AIR QUALITY INDEX (AQI) – COMPARATIVE STUDY AND ASSESSMENT OF AN APPROPRIATE MODEL FOR B&H

Samir Lemeš
University of Zenica, Polytechnic Faculty
Fakultetska 1, 72000 Zenica
Bosnia and Herzegovina

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ABSTRACT
The regulations on air quality in Bosnia and Herzegovina are based on European Union regulations and they rely on defined limits for concentrations of certain pollutants. Although the law stipulates that the public must be informed on the quality of environmental parameters in a clear, simple and easily understandable manner, this is not the case in practice. In many countries, the Air Quality Index (AQI) is used to inform the public about air quality, or the degree of pollution, which is calculated in different ways. This paper provides an overview of several AQI models used in various countries, as well as a suggestion for the most appropriate AQI to be used in Bosnia and Herzegovina.

1. INTRODUCTION
The latest, 3rd version of the International Vocabulary of Metrology (VIM) [1], defines "measurand" as the "quantity intended to be measured". In the second edition of the VIM and in the standard IEC 60050-300:2001, a measurand used to be defined as the "particular quantity subject to measurement". This change shifted the measurement theory towards more practical use. Instead of focusing on theoretical background, the measurement techniques are now focused on the intention, the real purpose of any measurement.
The reporting of the air quality measurement results uses two approaches: a) official measurements which are precise, well-defined, deeply regulated, butt too complicated to all but air-quality experts, and b) popular, which is less precise, but much more understandable by general public. It is obvious that official approach defines the air quality as a measurand from the 2nd version of VIM, while popular definition of air quality as a measurand needs to be redefined according to the new definition. The intention to measure the air quality means to provide the information which is easy to understand and to be used for particular actions. The Air Quality Index (AQI) could be the solution, but AQI scales differ from country to country because the air quality standards differ and organizations choose varying levels of categories, which presents an obstacle for comparison, and diminishes its usability. However, the quality of measurement data, which is questionable in Bosnia and Herzegovina, is out of scope of this paper, and it is a completely different issue.

Figure 1. How to inform the public on air quality? What is the meaning of displayed numbers?

The regulations on air quality in Bosnia and Herzegovina are based on European Union regulations, i.e. defined limits for concentrations of certain pollutants. Even the reactions to increased pollution rely only on specific pollutants – the alert/alarm episodes can be declared only when SO_2 hourly averages exceed the threshold of 500 μg/m^3 during 3 consecutive hours, measured on 3 different locations, when weather conditions are stable. Extremely high concentrations of PM10, PM2.5 or benzene are not used for any intervention measures, even though they occur very often in Zenica, Sarajevo, Tuzla, Lukavac or other heavily polluted Bosnian cities. Due to lack of the official data on air quality in the country, a number of civil society initiatives were introduced, which vary in approach and data quality, and often disinform or confuse the public. There is no official AQI adopted at the national level, and the intention of this paper is to recommend the most appropriate AQI model to be used and regulated in Bosnia and Herzegovina.

2. DIFFERENT APPROACHES TO AIR QUALITY INDEX

A Guidebook on Communication with the Public about Air Quality [2] states: "Air quality indices are meant to translate individual concentration measurements of a complex mixture of pollutants into a single figure indicating the relative quality of the ambient air. This can be done in numerous ways and many different indices exist. An index, is often thought of as a communication tool: "an essential simplification of complex information". AQI is pragmatically based on calculating sub-indices for each pollutant and the worst sub-index determines the overall AQI. The sub-indices are defined according to health-based recommendations, and may be short-term or long-term, depending on health impact of particular pollutants. Some air pollutants present health hazard even after short-time exposure, and some are hazardous only after long-term exposure. However, the main purpose is to perform action, either on polluter side (reducing emissions), or population side (avoiding exposure, particularly at sensitive groups), therefore the measurand in this case is not only the concentration of pollutants in the air, but also the health hazard level or response action needed.

Plaia and Ruggieri in [3] reviewed and compared a number of different air quality indices used worldwide, through a literature review spanning the period 1999-2009. They compared indices from USA; Canada, United Kingdom, France, Germany, Belgium and Italy. They concluded that differences among the indices are found in the number of index classes (and their associated colors) and related descriptive terms, in the pollutants considered, in class bounds, in averaging times, and in update frequency [3].

Similar research was performed by Wong et al. in [4], in order to develop the most appropriate air quality reporting system for Hong Kong. They have shown that Asian countries, such as Singapore, China, Thailand, Malaysia, South Korea, Taiwan, Hong Kong, use the US model, where pollutant concentrations are transformed onto a normalized numerical scale of 0 to 500, with an index value of 100 corresponding to the primary National Ambient Air Quality Standard (NAAQS) for each pollutant [4]. The AQI values of 100 in the US are set to the level of the short-term (< 24 hour) NAAQS. Where a long-term (e.g., annual) NAAQS has been established, the standard level is used as the AQI value of 50 (e.g., PM2.5). In the US, the NAAQS are defined by 4 elements: the indicator (what is measured in the air e.g., ozone or PM2.5); the averaging time (varies from 1-hour to annual); level and form (e.g., annual mean across 3 years or 98^{th} percentile). The protection provided by the standard combines these 4 elements. The authors in [4] also mentioned that some European countries and South Africa use dynamic indices, combining short-term and long-term exposure health hazards. Finally, they tested one of two Canadian indexing models and showed that there is a significant correlation between index values and hospital admissions for cardiovascular and respiratory diseases that are attributable to air pollution. The Canadian AQHI (Air Quality Health Index) model uses daily maximum of the 3-hour moving average in the construction of the statistical model, as a compromise between timeliness (using real-time data) and the delayed, cumulative effects of continuous exposure to air pollution [4]. AQHI uses the exposure-response relationship between air pollution and health from a time-series study of 12 major cities in Canada. Under an assumption of additive health effects of PM2.5, NO_2, and O_3, the AQHI iscalculated as the sum of excess mortality risk associated with the three pollutants, adjusted to a 1 to 10+ scale, which is subdivided into four categories [5].

European Common Air Quality Index (CAQI) was initially introduced in 2005, which lead Elshout, Leger and Heichto analyze in [6] how to incorporate PM2.5 data in AQI calculation. They discussed the average PM2.5/PM10 ratio because availability of data varies: some measure PM10, while some measure PM2.5 concentrations. WHO recommends that PM2.5/PM10 ratio is 0.5, UK uses ratio 0.7, and CAQI widely used in Europe uses ratio 0.6. However, in recent measurements performed in Bosnia and Herzegovina, more precisely by the mobile measuring station in Zenica in 2011, this ratio was between 0.9 and 1.0, which means that there were almost no differences between mass concentrations of PM10 and PM2.5 in winter period, or more than 90% of PM10 were particles smaller than 2.5 micrometers [21].

Another thorough review and comparison of 14 different indices, used worldwide or proposed for use by scientists, was performed in [7]. This research also suggested a set of eight criteria for an "ideal" index. The major differences between indices were found in the aggregation function, type and number of pollutants, number of index classes and related descriptive terms. All issues observed lead to conclusion that there is no an "ideal" index and that further research and action is needed.

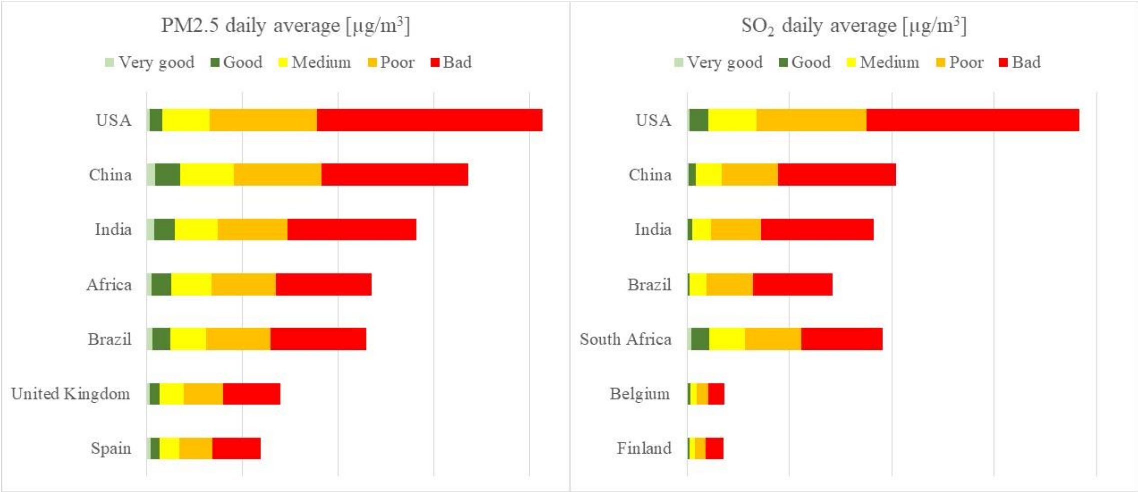

Figure 2. Example of differences between AQI classes in various countries (excerpt from [8])

Monteiro et al. in [8] presented a case study in Portugal, where regional environmental agencies were surveyed to check the needs for corrections of AQI used in Portugal. They questioned the need for inclusion of PM2.5 in AQI and observed the vast differences between AQI indices in various countries (Fig. 2). Similar researches were performed in India [9, 10] and Turkey [11].

2.1. U.S. AQI

The first air quality index was introduced in USA in 1976, as Pollutant Standards Index (PSI), which was calculated daily as the highest value of one of the five main air pollutants: particulate material (PM10), ozone (O_3), sulfur dioxide (SO_2), carbon monoxide (CO), and nitrogen dioxide (NO_2). The PSI was revised, renamed to the Air Quality Index (AQI), and subsequently implemented in 1999 by the U.S. EPA [7]. Mintz et al. in [12] explained the NowCast algorithm, which tries to compensate disadvantage of 24-hour AQI averaging by computing the most recent 12 hours of monitoring data. In such a way, a compromise was made between the long-term and short-term exposure hazards, trying to eliminate errors induced by rapid changes in pollution concentrations which occur during forest fires or strong winds. This method is currently being used in US AQI calculation. The NowCast calculation uses longer averages during periods of stable air quality and shorter averages when air quality is changing rapidly, such as during a wildland fire event [13]. The AQI is reported for the pollutant with the highest $I_p$value: 1-hour and 8-hour Ozone (ppm), 24-hour PM2.5 (µg/m^3), 24-hour PM10 (µg/m^3), 8-hour CO (ppm), 1-hour SO_2 (ppb), and 1-hour NO_2 (ppb) [13].

$$I_p = \frac{I_{Hi}-I_{Lo}}{BP_{Hi}-BP_{Lo}}\left(C_p - BP_{Lo}\right) + I_{Lo} \tag{1}$$

In equation (1), I_p is the index for pollutant p, C_p is the concentration of pollutant p, BP_{Hi} is the concentration breakpoint that is greater than or equal to C_p, BP_{Lo} is the concentration breakpoint that is less than or equal to C_p, I_{Hi} is the AQI value corresponding to BP_{Hi}, I_{Lo} is the AQI value corresponding to BP_{Lo}. The index is rounded to the nearest integer and the largest I_p for each pollutant is reported as AQI, in the scale from 0 to 500, divided into 6 descriptive categories (good, moderate, unhealthy for sensitive groups, unhealthy, very unhealthy and hazardous).

2.2. E.U. CAQI

The Common Air Quality Index (CAQI) was developed by the *Citeair* project in 2008, which was co-funded by the *InterReg IIIC* and *InterReg IVC* programs in Europe.

Index Class	Grid	ROADSIDE INDEX: Mandatory pollutant NO2	Mandatory pollutant PM10 1 hour	Mandatory pollutant PM10 24 hours	Auxiliary pollutant PM2.5 1 hour	Auxiliary pollutant PM2.5 24 hours	Auxiliary pollutant CO	BACKGROUND INDEX: Mandatory pollutant NO2	Mandatory pollutant PM10 1 hour	Mandatory pollutant PM10 24 hours	Mandatory pollutant O3	Auxiliary pollutant PM2.5 1 hour	Auxiliary pollutant PM2.5 24 hours	Auxiliary pollutant CO	Auxiliary pollutant SO2
Very High	>100	>400	>180	>100	>110	>60	>20000	>400	>180	>100	>240	>110	>60	>20000	>500
High	100	400	180	100	110	60	20000	400	180	100	240	110	60	20000	500
	75	200	90	50	55	30	10000	200	90	50	180	55	30	10000	350
Medium	75	200	90	50	55	30	10000	200	90	50	180	55	30	10000	350
	50	100	50	30	30	20	7500	100	50	30	120	30	20	7500	100
Low	50	100	50	30	30	20	7500	100	50	30	120	30	20	7500	100
	25	50	25	15	15	10	5000	50	25	15	60	15	10	5000	50
Very Low	25	50	25	15	15	10	5000	50	25	15	60	15	10	5000	50
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 3. Common Air Quality Index (CAQI) calculation grid used in EU since 2008 [14]

Three different indices have been developed: hourly, daily, and annual [7]. The hourly and daily common indices have 5 levels using a scale from 0 (very low) to > 100 (very high), based on pollutants of major concern in Europe: 1-hour NO_2 ($\mu g/m^3$), 1-hour and 24-hour PM10 ($\mu g/m^3$), 1-hour O_3 ($\mu g/m^3$), 8-hour CO ($\mu g/m^3$), 1-hour and 24-hour PM2.5 ($\mu g/m^3$) and 1-hour SO_2 ($\mu g/m^3$) [14]. The index is also differentiated as roadside/traffic (being representative of city streets with a lot of traffic) and city/background index, representing the general situation of the given agglomeration based on urban background monitoring sites. The pollutants are also divided into "core" or "mandatory" pollutants (NO_2, PM10 + O_3 in city index) and "auxiliary pollutants" (PM2.5, CO + SO_2 in city index).

2.3. Air Quality Indices in Western Balkan Countries

The Croatian Environmental Protection Agency uses European CAQI as the official indicator of air quality. Air pollution regulation in Serbia and in Bosnia and Herzegovina is also harmonized with EU Directive 2008/50/EC on ambient air quality and cleaner air in Europe.

In order to provide more accurate information about air quality below thresholds, Serbian Environmental Protection Agency introduced in 2011 their own index SAQI_11, with 5 classes (from "excellent" to "very polluted"). These classes are calculated for each pollutant: 1-hour and 24-hour SO_2 ($\mu g/m^3$), 1-hour and 24-hour NO_2 ($\mu g/m^3$), 24-hour PM10 ($\mu g/m^3$), 24-hour CO ($\mu g/m^3$), and 8-hour O_3 ($\mu g/m^3$) [15].

Averaging period	Pollutant	Limit value $\mu g/m^3$	Tolerant value $\mu g/m^3$	Excellent 1			Good 2			Acceptable 3			Polluted 4			Very polluted 5	
1h	SO2	350	500	0.0	-	120.0	120.1	-	220.0	220.1	-	350.0	350.1	-	500.0	>	500.0
	NO2	150		0.0	-	50.0	50.1	-	100.0	100.1	-	200.0	200.1	-	400.0	>	400.0
24h	SO2	125	125	0.0	-	50.0	50.1	-	75.0	75.1	-	125.0	125.1	-	187.5	>	187.5
	NO2	85	125	0.0	-	42.5	42.6	-	60.0	60.1	-	85.0	85.1	-	125.0	>	125.0
	PM10	50	75	0.0	-	25.0	25.1	-	35.0	35.1	-	50.0	50.1	-	75.0	>	75.0
	CO	5000	10000	0.0	-	2500	2501	-	3500	3501	-	5000	5001	-	10000	>	10000
	O3-8h max	120		0.0	-	60.0	60.1	-	85.0	85.1	-	120.0	120.1	-	180.0	>	180.0

Figure 4. Air Quality Index SAQI_11 used in Serbia since 2011 [15]

3. COMPARISON OF CATEGORIES AND THRESHOLDS

It is not easy to compare a number of indices used worldwide, because of different scales, thresholds, descriptive names, colors, pollutants, and averaging periods. We will try to make the comparison between the 3 indices used in US, EU (Croatia) and Serbia, in order to determine their differences and/or similarities. Such a comparison is not a straight forward task since these categories differ. The Table 1 demonstrates how AQI's differ for a single pollutant (PM2.5).

Table 1. U.S. AQI vs. EU AQI based on PM2.5 concentrations in μg/m³ [15, 16]

<table>
<tr><td rowspan="2">U.S. AQI</td><td rowspan="2" colspan="2">Good (0-50)</td><td rowspan="2" colspan="3">Moderate (51-100)</td><td rowspan="2" colspan="2">Unhealthy for Sensitive Groups (101-150)</td><td rowspan="2">Unhealthy (151-200)</td><td rowspan="2">Very Unhealthy (201-300)</td><td colspan="2">Hazardous</td></tr>
<tr><td>(301-400)</td><td>(401-500)</td></tr>
<tr><td>PM2.5</td><td colspan="2">0.0-12.0</td><td colspan="3">12.01-35.4</td><td colspan="2">35.5-55.4</td><td>55.5-150.4</td><td>150.5-50.4</td><td>250.5-350.4</td><td>350.5-500.4</td></tr>
<tr><td>EU AQI</td><td>Good</td><td colspan="2">Fair</td><td colspan="2">Moderate</td><td>Poor</td><td colspan="5">Very poor</td></tr>
<tr><td>PM2.5</td><td>0-10</td><td colspan="2">10-20</td><td colspan="2">20-25</td><td>25-50</td><td colspan="5">50-800</td></tr>
</table>

For more thorough comparison, thresholds and data grids are used, with remark about the difference of measurement units because U.S. EPA measures gases in volumetric (ppm/ppb) units and PM in mass units (μg/m³). The European regulation uses only mass units (μg/m³). Conversion cannot be performed accurately, because it depends on the molecular weight of the pollutant, and atmospheric temperature and pressure can affect the calculation. Typically, conversions for air pollutants are made assuming a pressure of 1 atmosphere and a temperature of 25 °C. For these conditions, the equation to convert from concentration in parts per billion to concentration in μg/m³ is:

$$concentration\ (\mu g/m^3) = 0.0409\ x\ concentration\ (ppb)\ x\ molecular\ weight \quad (2)$$

Therefore, the conversion factor for SO_2 (64 g/mol) is 2.62, for NO_2 (46 g/mol) it is 1.88. Using these conversion factors, pollutants (SO_2, NO_2, PM10 and PM2.5) and category grids for US EPA AQI, EU CAQI and Serbian SAQI_11 are summarized in Tables 2, 3 and 4, respectively.

Table 2. Pollutants and category grid for US EPA AQI

		SO_2		**NO_2**	**PM10**	**PM2.5**
AQI	Description	μg/m³ (1-hr)	μg/m³ (24-hr)	μg/m³ (1-hr)	μg/m³ (24-hr)	μg/m³ (24-hr)
50	Good	92		100	54	12
100	Moderate	197		188	154	35
150	Unhealthy for sensitive groups	485		677	254	55
200	Unhealthy	799		1220	354	150
300	Very unhealthy		1585	2348	424	250
500	Hazardous		2109	3100	504	350

Table 3. Pollutants and category grid for EU CAQI

		SO_2	**NO_2**	**PM10**		**PM2.5**	
CAQI	Description	µg/m^3 (1-hr)	µg/m^3 (1-hr)	µg/m^3 (1-hr)	µg/m^3 (24-hr)	µg/m^3 (1-hr)	µg/m^3 (24-hr)
25	Good	50	50	25	12	15	10
50	Fair	100	100	50	25	30	20
75	Moderate	300	200	90	50	55	30
100	Poor	500	400	180	100	110	60
> 100	Very poor	> 500	> 400	> 180	> 100	> 110	> 60

Table 4. Pollutants and category grid for SAQI_11

		SO_2		**NO_2**		**PM10**
SAQI_11	Description	µg/m^3 (1-hr)	µg/m^3 (24-hr)	µg/m^3 (1-hr)	µg/m^3 (24-hr)	µg/m^3 (24-hr)
1	Excellent	120	50	50	43	25
2	Good	220	75	100	60	35
3	Acceptable	350	125	200	85	50
4	Polluted	500	188	400	125	75
5	Very polluted	> 500	> 188	> 400	> 125	> 75

It is interesting to compare indices with primary standards for each pollutant [17, 18, 19], where one can see that limit concentrations of 1-hour SO_2 (200 and 350 µg/m^3), 24-hour PM10 (150 and 50 µg/m^3) or 1-hour NO_2 (200 µg/m^3) correspond to US AQI value 100 (20% of a maximum index), EU CAQI value 75 (75%) and Serbian SAQI_11 value 3 (75% of a maximum index). The chart in Figure 5 shows the differences between primary national standards for criteria pollutants, expressed in µg/m^3.

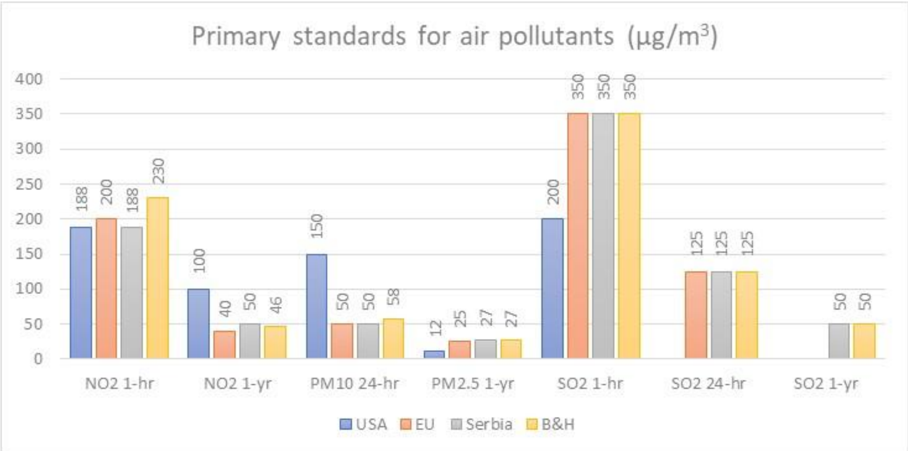

Figure 5. Primary standards for air pollutants used in USA, EU, Serbia and Bosnia and Herzegovina

3.1. Comparing Air Quality Indices with values reported in Bosnia and Herzegovina

In order to check whether the Air Quality Index can be used with real data, available official air quality reports for Bosnia and Herzegovina [20] were analyzed. The measurements from 16 locations are summarized in Figure 6, which shows annual average and maximum values of reported concentrations of primary air pollutants in Bosnia and Herzegovina (1-year, 1-hour and 24-hour averages). Table 5 shows the maximum annual averages and the maximum values ever recorded during the 3-year period.

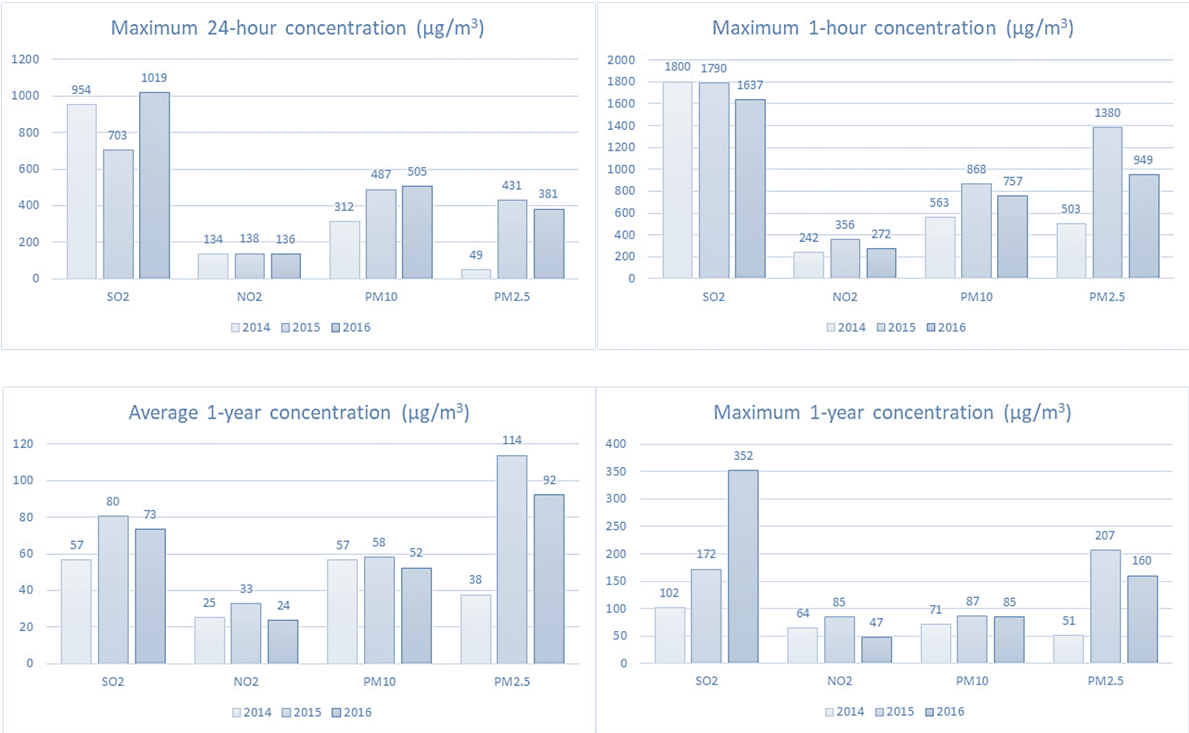

Figure 6. Maximum air pollutant concentrations in Bosnia and Herzegovina 2014-2016 [20]

Table 5. Air quality indices reached in Bosnia and Herzegovina in 2014-2016

	1-hr SO_2		**1-hr NO_2**		**24-hr PM10**		**24-hr PM2.5**	
	1-year average	max	1-year average	max	1-year average	max	1-year average	max
µg/m^3	80	1800	33	356	58	505	114	431
US AQI	40	500	10	120	50	500	180	> 500
EU CAQI	40	> 100	15	90	100	> 100	> 100	> 100
SAQI_11	1	5	1	4	3	5	n/a	n/a

Data from Fig. 6 and Table 5 shows that annual average concentrations of SO_2 reached 80 µg/m^3, and concentrations of NO_2 reached 33 µg/m^3, which corresponds to indices marked as "good/low/excellent". Simultaneously, the annual average concentrations of PM10 reached 58 µg/m^3,which corresponds to indices marked as "good" according to US AQI, "high" according to EU CAQI, and "acceptable" according to SAQI_11.
Maximum recorded values of concentrations reached or exceeded the highest values of indices in all but one pollutant (only NO_2 concentrations did not exceed the maximum value of SAQI_11 index). One must notice that SO_2 and PM2.5 concentrations can be extremely high, and such concentrations are way much higher than thresholds set in European indices. It can mean that EU scale cannot be used under such conditions, because the index value would almost permanently be marked as "very highly polluted". The EU scale could be used but it may not provide a level of specificity that would be helpful given recent BiH air quality because the "very poor" category covers such a wide range of ambient concentrations.

4. CONCLUSIONS

According to numerous comparative studies, it was already proved that air quality index cannot be unique globally, not only because of political reasons, but also due to differences in data availability, values reported, data collection dynamics, averaging periods and data ranges. "Very unhealthy air" is considered as "Moderately polluted" or "Acceptable" in different countries. There is also lack of consensus on which values of pollutant concentrations represent health hazard, and different countries have different criteria.

Having in mind all these facts, it is not simple to choose the most appropriate AQI model for a country. In case of Bosnia and Herzegovina, none of the observed indices is acceptable "as is", and the new index should be developed. In order to make the most appropriate choice, I would suggest the following:

- The real data about pollutant concentrations should be collected, during at least 3 years period, which would include the average and maximum values of concentrations.
- The concentration dynamics should be considered, to determine are there sudden changes in concentrations, i.e. can static data be used or time-averaging is needed?
- Although some pollutants lead to health hazard only after long-term exposure, the most appropriate averaging period should be chosen in order to cover the episodes when these pollutants are extremely high, even if the concentration of other pollutants are low.
- The AQI calculation formula should be rigorously defined and officially regulated, in order to avoid the possibility of errors and to enable automation.
- The chosen set of categories should be related to health hazard levels and accompanied by simple and easily understandable recommendations for general population.

5. ACKNOWLEDGEMENT

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