VERTICAL DISTRIBUTION OF SOLID POLLUTANTS IN SARAJEVO

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The concentration of air pollutants in Sarajevo basin is determined by the pollution from emission zones, and also by the meteorological conditions of the atmosphere, especially during the colder period of the year. Sarajevo basin, as well as all the other morphological depression forms that are basins, are poorly aerated when compared to open morph forms, especially plateaus. In addition, the basins are characterized by thermal inversions during the colder period of the year, of which the most important ones are those that occur with the descending of cold air masses down the mountain slopes into the bottom of the Sarajevo basin. They are combined with radiation inversions, accompanied by the fogs of the same name and can last for several days and weeks in the Sarajevo basin.

During temperature inversions the air is getting richer with pollutants whose concentration often exceeds the allowable limits. These pollutants contain solid pollutants that fall from the air on the surface, which can be covered by the snow that pollutants dirty during the colder period of the year. Snow retains pollutants in situ, at the site of accumulation and without blowing it away. This is reason enough to determine their amount by removing the roof seam layer of snow from a surface unit, filter it in its liquidity and then measure the precipitate.

***Keywords**: pollutants, morphological depression, temperature inversions, radiation inversions, inversion of descending air masses, snow, roof seam layer of snow, precipitate.*

INTRODUCTION

Determination of mass of solid pollutants, which are emitted into the air from the transmission installations over urban centers and industrial areas, is determined by the equivalent of by-products to the total amount of energy consumed. It should be noted that all the quantity of solid particles as a by-product of spent fuels does not remain in the layer of troposphere above the urbanized centers. One part of those is being dispersed by the air masses far from the place of emission even though they are not taken into the calculation of estimates.

The dispersion of pollutants is enhanced by the advection lability of low layers of the troposphere caused by uneven heat capacity of the surface. This phenomenon is more pronounced during the warmer period of the year when, generally, the harmful effects of pollutants in urban air are not felt. The same phenomenon occurs during the colder period of the year in times of unstable or indifferent atmosphere as a result of the negative vertical thermal gradient of moist air when it is being mixed intensively. In such circumstances, the pollutants are dispersed and taken far from the emission zone which makes their concentrations decrease and they cease to be life-threatening. During the stable atmosphere, when the vertical thermal gradient of dry air is positive, then the air temperatures increase with altitude and do not allow advective mixing of air and, in that way the dispersion of pollutants far from the emission centers. This is the most difficult situation when participation of pollutants in the air exceeds the concentration allowed for living by several times.

To determine the total amount, in this case the one of solid pollutants, we used the method of field sampling from snowy surface defined areas by the vertical profile of the Sarajevo basin; from its Bascarsija bottom (530 m) to the Vidikovac (1164 m) with the northern exposures and the control slope of southern exposures up to Crepoljsko (1524). The sampling of solid pollutants from the snow surfaces was performed at altitudes by the equidistance of 100 m. This phase of the research was carried out at the end of stable anticyclonic weather in which the temperature inversions occurred, with cyclonic weather condition of unstable atmosphere in which the temperature inversions were gone. Snow samples were collected into flacons and filtered in the laboratory and then their mass was measured with the analytical scale.

THE CLIMATIC POSITION OF SARAJEVO

The climatic position of Sarajevo is determined by climatic factors that define climatic elements and climate phenomena. Sarajevo is urbogenetically related to the central part of Sarajevo basin, which, in the regional-geographical terms, belongs to central Bosnia and Herzegovina and the sub-regional unit of Sarajevo-Zenica basin. Sarajevo urban complex covers southeastern part of this spacious and also the biggest basin within the Bosnian Dinaridic Mountains, as well as its peripheral parts, which end on the slopes of Trebevic and Crepoljsko, whose altitudes exceed 1000 m. On the far east end where Miljacka ends its gorge valley in Sarajevo field, the oldest urban nucleus of Sarajevo was formed. Sarajevo is also the capital of the Canton of the same name, which contains, apart from the four city municipalities: Stari Grad, Centar, Novo Sarajevo and Novi grad, also the municipalities of Vogosca and Ilidza. All these administrative units are well connected with city’s urban area and there is no evident difference of the whole urban system.

Sarajevo is a nodal core, which has a functional centrifugal conurbation competence within the same Canton, to which, apart from the above mentioned municipal administrative units, belong also: Hadzici in the southwest, Ilijas on the northeast and Trnovo in the southeast.

Sarajevo, with an average annual temperature of 9,5°C and an average precipitation of 932 mm, mostly belongs to depression-type of thermal regime of the continental variant, and according to the indexes of Köppen it belongs to Cfbx” which includes Sarajevo in the moderately warm and humid climate with warm summer and without the dry season. (Spahic, 2002). Climate postcard of Sarajevo needs to be complemented with specific thermal regime which is formed under the influence of temperature inversions which are characteristic of the colder part of the year and are followed by the radiation fogs in the transitional seasons, but rarely with advective fogs during the colder period of the year.

In the distribution of annual average temperatures (Fig. 1) the coldest month is January (-1.2 °C) and the warmest month is July (18.8 °C), so the average annual fluctuation is 20.0°C. During the year, the occurrences of frosty days are common in Sarajevo (days with an average temperature of less than 0°C), which are influenced by weather conditions, mostly by the radiation and advection. Such weather conditions are especially expressive in the Sarajevo basin and last on average for 93.4 days. In relation to the frosty days, the number of summer days (days with an average temperature higher than 25°C) in Sarajevo and its surroundings, is smaller and in average, during the year, there are 66.4.

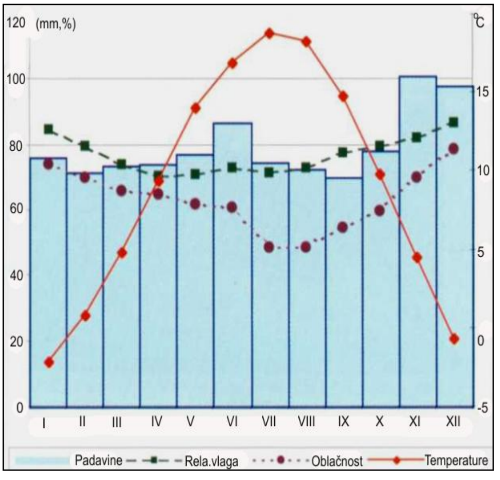

Fig 1. Climatic chart of Sarajevo with the average state of climatic elements and phenomena

Source: Spahić (2000)

Precipitation in the Sarajevo basin is within the limits of those in Sarajevo-Zenica basin and the average amount is 956 mm. They are fairly evenly distributed over the year in which the average maximum of 101 mm occurs in November and the average minimum of 70 mm occurs in September. On the average, the maximum amount of precipitation is 2106 mm, and the lowest annual average amount is 181 mm, so the ratio between these two values is 11.5:1.

Average annual cloudiness in the urban system of Sarajevo is 63%, which means that during an average year, more than the half of the sky is covered by the clouds. A warmer period of the year is brighter compared to colder period and that ratio is 69, 8%: 56, 8%. The annual distribution of bright and hazy days depends on the cloudiness. Above the Sarajevo there are 59, 9 clear days (days with the cloudiness lower than 20%) and 128, 6 hazy days (days with cloudiness over 80 %.)

Fogs in Sarajevo are quite common. During the year, Sarajevo, on the average, and especially its western lower part is fogged for 53.2 days, of which an average maximum of 8.6 days occurs in December and the minimum in July – 3, 1 days.

The annual flow of real insolation for the Sarajevo area is 1829.1 hours, which is 5.0 hours of average sunshine per day. According to these data, Sarajevo is placed among the averagely sunny places in our country. Aeration of Sarajevo basin is rather poor. The prevailing winds in it are from the eastern and western quadrants and are accounted for 30.5% of the total of the wind rose. The average annual duration of silence is 25.6%.

TEMPERATURE INVERSIONS ARE AIR POLLUTION IN SARAJEVO

Genesis and characteristic of inversion of lowering cold air masses

In special weather conditions, when the vertical thermal gradients is positive in closed relief depressions in form of valleys and basins, occur thermic turnovers that belong to the temperature inversions, thermic turnovers or frosts areas, as they are popularly called. For the occurrence of these phenomena, two conditions must be met: fully stable atmosphere or anticyclone weather and relief horizontal diversity of morphological depressions in the forms of basins and valleys within the mountainous morphological amphitheatric structure.
Anticyclone weather conditions causes the stratification of the atmosphere, whereby the lateral lifts are very strong which force slightly warmer air on the rapid vertical expansion

during which it is intensively cooled down. In the higher layers where the lateral lifts are weaker, the air expands, loses its energy and then it intensely cools down. Anticyclone weather condition implies the absence or much weakened air advection, high air pressure, generally reduced humidity and increase of turbulent variability which occurs with ascendant expansion of warm air at the higher altitudes and descendant subsidence of the colder air from higher to lower altitudes.

Fig. 2. Sarajevo basin overflowed with radiation fog at the time of temperature inversions

If anticyclone weather conditions occur in morphological depressions, then this turbulent pattern of warm and cold air complicates with the heat capacity of the substrate, which, during the day, affects the unevenly heated mountain peaks, mountain slopes and the bottom of the basins and valleys where the lower parts are warmer and the bottoms of the basins and valleys are the hottest. During the nighttime cooling, the air that is stationed on the surface of the basins and valleys, mountain slopes and mountain peaks is being cooled down. The mountain peaks and high mountain slopes that are heated during the day the least are cooling down the fastest, and depressions and valley bottoms are cooling down the slowest. Most heat is radiated from the surfaces of lower altitudes, so their heat expands into the highest altitudes, where it cools down and accumulates on the mountain peaks and the highest mountain slopes. Cool air from these altitude begins in the late night and early in the morning, to ''glide'' down the mountain slopes towards the area of expanded warm air at the bottom of the basins and valleys, cooling down the remaining slightly warmer air. This is how the radiation fogs occur; first thin, and during the reconstruction process of the following nights, their thickness increases so the fog is not rising during the coming days and is not dispersing. At the higher altitudes where the air is slightly cooler the radiation processes are weaker and therefore the radiation fogs are not formed.

The consequence of these conditions during the stable weather causes the daily warming of mountain peaks and their high slopes, while the low mountain slopes, the bottoms of the valleys and basins are overflowed with the radiation fogs that prevent the penetration of the solar radiation, so they have decreased daily heating. This leads to slightly lower temperatures of air in the valleys and basins in relation to the mountain peaks and their slopes. They can reach up to 6°C. During the day, mountain peaks and mountain slopes are very sunny, the sky is intensely clear; temperatures are more comfortable so the weather is nice. At the same time, at the bottom of the valleys and basins reins the foggy, cold and depressing weather, which, according to the meteorological terminology belongs to the bad weather.

Air pollution in the inversion layer

Foggy weather condition in basins and valleys can last as much as anticyclonic condition of the atmosphere. The longer it lasts, the colder, foggier and smokier it gets. In the inversion layer the air is stationed and it’s not rising above the inversion layer, because, above it a slightly warmer air is stationed that encourages its indifference so the air expands in the inversion layer at the closing of its height and it diverges to the edges of the basin or valley slopes.

The inversion of descending air masses takes place during the colder part of the year, when is the heating season, usually from the fossil fuels which produce a large amount of pollutants that dirty air in the city. The city traffic contributes to the participation of the pollutants in urban areas. The share of pollutants in urban areas depends from the pollution of the emission zones, type of fossil fuel and its energetic usability.

The smaller amounts of pollutants are being emitted by the natural gas, then oil and the biggest amounts are emitted from the coal. Coal with less heat capacity and less energy usability, produces extremely large amounts of pollutants that contaminate air. Their accumulating reaches the inversion layer in urban air due to lack of advection and extremely poor air turbulence.

Annual distribution of climatic elements in Sarajevo, which is located in the bottom of the Sarajevo basin, framed by the mountain terrain with valley, but truly narrow, openness to the east and west, regularly during the cold periods of the year, causes the occurrence of temperature inversions followed by the radiation fogs which are contaminated by the pollutants. Smoky and dirty fog is called smoke or smog. Pollutants over Sarajevo are present even during the summer but are reduced for the emission of thermal plants that are used to heat the living spaces. Pollutants in Sarajevo air, during the summer anticyclonic weather are produced by the public city transport and it forms photochemical smog. Fumigation is more common and it refers to the smoky fog, that is, as already mentioned, a side effect of the temperature inversions conditioned by the orographic set around Sarajevo field.

Smog is made of pollutants, usually smoke and soot, and those are usually formed as a result of burning fuel combustion, particularly fossil ones such as: coal, fuel oil and natural gas. Smog is emitted separately, as noted above, from the furnaces that generate heat; mostly heating plants, thermal plants and home furnaces. Pollutants are excreted by the cars as well, that burn fossil fuels. In addition to the above mentioned causes of the formation of smog, industry participates as well, especially dirty industries, such as: steel, cement and chemical industries. The pollutants that form smog usually include: Sulfur dioxide, nitrogen oxide and carbon monoxide. In addition to these, air pollution is caused also by the particulate matter such as: smoke and soot.

Sarajevo's air above the urbanized area is burdened with all kinds of pollutants, especially sulfur dioxide, nitrogen oxide, carbon monoxide, smoke and soot, for which there are three automatic monitoring stations and four locations of occasional air sampling. The monitoring data indicate the high level of participation of pollutants in the atmosphere above Sarajevo during the colder periods of the year, when their concentrations for the several times (for the 4 to 10 times), during the December of 2013 exceeded the maximum allowed value. The maximum permissible concentration of sulfur dioxide participation per one hour is prescribed at 350 μg/m^3, and in one day at 125 μg/m^3. During the year, the permissible concentration of sulfur dioxide must not be higher than 50 μg/m^3. The maximum concentration of nitrogen oxide per hour can be up to 200 μg/m^3, for one day up to 85 μg/m^3 and for one year the maximum concentration is defined up to 40 μg/m^3 of air. Maximum allowable values for carbon monoxide for one hour are 10 μg/m^3, one day 5 μg/m^3 and for one year up to 3 μg/m^3. The prescribed maximum permissible concentration of suspended particles for one day goes up to 50 μg/m^3, and for one year 40 μg/m^3 of air. (Air protection Act. Slobodne novine 4/10)

VERTICAL DISTRIBUTION OF POLLUTANTS

To determine the vertical distribution of solid pollutants in the Sarajevo basin in the absence of hypsometric monitoring, the first study was carried by the author in 1989, and then control study was conducted in 2009. Both studies were at the end of the anticyclonic weather. The beginning of anticyclonic weather marked the end of snowfall, and then began the period of temperature inversions and accumulation of solid pollutants on the snow. Snow is suitable for absorbing solid pollutants due to their permanent in situ presence without the possibility of blowing them off and accumulating them elsewhere. On the other hand, snow cover represents the ideal surface for the sampling of solid pollutants, because it sufficiently abstracts unevenness and vegetation cover.

Sampling of solid pollutants – the soot, as already mentioned, was done from the snow surface areas of 1m^2 per hypsometrical levels of equidistance of 100 m, on the profile from Bascarsija – Vidikovac. The same was done on the profile Bascarsija – Crepoljsko. When sampling the soot from the snow surfaces, attention was paid to the date of beginning and the end date of the snowfall, as well as the term boundaries of the start and the end of inversion states of temperatures in Sarajevo. In addition, at the Hydrometeorological Service, we closely monitored the data on concentrations of solid pollutants in the air above Sarajevo which served in this study as comparative data.

With quantitative determining of collected solid pollutants from the snow surfaces, it shows their distribution on the southern vertical profile from Bascarsija to Trebevic, which was identical to the one of the control profile Bascarsija – Crepoljsko. Distribution of the solid pollutants of vertical profile of the equidistance of 100 m is given in Table 1. Sampling of solid pollutants was done from the snow surfaces during the period of temperature inversions which lasted 10 days, from January 29th to February 6th in the 1989. The entire procedure of taking samples was tested a decade later. In both cases, the share of solid pollutants on snowy surfaces was almost identical.

Table 1.: Hypsometric quantitative distribution of solid pollutants by equidistance of 100 m on the profile Bascarsija – Tribasic, in the period from January 3rd to February 10th in 1989.

THE PLACE OF SAMPLING	Latitude (m)	Area km^2	Solid pollutants – soot (gr/m^2)	Total kg/km^2
Bascarsija	Up to 500	28,94	0,013	376,2
Bistrik (old railway station)	501 - 600	77,68	0,010	776,8
Hrid	601 - 700	44,01	0,024	1056,2
Bistrik - crossroads	701 – 800	26.77	0,016	428,3
Colina kapa	801 – 900	20,57	0,006	123,4
Kosmatica	901 – 1000	16,39	0,002	32,6
Trebevic - Vidikovac	1001 - 1100	12,52	0,000	
Total:		226.88		2,79 tons

From the Table 1, it is evident that the maximum concentration of solid pollutants contained on the surfaces of the snow was registered at the hypsometric position of 700 m and toward the higher altitudes this concentration decreases. The upper border zone to which the solid pollutants are distributed is of the altitude of 900 m, which clearly indicates the completion of the inverse layer above which there is no disposal of solid pollutants. Increased distribution of solid pollutants around hypsometrical levels of 700 to 800 m is explained by their horizontal dispersion up to the upper inversion layer. The share of solid pollutants deposited on the snow surfaces at higher altitudes is dramatically reduced because of their surpassing of the inversion layer of the air.

Based on the data of vertical distribution of solid pollutants it is possible to computationally reach the indicators of the overall quantitative burdens of certain hypsometrical levels by the pollutants and in the whole Sarajevo valley.

The share of the vertical distribution of solid pollutants in the Sarajevo basin directly allows the definition of the height of the inversion layer. According to the tabular data, the most common upper layer of fumed fog is up to the 800 m at most, and mostly at 700 m, i.e. it seizes the low layers of air above the Sarajevo up to the 300 m of relative height at most. According to the meteorological monitoring those are usually the most common heights of the radiation fogs as well.

DISCUSSION AND THE CONCLUSEION

In the absence of a monitoring divided at the vertical profile in Sarajevo basin, as well as the inadequate distribution of existing at the bottom of the valley, it was necessary to collect the samples of the solid pollutants deposited at the snowy surfaces using the indirect methods, and in order to calculate their distribution on the surface of equidistance of 100 m. Based on collected data on amount of solid pollutants on snowy surfaces, which were the most suitable for this task because of their stability in situ, some other parameters were detected as well, especially those on the heights of inversion layer in which the concentration of those pollutants was the highest.

According to the research results, it was shown that the largest concentration of pollutants was not at the lowest altitudes but that their quantity increases with altitude. The maximum concentration of pollutants was recorded at the relative altitude of about 300 m in relation to the starting point of measurements in Bascarsija. At first it is illogical but with deeper and comprehensive meteorological analyses it is accepted as very explanatory because the inversion of temperatures has its lower (topographic) and it’s upper (dry adiabatic) thermal boundary.

The lower boundary is permanent, while the upper boundary changes depending on the atmospheric stability. If the temperature changes for the dry adiabatic state of lower layers of the atmosphere are stable then the height of the inversion layer is higher and when these changes are in the phase of impaired stability or indifference, then the inversion layer is lower. This proves the maximum distribution of pollutants per vertical profile. During the stable atmosphere, the height of the inversion layer, bordered by the height of radiation fog, is 300 m at maximum. Its upper layer can’t go through, lifting slightly warmer air from the thermal plants and home furnaces. After the vertical thermal expansion the warmer air at the height of upper inversion layer is advectivelly being dispersed toward valley slopes, on which it deposits pollutants, and then, as the cooled air it goes down the slopes toward the bottom of the valley. The highest concentration of the deposited pollutants on the valley slopes defines the upper layer or thermal inversion above the Sarajevo.

Participation of pollutants in the air above the urbanized zone of Sarajevo is far higher in the colder period of the year compared to the warmer period. Namely, in the colder period of the year, the fossil fuels are burned for the heating of apartments, as well as because of the specific inversion weather conditions, which promote pollutant concentration. Since the heating season in Sarajevo lasts six months and under condition that the temperature inversions are common – then, on the urban surface during this period shall be suspended a total of 50 tons of solid pollutants.

The highest concentration of solid pollutants produced in the upper inversion layer at altitudes of 700 m, where more than 1 ton of solid pollutants is delayed in just 10 days. This data disproves the established hypothesis that higher altitudes of basin slopes are more comfortable and healthier to live in, compared to the valley bottom.

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