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GEOSPATIAL ANALYSIS OF THE STATE OF THE PARTICULATE MATTER (PM_{10}) INDICATOR FOR THE CITY OF SOFIA (BULGARIA)

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Abstract

The current research is focused on an extremely important topic in the last decade, namely, atmospheric air quality. Air quality is the subject of much discussion and attention for several key reasons: human health, environmental implications, climate change, economic challenges, legislation and regulations, and public awareness. Air pollution is a problem both locally and globally in Europe and around the world. Pollutants released into the air in one country can be transported in the atmosphere and affect air quality elsewhere. A large proportion of Europe's population lives in large cities, where levels of ozone, nitrogen dioxide and fine particulate matter (PM) pollution often exceed permitted levels, posing a serious health risk. The problem of air pollution is particularly pronounced in large cities with intensive traffic, high population concentration and industrial areas. In cities located in hollows, such as Sofia city, air masses are trapped, which makes it difficult to diffuse the pollutants into the atmosphere. Although air quality in Sofia and other European cities has improved, the problem has worsened again in recent years.

Keywords: air quality, PM10, GIS, pollution, „AirThings“ project

INTRODUCTION

The topic of ambient air quality has been extremely relevant in the last decade. Ambient air quality is the subject of much discussion and attention for several key reasons: human health, environmental implications, climate change, economic challenges, legislation and regulations, and public awareness. According to the European Environment Agency (Air quality in Europe report, 2014) air pollution is a problem both locally and globally in Europe and around the world. Pollutants released into the air in one country can be transported into the atmosphere and affect air quality elsewhere. As per EEA (2014), a large proportion of Europe's population lives in large cities, where levels of ozone, nitrogen dioxide and fine particulate matter (PM) pollution often exceed permitted levels, posing a serious health risk. The problem of air pollution is particularly pronounced in large cities with intensive traffic, high population concentration and industrial areas (Air quality in Europe report, 2014).

Air pollution, according to the World Health Organization (World health statistics, 2012), is a change in the natural characteristics of the atmosphere caused by various agents such as household combustion appliances, vehicles, industrial facilities and forest fires. This leads to morbidity and mortality, particularly affecting low- and middle-income countries. As per WHO (2012) air pollution is also linked to climate change and biodiversity loss.

Air pollution is recognized as a leading public health problem and a major environmental problem worldwide, deserving of increasing interest from the scientific community (Brunekreef & Holgate, 2002; Landrigan, 2017). Various pollutants can cause environmental risk, but the most dangerous ones according to experts from Sofiaplan (Vision for

Sofia, 2018) are fine particulate matter ($PM_{2.5}$ and PM_{10}), ozone (O_3), carbon monoxide (CO), sulfur dioxide (SO_2) and nitrogen dioxide (NO_2). There is ample evidence that exposure to polluted air, particularly with fine particulate matter (PM), increases morbidity and mortality in urban areas. According to the World Health Organization (World health statistics, 2012), exposure to polluted air causes 4.2 million deaths annually outdoors. This makes it the fourth highest risk factor for mortality in the world. It is important to note that 91% of the world population lives in places where air pollution exceeds the limits set by the WHO. According to a Lancet report (Landrigan, 2017), air pollution costs the world economy $4.6 trillion annually, which is 6.2% of the global economic turnover.

In recent decades, computers are used in all spheres of human life, including in planning and management of territory and regional development. According to Popov (2012), geographic information systems (GIS) are essential for organizing data on territories and spatially locating problems, providing methods for analysis and solving challenges. According to him, they excel in their ability for spatial analysis, which makes them an effective tool for uncovering new information about real-world objects and phenomena. Recent years have seen an increase in the application of GIS, especially in the field of regional development and ecology, as they play an important role in identifying and addressing environmental problems and supporting decision-making in various situations. GIS are an essential tool for analyzing and assessing the impact of various activities on the environment, as well as for the planning and management of regional and local development (Popov & Dimitrov, 2009).

According to data from the European Environment Agency (Air quality in Europe report, 2014), the urban air is twice as clean as in previous years, but public attitudes nevertheless rate the air as one of increasingly deteriorating quality. On the one hand, this is because the topic is given more attention compared to previous years, and on the other hand, due to the popular aspirations in the capital to improve the quality of urban life.

The main aim of the article is to perform an analysis of the concentration of fine dust particles (PM_{10}) with a size of 10 microns using data of the Sofia Municipality and the “AirThings” project.

MATERIALS AND METHODS

For the purpose of the present study, official data from the 22 sensor stations installed by the Metropolitan Municipality under the “AirThings” pilot project were used (Sofia Municipality, “AirThings” project, 2017). The Sofia Municipality has been a leading partner in this project since December 2017. It is aimed at protecting the purity of atmospheric air, in the context of global climate and environmental changes, and foresees the use of modern technologies and trends for atmospheric air monitoring. For the purposes of the project, an internet platform has been developed that visualizes and stores air data. The aim of the project is to build local networks of sensors for monitoring and measuring the quality of the ambient air.

In Sofia, the system consists of 22 stations for measuring atmospheric air quality and it measures in real time, by means of sensors, the most common air pollutants (PM, CO, NO_2, SO_2), temperature, humidity and atmospheric pressure. Each station sends information on these indicators to a system that is built on the principle of open data (Open Data System). The sensors are presented in the table below.

The map in Fig. 1 presents the 22 sensors that have been installed under the “AirThings” project. The numbers of each of the sensors match the sensor numbers from the table.

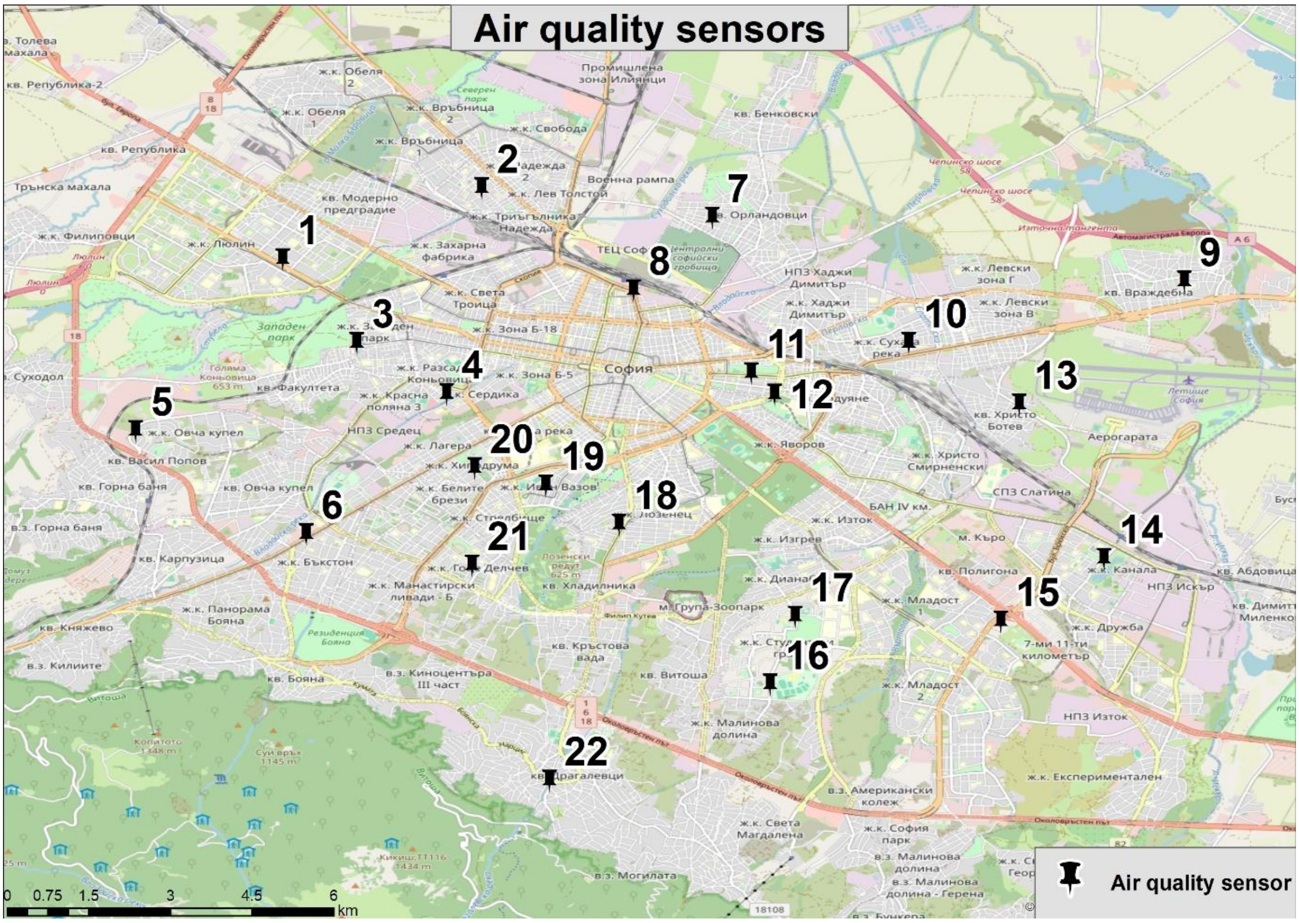


Fig. 1. Air Quality Sensors

Sensor	GPS	Address
1. "Lyulin 9" district	42°42'55.5 "N 23°15'52.4"E	"Gen. Casimir Ernrot" Str. Bl. 954
2. "Nadezhda" district	42°43'37.7 "N 23°17'50.9"E	“Nadezhda” district - “Kiril Drangov” Str. 55
3. "Alexander Stamboliyski" Blvd., "West Park"	42°42'05.7 "N 23°16'36.6"E	Blvd. "Al. Stamboliyski", at the bus turner
4. "Krasna Polyana" district	42°41'35.3 "N 23°17'30.0"E	"Osvobozhdenie" Str. 25
5. "President Lincoln" Blvd., "Ovcha Kupel" district	42°41'13.2 "N 23°14'25.1"E	“President Lincoln” Blvd. 121
6. „Ovcha Kupel“district	42°40'12.0 "N 23°16'06.5"E	"Gusla" Str. 1
7. "Orlandovtsi" district	42°43'20.1 "N 23°20'08.0"E	"Orlandovtsi" district - "Kiril Perlichev" Str. 42
8. Central Railway Station	42°42'42.1 6"N 23°19'09.4"E	At the intersection of "Princess Maria Louisa" Blvd. and "Hristo Botev" Blvd.
9. "Vrazhdebna"distict	42°42'42.2 "N 23°24'48.7"E	At the intersection of Str. 28 and Str. 59

10. "Poduyiane" district	42°42'05.7"N 23°22'04.8"E	50 meters west from the intersection of "Emanuil Vaskidovich" Str. 34-38
11. National Center for Infectious and Parasitic Diseases	42°41'47.8 "N 23°20'31.3"E	"Yanko Sakazov" Blvd. 48
12. Military Academy "G. S. Rakovski"	42°41'35.0 "N 23°20'45.1"E	"Evlogi Georgiev" Blvd. - after the bus stop
13. "Hristo Botev"district	42°41'29.1 "N 23°23'10.5"E	"East Tangenta" Str. 104
14. "Iskar" district	42°39'57.2 "N 23°24'00.98"E	"Krastyo Pastukhov" Str. 23
15. National Institute of Meteorology and Hydrology (NIMH)	42°39'19.9 "N 23°22'59.6"E	In the yard of NIMH, Buvl. "Al. Malinov", 1
16. Winter Palace of Sports	42°38'42.6 "N 23°20'42.5"E	„Akademik Stefan Mladenov" Str., 80
17. "Studentski" district	42°39'22.8 "N 23°20'57.3"E	on the street next to block 4 – "Prof. Boyan Kamenov" Str.
18. Metro station "James Boucher"	42°40'17.6 "N 23°19'12.5"E	garden in front of the church "St. Mina", Blvd. "James Boucher"
19. "Ivan Vazov" district	42°40'40.8 "N 23°18'29.0"E	"Yaroslav Veshin" Str. 22-26
20. Hippodrome Park	42°40'51.2 "N 23°17'46.7"E	"Bulair" Str. 11, block 15
21. "Borovo" clinic	42°39'53.2 "N 23°17'45.1"E	"Georgi Izmirliev" Str. 8
22. "Dragalevtsi" district	42°37'45.3 "N 23°18'31.1"E	"Narcis" Str. 2

An analysis of suitable locations for the implementation of a system of sensors for measuring air quality on the territory of Sofia was carried out on the basis of modern geostatistical and spatial-analytical operations made in a digital GIS (ArcMap 10.8.1) environment. The goal was to create a scientific basis for a correct model (from a spatial-functional point of view) for locating and deploying a representative sensor network for monitoring the air quality over the urbanized territory. An important clarification should be made: according to the municipality, the data are indicative and due to the specifics of the technologies used in the sensor stations, under certain conditions, a deviation in the measured indicators is possible.

Data processing and evaluation

For the purposes of the study, maps were created from a source - the "AirThings" project, which shows the maximum reported values for the various pollutants by year. Due to the huge amount of data for the period from 2020 to 2023 and for the purpose of clearer and easier understanding and perception of the presented information, the data has been equated to quarters corresponding to the EEA quarters, or more precisely: first quarter (January-March), second quarter (April-June), third quarter (July-September), fourth quarter (October-December).

The data was processed in Microsoft Office Excel, and the interpolation method used to create the maps in ArcMap 10.8.1 was IDW – Inverse Distance Weighted Interpolation.

RESULTS

For the purposes of the study, the data from the platform was processed and equated by a quarter, similar to the data from the EEA quarterly bulletins. The goal is to achieve easier understanding of the huge data set. After carrying out a thorough analysis of the data from the project's open data system, it was concluded that the most significant excesses were reported for the PM_{10} indicator.

A prerequisite for the retention of polluted air over the capital is the relief and climatic features of the studied territory. Due to the specificity of the geographical location of the municipality of Sofia, climatic features also play an important role in the formation of air quality. Sofia, both because of its location between Stara Planina, Vitosha and the western slopes of Ikhtimanska Sredna Gora, and because of its relatively high altitude, is one of the foggiest places in Bulgaria. It is characterized by long days with fog, no wind and temperature inversion, which create conditions for the accumulation and retention of pollutants over the city. The typical fog is thick or moderate in December - January, when the sky is not visible. The air temperature ranges from –5.0ºC to +5.0ºC, the relative humidity is 100% and the atmospheric pressure is in the range of 945 – 965 hPa.

The other big source of air pollution after heating is transport. During the winter months, the share of people who use their private cars to reach a certain destination increases more and more. The number of cars in the capital is increasing daily, which in turn leads to a deterioration of the air quality, and also creates traffic jams with the release of more harmful emissions at certain locations - for example, central intersections, boulevards and streets.

PM_{10} is undoubtedly one of the biggest air pollutants in recent years. They are one of the most important and significant indicators of air quality. They are the most recorded exceedances in the last decade, according to the EEA (Air quality in Europe report, 2014). According to the Bulgarian legislation (Ordinance No 12), the average 24-hour hygiene norm for the protection of human health is equal to 50 $\mu g/m^3$, and it should not be exceeded more than 35 times within a calendar year. Also, the average annual standard for the protection of human health (for one calendar year) is 40 $\mu g/m^3$. The research of the “AirThings” project data in the period 2020-2023 shows that there was not a single quarter during the research period for which an excess of the norms was not registered.

Analyzing the sensors of the “AirThings” project, the following summary can be made for the data available for 15 quarters; it is clear that for each of them an excess of the permissible norms for PM_{10} was reported. The most significant number of value exceedances were observed in the first and fourth quarters of the year (the cold months). However, a significant number of exceedances also occurred in the second and third quarters (the warm months). The most significant exceedance of the norms for the indicator in the period 2020-2023 was reported in the first quarter of 2022 by the sensor in the "Studentski" district and was equal to 1686.32 $\mu g/m^3$, which is slightly more than 30 times the excess of the 24-hour norm of 50 $\mu g/m^3$. Other similar values were reported in the fourth quarter of 2020 by the sensor at the National Center for Infectious and Parasitic Diseases - 874.29 $\mu g/m^3$ and in the third quarter of 2023 by the sensor at the Hippodrome Park - 827.04 $\mu g/m^3$.

Figures 2, 3, 4 and 5 present the maximum PM_{10} values for 2020. In the first quarter, all of the installed sensors reported excesses of the permissible norms for the indicator, with the reported values ranging from 57.23 $\mu g/m^3$ for the sensor at the National Institute of Meteorology and Hydrology (NIMH), to the third highest for the entire year - 516.170 $\mu g/m^3$ for the sensor at the National Center for Infectious and Parasitic Diseases. During the April-June period, 8 out of 22 sensors recorded exceedances of the norms - NIMH with 316.84 μg/m^3, for: "Iskar" district with 115.91 μg/m^3, "Hristo Botev" with 90.64 μg/m^3, "Alexander Stamboliyski" Blvd., "Zapaden Park" with 88.08 μg/m^3, "Orlandovtsi" district with 56.08 μg/m^3, National Center for Infectious and Parasitic Diseases with 55.65 μg/m^3, "Poduyiane" district with 55.44 μg/m^3, President Lincoln Blvd., „Ovcha Kupel“ district with 52.84 μg/m^3. In the third quarter, there were exceedances for 7 out of 22 sensors, ranging from 51.92 μg/m^3 for "Orlandovtsi" district to 394.43 μg/m^3, for "President Lincoln" Blvd., and for "Ovcha Kupel" district. Again, significant shifts in the norms were observed during the warm half of the year, which is not typical for the summer months. For the last part of the year, 21 out of 22 sensors reported an increase in the permissible norms, with the exception of the sensor at "Studentski" district. In this quarter, the second record value for the entire investigated period was recorded by the sensor at the National Center for Infectious and Parasitic Diseases - 874.29 μg/m^3. High values were recorded by many of the other sensors as follows: "Nadezhda" - 581.77 μg/m^3, "Hristo Botev" - 520.53 μg/m^3, "Orlandovtsi" - 438.52 μg/m^3, "Krasna Polyana" - 434.16 μg/m^3, "Lyulin 9" - 385.34 μg/m^3, Central Railway Station - 333.40 μg/m^3, "Dragalevtsi" quarter - 291.05 μg/m^3, "Poduyiane" district - 287.92 μg/m^3, "Alexander Stamboliyski" Blvd., West Park - 280.22 μg/m^3 and others.

Figures 6, 7, 8 and 9 present the reported maximum values of the PM_{10} indicator for 2021. As in the previous year, the increases were mainly in the first and fourth quarters of the year. During January-March period, all 22 sensors reported exceeding the norms, with the excesses being within the range - 82.57 μg/m^3 for the Hippodrome Park and 510.50 μg/m^3 for “ Hristo Botev” district. For the fourth quarter of the year, exceedances were also reported for the municipality's 22 sensors. The highest reported value was again from the sensor in the "Hristo Botev" - 335.76 μg/m^3, and the lowest this time from the "Studentski" district - 91.88 μg/m^3. In the April-June period, there were recorded exceedances of the norms for 11 out of a total of 22 sensors for the following districts: "Hristo Botev" - 102.82 μg/m^3, "Krasna Polyana" - 93.75 μg/m^3, "Iskar" - 74.73 μg/m^3, "Lyulin 9" - 72.5 μg/m^3, "Alexander Stamboliyski" Blvd.,West Park - 69.58 μg/m^3, NIMH - 66.35 μg/m^3, the Polyclinic "Vrazdebna" - 60.88 μg/m^3, "Dragalevtsi" - 60.77 μg/m^3, Hippodrome Park - 58.41 μg/m^3, “Orlandovtsi” - 54.67 μg/m^3 and the Military Academy "G. S. Rakovski" - 52.35 μg/m^3. For the period July-September, only 6 exceedances of the PM_{10} indicator were recorded, but some of them were significant and atypical for the summer months: "Nadezhda" - 540.66 μg/m^3, “Central Station” - 476.25 μg/m^3, metro station "James Boucher" - 144.52 μg/m^3.

Figures 10, 11,12 and 13 visualize the maximum values for PM_{10} in 2022. This was the year with a record excess throughout the period - 1686.32 μg/m^3 in the "Studentski" district, which was more than 30 times above the established norms. The exceedance was recorded in the first quarter of the year, and it was followed by another 20 sensors with exceedances, in the range of 63.98 μg/m^3 to 387.91 μg/m^3, excluding NIMH. During the two summer quarters, respectively, 6 and 9 sensors exceeded the norms, and for the period April-June they were within the limits - 51.33 μg/m^3 to 193.71 μg/m^3, for July-September - 51.77 μg/m^3 to 92.51 μg/m^3. At the end of the year, 19 out of 22 sensors exceeded the norms, and for some of the sensors the excesses were 5-6 times or more above the norm, such as for "Poduyiane" area with 354.07 μg/m^3, the Central Station with 310.15 μg/m^3, " Hristo Botev" with 301.31 μg/m^3 and others.

Figures 14, 15 and 16 present the maximum reported values for PM_{10} in the three quarters for which data were available in 2023. In January-March period, 19 out of a total of 22 sensors reported excesses in the values of the

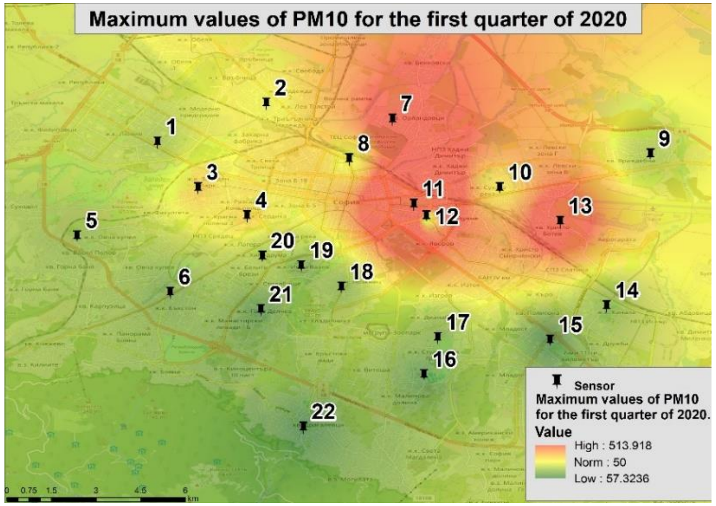


Fig. 2. Maximum values of PM10 for the first quarter of 2020.

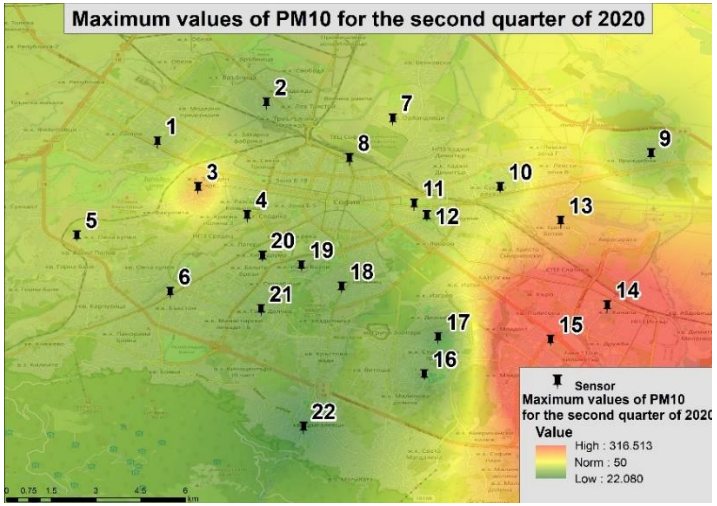


Fig. 3. Maximum values of PM10 for the second quarter of 2020.

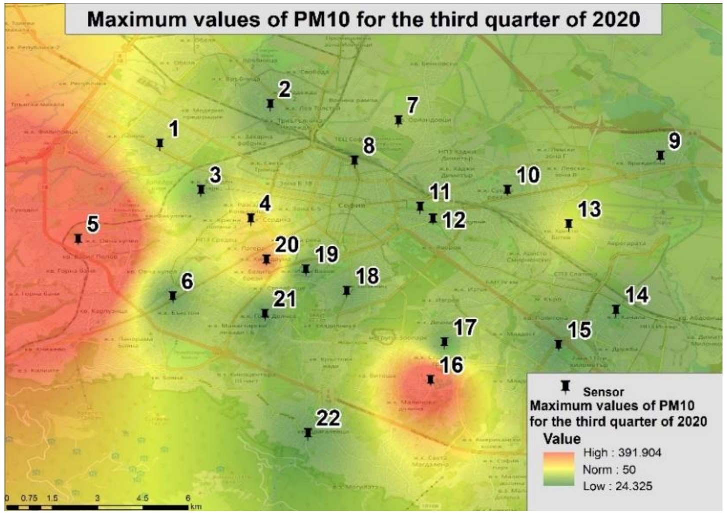


Fig. 4. Maximum values of PM10 for the third quarter of 2020.

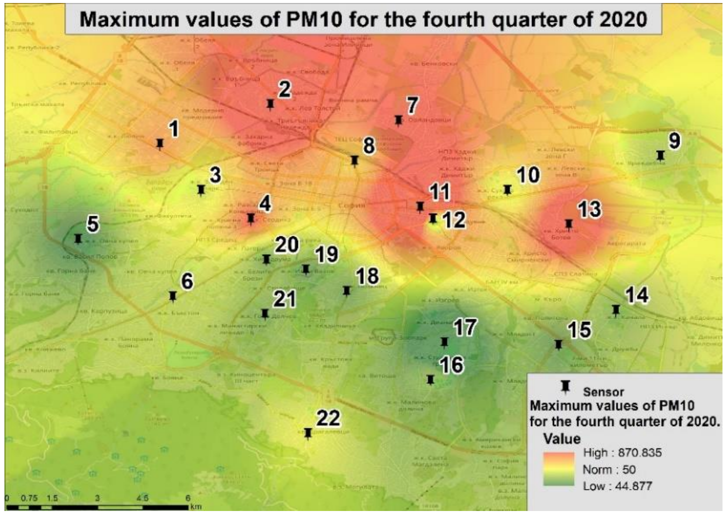


Fig. 5. Maximum values of PM10 for the fourth quarter of 2020.

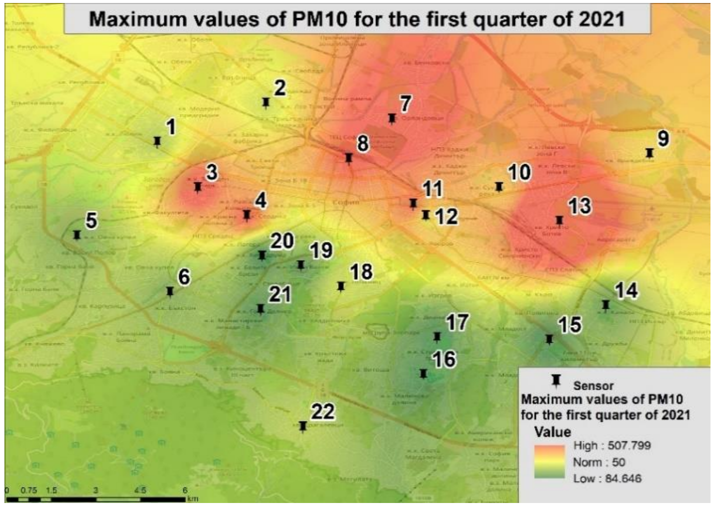


Fig. 6. Maximum values of PM10 for the first quarter of 2021.

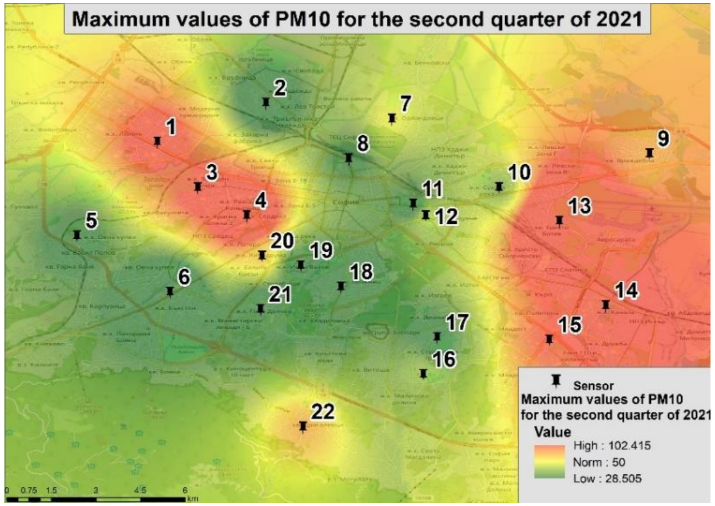


Fig. 7. Maximum values of PM10 for the second quarter of 2021.

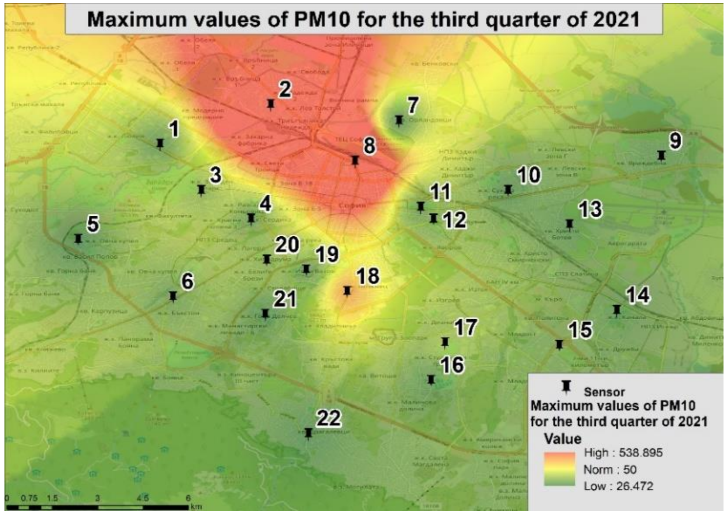


Fig. 8. Maximum values of PM10 for the third quarter of 2021.

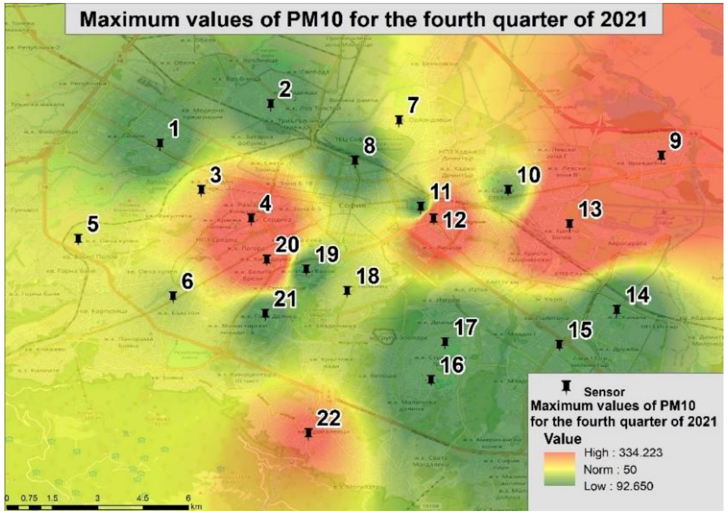


Fig. 9. Maximum values of PM10 for the fourth quarter of 2021.

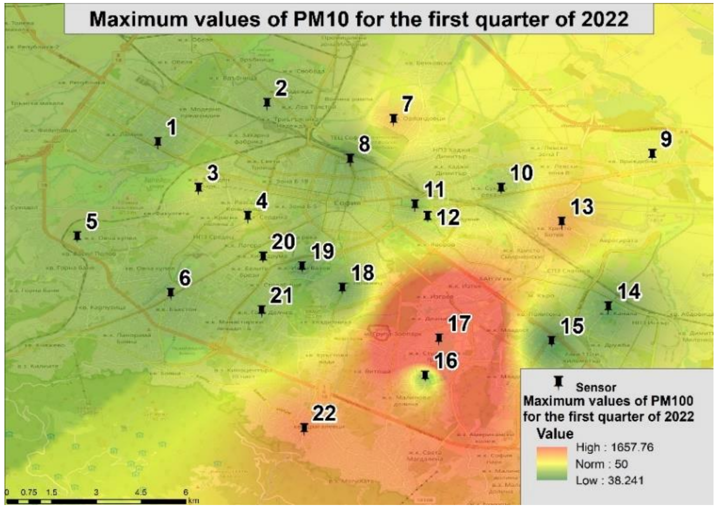


Fig. 10. Maximum values of PM10 for the first quarter of 2022.

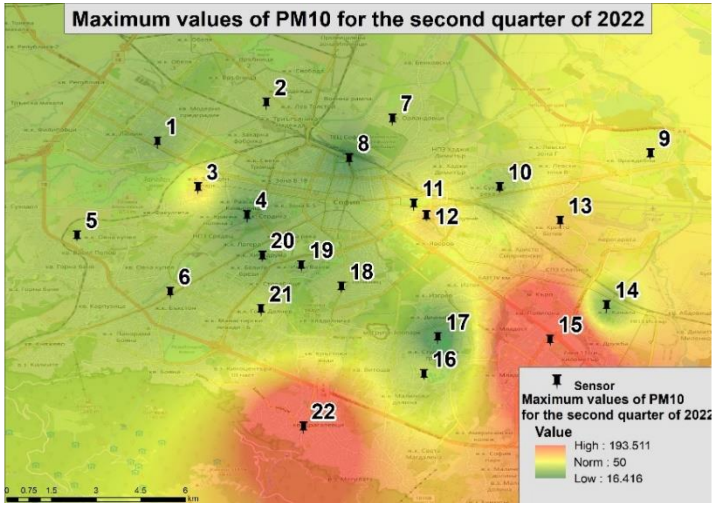


Fig. 11. Maximum values of PM10 for the second quarter of 2022.

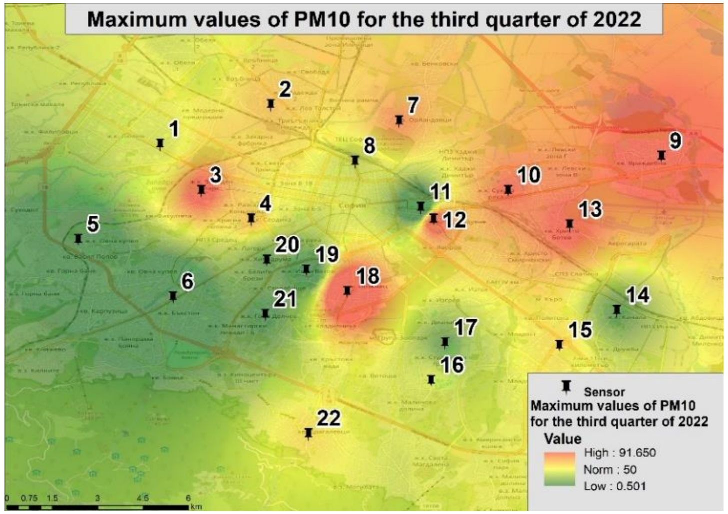


Fig. 12. Maximum values of PM10 for the third quarter of 2022.

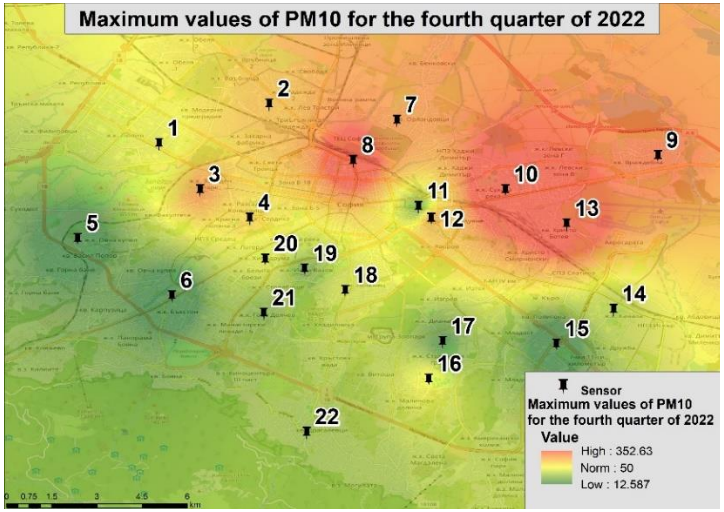
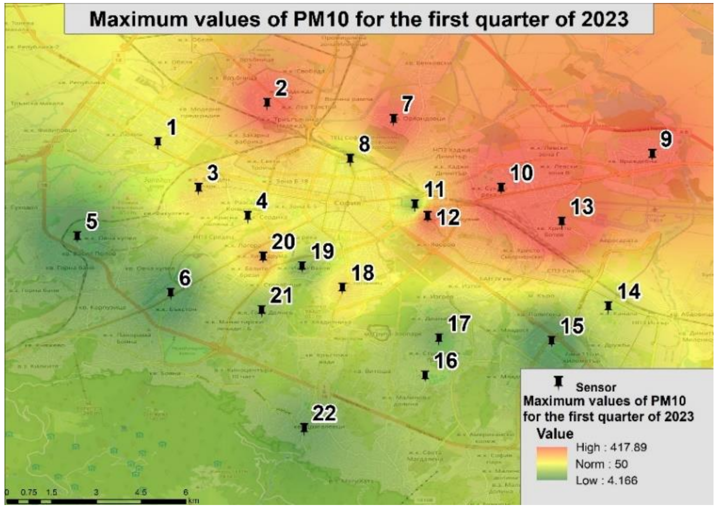


Fig. 13. Maximum values of PM10 for the fourth quarter of 2022.



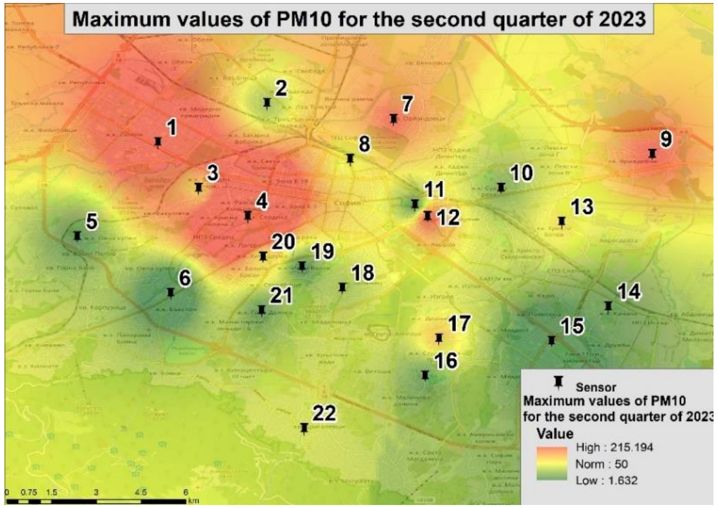


Fig. 14. Maximum values of PM10 for the first quarter of 2023. **Fig. 15.** Maximum values of PM10 for the second quarter of 2023.

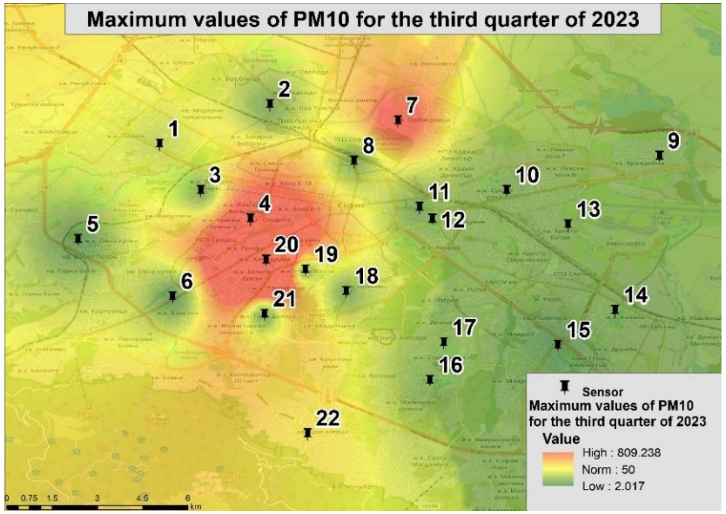


Fig. 16. Maximum values of PM10 for the third quarter of 2023.

indicator, with the exception of "Ovcha Kupel" area, "President Lincoln" Blvd. and NIMH. The sensor at the "Hristo Botev" district recorded the highest values - 419.25 μg/m^3, followed by the sensors at "Poduyiane" area - 409.04 μg/m^3, at the Military Academy "G. S. Rakovski" - 359.36 μg/m^3, in "Nadezhda" - 359.22 μg/m^3, "Orlandovtsi" - 348.84 μg/m^3, the Polyclinic "Vrazhdebna" - 342.28 μg/m^3, Park "Hippodrome" - 268.20 μg/m^3, "Alexander Stamboliyski" Blvd., West Park - 222.86 μg/m^3, "James Boucher" metro station - 216.31 μg/m^3, "Krasna Polyana" - 187.58 μg/m^3, "Lyulin 9" district - 179.85 μg/m^3, Central Station - 170.07 μg/m^3, Iskar district - 156.20 μg/m^3, Winter Palace of Sports - 119.02 μg/m^3, the National Center for Infectious Diseases and parasitic diseases - 109.44 μg/m^3, "Borovo" clinic - 98.89 μg/m^3, "Ivan Vazov" - 96.26 μg/m^3, "Studentski" district - 73.83 μg/m^3 and "Dragalevtsi" - 63.78 μg/m^3. The excesses of the permissible norms are significant, but not only the excesses make an impression, but also the significantly low values of three sensors that did not report excesses – at "President Lincoln" Blvd., for "Ovcha Kupel" district -17.99 μg/m^3, at NIMH - 3.89 μg/m^3. Such low values are atypical for the cold half-year and for sensors that in previous years reported significant excesses of the norms for the indicator. For the second quarter, 6 of the sensors recorded excesses, and for some of them, they were not at all low for the warm half-year - "Krasna Polyana" reported 220.14 μg/m^3, "Lyulin 9" - 104.94 μg /m^3, and the Military Academy "G. S. Rakovski" - 82.46 μg/m^3. In the third quarter, the third highest value for the entire investigated period was recorded - 827.04 μg/m^3 from the sensor in the Hippodrome Park.

CONCLUSION

Air pollution is a global problem requiring large-scale measures. Building a network of sensors is a key initiative to track and manage air pollution. In each of the investigated residential areas, an excess of the permissible norms for PM_{10} was reported. The most significant number of value exceedances were observed in the first and fourth quarters of the year (the cold months). The specific geographical conditions of Sofia increase the air quality problem. Official and unofficial sources of air pollution data currently exist, but they are insufficient. It is necessary to build a larger network of sensors and collect more data to improve analysis and measures to reduce pollution. In addition, emissions information needs to be more detailed in order to take effective action. Without access to data on traffic, heating and other sources of pollution, it is difficult to implement appropriate measures. Despite improvements in air quality over the past ten years, continued efforts are needed to achieve even better results.

Within the framework of the study, the set goal was fulfilled, namely a geospatial analysis of the state of the PM_{10} indicator for the city of Sofia for the period 2020-2023. For the objectives of the study, the most essential materials and methods were considered, namely the application of GIS for the purposes of ambient air quality, including a geospatial analysis of air quality data obtained from the "AirThings" project for measuring air quality by indicators. Through them, the results were obtained, helping to achieve the goal of the research – a geospatial analysis.

On a larger scale, ambient air quality has improved significantly in recent years. Despite its somewhat fluctuating values, the PM_{10} indicator recorded a decrease in values compared to the beginning of the period (2020). Despite the decrease in the reported maximum values, the indicator still reports values that exceed the established norms. It is necessary to maintain the positive trend towards a decrease in the reported maximum values of the indicator. It is important that Sofia municipality undertakes more "green" measures in order to improve the quality of atmospheric air.

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