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“Geospatial model for assessment of atmospheric air quality in the city of Sofia”

ABSTRACT

On a dissertation for the award of the educational and scientific degree “Doctor”
By scientific specialty “Cartography (incl. Thematic geographic mapping - Geographic information systems)”

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For the dissertation

The dissertation has a total volume of 287 pages. It consists of 187 pages of text and 100 pages of annex. It is structured in an introduction, 3 chapters and a conclusion. The list of the literature used contains 149 titles, of which 17 scientific developments in Bulgarian, 51 foreign scientific works, 38 normative, planning and strategic documents, 43 quarterly newsletters of the EEA. The dissertation contains 249 figures, of which 19 tables, 15 diagrams/schemes and 215 maps.

The dissertation was discussed and accepted for defense at an extended meeting of the "Cartography and GIS" department at the Faculty of Geology and Geography of Sofia University "St. Kliment Ohridski", held on March 19, 2024.

The defense of the dissertation will take place on June 28, 2024 at 14:00 in hall 287 of the rectorate of Sofia University "St. Kliment Ohridski" at an open meeting of a scientific jury composed of:

1. Prof. Dr. Boyan Kulov
2. Prof. Dr. Georgi Zhelezov
3. Prof. Dr. Stoyan Nedkov
4. Assoc. Dr. Bilyana Borisova
5. Assoc. Dr. Evgenia Sarafova

The materials are available to those interested in the "Cartography and GIS" department in the rectorate of Sofia University "St. Kliment Ohridski" at 15 Tsar Osvoboditel Blvd.

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1. INTRODUCTION

1.1. Relevance of the topic

Air pollution is a local, pan-European and global problem. Air pollutants released in one country can be carried into the atmosphere, worsening air quality elsewhere. A significant proportion of Europe's population lives in areas, particularly in large cities, where permissible air quality standards are exceeded: ozone, nitrogen dioxide and fine particulate matter (PM) pollution, which poses serious health risks to the population. Fine dust particles are released during the burning of fuel from cars, wood burning, household waste, industrial activities. Their accumulation in the environment leads to the formation of fogs, smog and dust. The problem of pollution is often observed in large cities, where there is increased traffic, population concentration and the presence of industrial enterprises. The problem is particularly pronounced in places where the city is located in a hollow - such as the city of Sofia, and natural streams cannot flow freely. This leads to the retention of air masses and stops the purification of the air in the city.

The air quality both in the capital - Sofia, and in other European cities reports significantly improved levels, in a global plan. On the one hand, this is due to the introduction of purification plants in the industry, which in the past was one of the most serious polluters. However, in recent years, air quality has again become a serious problem that is receiving considerable attention.

The geographical position and climatic characteristics of the city have a great influence on the quality of the atmospheric air. The air problem is very much geographically determined. Located in the Sofia field, typical phenomena such as temperature inversions and retention of fogs, determined by the relief of the territory, are observed in the capital. These phenomena are mostly observed during the winter months, which makes it difficult to clean the air. The geography of the city is one of the most serious prerequisites for the retention of dirty air, and for forming critical points for the indicators that measure its quality.

Despite the location and climatic features of the capital, one of the main sources of pollution in the city remains cars and heating, in particular the use of fossil fuels and biomass for domestic heating. This is a trend not only in the country, but also in Europe. In many of the zh. k.s, central heating does not function, as customers refuse the services of the zh. k. heating company and heat with solid fuel or electricity instead of steam. Fossil fuel-heated neighborhoods, as well as those that burn various types of waste for heating, are generally the poorest and most marginal neighborhoods with low-income residents. But at the same time, there are exceptions - a large part of the neighborhoods around Vitosha mountain use solid fuels for heating. Some of the commercial premises in the city, such as car repair shops,

warehouses and others burn unregulated waste in order to heat themselves during the winter months. Unregulated incineration of waste is carried out both in the home and in business - textile waste, plastics, oils, tires, household waste, etc.

Another factor influencing the air quality in the capital is the anthropogenic factor - the continuously increasing share of the capital's residents who use their personal cars for their daily movement in the city. In the country, there is a tendency to increase the number of used imported cars, most of which are diesel. The car fleet in the capital is increasing daily, which leads to serious problems, as catalytic converters and particulate filters are deliberately removed from cars, which emits a large share of harmful emissions.

Geographic information systems are used in the management of atmospheric air quality. They serve to produce in-depth geospatial analyzes and assessments, thereby supporting informed management decisions. Through them, maps and applications are created that help manage and monitor the quality of the atmospheric air. For this purpose, it is necessary to collect, analyze and process a significant amount of data, which will serve for further analysis and creation of maps, tables and graphs.

Geographic information systems are not only a convenient tool for visualizing spatial information, but also a tool for organization, modeling and analysis of various statistical data. In recent years, they have been increasingly used in the management and monitoring of air quality.

1.2. Aim

The aim of the present study is to implement a geospatial model for the assessment of atmospheric air quality.

1.3. Object of research

In order to achieve greater concreteness and practical applicability of the results, the territory subject to research was limited to the spatial scope of the city of Sofia. The choice of the research object was born from the personal interest in the territory and its familiarity. The city is the cultural and economic center of Bulgaria, which makes it a strong center of attraction. According to NSI data (as of 31.12.2021), the population of the capital is 1,274,290 people, which is about 17% of the country's population. The continuously increasing population leads to the gathering of many people with different needs in one place, which leads to deterioration of the quality of the atmospheric air.

1.4. Subject of research

The subject of research in the current development is the system of procedures for preparing a specialized GIS database and the implementation of a geospatial model for the assessment of atmospheric air quality. For this purpose, an appropriate set of scientific literature on the subject will be examined, as well as normative and strategic documents governing the management and monitoring of air quality.

1.5. Tasks

- To carry out a thorough analysis of the legal basis regulating the processes for monitoring of the air quality .
- To build specialized GIS databases.
- To carry out geospatial analysis.
- To carry out a comparative analysis between two sources of data for AQ
- Research and presentation of other potential sources of information on AQ

2. ATMOSPHERIC AIR QUALITY – BASIC CONCEPTS AND LEGISLATIVE FRAMEWORK

2.1. Atmospheric air - basic concepts

Air pollution, according to WHO, 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. Air pollution is also linked to climate change and biodiversity loss. Air quality monitors use different methods to detect pollutants, and the air quality index indicates the degree of pollution.

2.2. Air pollution

Air pollution is recognized as a leading public health problem and a major environmental health problem worldwide, deserving of increasing interest from the scientific community (Brunekreef, Holgate, 2002; Landrigan, 2017). Ambient air pollution can be caused by many different pollutants, although the following are the most commonly studied; particulate matter (PM), ground-level ozone (O3), carbon monoxide (CO), sulfur dioxide (SO2) and nitrogen dioxide (NO2) (Brook et al., 2004; Sheehan et al., 2016). In terms of particulate matter, the most commonly used to estimate the air quality are PM2.5 and PM10. There is ample evidence that both acute and chronic exposure to air pollution, particularly coarse and fine particulate matter, increases population morbidity and mortality (Liu et al., 2019; Sanyal et al., 2018). The World Health Organization (WHO) estimates 4.2 million deaths each year as a result of exposure to (outdoor) air pollution (WHO, 2018), making air pollution the fourth highest risk factor for death worldwide (Brauer , 2016). . It is also worth mentioning that 91% of the world's population lives in places where air quality levels exceed WHO limits (WHO, 2016). According to the Lancet report, pollution costs the world economy $4.6 trillion annually, corresponding to 6.2% of global economic output (GAHP, 2020).

2.3. Air pollutants

According to the Executive Director of the European Environment Agency, air pollution causes serious damage to both human health and ecosystems, with a significant proportion of the population continuing to live in an unhealthy environment. The improvement of air quality in Europe in recent decades has been remarkable, but particulate matter and ozone pollution are a serious problem for human health. Major pollutants include fine particulate matter, ozone, sulfur and nitrogen dioxide, carbon monoxide, benzene, lead, arsenic, nickel and cadmium. In Bulgaria, as of 2017, the main pollutants according to national and European legislation are defined as PM10, PM2.5, O3, NO2, SO2, benzo(a)pyrene and heavy metals. For air quality control, 47 stationary measuring points operate in the country, including automatic measuring stations, manual sampling points and systems for differential optical atomic absorption spectrophotometry.

2.2.1 Fine dust particles

The following norms for fine dust particles are regulated:

PM10:

- Average day-night norm - 50 μg/m3 (not to be exceeded more than 35 times a year);

- Average annual norm - 40 μg/m3

PM2.5:

- Average annual norm - 30 μg/m3 since 2010.

- Average annual norm - 25 μg/m3 from 01.01.2015.

- Average annual norm - 20 μg/m3 from 01.01.2020.

2.2.2. Ozone

The regulated norms are the following:

- Threshold for informing the population (average hourly value) - 180 μg/m3;

- Population warning threshold (average hourly value) - 240 μg/m3 (measured over three consecutive hours);

- Threshold for health protection (8-hour floating average value) - 120 μg/m3;

2.2.3. Sulfur dioxide

The regulated norms are the following:

- Average hourly rate - 350 μg/m3 (not to be exceeded more than 24 times a year)

- Average day-night norm - 125 μg/m3 (not to be exceeded more than 3 times a year)

- Alarm threshold – 500 μg/m3 (measured in three consecutive hours)

If the alarm concentrations are exceeded, the implementation of measures to limit the harmful effects of the pollutant is required.

2.2.4. Nitrogen dioxide

The regulated norms are the following:

- Average hourly rate. - 200 μg/m3 (not to be exceeded more than 18 times a year)

- Average annual norm - 40 μg/m3

- Alarm threshold – 400 μg/m3 (measured in three consecutive hours)

If the alarm concentrations are exceeded, the implementation of measures to limit the harmful effects of the pollutant is required.

2.2.5. Carbon monoxide

The following standard for carbon monoxide is regulated for the protection of human health:

- maximum eight-hour value during the day – 10 mg/m3 (not to be exceeded more than once a year).

2.2.6. Benzene

The following standard for benzene is regulated for the protection of human health:

- Average annual norm - 5 μg/m3.

2.2.7. Lead

By Ordinance No. 12 of July 15, 2010 (promulgated SG No. 58 of July 30, 2010) the following maximum permissible concentration of lead aerosols in atmospheric air was adopted:

- Average annual norm - 0.5 μg/m3.

2.2.8. Cadmium

Our legislation defines the following maximum permissible concentrations for cadmium in atmospheric air according to Ordinance No. 11 of 14.05.2007 on standards for arsenic, cadmium, nickel and polycyclic aromatic hydrocarbons in atmospheric air (Official Gazette No. 42 of 29.05.2007):

- annual average Maximum permissible concentration - 5 ng/m3.

2.3. Normative documents, laws, strategies for air quality

Different countries' legislations focus on the protection of the environment and resources. In Bulgaria, legislation in this area is divided into general law and special laws, with the main law being the Environmental Law. Among the special laws is the Clean Air Act, which has a key impact on air quality.

Over time, public relations related to substances and activities that pollute the atmosphere have become increasingly important, with the largest polluter being the chemical industry. Pollution is a problem that requires regulation and meeting international requirements. Bulgaria is a party to various international conventions and agreements for the protection of the environment and clean air. The country's legislation also includes transposed EU directives, such as the Environmental Protection Act and the Clean Air Act, as well as various regulations on air quality assessment and management. Strategic documents and programs for air quality management at the national and local level are also important.

3. GEOGRAPHIC INFORMATION SYSTEMS AND THEIR APPLICATION FOR THE PURPOSES OF ATMOSPHERIC AIR QUALITY MANAGEMENT

3.1. Application of GIS in the planning and management of the territory and regional development. Current trends in the use of GIS

In recent decades, computers are used in all spheres of human life, including planning and management of the territory and regional development. According to Prof. Popov (2012), modern society is “informational”, with information technologies playing an important role in accelerating the processes of obtaining and using new knowledge. Geographical information systems (GIS) are essential for organizing data on territories and spatial localization of problems by providing methods for analyzing and solving challenges According to Prof. Popov, GIS are distinguished by their ability for spatial analysis, which makes them an effective tool for revealing new information about real-world objects and phenomena In recent years, there has been 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 evaluating the impact of various activities on the environment, as well as on the planning and management of regional and local development.

3.2. Creating a GIS database: stages and procedures. Spatial databases and spatial analysis.

For the purposes of the scientific work, specialized databases were created to help carry out the research. In this case, the database stores the data in tabular format. Two main sources were used: the Environment Executive Agency and the AirThings project. EEA is an administration under the Minister of Environment and Water for the implementation of management, coordination and information functions in relation to the control and protection of the environment in Bulgaria. It designs and manages the National Environmental Monitoring System and information on the state of environmental components and factors for the entire country. The Agency's sensor data is considered a reliable source

of information and complies with the regulatory framework. Those of the EEA are in the form of quarterly bulletins on the state of the environment, in particular air. The quarters used for the study are from the beginning of 2013 to the end of the third quarter of 2023, since at the moment the bulletin for the last - fourth quarter of 2023 is not yet available on the Agency's website. The idea of the large studied period is an attempt to follow a trend in the change of the air quality in the last decade. As the data are provided in two formats .pdf and .doc and are publicly available. After downloading all the necessary quarters, the EEA data were synthesized to the required extent and converted into tables using Microsoft Excel, and for each indicator a separate table was created showing the maximum reported value for the indicator. Tables were created for each indicator that affects the topic of the scientific work, and after a thorough analysis, the indicators for which no exceedances of the maximum permissible norms were registered were excluded from the study. In fig. 1 presents an excerpt from a table for the PM10 indicator. After entering all the values for the indicators through a function in Excel (Conditional Formatting – Highlight Cell Rules – Greater than), the norm for the indicator is set according to Ordinance No. 12. The function used colors in red every single exceedance of the norm that was registered in the given quarter. The ready-made table is added to ArcMap and attached to the EEA sensor layer, after which the data is visualized in the attribute table of the layer. These actions have been applied to all indicators reporting norm exceedances.

Сензор	ЯНУ - МАР 2013	АПР - ЮНИ 2013	ЮЛИ - СЕПТ 2013	ОКТ - ДЕК 2013	ЯНУ - МАР 2014	АПР - ЮНИ 2014	ЮЛИ - СЕПТ 2014	ОКТ - ДЕК 2014
София - Дружба	137,98	85,36	90,88	376,86	217,82	64,36	59,91	215,58
София - ИАОС/Павлово	181,62	50,01	40,68	361,69	373,17	70,12	47,73	238,02
София - Надежда	174,71	70,76	48,25	285,36	226,2	58,26	107,78	231,39
София - Орлов мост	194,8	71,44	49,74	413,24	371,8	60,17	59,92	293,31
София – Младост	0	0	0	0	0	0	0	0
София - Хиподрума	153,26	61,56	38,57	374,98	409,41	59,6	46,32	275,45
София Област - Копитото	50,41	50,75	41,91	45,37	41,37	76,94	0	54,43

Fig. 1. Excerpt from a table for the PM10 indicator (EEA)

The data from the Sofia Municipality under the AIRTHINGS project were requested through an application for access to public information through the 24-hour Contact Center of the Sofia Municipality created by the municipality for reporting deviations in the urban environment of Sofia, letters, proposals, inquiries, complaints and applications for access to public information'. Pursuant to Art. 3, para. 1 and Art. 28, para. 1 of the Law on Access to Public Information.

The developed information system/platform for collecting, storing and visualizing atmospheric air quality data - AIRTHINGS, through which the data for air quality were downloaded, is a system built on the principle of open data (Open Data System) and allows their publication in a machine-readable format.

It provides a completely open REST API for extracting the accumulated data from measurements and can provide them in the most used Internet formats (JSON, XML, CSV), according to the parameters of the request from the client. The data is free to be monitored and analyzed as needed by any user of the platform.

For the purposes of the research paper, the data from the platform were processed and equated by quarter, similar to the data from the EEA quarterly bulletins. The goal is an easier understanding of the huge data set and an attempt to compare the two types of sensors and the values they register.

Creating a database for research purposes from the AirThings project is an extremely time-consuming task. In raw form, the metric tables for a total of 15 quarters are over 30,000 rows per metric, making them difficult to research and process. For the purposes of the scientific work, they are equated according to the quarters of the EEA – January-March, April-June, July-September, October-December. Since the project started in 2017 and the sensors started working days before the end of 2019, the values for the last days of 2019 are not included in the study. The values used for the purposes of the scientific work are limited in the period 2020-2023. The last quarter of the year is again not included in the study, because at the time of data processing, there are no values for it yet. Processing this type of information takes a significant amount of time. In theory, the platform storing the project data should export the amount of information in an .xlsx file, but in practice this does not happen, due to an unspecified problem. In fig. 2 presents a table of raw values. Again, using Microsoft Excel, the values are broken down by quarter. The processed tables look like this (Fig. 3). As from all reported values, only the maximum reported value for each quarter and for each of the sensors was subtracted. The table is added to ArcMap and attached to the sensor layer of the project. After that was used for the purposes of the study.

time				PM10	Station	PM10
09	28	2023	28.9.2023	6.94051933222554	Парк „Хиподрума“ - При повишена влажност е възможно да и	6,94051933
09	27	2023	27.9.2023	7.13881868110348	Парк „Хиподрума“ - При повишена влажност е възможно да и	7,13881868
09	26	2023	26.9.2023	7.46617264460695	Парк „Хиподрума“ - При повишена влажност е възможно да и	7,46617264
09	25	2023	25.9.2023	7.92657470515311	Парк „Хиподрума“ - При повишена влажност е възможно да и	7,92657471
09	24	2023	24.9.2023	10.134160204861	Парк „Хиподрума“ - При повишена влажност е възможно да и	10,1341602
09	23	2023	23.9.2023	11.3386389047658	Парк „Хиподрума“ - При повишена влажност е възможно да и	11,3386389
09	22	2023	22.9.2023	9.55086884614524	Парк „Хиподрума“ - При повишена влажност е възможно да и	9,55086885
09	21	2023	21.9.2023	8.71809868826812	Парк „Хиподрума“ - При повишена влажност е възможно да и	8,71809869
09	20	2023	20.9.2023	10.6689465316359	Парк „Хиподрума“ - При повишена влажност е възможно да и	10,6689465
09	19	2023	19.9.2023	7.12972086928119	Парк „Хиподрума“ - При повишена влажност е възможно да и	7,12972087
09	18	2023	18.9.2023	9.14230232631302	Парк „Хиподрума“ - При повишена влажност е възможно да и	9,14230233
09	17	2023	17.9.2023	9.67502743531559	Парк „Хиподрума“ - При повишена влажност е възможно да и	9,67502744
09	16	2023	16.9.2023	5.92783580347067	Парк „Хиподрума“ - При повишена влажност е възможно да и	5,9278358
09	15	2023	15.9.2023	5.01631585932553	Парк „Хиподрума“ - При повишена влажност е възможно да и	5,01631586
09	14	2023	14.9.2023	3.23809554374294	Парк „Хиподрума“ - При повишена влажност е възможно да и	3,23809554
09	13	2023	13.9.2023	3.13358958684966	Парк „Хиподрума“ - При повишена влажност е възможно да и	3,13358959
9	12	2023	12.9.2023	2.89022554313401	Парк „Хиподрума“ - При повишена влажност е възможно да и	2,89022554
9	11	2023	11.9.2023	9.19292474065112	Парк „Хиподрума“ - При повишена влажност е възможно да и	9,19292474
9	10	2023	10.9.2023	10.0539378587034	Парк „Хиподрума“ - При повишена влажност е възможно да и	10,0539379
9	9	2023	9.9.2023	10.5845764592588	Парк „Хиподрума“ - При повишена влажност е възможно да и	10,5845765
9	8	2023	8.9.2023	277.259650129565	Парк „Хиподрума“ - При повишена влажност е възможно да и	277,25965
9	7	2023	7.9.2023	827.040902108778	Парк „Хиподрума“ - При повишена влажност е възможно да и	827,040902
9	6	2023	6.9.2023	569.205430248353	Парк „Хиподрума“ - При повишена влажност е възможно да и	569,20543
9	5	2023	5.9.2023	341.251785737571	Парк „Хиподрума“ - При повишена влажност е възможно да и	341,251786
9	4	2023	4.9.2023	246.804105527889	Парк „Хиподрума“ - При повишена влажност е възможно да и	246,804106

Fig. 2. Table of raw data from the AirThings project

Сензор	Януари - Март 2020	Април - Юни 2020	Юли - Септември 2(	Октомври - Декемв	Януари - Март 2021	Април - Юни 2021	Юли - Септември 2(	Октомври - Декемв
29 ДКЦ - „Борово“	63,25796855	33,88085059	24,67399128	208,43147163	92,86244500	34,79823075	26,27876663	112,05417378
бул. „Александър Стамболийски“, Западен	146,39068456	88,07995919	41,58545636	280,21964412	318,98340906	69,58777012	56,75189564	175,55355642
бул. „Президент Линкълн“ ж.к.„Овча купел“	88,72176703	52,84003620	394,43750247	158,18154932	125,53722117	41,00595832	26,04570091	163,31479900
Военна академия „Г. С.Раковски“	105,84359248	45,08419886	40,16946158	239,40886900	210,35354225	52,35788205	48,96423628	309,59073506
ж.к. „Иван Вазов“	77,96147064	35,11957618	28,09114765	188,53718130	101,52359398	37,26459694	36,07574973	106,70902711
ж.к. „Люлин“ 9	96,58810613	44,19542764	60,93919307	385,34440320	157,15280987	72,50107333	35,27522874	101,25111846
Зимен дворец на спорта	65,00977182	29,16870127	181,51611487	223,44521787	93,34721872	49,83911299	31,44824037	103,12564878
кв. „Драгалевци“	58,69237449	22,03404773	28,73674489	291,05298272	158,31187047	60,77398564	28,92907735	206,63207462
кв. „Орландовци“	215,74489109	56,08572825	51,92783581	438,52865872	369,05415765	54,67652421	31,59394558	167,89722221
кв. „Христо Ботев“	237,84145856	90,64751606	73,71798966	520,53895299	510,50184047	102,82119188	30,92268311	335,76923436
Метростанция „Джеймс Баучер“	84,72579509	33,27317441	30,68341143	198,44085653	171,52677689	36,11161832	144,52547362	157,61212731
Национален център за заразни и паразитни	516,17018142	55,65786848	37,11878383	874,29950180	290,25324640	39,66888918	37,03724506	106,06018841
НИМХ	57,23357662	316,84334658	24,28827544	184,62791761	84,51800203	66,35506650	43,66003488	113,13044896
Парк „Хиподрума“	97,87548097	41,03117158	126,24159319	206,03843214	82,57584045	58,41171960	53,18798835	285,14069220
Поликлиника „Враждебна“	98,55811942	40,96261118	33,95159123	244,79406413	213,67713323	60,88748538	32,75270952	270,10909720
РА „Красна поляна“	143,54679473	47,03519369	89,83946178	434,15979175	295,69470957	93,75442595	38,27998951	275,90447491
РА „Надежда“	123,22329929	35,76152121	33,92514082	581,77267535	173,64790295	35,84320575	540,66902302	109,26916332
район „Искър“	87,55611615	115,91751680	30,33009466	219,04424590	110,78492644	74,73458513	33,21510518	93,20801899
район „Подуяне“	131,63679216	55,44614120	39,86402042	287,92085221	226,51369303	47,99788987	29,68969339	135,62529901
район „Студентски“	80,14380903	25,39486509	29,76465729	40,69236292	85,52817188	40,66933543	65,48482623	91,88107963
район„Овча купел“	78,04216849	41,09572946	31,85435786	256,58816118	126,22998535	28,43160902	40,73181749	151,80996678
Централна гара	120,59251063	45,65465192	39,48564624	333,39962210	295,03023677	41,99506344	476,25164510	96,11221493

Fig. 3. Excerpt from a table for the PM10 indicator (AirThings)

Names of the 22 AQ sensors, exact geographic coordinates, administrative address and a description of where the station's installation location were also provided by the Municipality. A point layer was created using the table in ArcMap, and the data from the table provided by the Municipality was attached to it.

4. GEOSPATIAL MODEL FOR THE ASSESSMENT OF ATMOSPHERIC AIR QUALITY IN THE CITY OF SOFIA

One of the most topical environmental topics in the last few years in the Sofia Municipality is that of Air Quality. According to the EEA data, the air in the city is twice as clean compared to previous years, but despite this, public attitudes assess the air as one of increasingly deteriorating quality. On the one hand, this is due to the more significant and great topicality of the topic compared to previous years, and on the other hand, the desire of the population of the capital to improve the quality of life in the city.

For the purpose of the present study, official data from the Environmental Executive Agency (EEA) and the 22 sensor stations installed by the Sofia Municipality under the AIRTHINGS pilot project were used.

4.1. Environment Executive Agency (EEA)

EEA is an administration under the Minister of Environment and Water for the implementation of management, coordination and information functions in relation to the control and protection of the environment in Bulgaria. It designs and manages the National Environmental Monitoring System and information on the state of environmental components and factors for the entire country. The Agency is a National Coordination Center of the European Environment Agency (EEA). The European

Environment Agency is the body of the European Union established to provide timely, targeted, relevant and reliable information about the environment to both policy makers and the public.

The EEA data are in the form of quarterly bulletins on the state of the environment, particularly air. The quarters used for the study are from the beginning of 2013 to the end of the third quarter of 2023, since at the moment the bulletin for the last - fourth quarter of 2023 is not yet available on the Agency's website. The idea of the large studied period is an attempt to follow a trend in the change of the air quality in the last decade.

A disadvantage of the EEA sensors is their insufficient density on the territory of the city. This, in turn, implies difficulties in the study of AQ. The Agency's sensors are grossly insufficient in number relative to the city's territory and its population. The network of sensors should be optimized and supplemented by new devices. They are located at a great distance from each other and can hardly give a clear idea of the state of the air in some parts of the city. A clustering of some of the sensors is observed in the central, western and eastern parts of the city - Pavlovo, Hippodrome, Orlov Most, Mladost, Druzhba, while for the northern zh. k.s only AMS Nadezhda reports data for air quality. After the relocation of AMS Orlov Most to zh.k Mladost, assessing the state of the air becomes even more difficult. It is necessary to deploy a large number of new sensors in all parts of the city – zh.k. Lyulin, zh.k. Obelya, Moderno predgradie, zh.k. Nadezhda, zh.k. Orlandovtsi, zh.k. Hadji Dimitar, zh.k. Levski, zh.k. Vrazdebna, zh.k. Zone B-18, around Sofia Airport, on the outskirts of the city, around large industrial enterprises, the neighborhoods at the foot of Vitosha and of course in the central city parts and at key intersections - e.g. Slivnitsa Blvd., K. Velichkov Blvd., Opalchenska Blvd., Tsarigradsko Shose Blvd. and the area of Orlov Most, as well as many others. A greater density of sensors is needed to get a clear and realistic picture of the state of the air quality.

4.2. The AIRTHINGS project

Sofia Municipality is a leading partner in the AIRTHINGS project, launched in December 2017, aimed at improving the quality of ambient air. The project uses modern technologies for air quality monitoring and includes local networks of sensors in different cities, such as Sofia, Thessaloniki, Nicosia, Tirana and Ohrid. The total number of meters is 100, located in all participating cities. The project also develops and maintains an Open Data System for the visualization and storage of atmospheric quality data. There are 22 air quality measurement stations in Sofia, which transmit data on PM, CO, NO2, SO2, temperature, humidity and pressure in real time. The project is financed by the European Union through the “Balkans - Mediterranean” Program (2014 - 2020) and has a duration of 24 months. Within the

framework of the project, an analysis of suitable locations for deployment of sensors for monitoring atmospheric quality in Sofia is carried out, using modern geostatistical and spatial-analytical operations. However, the data are indicative and subject to deviation due to the specifics of the technologies used in the sensor stations.

Despite the larger number of sensors on the project compared to the EEA sensors, there is again a lack of sufficient network density to allow for a more accurate estimation of the AQ. The network consisting of 22 sensors reporting AQ indicators is again insufficient and many parts of the city are observed that are not equipped with sensors. A significant problem in deploying the sensors according to the project is that there are no sensors in the central city areas, where, given the presence of increased traffic, some of the highest values of the air indicators are reported. The network of sensors should be optimized and supplemented by new devices. It is necessary to deploy a large number of new sensors in all parts of the city - e.g. zh.k. Lyulin, zh.k. Obelya, zh.k. Moderno predgradie, zh.k. Nadezhda, zh.k. Orlandovtsi, zh.k. Hadji Dimitar, zh.k. Levski, zh.k. Vrazdebna, zh.k. Zone B-18, around Sofia Airport, on the outskirts of the city, around large industrial enterprises, the neighborhoods at the foot of Vitosha and of course in the central city parts and at key intersections - e.g. Slivnitsa Blvd., K. Velichkov Blvd., Opalchenska Blvd., Tsarigradsko Shose Blvd. and the area of Orlov Most, as well as many others.

4.3. Air quality in the country

According to the World Health Organization (WHO) and the European Environment Agency (EEA), Bulgaria ranks among the countries with the most polluted air. Figure 4 below shows the countries with the most air quality-related deaths according to the WHO in 2012. The top three places are occupied by Ukraine, Bulgaria and Belarus. According to the WHO, 118 people die annually in the country for every 100,000 people due to air pollution with fine dust particles.

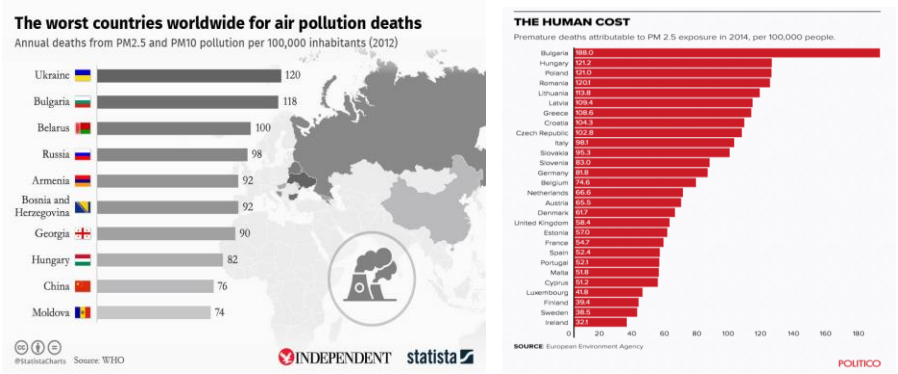


Fig. 4. Countries with the most air quality-related deaths according to the WHO for 2012 /WHO/ (left)

Fig. 5. Countries with the most air quality-related deaths according to EEA 2014 /EEA/ (right)

According to the European Environment Agency (EEA), in 2014, Bulgaria ranks first in terms of the number of victims due to air pollution with PM2.5. The data in Figure 5 indicate that for every 100,000 people, 188 people die from exposure to air pollution.

According to the United Nations Environment Program (UNEP), 19 µg/m3 is the average annual value of fine particulate matter to which every person in the country is exposed. This value is 3.8 times higher than WHO guidelines and recommendations. Furthermore, fig. 6., also shows the deaths per 100,000 people due to fine particulate pollution in 2019 in the country, which equates to 131 or a total of 9,072 in the country.

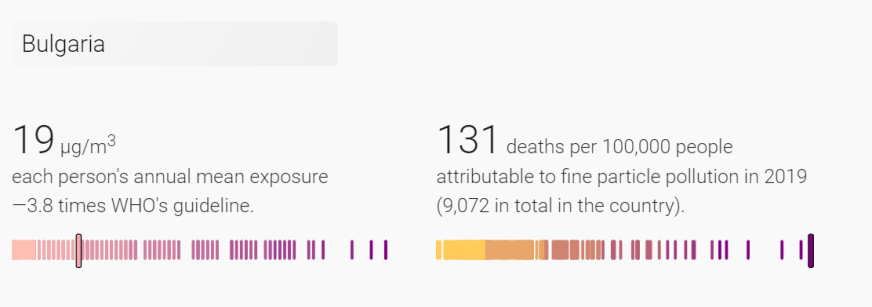


Fig. 6. Average human exposure and mortality due to PM in Bulgaria in 2019. (Source: UNEP - United Nations Environment Programme)

4.4. Main sources of emissions in Sofia Municipality

One of the most serious polluters of air quality during the winter months in the Capital is domestic heating with solid and liquid fuels. There is a lack of reliable information on the number and consumption of households by types of sources. Data on the quality of fuels used for domestic heating are not collected, therefore domestic heating emissions cannot be accurately calculated, nor can they be spatially distributed on the city map. Available estimates of the share of domestic heating in total emissions are based on expert opinion and, at best, on indirect estimates, which, although subject to error, at this stage provide the most reliable data, but they cannot show the real picture.

A significant part of the dwellings, heated with solid and liquid fuels, are located in heated and gasified areas. However, a large part of the population gives up heating because of the high bills for the heating season, which gives rise to the search for alternative ways of heating. Switching to gas heating is efficient but expensive as it requires the construction of a new installation. Due to the low standard of living of part of the population in the capital, it is almost impossible to allocate funds for the construction of a gas installation in households. Another problem is the lack of a gas transmission network in some

areas of the city. Even with the availability of financial resources and a desire on the part of a household to switch to gas heating, the lack of a network prevents this activity.

According to population census data from NSI, the majority of households in the Sofia Municipality are heated by central heating (CHP and gasification), about ¼ by electricity and only about 12% by solid and liquid fuels, which are the only sources of heating with significant air pollutant emissions.

The maps below have been prepared for the purposes of this study using census data from the NSI and are divided by different sources of heating - electricity, steam, coal, wood and oil.

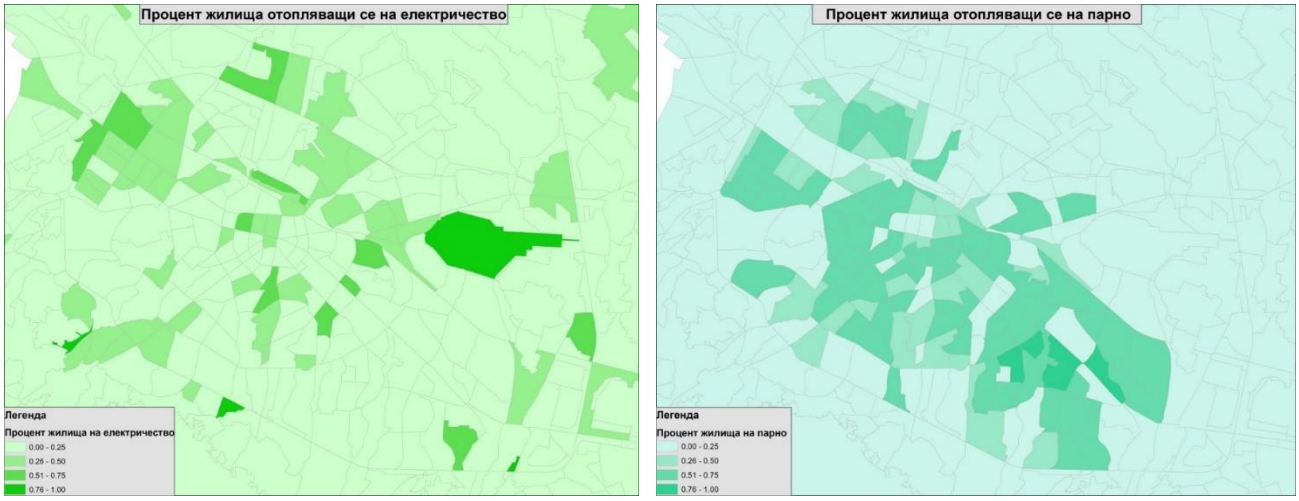
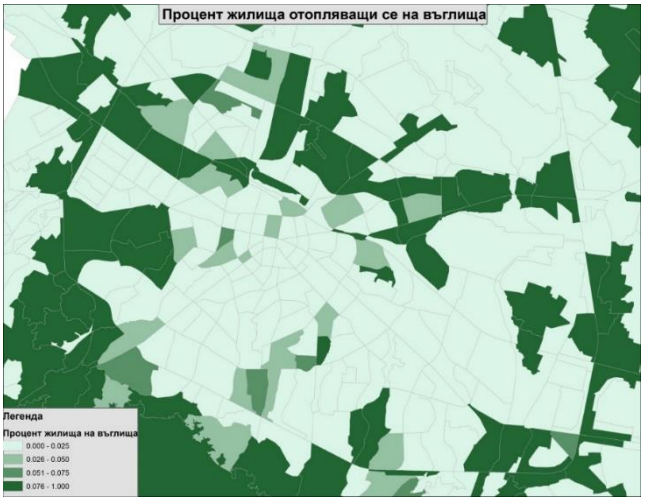


Fig. 9. Percentage of homes heated by electricity (left)

Fig. 10. Percentage of homes heated by domestic heating (right)

Fig. 9 shows households in the city heating with electricity. According to the data, electricity heating with more than 25% is in the areas of Lyulin, Poduene and parts of the center where central heating is used less.

The map shows the dwellings in the capital that are heated by heat (Fig. 10). Central heating is used in most of the city. In several zh. k.s it is even over 75%. – e.g. Mladost 1 and Darvenica.



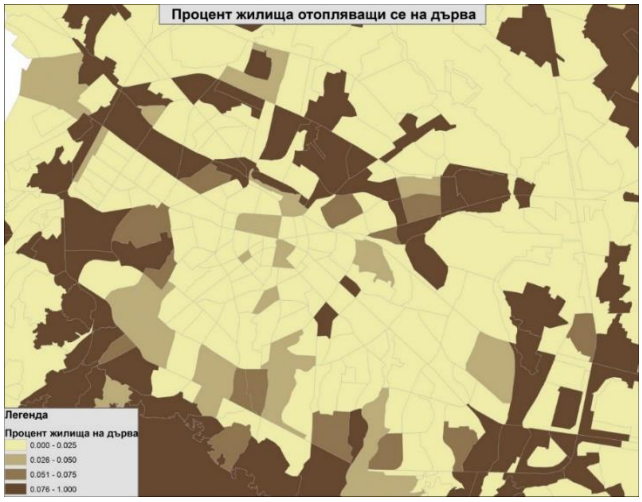


Fig. 11. Percentage of homes heated with coal (left)

Fig. 12. Percentage of homes heated with wood (right)

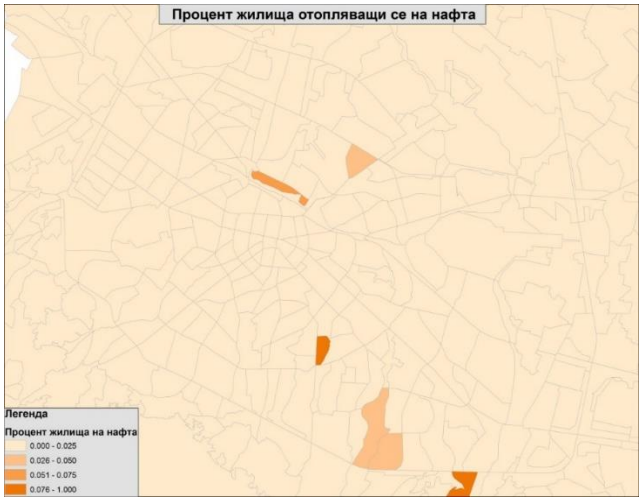


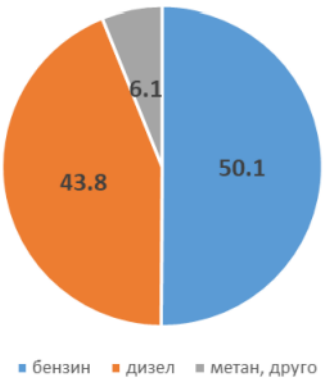
Fig. 13. Percentage of homes heated with oil

Figures 11, 12 and 13 show the percentage of homes that are heated with coal, wood and oil. The data show that people are heated with similar sources of heating in areas with mostly low-rise buildings - Fakulteta, Moderno Predgradie, Orlandovtsi, Hristo Botev, Gorublyane, as well as with mixed buildings such as Hadji Dimitar, Levski V and G. It is interesting that heating of wood (between 2.5 and 5%) is also in the center - the northwestern parts and between Vitosha, Patriarch Evtimiy, Graf Ignatiev, Rakovski, Tsar Osvoboditel boulevards. A significant part of the dwellings, heated with solid and liquid fuels, are located in heated and gasified areas. However, a large part of the population gives up heating because of the high bills for the heating season, which gives rise to the search for alternative ways of heating. Switching to gas heating is efficient but expensive as it requires the construction of a new installation. Due to the low standard of living of part of the population in the capital, it is almost

impossible to allocate funds for the construction of a gas installation in households. Another problem is the lack of a gas transmission network in some areas of the city. Even with the availability of financial resources and a desire on the part of a household to switch to gas heating, the lack of a network prevents this activity.

Another important source of air quality in Sofia is transport. Compared to domestic heating pollution, transport is easier to assess. The data for all registered vehicles is kept at the Ministry of the Interior. Despite the availability of data on emission factors for each vehicle, there are obstacles such as lack of information on the number of cars, traffic pattern and discrepancy between the pollution levels according to the manufacturer and actual measurements. There is an increase in diesel cars and gasoline cars with gas systems. The share of cars with propane-butane and methane is relatively small.

Analyzing the sources of emissions in Sofia shows that domestic heating is the main source of fine dust particles (PM10 and PM2.5), while motor vehicles have a significant contribution to nitrogen oxides (NOx). The ratio of emissions is 55.97% from domestic heating, 31.50% from area sources and 10.78% from motor vehicles for PM10. For PM2.5, domestic heating is 73.28%, area sources - 14.10%, and motor transport - 11.13%. For NOx, motor transport is 78.73%, industry - 15.55%, and domestic heating - 5.72%. The composition of CO is mainly from domestic heating and motor vehicles.



Източник	***ФПЧ$_{10}$***	***ФПЧ$_{2.5}$***	***ПАВ***	***NOx***	***CO***
	t/год	***t/год***	***kg/год***	***t/год***	***t/год***
промишлени източници	51.3	49.0	0.00	1320	121.1
битово отопление	2,626	2,567	0.534	486	16886
автотранспорт	505.66	390	0.00207	6684	7432
строителство	31.0	3.1	0	0	0
Ресуспендирани частици от площни източници	1478	494	0	0	0
Общо	***4692***	***3503***	***0.53607***	***8490***	***24439***
	ФПЧ$_{10}$	***ФПЧ$_{2.5}$***	***ПАВ***	***NOx***	***CO***
промишлени източници	1.09%	1.40%	0.00%	15.55%	0.50%
битово отопление	55.97%	73.28%	99.61%	5.72%	69.09%
автотранспорт	10.78%	11.13%	0.39%	78.73%	30.41%
строителство	0.66%	0.09%	0.00%	0.00%	0.00%
Ресуспендирани частици от площни източници	31.50%	14.10%	0.00%	0.00%	0.00%

Fig. 14. Distribution of registered motor vehicles by type of fuel as of 2018 (Source: Comprehensive program for improving the quality of atmospheric air in the territory of the Sofia Municipality for the period 2021-2026) (left)

Fig. 15. Emissions from the main sources on the territory of the Sofia Municipality for 2018 (Source: Complex program for improving the quality of atmospheric air in the territory of the Sofia Municipality for the period 2021-2026) (right)

4.5. Measuring air quality by indicators.

For the scientific work, maps were created from two sources - Environment Executive Agency (EEA) and the AIRTHINGS project. They show the maximum reported values of various pollutants over the years. The data from the EEA covers the period 2013-2022, to which 3 quarters from 2023 are added. Exceedances of the norms for benzene, nitrogen dioxide, ozone, PM2.5 and PM10 were registered. Data from the AIRTHINGS project starts in late 2019 and is also presented in quarters corresponding to those of the EEA.

The geographical location of the Sofia Municipality and the climatic conditions are essential for air quality. Sofia Field, surrounded by Stara Planina, Vitosha and Ikhtimanska Sredna Gora, is known for long periods of fog, no wind and temperature inversions, which help to retain pollutants in the air mass above the city.

Apart from domestic heating, cars are a significant source of pollution, especially during the winter months. The increasing number of cars contributes to increasing congestion and increasing emissions in the city centre.

The data was processed in Microsoft Office Excel and the interpolation method used to create the maps in ArcMap was IDW.

4.6. Geospatial analysis of EEA data

Figures 16 and 17 present the total number of exceedances of the norms of the relevant indicators for the entire studied period. The most significant exceedances registered for the PM10 indicator, respectively 2928 exceedances in the winter months of the researched period. Followed by 975 exceedances of Nitrogen Dioxide and 25 Ozone standards. Data on the total number of exceedances for the indicators PM2.5 and benzene are not provided in the quarterly bulletins on the state of the air from the EEA, which creates some difficulties in the accurate assessment of these two indicators. During the summer months, the most significant exceedances of the standards come from the two ozone indicators - the short-term target ozone standard, respectively, 489 exceedances, and also 65 exceedances for the hourly average ozone standard. Ozone was followed by 333 exceedances of PM10 and 72 for nitrogen dioxide. From fig. 11 and fig. 12 it is clear that indicators such as sulfur dioxide and carbon dioxide will be dropped from the study, since they did not register excesses during the studied period.

An important clarification for the entire scope of the study of data from the EEA is the relocation of the sensor from Orlov Most to the residential area Mladost. The change took place in the fourth quarter of 2015, during which the new sensor was installed in Mladost, while the one at Orlov Most is still functioning. The data in the fourth quarter of 2015 for the two sensors could not be considered correct

due to the change in the location of the sensor and thus would create a distortion in the research for the specific quarter. Since the first quarter of 2016, the Orlov Most sensor is not functioning and does not record values for AQ indicators. According to unofficial data from the EEA, the sensor was moved due to the construction of the third metrodiameter in the capital.

On the maps created for the purposes of the study, the change in the location of the sensor is observed. From the first quarter of 2013 to the third quarter of 2015, only AMS Orlov Most is visible on the maps. In the fourth quarter of 2015, both sensors appeared on the maps, and in the first quarter of 2016, until now, only AMS Mladost is functioning and recording data.

ПРЕВИШЕНИЯ НА НОРМИТЕ ЗА ПЪРВО И ЧЕТВЪРТО ТРИМЕСЕЧИЕ НА ИЗСЛЕДВАНИЯ ПЕРИОД																						
Показател	I_2013	IV_2013	I_2014	IV_2014	I_2015	IV_2015	I_2016	IV_2016	I_2017	IV_2017	I_2018	IV_2018	I_2019	IV_2019	I_2020	IV_2020	I_2021	IV_2021	I_2022	IV_2022	I_2023	Общо превишения за периода
Серен диоксид - средночасови	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Серен диоксид - средноденонощни	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1
Азотен Диоксид - средночасови	1	67	19	25	75	32	114	45	318	4	98	42	11	67	12	26	8	1	1	7	2	975
ФПЧ 10	152	276	261	192	153	214	156	162	220	114	127	151	96	123	121	101	69	47	55	97	41	2928
ФПЧ 2.5	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?
Озон - средночасови	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Озон - краткосрочна целева норма	4	0	16	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	4	0	0	25
Въглероден оксид	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Бензен	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?

Fig. 16. Exceedances of norms for the first and fourth quarters of the researched period

ПРЕВИШЕНИЯ НА НОРМИТЕ ЗА ВТОРО И ТРЕТО ТРИМЕСЕЧИЕ НА ИЗСЛЕДВАНИЯ ПЕРИОД																						
Показател	II_2013	III_2013	II_2014	III_2014	II_2015	III_2015	II_2016	III_2016	II_2017	III_2017	II_2018	III_2018	II_2019	III_2019	II_2020	III_2020	II_2021	III_2021	II_2022	III_2022	II_2023	III_2023	Общо превишения за периода
Серен диоксид - средночасови	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Серен диоксид - средноденонощни	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Азотен Диоксид - средночасови	0	0	0	0	0	67	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	72
ФПЧ 10	37	11	21	13	5	33	25	5	32	10	17	4	16	2	25	11	17	22	6	12	0	9	333
ФПЧ 2.5	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?
Озон - средночасови	0	0	0	1	0	2	0	3	2	7	10	0	0	5	0	8	14	12	0	1	0	0	65
Озон - краткосрочна целева норма	34	64	14	25	0	64	4	32	9	30	18	3	5	38	13	27	9	44	1	12	6	37	489
Въглероден оксид	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Бензен	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?

Fig. 17. Exceedances of norms for the second and third quarter of the researched period

4.6.1. Benzene

Норма	Период на осредняване	Стойност	Дата, към която нормата трябва да бъде спазена
Бензен			
Средногодишна норма за опазване на човешкото здраве	**една календарна година**	**5 µg/m3**	**1.01.2010 г.**

Fig. 18. Average annual rate of benzene according to Ordinance No. 12

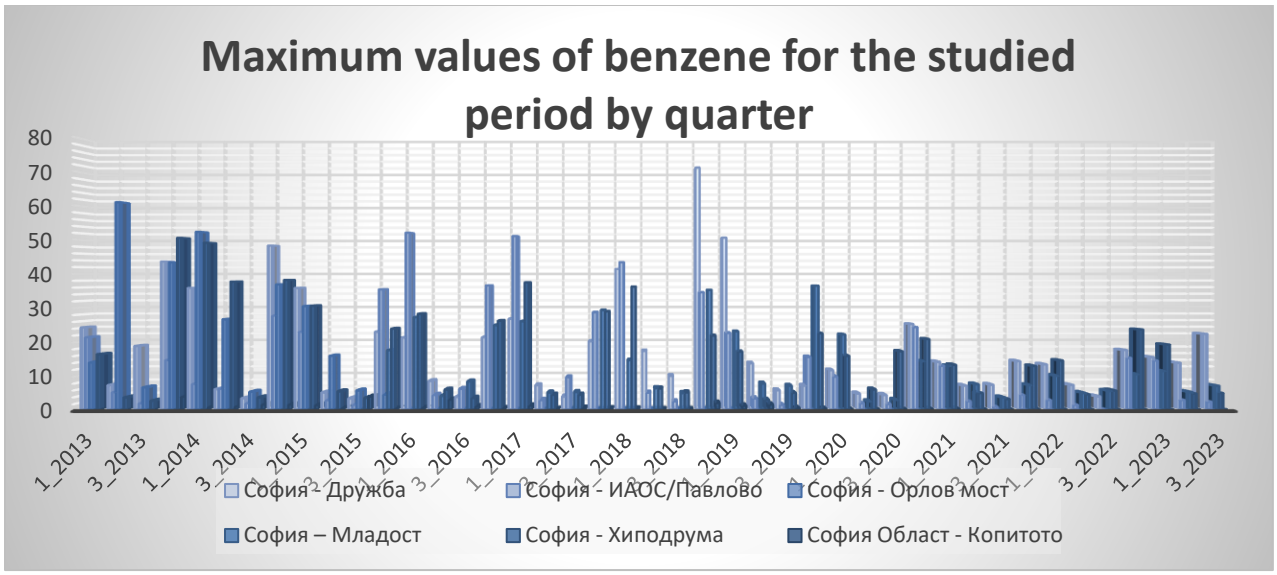


Fig. 19. Maximum values of benzene for the studied period

Fig. 18 presents the average annual standard for the protection of human health for benzene. The source is Ordinance No. 12, according to which the norm is 5 micrograms per cubic meter. In fig. 19. The maximum values of benzene for the studied period, broken down by quarter, are presented. The general picture indicates that during the studied period the values are fluctuating, however, there is a pronounced tendency to reduce air pollution with benzene. An important clarification is that in the quarterly bulletins on the status of the EEA, the agency does not provide data on how many times the norms were exceeded, only the maximum reported value for the indicator and the number of registered measurements are provided, which in turn leads to significant confusion and ambiguity.

Since the end of 2020, there has been a decrease in the maximum reported values for the indicator, despite a slight increase in the last few quarters. The highest reported value for benzene was from AMS Druzhba in the fourth quarter of 2018, respectively 71.36 µg/m3. An important clarification is that during the researched period there is not a single quarter in which benzene norms were not exceeded.

Figures 20, 21, 22, 23 present all quarters of the calendar year 2013 with the maximum reported values for benzene. The most significant excesses were registered in the second quarter of 2013, with AMS Orlov Most reporting a maximum value of 61.16 µg/m3. For all other sensors, with the exception of AMS Kopitoto, exceedances of the norm of 5µg/m3 were reported. During the cold months, all sensors except AMS Kopitoto reported exceedances, while during the summer months only two or three of the sensors exceeded the norms /AMS Druzhba, AMS Pavlovo, AMS Orlov most/.

Figures 24, 25, 26 and 27 present the quarters of the calendar year 2014 with the maximum reported values for the benzene indicator. The most significant excesses of norms were again registered

in the cold months - in the first and fourth quarters of the year. The largest excess was recorded by AMS Orlov Most - 52.41 μg/m3 and AMS Hippodrome - 49.2 μg/m3 in the first quarter of the year, followed by AMS Druzhba - 48.35 μg/m3 in the fourth quarter of the year. Significant excesses of the norm of 5 μg/m3 were also registered in the summer months in the Orlov Most and Hippodrome areas, respectively 26.61 μg/m3 and 37.73 μg/m3. No exceedances were again registered for AMS Kopitoto.

Figures 28, 29, 30 and 31 show the quarters of 2015 with their maximum measured values for benzene. Compared to the previous two years, the maximum measured values are about 20 units lower, however, the exceedances of the norm are significant. The registered excesses are the highest during the winter months of the first quarter of the year, respectively 35.86 μg/m3 – AMS Druzhba, 30.61 μg/m3 – AMS Hippodrome and 30.48 μg/m3 – AMS Orlov Most. The limits were exceeded between 6 and 7 times, compared to 12 times at the beginning of the study period (2013). No exceedances were again registered for AMS Kopitoto. It is important to note the relocation of the sensor from Orlov Most to the gh. Mladost in the last quarter of 2015, as AMS Orlov Most, was replaced by AMS Mladost. Given the new location of the sensor, the maximum values obtained will be much lower than those reported at one of the busiest intersections in the city, namely that of Orlov Most. This, in turn, leads to a distortion in the research for each indicator.

Figures 32, 33, 34 and 35 show the quarters of 2016. The most significant excesses were again reported in the winter months - 52.15 μg/m3 for AMS Pavlovo, and for the entire studied period this is the highest value recorded for this sensor. Exceedings during the cold months are reported for all sensors, except for AMS Kopitoto. During the summer months, the norms were exceeded significantly less than in previous years, nearly 1 time, with the highest reported being 8.29 μg/m3 for AMS Druzhba.

Figures 36, 37, 38 and 39 show the quarters of 2017 and their maximum measured values for benzene. Similar to the previous year, the largest exceedance of the norm was reported by AMS Pavlovo – 51.17 μg/m3, which is the second highest value for benzene recorded for the studied period by the particular sensor. The norms were exceeded between 4 and 10 times in the winter months, while in the summer months they were exceeded almost once above the norm, again by AMS Pavlovo – 9.52 μg/m3. Due to the location of AMS Kopitoto, no exceedances for the sensor were again recorded.

Figures 40, 41, 42 and 43 show the quarters of 2018 and their maximum values for benzene. In this calendar year, the highest value for benzene was recorded for the entire investigated period - 71.36 μg/m3 from AMS Druzhba. With this value, the norm is exceeded about 14 times. The picture remains the same for the winter months, namely the highest recorded exceedances. In the second quarter of the

year, AMS Druzhba reported a significantly high value registered for the summer months – 17.28 μg/m3. As in previous years, AMS Kopitoto did not report any exceedances of benzene standards.

Figures 44, 45, 46 and 47 show the quarters of 2019 with their maximum values. The sensor in Druzhba again reported the highest value for benzene, namely 50.69 μg/m3, or about 10 times the norm. The trend of more polluted cold months is again maintained, as well as that of no pollution for AMS Kopitoto.

In fig. 48, 49, 50 and 51 present the quarters of 2020 and their maximum recorded values for benzene. The year 2020 is one of the years with the lowest reported exceedances of the norms of the entire studied period. Some of the excesses in the cold months are equal to the excesses in the summer months for previous years. The highest values for the first and fourth quarter are 22.1 μg/m3 and 25.21 μg/m3, respectively, for AMS Mladost and AMS Druzhba. During the two warm quarters, excesses were registered only for AMS Hippodrome, 5.9 μg/m3 and 17.17 μg/m3, respectively.

Figures 52, 53, 54 and 55 show the quarters of 2021. Similar to the previous year, the norm exceedances are much smaller in value compared to the same in previous years. The maximum reported value was 14.25 μg/m3 for AMS Druzhba in the fourth quarter of the year. The summer months report no more than 7.4 μg/m3. Exceedances for AMS Kopitoto, as well as during the entire studied period, were again not observed.

Figures 56, 57, 58 and 59 present the state of benzene for the year 2022. Similar to the previous two years, exceedances are significantly lower. The maximum reported value is from AMS Hippodrome 23.61 μg/m3, in the fourth quarter of the year. The maximum values for the warm months are 7.22 μg/m3 for the sensor in the zh.k. Druzhba. AMS Kopitoto values are again zero or close to zero.

In Figures 60, 61 and 62, only the first three quarters of 2023 are presented, as the official data from the EEA for the quarterly bulletins are not yet available. However, there are again no shortages of benzene standards. It is interesting to note that in the third quarter of the year AMS Druzhba reported a higher value for benzene than in the first quarter (winter months), namely 22.31 μg/m3, while the highest value for the cold months was equals 19.14 μg/m3.

Despite the availability of data from the quarterly air quality bulletins of the EEA, the data for the given 5 sensors are insufficient to make an accurate assessment of the state of the air in the capital. The lack of a sufficient number of sensors located on the territory of the city makes the study and analysis of the obtained data extremely difficult. It is necessary to deploy a greater number of sensors to report the air quality in the city, such as key intersections, places with agglomeration of population, places with

population heating with solid fuel, around industrial areas, Sofia Airport, construction sites and facilities and other infrastructure that may be critical for the air condition in Sofia.

Fig. 20. Maximum values of benzene for the first quarter of 2013

4.6.2. O_3 – ozone

Краткосрочни целеви норми (КЦН) и горни оценъчни прагове (ГОП) за озон			
Норма	**Период на осредняване**	**Стойност**	**Дата, към която КЦН следва да бъде спазена (1)**
КЦН/ГОП за опазване на човешкото здраве	**Максимална 8-часова средна стойност в рамките на денонощието (2)**	**120 µg/m3, да не се превишава в повече от 25 дни на календарна година, осреднено за тригодишен период (3)**	**1.01.2010 г.**

Fig. 63. Short-term target norms and upper assessment thresholds for ozone, according to Ordinance No. 12

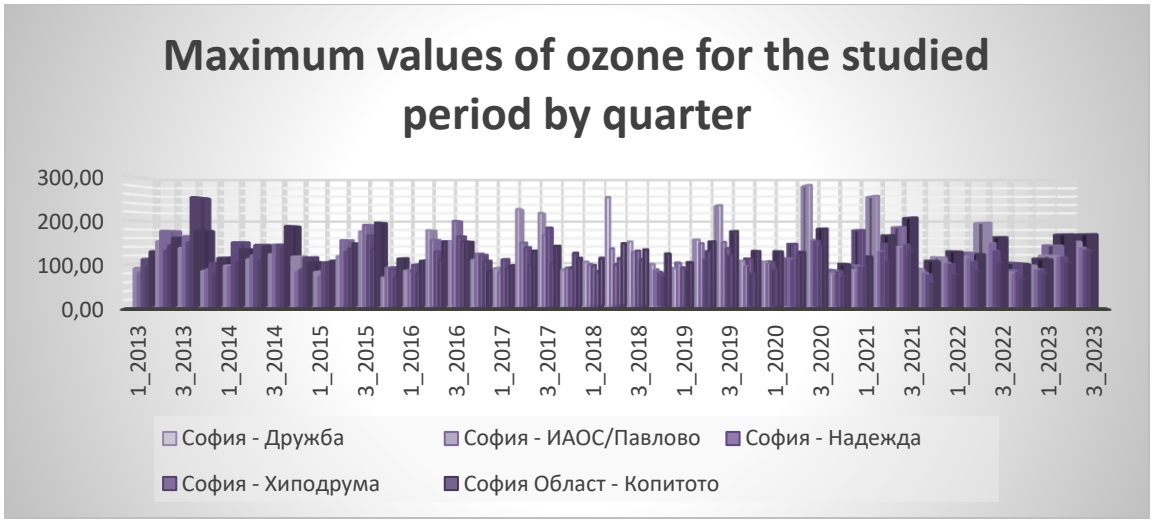


Fig. 64. Maximum values of ozone for the studied period by quarter

On fig. 63 the short-term target norms and upper assessment thresholds for ozone are presented. The source is Ordinance No. 12, according to which the norm is 120 μg/m3. In fig. 64 presents the maximum values of ozone for the studied period, broken down by quarter. The general picture indicates that during the studied period the most serious excesses are registered in the warm months - second and third quarter of each calendar year. This is due to the fact that sunlight is required to form ozone, which is why there is a distinct increase in its values from north to south and during the warm half-year. It is also more concentrated at higher altitudes. And it's also one of the main ingredients in smog. During the studied period, a total of 579 exceedances of the ozone standards were registered, respectively 25 in the autumn-winter months and 554 in the spring-summer months. There is no tendency to decrease the maximum values of the indicator, however, an important clarification is that during the studied period there were 12 out of a total of 43 quarters without exceeding the norms. The highest reported value for ozone was registered by AMS Druzhba in the third quarter of 2020 – 281.74 μg/m3. It is important to note that the sensors Orlov Most (until the fourth quarter of 2015) and Mladost from (from the fourth quarter of 2015) do not collect ozone data. This, in turn, significantly complicates the assessment of the given indicator.

Figures 65, 66 and 67 present the three quarters of the calendar year 2013, during which exceedances of ozone standards were registered. The most significant exceedances of the norms are in the summer months, as in the third quarter of the corresponding year, AMS Hippodrome reported a value of 253.76 μg/m3. In the first quarter of the year, there was only one exceedance of the norm by AMS Kopitoto – 129.57 μg/m3. There were no exceedances of norms in the fourth quarter of the year.

Figures 68, 69 and 70 present the first three quarters of 2014. Exceedances of norms are again absent for the last quarter of the year. The highest value for ozone was registered by AMS Kopitoto – 187.57 μg/m3. In the January-March period, two exceedances were registered by AMS Kopitoto and AMS Nadezhda, respectively 134.03 μg/m3 and 150.45 μg/m3. There are no rate jumps again in the fourth quarter of the year.

Figures 71 and 72 present the two quarters of 2015 with registered excesses for the indicator. They were recorded during the warm half-year - April-June and July-September. The highest value was again registered by AMS Kopitoto – 195.22 μg/m3. The first and fourth quarters of the year did not exceed the norms.

Figures 73, 74, and 75 depict the three quarters of 2016 with exceedances of ozone standards. The first quarter of the year did not register any excesses. In contrast, the second, third and fourth marked

excesses. The highest value for the year is from AMS Pavlovo – 199.30 μg/m3, during the period July-September. In the last quarter of the year, two of the sensors registered exceedances of the norms - AMS Pavlovo and AMS Nadezhda, with 123.64 μg/m3 and 120.71 μg/m3, respectively, and the reported values are close to the limit norm of 120 μg/m3.

Figures 76, 77 and 78 visualize the three quarters of 2017 with exceedance of ozone standards. The exceedances of the norms are one of the most significant for the entire period. Values of 226.42 μg/m3 and 217.48 μg/m3 were registered for AMS Druzhba in the second and third quarters of the year. The only sensor that does not report an excess during the summer months is AMS Hippodrome. However, it is the only sensor that registered an excess in the last quarter of the year – 125.82 μg/m3.

Figures 79, 80 and 81 present the three quarters of 2018 with ozone exceedances. The first quarter of the year did not report excesses of norms. Second quarter reported values of 254 μg/m3 for AMS Druzhba, however AMS Nadezhda and AMS Hippodrome did not report exceeding the norms. The third quarter registered exceedances for all sensors, except for the Hippodrome.

Figures 82, 83 and 84 visualize the three quarters of 2019 with recorded exceedances of ozone standards. In the period January-March, no exceedances of the norms were reported. The largest number of exceedances occurred in the second and third quarters of the year, as in the second quarter all sensors, except for AMS Nadezhda, exceeded the norms, and in the third quarter, all sensors, except for AMS Hippodrome, exceeded the threshold values. In the second quarter, the maximum value was 156.53 μg/m3 for AMS Druzhba, and in the third, the maximum value was 176.15 μg/m3 for the Kopitoto sensor. In the last quarter of the year, an excess was registered by only one sensor – the Kopitoto with 130 μg/m3.

Figures 85, 86 and 87 present the three quarters of 2020 with registered exceedances of norms. In the October-December period, there were no violations of the norms. At the beginning of the year, only one sensor reported an excess - Kopitoto, with 129 μg/m3. It is important to note that, due to technical reasons, AMS Druzhba did not collect data for the second quarter of the year, which leads to distortions in the research for this indicator. Exceedances were recorded for three of the remaining four sensors - AMS Nadezhda, AMS Hippodrome and AMS Kopitoto, with the highest values reported by the sensor in zh.k. Nadezhda. In the third quarter of 2020, the highest value for the entire studied period was measured - 281.74 μg/m3. Exceedances of the norms for the specific quarter were also measured for all other sensors.

Figures 88, 89 and 90 present the three quarters of 2021 with measured exceedances of ozone standards. Similar to several of the previous years of the period under study, no excesses were reported for the fourth quarter of the year. The first quarter registered only one sensor exceeding the ozone standards - AMS Nadezhda with 178.30 μg/m3. In the second quarter, one of the highest values for ozone was reported - 256.65 μg/m3 for AMS Druzhba, and all other sensors, except for AMS Hippodrome, also reported air pollution with ozone. In the third quarter, the highest value is also significantly higher than some of the previous years – 207 μg/m3 for AMS Kopitoto. During the July-September period, all functioning sensors measured exceedances of the norms.

Figures 91, 92 and 93 visualize the three quarters with registered exceedances of norms for the year 2022. In the October-December period again no exceedances of the norms were measured. It is impressive that throughout the year not a single exceedance of the ozone standards was registered for the AMS Hippodrome. In the first quarter, AMS Kopitoto exceeded the ozone limit with a value of 129 μg/m3. In the second quarter, only two sensors exceed the limits - AMS Pavlovo and AMS Kopitoto, with 126 μg/m3 and 123 μg/m3, respectively. In the third quarter, the highest reported value was equal to 195 μg/m3 for AMS Druzhba.

Figures 94 and 95 present the two quarters with exceedances of the norms for 2023. No exceedances were reported in the first quarter of the year. In the second quarter, AMS Pavlovo and AMS Kopitoto reported values of 142.91 μg/m3 and 168.36 μg/m3. In the most recent quarter for which data is currently available, namely the third quarter of 2023, all five sensors reported exceeding the standards, with the maximum being 168 μg/m3 for the Kopitoto AMS.

Despite the availability of data from the three-monthly bulletins for the AQ of the EEA, the data for the given 5 sensors are insufficient to make an objective assessment of the state of the air in the capital. The lack of a sufficient number makes it difficult to assess the air quality. The need to place additional new sensors is increasing.

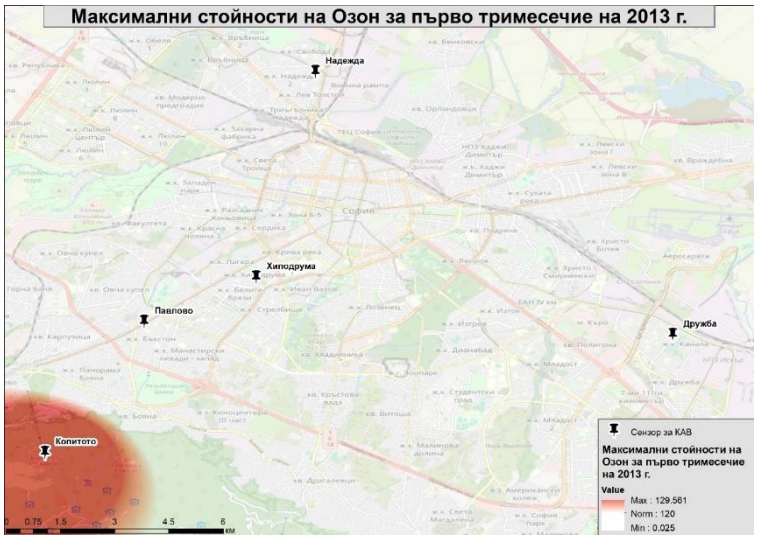


Fig. 65. Maximum ozone values for the first quarter of 2013.

4.6.3. NO2 –nitrogen dioxide

Норма	Период на осредняване	Стойност	Дата, към която нормата трябва да бъде спазена
Азотен диоксид и азотни оксиди			
Средночасова норма за опазване на човешкото здраве	1 час	200 µg/m3 NO2 (да не бъде превишавана повече от 18 пъти в рамките на една КГ)	1.01.2010 г.
Средногодишна норма за опазване на човешкото здраве	една календарна година	40 µg/m3 NO2	1.01.2010 г.
Норма за опазване на растителността (не се прилага в непосредствена близост до източниците)	една календарна година	30 µg/m3 (NO+NO2)	-

Fig. 96. Norms for nitrogen dioxide and nitrogen oxides according to Ordinance No. 12.

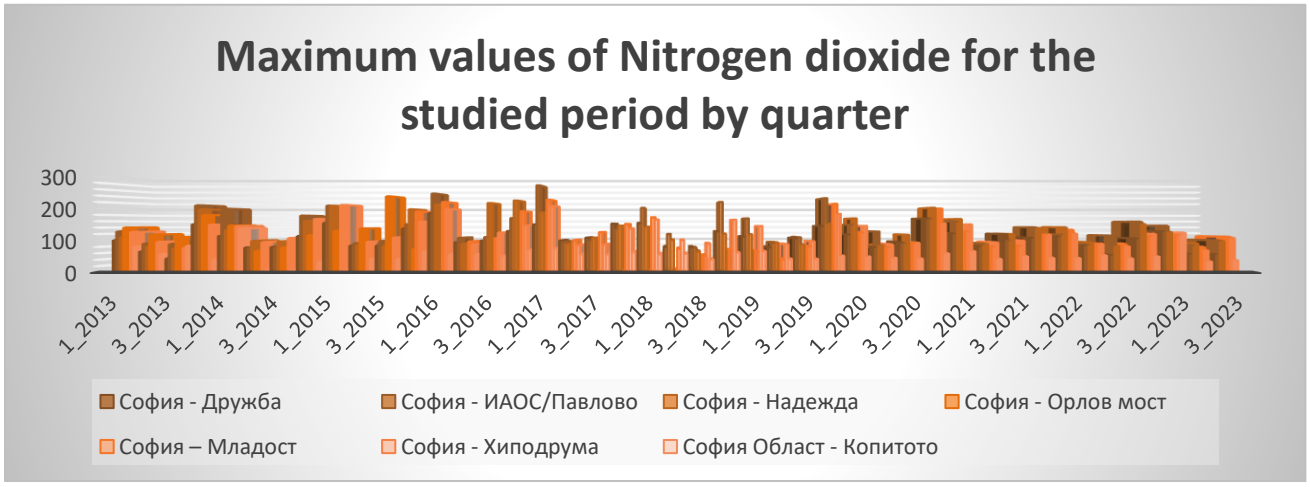


Fig. 97. Maximum values of nitrogen dioxide for the studied period by quarter

In fig. 96, the average hourly norm for the protection of human health, the average annual norm for the protection of human health and the norm for the protection of vegetation for nitrogen dioxide and nitrogen oxides are presented. The source is Ordinance No. 12 and according to it, the average hourly rate is equal to 200 μg/m3, and an important requirement is that this rate is not exceeded more than 18 times a year, the average annual rate is equal to 40 μg/m3, and the rate for the protection of vegetation at 30 μg/m3.

Nitrogen dioxide is the second indicator, after PM10, with the most recorded exceedances for the entire studied period - 1047. Most of them - 975 were registered in the cold half-year - first and fourth quarters, and the rest - 72, in the warm half-year – second and third quarter. Exceedances are numerous, but the maximum reported value is 275.5 μg/m3, recorded by AMS Pavlovo, in the first quarter of 2017. Exceeding the norms comes mainly from sensors in Pavlovo, Nadezhda, Hippodrome, Mladost and AMS Orlov Most. until the end of its operation in 2015 (fig. 97). For AMS Druzhba and AMS Kopitoto, no exceedances of the norms were reported during the entire investigated period.

Figure 98 shows the maximum reported value for the indicator in the fourth quarter of 2013. This is the only quarter with an excess of the norm for the entire calendar year 2013. AMS Hippodrome reported a value of 211.39 μg/m3. According to the data from the EEA, in the fourth quarter of 2013, 67 exceedances of the norm were registered. In the absence of data that any of the other sensors exceeded the limit, AMS Hippodrome therefore exceeded the limits a further 67 times during the quarter, with the corresponding highest recorded value being 211.39 μg/m3.

Figure 99 shows the maximum reported value for the first quarter of 2014. The maximum value is just over 200 μg/m3 – 200.33 μg/m3. No other exceedances for the entire year were recorded for any of the sensors. Given the limit value that AMS Hippodrome reported, it is difficult to talk about significant pollution with nitrogen dioxide throughout the year.

Figures 100 and 101 show the maximum registered values for the calendar year 2015. In this case, the total number of exceedances for the year is 174. In the first quarter of the year, the sensors that registered exceeding the norms were AMS Pavlovo, AMS Nadezhda and AMS Hippodrome, respectively with 210.29 μg/m3, 210.07 μg/m3 and 212.45 μg/m3. In the third quarter of the year, only AMS Orlov Most reported an excess - 240.04 μg/m3.

Figures 102, 103 and 104 visualize the maximum values for nitrogen dioxide in 2016. This is the year with the most quarters with exceedances recorded, a total of 3 out of 4. The total number of exceedances according to the EEA is 189 for the year. In the first quarter, AMS Pavlovo, AMS Nadezhda

and AMS Mladost registered respectively – 248.8 μg/m3, 214.25 μg/m3 and 221.96 μg/m3. AMS Nadezhda is the only sensor that reports exceedances of norms in the third and fourth quarter of the year, 218.4 μg/m3 and 226.55 μg/m3, respectively.

Figure 105 presents the first quarter of 2017 and its maximum reported values. During the entire studied period, in the period January-March, the highest value for nitrogen dioxide was recorded - 275.2 μg/m3 from AMS Pavlovo, followed by 229.13 μg/m3 for AMS Mladost and 209.42 μg/m3 for AMS Hippodrome. This is also the period with the largest total number of registered violations of the norms – over 300.

Figures 106 and 107 visualize 2018 and its exceedances of nitrogen dioxide standards. The excesses were recorded again in the cold months - the first and fourth quarters of the year. For both quarters, the only sensor that exceeded the limit values was AMS Pavlovo, with 202.98 μg/m3 for the first and 221.98 μg/m3 for the fourth quarter of the year, respectively.

Figure 108 shows 2019 with its fourth quarter overruns. This is the penultimate quarter of the research period that registered deviations in nitrogen dioxide norms. The sensors that reported the excesses were AMS Pavlovo and AMS Mladost, with 233.9 μg/m3 and 215.99 μg/m3, respectively.

Figure 109 shows the last quarter with an exceedance of the norm for nitrogen dioxide during the entire investigated period. It was registered in the last quarter of 2020. Two sensors reported the excess - AMS Nadezhda and AMS Mladost, with 203.47 μg/m3 and 200.9 μg/m3, respectively. The excesses in this year are not significant, with just over 3 μg/m3.

A positive trend has been observed in the last years of the research period 2013-2023, since the end of 2020, no exceedances of the norm of 200 μg/m3 have been registered. Despite this positive trend and the availability of data from the quarterly newsletters of the EEA, the data for 5 sensors are extremely insufficient to make an objective assessment of the state of the air quality and its contamination with nitrogen dioxide and nitrogen oxides. The need arises for the deployment of more sensors on the territory of the municipality, which are concentrated in the most problematic places for air in the city, namely at key intersections, places with agglomeration of the population, places with a population heating with solid fuel, around industrial zones, around Sofia Airport and other critical infrastructure.

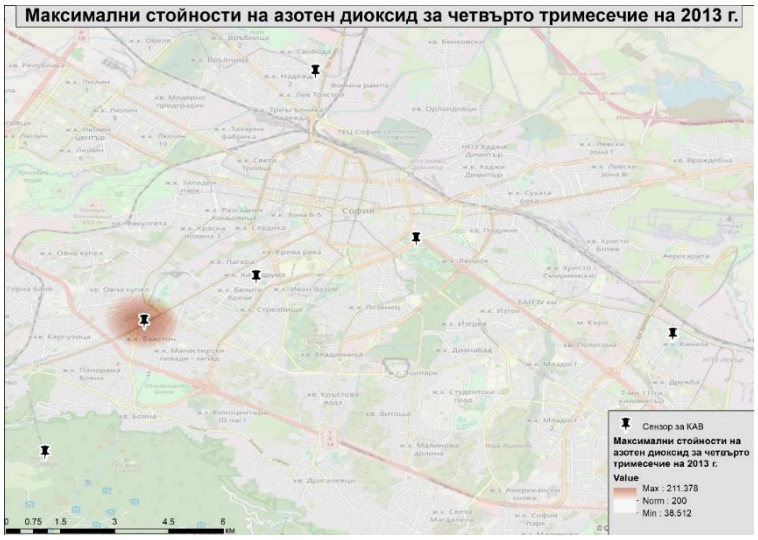


Fig. 98. Maximum nitrogen dioxide values for the fourth quarter of 2013.

4.6.4. PM2,5

Норма	Период на осредняване	Стойност	Дата, към която нормата трябва да бъде спазена
Фини прахови частици (ФПЧ2,5)			
Етап 1			
Средногодишна норма за опазване на човешкото здраве	**една календарна година**	**25 µg/m3 ФПЧ2,5**	**1.01.2015 г.**
Етап 2			
Средногодишна норма за опазване на човешкото здраве	**една календарна година**	**20 µg/m3 ФПЧ2,5**	**1.01.2020 г.**

Fig. 110. Norms for PM2,5 according to Ordinance No. 12

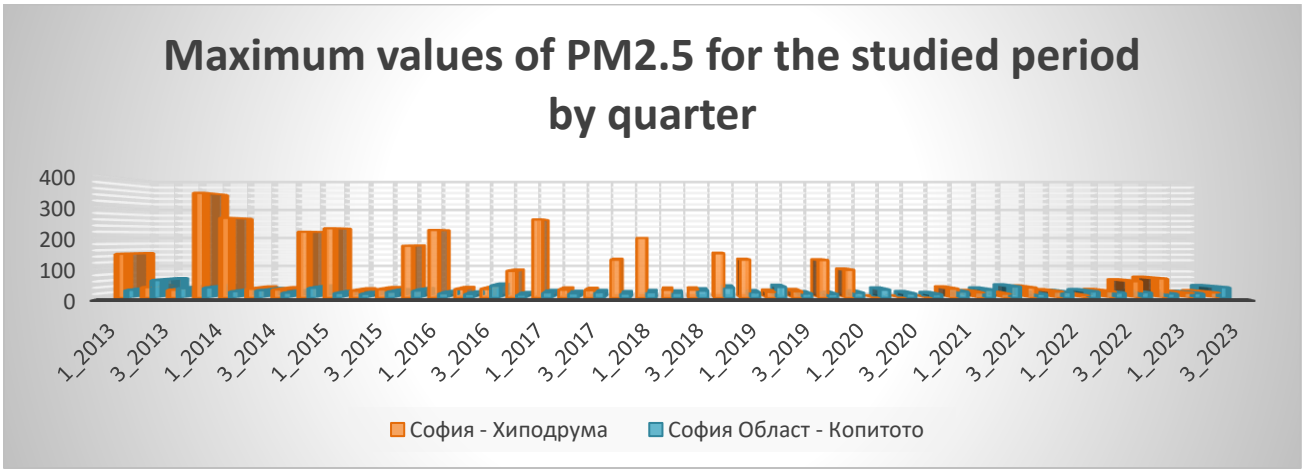


Fig. 111. Maximum values of PM2.5 for the studied period by quarter.

The indicator PM2.5 is one of the most significant for the study and analysis of the state of atmospheric air in the city. Fine dust particles with a size of 2.5 microns are one of the biggest air pollutants in Sofia, and their evaluation and analysis are almost impossible, irrelevant or minimized. This

is due to the fact that for the territory of the entire city, only two sensors collect data for this important indicator, these are AMS Hippodrome and AMS Kopitoto. PM2.5 are significantly more harmful to health than PM10, and yet only two sensors collect data on them. Over the years, there has been a change in the norm for PM2.5 (Fig. 110) from 25 μg/m3 at the beginning of 2015, decreasing to 20 μg/m3 at the beginning of 2020. In the quarterly bulletins on the status of the AQ from the EEA, the agency does not provide data on how many times the norms were exceeded, only the maximum reported value for the indicator and the number of recorded measurements are provided, which in turn leads to considerable confusion and ambiguity.

Given the presence of only two sensors reading PM2.5, the maps created for the purposes of scientific work look absolutely identical, since the method used to create them is IDW interpolation, which requires a larger number of points. Inverse distance-weighted (IDW) interpolation can be used when starting points with known values are dense enough to calculate how they vary across the study area. In the absence of a higher number of points, the cards look identical, the only difference being the color used when reporting overages.

During the research period 2013-2023, the norms for PM2.5 have changed their limits, from 25 μg/m3, to 20 μg/m3 at the present moment. The change was taken into account when creating the scientific work. For the 43 quarters studied over the years, there are only 5 quarters for which no exceedance of the norms for the indicator was reported. Two of them were before lowering the norms from 25 to 20 μg/m3, in the second quarter of 2015 and in the third quarter of 2019. From the beginning of 2020, there is a clear tendency to decrease the maximum values for PM2.5, compared to the beginning of the period (Fig. 111). The highest measured value for the entire studied period was registered by AMS Hippodrome - 349.54 μg/m3, which is about 14 times the excess of the norms from Ordinance No. 12. An important clarification in the study of the indicator is the lack of data for the greater part of 2020 - the second, third and fourth quarters did not record data for the AMS Hippodrome, due to technical reasons that have not been specified by the EEA. The absence of these data leads to a significant distortion in the study of the indicator, because AMS Kopitoto continues to record values during this period that exceed zero values for AMS Hippodrome.

Figures 112, 113, 114 and 115 show the maximum values of PM2.5 for the calendar year 2013. Exceedances were registered for both sensors, and for all quarters of the year. As mentioned, the most significant exceedance for the entire study period was reported in the last quarter of 2013 – 349.54 μg/m3 from AMS Hippodrome. In the first quarter, the sensor in the Hippodrome recorded values of 147.27

μg/m3, which again exceeded the norms for PM2.5 significantly. The warm months also report an excess of the norms, but not as much as in the cold months. It is noticed that during the summer months AMS Kopitoto reports higher values than AMS Hippodrome, respectively 60.2 μg/m3 for the second quarter and 33.1 μg/m3 for the third quarter, while in the Hippodrome the values reach 36.68 μg/m3 for the second and 27.81 μg/m3 for the third quarter.

Figures 116, 117, 118 and 119 show the maximum values of the indicator for 2014. AMS Hippodrome recorded norm exceedances during the four quarters - 266.5 μg/m3 for the first quarter, 31.05 μg/m3 for the second quarter, 28.64 μg/m3 for the third quarter and 220.42 μg/m3 for the fourth quarter. AMS Kopitoto reports excesses for only two of the quarters - 26.30 μg/m3 for the second and 34.4 μg/m3 for the fourth quarter.

Figures 120, 121 and 122 show the maximum measured values for three quarters of 2015. For the second quarter of the year, no exceedances were reported for either of the two available sensors. The sensor in the Hippodrome reports excesses in the first, third and fourth quarter, respectively - 232.01 μg/m3, 29.04 μg/m3 and 173.8 μg/m3. Exceedances at the Kopitoto sensor were recorded in the last quarter of the year – 25.2 μg/m3.

Figures 123, 124, 125 and 126 show the maximum values of PM2.5 for the calendar year 2016. Exceeding the set norms for each of the quarters for AMS Hippodrome, the most significant being again in the winter months, respectively 226.39 μg/m3 for the first quarter, 90.18 μg/m3 for the fourth quarter. During the warm months, the excesses are respectively 29.77 μg/m3 for the second and 30.5 μg/m3 for the third quarter. The Kopitoto sensor reported one exceedance for the third quarter - 41.2 μg/m3, which is higher than the exceedance for the same quarter for the AMS Hippodrome. The fourth quarter is the first cold quarter for the entire studied period, during which values of excess below 100 μg/m3 were reported.

Figures 127, 128, 129 and 130 visualize the highest values of the indicator for 2017. An impression is made by the absence of exceeding the norms of the Kopitoto sensor. However, the other AMS Hippodrome reported exceeding the norms for all quarters – 261.3 μg/m3 for the first, 28.04 μg/m3 for the second, 26.48 μg/m3 for the third and 127.71 μg/m3 for the fourth quarter. As in previous years, the cold half-year has significant excesses compared to the warm half-year.

Figures 131, 132, 133 and 134 show the maximum values for PM2.5 in 2018. Each of the quarters during the year reported an excess of the norms at the AMS Hippodrome, the highest values are again in the cold half-year, and the lowest in the warm half-year, respectively 199.77 μg/m3 for the first, 27.56

μg/m3 for the second, 27.78 for the third and 148.67 μg/m3 for the fourth quarter. AMS Kopitoto registered an excess only in the fourth quarter of the year, with a value of 34.9 μg/m3.

Figures 135, 136 and 137 present the three quarters of 2019, which reported exceeding the norms for the indicator. The recorded exceedances in the first and fourth quarters for the Hippodrome sensor were similar in value, 127.8 μg/m3 and 126.25 μg/m3 respectively. In the second quarter, the sensor did not register an exceedance of the norms, unlike AMS Kopitoto, which reported 37 μg/m3 in this quarter. The third quarter did not mark any exceedances of the norms.

Figures 138 and 139 present two of the four quarters with reported maximum values for the indicator in 2020. Data for the second, third and fourth quarters for AMS Hippodrome are not available because, according to the EEA, due to technical problems, the sensor was not operational for nearly 9 months. The problems stopping the operation of a sensor of essential importance for the monitoring of air quality are not specifically specified. Despite the absence of data from the Hippodrome sensor, the Kopitoto sensor collects data for the entire year, registering only one exceedance in the second quarter of 2020 – 28.1 μg/m3. AMS Hippodrome reported an excess of values in the only quarter of the year during which it recorded data, respectively 93.75 μg/m3. The lack of data on PM2.5 significantly distorts the research and makes it difficult to track the state of the AQ for the specific indicator. The first quarter of 2020 is the second winter period during which the values of the indicator fall below 100 μg/m3.

Figures 140, 141, 142 and 143 present the year 2021 and its maximum reported values for the two active sensors. This is the first year since the beginning of the research period with a significant decrease in the measured maximum values. Although both sensors reported exceedances, their values were significantly lower than previous years. AMS Hippodrome reports an excess only in the cold half-year, respectively 31.57 μg/m3 for the first and 37 μg/m3 for the fourth quarter. AMS Kopitoto reports an excess in the first, second and third quarters, respectively 21.9 μg/m3, 28.1 μg/m3, and 38.7 μg/m3, and again in the summer months it reports higher values than AMS Hippodrome. The year 2021 marks the beginning of a clearly expressed trend towards a significant decrease in the values of PM2.5.

Figures 144, 145, 146 and 147 visualize the maximum reported values for the calendar year 2022 for the PM2.5 indicator. AMS Hippodrome has reported three quarters with norm exceedances - 22.01 μg/m3 for the first, 22.88 μg/m3 for the third and 56.36 μg/m3 for the fourth quarter. It is impressive that in the July-September period the sensor in the Hippodrome recorded a higher value than in the January-March period. The Kopitoto sensor recorded only one exceedance of the norms in the April-June period – 22.4 μg/m3, again exceeding the values reported by the Hippodrome sensor.

Figures 148 and 149 present the exceedances of the norms for PM2.5 in the first and third quarters of 2023. Exceeding the norms was not registered in the second quarter of the year. At the time of preparation of the scientific work, data for the fourth quarter of the year are not yet available. The two active sensors each report one quarter with an excess - AMS Hippodrome - 65.29 µg/m3 for the first quarter and AMS Kopitoto - 36.27 µg/m3 for the third quarter.

It can be concluded that there is a positive trend in the last years of the researched period. The reported maximum values are significantly lower, for comparison in the last quarter of 2013. AMS Hippodrome reports its highest value – 349.54 µg/m3, while in the same quarter of 2021 the value is 35 µg/m3. However, there has not yet been a quarter of the cold half-year in which there were no exceedances of the norm for the particular sensor. As it was mentioned, the lack of sensors reporting the PM2.5 indicator is a significant problem for the monitoring of atmospheric air in the city of Sofia. The two active sensors are insufficient to make an objective assessment of the state of the air quality and its contamination with fine dust particles with a size of 2.5 microns. Again, the need arises for the deployment of more sensors on the territory of the municipality, which are concentrated in the most problematic places for the air in the city, namely at key intersections, places with agglomeration of the population, places with a population heating with solid fuel, around industrial zones, around Sofia Airport and other critical infrastructure.

Fig. 112. Maximum values of PM2.5 for the first quarter of 2013.

4.6.5. PM10

Норма	Период на осредняване	Стойност	Дата, към която нормата трябва да бъде спазена
Фини прахови частици (ФПЧ10)			
Средноденонощна норма за опазване на човешкото здраве	24 часа	50 µg/m3ФПЧ10 (да не бъде превишавана повече от 35 пъти в рамките на една КГ)	1.01.2005 г.
Средногодишна норма за опазване на човешкото здраве	една календарна година	40 µg/m3 ФПЧ10	1.01.2005 г.

Fig. 150. Norms for PM10 according to Ordinance No. 12

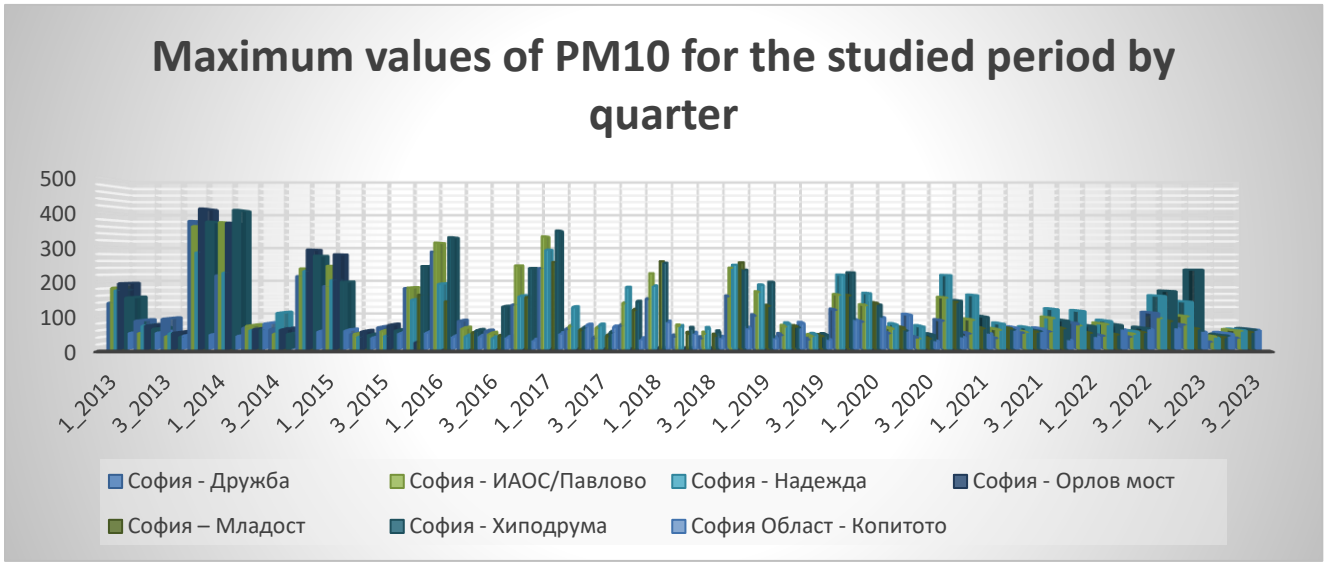


Fig. 151. Maximum values of PM10 for the studied period by quarter.

Fine dust particles with a size of 10 microns are one of the most important and significant indicators examining the state of the air in recent years. The indicator is by far the biggest air pollutant in the city, with the most recorded exceedances in the last decade. For the entire studied period from the beginning of 2013 to the third quarter of 2023, a total of 3,261 exceedances of the norms were reported for PM10. According to Ordinance No. 12, the average daily norm for the protection of human health is equal to 50 µg/m3, and it should not be exceeded more than 35 times within one calendar year, and the average annual norm for the protection of human health (for one calendar year) is 40 µg/m3. From the beginning of the study to the present day, there is not a single calendar year in which the indicator was not exceeded significantly more than 35 times, and there was an excess by quarter for almost all quarters, with the exception of the third quarter of 2019 and the second quarter of 2023. In comparison, during the calendar year 2013, the standards were exceeded a total of 476 times, with a standard of 35. Despite the significant total number of all exceedances, there was a slight downward trend in the reported maximum

values of 10 micron PM during the study period, which does not make the air condition healthier for the human body, as the values are again significantly above the health protection norm.

Despite the essential importance of the indicator, its evaluation and analysis are extremely difficult and minimized, given the absence of a sufficient number of sensors monitoring its values. For the territory of the city, 6 sensors report data for PM10, and at the end of 2015, one of the most important - AMS Orlov Most, was replaced by AMS Mladost, which significantly impedes the analysis of the state of the air traffic control system in the central city parts. According to unofficial data from the EEA, the relocation of the sensor is due to the start of the construction of the third metrodiameter in the capital. The sensor is disconnected from the air quality monitoring network, although it registered record values such as - 413.24 μg/m3 at the end of 2013, which is also the maximum reported value for the entire investigated period.

Figures 152, 153, 154 and 155 show the quarters of 2013, for which the norms were exceeded. The excesses are most significant in the cold months, and smaller in the warm months. This is the year in which a record value was reported for the entire investigated period – 413.24 μg/m3 from AMS Orlov Most in the fourth quarter of the year, followed by 374.98 μg/m3 for AMS Hippodrome in the same quarter. The first quarter of 2013 again recorded the highest value for AMS Orlov Most – 194.8 μg/m3, compared to the other sensors. Exceeding the norms were registered for all sensors, as at AMS Kopitoto, the value is at the limit - 50.41 μg/m3. The second quarter of the year recorded exceedances for all sensors, with the highest reported being 85.36 μg/m3 from AMS Druzhba, and the lowest from AMS Pavlovo – 50.01 μg/m3, which is on the border. In the third quarter of the year, things are different, only AMS Druzhba reports an excess of 90.88 μg/m3, all other sensors and their values are normal.

Figures 156, 157, 157 and 159 visualize the maximum values for PM10 in 2014. The year is the second in a row with recorded record values for the studied period. The first quarter reports some of the highest values - 409.41 μg/m3 for AMS Hippodrome, 373.17 μg/m3 for AMS Pavlovo, 371.8 μg/m3 for AMS Orlov Most, 226.2 μg/m3 for AMS Nadezhda, 217.82 μg/m3 for AMS Druzhba, while AMS Kopitoto registered normal levels of the indicator. During the two warm quarters, norm exceedances were again recorded, ranging from 58.26 μg/m3 to a maximum of 107.78 μg/m3, and due to technical reasons for the third quarter of the year, data for the Kopitoto sensor is missing. For the last part of the year, the October-December period, each of the sensors recorded an excess of the norm of 50 μg/m3, the lowest being for AMS Kopitoto - 54.43 μg/m3, and the highest for AMS Orlov Most 293.31 μg/m3.

Figures 160, 161, 162 and 163 show the maximum values for the indicator in 2015. An important clarification for the year under review is the relocation of the sensor from Orlov Most to the residential area Mladost. For a short time in the third quarter of the year, the two sensors functioned in parallel, and AMS Orlov Most did not report any exceedances (22.98 μg/m3) of the norm, as it worked for a very small part of the quarter. This, in turn, leads to a distortion of the data for the period. Since AMS Orlov Most is one of the sensors with the highest exceedances, it is impossible to report values of 22.98 μg/m3 in the autumn-winter quarter, compared to AMS Kopitoto, which reports 50.38 μg/m3 or AMS Hippodrome recorded the maximum value for the period – 245.27 μg/m3. In the first part of the year, the norms were exceeded for all sensors - from 57.09 μg/m3 for AMS Kopitoto to 279.44 μg/m3 for AMS Orlov Most. The second quarter of the year exceeded the norm only at AMS Orlov Most - 53.09 μg/m3. Third quarter recorded exceedances for 4 out of 6 sensors, within 55.32 μg/m3 – 72.1 μg/m3.

Figures 164, 165, 166 and 167 visualize the maximum values for PM10 in 2016. As in the previous years, here, the maximum values for the indicator were recorded in the cold half-year. The record values for the year were recorded in the January-March period, with AMS Hippodrome and AMS Pavlovo reporting 329.4 μg/m3 and 313.48 μg/m3, respectively, followed by AMS Druzhba with 287.46 μg/m3, AMS Nadezhda with 193.42 μg/m3 and AMS Mladost with 141.19 μg/m3, and AMS Kopitoto did not register an excess for the specific quarter. In the second quarter, the situation is as follows - 4 out of 6 sensors report exceeding the norms: Druzhba, Pavlovo, Mladost and Hippodrome. In the third quarter, only two of the six sensors exceeded the norms - Hippodrome with 126.06 μg/m3 and Druzhba with 54.03 μg/m3. In the fourth quarter, almost all measuring stations reported exceeding the norms, with the exception of AMS Kopitoto. Similar to the beginning of the year, AMS Hippodrome and AMS Pavlovo registered the highest values.

Figures 168, 169, 170 and 171 show the excesses of the indicator in 2017. The maximum value for the year was reported by AMS Hippodrome - 348.82 μg/m3, which is the third record value for the entire studied period, followed by AMS Pavlovo with a significantly exceeded norm - 331.98 μg/m3, followed by AMS Nadezhda - 293, 34 μg/m3, AMS Mladost – 257.14 μg/m3 and AMS Druzhba with 238.97 μg/m3, while for AMS Kopitoto no excesses were reported. During the April-June period, all measuring stations reported exceeding the norms, including AMS Kopitoto, which ranks second in measured value - 71.79 μg/m3, preceded only by AMS Nadezhda with 124.39 μg/m3. The third quarter recorded exceedances for four of the six sensors. The year ends with recorded maximum values from

AMS Nadezhda 182.82 μg/m3, followed by Hippodrome, Pavlovo, Mladost and Druzhba with respectively 140.76 μg/m3, 136.04 μg/m3, 116.46 μg/m3 and 70.06 μg/m3.

Figures 172, 173, 174 and 175 present the maximum values of PM10 for the calendar year 2018. This is the first year since the beginning of the research period with such a small number of exceedances in the summer months - AMS Hippodrome and AMS Nadezhda report an exceedance for the third quarter and AMS Hippodrome, AMS Nadezhda and AMS Pavlovo, with the maximum reported value for both quarters being below 70 μg/ m3. The cold months are again marked by a significant excess of the permissible norms - AMS Mladost reports the highest values in the first and fourth quarters of the year, respectively 259 μg/m3 and 255.96 μg/m3. For the period January-March, the excesses are in the range of 81.05 μg/m3 (Kopitoto) - 259 μg/m3 (Mladost), and for the period October-December 62.99 μg/m3 (Kopitoto) - 255.96 (Mladost).

Figures 176, 177 and 178 show the three quarters of 2019 that exceeded the norms for the PM10. This is the first year of the entire period under study that did not register an excess in one of its quarters, in this case it was the July-September quarter. During the January-March period, for the first time since the beginning of the researched period, excesses with a value below 200 μg/m3 were reported, the highest being from the AMS Hippodrome - 197.67 μg/m3, and the Kopitoto sensor did not report any excesses. The second quarter recorded values of excesses below 80 μg/m3, the highest being for AMS Kopitoto - 77.33 μg/m3. At the end of the year, the highest values for the indicator were reported from AMS Hippodrome - 226.32 μg/m3, followed by AMS Nadezhda with 219.54 μg/m3, AMS Pavlovo with 161 μg/m3, AMS Mladost with 159 μg/m3 , AMS Druzhba with 117 μg/m3 and AMS Kopitoto with 87.6 μg/m3.

Figures 179, 180, 181 and 182 present the excesses of the indicator in 2020. During the first part of the year (January-March), the norms were exceeded for each sensor, with values in the range of 82.55 μg/m3 - 164.94 μg/m3, respectively for AMS Druzhba and AMS Nadezhda. It is impressive that during this quarter AMS Kopitoto reports higher values than AMS Druzhba - 94.76 μg/m3. The second quarter of the year was marked by exceedances for five of the six sensors, with values within 56.82 μg/m3 for AMS Hippodrome and 101.86 μg/m3 for AMS Kopitoto. Impressive is the Kopitoto sensor, which reports the highest value compared to all other sensors. The period July-September marks an excess for only one sensor – Nadezhda, with 67.4 μg/m3. At the end of the year, there is a jump in the norms for every single sensor, with the exception of AMS Kopitoto. The highest recorded value is from AMS

Nadezhda – 218.27 μg/m3, followed by 152.29 μg/m3 for AMS Pavlovo, 143.31 μg/m3 for AMS Hippodrome, 140.31 μg/m3 for AMS Mladost and 85 .62 μg/m3 for AMS Druzhba.

Figures 183, 184, 185 and 186 visualize the excesses for PM10 in 2021. There are exceedances of the norms in all four quarters, and as usual they are most significant in the autumn-winter months. The January-March period recorded values in the range of 63.3 μg/m3 - 159.24 μg/m3, respectively for AMS Mladost and AMS Nadezhda. Two of the sensors do not report excesses - Kopitoto and Druzhba. The second quarter was characterized by an excess of norms for five of the total six sensors. Its values are within 58.98 μg/m3 - 75.6 μg/m3, with only the sensor in the housing. Druzhba does not exceed the norms. The third quarter of the year presents an excess of the norms for each automatic measuring station: 50.46 μg/m3 – 64.29 μg/m3. The values are not record-breaking, but they are still out of the norm. At the end of the year, the exceedances of PM10 were lower compared to the first quarter of the year, respectively in the range of 54.3 μg/m3 - 118.31 μg/m3 (AMS Druzhba - AMS Nadezhda), while AMS Kopitoto did not exceeds the value of 50 μg/m3.

Figures 187, 188, 189 and 190 present the maximum values of PM10 for the four quarters of 2022. The first quarter of 2022 reported the lowest maximum values compared to any other first quarter for the entire period studied. Values vary within the limits of 50.09 μg/m3 for the sensor in the housing. Mladost, up to the maximum 112.9 μg/m3 for the station in zh.k. Nadezhda. AMS Hippodrome - 68.97 μg/m3, AMS Pavlovo - 71.4 μg/m3, AMS Druzhba - 77.9 μg/m3, and AMS Kopitoto do not exceed 50 μg/m3, respectively. The April-June period reports an exceedance for four out of six sensors, with the exception of AMS Druzhba and AMS Mladost. The values for the remaining stations ranged from 59.58 μg/m3 to 83.94 μg/m3. The situation is similar for the third quarter - two sensors do not exceed the norms (AMS Druzhba and AMS Pavlovo), and for the rest the values vary between 51.96 μg/m3 and 62.69 μg/m3. The period October-December reports significantly higher values compared to the period January-March, and crossing the norms were reported by all sensors. The lowest value is for AMS Kopitoto – 63.1 μg/m3, followed by 84.49 μg/m3 for AMS Mladost, 93.22 μg/m3 for AMS Pavlovo, 107.63 μg/m3 for AMS Druzhba, 157, 44 μg/m3 for AMS Nadezhda, reaching the highest for AMS Hippodrome – 171.5 μg/m3.

Figures 191 and 192 present the two quarters of 2023 that exceeded the established norms for PM10. At the current time of development of the research paper, the data for the fourth quarter of 2023 has not yet been collected and published. In the first quarter of the year, all stations for measuring PM10 registered excesses of the permissible norms. The most serious is the excess of AMS Hippodrome -

234.47 µg/m3, followed by 140.48 µg/m3 for housing. Nadezhda, 98.54 µg/m3 for AMS Pavlovo, 73.99 µg/m3 for housing. Druzhba, 62.77 µg/m3 for housing. Mladost and 53.26 µg/m3 for AMS Kopitoto. The April-June period did not exceed the set norms for the indicator, but contrary to it, the July-September period registered an excess for all sensors except AMS Druzhba. The excesses for them are not significant, below 59 µg/m3, but they are still reported as such.

Fine dust particles are one of the most serious and harmful air pollutants in the city. It is difficult to follow a trend of significant reduction in PM10 pollution, as they are of relatively erratic values. However, they report an almost double decrease compared to the first years of the study (Fig. 151).

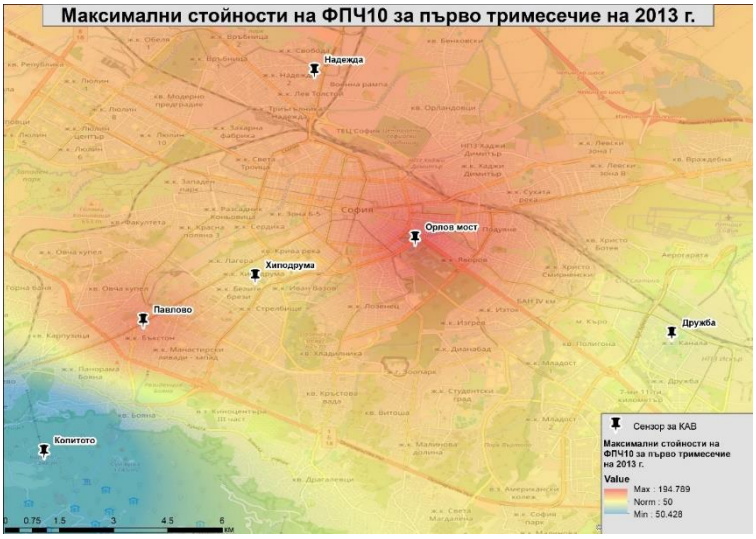


Fig. 152. Maximum values of PM10 for the first quarter of 2013.

4.7. Geospatial analysis from the AIRTHINGS project

As mentioned, in Sofia the system consists of 22 stations for measuring the quality of atmospheric air, which measure in real time, by means of sensors, the most common air pollutants (PM, CO, NO2, SO2), temperature, humidity and pressure. Each station sends information on indicators to a system that is built on the principle of open data (Open Data System). An extremely important clarification is that, according to the Sofia Municipality, the data from the sensors 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.

For the purposes of the research paper, the data from the platform were processed and equated by quarter, similar to the data from the EEA quarterly bulletins. The goal is an easier understanding of the huge data set and an attempt to compare the two types of sensors and the values they register. When deploying the sensors under the AIRTHINGS project, four out of the six sensors from the national

monitoring system of AQ were replaced by four out of the twenty-two sensors under the project of the Sofia Municipality, namely - Hippodrome ("Hippodrome" park), Pavlovo (zh. k. " Ovcha Kupel"), Mladost (NIMH) and Druzhba (zh. K. Iskar) (fig. 188). It would follow that the data from the 4 sensors on the project coincide with those from the EEA, or have very slight discrepancies. The idea of the study is not only to present a second source of data for the AQ, but also to compare the obtained values by quarter.

After carrying out a thorough analysis of the data from the project's open data system, it was concluded that exceedances were reported only for the indicators ozone, PM2.5 and PM10.

Fig. 193. AIRTHINGS project sensors and EEA sensors overlapping.

4.7.1 Ozone

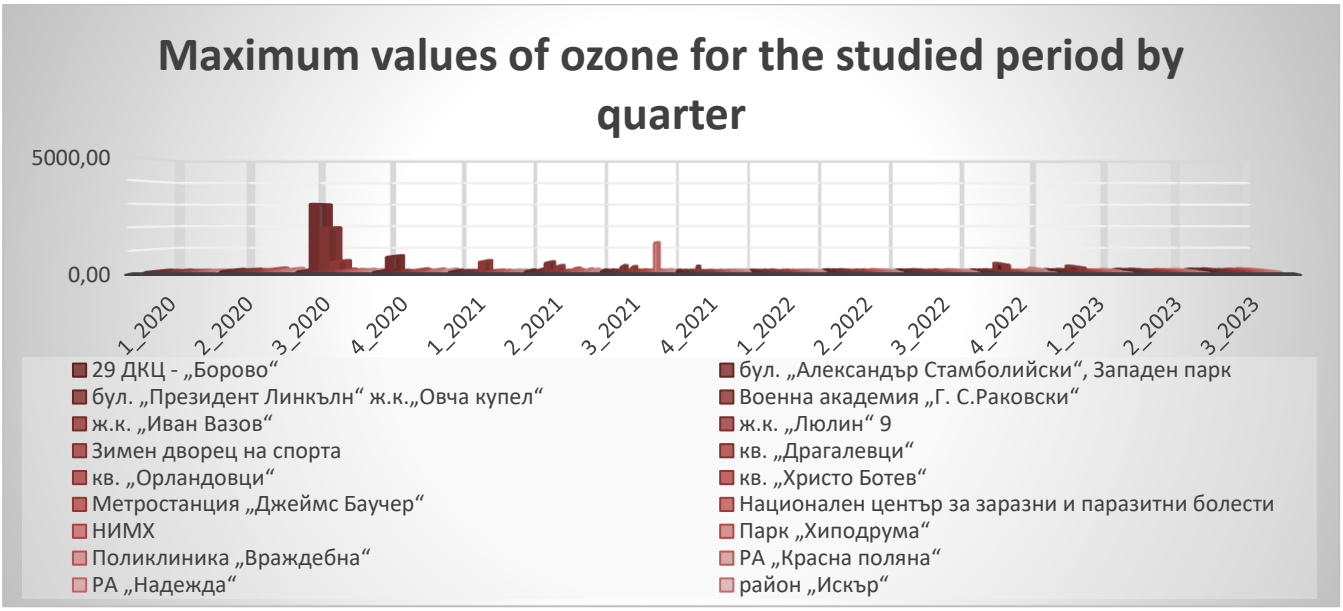


Fig. 194. Maximum values of ozone for the studied period by quarter.

In fig. 64 the short-term target norms and upper assessment thresholds for ozone are presented. The source is Ordinance No. 12, according to which the norm is 120 μg/m3. In fig. 194, the maximum values of ozone for the studied period, broken down by quarter, are presented. It would be difficult to talk about tracking a trend for the short period studied, since the sensors of the project start their work days before the end of 2019. But given the characteristics of the indicator, the most significant excesses can be observed in the warm months - the second and third quarters of each year. This is due to the fact that sunlight is required to form ozone, which is why there is a distinct increase in its values from north to south and during the warm half-year. It is also more concentrated at higher altitudes. During the researched period - 15 quarters, exceedances of norms were reported in 9 of them. A very small part of the air quality sensors report exceeding the norms - no more than three sensors per quarter. The highest reported value for the ozone indicator was recorded by the sensor in zh.k. "Ivan Vazov" - 2994.22 μg/m3, in 2020.

Figure 195 shows a comparison of the data between the two sources - EEA and the project of the Sofia Municipality - AIRTHINGS. A closer comparison between the values for overlapping sensors reveals huge differences - the lower reported ozone values are "in favor" of the sensors of the Sofia Municipality, while the values revealing the real excesses for the indicator are those maintained by the EEA, part of the National air quality monitoring system. The data from the Executive Agency for the Environment should be considered a reliable and official source, as they are part of the National Monitoring System, consisting of 55 points scattered throughout the country, and monitoring air quality since the beginning of 2002 (presence of the first Quarterly State of the Environment Bulletins). In addition, the Agency is a National Coordination Center of the European Environment Agency (EEA).

AMS Mladost is not present in fig. 195, because the EEA sensor does not collect data for the ozone indicator. However, three of the sensors overlap: AMS Hippodrome with Hippodrome Park, AMS Druzhba with Iskar area, AMS Pavlovo with Ovcha Kupel area. Throughout the period in which the sensors overlap - 2020, 2021, 2022 and part of 2023 - significant discrepancies in values are recorded. For the entire period, the sensor of the Sofia Municipality - Hippodrome park recorded only one excess - 134.56 μg/m3, while AMS Hippodrome recorded 4 exceedances of the norms, respectively 121.16 μg/m3, 141.08 μg/m3, 131 .94 μg/m3 and 130.67 μg/m3. The other overlapping sensors - "Iskar" and "Ovcha Kupel" - did not report exceeding the norms at all, while AMS Druzhba and AMS Pavlovo for the same period recorded 5 and 7 maximum values, respectively, exceeding the established norms. Upon further examination of the data presented in Fig. 190, a significant difference is observed in the reported

values themselves - the values reported by the sensors of the Sofia Municipality are several times lower than those of the sensors of the EEA.

AIRTHINGS	1_2020	2_2020	3_2020	4_2020	1_2021	2_2021	3_2021	4_2021	1_2022	2_2022	3_2022	4_2022	1_2023	2_2023	3_2023
Парк „Хиподрума“	5.54	134.56	43.52	45.42	37.15	24.97	36.53	15.63	20.76	26.63	25.38	35.00	51.52	59.44	84.43
район „Искър“	17.37	67.98	44.91	91.50	0.74	18.79	44.84	30.78	37.44	45.61	48.52	29.58	48.34	56.72	69.29
район„Овча купел“	0.00	27.86	33.71	27.64	28.93	79.48	54.35	12.23	19.82	26.66	30.81	11.60	31.69	35.48	44.21
ИАОС	**1_2020**	**2_2020**	**3_2020**	**4_2020**	**1_2021**	**2_2021**	**3_2021**	**4_2021**	**1_2022**	**2_2022**	**3_2022**	**4_2022**	**1_2023**	**2_2023**	**3_2023**
Хиподрума	88.29	121.16	141.08	71.52	92.77	106.56	131.94	58.83	77.43	84.33	104.02	65.58	79.49	104.52	130.67
Дружба	104.89	0.00	281.74	77.99	86.10	256.65	139.85	88.98	115.11	116.90	195.27	81.05	96.66	118.97	151.72
Павлово	102.93	112.85	155.39	85.27	96.79	130.15	185.41	80.80	103.14	126.32	148.82	85.57	88.63	142.91	138.53

Fig. 195. Differences in ozone values between the two investigated sources.

Figures 196, 197 and 198 present the maximum ozone values for three of the four quarters of 2020. Exceeding the norms was not registered in the first quarter of the year. In the second quarter, only one sensor registered exceeding the norm - Hippodrome Park, with 134.56 µg/m3. For comparison, in the second quarter of the same year, AMS Hippodrome (EEA) reported a value of 121.16 µg/m3. The values reported by the two sensors differ by about 13 µg/m3. In the third quarter, a total of 3 of the 22 installed sensors recorded exceedances. In this quarter, the record value for the sensor was reported: "Ivan Vazov" - 2994.22 µg/m3, followed by zh.k. "Dragalevtsi" sensor with 1963.78 µg/m3 and the "James Boucher" metro station sensor with 470.05 µg/m3. In the fourth quarter of the year, only one exceedance was recorded for the sensor "Ivan Vazov" - 689.99 µg/m3. It is striking that when one of the sensors of the Sofia Municipality reports an exceedance of the norms, the values are significantly higher than what it usually reports and than what the sensors from the EEA have ever registered. For comparison, the highest value for ozone reported by the EEA was 281.74 µg/m3 (AMS Druzhba) over a period of 11 years, while the highest from the sensors of the AIRTHINGS project was 2994.22 µg/m3 (zh. k."Ivan Vazov"). The measurement unit for both sensors is micrograms per cubic meter.

Figures 199, 200, 201 and 202 show the quarters of 2021 that reported exceedances of ozone standards. During the January-March period, the sensor in the "Hristo Botev" district reported a value of 469.60 µg/m3. The second quarter was marked by exceedances for three of the sensors - Winter Palace of Sports, "Hristo Botev" quarter and "Vrajdebna" Polyclinic, respectively 416.43 µg/m3, 247.57 µg/m3 and 133.76 µg/m3. The July-September period reports a record value for the entire year 2021 - 1287.15 µg/m3 from "Nadezhda" sensor, followed by 241.99 µg/m3 for the Winter Palace of Sports and 196.44 µg/m3 for the "Hristo Botev" quarter. The last excess of the year was recorded by the sensor of the Winter Palace of Sports - 213.40 µg/m3.

Figure 203 shows the two excesses of the indicator for the year 2022. They were registered by the sensors in “Orlandovtsi” and “Studentski”, respectively 341.61 µg/m3 and 124.11 µg/m3.

Figure 204 presents the only ozone excess for the available data from the three quarters of 2023. The reported value is 220.81 µg/m3 from the sensor in zh. k. “Orlandovtsi”.

Fig. 196. Maximum ozone values for the first quarter of 2020.

4.7.2. PM2,5

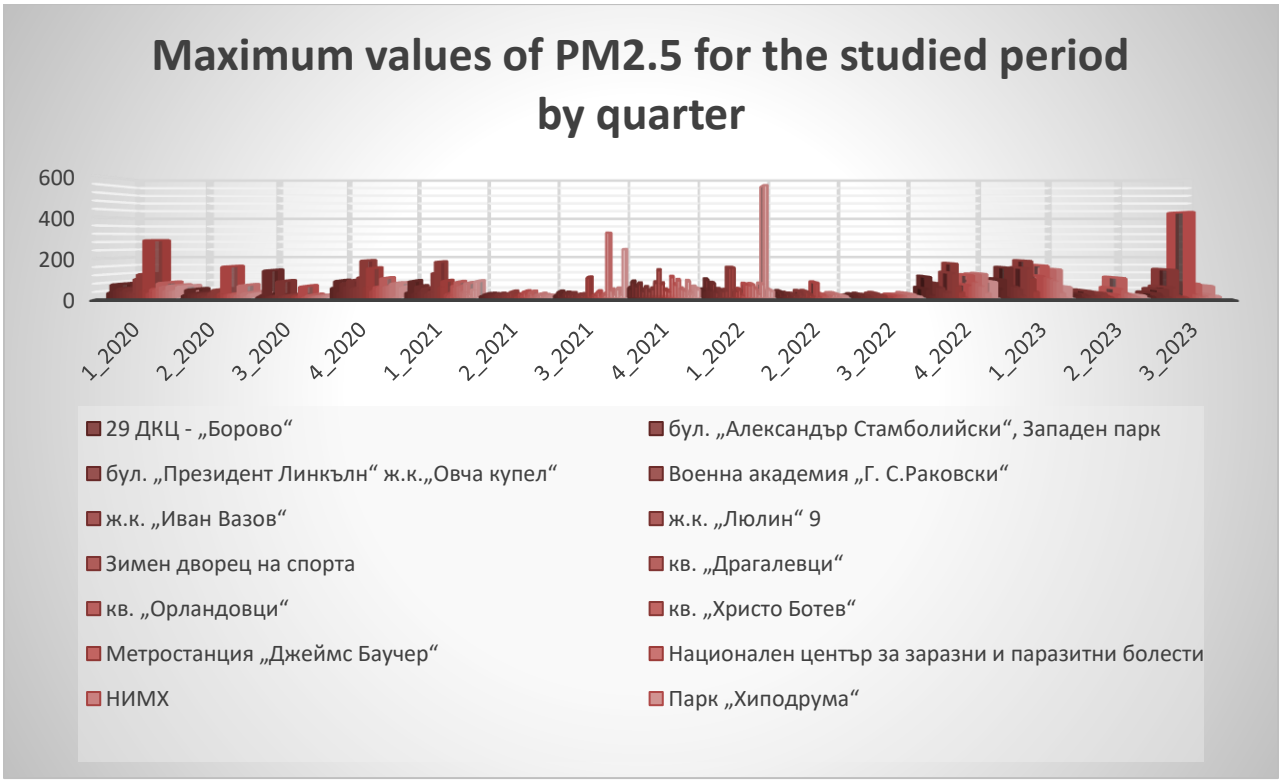


Fig. 205. Maximum values of PM2.5 for the studied period by quarter

The norm for the indicator has undergone some changes over the years - from 25 μg/m3 at the beginning of 2015, it decreased to 20 μg/m3 at the beginning of 2020. Figure 205 shows the maximum values for PM2.5 for the studied period (2020 - 2023). During the period, there is no quarter that did not register an excess of the norms. The data that the sensors of the project present are quite variable and hinder the tracking of a trend for the indicator. The highest measured value of the indicator equals 560.39 μg/m3 for the sensor in "Studentski", in the first quarter of 2022. This record excess is nearly thirty times above the established norms for PM2.5. It is also interesting to note the second record excess of the norm, which was measured during the warm half-year - 428.28 μg/m3 from the sensor in the Hippodrome park. Experience shows that such values are atypical for the summer months. For comparison, in the same quarter AMS Hippodrome (EEA) reports a value of 18.78 μg/m3, which is slightly above the norm of 20 μg/m3.

The use of 22 sensors to analyze the state of the indicator would greatly facilitate the tracking of its values. Making a comparative analysis between the data from the EEA and the AIRTHINGS project is almost impossible, since only two EEA sensors monitor the amount of PM2.5 in the air - AMS Kopitoto and AMS Hippodrome. However, a partial comparison can be made with the Hippodrome Park sensor responding to the Hippodrome AMS. Figure 206 presents a comparison of the data between the two sources - EEA and the project of the Sofia Municipality - AIRTHINGS, with the cells marked in red representing values exceeding the norms. A significant problem with the analysis attempt is the lack of data for the second, third and fourth quarters of 2020, as according to the quarterly state of the environment bulletins from the EEA, the sensor was not operational due to technical reasons. Accordingly, no excesses were registered for the three quarters. It is clear from the figure that the sensors of the Sofia Municipality register 12 exceedances for the sensor in question, while the data from the EEA point to only 7 exceedances of the maximum permissible norms. Again, the following trend can be observed - when the sensors of the Sofia Municipality report exceedances, they register significantly higher values than those of the Environmental Protection Agency, and in case they do not register any, their values are lower than those of the Agency. The most significant differences in the reported values for the two overlapping sensors were reported in the third quarter of 2023, with the difference between the two being just over 400 μg/m3. Such are observed in the fourth quarter of 2021, with the difference between the two again being significant – 71 μg/m3, as well as the first quarter of 2023, where the difference is just over 45 μg/m3. One of the few quarters with significantly close values measured by the sensors is the second quarter of 2022, during which both sensors did not report exceedances, and the

reported values equaled 8.31 μg/m3 for the sensor of the Sofia Municipality and 9, 89 μg/m3 for AMS Hippodrome.

Analyzing separately the sensors of the AIRTHINGS project, the following summary can be made, for the data available for 15 quarters, it is clear that in each of them an excess of the permissible norms for PM2.5 was reported. The most significant number of value exceedances are 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).

Figures 207, 208, 209 and 210 show the maximum reported values for PM2.5 for the calendar year 2020. In the first quarter, all sensors reported exceeding the norms, and their values ranged from 27.99 μg/m3 for the NIMH sensor to 288.44 μg/m3 for the sensor at the National Center for Infectious and Parasitic Diseases. For the second quarter, 15 out of a total of 22 sensors registered exceeding the norms, and the exceedances were within the range of 20.05 μg/m3 - 157.76 μg/m3, respectively for the sensor at the "Vrajdebna" polyclinic and for the sensor at NIMH. The sensors without reported exceedances for the period April-June are a total of 7 - 29 hospital - "Borovo", zh. k. "Ivan Vazov", Winter Palace of Sports, "Dragalevtsi", "James Boucher" metro station, RA "Nadezhda" and "Studentski" district. The July-September period reports only three exceedances of the norms for PM2.5, but they are significant - 138.19 μg/m3 (President Lincoln Blvd. Ovcha Kupel), 84.13 μg/m3 (Winter Palace of Sports) and 58.61 μg/m3 (Hippodrome Park). The fourth quarter of the year reported exceedances for 21 of the total 22 sensors, with only the sensor in the "Studentski" area reporting low values. The excesses for the others are in the range of 31.72 μg/m3 – 186.85 μg/m3.

Figures 211, 212, 213 and 214 visualize the maximum values for the indicator in 2021. Similar to the previous year, the winter months again had the maximum number of sensors exceeding the norms - the first quarter reported exceedances for 21 out of a total of 22 sensors (excluding Hippodrome Park), and the fourth quarter reported exceedances for all 22 sensors. Recorded data for the indicator range from 21.55 μg/m3 ("Studentski") to 180.45 μg/m3 (Hristo Botev quarter) for the first quarter of the year and within 32.16 μg/m3 ("Studentski") - 139.82 μg /m3 ("Hristo Botev"). The second and third quarters of the year were marked by four and eleven sensors with reported exceedances, respectively. In the period April-June, the sensors exceeded the norms: "Hristo Botev" - 30.35 μg/m3, NIMH - 21.30 μg/m3, Hippodrome Park - 31.71 μg/m3 and "Krasna Polyana" - 29.73 μg/m3. A strong impression is made by the third quarter of the year, which, in addition to reporting exceedances for 11 out of 22 sensors, also reported the highest exceedance of norms for the entire calendar year – 325.87 μg/m3 for the sensor in

the residential area. Hope. Such excesses of the norms are atypical for the warm half-year. One of the possible causes is a lack of sensor calibration.

Figures 215, 216, 217 and 218 show the maximum values for PM2.5 in the calendar year 2022. This is the year with the recorded record excess for the indicator - 560.39 μg/m3 for the sensor in the "Studentski" district, in the first quarter of 2022. This record excess is nearly thirty times above the established norms for PM2.5 and is quite atypical for the mentioned sensor, as the highest value reported by it is slightly above 60 μg/m3. During this quarter, 21 out of 22 sensors, excluding the sensor at NIMH, reported elevated values, ranging from 23 to 560 μg/m3. The second and third quarter recorded respectively 8 and 3 sensors with exceedances, and for the second quarter the limits of the exceedances were within the limits - a little over 21 μg/m3 to a little over 77 μg/m3, and in the third quarter they were between 21 and 23 μg/m3. The October-December period reports exceedances for 19 out of 22 sensors, with the exception of President Lincoln Blvd. Ovcha Kupel, NIMH and zh. k. Ovcha Kupel. The permissible values for the indicator were exceeded in the limits - 27 μg/m3 and 172 μg/m3.

Figures 219, 220 and 221 present the exceedances of norms in three of the four quarters of the year 2023, and at the time of preparation of the scientific paper, the data for the fourth quarter of the year is not yet available. The first quarter of the year registered exceedances for 18 of 22 sensors, with the exception of President Lincoln Blvd. "Ovcha Kupel", "Dragalevtsi", NIMH and "Ovcha Kupel", the others report excesses within 28 μg/m3 - 185 μg/m3. The second and third quarters reported exceedances in 9 sensors, with some of the sensors being different for different quarters. The period April-June registered exceeding the norms for - "Alexander Stamboliyski" Blvd., Zapaden Park - 20.91 μg/m3, Military Academy "G. S. Rakovski" - 20.59 μg/m3, zh. k. Lyulin 9 - 36.13 μg/m3, "Orlandovtsi" quarter - 24.93 μg/m3, "Hristo Botev" quarter - 27.05 μg/m3, Hippodrome Park - 21.04 μg/m3, Polyclinic "Vrajdebna" - 48.70 μg /m3, RA "Krasna Polyana" - 101.14 μg/m3, RA "Nadezhda" - 26.31 μg/m3. An interesting clarification is that in the third quarter of the year the sensor at the Hippodrome park reported a record value for the entire period under investigation - 428.28 μg/m3, while its maximum exceedance of the norms so far was slightly above 110 μg/m3 for the cold half-year. Such excesses are again atypical for the warm part of the year and may be due to an uncalibrated sensor.

The data processed by the sensors of the Sofia Municipality are extremely dynamic, unstable and difficult to carry out a qualitative analysis of the state of the PM2,5. They do not come close in value to the processed data from the EEA, and the lack of more than one sensor that overlaps with the municipality's sensors makes their comparison even more difficult.

AIRTHINGS	1_2020	2_2020	3_2020	4_2020	1_2021	2_2021	3_2021	4_2021	1_2022	2_2022	3_2022	4_2022	1_2023	2_2023	3_2023
Парк „Хиподрума“	48.06	20.35	58.61	56.38	18.50	31.72	31.34	105.96	69.79	8.31	14.25	66.94	111.23	21.05	428.29
ИАОС	1_2020	2_2020	3_2020	4_2020	1_2021	2_2021	3_2021	4_2021	1_2022	2_2022	3_2022	4_2022	1_2023	2_2023	3_2023
Хиподрума	93.75	0.00	0.00	0.00	31.57	19.02	14.89	35.00	22.01	9.89	22.88	56.36	65.29	17.41	18.78

Fig. 206. Differences in the values for PM2.5 between the two studied sources

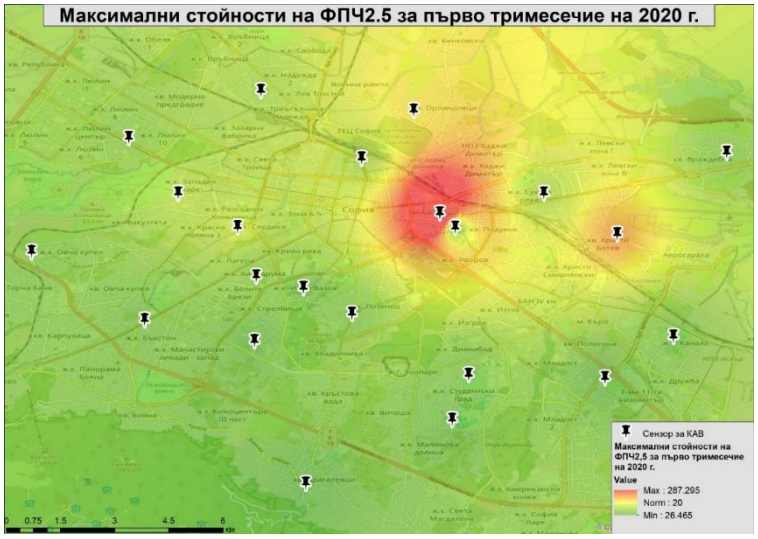


Fig. 207. Maximum values of PM2.5 for the first quarter of 2020.

4.7.3. PM10

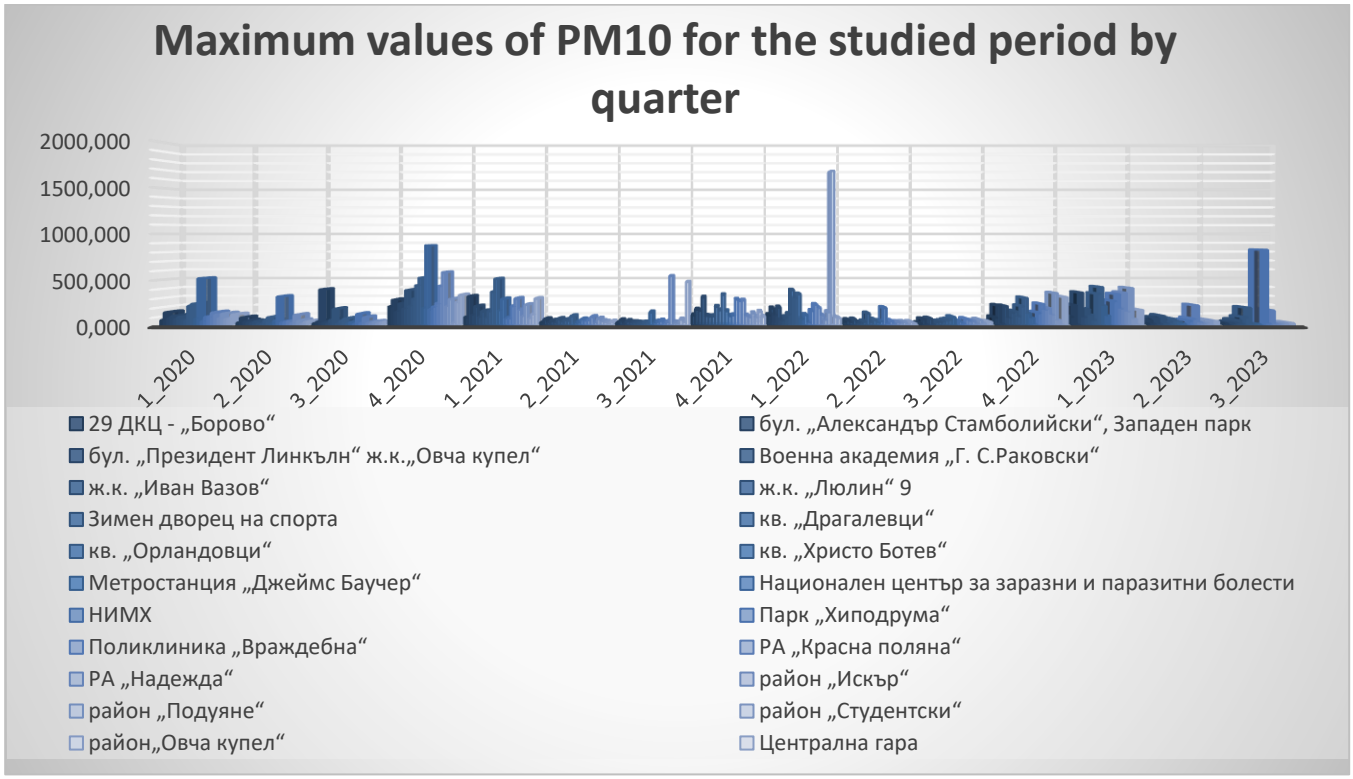


Fig. 222. Maximum values of PM10 for the studied period by quarter.

PM10 are undoubtedly one of the biggest air pollutants in recent years. They are one of the most important and significant indicators examining the state of the air. They are the most recorded exceedances for the last decade according to the EEA. The average day-night norm for the protection of human health is equal to 50 μg/m3, and it should not be exceeded more than 35 times within a calendar year, and the average annual norm for the protection of human health (for one calendar year) is 40 μg /m3. The research of the AIRTHINGS project data in the period 2020-2023 shows that there is not a single quarter during the research period for which an excess of the norms was not registered.

Figure 222 presents a graph with the maximum values of PM10 for the studied period by quarter. The data processed by the sensors of the Sofia Municipality are extremely dynamic, unstable and difficult to carry out a qualitative analysis of the state of the indicator. The use of 22 sensors to analyze the state of the indicator would greatly facilitate the tracking of its values. Making a comparative analysis between the EEA data and the AIRTHINGS project is considerably difficult because only four of the sensors overlap. However, a partial comparative analysis can be carried out for the Hippodrome sensor park corresponding to the Hippodrome AMS; zh. k. "Iskar", in charge of AMS Druzhba; "Ovcha Kupel" region, responsible for AMS Pavlovo and NIMH, responsible for AMS Mladost. Figure 223 shows a comparison of the data between the two sources - EEA and the project of the Sofia Municipality - AIRTHINGS, with the cells marked in red representing values exceeding the norms. In some of the quarters, the values reported by the two sources are relatively close, but nowhere do they match exactly. However, in most of the data presented in figure 218, there are record discrepancies in the values that cannot remain unnoticed. The most significant discrepancy in the values was recorded in the third quarter of 2023, with the sensor at the Hippodrome park and AMS Hippodrome reporting the following values: 827.04 μg/m3 for the first and 58.88 μg/m3 for the second. This is a difference of nearly 770 μg/m3, which is a record for the studied period. The next significant discrepancy is observed in the fourth quarter of 2021, where the same two sensors report a difference of about 200 μg/m3 - 285.1 μg/m3 for Hippodrome Park and 85.01 μg/m3 for AMS Hippodrome. Again, the following trend can be observed - when the sensors of the Sofia Municipality report exceedances, they register significantly higher values than those of the Environmental Protection Agency, and in case they do not register any, their values are lower than those of the Agency.

AIRTHINGS	1_2020	2_2020	3_2020	4_2020	1_2021	2_2021	3_2021	4_2021	1_2022	2_2022	3_2022	4_2022	1_2023	2_2023	3_2023
Парк „Хиподрума“	97.875	41.031	126.242	206.038	82.576	58.412	53.188	285.141	161.116	31.158	27.977	141.307	268.197	53.048	827.041
район „Искър“	87.556	115.918	30.330	219.044	110.785	74.735	33.215	93.208	66.988	35.326	27.876	122.130	156.204	27.119	20.851
район„Овча купел“	78.042	41.096	31.854	256.588	126.230	28.432	40.732	151.810	95.257	38.535	2.928	12.254	17.995	4.463	7.374
НИМХ	57.234	316.843	24.288	184.628	84.518	66.355	43.660	113.130	37.819	193.715	47.691	16.665	3.900	1.581	1.987
ИАОС	1_2020	2_2020	3_2020	4_2020	1_2021	2_2021	3_2021	4_2021	1_2022	2_2022	3_2022	4_2022	1_2023	2_2023	3_2023
Хиподрума	131.77	56.82	42.9	143.31	95.83	59.38	55.36	85.01	68.97	72.39	62.79	171.5	234.47	41.95	58.88
Дружба	82.55	48.97	36.86	85.62	48.17	35.14	50.46	54.3	77.9	42	38.93	107.63	73.99	24.25	35.77
Павлово	130.54	62.04	33.26	152.59	87.68	58.98	52.35	93.37	71.4	75.54	47.47	93.22	98.54	39.5	56
Младост	136.88	64.54	33.23	140.31	63.3	63.08	53.42	63.42	50.09	45.35	51.96	84.49	62.77	37.52	52.76

Fig. 223. Differences in the values for PM10 between the two studied sources.

Analyzing separately the sensors of the AIRTHINGS project, the following summary can be made, for the data available for 15 quarters, it is clear that in each of them an excess of the permissible norms for PM10 was reported. The most significant number of value exceedances are 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 for the period from 2020-2023 was reported in the first quarter of 2022 by the sensor in the "Studentski" district and is equal to 1686.32 µg/m3, which is slightly more than 30 times the excess of the norm of 50 µg/m3. No information is available from the Sofia Municipality explaining such record value overruns. 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 µg/m3 and in the third quarter of 2023 by the Hippodrome Park - 827.04 µg/m3. Again, no data is available to explain such excesses of the norms.

Figures 224, 225, 226 and 227 present the maximum values of PM10 for the calendar year 2020. In the first quarter, all of the installed sensors exceeded the permissible norms for the indicator, with the reported values ranging from 57.23 µg/m3 for NIMH to the third highest for the entire year - 516.170 µg/m3 for 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/m3, "Iskar" district with 115.91 µg/m3, "Hristo Botev" quarter with 90.64 µg/m3, "Alexander Stamboliyski" blvd., Zapaden Park with 88.08 µg/m3, "Orlandovtsi" district with 56.08 µg/m3, National Center for Infectious and Parasitic Diseases with 55.65 µg/m3, "Poduyane" district with 55.44 µg/m3, "President Lincoln" blvd., zh.k. "Ovcha Kupel" with 52.84 µg/m3. In the third quarter, there were exceedances for 7 out of 22 sensors, ranging from 51.92 µg/m3 for "Orlandovtsi" quarter to 394.43 µg/m3 for "President Lincoln" Blvd. "Ovcha Kupel". Again, significant shifts in norms are observed during the warm half-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 "Student" 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/m3. High values were recorded by many of the other sensors: "Nadezhda" RA - 581.77 μg/m3, "Hristo Botev" quarter - 520.53 μg/m3, "Orlandovtsi" quarter - 438.52 μg/m3, "Krasna Polyana" RA - 434.16 μg/m3, g.k. "Lyulin" 9 - 385.34 μg/m3, Central Station - 333.40 μg/m3, "Dragalevtsi" district - 291.05 μg/m3, "Poduyane" district - 287.92 μg/m3, "Alexander Stamboliyski" Blvd., Zapaden Park - 280.22 μg/m3 and others.

Figures 228, 229, 230 and 231 present the reported maximum values of the indicator for 2021. As in the previous year, the increases were mainly in the first and fourth quarters of the year. During the period January-March, all 22 sensors reported exceeding the norms, with the excesses being within the limits - 82.57 μg/m3 for the "Hippodrome" park - 510.50 μg/m3 for the "Hristo Botev" quarter. The fourth quarter of the year also reported exceedances for the 22 sensors of the Sofia Municipality. The highest recorded value is again from the sensor in the "Hristo Botev" quarter - 335.76 μg/m3, and the lowest this time from the "Studentski" district - 91.88 μg/m3. The April-June period recorded exceedances of the norms for 11 out of a total of 22 sensors - "Hristo Botev" district - 102.82 μg/m3, RA "Krasna Polyana" - 93.75 μg/m3, "Iskar" district - 74.73 μg/m3, zh. k. "Lyulin" 9 - 72.5 μg/m3, "Alexander Stamboliyski" Blvd., Zapaden Park - 69.58 μg/m3, NIMH - 66.35 μg/m3, Polyclinic "Vrazhdebna" - 60.88 μg/m3, "Dragalevtsi" quarter - 60.77 μg /m3, "Hippodrome" Park - 58.41 μg/m3, "Orlandovtsi" quarter - 54.67 μg/m3 and Military Academy "G. S. Rakovski" - 52.35 μg/m3. For the July-September period, only 6 exceedances of the PM10 indicator were reported, but some of them are significant and atypical for the summer months: RA "Nadezhda" - 540.66 μg/m3, Central Station - 476.25 μg/m3, metro station "James Boucher" - 144.52 μg/m3.

Figures 232, 233, 234 and 235 visualize the maximum values for PM10 for the year 2022. This is the year with the recorded record excess for the entire period - 1686.32 μg/m3 in the "Studentski" district, which is a little more than 30 times above the established norms. The exceedance was recorded in the first quarter of the year and was followed by another 20 sensors with exceedances, in the range of 63.98 μg/m3 to 387.91 μg/m3, 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/m3 to 193.71 μg/m3, for July-September - 51.77 μg/m3 to 92.51 μg/m3. 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 the "Poduyane" area with 354.07 μg/m3, the Central Station with 310.15 μg/m3, quarter " Hristo Botev" with 301.31 μg/m3 and others.

Figures 236, 237 and 238 present the maximum reported values for PM10 in the three quarters for which data are available for 2023. During the January-March period, 19 out of a total of 22 sensors reported excesses in the values of the indicator, with the exception of the "Ovcha Kupel" area, "President Lincoln" Blvd., "Ovcha Kupel" residential complex and NIMH. The highest values were recorded by the sensor in the "Hristo Botev" district - 419.25 μg/m3, followed by the sensors in the "Poduyane" area - 409.04 μg/m3, Military Academy "G. S. Rakovski" - 359.36 μg/m3, RA "Nadezhda" - 359.22 μg/m3, quarter "Orlandovtsi" - 348.84 μg/m3, Polyclinic "Vrazhdebna" - 342.28 μg/m3, Park "Hippodrome" - 268.20 μg/m3, "Alexander Stamboliyski" Blvd., Zapaden Park - 222.86 μg/m3, "James Boucher" metro station - 216.31 μg/m3, RA "Krasna Polyana" - 187.58 μg/m3, g.k. "Lyulin" 9 - 179.85 μg/m3, Central Station - 170.07 μg/m3, "Iskar" district - 156.20 μg/m3, Winter Palace of Sports - 119.02 μg/m3, National Center for Infectious Diseases and parasitic diseases - 109.44 μg/m3, 29th hospital "Borovo" - 98.89 μg/m3, g.k. "Ivan Vazov" - 96.26 μg/m3, "Studentski" district - 73.83 μg/m3 and "Dragalevtsi" district - 63.78 μg/m3. The excesses of the permissible norms are significant, but not only the excesses make an impression, but also the significantly low values of three of the sensors that do not report excesses - "Ovcha Kupel" area -17.99 μg/m3, "President Lincoln" blvd. k. "Ovcha Kupel" - 14.56 μg/m3, NIMH - 3.89 μg/m3. 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 are not at all low for the warm half-year - RA "Krasna Polyana" recorded 220.14 μg/m3, g.k. "Lyulin" 9 - 104.94 μg/m3, Military Academy "G. S. Rakovski" - 82.46 μg/m3. In the third quarter, the third highest value for the entire investigated period was recorded - 827.04 μg/m3 from the sensor in the "Hippodrome" park.

As with the data processed by the sensors of the Sofia Municipality for the indicator ФРЧ2.5, so for ФРЧ10, they are extremely dynamic, unstable and difficult to carry out a qualitative analysis of the status of the indicator. They do not come close in value to the processed EEA data, as can be seen in Figure 218.

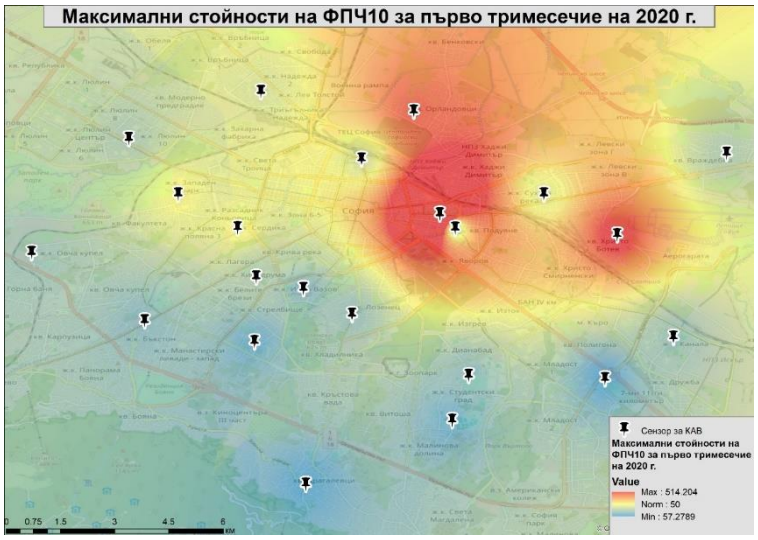


Fig. 224. Maximum values of PM10 for the first quarter of 2020.

4.8. Interactive map

An interactive map was created for the purposes of the scientific work and, more specifically, tracking the state of the air quality in the city of Sofia, as well as the possibility that every user has access to the research, and the data generated and processed in a GIS environment. This was done through the ArcGIS Online cloud-based mapping and analytics tool, through which organizations and individual users can create interactive maps and applications and share them with other organizations/users/public groups, etc.

All data from the quarterly bulletins on the state of the environment of the Environmental Protection Agency, as well as the data requested by the Sofia Municipality and downloaded from the AirThings platform are available in the interactive map (Fig. 239).

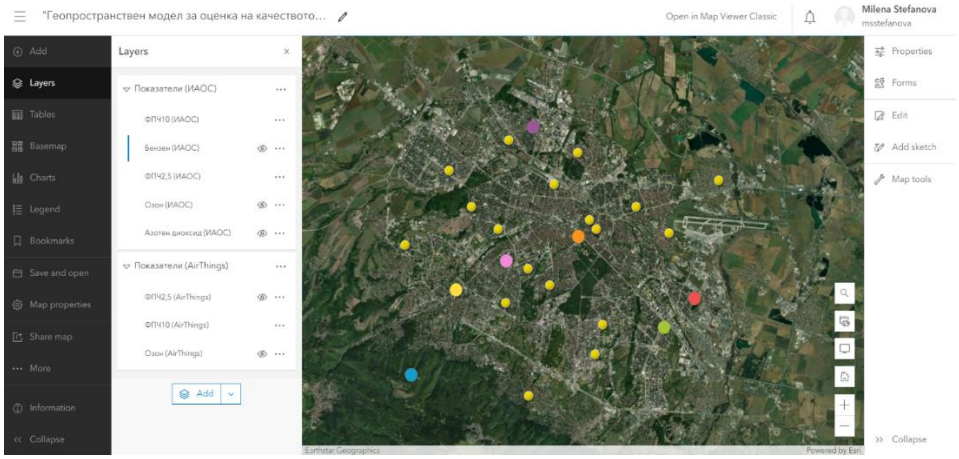


Fig. 239. Interactive map "Geospatial model for assessment of atmospheric air quality in the city of Sofia"

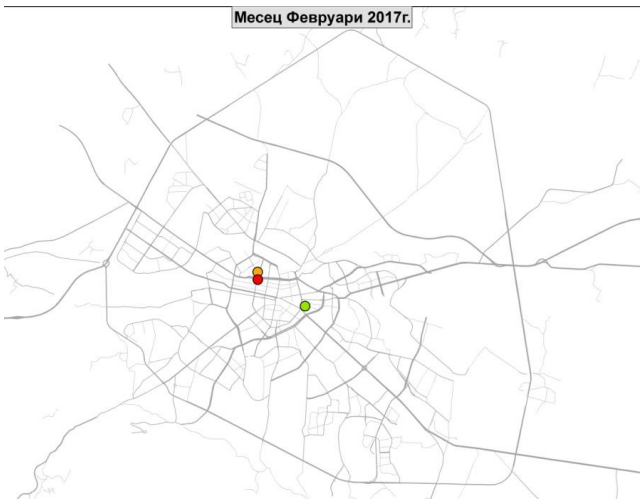
All generated and processed data can be viewed, downloaded and used via the following link::
https://www.arcgis.com/apps/mapviewer/index.html?webmap=cbfa95910f5e45c0b648c56309475a08&fbclid=IwAR039f1rUnzUGAM82gC9oiOimJlyDSJ-1avBF0iIGVORJntalc3lLskxL54 ,
or through the created QR code for better operability:

4.9. Potential sources of air quality data

4.9.1. Luftdaten project

The Luftdaten project, launched in Stuttgart, Germany, aims to draw attention to the problems of air quality in cities and the lack of sustainable measures by the authorities. The project now operates in 26 countries, including Bulgaria since 2017, using an online platform to visualize sensor data for fine particulate matter and atmospheric conditions. In Bulgaria, the platform is called Air Tube and includes over 750 sensors, more than half of which are in Sofia. The system has several advantages, such as the low prices of the sensors and the possibility of participation by the general public without specialized assistance. Disadvantages include the uneven distribution and height of sensor placement, which can lead to inadequate data. And although the results of the sensors do not correspond to the professional stations, they are considered a useful source of operational information about the air quality of the city.

The data that these sensors report are not used in the scientific work, as they do not comply with the regulations. However, they are a source that provides operational information and has a very good density over the city's territory.



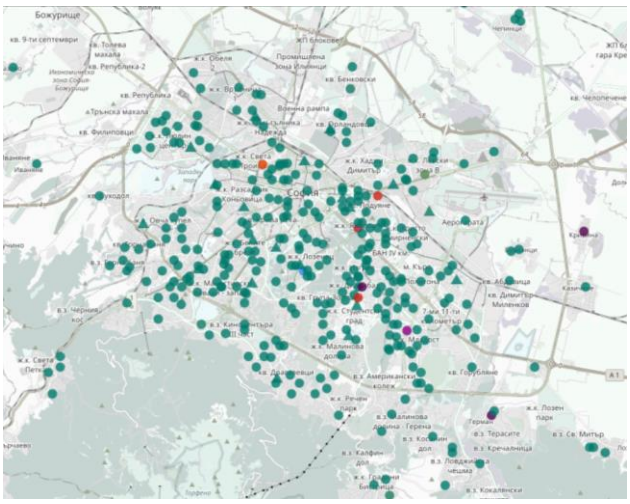


Fig. 240. Air Tube sensors in February 2017 (left)

Fig. 241. AirTube sensors in the month of December 2023 (Source: airtube.info)

4.9.2. Project of the National University Center for Geospatial Research and Technology (NUCGRT) and the Sofia Municipality

At the beginning of 2023, the National University Center for Geospatial Research and Technologies (NUCGRT) at Sofia University "St. Kliment Ohridski" begins the implementation of a project related to regular monitoring of atmospheric air quality in the city of Sofia. The project is implemented jointly with the Municipality of Sofia and lasts 12 months. For this purpose, a professional calibrated multisensor installed on an unmanned aerial system (UAS) was used.

Figures 237 and 238 present the data for the two indicators - PM2.5 and PM10 for collected on February 16, 2023. For both indicators, significant excesses of the established norms were registered, respectively 20 µg/m3 for PM2.5 and 50 µg/m3 for PM10. It can be clearly observed that the values of PM2.5 exceed the permissible values several times, and they range from about 165 to about 210 µg/m3, which is nearly ten times above the norm. The situation for PM10 is not very different, the norms are exceeded several times, within about 185 to about 260 µg/m3. In the images captured by the UAS, light traffic is observed, despite the reported high values. Therefore, with more intense and active rush-hour traffic, the rate exceedances should be even higher.

Figures 239 and 240 visualize values for both indicators measured on April 7, 2023. On both maps, significantly lower values can be observed compared to the previous two. During the warm half-year, exceedances of the norms exist again, but they are within about 55-70 µg/m3 for PM2.5 and about 55-75 µg/m3 for PM10. Traffic is again not heavy.

Figures 241 and 242 show values for the same indicators measured on August 15, 2023. An excess was reported only for PM2.5 – slightly above 25 μg/m3. No excess of norms was reported for PM10.

Figures 245 and 246 present the maximum reported values for both indicators. Excesses were reported for both PM2.5 and PM10. PM2.5 register excesses in the range of 58-123 μg/m3. While PM10 exceeds the norms in the range of around 62-135 μg/m3.

Unmanned aerial systems are an innovative way to monitor air pollution, through which the state of the air can be monitored in real time, in areas with significant prerequisites for the deterioration of air pollution, in areas with critical infrastructure. They are one of the solutions for tracking areas with local specifics of pollution that cannot be valid for the entire city.

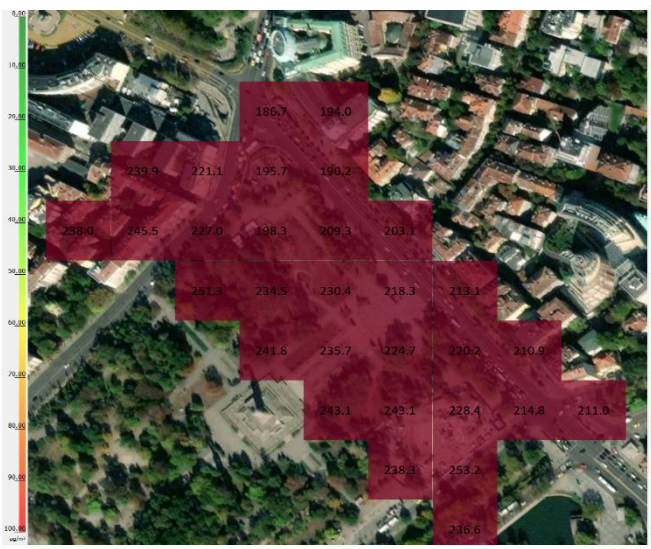


Fig. 243. Values of PM10, measured in the area of Sofia University on 16.02.2023 (Source: NUCGRT) (left)

Fig. 245. Values of PM10, measured in the area of Sofia University on 04/07/2023 (Source: NUCGRT) (right)

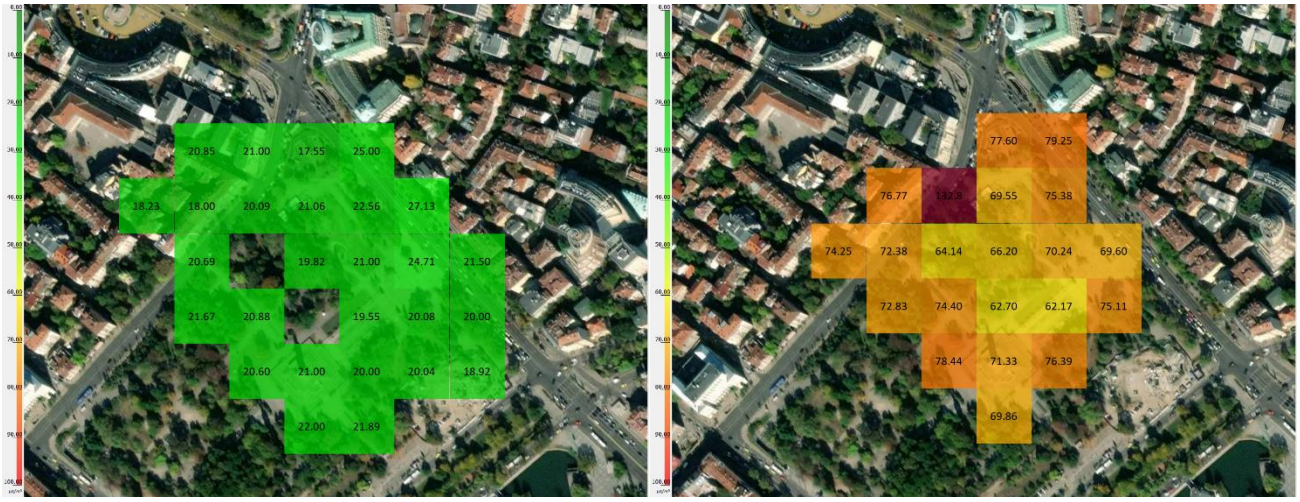


Fig. 247. Values of PM10, measured in the area of Sofia University on 15.08.2023 (Source: NUCGRT) (right)

Fig. 249. Values of PM10, measured in the area of Sofia University on 21.11.2023 (Source: NUCGRT) (right)

5. CONCLUSION

Atmospheric air pollution is one of the major global problems of an extremely large scale that requires the adoption of far-reaching measures. Building a network of sensors to monitor air pollution and locate polluted areas is one of the main measures that countries internationally must take. In this way, accurate and timely information will be provided, according to which specific measures can be taken at local, regional, national and international levels to deal with the situation. The problem of air quality is very much geographically determined. Especially for Sofia, this is a problem that is partly due to the natural geography, given the fact that the capital is located in a hollow.

At the moment, the official sensors of the EEA, the sensors of the AirThings project of the Sofia Municipality, reporting data on the quality of atmospheric air, are functioning on the territory of the country. The uneven coverage of the sensors to the EEA throughout the country, including the capital, as well as the dynamic and inconsistent data from the sensors to AirThings, make analyzing the air quality extremely difficult. According to the Sofia Municipality, the data from the sensors of the AirThings project 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. On the other hand, the limited number of automatic measuring stations of the Agency hinders the implementation of detailed analyzes and studies, because despite the small number of sensors that have been placed, some of them do not report and do

not collect data on some of the studied air pollutants. The sensors provided by the EEA are considered reliable information on the quality of atmospheric air, but there is a need to build a significant number of new devices to cover the territory not only of the capital, but also of the entire country, this in turn would lead to more adequate, successful and detailed analyzes and studies of this problem, namely - atmospheric air pollution. The available information on emissions by pollution sources is not detailed enough and even more data is needed to be able to carry out sufficiently well-founded analyzes on the basis of which the correct and most effective measures can be taken to lead to improvement of the air condition in Sofia. The biggest drawback of the data is perhaps its lack of spatial dimension, i.e. the possibility to associate different territories in the city with different types of pollutants and degrees of pollution. The available data, on the one hand, can be used to take measures that will give some result, but on the other hand, the lack of sufficient specific information can still doom the measures to failure or low efficiency.

The AirTube platform, which has been operating in the country since 2017, also provides air quality data, but they are not official, do not comply with the regulations and cannot be considered completely reliable. This, in turn, makes their use difficult and practically inapplicable, despite the large range of operational information they present. Air quality can only be properly measured by a network of sensors that provide adequate coverage.

In connection with domestic heating and transport in the capital without data on the actual condition of the cars during the annual technical inspections - presence of catalysts and particulate filters, engine condition, etc.; traffic pattern in Sofia by months, days and hours; type of cars in the neighborhoods and others, there is no way to take the most effective measures to reduce pollution from transport. Accordingly, without data on the homes that are heated with solid and liquid fuels; fuel quality; the spatial distribution of all types of heating sources by neighborhood, etc. there is no way to predict the most effective measures to reduce emissions from domestic heating. Without data on the other sources of pollution, which are most often neglected, there is also no way to establish the real pollution from transport and domestic heating. Unregulated waste burning is a source of pollution about which extremely little is known.

Within the framework of the dissertation, the stated tasks and purpose were fulfilled. In order to achieve the main goal, namely the implementation of a geospatial model for the evaluation of the air quality in the city of Sofia, the specified tasks were completed. For the purposes of the research, an in-depth analysis of the regulatory framework was made, a large volume of regulatory documents were examined - directives of the European Union, laws, strategic documents, regulations, programs, etc. As

they are an extremely important basis for the implementation of the subsequent analysis. The procedures for the preparation of the GIS database, which are the basis for the implementation of the geospatial model for the evaluation of the air quality, were described. The geospatial analysis and the comparative analysis between the data from two sources were also carried out, which were subsequently used to create an interactive map in ArcGIS Online. Two additional sources of information that could be used in analyzes were also provided, describing the opportunities and obstacles to this happening.

On a larger scale, ambient air quality for Sofia has improved significantly, and has continued to improve over the last ten years or more. When comparing the indicators from 10 years ago and more, about 30-40% decrease in norms is clearly observed, which shows a positive trend. Nevertheless, it is necessary for the municipality to undertake more and more "green" measures to continue the positive trend of recent years. The air problem in Sofia needs not only to ensure the financial effectiveness of the measures in relation to it, but also to find ways to solve it as quickly as possible. It is necessary to realize that we all coexist together in this city and the daily decisions of each of us affect everyone, including ourselves.

CONTRIBUTIONS:

1. For the purposes of the scientific work, an in-depth analysis and review of the regulatory framework regulating the processes for monitoring the quality of atmospheric air was carried out. The most significant directives of the European Union, laws, regulations, strategies and programs, without which it would not be possible to establish certain norms and frameworks for the AQ, are examined.

2. A specialized GIS database was created, for the purposes of which two main sources were used: the Environmental Executive Agency and the project of the Sofia Municipality "AirThings". The data has been thoroughly examined and analyzed for the purposes of the study.

3. A detailed geospatial analysis of the two available sources: EEA and the "AirThings" project, and more precisely of the indicators they study, namely - benzene, ozone, nitrogen dioxide, PM2.5 and PM10, was carried out. The analysis was carried out using the created GIS database.

4. On the basis of the created GIS database, a comparative analysis was carried out between the two available sources. For this purpose, data from the Sofia Municipality project were equated by quarter, similar to the EEA quarters.

5. For the purposes of the scientific work, other potential sources of information that could be used to study the state of the air in the city and the country were studied and presented.

List of publications related to the topic of the dissertation:

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