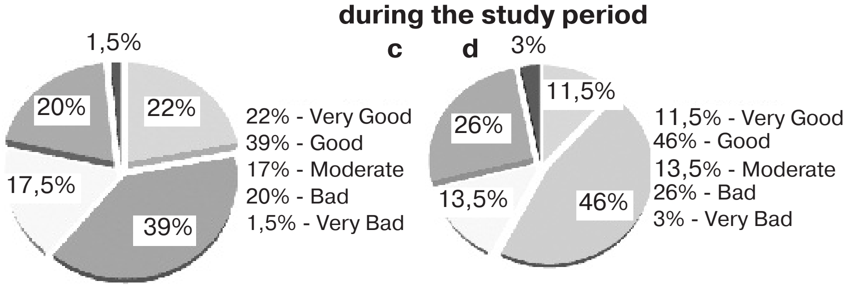


Table 3

Comparison of PM_{10} and $PM_{2.5}$ limits set by WHO, EEA, EPA

Pollutant	Averaging period	WHO limits	EEA(EU) limits	EPA(US) limits
PM_{10}	24-hour	50 $\mu g/m^3$	50 $\mu g/m^3$	150 $\mu g/m^3$
	annual	20 $\mu g/m^3$	40 $\mu g/m^3$	-
$PM_{2.5}$	24-hour	25 $\mu g/m^3$	-	35 $\mu g/m^3$
	annual	10 $\mu g/m^3$	25 $\mu g/m^3$	15 $\mu g/m^3$

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, of 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 EU. This is explained by the fact that the AQI categories are developed taking into account existing 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 when 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.

ЛІТЕРАТУРА

1. Health risks of air pollution in Europe – HRAPIE : technical report. Copenhagen : WHO Regional Office for Europe, 2014. 65 p.
2. Kanchan, Amit Kumar Gorai, Pramila Goya. A Review on Air Quality Indexing System. *Asian Journal of Atmospheric Environment.* 2015. Vol. 9 (2). P. 101-113.
3. Fensterstock J.C., Goodman K., Duggan G.M. et al. The Development and Utilization of an Air Quality Index. 62-nd Annual Meeting of the Air Pollution Control Association. 1969. Paper № 69-73.
4. US EPA.Technical Assistance Document for the Reporting of Daily Air Quality – the Air Quality Index (AQI). 2012. 26 p.
5. About the Air Quality Health Index. URL : *https://www.canada.ca/en/environment-climate-change/services/air-quality-health-index/about.html*
6. Ayres J.G., Holgate S. Review of the UK Air Quality Index. A report by the Committee on the Medical Effects of Air Pollutants. 2011. URL : *https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/304633/COMEAP_review_of_the_uk_air_quality_index.pdf.*
7. Air quality index review in some European and USA. 2005. URL : *https://www.uwe.ac.uk/integaire/database-new/view_example_id_552.html*
8. Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on Ambient Air Quality and Cleaner Air for Europe. *Official Journal of the European Union.* 2008. Vol. 51. L 152.P. 1-44.
9. CITE AIR II. CAQI Air Quality Index. Comparing Urban Air Quality Across Borders-2012 / European Regional Development Fund. 2012. 38 p.
10. Services to Develop an EU Air Quality Index. EU AQI Final Report / Ricardo Energy and Environment. United Kingdom, 2016. 25 p.
11. Какарека С.В. Оценка суммарного загрязнения атмосферного воздуха. *География и природные ресурсы.* 2012. № 2. С. 14-20. URL : *http://www.izdatgeo.ru/pdf/gipr/2012-2/14.pdf*
12. Турос О.І., Маремуха Т.П., Петросян А.А., Брезіцька Н.В. Дослідження забруднення атмосферного повітря зваженими частками пилу [PM_{10} та $PM_{2.5}$] у м. Києві. *Довкілля та здоров'я.* 2018. № 4. С. 36-39.
13. US EPA. Criteria Air Pollutants. URL : *https://www.epa.gov/criteria-air-pollutants/naaqs-table*

REFERENCES

1. Health Risks of Air Pollution in Europe – HRAPIE : Technical Report. Copenhagen : WHO Regional Office for Europe; 2014 : 65 p.
2. Kanchan, Amit Kumar Gorai and Pramila Goya. *Asian Journal of Atmospheric Environment.* 2015 ; 9 (2) : 101-113.
3. Fensterstock J.C., Goodman K., Duggan G.M. et al. The Development and Utilization of an Air Quality Index. 62-nd Annual Meeting of the Air Pollution Control Association. 1969 ; Paper № 69-73.
4. US EPA.Technical Assistance Document for the Reporting of Daily Air Quality – the Air Quality Index (AQI). 2012 : 26 p.
5. About the Air Quality Health Index. URL : *https://www.canada.ca/en/environment-climate-change/services/air-quality-health-index/about.html*
6. Ayres J.G. and Holgate S. Review of the UK Air Quality Index. A Report by the Committee on the Medical Effects of Air Pollutants. 2011. URL : *https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/304633/COMEAP_review_of_the_uk_air_quality_index.pdf.*
7. Air Quality Index Review in Some European and USA. 2005. URL : *https://www.uwe.ac.uk/integaire/database-new/view_example_id_552.html*
8. Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on Ambient Air Quality and Cleaner Air for Europe. *Official Journal of the European Union.* 2008 ; 51; L 152 : 1-44.
9. CITE AIR II. CAQI Air Quality Index. Comparing Urban Air Quality Across Borders-2012 / European Regional Development Fund. 2012 : 38 p.
10. Services to Develop an EU Air Quality Index. EU AQI Final Report / Ricardo Energy and Environment. United Kingdom ; 2016 : 25 p.
11. Kakareka S.V. Geografiia i prirodnye resursy. 2012 ; 2 : 14-20. URL : *http://www.izdatgeo.ru/pdf/gipr/2012-2/14.pdf* (in Russian).
12. Turos O.I., Maremukha T.P., Petrosian A.A. and Brezitska N.V. Dovkillia ta zdorovia (*Environment and Health*). 2018 ; 4 (89) : 36-39 (in Ukrainian).
13. US EPA. Criteria Air Pollutants. URL : *https://www.epa.gov/criteria-air-pollutants/naaqs-table*

Надійшла до редакції 21.11.2018