COMPARATIVE ANALYTICAL DATA OF AIR QUALITY IN BANJA LUKA CITY

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REVIEW SCIENTIFIC PAPER

ISSN 2637-2150
e-ISSN 2637-2614
UDC 504.3.054(497.6):[614.71:628.8
DOI 10.7251/STED2201039K
COBISS.RS-ID 136254977

Paper Submited: 28.02.2022.
Paper Accepted: 05.04.2022.
Paper Published: 30.05.2022.
http://stedj-univerzitetpim.com

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ABSTRACT

In order to efficiently manage air quality at the location of Banja Luka city, a functional system for monitoring and controlling the degree of air pollution, that is to say air quality monitoring, has been established. Air quality monitoring is performed by the Mobile Ecological Laboratory (MEL) at three locations in the settlements of Paprikovac, Borik and the City Centre. The objectives of air quality monitoring can be divided into two groups: the first group consists of the objectives of the monitoring program for a medium-industrialised city with an existing or potential problem of air pollution. The second group consists of special air quality monitoring objectives, whose nature is such that their implementation is a matter of free choice, and usually more complex solutions are required. The basic air quality monitoring program should provide the essential data needed to develop air quality standards and enable the development of an acceptable air quality protection program. The goal of the basic air quality monitoring program is: to monitor long-term trends in air pollution in order to determine the degree of improvement or deterioration of air quality in urban and industrial environments. Measurements are usually performed at multiple measurement sites by collecting and analysing a 24-hour sample. Measurement data for at least five consecutive years are required to determine air pollution trends. Air quality is assessed based on the obtained data and on the basis of comparison with standards. In accordance with the above, this paper presents the air quality through the values of the following pollutants: SO_2, O_3, CO, NO_2, PM_{10} and Soot. The air quality of Banja Luka (from the aspect of the presence of sulphur dioxide and soot) was analysed, before and after the war, based on the available literature.

Key words: air pollution, air quality, pollutants.

INTRODUCTION

Certain, suitable conditions on the earth - temperature, an air layer (especially ozone) that protects its surface from cosmic and other radiation and provides sufficient

oxygen, water, fertile soil and abundant solar radiation

n - have provided a varied life on earth. For millennia, normal natural conditions have enabled a comfortable human life, and the biosphere has been powerful enough to counteract the negative effects of all human activities. However, due to offensive, unilateral and uncontrolled technological development, extensive depletion of natural resources, uncontrolled population growth, as well as insufficient knowledge and environmental ethics, huge quantities of waste are emitted into the environment in the present century, degrading it. Intense pollution in recent decades seems to be approaching a critical point. This can lead to disturbances in the biosphere with unprecedented consequences (Cukut, et al., 2011).

The vast mass of air, with the great power of self-purification, waters of the earth, with a great capacity of receiving waste, the vast expanses of land, have until recently appeared to be limitless recipients of man-made waste materials. However, the capacities of these recipients are limited, which is beginning to be understood, and so humanity, in its own interest, has begun to protect and sustain the environment. Polluted air means air containing substances harmful to the human organism, flora, fauna, natural and man-made goods in quantities and concentrations above those contained in the pure, and above the limits prescribed by the Law on Air Quality and regulations adopted based on the Law (Ilić, 2015).

The provision of the required air quality is achieved by bringing in limits, in accordance with the valid rulebooks, the quantities of hazardous substances discharged from the sources of pollution, by regulating the method and place of their discharge (emission), the choice of fuels, the use of specific additives, the installation of purifiers, the ban on work, and for new plants with the choice of appropriate technology and location, with the installation of air pollution control devices in accordance with the planned air quality and the total existing air pollution (emissions). In Republic of Srpska, pioneering air quality monitoring first began in Banja Luka in the 1980s, with the interruption of monitoring from 1992 to 1998, and it became the leader and initiator of the development of the monitoring network in Republic of Srpska. The analyses of sulphur dioxide (SO_2) and soot (black smoke) were done. Over time, the number of analysed parameters expanded to nitrogen oxides (NO_X) and carbon monoxide (CO) (Ilić, & Preradović, 2009).

Based on literature data, the pre-war period is mainly characterised by air quality of the fourth class - the zone of critical pollution, while the post-war period varies between the first and second class of air quality - from the clean air zone to the endangered area. This difference is a consequence of the cessation of work of numerous industrial capacities in the territory of Banja Luka in the post-war period (Knežević, Cukut, Dunović, Komlenić, & Lazić, 2009).

Analysis of Banja Luka air quality, in the period before and after the war (1992-1995) from the aspect of the presence of soot and sulphur dioxide

In the 1970s, Banja Luka was a city with insignificant air pollution. It was not until the early 1980s that air pollution became more prominent, and since 1985 the concentrations of basic indicators of atmospheric pollution (sulphur dioxide, soot, dust) have exceeded the upper limit of permissible values. This can be clearly seen if the concentration of SO_2 µg/m³ in Banja Luka is compared with some world capitals and industrial centres - in 1983, all cities (except Banja Luka and Rome) recorded a decrease in the concentration of SO_2 µg/m³ compared to 1975 (Figure 1).

This trend of increasing atmospheric pollution is related to the development of industry in that period. The then Institute of Occupational Safety kept a register of sources of air pollution in the Banja Luka area, and among the largest sources of air pollution were: Incel-Energana, Incel-Celuloza, Gradska toplana, Incel-Poliester, Banjalučka pivara, Valjaonica HVT-Unis,

Vitaminka, R.Čajavec-Novakovići, Blik, KBC Paprikovac, Žitoprodukt, R.Čajavec-Palos (Lolić,1989). However, the war and post-war period decimated the industrial capacities of Banja Luka and the Republic of Srpska, which affected the improvement of air quality (Figures 2 and 3).

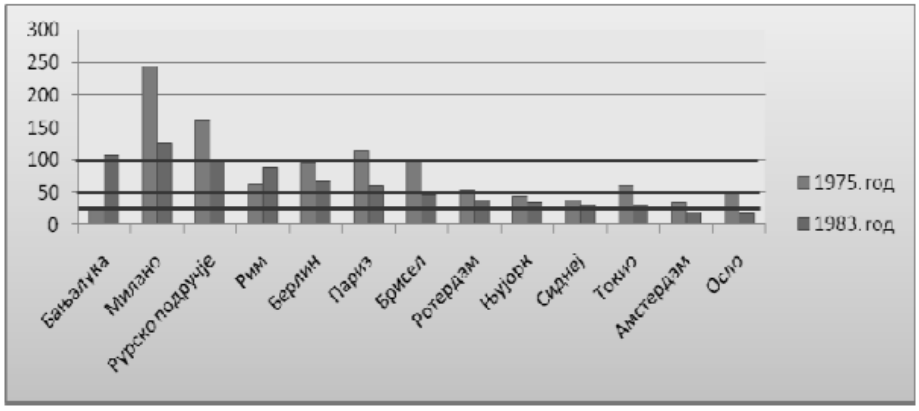

Figure 1. Comparison of average annual SO_2 µg/m³ concentrations in Banja Luka and some world capitals for 1975-1983 (Lolić,1989).

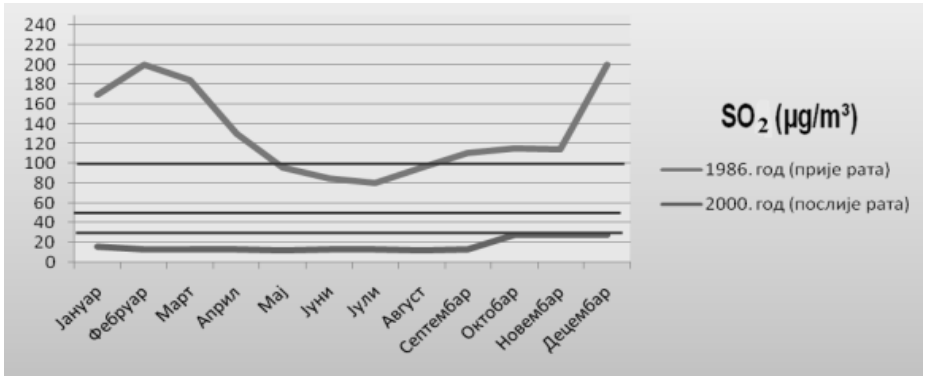

Figure 2. Comparison of the average monthly concentration of SO_2 (µg/m³) for 1986 and 2000 in Banja Luka

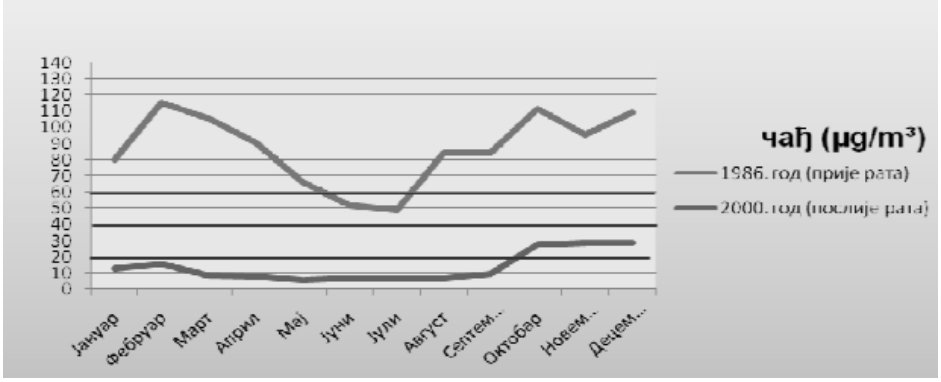

Figure 3. Comparison of the average monthly concentration of soot (µg/m³) for 1986 and 2000 in Banja Luka

The difference in air quality in the pre-war and post-war period can best be seen through an analysis of the above figures and graphs. Observing Figures 2 and 3, the following can be noticed: air quality, from the aspect of the presence of SO_2 and soot, in the pre-war period, was in the fourth class (critical pollution zone), except in the summer months, when it was in the third zone, while the post-war period is characterised by a favourable situation from the aspect of the concentration of CO_2 and soot in the city - variation between the first and second class of air, with a tendency to increase during the winter months. All the above leads to a conclusion that in the post-war period air pollution was significantly reduced (due to the cessation of industrial capacity, which led to a kind of pauperization of the city, but also to improving environmental conditions), and that the presence of sulphur dioxide is satisfactory, but shows an increase in the value of concentration in the winter. Also, a significant part of the pollution comes from motor vehicles (constant pollution throughout the year), and a smaller part of the pollution is released by industrial plants. This is also the case with the concentration of soot, so in the post-war period its concentration is significantly reduced, but the highest concentrations of soot occur during the heating season as a result of insufficient combustion of fossil fuels (Kuzmanović, 2012).

Impact of airborne particles on solar radiation, climate and vegetation

Airborne particles have a significant effect on the weather near the ground. They affect the intensity of solar radiation reaching the ground. The particles scatter solar rays into different wavelengths, depending on the size of the particles, their concentration, their nature, etc., and they frequently absorb some of the sun's radiation (Silibello, Allura, Finardi, Bolignano & Sozzi, 2015).

Atmospheric haze as a result of air pollution can be so large that the sun appears red, although there are no clouds, which is a special case of sunrise and sunset (Bai, Wang, Ma, & Lu, 2018).

In terms of total sun radiation, urban areas are estimated to receive less sun's rays than suburban areas by 20%. The reason for this is the action of airborne particles, which scatter, thereby reduce solar radiation, especially reduce the intensity of ultraviolet radiation reaching the ground. Visibility is globally diminished due to the presence of airborne particles.

Reducing the light intensity of radiation passing through the air to the ground causes two optical effects related to the air molecules and airborne particles:

- sorption of light energy and
- scattering of light.

Solids can also act as phytotoxicants because they precipitate on green leaves, flowers or branches. Sulphuric acid aerosols can deposit on the leaves of plants and thus have a very detrimental effect. The solids together with the components (molecules) present in the air create larger particles, that is, solids, which serve as nuclei around which either crystals or droplets are formed (e.g. mist formation due to water vapour saturation in the presence of solids in the air). The air in which pure water vapour is present, without particulate matter, should be saturated to form a condensed phase. A reason for this is a large energy barrier that separates molecules that are in the vapour state. It is necessary to overcome this barrier to produce larger aggregates, in this case water droplets (Scott, &Diab, 2000).

However, if particles are present, a thin layer of adsorbed molecules is formed on their surface, so that other present molecules are bound to this layer. This is the phenomenon of nucleation. This is especially prominent in urban areas, where the frequent occurrence of fog is a direct consequence of this effect. Areas with a higher content of airborne particles are also subject to higher rainfall (Hong, & Hu, 1999).

Impact of airborne particles on human respiratory tract, toxicity

In urban areas, human exposure to airborne particles can damage health. Particles enter the human body through the respiratory organs (respiratory system). This can directly damage the respiratory organ or indirectly damage other organs. Deposition of particulate matter in the respiratory system occurs due to inertial collisions of the particles with the tissue, due to adhesion, gravitational deposition and as a result of diffusion. Particles of larger diameter and mass are easier to deposit and retain in the respiratory system (Chahine, et al., 2007).

Impact on sulphur dioxide in the atmosphere on humans and vegetation

Sulphur compounds, as pollutants, are emitted into the atmosphere in natural processes, mainly in the form of sulphur-hydrogen and various industrial and energy processes (anthropogenic origin). Sulphur compounds of anthropogenic origin are largely produced by the combustion of fossil fuels and from certain industrial processes. Sulphur oxides such as sulphur dioxide (SO_2), sulphur trioxide (SO_3), sulphuric acid (H_2SO_4) and salts of these acids are common pollutants found in the air. Other sulphur oxides have not been detected in the air, although the presence of S_2O_7 can theoretically be expected as a result of the sulphur dioxide and ozone reaction (Catalano, Galatioto, Bell, Namdeo, & Bergantino, 2016).

Sulphur dioxide is colourless, does not burn nor creates explosive mixtures. Its odour is pungent (most people can smell it already at its 1ppm air concentrations). It dissolves well in the water (11.3 g/100 ml water at room temperature). The most important physical characteristics of this pollutant are given in the following table. (Akhra, Fahad, Saiqa, Noshila, & Saba, 2016).

Table 1. Physical properties of sulphur dioxide

Density g/l	2,927 at 0 ^oC and 101325 Pa
Melting point ^oC	-75.46
Boiling point ^oC	-10.02
Critical temperature ^oC	157.2
Critical pressure MPa	7.9
Evaporation heat kJ/mol	24.9

From the aspect of air pollution, the reactions of sulphur dioxide in the atmosphere that produce SO_3, H_2SO_4 or sulphuric acid salts are important. These reactions can be photochemical or catalytic. Sulphur dioxide at room temperature can also react as an oxidizing agent. Sulphur dioxide in contact with vegetation can cause two types of leaf damage: acute and chronic damage (Desonie, 2007).

Acute damage, caused by a relatively short effect of higher concentrations of sulphur dioxide, is manifested in the damage to the cells being dried. The disease is manifested by a change in colour, which becomes similar to ivory, and sometimes changes to burgundy (Knežević, et al., 2009).

Epidemiological studies have shown that the effect of sulphur dioxide on the human respiratory system depends on its concentration in the air. Some studies, although insufficiently systematic, show an association between increased mortality and increased concentrations of sulphur dioxide in the air. This is especially the case in certain urban areas where air pollution is high. Studies have shown that certain concentrations of sulphur dioxide led to the following toxic effects on humans:

- at an average sulphur dioxide daily concentration of 0.52 ppm, in the presence of higher concentrations of particulate matter, an increased mortality of the population occurs;
- at a sulphur dioxide concentration of 0.25 ppm, in the presence of smoke (soot) of about 0.30 ppm, mortality of the population increases;
- sulphur dioxide concentrations ranging from 0.11 to 0.19 ppm (daily average) and the presence of particulate matter increase the respiratory problems of the elderly and sick;
- when sulphur dioxide concentrations are 0.21 ppm and of soot about 0.10 ppm, people with chronic lung disease have deteriorating symptoms.

Nitrogen oxides and their effects

Nitrogen oxides are considered to be a mixture of nitrogen oxides, among which the highest biological activity is manifested by nitrogen monoxide (NO), nitrogen dioxide (NO_2) and nitrogen tetroxide (N_2O_4). In nature, these gases are formed in volcanoes, they follow thunderstorms and the action of bacteria with organic compounds. In urban areas they are found in high concentrations. They occur in significant quantities when burning coal, paper, wood, especially in cases of fire (Đurić, Božić, Babić, Stojanović, & Vidaković, 2015).

Their important source is traffic, especially when burning diesel fuel in vehicle engines. Motor vehicles emit nitrogen dioxide and nitrogen monoxide at the same time. Nitrogen oxide oxidizes to nitrogen dioxide very quickly in air, slowly in reactions with oxygen, and much faster in reactions with ozone as an oxidant. Due to that, there are low concentrations of ozone near the sources of nitrogen oxides. Under production conditions, nitrogen oxides are formed during fermentation in silos, where nitrogen dioxide is most present in the gas mixture. They also occur as a result of production conditions in the production of nitric acid, explosives, nitrates, fertilizers, in the industry of aniline dyes, celluloids, photographic films, in electric welding, mine explosion, in the action of nitric acid on organic matter (Yang, & Wang, 2017).

Nitrous gases penetrate the body through the respiratory system where they build nitric and nitrous acid on the moist mucosa. Due to their poor solubility in water, this process takes place more in the lower than in the upper respiratory tract. Even small amounts of inhaled nitrogen oxides, due to the secretion of histamine, can increase airway resistance and reduce the diffusion capacity of the lungs. The reaction of nitrous gases with alkaline components of the mucous membrane produces nitrates and nitrites, so a certain amount of methaemoglobin is formed, which interferes with the transfer of oxygen to erythrocytes, and nitrates and nitrites can lead to vasodilation and drop in blood pressure. Manifestations that occur when inhaling higher concentrations of nitrogen oxides depend on the proportion of individual oxides in the inhaled mixture. The most common are nitrogen monoxide and nitrogen dioxide (Sharma, Agarwal, Eastwood, Gupta, & Singh, 2018).

Irritation of the upper respiratory tract and conjunctiva of the eyes mainly causes: scratching, tearing and burning in the eyes; scratching, burning in the nose and throat and irritating cough. Occasionally there is pain behind the sternum, headache and vomiting with difficult breathing due to inability to breathe. This is followed by a latent period usually from 6 to 12 hours and the development of pulmonary oedema. Up to 30 $\mu g/m^3$ of nitrogen oxides in the air classify the air into slightly polluted air, and more than 60 $\mu g/m^3$ represents a zone of critical pollution (Tang, 1979).

Carbon oxides and their effects

Carbon monoxide is a slightly lighter gas than air and is the product of incomplete combustion of organic matter. In nature, it is generated from the primary oxidation of methane in the air and emissions from the ocean. In industry, it

occurs in all processes where incomplete oxidation of carbon-containing substances takes place (metallurgy, gas plants, distillation of coal, wood, oil, coal mines, paper production, etc.). It is part of lighting gas (6-13%), generator gas (22-34%) and water gas (41-50%). The explosion of gunpowder produces 3-9% of carbon monoxide, and the exhaust gases from internal combustion engines contain up to 9%. Carbon monoxide is the most widespread environmental pollution in industrial regions and in urban areas. It enters the body by inhalation, quickly passes through the alveolar-capillary membrane in the lungs and binds to haemoglobin in the erythrocyte, expelling oxygen. Such carboxy-haemoglobin is not able to carry oxygen, nor to give oxygen to tissues (Zhang, Bocquet, Mallet, Seigneur, & Baklanov, 2012).

In addition, carbon monoxide makes it difficult to release the remaining oxygen bound to haemoglobin, so even that amount of oxygen cannot be efficiently used in the tissue. With an increased partial pressure of carbon monoxide, there may be a decrease in the partial pressure of carbon dioxide, which causes an increase in blood pH, and this increase makes it even more difficult to release oxygen from the blood into the tissues. Carbon monoxide has no direct effect on the respiratory system, but acts indirectly by interfering with the transfer of oxygen and its release to tissues.

Exposure to low concentrations of carbon monoxide causes general symptoms: weakness, exhaustion, dizziness, headache accompanied by tightness and pulsation in the temples, dyspnoea, palpitations, nausea, vomiting, intoxication, weakness in the legs and apathy. Up to 1000 μg/m^3 of carbon monoxide in the external environment makes the air slightly polluted, and over 4000 μg/m^3 is a zone of critical pollution (Law on Air Protection [LAP], 2017).

Ozone and its effects

Ozone is a gas composed of three oxygen atoms formed by the action of ultraviolet light on molecular oxygen. It is found in the stratosphere (in the amount of about 10 ppm-parts per million) and in the troposphere (1 ppm) as a natural ingredient.

It comes to the atmosphere from various processes in such a way that it is created from volatile organic components and nitrogen oxides: when heated by electric arc, from exhaust gases of internal combustion engines, created by using high voltage electrical equipment, electric discharge, using mercury lamps, printing on plastic surfaces in the graphic industry, in water purification, in bleaching processes in the textile and other industries, in photocopying, etc. Ozone is a highly reactive agent. It exhibits the properties of free radicals because it contains two unpaired electrons. In contact with the fluid in the respiratory and other systems, it forms the free hydroxyl radical (OH), which is one of the most active chemical oxidants. As a free radical, ozone causes lipid peroxidation and oxidation of thiol, amino and protein groups of cells. It has a strong irritating effect on the mucous membranes of the eyes and upper respiratory tract.

At lower concentrations it acts on enzyme activity. In high concentrations, it causes disorders of primary oxidative reactions, interferes with primary and secondary defence mechanisms. Mild exposure to lower concentrations of ozone causes irritation of the mucous membranes of the eyes and upper respiratory tract in the form of narrowing, burning in the eyes, scratching in the throat, tightness of the sternum and pain in the form of burning or tearing in the chest, which increases with inspiration and decreases with expiration, and leads to unproductive cough. Exposure to higher concentrations causes dyspnoea, cyanosis and pulmonary oedema. Prolonged exposure to ozone reduces lung function. It affects the development of chronic obstructive pulmonary disease.

The Regulation on air limit values does not set a limit value for ozone in the external environment, but gives a limit of 150 μg/m^3 that must not be exceeded more than 21 times in a calendar year for a sampling period of 8 hours.

Impact of airborne particles on humans and materials

The intake of these compounds into the respiratory system by inhalation depends on the size of the carrier particles. These compounds cannot elute rapidly with small diameter soot particles. Particles with an average diameter of less than 0.04 μm, due to their high adsorption capacity, can completely adsorb polynuclear aromatic hydrocarbons. However, with particles larger than 0.04 μm in diameter, these compounds are released by the solvent. The rate of release of the compounds increases with increasing particle size. Therefore, the introduction of larger-diameter solid particles with polynuclear aromatic hydrocarbons into the human respiratory system can lead to lung or other organ cancers. The scheme on figure 4 shows the deposition of particulate matter in the respiratory tract (according to the Task Group Lung Dynamics model), (Radić, Knežević, Lazić, & Arsenović, 2006).

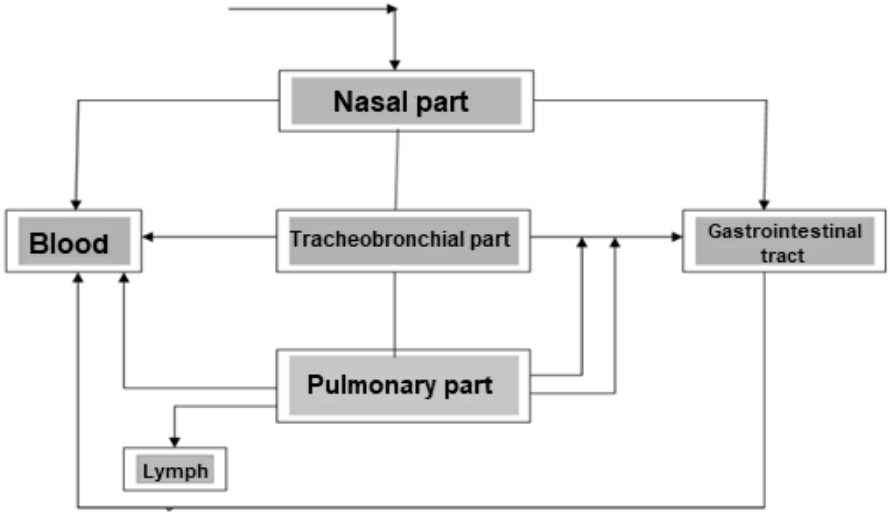

Figure 4. Scheme showing the deposition of particulate matter in the respiratory tract (according to the Task Group Lung Dynamics model)

The model in the previous figure shows how, in addition to directly affecting the respiratory system, airborne particles can much more seriously affect other vital organs through the blood. Causes of diseases and other organs from cancer, other than the lungs, can therefore be sought among the pollutants that appear in the air. Airborne particles can mechanically and chemically affect materials as well. The nature and methods of these effects depend on the chemical activity of the particles and the nature of the material. They chemically dissolve materials in a way that they bind the nuclei to gases or strong acids, which they carry, or simply by their corrosive activity. Particles in the atmosphere also negatively affect buildings. They and soot particularly, form a layer on the wall, brick, marble, stone, glass, which is hard to wash off by rain, so that in addition to its negative effect, it also has an effect on the aesthetic appearance (Stern, 1977).

MATERIAL AND METHODS

The concentrations of SO_2, O_3, CO, NO_2, PM_{10} and soot were monitored by the equipment listed in the table 2 and figures 5, 6, 7 and 8.

Table 2. Air pollutant monitoring equipment

No.	Name of the measuring /testing equipment	Manufacturer	Tip	Measuring scope	Measurement method	Calibration certificate no.
1	Analyser SO2	HORIBA, JAPAN	APSA-370	0-1000 µg/m3	BAS EN 14212:2013 Ultraviolet fluorescence	211/2019
2	Analyser NO/NO2/NOx	HORIBA, JAPAN	APNA-370	NO: 0-1200 µg/m³ (0-960 ppb) NO2: 0-500 µg/m³ (0- 260 ppb)	BAS EN 14211:2013 chemiluminescence	212/2019
3	Analyser CO	HORIBA, JAPAN	APMA-370	0- 100 mg/m³	BAS EN 14626:2013 non-dispersive infrared spectroscopy	210/2019
4	Analyser O3	HORIBA, JAPAN	APOA-370	0- 500 µg/m³	BAS EN 14625:2013 ultraviolet photometry	213/2019
6	Metrology set	-	-	0-30 m/s	optoelectronic	
7	NETZ "ALCYON" Three-component anemometer for wind speed and direction	-	-	0-30 m/s	optoelectronic	
8	THOMMEN M-105.04 Barometer	-	-	900 - 1100 hPa	electro-mechanical	
9	Gravimetric sampler of solid particles TSP, PM10 and PM2.5	Digitel AG Hegnau, Switzerland	DPA14	-	standard gravimetric method	II-20/264
10	Electronic scales METTLER TOLEDO	Mettler Toledo GmbH, Switzerland	XPR206DR/M	0.01mg/ 0.005mg – 220gr	-	220-B73-20-1

Figure 5. Gravimetric sampler of solid particles TSP, PM10 and PM2.5

Figure 6. Electronic scales METTLER TOLEDO

Figure 7. Analysers HORIBA JAPAN

Figure 8. Movable ecological laboratory (MEL)

LOCATIONS OF MEASURING POINTS

For the assessment of air quality in the Banja Luka city region, continuous measurements of immission concentrations were performed by mobile ecological laboratory (MEL) in the period from 2017 to 2021, in accordance with the Regulation on air quality values (Regulation on air quality values [RAQV], 2012).

Coordinates of measuring points (Figure 9):

MM1 - 44°46'50"N
- 17°10'37"E

MM2 - 44°46'14"N
- 17°12'55"E

MM3 - 44°46'18"N
- 17°11'21"E

Air quality measurement included the following parameters:

- Carbon monoxide- CO,
- Sulphur dioxide - SO_2,
- Nitrogen oxides- NO_2,
- Suspended particles - PM_{10},
- Ozon - O_3.

Figure 9. Satellite image of the location (Google Earth)

LIMIT VALUES OF AIR QUALITY

The Regulation on air quality values (RAQV, 2012) establishes the limit and tolerance values of air quality with the aim of protecting human health, vegetation and natural eco-systems, as well as maximum permissible concentrations of pollutants in the air in case of measurements for specific purpose. According to the mentioned regulation, the air quality values represent the numerical values of limit values for air pollutants levels, namely the lower and upper limits for assessing air quality, critical levels, tolerance limit and tolerance values, target values and long-term targets of air pollutants, concentrations hazardous for human health and concentrations reported to the public (Zhang, et al., 2012).

Air pollutants are monitored by measuring concentrations for sulphur dioxide, nitrogen dioxide and nitrogen oxides, suspended particles (PM10, PM2.5), carbon monoxide, ground-level ozone and soot in the air, with automatic measuring instruments and/or sampling by analysis (Regulation on air quality values, 2012).

Limit and tolerance values and tolerance limits for sulphur dioxide, nitrogen dioxide and carbon monoxide are given in the table 3 and 4.

In the zone and agglomerations where the level of subject polluting substances is below limit values established by the above tables, it is necessary to keep the concentrations of polluting substances at a level below limit values. For polluting substances for which no tolerance limit was prescribed, as a tolerance value is taken their limit value.

Limit and tolerance values are a basis for:

- Air quality assessment,
- Division of zones and agglomerations in the category based on the air pollution level and
- Air quality management.

Limit values of air polluting substance levels, which are prescribed by this Regulation must not be exceeded once they are reached. Concentrations of sulphur dioxide, nitrogen dioxide and ground-level ozone, which are hazardous for human health are given in the tables 5, 6 and 7.

Table 3. Limit, tolerance values and tolerance limits for human health protection

Sampling period	Limit value	Tolerance limit	Tolerance value*
Sulphur dioxide			
One hour	350 μg/m^3	21.4 μg/m^3	371.4 μg/m^3
One day	125 μg/m^3	-	125 μg/m^3
Calendar year	50 μg/m^3	-	50 μg/m^3
Nitrogen dioxide			
One hour	150 μg/m^3	10.7 μg/m^3	160.7 μg/m^3
One day	85 μg/m^3	5.7 μg/m^3	90.7 μg/m^3
Calendar year	40 μg/m^3	2.9 μg/m^3	42.9 μg/m^3
Carbon monoxide			
Maximum daily 8-hour value	10 mg/m^3 (10000 μg/m^3)	0.9 mg/m^3 (900 μg/m^3)	10.9 mg/m^3 (10900 μg/m^3)
One day	5 mg/m^3 (5000 μg/m^3)	0.7 mg/m^3 (700 μg/m^3)	5.7 mg/m^3 (5700 μg/m^3)
Calendar year	3 mg/m^3 (3000 μg/m^3)	-	3 mg/m^3 (3000 μg/m^3)
Suspended particles PM_{10}			
One day	50 μg/m^3	3.6 μg/m^3	53.6 μg/m^3
Calendar year	40 μg/m^3	1.1 μg/m^3	41.1 μg/m^3

*The tolerance limit is shown for 2020 (from 1 January 2015 and every 12 months thereafter reduced to equal annual percentages to reach 0% by 1 January 2021)

Table 4. Target value for ground-level ozone

Target value for ground-level ozone		
Target	Period of calculating average value	Target value
Human health protection	Maximum daily 8-hour mean value	120 μg/m^3

Table 5. Concentrations of sulphur dioxide and nitrogen dioxide, hazardous for human health

Pollutant	Concentration hazardous for human health
Sulphur dioxide	500 μg/m^3
Nitrogen dioxide	400 μg/m^3

Table 6. Concentrations of ground-level O_3, which are hazardous for human health and concentrations of which the public is notified

Purpose	Period of averaging	Limit
Notification threshold (μg/m3)	1 hour	180 μg/m^3
Warning value (μg/m^{3*})	1 hour*	240 μg/m^3

*In a zone or agglomeration, exceedances of the limit are established or foreseen for three consecutive hours, with the aim of adopting short-term action plans to protect human health or the environment as needed.

Table 7. Maximum permissible values for the purpose of dedicated measurements for TSS

Period of taking the mean value of measurements for total suspended solids	Maximum permissible value
One day - 24h	250 µg/m^3
Calendar year - 365 days	90 µg/m^3

Concentrations hazardous for human health are measured during three consecutive hours at locations that are representative for the air quality in the territory whose area is not smaller than 100 km^2, or in the zone or agglomerations, if their area is smaller.

PAPER RESULTS AND DISCUSSION

Table 8 and Figures 10 and 11 shows the values of average annual concentrations of SO_2, O_3, CO, NO_2, PM_{10} and soot in Banja Luka City for the period 2017 to 2021. The results of measuring the concentrations of SO_2, O_3, CO, NO_2, PM_{10} and soot in the air of the city of Banja Luka show that the measured annual value average was the highest during 2017.

Table 8. Values of average annual concentrations of SO_2, O_3, CO, NO_2, PM_{10} and soot

Pollutant	**Banja Luka**				
	2017	**2018**	**2019**	**2020**	**2021***
CO(mg/m^3)	1.13	0.60	0.62	0.61	0.65
SO_2 (µg/m^3)	23.87	8.70	8.23	8.02	8.24
Soot (µg/m^3)	13.20	13.74	14.30	20.07	16.29
PM_{10} (µg/m^3)	38.67	27.19	28.71	40.64	32.78
O_3 (µg/m^3)	45.03	33.72	35.87	33.83	39.21
NO_2 (µg/m^3)	30.20	23.64	27.22	19.86	19.17

*Note: December is not included in the calculation of the average for 2021

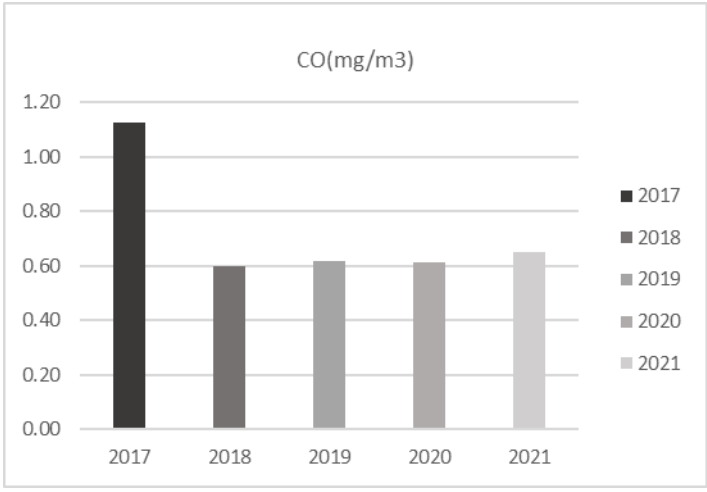

Figure 10. Average annual values of CO in Banja Luka for the period 2017- 2021

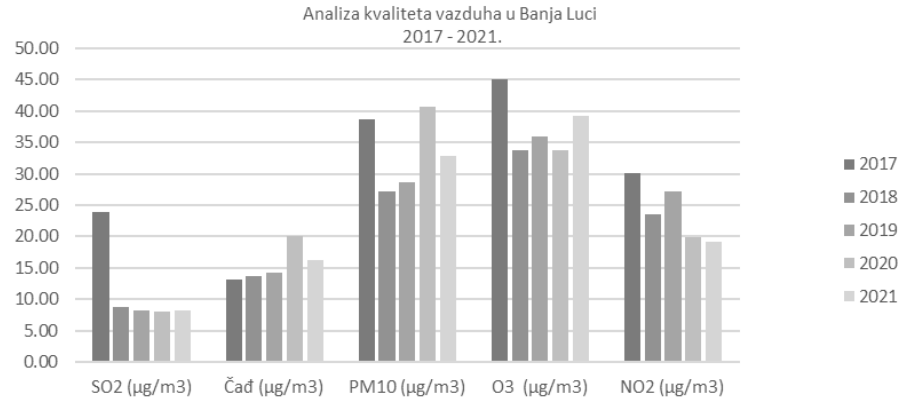

Figure 11. Analysis of air quality in Banja Luka

CO The analysis of data on the concentrations of carbon monoxide in the period from 2017 to 2021 shows a great difference in the average at the annual level in 2017 in comparison to the others. The year 2017 recorded the annual concentration average of CO of 1.13 mg/m^3, while the following four years recorded an annual average of 0.60 – 0.65 mg/m^3. The calculated annual concentration average of carbon monoxide leads to a conclusion that in the observed period the quantity of CO was significantly below average. The limit annual value of CO amounts to 3 mg/m^3, according to the Regulation on air quality values (RAQV, 2012)

SO_2 The analysis of data on the concentrations of sulphur-dioxide in the period from 2017 to 2021 shows a great difference in the average at the annual level in 2017 in comparison to the others, as well as when it comes to CO. The year 2017 recorded the annual concentration average of SO_2 of 23.87 µg/m^3, while the following four years recorded an annual average of 8.02 – 8.70 µg/m^3. The calculated annual concentration average of sulphur-dioxide leads to a conclusion that in the observed period the quantity of SO_2 was significantly below average. The limit annual value of SO_2 amounts to 50 mg/m^3, according to the Regulation on air quality values (RAQV, 2012).

SOOT According to the Regulation on air quality values (RAQV, 2012) the maximum permissible concentration of soot at the level of calendar year amounts to 50 µg/m^3. The concentrations measured in the observed period were significantly lower. The highest annual mean value was measured in 2020 and amounted to 20.07 µg/m^3, and the lowest in 2017 and amounted to 13.20 µg/m^3.

PM_{10} The state of air quality depending on the presence of the atmospheric pollutant suspended solids (PM_{10}), in relation to the recorded concentrations did not change significantly in the observed period. The values of PM_{10} at the level of calendar year ranged between 27.19 µg/m^3 (2018) and 40.64 µg/m^3 (2020). According to the Regulation on air quality values (RAQV, 2012) the limit value at the level of calendar year amounts to 40 µg/m^3. The above stated leads to a conclusion that in the territory of Banja Luka City the most important pollutant in determining air quality is PM_{10}.

NO_2 The analysis of data on the concentrations of nitrogen dioxide in the period from 2017 to 2021, shows that the mean annual values have linearly declined since 2017. The year 2017 recorded the annual concentration average of NO_2 of 30.20 µg/m^3 while it dropped to 19.17 µg/m^3 by 2021. According to the Regulation on air quality values (RAQV, 2012) the maximum permissible concentration of nitrogen dioxide at the level of calendar year amounts to 40 µg/m^3.

CONCLUSION

The analysis of data on the concentrations of pollutants in the period from 2017 to 2021 shows a significant decrease in the concentration of most pollutants compared to 2017. The greatest deviation is observed in the concentration of sulphur dioxide, which is more than three times higher in 2017 compared to others. Sulphur dioxide is present here as a pollutant from anthropogenic sources, i.e., it occurs as a result of direct combustion of fossil fuels, it is prominent where energy sources such as coal and fuel oil are mostly used.

The Regulation on air quality values (RAQV, 2012) prescribes limit values at the level of calendar year. When we compare the values measured in the period 2017-2021, we can notice that the PM_{10} pollutant in 2020 (40.46 $\mu g/m^3$) exceeded the limit value which amounts to 40 $\mu g/m^3$. This leads to a conclusion that that in the territory of Banja Luka City the most important pollutant in determining air quality is PM_{10}.

Significant differences in the air quality of pre-war and post-war Banja Luka can also be noticed, from the aspect of the presence of sulphur dioxide and soot. The main reason for the improved environmental picture is the shutdown of industrial facilities, which were significant polluters of the environment. It is important to mention that the pre-war and post-war period should serve as a basis for understanding some future ecological and economic development of the city. We should not improve the ecological picture by stopping economic development, but we should progress economically in accordance with environmental laws. The main goals of future development programs should be in line with sustainable development. This setting is important because Banja Luka is today a city, which, when it comes to the environment, faces numerous challenges and major interventions in space.

All the above leads to a conclusion that in the post-war period air pollution is significantly reduced[1], and that the presence of sulphur dioxide is at a satisfactory level, showing that the concentration value increases in winter. Also, a significant part of the pollution comes from motor vehicles (constant pollution throughout the year), and a smaller part of the pollution is released by industrial plants. This is also the case with the concentration of soot, so in the post-war period its concentration is significantly reduced, but the highest concentrations of soot occur during the heating season as a result of insufficient combustion of fossil fuels.

LITERATURE

Akhra, A., Fahad, N. C., Saiqa, N., Noshila, Z., & Saba, A. (2015). Causes of Ozone Layer Depletion and Its Effects on Human. *Atmospheric and Climate Sciences*, *6*(01), 129-134.

Cukut, S., Dunović, S., Knežević, N., Nešković-Markić, D., Šobot-Pešić, Ž. i Lazić, V. (2011). Analysis of air quality in Banja Luka city in 2010. Conference proceedings, *XIII YUCORR, International Conference - exchange of experiences in the field corrosion, protection of materials and environment,* (pp 223-230). Tara, Serbia: Serbian Society of Materials Protection.

Catalano, M., Galatioto, F., Bell, M., Namdeo, A., & Bergantino, A. S. (2016). Improving the prediction of air pollution peak episodes generated by urban transport networks. *Environmental science & policy*, *60*, 69-83.

Chahine, T., Baccarelli, A., Litonjua, A., Wright, R. O., Suh, H., Gold, D. R., Sparrow, D., Vokonas, P., & Schwartz, J. (2007). Particulate air pollution, oxidative stress genes, and heart rate variability in an elderly cohort. *Environmental health perspectives*, *115*(11), 1617-1622.

[1] Due to the termination of work of industrial capacities, which led to a kind of pauperisation of the city, but also to the improvement of environmental conditions.

Desonie, D. (2007). *Atmosphere Air Pollution and Its Effects*. New York: Chelsea House Publications.

Hong, Z. & Hu, F. (1999) Advances in theories and methods of air pollution prediction. *Climate Environment Research*, *4*, 225–230.

Ilić, P. (2015). *Air pollution and control in the function of environmental protection.* Banja Luka: Independent University.

Ilić, P., & Preradović, L. (2009). Simulation of pollution, ie modelling levels of nitrogen dioxide and meteorological parameters. *grkg/Humankybernetik*, *50*(3), 146-150.

Knežević, N., Cukut, S., Dunović, S., Komlenić, V., & Lazić, V. (2009). Analyses of air quality in the region of city of Banjaluka. *2nd Symposium of chemistry and Environment*, Bar: Chemical Society of Montenegro.

Kuzmanović, D. (2012). *Analysis of air quality in Banja Luka, in the period before and after the war (1992-1995) (from the aspect of the presence of soot and sulphur dioxide).* Banja Luka: University of Banja Luka, Faculty of Natural Sciences and Mathematics.

Bai, L., Wang, J., Ma, X., & Lu, H. (2018). Air pollution forecasts: An overview. *International journal of environmental research and public health*, *15*(4), 780.

Lolić, B. (1989). *Influence of atmospheric pollution on functional changes in the lungs and the frequency of respiratory diseases in children*. Master's thesis. Zagreb.

Law on Air Protection. Official Gazette of Republic of Srpska, 124/11 & 46/17.

Đurić, N., Božić, N., Babić, R., Stojanović, B., & Vidaković, M. (2015). Monitoring of total nitrogen oxides in the air of the city of Bijeljina. *Archives of Technical Sciences*, *3*(3), 141-148.

Radić, R., Knežević, N., Lazić, V., & Arsenović, B. (2006). Influence of suspended solids on air quality in the city of Banja Luka. *Conference Proceedongs, XX Symposium on Corrosion and Material Protection*, (str.129-134). Podgorica: Montenegrin Society for Material and Environmental Protection.

Regulation on air quality values. Official Gazette of Republic of Srpska, 124/12.

Stern, A. C. (1977). *Air Pollution, The Effects of Air Pollution*. New York: Academic Press.

Silibello, C., D'Allura, A., Finardi, S., Bolignano, A., & Sozzi, R. (2015). Application of bias adjustment techniques to improve air quality forecasts. *Atmospheric Pollution Research*, *6*(6), 928-938.

Scott, G. M., & Diab, R. D. (2000). Forecasting air pollution potential: a synoptic climatological approach. *Journal of the Air & Waste Management Association*, *50*(10), 1831-1842.

Sharma, N., Agarwal, A. K., Eastwood, P., Gupta, T., & Singh, A. P. (2018). Introduction to air pollution and its control. In *Air Pollution and Control* (pp.3-7). Singapore: Springer.

Tang, Y. (1979). Air pollution prediction. *Environmental Pollution Control*, *3*, 10–12.

Yang, Z., & Wang, J. (2017). A new air quality monitoring and early warning system: Air quality assessment and air pollutant concentration prediction. *Environmental research*, *158*, 105-117.

Zhang, Y., Bocquet, M., Mallet, V., Seigneur, C., & Baklanov, A. (2012). Real-time air quality forecasting, part I: History, techniques, and current status. *Atmospheric Environment*, *60*, 632-655.