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AIRTHINGS

European Union
European Regional Development Fund

REPORT
Results and suggestions for locating the network of sensors for monitoring the atmospheric air quality - Summary

Pursuant to

Contract SOA 18-GD 55-496/27.08.2018,

subject "Analysis of the appropriate locations for realization of a network of sensors for observation of the atmospheric air on the territory of the Sofia Municipality"

MINISTRY OF REGIONAL DEVELOPMENT AND PUBLIC WORKS
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TABLE OF CONTENT

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Air pollution is one of the main environmental issues that need to be addressed in the EU, since clean air is essential for the good health and a major human need. EU legislation recognizes this need by providing legal protection through Directive 2008/50 / EC, which imposes strict restrictions on atmospheric air pollution levels. There are EU standards for fine particulate matter (PM_{10}), ozone, sulfur dioxide, nitrogen oxides, lead and other pollutants that may have adverse effects on human health or ecosystems. Directive 2015/1480 sets out rules on reference methods, validation of data and the location of sampling points for the assessment of atmospheric air quality.

According to the Bulgarian National Legislation, the main responsibility for establishing and observing policies on air cleanliness and monitoring of atmospheric air quality is the Ministry of Environment and Waters. Undeniable fact is that all public authorities, including local authorities, must take legitimate and coordinated measures to ensure clean air. Under the CAA Art.(2) Municipal authorities, in coordination with the Minister of Environment and Waters, may establish local systems for monitoring and control of the atmospheric air quality (AAQ) in areas within their territory.

That is why improving of the atmospheric air quality is a key priority for the municipality. A number of large-scale measures have been taken and carried out in all sectors concerning air pollution and reducing atmospheric pollutants.

Sofia Municipality is one of the six Areas for Assessment and Management of Atmospheric Air Quality - Agglomeration - Sofia, approved by Order No. 969 / 21.12.2013 of the Minister of Environment and Water in relation to the implementation in 2013. zoning of the country.

At the national level, the AAQ on the territory of the Sofia Municipality is controlled with 7 automatic measuring stations (AMS) – 5 in Sofia City, included in the National Environmental Monitoring System of the Ministry of Environment and Waters, whose data are sent to the European Environment Agency.

1. Requirements related to the type, location and range of atmospheric air monitoring sites

The monitoring stations have the following classification:

• **Transport-oriented monitoring stations** are those where the number of vehicles crossing a circle with a radius of 50 m is not less than 2500 vehicles per day.
• **Industrial-oriented monitoring stations** are those where there is a predominant impact of emissions from production and other activities.
• **Urban background monitoring stations** are those located in a built-up area of a city that do not meet the criteria of point 2.
• **Out-of-town background monitoring** stations are located 3-10 km away from a city that does not meet the criteria of items 2 and 3.
• **Regional monitoring stations** are located 10-50 km from a city that does not meet the criteria of items 2 and 3.

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• **Remote monitoring stations** are located more than 50 km from a city that does not meet the criteria of items 2 and 3.

2. Technological requirements necessary for the selection of sensors for measuring ambient air quality

Detection range and detection limit: Environmental pollutants can often be present at very low concentrations, especially when measurements are made away from the source of contamination.

Precision & Deviation: Accuracy and deviation are terms that refer to the accuracy of sensor measurement. Accuracy is the overall agreement of measuring the sensor with true value.

Calibration requirements identification: Calibration is the process of checking and adjusting the instrument measurements to ensure that it reads accurate data. Calibration compares the instrument's reaction with a known reference value.

Reaction time. The sensor may be fast or slow to measure a pollutant in the air. A sensor that reacts quickly can be useful for mobile monitoring and monitoring of very rapid changes in pollutant concentrations.

Endurance and construction quality check: Resistance refers to the sensor's ability to withstand wear and work.

Packaging: "Packaging" refers to the material used to retain the components of the sensor system. The packaging can be used to provide protection against water, light, temperature fluctuations (by adding heaters or fans) and electromagnetic noise.

Sensor Usability: Usability refers to the ease of use of the sensor.

Price: The value of the sensor technology may vary considerably depending on the pollutant being measured and the degree of accuracy and sensitivity it needs.

Potential "Red Flags": When investigating a sensor, it is important to take into account the demonstrated performance, repeatability, and feedback from past users.

3. Quality of the sensor collected information on air quality

The five basic steps for collecting useful data with air sensors are (1) asking a question, (2) developing an approach, (3) determining the location of the sensor, (4) collecting measurements, and (5) understanding and reporting the results.

- **Ask a question.** It is important to take the time to identify and document clearly what kind of question you would like to answer before starting to develop your measurement collection plan. A simple question, such as "Do you have higher concentrations of ozone in the afternoon than in the morning in my neighborhood?" can help you get started.

- **Develop an approach.** Once you have the question you want to answer, it's time to plan how the measurements will be made. Consider these questions:
  - ✓ The size of the problem.
  - ✓ Who, what, where, when and how. Who will take the measurements? What measurements are needed? Where and when should measurements be made? How much time should the measurements take and how should samples be taken?
  - ✓ The number and quality of sensors needed.
  - ✓ The means (e.g. funding, knowledge) and the work that will be needed.
  - ✓ How the data will be collected and stored.
  - ✓ How will you ensure that your data is of good quality and the degree of quality you need?
  - ✓ What additional data (such as meteorology, other pollutants, site information) are needed to answer your question?
- **Determining the location of the sensor.**
- **Why this matters**: Concentration of air pollution can be significantly affected by local sources, buildings and other structures, among other factors.
- **Collecting measurements**. With its measurement approach, which is clearly defined and the sensor is correctly located, data collection begins.
- **Analyzing and interpreting the results**. The way in which audience performance is presented is crucial to successfully sharing data comprehension and achieving the sensor-based air quality data collection objectives.

4. Technical requirement for the information systems and sensors

Air quality monitoring is a complex and high-tech process that depends not only on the complex nature of atmospheric air characteristics in different parts of Sofia's urban territory but also on the quality and parameters of the sensor system used and their specific localization. Although it may take years to get a comprehensive understanding of air pollution, there are some basic principles and conditions that are essential for the future system. The reporting of those will provide a good basis to build an adequate system of continuous monitoring of the air quality characteristics of the city and associated adjacent territories. Below are listed some of these basic conditions and principles to be considered when making air quality measurements:

- **Location selection**: Many pollutants have high spatial variability, i.e. their concentration varies over long or even short distances. This makes the sensor place a very important factor in the design of any monitoring study or system. Concentrations for most pollutants will almost always be highest near the source and will decrease rapidly within the first few hundred meters of the source. If multiple sources are widespread in a given area, pollutant concentrations may be more similar but will still change from location to location. Other factors, including type of pollutants and local atmospheric conditions, will also influence the variability of the concentration of a pollutant. Careful research on finding the sensor type will play an important role in determining whether the data that is collected is representative and useful.

- **Pollutant type:** Some pollutants can be emitted directly from the source (primary pollutants), while others can be formed as products of chemical reactions in the air (secondary pollutants). Primary pollutants are often more localized (i.e. close to the source) and may have greater variability in distances from secondary pollutants. It is important to consider whether a pollutant is of primary importance or of secondary importance in deciding where and how to collect monitoring data. Whether the pollutant comes from artificial or natural sources (or both) is also an important factor. While measurements usually focus on man-made sources of pollution, all known sources should be taken into account when developing a monitoring study. Pollutants coming from unknown sources can compromise the usefulness and accuracy of the data retrieved.
- **Meteorological processes -** including sunlight, temperature, humidity and clouds - can affect the concentrations of the pollutants. For example, stagnant air may lead to a gradual increase in concentrations of pollutants, while strong winds can reduce concentrations by spreading pollutants in a larger geographic area. Understanding how climatic conditions can impact pollution concentration and data collection is important in gathering accurate information and interpreting trends in data;
- **Pollutant variation over time:** Concentration of pollutants may vary considerably depending on the time of the day, the day of the week and the season. These differences can be attributed to changes in emission patterns, temperature, schedule of source activity (e.g. weekly traffic patterns) and differences in forming processes. Daily, weekly and seasonal variations are important considerations when developing a measurement plan and will guide the timing and conditions under which measurements are to be taken.
- **Sensor response time:** This is a key attribute in determining whether true pollutant fluctuations can be captured. The detection of a fast changing or short-lasting pollutant jet may be important in seconds. In other applications, such as monitoring overall trends in outdoor air quality, detection of tens of minutes may be enough.

Another very important element is related to what information should be collected, which will at the same time be relevant to the detection of those pollutants in the air that are of interest to the monitoring system. In this regard, some important requirements for the future air quality system in Sofia should be taken into account.

The most important of these are:

- **Air pollutant of interest:** Pollutants: SO_2, NOx, ozone, CO, CO_2, methane and benzene. Pollutants solid particles are: $PM_{2.5}$, PM_{10}, lead and black carbon.
- **Type:** Pollutants can be directly emitted (primary pollutants) or formed in the atmosphere by chemical reactions (secondary pollutants). CO, emitted directly from

incineration processes (such as exhaust gases) is an example of a primary pollutant. Ozone formed by the reaction of NOx and volatile organic compounds in the presence of sunlight is a secondary pollutant. Some pollutants, such as PMI, may have both primary (e.g. "Black carbon", i.e. soot - the most absorbing light component of PM produced from solid fuel and diesel engines) and secondary (e.g. sulphate, nitrate) components.

- **Detection Limits:** The detection limit is the lowest environmental pollutant concentration that a sensor or other tool can routinely detect. Detection limits are set to inform citizens and scientists about what limits for detecting sensors would be practical.
- **Scope to be expected:** Concentrations near the sources (in the vicinity and in the wind direction of a large power plant or on the road, for example) may be at the upper end of the range or even higher. On the other hand, pollution in an area that is not close to a particular source is more likely to be at the low end of the range.

According to the AIRTHINGS project's concept for a air quality monitoring system, each measuring station (22 in total) must be equipped with sensors to measure PM_{10}, $PM_{2.5}$, CO, NO_2 SO_2, O_3, temperature, humidity and pressure. All measured values must be transmitted in a continuous mode to the station (via a communication module), as electrical quantities or by a serial protocol containing the values of the measured electrical quantities. In order to minimize the possibility of emergency (especially considering that the equipment is directly located in an open environment), the project envisages the connection of the sensors to the measuring station by means of electric conductors, securely secured by suitable couplings, without soldering of the sensor wires to the electrical elements of the station.

In order to ensure the collection of reliable information on air quality in Sofia, taking into account both the principles and conditions set out above and the requirements of existing regulations, the respective sensors and their minimum technical characteristics, which should operate as a unified automated system.

Based on the requirements of the legislation and the specificities that will be taken into account when sensors are located (technical, climatic, etc.), there are the minimum technical requirements for the sensors, which are described in detail in the previous report.

On the basis of the elaborated analysis we can make the following main conclusions regarding the technical characteristics of the sensors and their localization requirements:

- The planned and projected scope of the measuring component of the air quality monitoring system in Sofia is fully in line with the requirements of the current regulatory framework in this regard. In view of the functions and purpose of the future system, there are basically two types of monitoring points - Transport-oriented monitoring stations and City-based monitoring points;
- The minimum technical requirements for the sensors are in accordance with established standards for such systems and are technologically capable of providing the necessary information on air quality in sufficient volume and quality;
- Technologically, with a view to establishing an adequate location for sensors, it is necessary to take into account both sources and concentration zones of pollutants and

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the availability of relevant technical capabilities, including in terms of power supply and communication connectivity;

- It is noteworthy that in determining the minimum requirements for the sensors there is some variation in the requirements to the environmental conditions in which they should operate. For example, for some sensors, a range of -10 and +50 ℃ (for example, carbon monoxide sensor requirements) is set, and for others - from 40 to + 85 ° C (for weather sensors). Additionally, a temperature that is set for the entire measuring station is from -10 ° to + 50 ° C. This diversity of requirements could make it difficult to get the stations together and bring them into operational mode. At the same time, the requirement for the system to operate only above -10 ° suggests that the monitoring process may be interrupted at certain times because temperatures may fall and remain below this level during the winter period, especially in temperature inversion conditions;
- Many pollutants have high spatial variability; their concentration varies over long or even short distances. This makes the sensor site an important factor in the design of each monitoring study. Concentrations for most pollutants will almost always be highest near the source and will decrease rapidly within the first few hundred meters of the source. If multiple sources are widespread in a given area, pollutant concentrations may be more similar but will still change from location to location. Other factors, including type of pollutants and local atmospheric conditions, will also influence the variability of a pollutant's concentration. Sensitive positioning of the sensor will play an important role in determining whether the data that is collected is representative and useful.
- Concentration of pollutants may vary considerably depending on the time of the day, the day of the week and the season. These differences can be attributed to changes in emission patterns, temperature, source activity schedule (e.g. weekly traffic patterns) and differences in forming processes. Daily, weekly and seasonal variations are important considerations when developing a measurement plan and will guide the timing and conditions under which measurements are to be taken.

5. Classification of the localization factors

- Genetic (basic) factors

❖ Transport

Transport is the main and permanent source of emissions on the territory of Sofia Municipality. The fleet in our country mainly consists of imported, second-hand diesel cars. Apart from the use of old cars in Bulgaria, there is another problem related to the deliberate removal of catalysts and particulate filters due to their high cost of replacement at the end of life of these parts or their theft due to the precious metal content. The problem is at the national level, but given that the fleet of Sofia Municipality is the largest, the problem will not only continue to exist but also deepen if no action is taken.

The intensity of road traffic over the last few years is very dynamic, both in day hours and in different days and seasons. Due to the repairs and construction of new sections of the subway, the organization of the traffic was changed in some parts of the city. Some of the lines are closed and drivers prefer alternative routes. These circumstances lead to congestion in other areas, especially at peak hours. The columns formed the long-term operation of motor vehicles at low revs and the climatic conditions (low temperature and low speed of air movement) determine the level and retention of pollutants in the ground layers.

Figure 1. Typical traffic in Sofia – example 1

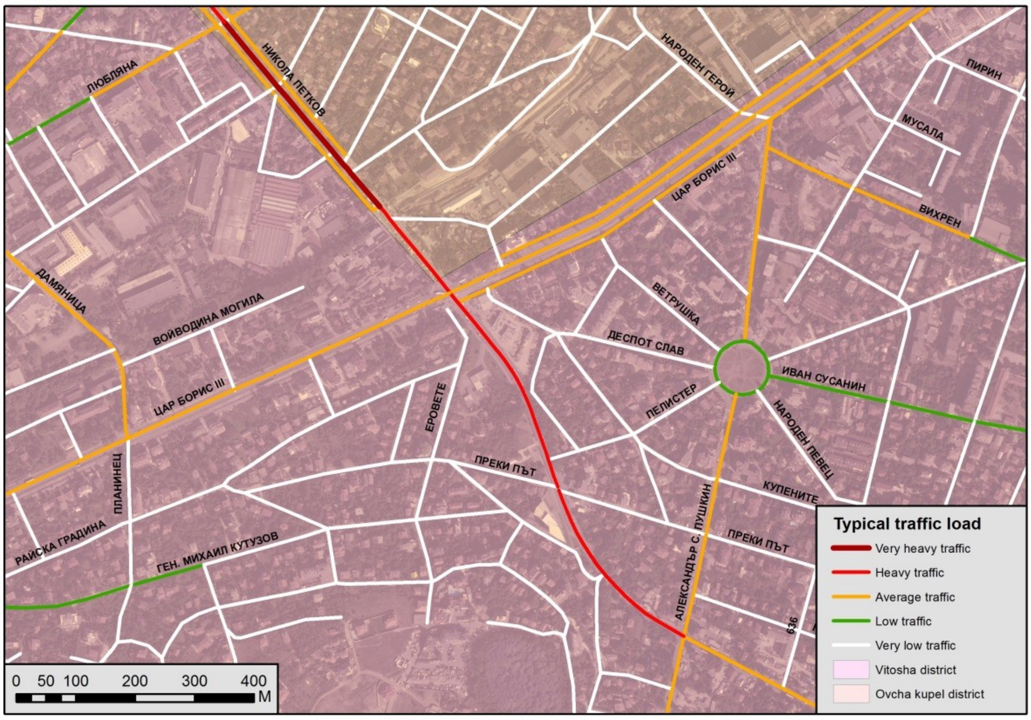

Figure 2. Typical traffic in Sofia – example 2

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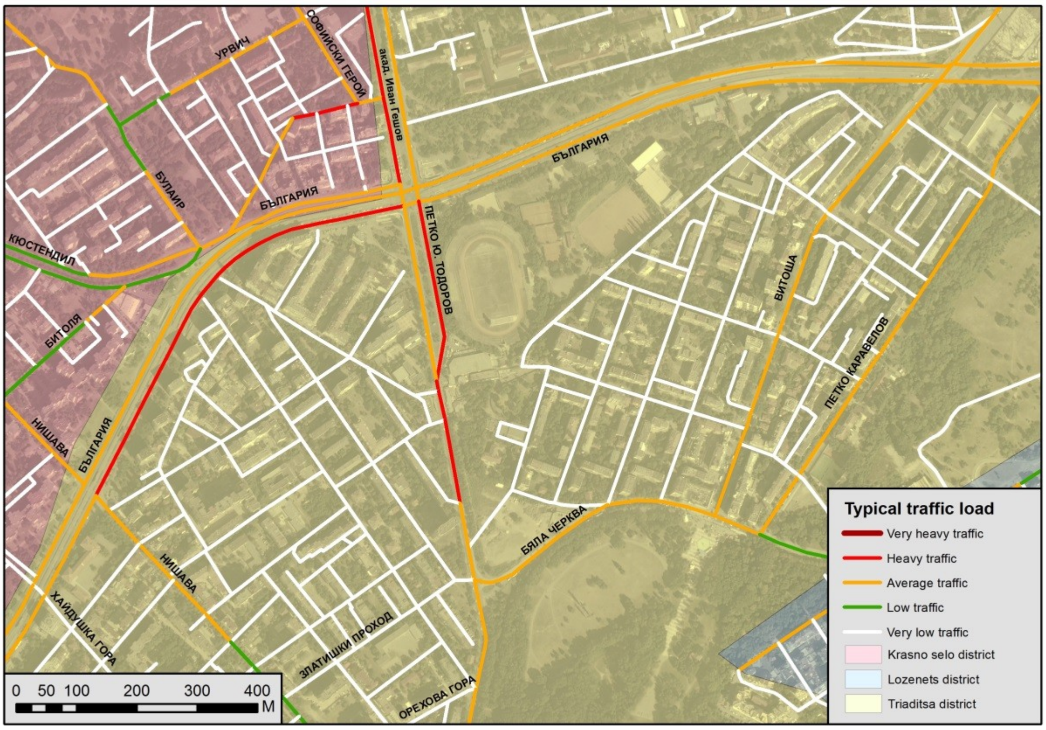


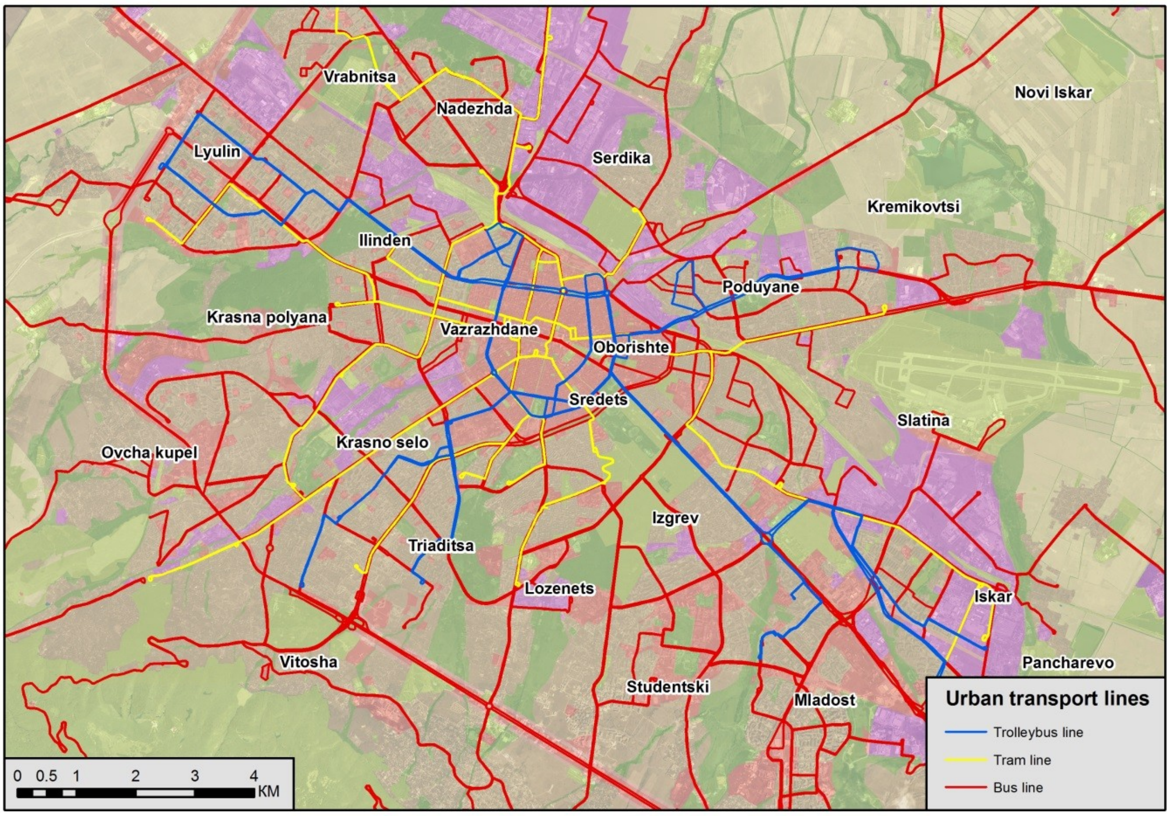
Public transport

Bus transport is the main transport to the capital. Annual travel trips are 260 million, compared with tram travels is 2 times more, 4 times more with a trolley and 10 times more with a subway. The bus routes are in minimum limits, sometimes duplicated by trolleybuses and a part of them are subject of closure. There are 101 Lines (by 2018), of which 49 are urban routes with a length of more than 2500 km, with an average distance between the stops of 625 m, an average operating speed of 19.4 km / h and a length of the bus network of 1 289 km. (2009 data).

There are two types of lines in the tramway - narrow and normal, with the former prevailing. The number of lines is 14, the length of the routes is 286.21 km, the average intercity distance is 92.5 m, the average operating speed is 12.7 km / h. Towards the end of 2016 the tram network in Sofia is 137 km using 2 types of lines - 1009 mm gauge and 1435 mm normal gauge. Tramway transport has partial upgrades on some of the new routes, but modern management systems have not been introduced. In the morning peak period, 150 trams run along the network.

At present, trolleybus services serve up to 60 million passengers per year with 9 lines with a length of 194.48 km, an intermediate intersection of 470 m, an average operating speed of 14.4 km / h and a trolley network length of 112 km.

Figure 3. Urban transport scheme in Sofia



Source: Urban mobility center

The metro is a transport, developed only in Sofia and commenced operation on January 28, 1998. The subway currently has 2 lines with a total length of 39 km and 34 metro stations. Metrodiameter 1 is in the direction northwest - southeast. The construction was started in the 1980s and by 2015 it has a total of 23 stations and a length of 28 km. Metro 2 is on the north-south direction. The stations of the National Palace of Culture and the Hemus Hotel were built during the construction of the National Palace of Culture (NDK) in the 1980s. The line was put into operation on 31 August 2012. Metro 3 will be in the southwest-northeast direction. The construction of the first stretch began in 2015.

Figure 4.Metro scheme in Sofia, incl. the third metrodiameter (still in constructions)

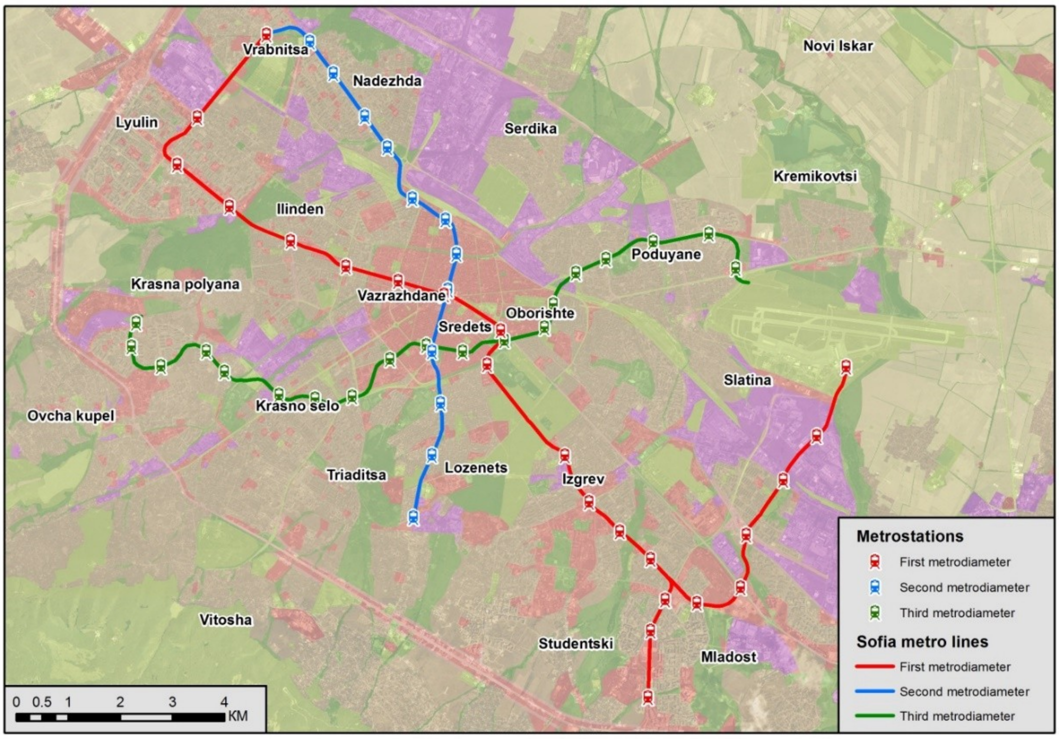
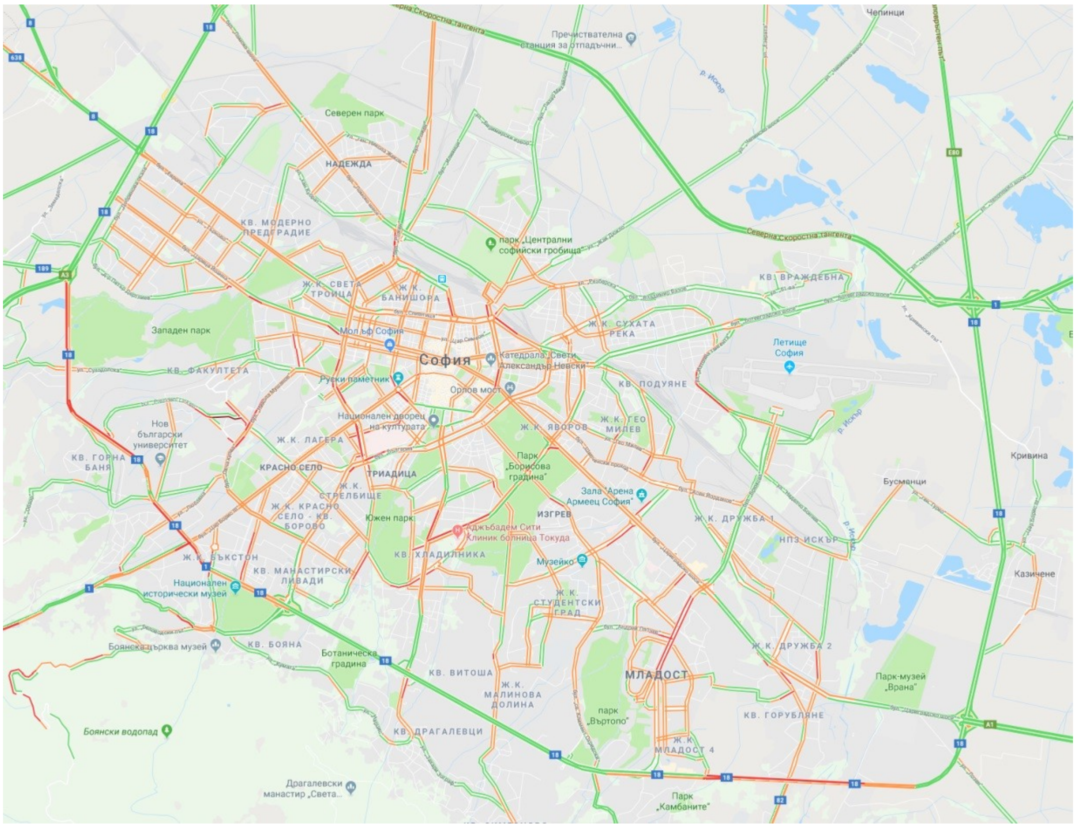


Figure 5. Typical traffic load in Sofia



- **Areas with intensive loads on the transport infrastructure**

- In peak hours of the day (morning 08:00-10:00 and 16:30-19:00) at the major crossroads, boulevards and streets, the areas around the central station and the bus station;

Crossroads with the greatest number of crashes over the years are heavily loaded.

In first place with the most traffic accidents the circular intersection of "Tsarigradsko Shousse" Blvd. and "G.M. Dimitrov" Blvd. - "Asen Yordanov" Str. In the morning, this junction, and in particular the connection from Tsarigradsko shousse Blvd. towards Mladost residential area to the circular is clogged and has a depleted capacity.

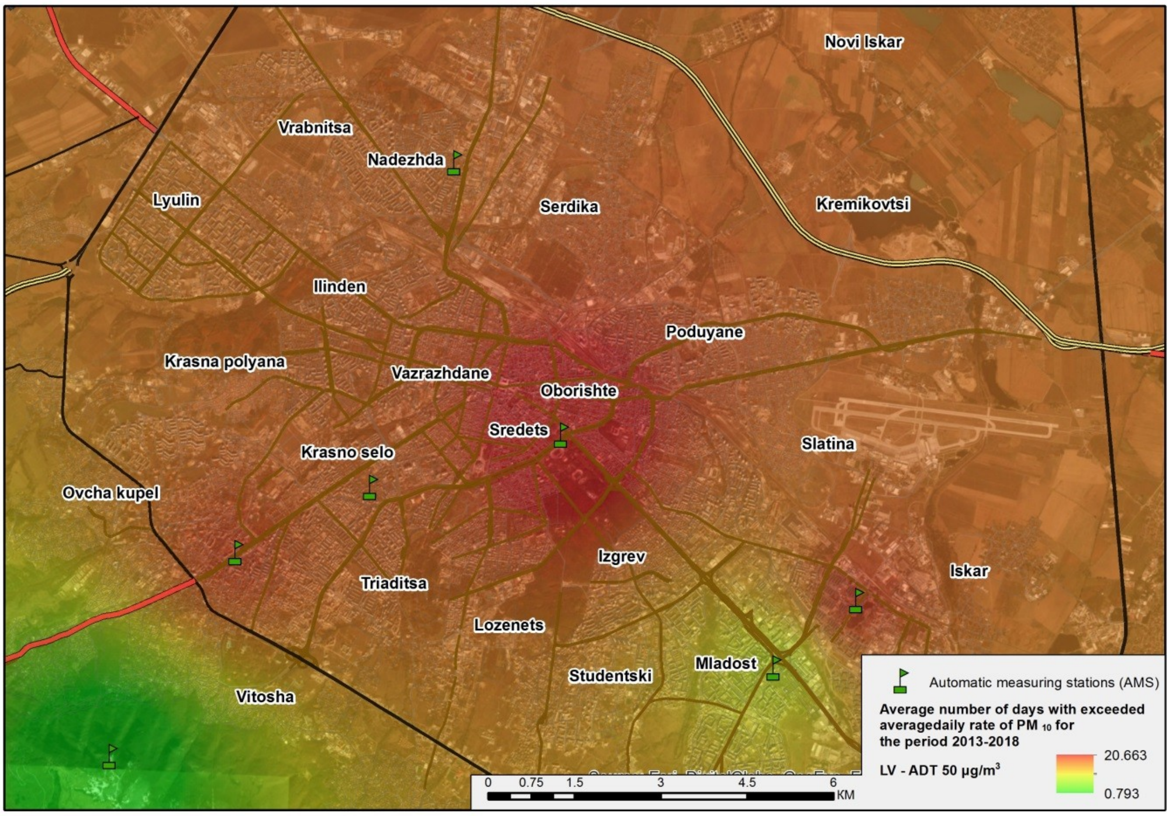
Second is the knot of the ring road with "Simeonovsko shousse", which is a "diamond seam" type. In the morning the connection from the Ring Road to Simeonovsko shousse is overloaded and clogged and even obstructs the traffic around the ring road.

According to the statistics for 2016 the junctions that are next in line are: Acad. Ivan Evstratiev Geshov Blvd and Bulgaria Blvd., Todor Kableshkov Blvd., Todor Aleksandrov Blvd., Odrin Str., Vasil Levski Blvd., and Slivnitsa Blvd.

- **Main Pollutants Affecting Air Quality**

When analyzing the data on the average daily rate (ADR) for 2017, it can be seen that only "Kopitoto" station exceeds the incidence rate - 4 per year. At the other stations, the ADR was over 96 times in "Nadezhda" station (i.e. 96 days a year the average daily concentration was exceeded), 39 - Mladost, 71 - Hipodruma, 65 - Pavlovo, 46 – Druzhba station. These exceedances are mainly during the winter months (heating season). Apart from the seasonality of pollution, it is important to pay attention to the data on average hourly concentrations. They show that in some parts of Sofia the peak of pollution is in the evening when people are at home, and elsewhere - the day when people are at work. Peak is also noticeable in the morning hours of the day when people go to work.

Figure 6.Average number of days with exceeded average daily rate of PM 10 for the period 2013-2018



- *Areas with traditional air pollution problems* - Average number of PM_{10} exceedances of PM_{10} for the period 2013-2018 according to the rates measured in the automatic measuring stations.

  - ❖ Exceedances of the norms exist in Nadezhda, Mladost, Hipodruma, Pavlovo, Druzhba stations.

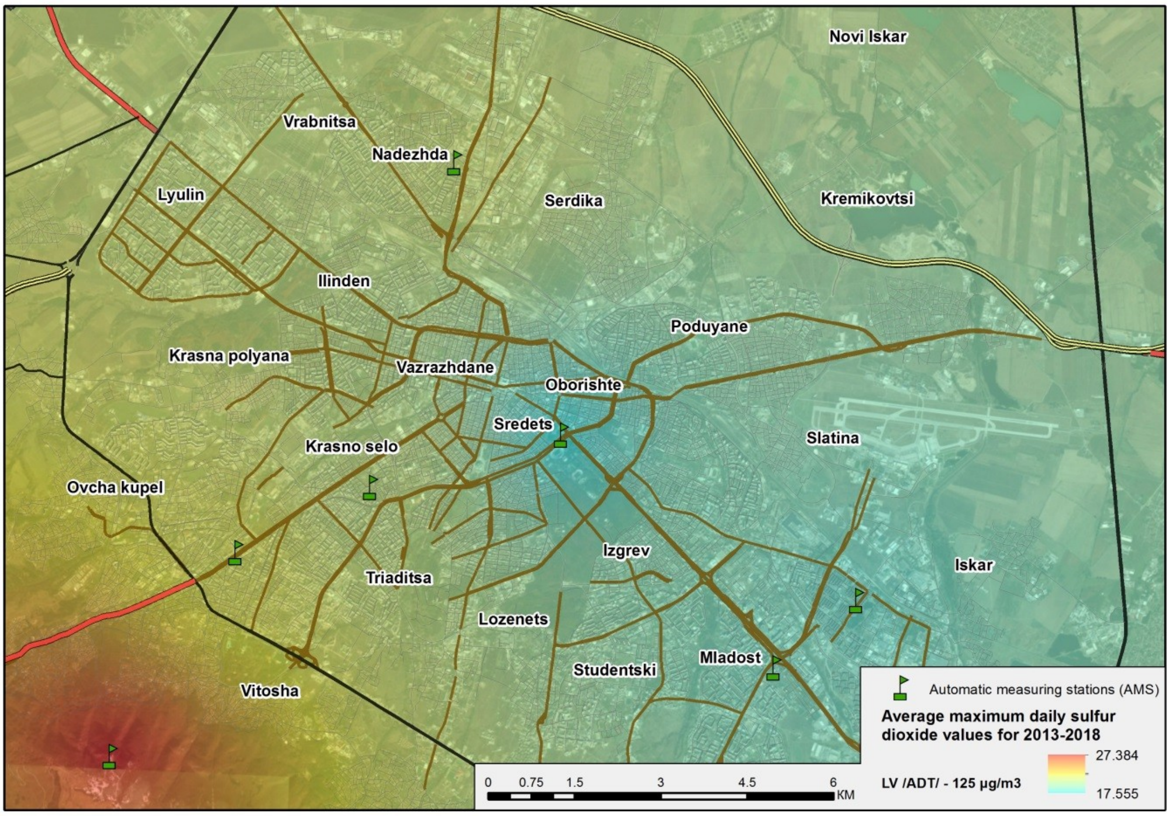
The neighborhoods that are heated by solid and liquid fuels as well as those burning different types of heating waste are generally the poorest and most endangered neighborhoods whose inhabitants are low-income and socially isolated. There are also exceptions to this trend - the neighborhoods of the sub-loop collar of Vitosha mountain and the business premises (garages, paint shops, warehouses, etc.), which also burn unregulated waste.

The main source of dust is the household sector, major roads and construction. Irregular cleaning of the street network also has a significant impact on the amount of registered dust.

The automatic stations show a decrease in the measured annual average concentrations in 2017, which is mainly due to the measures taken in this direction compared to the previous 2016.

Sulfur dioxide belongs to the group of sulfur oxides (SOx), which are formed when burning fuels with high sulfur content. The main anthropogenic source of sulfur dioxide is the burning of natural fuels (Thermal Power Plant, household sources), as well as the metallurgy and the chemical industry. Sulfur dioxide and NOx are major components of "acid rain". By sulfur dioxide indicator there are no exceedances for the average and daily average values in the automatic and manual measuring stations in the territory of Sofia-city and Sofia region for 2017. The trend has been preserved for the past 5 years.

Figure 7.Average maximum daily sulfur dioxide values for 2013-2018

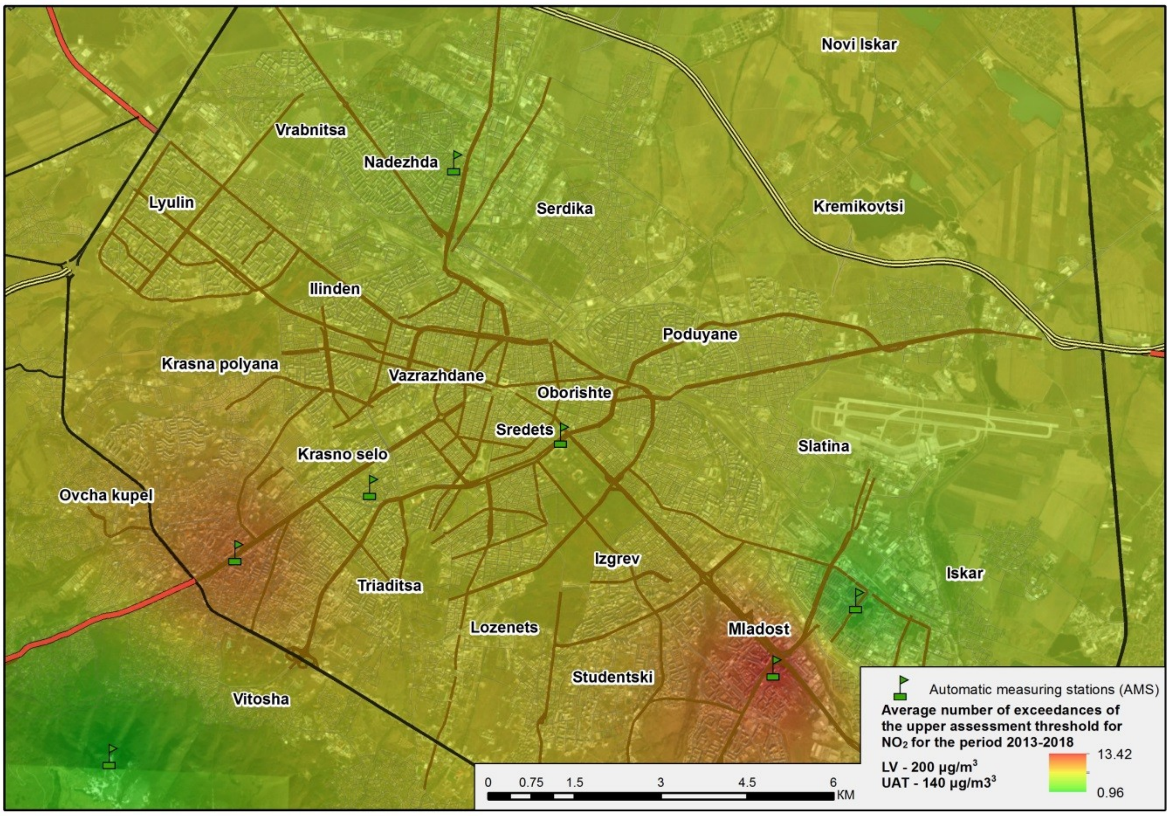


- *Areas with traditional air pollution problems* – ***Sulphur dioxide*** – Pavlovo Station

Nitrogen dioxide is formed in combustion processes. Major sources are motor vehicles, thermal power plants (TPPs), some industrial plants, and smoking. Under the influence of intense sunlight and in the presence of volatile organic compounds in the atmospheric air, nitrogen dioxide interacts chemically, resulting in the formation of the secondary pollutant - ozone.

In 2017 there was an increase in the average hourly concentrations of nitrogen dioxide (NO2), with 20 exceedances in the past year in Pavlovo, Mladost stations - 6 exceedances, at Hipodruma - 2 exceedances, at the rate of the indicator - 200 µg / m^3. At Pavlovo exceeded the allowed number of exceedances - more than 18 times per calendar year. At one of the points, there is a clear tendency to decrease the measured annual average concentrations, which is mainly due to the measures taken in this direction. In 2016, there was a decrease in the average hourly concentrations of nitrogen dioxide (NO2), with 18 numbers in the past year. exceedances at Pavlovo, Mladost, Nadezhda station at a standard rate of 200 µg / m^3, but not exceeding the permitted number of exceedances - more than 18 times per calendar year.

Figure 8. Average number of exceedances of the upper assessment threshold for nitrogen dioxide (NO_2) for the period 2013-2018

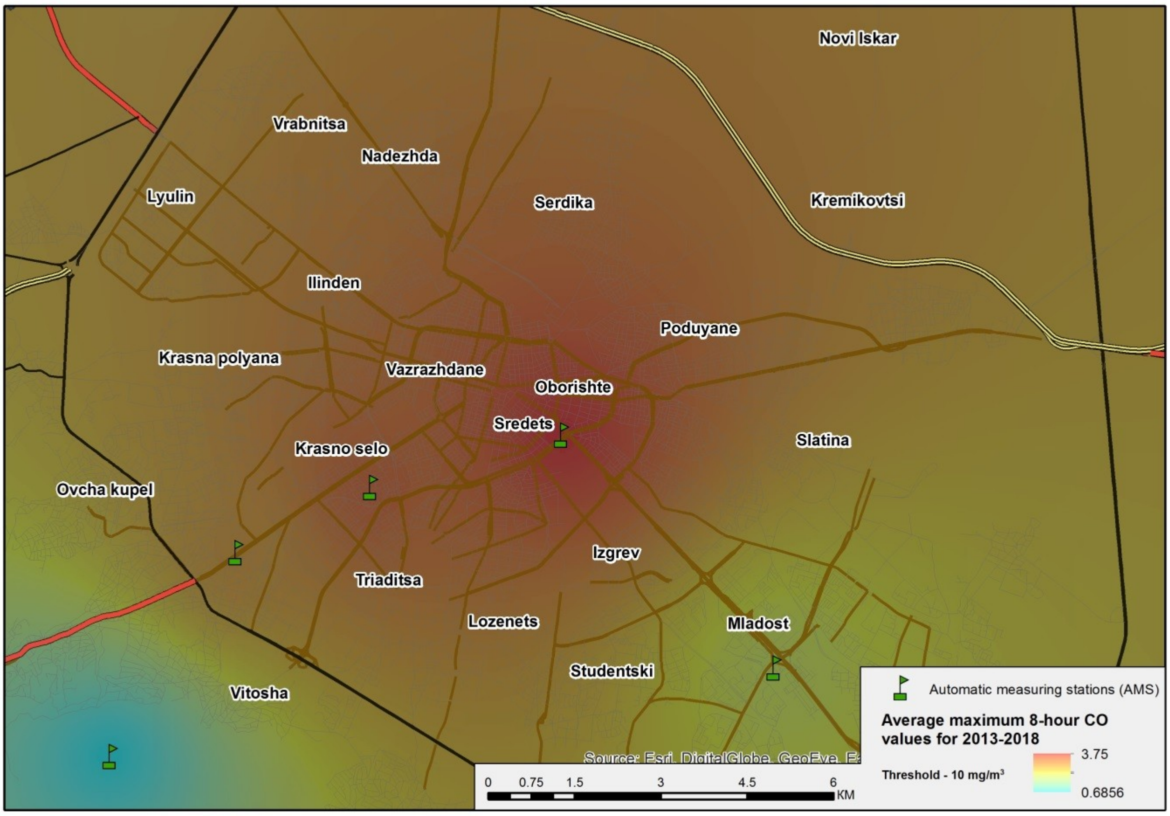


- *Areas with traditional pollution problems* – Nitrogen dioxide **(NO_2)**

  - Pavlovo and Mladost stations - at an upper assessment threshold 140 µg/ m^3 and Nadezdha station (at a rate– 200 µg/m$^{3)}$

Carbon oxide is a colorless gas, odorless, slightly lighter than air, burning gas. It is one of the most widespread atmospheric pollutants that is formed by the incomplete combustion of carbon-containing materials. The largest source of CO is the road transport - over 65% of the total emitted quantity for the country. The automatic stations that measure CO are in Pavlovo, Mladost, Hipodruma and Kopitoto and no exceedances have been measured at an 8-hour rate of 10 µg / m^3.

Figure 9.Average maximum 8-hour CO values for 2013-2018



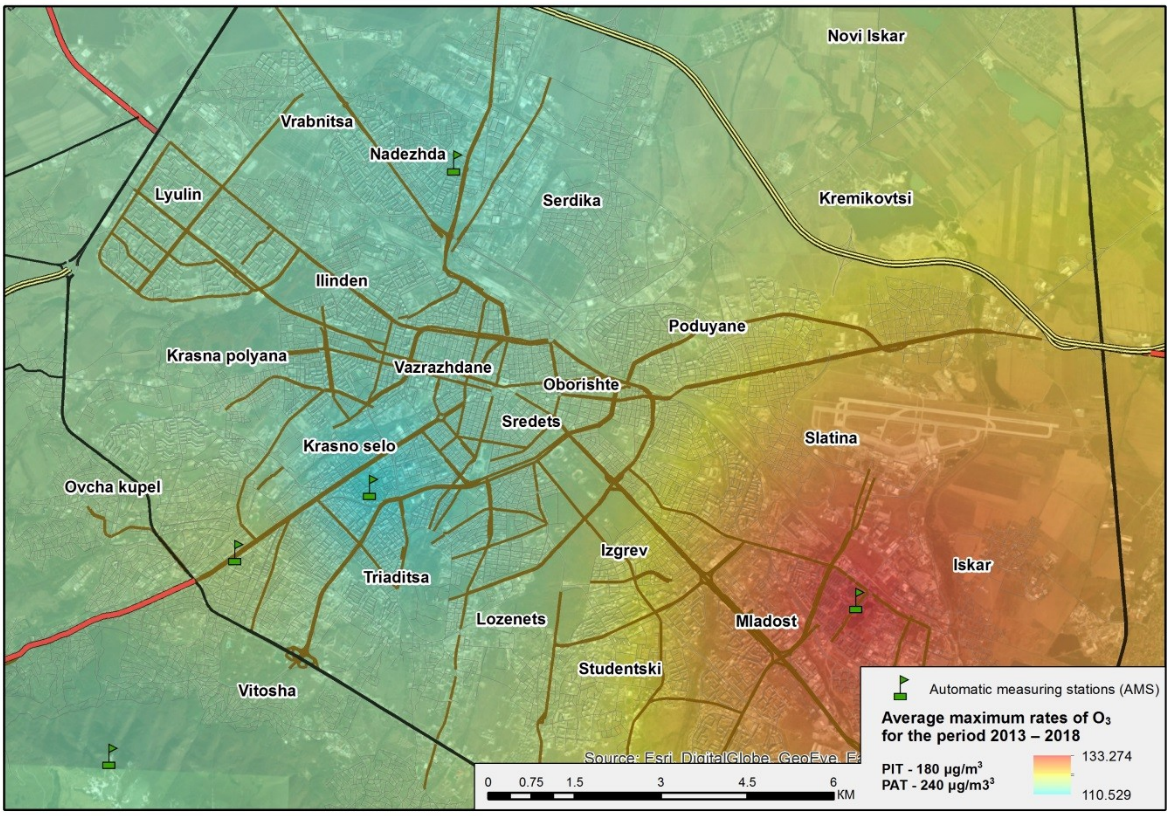
- *Areas with traditional air pollution problems – Average maximum 8 hours rates of carbon oxide* – (CO) for the period 2013-2018

    - Orlov most Station (The station was closed. From October 2015 the automatic station has been moved to a new site – Mladost station Sofia)

Ozone is a gas that occurs in the upper part of the atmosphere from 30 to 50 km. above the ground and in the ground air layer. The high ozone layer has protective functions that protect against ultraviolet rays while in the ground layer it can have an adverse effect. Ozone is a powerful oxidant. It is not emitted directly into the atmosphere. It is formed by the interaction of nitrogen oxides and volatile organic compounds under the influence of high temperatures and sunlight. There are no anthropogenic emissions in the air. The natural background ozone in the air is about 30 µg / m3 but can reach much higher values (eg 120 µg / m^3).

In 2017 the automatic measuring stations (AMS) on the territory of Regional Inspectorate of Environment and Water (RIEW) - Sofia reported 9 exceedances of the information threshold (180 µg / m^3) in AMS Druzhba and AMS "Nadezhda". No exceedance of the Population Alert threshold (240 µg / m^3) has been reported.

Figure 10. Average maximum rates of O_3 for the period 2013 – 2018



- *Areas with traditional air pollution problems - ozone* **(O_3)** – average maximum rates for the period 2013-2018

❖ Mladost, Druzhba and Kopitoto AMS

On the territory of the Sofia Municipality there are several areas, which directly affect the AAQ:

- City center, dense areas and intensive traffic;
- Industrial areas;
- Households used in households mainly during the winter season, solid or liquid fuels for heating.

For the municipality, the AAQ is formed by emissions from road transport, industry and the domestic sector. In recent years, due to the significant increase in traffic intensity, congestion in peak hours is a common occurrence in many areas of the capital.

Road transport is the largest source of pollution - 57% of total NOx emissions, 93% of CO emissions, 70% of CO_2 emissions, 83% of N_2O, which places particular attention on trafficking in Sofia.

The sites of "Toplofikatsia - Sofia" EAD operate with natural gas. All systems are equipped with self-contained Continuous Measurement systems and their own periodic monitoring of harmful substances released into the atmospheric air.

A large part of the Sofia Municipality region is gasified, which leads to the reduction of emissions of dust, nitrogen oxides and sulfur dioxide.

- **Heating of households**

Heating is undoubtedly the main pollutant of the atmospheric air during the winter months in the municipality. However, there is no database of addresses that are heated on coal, wood and liquid fuels, as well as fuel quality data - ash content, moisture content, etc.

During the local heating season the main source of particulate contamination is the burning of solid and liquid fuels in the household. The reason for this is the specific weather conditions during the winter season, which reduces the possibility of dispersion of atmospheric pollutants. Fine dust particles are emitted directly into the atmosphere (primary emissions) or formed from the gases emitted into the atmosphere - precursors of fine particulate matter (secondary emissions).

Heat Supply

Centralized heat supply of Sofia is realized by Toplofikatsia Sofia EAD, the territory within the licensed area includes the whole city part, except for the districts and areas of Orlandovtsi, Malashevtsi, Manastirski livadi, Krastova vada, Vitosha Mountain, Malinova Dolina, Sredorek and Gerena. In this area are also the industrial zones for the Sofia and Iskar stations.

The heat sources are concentrated in four main power stations serving four heat supply regions - Sofia, Sofia East, Zemlyane and Lyulin. The heat transmission network is two-pipe and is controlled by changing the temperature of the heat carrier depending on climatic conditions. The main part of the network was built up to the 1990s by obsolete and long-denied technologies, with poor construction quality. The total length of the heat transmission network is 968 km and about three quarters of it is laid in impassable channels without the possibility of effective prophylaxis. Under the Sofia Rehabilitation Project, heat exchangers are gradually being replaced with pre-insulated pipes, but the process needs to be accelerated.

The sites of "Toplofikatsia - Sofia" EAD operate with natural gas. All systems are equipped with self-contained Continuous Measurement systems and their own periodic monitoring of harmful substances released into the atmospheric air.

No information has been received at the moment by Toplofikacia - Sofia for the heat transmission network on the territory of Sofia Municipality.

Gas transmission network

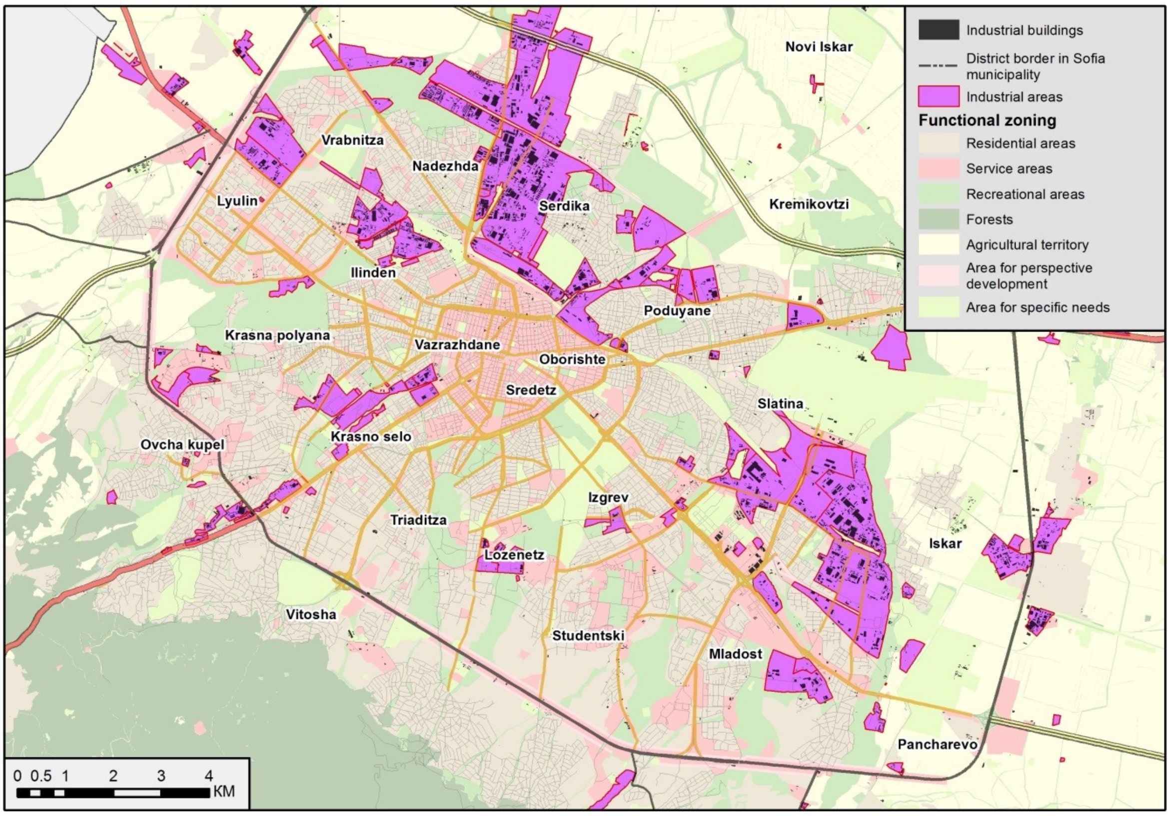
The gas supply of Sofia and the surrounding area is carried out through deviations from the two branches of the gas transmission ring of the country. Gas distribution stations (GCS) are built into each diversion, where the high pressure reduction (55 bar) from the transmission gas line is carried out to a pressure of 6 bar, 10 bar, 12 bar and 16 bar. The approximate length of the completed gas distribution network owned by SofiaGAS AD in the SO is about 421 km.

The main facilities of the gas distribution network are the gas distribution stations, which supply the Obelya neighborhoods, Obelya 1 and Obelya 2, Moderne suburb and Zaharna Fabrika, Kazichene and Krivina , "Sofia" Airport, "Mladost 4" and the Business Park, the neighborhoods at the foot of Vitosha Mountain and others.

At present, no information on the gas transmission network has been received on the territory of Sofia Municipality.

- ❖ **Aggregation of construction and production sites, industrial zones**

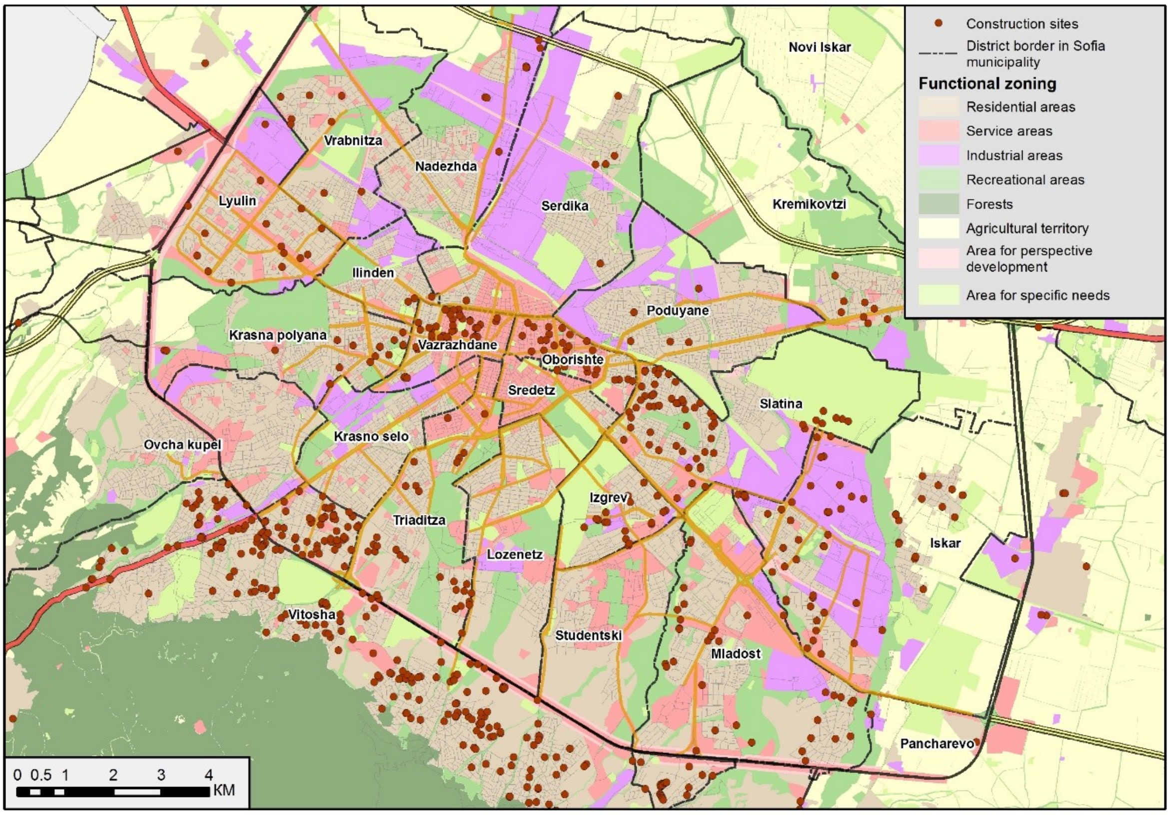
Figure 11. Industrial zones and industrial buildings in Sofia Municipality



Aggregation of industrial buildings and production zones:

- Warehouse production zone Modern suburb
- Zaharna fabrika District
- Scientific production zone (SPZ) Iliantzi – east
- SPZ Voenna rampa
- SPZ Sredetz
- SPZ Iskar – north and west
- Gorubliane District

Figure 12. Construction site in Sofia municipality



Aggregation of construction sites:

- Dragalevtzi District, Kinocentur villa zone, Panorama District – Boyana, Pavlovo District, Manastirski livadi District, Zone B-18, the city center, Reduta District, Malinova dolina District.

For the period 2018-2019, the most building permits were issued in the area of SPZ "Hladilnika", Ovcha Kupel and Druzhba, where a housing boom is also expected.

- **Environmental factors (secondary)**

The Sofia valley extends in the direction northwest-southeast between Stara Planina in the north and Viskyar, Lyulin, Vitosha and Lozenska in the south. Several small rivers flow into its territory. The Sofia valley consists of two main parts - a valley (bottom) and a fence of mountain slopes.

The main climatic factors are the solar radiation, the atmospheric circulation and the surface of the ash, characterized by the shape of the relief and its exposure to the directions of the world, its altitude, etc.

The large-scale factors (radiation and circulatory) are subjected to the active transformation effect of the local heterogeneity of the floating surface - species and vegetation, creep, presence of large ponds. A decisive importance for the climatic specificity of the municipality is its valley character. As a result of the transformation of passing air masses of different origins, the area is characterized by a greater frequency of western and southwest winds, thermal inversions, radiation fogs and inversion clouds during the cold half.

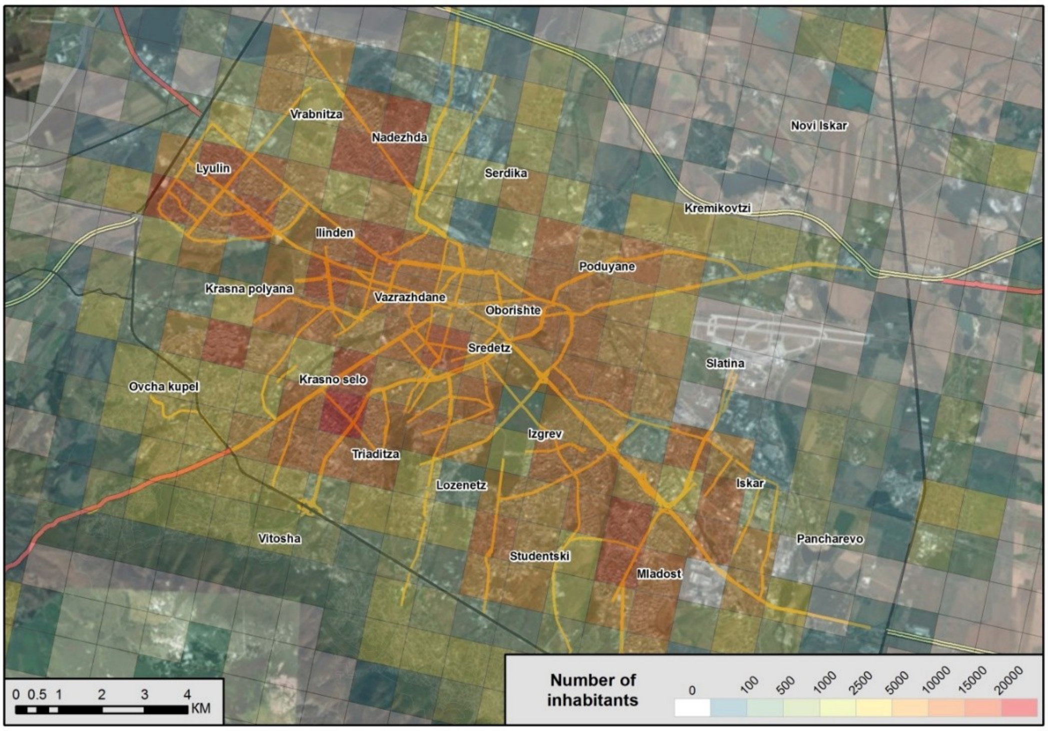
The geographic location and the local climatic characteristics of Sofia have a big role for air quality. Temperature inversions and the associated mists are a very typical phenomenon for the Sofia field. These phenomena are especially characteristic of the winter months, which makes it very difficult to distract the pollutants in the air. This situation actually determines the AAQ of Sofia as a very difficult problem solving, which means that its solution requires serious efforts from all authorities and citizens

- **Demographic factors**

Sofia Municipality has a population of 1 316 557 (December 2014), as to 31.12.2017 the population has increased to 1 325 429 (according to NSI data).

The density of the population in Sofia-city is very high - 960 people / sq. km, 14.5 times higher than the average density in the country, 66.3 people / sq. km. In 2001-2011 the population of the district increased by 10.3%.

Figure 13. Number of population on the territory of Sofia Municipality



Despite the tendency of preservation and decrease of the measured average annual rates for some of the indicators characterizing the AAQ, compared to previous periods, it should be taken into account that during the different seasons an increase of some of the indicators (mainly PM_{10}) depends also on:

- the large territorial coverage of Sofia Municipality and Sofia District, which determines a larger concentration of production in certain regions;
- the high number of roads and their traffic during the year, as well as the construction;
- weather conditions of the area (higher percentage of days with wind speeds below 1.5 m/s, low temperatures, fog days and temperature inversions);

- the large number of households heating solid fuels, despite the gasification and heating of the capital.

6. Localization analysis model

The localization analysis model implies the use of an integrated approach that has the character of an integrated assessment analytical procedure using three basic methods:

• Analytical hierarchical process (AHP) to assess the impact of localization factors

• Rank Order Method (ROM)

• Overlay-geospatial multicriteria localization analysis, providing a quantifiable result in the form of an analytic digital synthesis map (raster GIS based layer), containing a comparative georeferenced ball estimate of each location within the surveyed territory.

Analytical hierarchical process - AHP

The analytical hierarchical process is a structured mathematical technique for multicriteria analysis developed by Thomas Saaty[1], in which the hierarchical comparative model assesses the degree of importance of the individual criteria. The degree of importance (weights) is determined for every two pairs of the comparison criteria, which is obtained by comparing the relative importance of the criteria in pairs. The table below presents a reference table describing the importance of the criteria:

Table 1 Reference table describing the importance of the criteria

Influence intensity	Description
1	Equal weight (importance)
3	Medium weight (importance)
5	Major weight (importance)
7	Very major weight (importance)
9	Extreme weight (importance)
2,4,6,8	Intermediate values
Reciprocal	Reverse Action Criteria

Another very important point in the application of this approach is the assessment of the consistency of the individual weights, which is obtained through the so-called Consistency Index (CI) and the ratio of the Consistency Index (CR). The two metrics are calculated using the formulas below:

$$CI = (\lambda_{max} - n) / (n - 1) \quad (1)$$

[1] Saaty, T.L., 1980. The Analytic Hierarchy Process: Planning, Priority Setting, Resource Allocation. McGraw-Hill, New York, NY

where **n** is the number of the corresponding criteria

λmax- the largest natural value in the comparator matrix

$$CR=CI/RI \qquad (2)$$

Where RI is a constant value, derived from the average random value of the Consistency index based on **n.**

The AHP approach procedure for building the current model to determine the potential location of sensors for monitoring and monitoring atmospheric air quality includes 6 logical and chronologically related stages:

1) Defining the unstructured problem of determining the potential locations and determining the model's target results
2) Analyzing the problem and defining the criteria to be used in the procedure - in this case we divide the factors of three main groups - genetic (sources of pollution and their spatial projection), secondary (influencing the pattern of pollution) and factors on which the problem affects (the spatial distribution of the population)
3) Constructing a matrix with influence (severity) of the individual criteria (factors)
4) Determination of the relative weights of the individual criteria (factors)
5) Check the consistency of the weights
6) Final weighting (degree of importance of individual criteria).

Rank Order Method (ROM)

Another method to be used in the present task is the Method of Ranking Factors and their Reclassification. All criteria and their weights through the application of this method will be evaluated and ranked by degree of importance. This is based on the following formula:

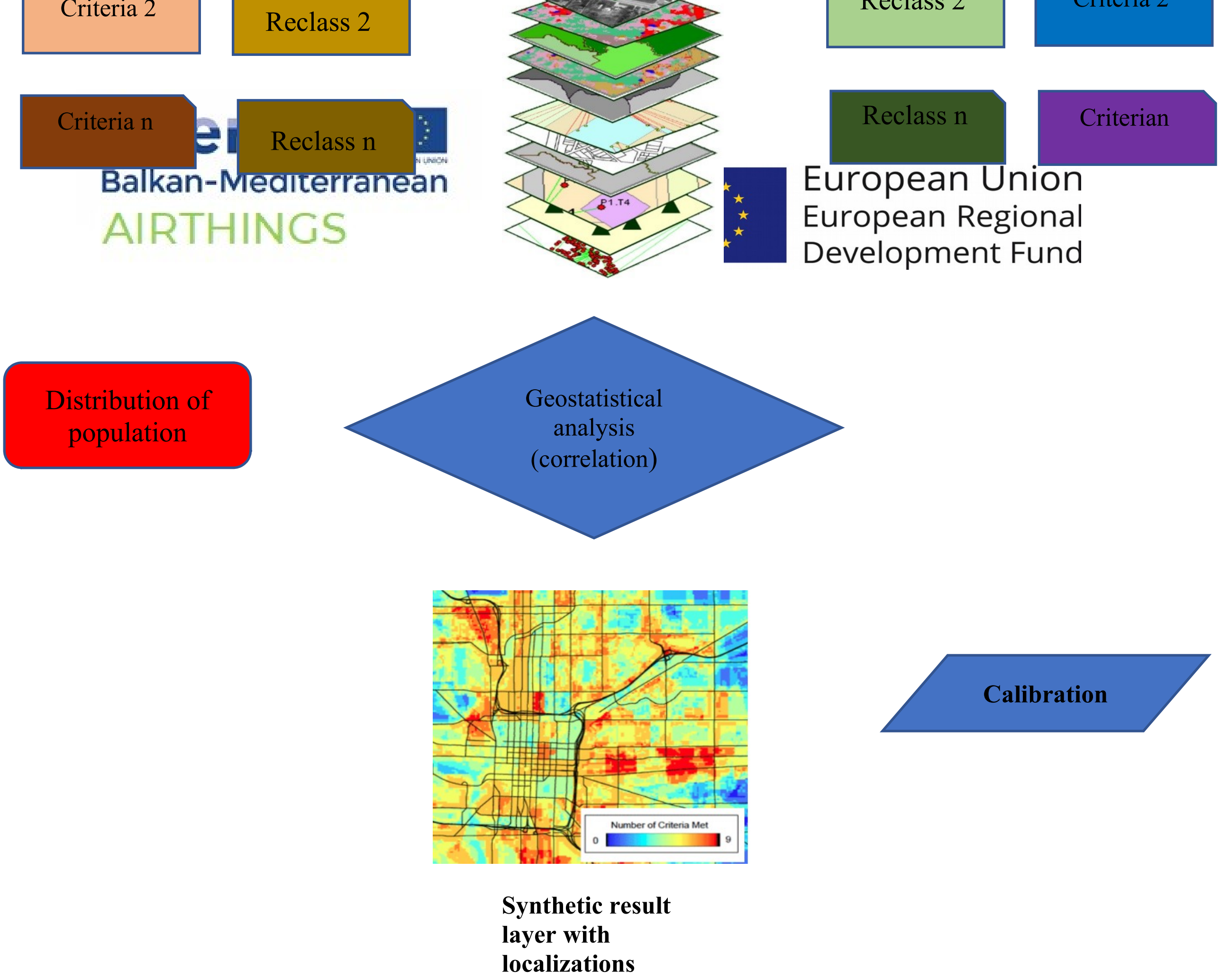
$$W(i)=2(n-i+1)/n(n+1)$$

where i- is the ranked position of the relevant criteria (factor)

n- number of criteria

Overlay-geospatial multicriteria localization analysis: By applying this method, geospatial integration and assessment of specified criteria is performed, the result being a synthesized digital map, which presents spatial sizing of territory on the basis of suitability and localization. In this case, the suitability for localization is expressed in a spatial combination of the criteria for the potential location of the AAQ monitoring sensors.

In schematic terms, the model has the following general appearance:



The result of the location model will be a synthetic layer with integrated and weighted localization criteria (genetic and secondary) that will be correlated and normalized with the spatial distribution of the population. This will ensure that the potential locations of the sensors do not differ from the concentration of the population, which in turn is the reason for future monitoring.

Subsequently, the results obtained will be subject to additional scrutiny and coordination with the Assignor, which will end with a definitive determination of the sensor locations.

7. Description and classification of input parameters (data)

The input parameters of this model are selected on the basis of the preliminary spatial analysis of the collected and processed data, quantitatively and qualitatively characterizing the identified genetic and secondary localization factors. Those factors are decisive in deciding the spatial location of the system by a sensor system for monitoring the quality of the atmospheric air of the City of Sofia.

The input parameters are:

- **Number of Sensor Locations** - 22: The number of sensors is a finite and imperative set-up limiter, which predominantly determines the degree of coverage of the surveyed area. Moreover, the relatively limited amount of locations (22) implies a relatively large variation of the proposed specific spatial configurations from suitable locations. In the present case, two alternatives have been proposed within the framework of the present task, which have been assessed geostatically by using the so called "Thissen polygons"[2], which allows quantitative investigation of the coverage of potential locations in relation to the target area. This approach provides information on the spatial coverage of the potential locations over the target area.
  - ✓ In the first option, the purpose is to search for potential locations within the urbanized territory of Sofia, where the maximum result of the assessed combined influence of the localization factors is present.
  - ✓ The second option relies on a shared influence of the severity of the localization factors and the achievement of a higher degree of uniformity of the potential locations within the study space.
  - ✓ The third option, in addition to taking into account the outcome of the combined (integrated) influence of the factors and taking into account the relatively uniform and representative location of the sensor locations, includes additional technical criteria related to the technical and logistic provision of the sensors, namely identifies public buildings and objects - municipal property to be used.

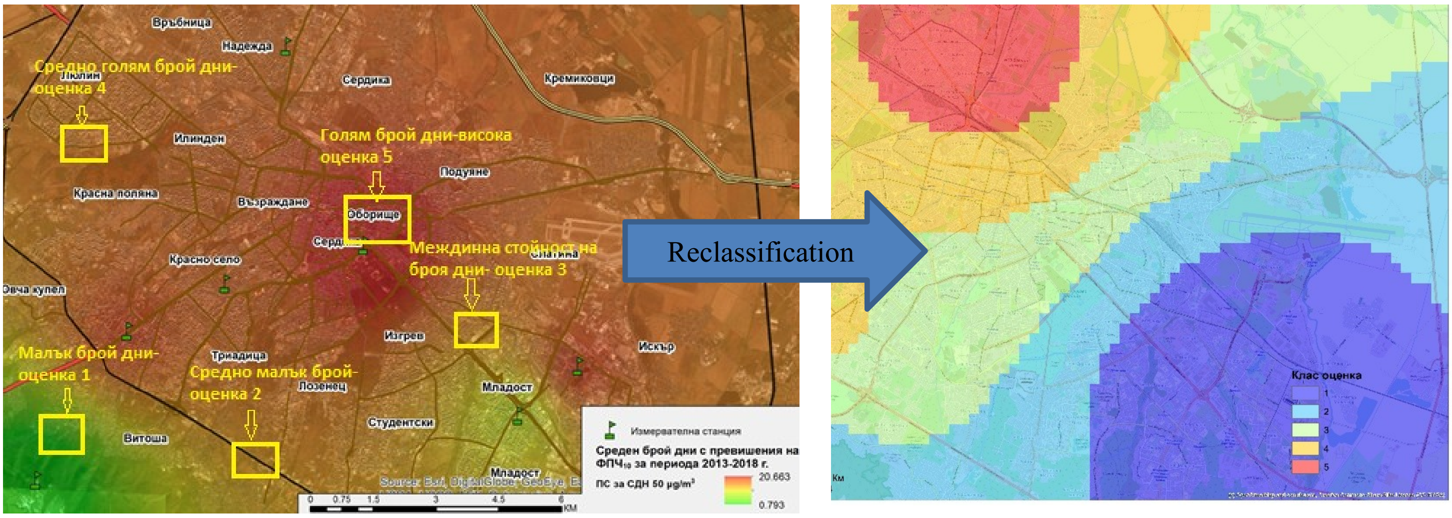
- **Genetic factors:**
  - Basic Pollutants: A synthetic geostatistical surface generated on the basis of spatial integration (spatial overlay), representing cumulatively the geographical distribution of the main atmospheric air pollutants (PM_{10}, average maximum rates of sulfur dioxide, nitrogen dioxide and carbon dioxide). Because of the small number of locations with stable and certified data for each of the pollutants, a spatial distribution pattern was generated on the territory of Sofia city through simple IDW[3] interpolation, subsequently each of the generated layers is reclassified in 5 grades (1 - least polluted, 5 - highest). The Rank Order Method (ROM) described above in this report is used for this purpose.

[2] https://onlinelibrary.wiley.com/doi/pdf/10.1002/9781118786352.wbieg0157

[3] Inverse Distance Weighted Interpolation

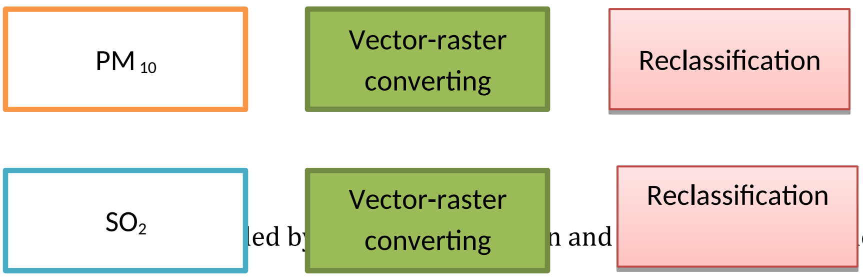
Subsequently, same are integrated into a common raster layer based on a simple arithmetic overlay, with no weight ratios being used - i.e. and the four layers have equal influence.

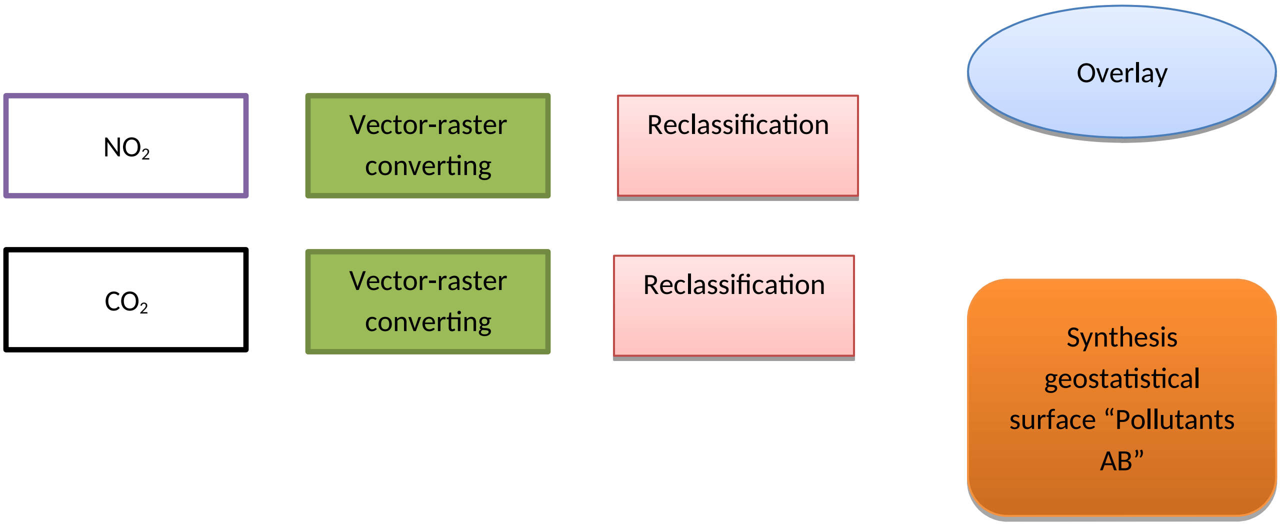
The figure below illustrates the principle of reclassification, in which case the layer representing the number of days with an excess concentration of PM_{10} is used:



This reclassification approach is applied to all localization factors (genetic, environmental factors, and demographic), thus achieving the necessary unification of the assessment data, while allowing them to be spatially integrated through overlay operations to obtain a comprehensive assessment of the localization potential of the territory.

The principle scheme for creating the variable so described has the following general appearance:

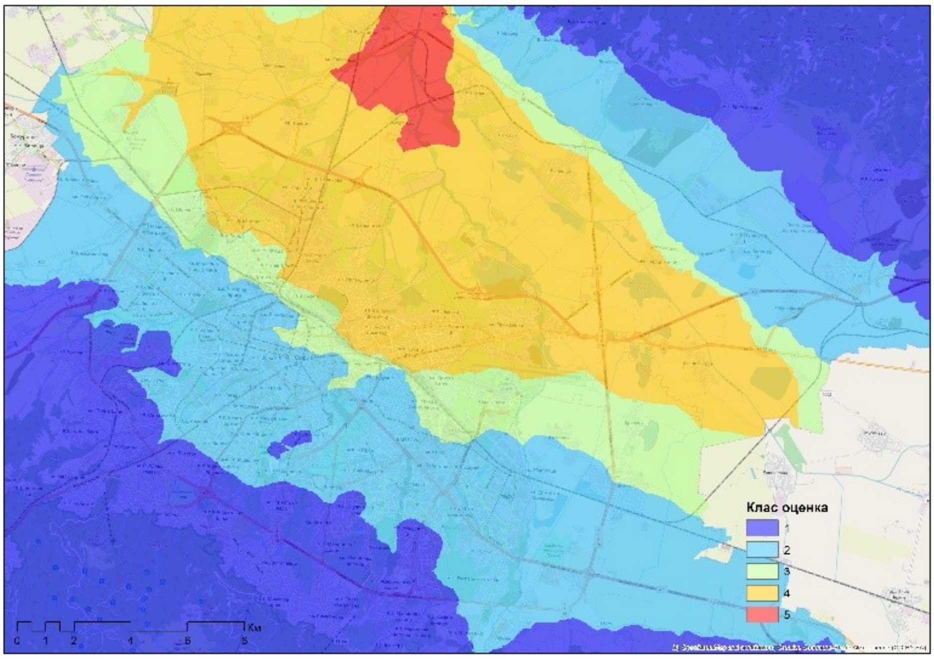




- **Aggregation of construction and polluting sites and industrial zones -** the localization factor is included as a layer of discrete polygonal objects which are consequently converted into a raster layer
- **Loading of the main roads -** due to lack of other qualitative information, traffic load information generated by statistical processing of static public traffic data from the Google Maps platform is used;

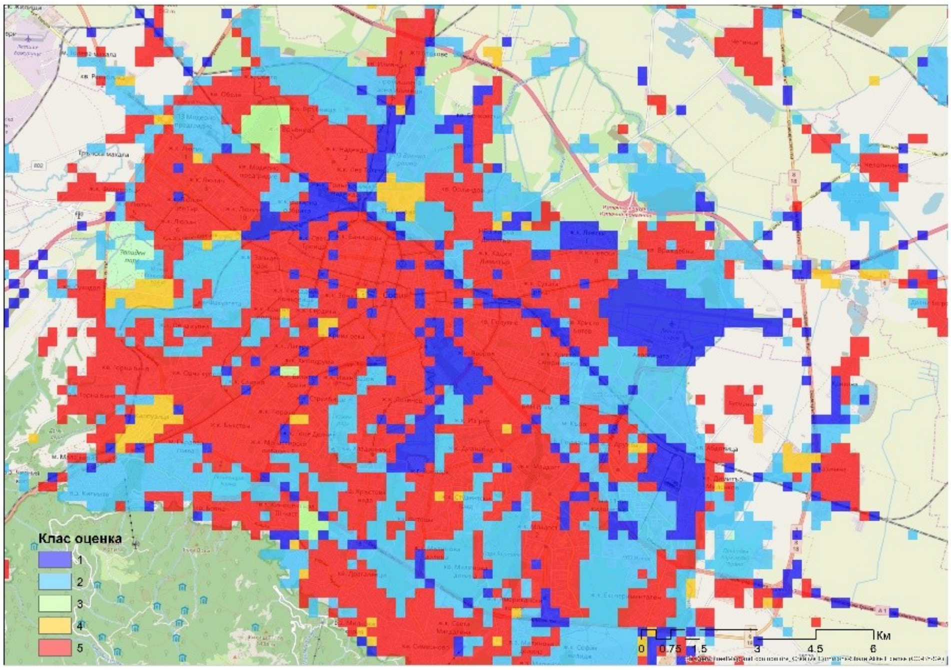
- **Environmental factors**

  - **Relief** - a digital model of relief, which is subsequently reclassified to 5 classes, the higher the altitude, the lower the class is the respective territory, and vice versa, the lower the altitude, the higher the area class. It is believed that the decrease in the relief implies "retention" of air masses (respectively air pollutants), especially during the cold half of the year. On the figure below the model of reclassification of the relief within the territory of Sofia is represented:



- **Urban environment -** a complex spatial index for the classification of the urbanized territory based on its spatial structure is used for this purpose.[4] It is a combination of the mode of construction in the respective territory and the prevailing land cover. Subsequently, the generated layer is reclassified, with more intensive built-up areas with less and less vegetation and with limited open spaces getting higher, and vice versa in less urbanized areas, with more open spaces and more vegetation - lower class (again a relative scale of 1 to 5 is used). The described model of spatial reclassification of the urban environment has the following geographic configuration:

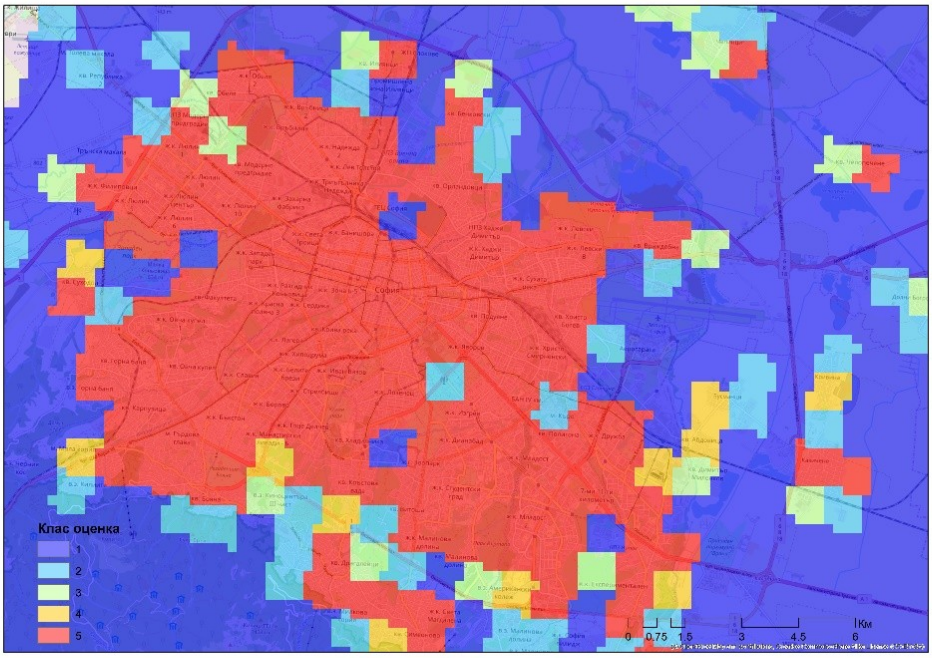
[4] Nedkov S, Zhiyanski M, Dimitrov S, Borisova B, Popov A, Ihtimanski I, Yaneva R, Nikolov P, Bratanova-Doncheva S (2017) Mapping and assessment of urban ecosystem condition and services using integrated index of spatial structure. One Ecosystem 2: e14499, https://oneecosystem.pensoft.net/articles.php?id=14499



- **Demographic factors**

  - The spatial distribution of the population based on the NSI grid developed for distribution of the population[5]. It presents the distribution of the population in a grid network measuring 1 x 1 km (1 km / h). Subsequently, the model has been converted to a raster format and has been reclassified in 5 classes depending on the number of population, as in the central part as well as in the two large complexes in the eastern and western periphery a higher concentration of population is observed and they have higher values of the ball estimates (4 and 5) respectively:

[5] http://www.nsi.bg/bg/content/12305/%D0%B3%D1%80%D0%B8%D0%B4-%D0%BD%D0%B0-%D0%BD%D0%B0%D1%81%D0%B5%D0%BB%D0%B5%D0%BD%D0%B8%D0%B5%D1%82%D0%BE-1-%D0%BA%D0%B2%D0%BA%D0%BC-%D0%BF%D1%80%D0%B5%D0%B1%D1%80%D0%BE%D1%8F%D0%B2%D0%B0%D0%BD%D0%B5-2011



Additional air data, mainly for its calibration and modification, is used in the model. However, they are not spatially differentiated (i.e. they are common to Sofia and not differentiated for individual parts of the urbanized area), which does not allow direct inclusion in the localization model.

For the purposes of calibrating the proposed model, additional climate data is used that are primarily used to interpret the values obtained and to combine the information strata quantifying the estimates of the individual localization factors. However, they are not spatially differentiated (i.e. they are common to Sofia and not differentiated for the individual parts of the urbanized area), which does not allow direct inclusion in the localization model.

8. Localization model limitations

The developed model has certain limitations, the most important of which are:

- *Limited spatial representativeness of the data on air pollution* - for the territory of Sofia the automatic measuring stations are 5 in number by 2018: Druzhba, Pavlovo, Mladost, Hipodruma and Kopitoto

- *Data deficiency* - some of the data that would contribute to a more complete and accurate determination of sensor locations is not available, such as:
  - ✓ household heating data;
  - ✓ Current data on the Sofia Municipality's heat transmission network
  - ✓ Current data on the gas transmission network
  - ✓ Traffic load information

- *Statistical errors and uncertainty of the model.*

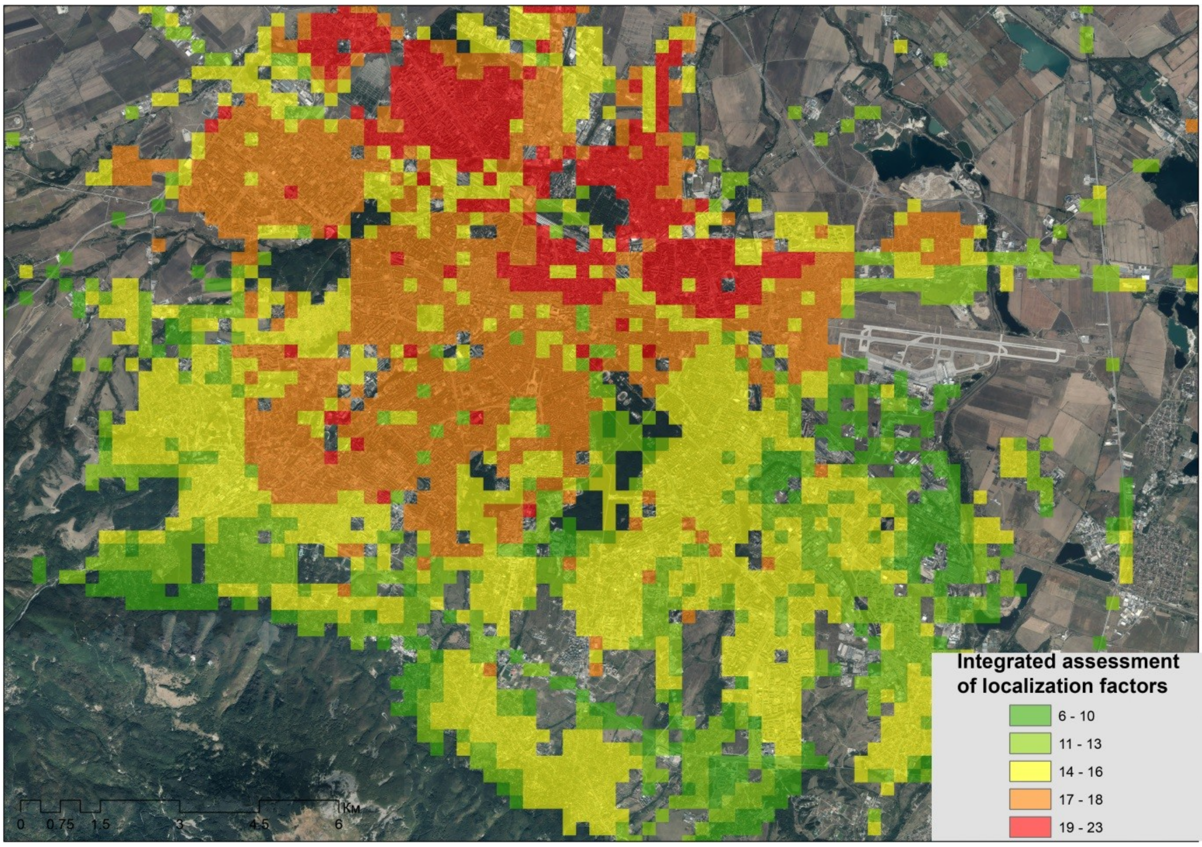
9. Interpretation of the results and justification of the selected potential locations

As a result of the application of the developed integrated localization model, a synthesis raster layer with a spatial resolution of 50 m was obtained which presents a quantitative assessment of the potential of the individual parts of the studied territory of Sofia Municipality.

The space is "fragmented" on individual cells, reflecting the power of influence of the individual factors, resulting from the application of weighted overlay - spatial integration of data quantifying the individual groups of factors achieved by spatial algebraic function. For each localization factor, weighted factors are determined, which are generated through the Analytical Hierarchical Process (AHP), which further are subsequently ranked using the Rank Order Method (ROM). Genetic factors are estimated at a weighting of 30%, while the other environmental factors have weight ratios between 5 and 15%.

Following the application of this algorithm, the following result was obtained:

Figure 14. „Fragmented“area of Sofia Municipality, reflecting the power of influence of the different factors



As it can be seen, there is a clear spatial differentiation on the territory of Sofia Municipality regarding the degree of integrated influence of the localization factors.

The highest values of the integrated assessment are the territories in the northern part of the municipality, which geographically coincide with the localization of the majority of the industrial sites within the Sofia valley. An additional influence on the formed spatial configuration of the localization potential had also the character of the relief (the bottom part of the lower part of the Sofia field), the specificity of the urban topography and the direction of the prevailing atmospheric transmission (northwest - southeast).

The second area of significance is formed in the actual urban area and covers a territory with a significant concentration of population, heavy construction and a diverse and mixed urban topography. The zone is relatively homogeneous and covers the western and central parts of Sofia.

The eastern and southern parts of the urbanized area are the lowest, the reasons for which are related to the following main factors:

- Unbalanced distribution of data from existing automatic monitoring stations (i.e. there is an effect of distortion of the information from the few stations and their poor representation in the southern and south-eastern parts of the city);
- Environmental factors - atmospheric transmission and relief (including a less pronounced inversion effect during the cold half of the year);
- More and more evenly distributed green areas;
- Transport infrastructure with fewer "narrow spots" in comparison with the central part of the city.

10. Proposal for spatial configuration of possible sensor locations

Based on the developed spatial potential analysis, within the implementation of the current task, specific deployment locations for the sensors from the future air monitoring system are defined. **Three suggestions are considered:**

Suggestion 1:

Suggestion 1 includes 22 locations, where the main assessment is the complex evaluation obtained on the basis of the proposed localization model. The maximum values of the assessment (i.e. a combination of localization factors) are sought; on the other hand, it is intended to achieve a higher degree of representativeness in the territories with a higher population density. The formed configuration will provide information that takes into account the spatial distribution of localization factors and also the nature of the geographical environment, and will be compliant to the territorial distribution of the population.

Based on this, the following locations are suggested:

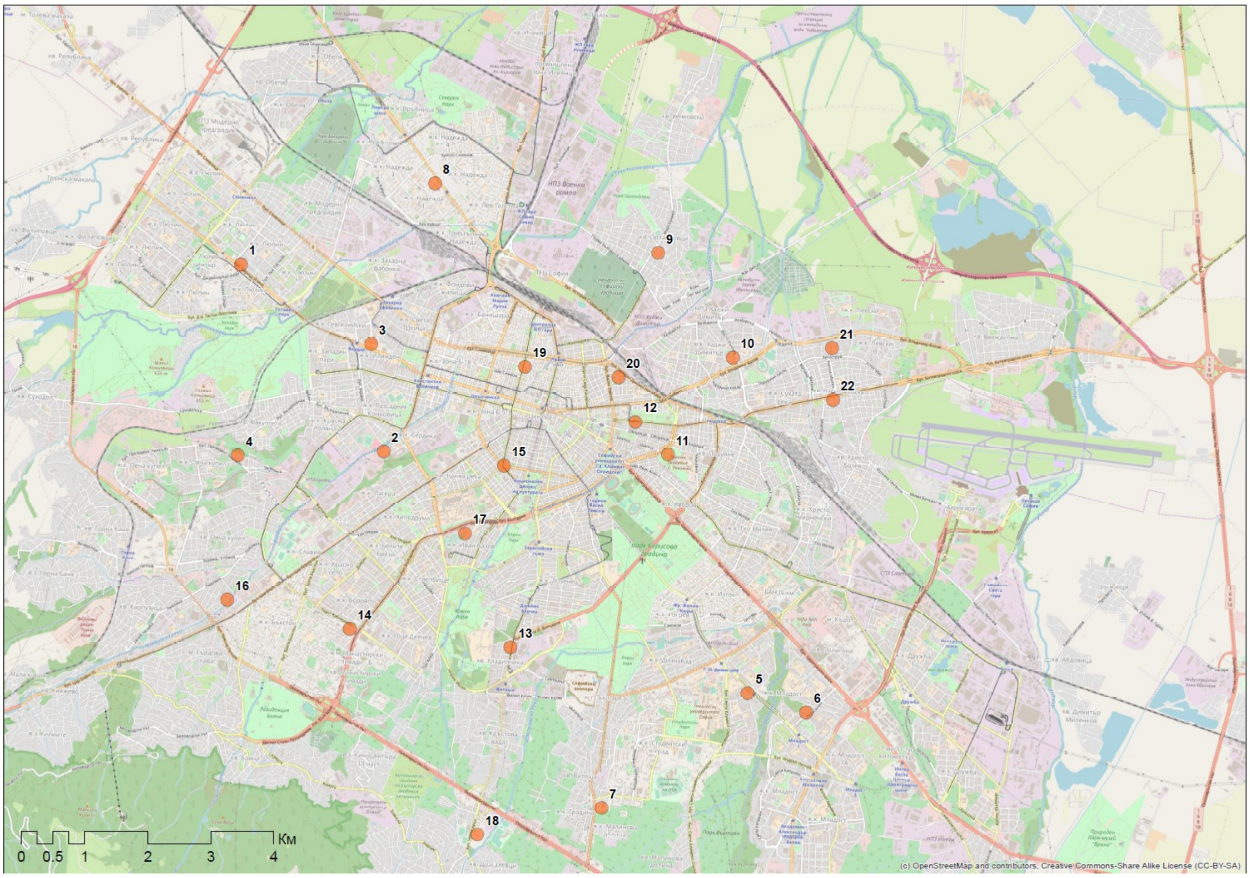
Table 3. Suggestion 1 with defined relative locations of the sensors:

Identification	**Coordinates X**	**Coordinates Y**	**Relative location**
1	193887.5153	4736106.208	Tzatitza Yoana Blv., Lulin 10
2	196145.6285	4733147.288	Ivan Ivanov Blv., Vazrazhdane
3	195947.1486	4734849.587	Todor Aleksanrov Blv., r.c. St. Troytza
4	193833.0563	4733083.89	President Linkoln Blv., Ovcha kupel
5	201910.623	4729315.452	Plovdivsko shousse Str., Musagenitza
6	202837.7748	4729010.856	Yerosalim Blv., Mladost 1
7	199598.68	4727500.29	Simeonovsko shousse Blv., Studentski grad
8	196957.6283	4737389.21	Lomsko shousse Blv., Nadezhda
9	200496.7074	4736289.495	Bosilegradska Str., Orlandovtzi
10	201678.3977	4734633.658	Vasil Kanchev Str., Hadzhi Dimitur
11	200649.5632	4733098.632	Voenna akademia
12	200133.6751	4733614.52	Yanko Sakuzov Str., Oborishte
13	198154.6533	4730045.004	Cherni vrah Blv., Lozenetz
14	195609.1475	4730334.591	Kazbek Str., Borovo
15	198052.2343	4732924.498	Praga Blv., City center
16	193667.1104	4730799.445	Voivodina mogila Str., Ovcha kupel
17	197434.1302	4731848.098	Balsha Str., Triaditza
18	197630.6624	4727079.937	Cherni vtuh Blv., Dragalevtzi
19	198383.2994	4734487.033	Hristo Botev Blv., City center
20	199866.1775	4734321.477	Beli Iskar Str., City center
21	203249.8377	4734783.137	Vladimir Vazov Blv., r.c. Vasil Levski
22	203265.5219	4733960.747	Botevgradsko shousse Blv.

In spatial terms they have the following distribution:

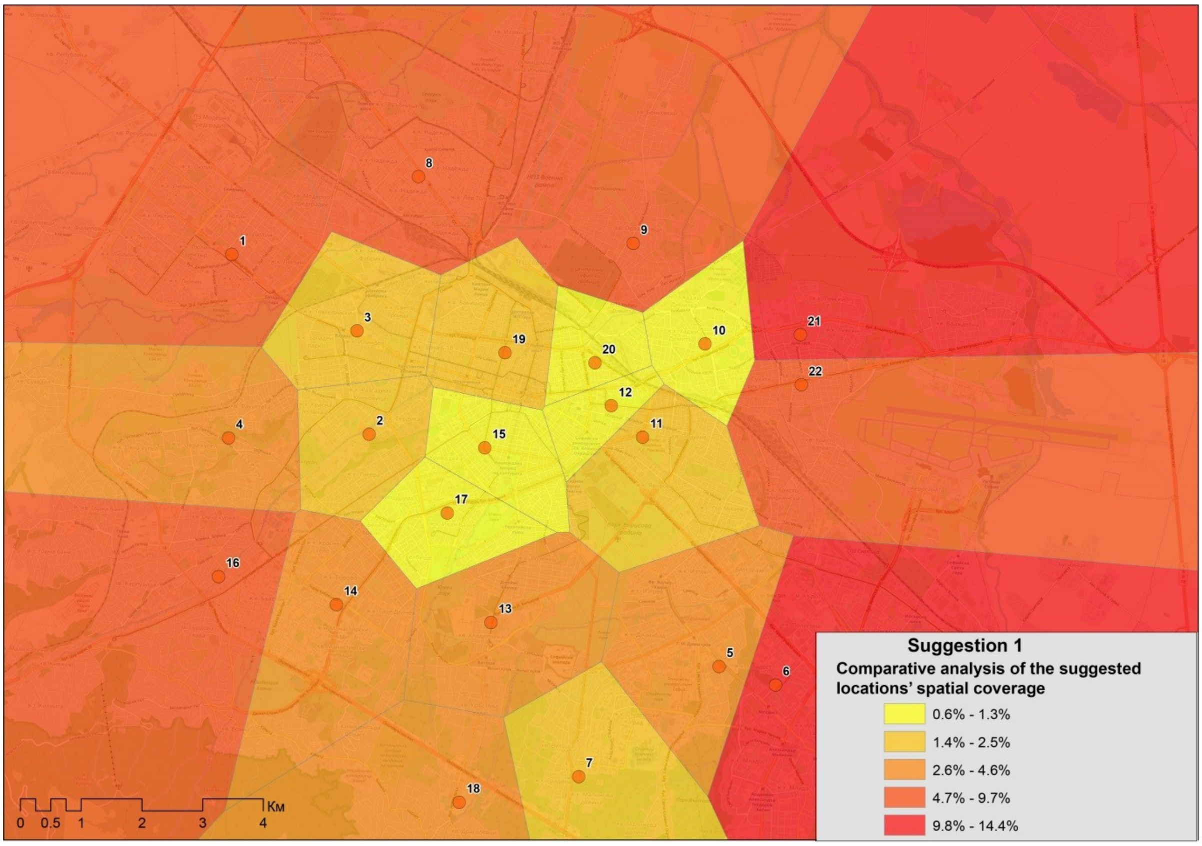
Project co-funded by the European Union and National Funds of the participating countries

Figure15. Spatial distribution of the relative locations – Suggestion 1



This pattern of distribution implies a greater density of potential locations in the central city area as well as in the northern periphery of the urbanized area where higher value of the integrated assessment is observed.

Figure 16. Comparative analysis of the spatial coverage of the suggested locations - Suggestion 1



As can be seen from the map, the central parts are expected to accommodate sensitive information in smaller areas of the city, while in the east and west they should provide data for larger areas.

Suggestion 2

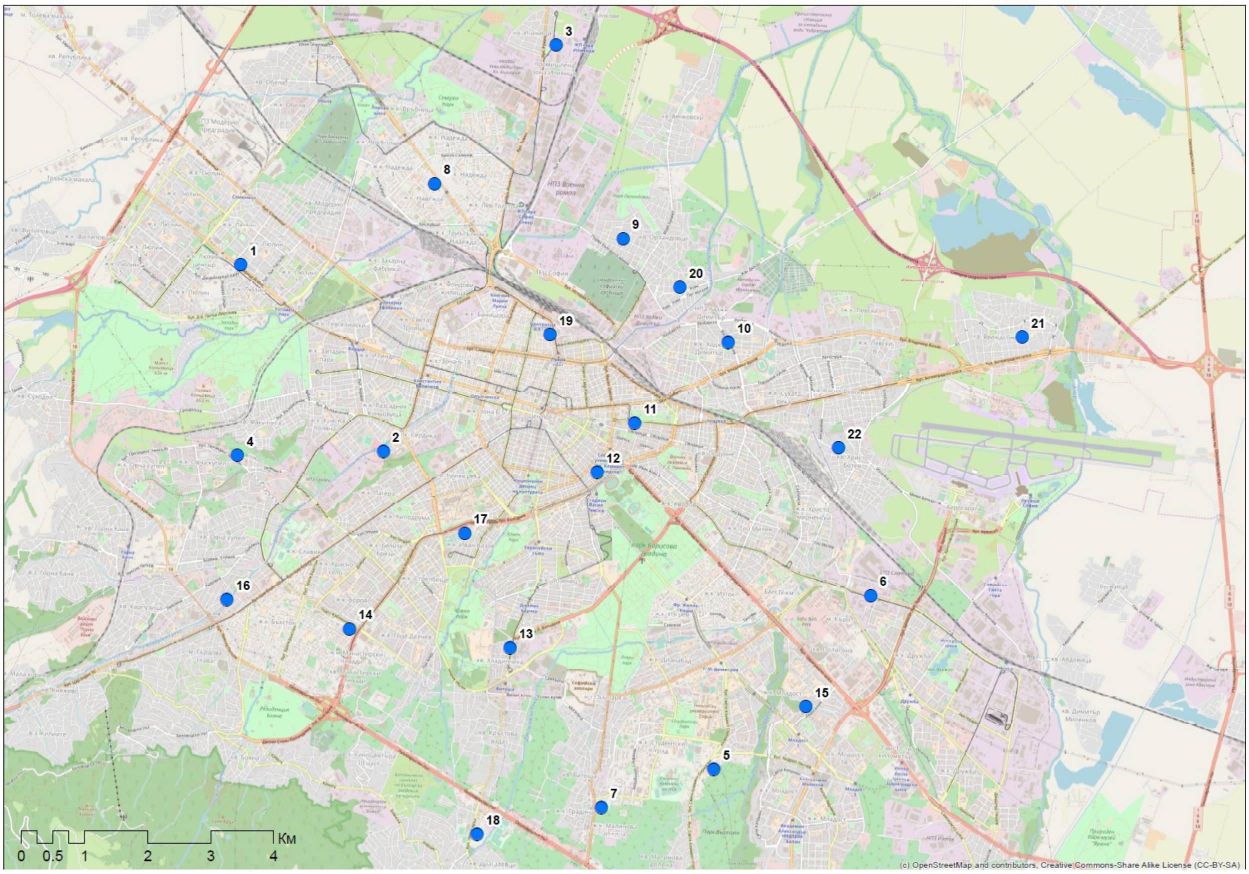
Suggestion 2 achieves a relatively greater uniformity in the location of the system sensors, taking into account the specificities of the territory in terms of the spatial distribution of the combination of localization factors:

Table 4. Suggestion 2 with defined relative locations of the sensors:

Identification	Coordinates X	Coordinates Y	Relative location
1	193887.5153	4736106.208	Tzaritza Yoana Blv., Lulin 9
2	196145.6285	4733147.288	Inzh.Ivan Ivanov Blv., Vazrazhdane
3	199007.502	4739920.778	Rozhen Blv., Iliantzi
4	193833.0563	4733083.89	President Lincoln Blv., Ovcha kupel
5	201381.8205	4728110.958	St. Kliment Ohridski Blv., Darvenitza
6	203866.0018	4730861.664	Assen Yordanov Blv., Slatina
7	199598.68	4727500.29	Simeonovsko shousse Blv., Studentski grad
8	196957.6283	4737389.21	Lomsko shousse Blv., Nadezhda
9	199949.1715	4736518.679	Kiril Parlichev Str., Orlandovtzi
10	201611.285	4734877.227	Vasil Kanchev Str., r.c. Hadzhi Dimitar
11	200127.9802	4733595.696	Yanko Sakazov Str., Oborishte
12	199534.4691	4732817.575	General Gurko str., City center
13	198375.8341	4730060.624	Cherni vrah Blv., Lozenetz
14	195609.1475	4730334.591	Kazbek Str., Borovo
15	202841.0899	4729101.46	Mitropolit S.Slivenski Str., Mladost 1
16	193667.1104	4730799.445	Voivodina mogina Str., Ovcha kupel
17	197434.1302	4731848.098	Bulgaria Blv., r.c. Ivan Vazov
18	197630.6624	4727079.937	Cherni vrah Blv., Dragalevtzi
19	198786.7898	4734998.562	Maria Luiza Blv., Hotel Ramada Sofia
20	200846.0315	4735748.332	59 Primary school Vasil Levski
21	206270.3271	4734958.821	27 Str., r.c. Vrazhdebna
22	203359.9984	4733204.065	Mimi Balkanska Str., r.c. Hristo Botev

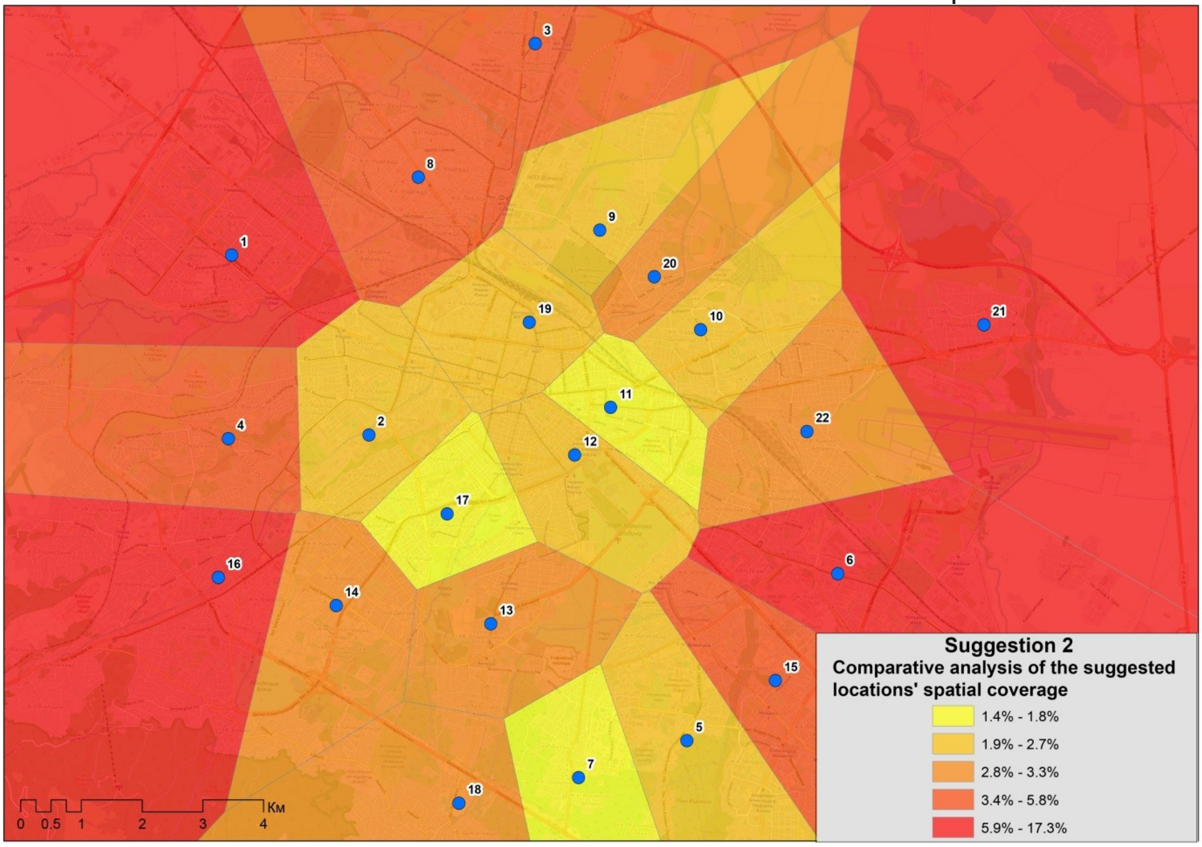
In spatial terms they have the following distribution:

Figure 17. Spatial distribution of the relative locations – Suggestion 2



Suggestion 2 implies achieving a higher degree of uniformity in the coverage of the target territory while taking into account the specificities of the combination of localization factors and population distribution. This is particularly well illustrated by the comparative analysis of the spatial coverage of the network of potential locations, which is visualized in the scheme below:

Figure 18. Comparative analysis of the spatial coverage of the suggested locations– Suggestion 2



In the central parts as can be seen from the scheme the sensors are expected to cover information areas smaller in size than the territory of the city, while in the east and west they should provide data relating to larger areas

Suggestion 3

Suggestion 3, in addition to taking into account the outcome of the combined (integrated) influence of the factors, and taking into account the condition of a relatively uniform and representative location of the sensor locations, also includes additional technical criteria related to the technical and logistic provision of the sensors, public buildings and objects - municipal property to be used.

The proposed suggestion is the most optimal in terms of location, availability of power and telecommunication networks, and access to the building of a technical team when installing and maintaining the sensor.

A photo of the subject is also attached to the justification, which will be subject to further investigation by a technical team to determine the specific location of the sensor.

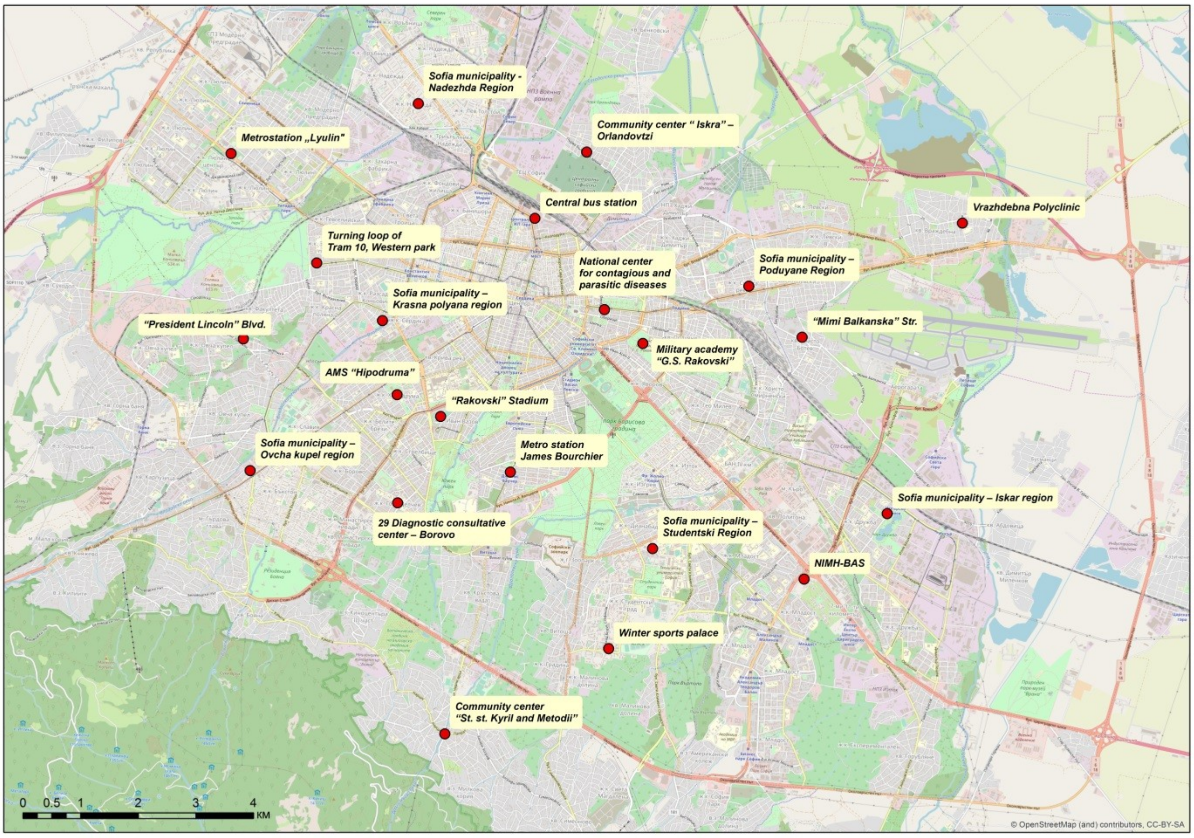
Table 2. Suggestion 3 with defined objects for the positioning the sensor network

Identification	Coordinates X	Coordinates Y	Address
1. Metrostation „Lyulin“	193618.2617	4736301.56	Tzaritza Yoana Blv., Lulin 9
2. Sofia municipality – Krasna polyana Region	196246.550705	4733402.55922	25 “Osvobozhdenie” Str.
3. Turning loop of Tram 10, Western park	195107.053	4734401.021	“Alexander Stambolyiski” Blvd.
4. “President Lincoln” Blvd.	193833.0534	4733083.906	“President Lincoln” Blvd. Ovcha kupel
5. Sofia municipality –Studentski Region	200932.6231	4729444.922	Bl. 5, Studentski grad
6. National Institute of Meteorology and Hydrology - BAS	203562.5428	4728914.087	“Tzarigradsko shoes” Blvd.
7. Winter sports palace	200170.5446	4727706.46	“Akad. Asen Stefanov” Blvd.
8 Sofia municipality - Nadezhda Region	196869.2193	4737168.813	55 “Kyril Drangov” Str., Nadezhda 1
9. Community center “ Iskra” – Orlandovtzi	199791.2129	4736327.844	“Purva bulgarska armia” Blvd., Orlandovtzi
10. Sofia municipality - Poduyane Region	202605.4812	4733999.907	51 “Plakalnitza” Str.
11. Military academy “G.S. Rakovski”	200766.6234	4733005.072	82 “Evlogi and Hristo Georgievi” Blvd., Oborishte region
12. National center for contagious and	200099.2106	4733591.125	26 “Yanko Sakusov” Blvd., Oborishte region

parasitic diseases			
13. Metro station James Bourchier	198465.4513	4730770.724	"Chervi vruh" Blvd., Lozenetz region
14. 29 Diagnostic consultative center – Borovo	196508.4063	4730237.639	8 "Georgi Izmirliev"
15. Sofia municipality – Iskar region	205005.3074	4730051.899	18 "Krastyo Pastruhov" Str., Druzba 1
16. Sofia municipality – Ovcha kupel region	193948.1383	4730798.533	136B "Tzar Boris III" BlvdOvcha kupel
17. "Rakovski" Stadium	197256.3758	4731737.361	"Balsha" str., Ivan Vazov
18. Community center "St. st. Kyril and Metodii"	197330.1683	4726226.648	6 „Tzar Ivan Alexander" Sq., Dragalevtzi
19. Central bus station	198892.5801	4735177.19	"Maria Luiza" Blvd., City center
20. Automatic measuring station "Hipodruma"	196501.0727	4732115.987	Hipodrima Park
21. Vrazhdebna Polyclinic	206311.4984	4735095.731	„28" Str., Vrazhdebna
22. "Mimi Balkanska" Str.	203529.4255	4733113.68	"Mimi Balkanska" Str., Hristo Botev

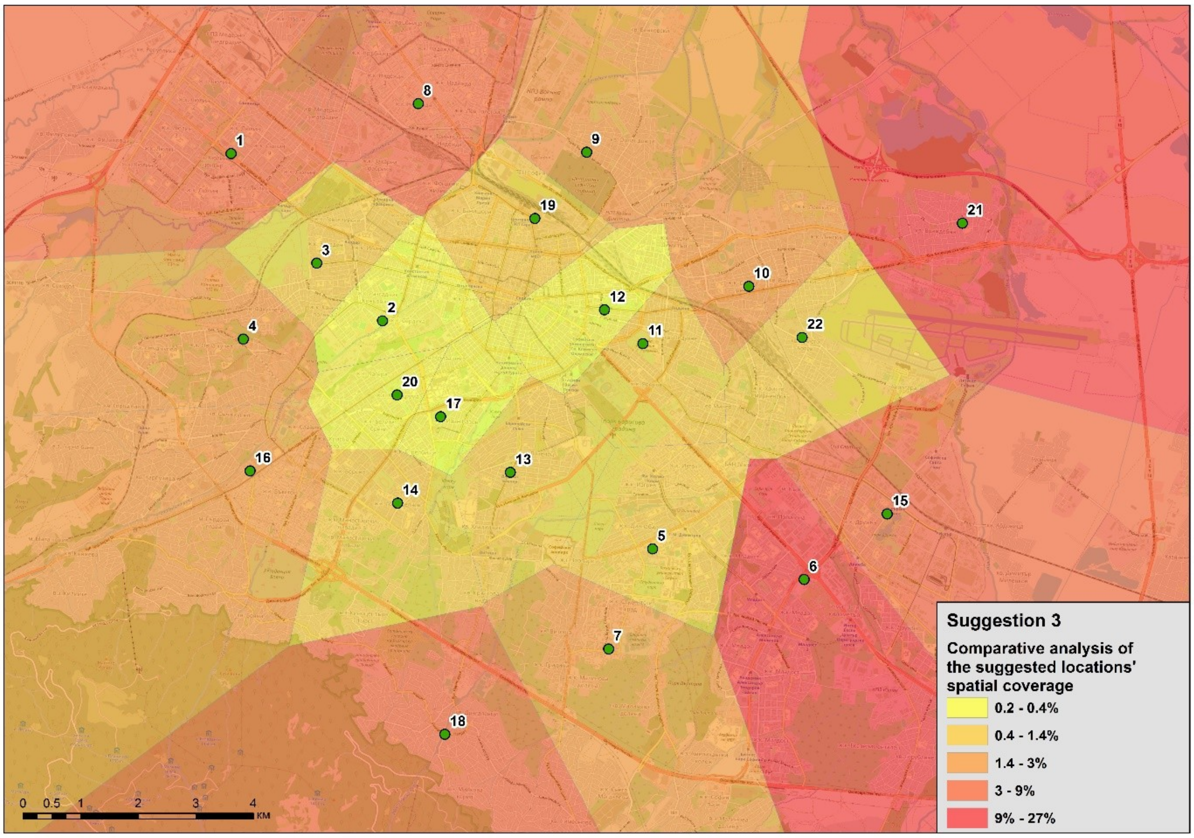
The proposed locations are explained in Annex 3 to the report.

Figure 19. Spatial distribution of locations for sensor network deployment - Suggestion 3



The choice of locations implies the achievement of a greater degree of uniformity in the coverage of the target territory while taking into account the specificities of the combination of localization factors and population distribution. At the same time, specific objects are sought - municipal property, which will facilitate the technical and logistic provision of the sensors.

Figure 20. Comparative analysis of the spatial coverage of the suggested locations– Suggestion 3



In the central areas, the sensors are located to cover information areas smaller in size than the territory of the city, while the peripheral data will be provided for larger areas.