Czech University of Life Sciences Prague

Faculty of Economics and Management

Department of Information Engineering

Bachelor Thesis

Comparative analysis of GIS tools and data for the geographic distribution of Air Pollution: a case study

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Faculty of Economics and Management

BACHELOR THESIS ASSIGNMENT

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Informatics

Thesis title

Comparative analysis of GIS tools and data for the geographic distribution of Air Pollution: a case study

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Objectives of thesis

The main goal is to research, evaluate, and compare the capabilities of available GIS platforms, tools, and datasets that are used for air pollution analysis. The technical aspects, such as data integration, performance, ease of use, and extensibility, will be key. Another objective of the research is the case study of the geographic distribution of air pollution in the Czech Republic, focusing on major emission sources (e.g., industrial zones, traffic congestion) and the areas most affected by poor air quality. The case study will be used as a practical example for GIS tools comparison. The results of the case study will be provided through the application that shows interactive layers for air pollution data across different regions and allows users to toggle between these layers.

Methodology

The first phase focuses on selecting multiple GIS tools for comparison to perform the data analysis and application building. Then we summarize the strengths and weaknesses of each tool in terms of usability, performance, and applicability to air quality analysis.

The next step is the analysis of the geographic distribution of air pollution, focusing on emission sources and impact zones. The collection of data includes historical and real-time air quality data. The primary sources of data are open-source air quality databases, satellite data, government and other public resources.

Developing an application that visualizes real-time or historical air pollution data across selected regions using tools which perform best in terms of ease of use, performance, and extensibility. An outcome includes the clear understanding of which tool set is most suitable for your specific needs and shows the critical areas where air pollution poses the greatest threat to public health, which can be used for potentially guiding policymakers in mitigation strategies.

The proposed extent of the thesis

30-40

Keywords

GIS, Interactive mapping, Dynamic layers, ArcGIS, Air pollution, Emission sources, Impact zones

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Recommended information sources

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Expected date of thesis defence

2024/25 SS – PEF

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Electronic approval: 04. 11. 2024

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Prague on 10. 02. 2025

Declaration

I declare that I have worked on my bachelor thesis titled "Comparative analysis of GIS tools and data for the geographic distribution of Air Pollution: a case study" by myself and I have used only the sources mentioned at the end of the thesis. As the author of the bachelor thesis, I declare that the thesis does not break any copyrights.

In Prague on 15.03.2025 ______________________________

Acknowledgement

I would like to thank Ing. Jakub Konopásek, Ph. D. and all other persons, for their advice and support during my work on this thesis.

Comparative analysis of GIS tools and data for the geographic distribution of Air Pollution: a case study

Abstract

This bachelor thesis explores the functions of different GIS tools and examines air pollution in the Czech Republic using them.

The theoretical part provides an overview of selected GIS technologies, including ArcGIS, QGIS, and Google Earth Engine (GEE), and then summarises their capabilities for spatial analysis. It also discusses air pollutants, their sources, and their impact on human health. It also covers an analysis of various data sources, including satellite imagery, ground-based monitoring stations, and the best use cases for this data.

In the practical part, air quality data was collected, analyzed, and mapped using ArcGIS Pro, ArcGIS Online, ArcGIS Insights, and ArcGIS StoryMaps, which were selected after tools comparison. The results include an interactive web application that presents key findings through maps, interactive histograms, and visualizations. The chosen tools from ArcGIS provided accurate analysis and effective data presentation.

This study also demonstrates how GIS can support environmental monitoring related to air quality management. The findings may be helpful for policymakers and researchers in improving air quality management.

Keywords: GIS, Interactive mapping, Dynamic layers, ArcGIS, Air pollution, Emission sources, Impact zones

Srovnávací analýza GIS nástrojů a dat pro geografické rozložení znečištění ovzduší: případová studie

Abstrakt

Tato bakalářská práce se zabývá funkcemi různých nástrojů GIS a zkoumá pomocí nich znečištění ovzduší v České republice.

Teoretická část poskytuje přehled vybraných technologií GIS, včetně ArcGIS, QGIS a Google Earth Engine (GEE), a poté shrnuje jejich možnosti pro prostorovou analýzu. Dále se zabývá látkami znečišťujícími ovzduší, jejich zdroji a jejich vlivem na lidské zdraví. Zahrnuje také analýzu různých zdrojů dat, včetně satelitních snímků, pozemních monitorovacích stanic a nejlepších případů využití těchto dat.

V praktické části byla data o kvalitě ovzduší shromážděna, analyzována a zmapována pomocí aplikací ArcGIS Pro, ArcGIS Online, ArcGIS Insights a ArcGIS StoryMaps, které byly vybrány po porovnání nástrojů. Součástí výsledků je interaktivní webová aplikace, která prezentuje klíčová zjištění prostřednictvím map, interaktivních histogramů a vizualizací. Vybrané nástroje od společnosti ArcGIS poskytly přesnou analýzu a efektivní prezentaci dat.

Tato studie také ukazuje, jak může GIS podporovat monitorování životního prostředí související s řízením kvality ovzduší. Zjištění mohou být užitečná pro tvůrce politik a výzkumné pracovníky při zlepšování řízení kvality ovzduší.

Klíčová slova: GIS, Interaktivní mapování, Dynamické vrstvy, ArcGIS, Znečištění ovzduší, Zdroje emisí, Dopadové zóny

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1. Introduction

We are lucky to live in today's digital world. Data and its analysis are becoming very important and useful for assessing and predicting many things and events. Based on these facts, geospatial data analysis and cartography play a huge role in different disciplines, such as urban planning, environmental monitoring, and health care. Together with the technology growth, the demand for accurate, real-time geospatial data is also increasing, making an impact on industries such as climate research, smart cities, transport, and epidemiology.

However, together with technological advancements and urbanization, emissions have also increased, making air pollution a major environmental and public health challenge, particularly in many European countries. Industrial activities, transportation, and energy production play a key role in the rising levels of pollutants such as particulate matter ($PM_{2.5}$, PM_{10}), nitrogen dioxide (NO_2), and ground-level ozone (O_3) (WHO, 2021). Many European cities exceed air quality limits set by the World Health Organization (WHO) and the European Environment Agency (EEA), which may lead to problems with environment, agriculture, and people’s health. As air pollution continues to get worse, monitoring and analysis of its impact have become more important than ever. Based on that, the GIS technologies may play a huge role in the future, as they also help to predict trends.

In the theoretical part of this study, different GIS tools and datasets will be overviewed and later compared based on different parameters. For GIS tools, it includes usability, system requirements, data integration capabilities, spatial analysis, and visualization tools. Datasets will be evaluated based on parameters such as data source (satellite imagery, ground-based stations, or modeled data), spatial and temporal resolution, accuracy, coverage, availability, and compatibility with GIS platforms.

The best-performing software and datasets will then be used in the practical part to analyze air pollution across the Czech Republic and develop an interactive GIS-based web application, showing distribution via interactive mapping and graphs.

2. Objectives and Methodology

2.1 Objectives

The main goal is to research, evaluate, and compare the capabilities of available GIS platforms, tools, and datasets that are used for air pollution analysis. The technical aspects, such as data integration, performance, ease of use, and extensibility, will be key. Another objective of the research is the case study of the geographic distribution of air pollution in the Czech Republic, focusing on major emission sources (e.g., industrial zones, traffic congestion) and the areas most affected by poor air quality. The case study will be used as a practical example for GIS tools comparison. The results of the case study will be provided through the application that shows interactive layers for air pollution data across different regions and allows users to toggle between these layers.

2.2 Methodology

The first phase focuses on selecting multiple GIS tools for comparison to perform the data analysis and application building. Then we summarize the strengths and weaknesses of each tool in terms of usability, performance, and applicability to air quality analysis.

The next step is the analysis of the geographic distribution of air pollution, focusing on emission sources and impact zones. The collection of data includes historical and real-time air quality data. The primary sources of data are open-source air quality databases, satellite data, government and other public resources.

Developing an application that visualizes real-time or historical air pollution data across selected regions using tools which perform best in terms of ease of use, performance, and extensibility. An outcome includes the clear understanding of which tool set is most suitable for your specific needs and shows the critical areas where air pollution poses the greatest threat to public health, which can be used for potentially guiding policymakers in mitigation strategies.

3. Literature Review

3.1 Introduction to GIS and its applications

3.1.1 Definition of geographic information systems (GIS).

According to Esri, a leading GIS software provider, GIS is a technology that is used to create, manage, analyze, and map all types of data. GIS connects data to a map, integrating location data (where things are) with all types of descriptive information (what things are like there). This provides a foundation for mapping and analysis that is used in science and almost every industry. The benefits include improved communication, efficiency, management, and decision-making (Esri, 2025).

Geographic Information Systems (GIS) is now more important than ever. Nowadays, these tools are becoming essential for analyzing, managing, and visualizing spatial data across various disciplines. A GIS is a system designed to capture, store, manipulate, analyze, manage, and present geographic data (Bolstad, 2016). Unlike traditional mapping techniques, GIS integrates multiple data sources. It makes spatial analysis with data-driven decision-making possible.

However, GIS is not only about mapping. ArcGIS Online, for instance, enables users to create, share, and analyze spatial data in a cloud-based environment, facilitating collaboration and access to a vast repository of geographic information (Esri, 2025). One of the key advantages of GIS is its ability to integrate spatial and non-spatial data from various sources such as satellite imagery, census data, GPS, and real-time sensor networks (Bolstad, 2016). This integration allows for in-depth analyses based on more than one factor and allows for conclusions and predictions that are valuable for both research and decision-making. With the development of cloud computing and spatial analytics based on artificial intelligence, GIS is transforming into a more dynamic and interactive tool for real-time monitoring and policy planning.

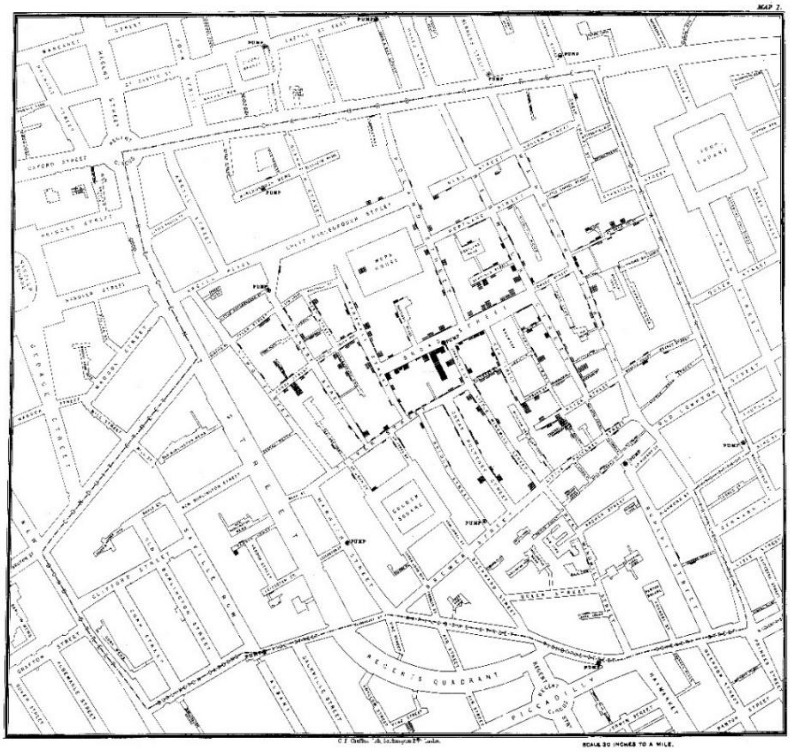
GIS technology is widely used in urban planning, environmental management, transportation, disaster response, and public health (Burrough & McDonnell, 1998). For example, in urban planning, GIS helps city authorities analyze land and build schemes for future infrastructure construction. In environmental management, GIS plays an important role in monitoring deforestation, managing water resources, and analyzing air pollution. In healthcare, GIS is used to map disease outbreaks or epidemics, analyze the availability of healthcare, and identify public health risks.

3.1.2 Evolution of GIS technologies and its use

The roots of cartography and mapping go back a long way. The first maps, which were created hundreds and thousands of years ago, were used for exploration, strategizing, and planning. As population grew, there was a huge need for a more advanced method of mapping and analyzing geographic information, something that traditional maps could not effectively show.

One of the earliest instances of spatial analysis occurred in 1854 during the cholera outbreak in London, where physician John Snow mapped the locations of cholera cases (Picture 1).

Picture 1. John Snow's original map showing the outbreak of cholera against the location of the water pumps.



Source: https://en.wikipedia.org/wiki/File:Snow-cholera-map-1.jpg

By overlaying the cases on a street map, he identified a contaminated water pump as the source of the outbreak, leading to one of the first recorded uses of spatial analysis for public health (McLeod, 2013). This work proved that geographic data with proper analysis could show hidden relationships and drive decision-making in critical situations.

The formal development of GIS began in the 1960s, when machines allowed scientists to analyze spatial data digitally. The first true GIS, the Canada Geographic Information System (CGIS), was developed in 1963 by Roger Tomlinson, often referred to as the "father of GIS" (Esri, 2025). CGIS introduced the ability to store and process large amounts of geographic data in a digital format, allowing for more advanced analysis than traditional paper maps. This system was used primarily for land use management and resource planning in Canada (GISGeography, 2023).

In the 1970s and 1980s, GIS developed further with vector and raster data models, which allowed spatial features to be stored as points, lines, and polygons. In 1982, Esri released Arc/INFO, one of the first commercial GIS software applications, marking the beginning of GIS adoption beyond government and academic institutions (USC GIS Graduate Programs, 2025). However, due to its complexity and high cost, GIS was still primarily used by specialists.

The 1990s saw a revolution in GIS technology with the introduction of graphical user interfaces (GUIs) that made GIS tools more accessible to other users. The launch of ArcView GIS in 1991 provided a user-friendly interface that made interaction with spatial data possible for non-specialists. During this period, global positioning system (GPS) technology became widely available, which improved the accuracy of geospatial data collection (Steenson, 2019.). In addition, satellite remote sensing and LiDAR technologies were developing, which also created new opportunities for data collection.

Internet-based GIS launched in the early 2000s, which gave users access to geospatial data online. Google Earth, launched in 2005, played a key role in popularizing GIS and made satellite imagery publicly available. Open-source GIS platforms such as QGIS have also become available, offering an alternative to commercial GIS software.

During the last decade, GIS has grown into a cloud-based, artificial intelligence-driven, real-time technology. Cloud-based GIS platforms such as ArcGIS Online and Google Earth Engine allow users to analyze vast amounts of geospatial data without requiring powerful local hardware (Esri, 2025). The recent developments in artificial intelligence (AI) and machine learning (ML) have completely revolutionized GIS applications. AI-based GIS tools can now identify patterns, automate spatial analysis, and improve predictive modeling for applications such as climate change assessment and disaster response (USC GIS Graduate Programs, 2025). Real-time GIS using IoT (Internet of Things) sensors is being used to develop smart cities, traffic management, and environmental monitoring (Steenson, 2019). In smart cities, GIS integrates real-time IoT data from air quality sensors to optimize traffic management and reduce vehicle emissions, improving urban air quality (Zhang et al., 2021). GIS has come a long way, evolving from simple paper maps to powerful AI-driven, cloud-based tools. Today, it’s more than just mapping—it’s a vital tool for urban planning, environmental monitoring, and disaster response. With AI, machine learning, and IoT, GIS now provides real-time insights, helping cities manage traffic, track pollution, and respond to emergencies more efficiently. As technology keeps advancing, GIS will play an even bigger role in tackling global challenges like climate change and sustainability, making it an essential tool for smarter decision-making in the future.

3.1.3 Overview of GIS applications in environmental science, specifically for air pollution analysis

GIS is widely used to collect, analyze, and visualize air pollution data. As the issue of air quality and its impact on human health is very important today, it has become an important tool for environmental policy and management. One of the main applications of GIS in air pollution studies is the tracking and visualization of pollutant concentrations in different regions. By integrating real-time data from various sources—such as satellite imagery, ground monitoring stations, and meteorological models—GIS enables researchers and policymakers to assess pollution levels more accurately (Gurjar, Molina & Ojha, 2010).

GIS tools help to track the dispersion of different pollutants such as nitrogen oxides, sulfur dioxide, carbon monoxide, and particulate matter, and most importantly, help to pinpoint major emission sources, such as power plants, highways, and industrial zones. As a result, GIS allows authorities to map and visualize pollution concentrations in urban and industrial areas, helping to identify pollution sources and affected communities (Burrough & McDonnell, 1998).

Beyond air pollution, GIS plays a critical role in various environmental applications. In climate change monitoring, GIS is used to analyse temperature variations, deforestation patterns, and rising sea levels over time (Bolstad, 2016). It also contributes to disaster management, where GIS tools help predict and respond to natural disasters such as wildfires, floods, and hurricanes by identifying high-risk areas and planning evacuation routes (De Smith, Goodchild & Longley, 2007). Additionally, GIS is widely applied in biodiversity conservation, assisting in habitat mapping, species distribution analysis, and ecosystem monitoring to support wildlife protection efforts (Gurjar, Molina & Ojha, 2010).

Based on the above, it is safe to say that the application of GIS in air pollution analysis goes beyond simple data visualization—it enables comprehensive monitoring, source identification, risk assessment, and predictive modeling. By integrating multiple data sources and analytical techniques, GIS provides science-based insights that help policymakers develop effective pollution control measures. As GIS technology continues to evolve, introducing artificial intelligence, IoT sensors, and real-time monitoring networks, its role in air quality management will only increase.

Overall, GIS transforms raw spatial data into insights that guide research, policymaking, and urban planning. Its ability to visualize complex datasets interactively makes it easier to identify patterns and relationships that might not be visible in tabular data. In environmental studies, GIS helps illustrate pollution gradients, highlight vulnerable communities, and track changes over time—making it an indispensable tool for sustainable development and public health.

3.2 Overview of different of GIS tools and technologies

GIS technology has progressed significantly for the last decade. Nowadays they provide a range of tools for managing, analyzing, and visualizing spatial data. This part focuses on an overview of tools, differences, basic functionality, and applications. Understanding that is critical to selecting the most appropriate platform for specific needs.

3.2.1 Core features of GIS software

Most GIS software share common features that enable users to manage and analyze spatial data effectively. These core features include data processing, spatial analysis, visualization, and extensibility. One of the primary functions of GIS software is to handle spatial and non-spatial data. This includes:

- Importing and exporting different geospatial formats (e.g., Shapefiles, GeoJSON, KML, raster data).

- Storing data in spatial databases such as PostGIS and Esri Geodatabase (Bolstad, 2016).
- Managing attribute tables that link geographic features to descriptive data, enabling relational data analysis.

Efficient data management ensures accurate spatial representation and supports complex analyses such as geocoding, network analysis, and land-use classification (Longley et al., 2015).

GIS software enables spatial analysis, which involves examining spatial patterns, relationships, and trends. Some key analytical functions include overlay analysis, buffering, spatial interpolation, and network analysis. Overlay analysis involves combining multiple spatial layers to identify patterns and relationships within geographic data. Buffering is used to create zones around specific features, allowing for the analysis of proximity impacts. Spatial interpolation helps estimate unknown values based on known data points, making it particularly useful in air pollution mapping (Gao & Cheng, 2020). Network analysis is applied in transportation planning to determine optimal routes, service areas, and accessibility (Miller & Shaw, 2015). These tools allow users to conduct in-depth studies, from identifying pollution hotspots to predicting disaster-prone areas.One of the most important aspects of GIS is its ability to visually represent spatial data. Effective visualization allows for better communication of complex information. GIS software provides:

- Cartographic tools – Enabling the creation of maps with customized symbology, labels, and legends.
- Thematic mapping – Displaying spatial variations in data such as population density, temperature changes, or pollution levels.
- 3D visualization – Helping users analyze terrain, city models, and environmental changes (Zhang et al., 2021).

Modern GIS platforms are highly flexible, allowing users to expand their capabilities with plugins and APIs. In QGIS, users can install or develop plugins to introduce new tools and automate workflows, making the software more powerful and tailored to specific needs. ArcGIS offers APIs in Python and JavaScript, enabling developers to customize applications, integrate GIS with other platforms, and build web-based mapping solutions. Google Earth Engine provides an API for large-scale geospatial analysis, leveraging cloud computing to process vast amounts of satellite imagery and environmental data (Gorelick et al., 2017). This extensibility ensures that GIS software stays relevant as technology advances, incorporating artificial intelligence, big data analytics, and real-time processing to meet evolving challenges (Esri, 2025).

Whatever the type of software, core GIS functions are still the same. It includes data processing, spatial analysis, and mapping, which are essential tools for decision-making processes.

3.2.2 Overview of open-source and proprietary GIS tools

GIS software can be classified into two main categories: open-source and proprietary. The choice between them depends on factors such as cost, functionality, ease of use, and the specific requirements of a project.

Open-source GIS tools are available for free, which makes them a popular choice for researchers, government agencies, and businesses looking for cost-effective solutions. They are highly customizable and benefit from community-driven development. Some of the most widely used open-source GIS tools include:

- **QGIS (Quantum GIS)** – One of the most powerful open-source GIS tools, QGIS supports a wide range of data formats, spatial analysis functions, and visualization tools. It allows users to extend its capabilities through plugins and integrates well with other GIS tools (Graser, 2016).
- **Google Earth Engine (GEE)** – A cloud-based platform that enables large-scale geospatial analysis, particularly for environmental monitoring and remote sensing applications. GEE provides access to extensive satellite imagery and powerful computation capabilities (Gorelick et al., 2017).
- **Leaflet** – A lightweight JavaScript library designed for interactive web mapping. It is widely used for developing web-based GIS applications and allows for easy integration with OpenStreetMap (Chaturvedi, 2020).

Proprietary GIS software is developed and maintained by private companies, often providing more polished interfaces, dedicated technical support, and specialized features. These tools are widely used in commercial, government, and industrial applications. Some leading proprietary GIS tools include:

- **ArcGIS (Esri) –** One of the most comprehensive GIS platforms, ArcGIS offers robust spatial analysis, mapping, and real-time data integration. It provides cloud-based solutions through ArcGIS Online and supports AI-driven geospatial analytics (Esri, 2025).
- **MapInfo** – A desktop GIS application used for mapping and spatial analysis, particularly in business and government sectors. It supports geospatial modelling and integrates well with databases (Pitney Bowes, 2019).
- **ERDAS Imagine** – A remote sensing software specializing in image processing and raster data analysis, widely used in environmental monitoring and land-use planning (Hexagon Geospatial, 2020).

The table below provides a basical overview of the software mentioned above.

Table 1. GIS tools overview

Feature	**QGIS**	**Google Earth Engine**	**Leaflet**	**ArcGIS**	**Map Info Pro**	**Erdas imagine**
Type	Open-source	Open-source	Open-source	Proprietary	Proprietary	Proprietary
Developer	QGIS community	Google	Open-source community	Esri	Pitney Bowes	Hexagon Geospatial
Cost	Free	Free	Free	Paid	Paid	Paid
Primary use	Mapping, spatial analysis	Big data analysis, remote sensing	Web-based interactive mapping	Professional GIS, geospatial modeling	Location intelligence, business mapping	Remote sensing, satellite imagery analysis
3D capabilities	Limited	Yes	No	Yes	Limited	Yes
Cloud integration	Yes	Fully cloud-based	Yes	Yes	Yes	Limited
Mobile compatibility	Yes (QField)	Yes (Web-based)	Yes (Web-based)	Yes (ArcGIS Mobile)	Limited	No

Source: own processing

ArcGIS remains a leader in the GIS industry, offering advanced solutions for spatial analysis and decision-making. They are implementing new features in their software on an ongoing basis. It includes automation, big data integration, and real-time geospatial analytics, making ArcGIS the most popular and innovative platform for solving global challenges.

3.3 Air pollution and its geospatial aspects

3.3.1 Air pollution sources

The World Health Organization defines air pollution as any chemical, physical, or biological agent that affects the natural properties of the atmosphere, contaminating either interior or outdoor environments (WHO, 2021). When we think of sources of air pollution, we usually imagine buildings with big smokestacks like power plants and factories. Of course, such buildings contribute enormously to pollution not only to the air but also to the water and land around them. However, only about a quarter of air pollution comes from smokestacks. The rest comes from a wide variety of everyday sources. Household combustion devices, motor vehicles, and forest fires are also common sources of air pollution (NIEHS, 2025).

3.3.2 Types of pollutants

Air pollutants are different in their composition and impact on health and the environment. There are some primary pollutants, which are directly emitted from sources, and secondary pollutants, which form through chemical reactions in the atmosphere. Primary pollutants are particulate matter ($PM_{2.5}$ and PM_{10}), nitrogen oxides (NO_x), sulfur dioxide (SO_2), carbon monoxide (CO), volatile organic compounds (VOCs), ammonia (NH_3), and lead (Pb), while secondary ones are ground-level ozone (O_3), peroxyacetyl nitrates (PANs), and acid rain components such as sulfuric acid (H_2SO_4) and nitric acid (HNO_3).

Particulate matter ($PM_{2.5}$and PM_{10}) consists of tiny airborne particles that can penetrate deep into the respiratory system, increasing the risk of lung diseases and cardiovascular issues (Gurjar et al., 2010).

Noxious gases, which include carbon dioxide, carbon monoxide, nitrogen oxides (NO_x), and sulfur oxides (SO_x), are components of motor vehicle emissions and consequences of the industrial processes (EPA, 2023).

Ozone (O_3), which is mostly known as smog is created when pollutants from cars, power plants, and other sources chemically react in the presence of sunlight (WHO, 2021).

The toxicity of PAN is higher than that of ozone. Eye irritation from photochemical smog is caused more by PAN and other trace gases than by ozone, which is only sparingly soluble (Seinfeld & Pandis, 2016).

Long-term exposure to polluted air is linked to severe health conditions, including respiratory diseases, cardiovascular problems, and premature mortality. PM2.5, for instance, has been identified as a major factor in **lung cancer and heart disease** (Gurjar et al., 2010).

3.3.3 Effects of pollution on health and environment.

The spread of air pollution is highly dependent on geographic and climatic conditions. Mountainous areas can trap pollutants, leading to prolonged exposure in valleys, while coastal regions often benefit from strong winds that help disperse contaminants. Urban heat islands, created by dense infrastructure and limited vegetation, can intensify pollution levels in cities. GIS tools play a critical role in mapping and analyzing these patterns, providing insights into the movement of pollutants over time and aiding in the development of targeted mitigation strategies (de Smith et al., 2007). By integrating satellite data, real-time sensor readings, and meteorological models, GIS enables a more precise understanding of how pollution behaves across different environments.

3.4 GIS data sources for air pollution analysis

To understand air pollution or any other patterns, it requires reliable data from different sources. Geographic Information Systems (GIS) help analyze this data. The main sources of air pollution data include public datasets and APIs, which provide large-scale and real-time pollution measurements, and data collection methods, which include satellite data, ground-based monitoring, and crowdsourced data.

3.4.1 Data collection methods

Air pollution data is collected using different methodologies, such as satellite remote sensing, ground-based monitoring stations, and crowdsourced contributions. Remote sensing technologies allow large-scale air pollution monitoring, offering continuous and consistent data on atmospheric pollutants.

Satellites are one of the most effective ways to monitor air pollution over large areas. Instruments like TROPOMI (Sentinel-5P), MODIS, and OMI measure pollutants in the atmosphere. They allow researchers to track long-term trends and identify pollution hotspots. However, satellite data needs to be combined with ground measurements for better results.

Regulatory agencies and research institutions use ground-based air quality monitoring stations that provide real-time, high-accuracy data on different pollutants. These stations typically measure particulate matter ($PM_{2.5}$, PM_{10}), gaseous pollutants (CO, NO_2, SO_2, O_3), and meteorological factors (temperature, wind speed). Ground-based monitoring data is used to validate satellite-based observations and provide localized air quality insights for urban planning, environmental regulations, and public health assessments (EEA, 2024).

New technologies have made it possible for individuals to contribute air quality data using low-cost sensors. Platforms like PurpleAir and AirVisual allow people to install sensors in their homes or neighborhoods, providing hyper-local pollution data. Although crowdsourced data may not be as accurate as official monitoring stations, it helps fill gaps in areas where official data is unavailable.

3.4.2 Public datasets and APIs overview

Publicly available datasets and APIs offer information on air quality, collected by satellites, environmental organizations, and government agencies. These sources show real-time and historical data, helping researchers and policymakers track pollution trends and make correct decisions. Each of them uses different key parameters for analysis and represents different types of data sources.

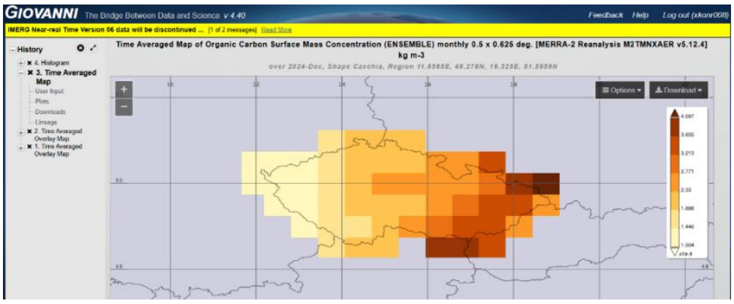
Table 2. Summary of different datasets

Data sources	Type	Key parameters	Base formats
Sentinel-5P (ESA, NASA)	Satellite-based	NO_2, SO_2, CO, CH_4, O_3	NetCDF, HDF, GeoTIFF
OpenAQ	Real-time monitoring	$PM_{2.5}$, PM_{10}, CO, NO_2, SO_2, O_3	JSON, CSV, API access
EEA (European Environment Agency)	Ground-based and satellite data	Pollutant levels, meteorological data	CSV, JSON, XML, API access
WHO Air Pollution Database	Global health monitoring	Annual air quality reports	CSV, Excel, PDF
PurpleAir (Crowdsourced)	IoT sensor network	$PM_{2.5}$, PM_{10}	JSON, CSV, API access

Source: own processing

The Sentinel-5P satellite, operated by the European Space Agency (ESA), monitors air pollution globally. It uses advanced sensors to measure harmful gases such as nitrogen dioxide (NO_2), carbon monoxide (CO), sulfur dioxide (SO_2), ozone (O_3), and methane (CH_4). This data is useful for identifying pollution sources and studying environmental changes over time. Since it provides daily global coverage, it is one of the most widely used datasets for air quality research (ESA, 2018). Retrieved data usually comes in TIFF format and looks like the picture below:

Picture 2. Retrieved satellite data



IMERG Near-real Time Version 06 data will be discontinued ... [1 of 2 messages] Read More

Time Averaged Map of Organic Carbon Surface Mass Concentration (ENSEMBLE) monthly 0.5 x 0.625 deg. [MERRA-2 Reanalysis M2TMNXAER v5.12.4] kg m-3

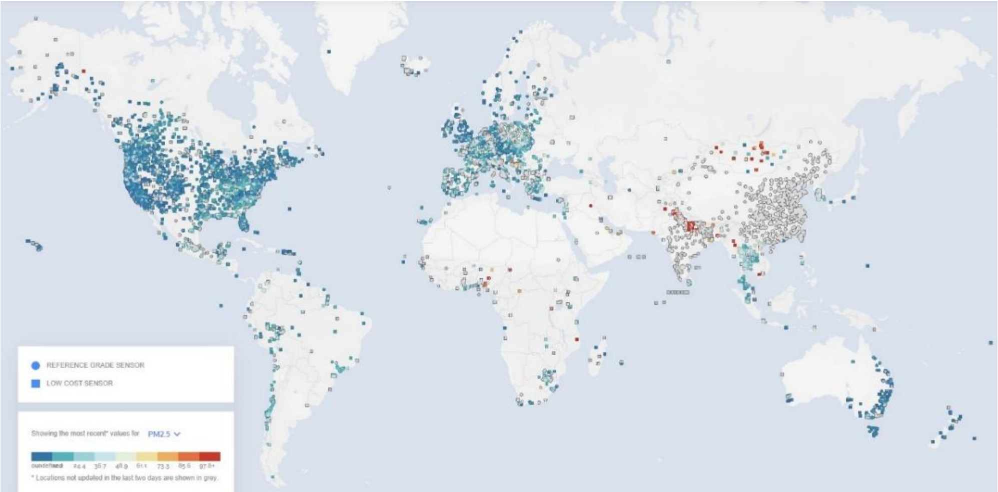
over 2024-Dec, Shape Czechia, Region 11.6565E, 48.278N, 19.325E, 51.5959N

Source: NASA Giovanni (2025)

OpenAQ is a non-profit platform that collects air quality data from official monitoring stations worldwide. It provides real-time measurements of pollutants like fine particulate matter ($PM_{2.5}$, PM_{10}), ozone, and nitrogen dioxide.

The platform is open-source, meaning researchers, policymakers, and the public can freely access and use the data for analysis.

Picture 3. Pollution representation via OpenAQ



Source: OpenAQ (2023)

There are also a few government agencies that provide high-quality air pollution data, such as the Environmental Protection Agency (EPA) in the United States, the World Health Organization (WHO), and the European Environment Agency (EEA). These sources are highly reliable and are often used for environmental regulations and public health research (WHO, 2021).

4. Practical Part

During the practical part, the air pollution in the Czech Republic was analyzed with a focus on four key pollutants: $PM_{2.5}$, PM_{10}, NO_2, and O_3. The data from the European Environment Agency (EEA) was processed and visualized air quality information through ArcGIS Pro spatial analysis tools. The results of the analysis were presented as a web application, which was created using ArcGIS Online, ArcGIS Insights, and ArcGIS StoryMaps.

4.1 Choosing and pre-processing of dataset

4.1.1 Obtaining data

The data collection methods and public data sources were overviewed in the theoretical part. Based on that information, since this research focuses on local air pollution analysis, ground-based station data is the best option. Unlike satellite data, ground-based sensors offer highly accurate measurements of pollutants. Additionally, while retrieving satellite data (Picture 2) it turned out that this type of data is often pre-processed using models and assumptions. Ground-based stations, on the other hand, provide raw, directly measured concentrations and are usually stored in user-friendly formats, such as CSV, JSON, or databases, making it easier to integrate into GIS tools like ArcGIS. For global or long-term studies, I would recommend combining both ground-based and satellite data to achieve the most accurate results.

For the analysis of air pollution in the Czech Republic, I utilized DBF (dBase File) datasets obtained from the European Environment Agency. The dataset can be accessed by this link: https://www.eea.europa.eu/en/datahub/datahubitem-view/b51e1091-4459-4a1e-8dbc-dd7a30949b90.

DBF format is flexible and commonly used for storing attribute data in GIS applications. It could be easily converted to JSON or CSV. These datasets contain station-based air quality measurements (annual averages) for air pollutants like $PM_{2.5}$, PM_{10}, NO_2, and O_3, which are calculated based on hourly or daily measurements from air quality monitoring stations. There are different datasets for each type of station, such as rural, urban, and suburban, which will be combined later for more accurate analysis. The dataset was published in 2022 and contains measurements from stations all over Europe.

4.1.2 Data merging using Python

The European Environment Agency provides datasets for rural, urban, and suburban stations. To perform the most accurate analysis of air pollution in the Czech Republic, 3 datasets were merged into one file for each pollutant. This step was necessary to obtain a complete dataset for spatial analysis and was performed using Python. The code below was used for merging observational values of the air quality monitoring stations for PM2.5.

Picture 4. Merging datasets using Python

```python
import pandas as pd
from simpledbf import Dbf5

# Load DBF files into Pandas DataFrames
df1 = Dbf5("D:\Downloads\pm25\st_rb_2019_pm25.dbf").to_dataframe()
df2 = Dbf5("D:\Downloads\pm25\st_usb_2019_pm25.dbf").to_dataframe()
df3 = Dbf5("D:\Downloads\pm25\st_ust_2019_pm25.dbf").to_dataframe()

# Merge the DataFrames
merged_df = pd.concat([df1, df2, df3], ignore_index=True)

# Save merged data as DBF
merged_df.to_csv("D:\Downloads\pm25\$avg_pm25_total.dbf", index=False)

print("Merged!")
```

Source: own processing

The same approach was performed for other data files, including measurements for PM_{10}, NO_2, and O_3.

4.2 Choosing a toolset

4.2.1 Comparison of QGIS, ArcGIS and Google Earth Engine

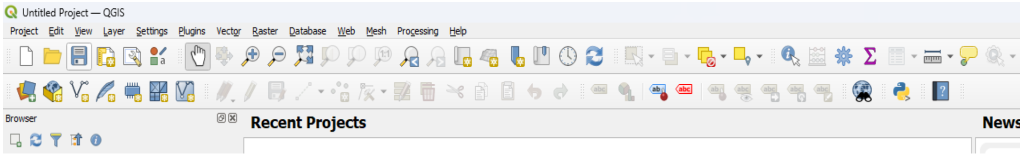
The most popular GIS tools are ArcGIS, QGIS, and Google Earth Engine (GEE). Below is a comparison based on key parameters, including usability, system requirements, data integration capabilities, spatial analysis functions, visualization features, and web application building.

Usability is a key factor for any software; it shows how easily users can interact with the software. ArcGIS provides a user-friendly interface with an extensive GUI and built-in templates, making it easy to use for professionals. Also, it has the ArcGIS online platform, which is even more user-friendly. The documentation could be found on official websites, and the community is big and helps with some issues on forums.

Google Earth Engine is a cloud-based platform used for large-scale geospatial processing, with a focus satellite imagery. It requires coding skills in JavaScript or Python, which can be a barrier for users without programming experience.

QGIS is an open-source alternative, which offers flexibility but requires more customization. Its user interface is less intuitive for beginners compared to ArcGIS, and some advanced functions may require additional plugins or scripting, which makes it less streamlined for certain workflows. Another notice after opening this tool is that menu bar buttons are not labeled, which makes navigation extremely hard (Picture 4).

Picture 5. QGIS Interface



Source: own processing

Another key aspect, which is important, is **system requirements**. ArcGIS Pro is a high-performance GIS software that requires a powerful CPU, a dedicated GPU, and an SSD for handling large datasets. However, ArcGIS also offers ArcGIS Online, which allows users to work from any device with a browser. QGIS does not have separate desktop and online versions—it runs as a standalone application on multiple operating systems.

However, QGIS tends to work slower than ArcGIS, especially when processing large datasets. Google Earth Engine is cloud-based, meaning it does not require local processing power. The only software that provides both web and desktop versions is ArcGIS. It makes it the most flexible and popular GIS tool because it can be used on any device and does not depend on the internet connection. A table below shows some system requirements and features of these 3 tools:

Table 3. System Requirements comparison of ArcGIS, QGIS, and GEE

GIS tool	Operating system	Recommended hardware	Cloud-based option	Offline mode
ArcGIS Pro	Windows 10/11 (64-bit)	**CPU:** Intel i7 or higher / **RAM:** 16GB+ / **GPU:** Dedicated (NVIDIA/AMD) / **Storage:** SSD	Yes (ArcGIS Online)	Yes
ArcGIS Online	Windows, macOS, Linux	None (Runs in a browser)	Yes	No
QGIS	Ground-based sensors	**CPU:** Intel i5 or higher / **RAM:** 8GB+ / **GPU:** Integrated or low-end dedicated / **Storage:** SSD recommended	No	Yes
Google Earth Engine	Web-based (Any OS)	None (Runs in a browser)	Yes	No

Source: own processing

When talking about **data integration,** ArcGIS outperforms QGIS and Google Earth Engine (GEE) in several key areas, based on the information from literature revirew. ArcGIS handles all major GIS and air pollution data formats, including geodatabases, raster, or vector data. It also could be connected to enterprise databases, making large-scale air pollution data management. Google Earth Engine cannot connect to external databases at all, while QGIS has limitations in database connectivity and does not have a good optimization to work with massive datasets.

Spatial analysis tools allow users to receive statistics and visualization from geographic data. It includes interpolation, clustering, geostatistics, spatial modeling, and network analysis. ArcGIS provides a full set of tools needed for air pollution research; this includes tasks such as interpolation of pollutant concentrations, hotspot detection, and network analysis for traffic-related emissions. It has built-in tools such as Kriging and IDW (Inverse Distance Weighting), which are essential for estimating air pollution concentrations between monitoring stations. QGIS is not so flexible and depends on plugins. It also supports the IDW approach, but Kriging or 3D analysis is not available. Google Earth Engine is good only for raster analysis and remote sensing, while there is no support for local vector analysis, making it unsuitable for working with ground-based air pollution station data. Based on that, ArcGIS is the most universal for air pollution research, as its toolset is the biggest one compared to other GIS applications and allows for the performance of different types of analysis.

The last factor used for comparison is web application building. Among the compared tools:

- ArcGIS provides the most advanced web GIS development environment. It offers ArcGIS Online, Experience Builder, Dashboards, and StoryMaps for creating interactive and professional applications with minimal coding.
- QGIS has minimal built-in web capabilities but supports web mapping through QGIS2Web and GeoServer. However, these tools require manual setup and technical expertise, making them less accessible for users who need a ready-to-use web GIS solution.
- Google Earth Engine is fully cloud-based, allowing large-scale environmental analysis, but does not provide custom web application development features. While users can embed interactive pollution maps, there is no dedicated tool for building full-featured web GIS applications.

After evaluating the most popular GIS tools based on different parameters, ArcGIS remains the most comprehensive and flexible solution for air pollution research. It has powerful analytical tools, extensive format support, a user-friendly interface, and provides many web application capabilities. These factors make it ideal for handling any type of air quality data, such as ground-based and satellite data, while other GIS tools like QGIS and GEE do not have such a wide choice in analysis tools and cannot handle all data formats well. Also, while ArcGIS presents a huge number of tools for web development and integration of maps into web applications, QGIS and GEE do not have even half of these capabilities. A point of contention might be the price of a license in ArcGIS, but ESRI works with many universities around the world, allowing students to use their tools for free. These universities also include Czech University of Life Sciences in Prague (CZU).

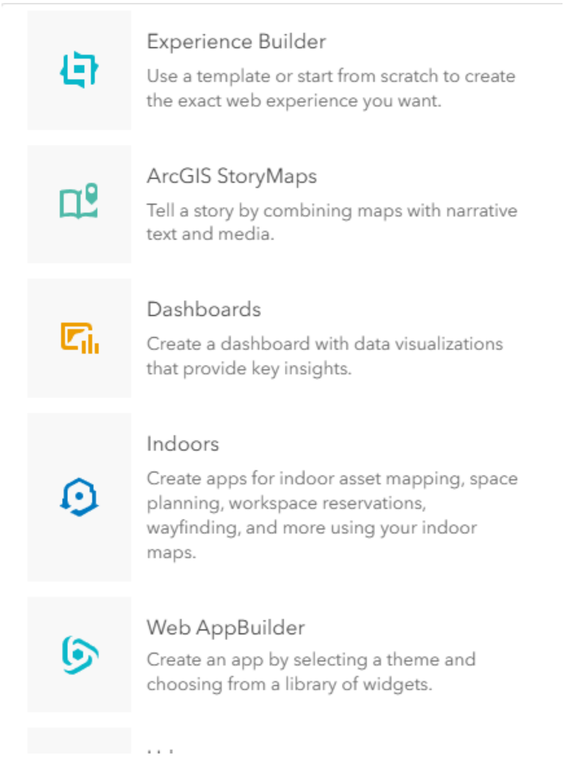
4.2.2 ArcGIS tools

For the case study, the ArcGIS products will be used. The desktop Pro version was already described, but such tools as ArcGIS Insights and web application building tools will also be used.

ArcGIS Insights is a data analytics tool that is used to create interactive visualizations such as histograms, scatter plots, and heatmaps. These visualizations will be used in the web application to allow users to see statistics and interact with data.

Esri provides several web GIS development tools to create interactive and user-friendly applications. It includes **ArcGIS Experience Builder, ArcGIS Dashboards, ArcGIS StoryMaps,** and **ArcGIS Web AppBuilder**. They all can be accessed through ArcGIS online after logging.

Picture 6. ArcGIS web application building tools



Experience Builder
Use a template or start from scratch to create the exact web experience you want.

ArcGIS StoryMaps
Tell a story by combining maps with narrative text and media.

Dashboards
Create a dashboard with data visualizations that provide key insights.

Indoors
Create apps for indoor asset mapping, space planning, workspace reservations, wayfinding, and more using your indoor maps.

Web AppBuilder
Create an app by selecting a theme and choosing from a library of widgets.

Source: own processing

The StoryMaps tool will be used for application building, as it has all the necessary tools for this research. It allows integration of interactive mapping, dashboards, and multimedia and supports import from ArcGIS Insights. This tool creates professional-looking web applications and does not require high coding skills.

4.2.3 Comparison of Analysis techniques

Geospatial analysis techniques are a must-have for understanding the distribution of air pollution and its relationship with environmental and human factors. These techniques allow researchers to identify emission sources, pollution dispersion patterns, and impact zones. Some of them are spatial interpolation methods, hotspot analysis, geostatistical modeling, and analysis using machine learning (ML) and AI.

- Kriging: A geostatistical interpolation method that considers spatial autocorrelation to predict pollution levels across a region. It is useful for estimating pollutant dispersion from emission sources and identifying areas with high exposure risks (de Smith et al., 2007).
- Inverse Distance Weighting (IDW): A simpler interpolation method that assumes closer data points have a greater influence on estimated values. IDW is often applied in air quality mapping to visualize pollutant concentrations and define impact zones around emission sources (Longley et al., 2015).

Another method of geospatial analysis is hotspot analysis. This technique helps identify highly polluted areas, allowing policymakers to focus mitigation efforts where pollution poses the greatest health risks. These methods help differentiate between persistent pollution hotspots near industrial zones and temporary peaks caused by specific events like traffic congestion or wildfires (Longley et al., 2015).

In this study, Inverse Distance Weighting (IDW) interpolation and Hotspot analysis will be used as primary geospatial methods for analyzing air pollution data. Inverse Distance Weighting (IDW) is chosen as the interpolation method because it is straightforward, efficient, and the most effective for local-scale air pollution mapping. This method is also suitable for our datasets, which include ground- based measurements from monitoring stations. Hotspot analysis may also be used as an additional technique to compare spatial patterns.

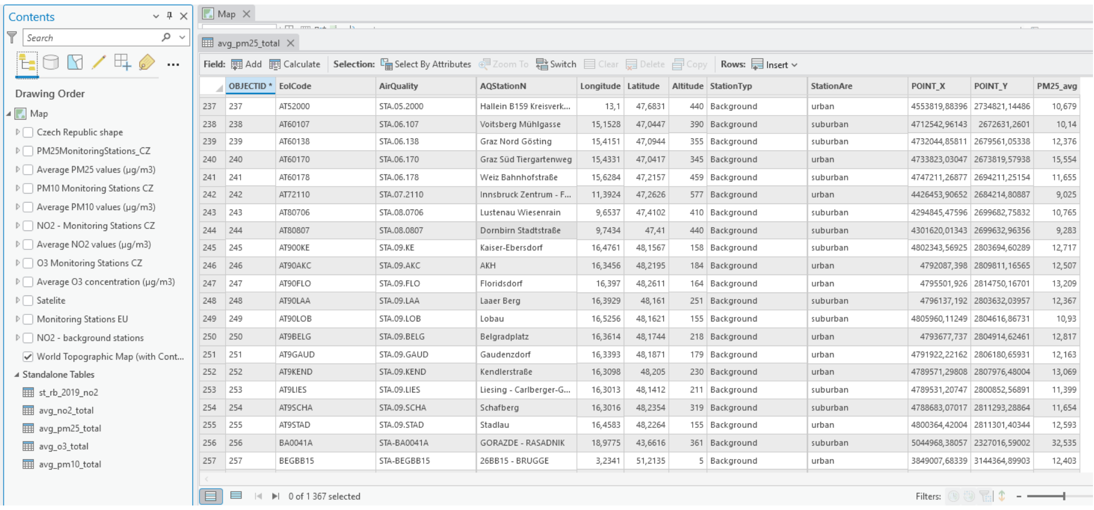
4.3 Working in ArcGIS Pro

4.3.1 Uploading database and shapefile to ArcGIS Pro

To upload the data to ArcGIS Pro, the new project was created first. Then the dataset was uploaded by pressing the "*Add data*" button and choosing the appropriate file.

The databases appear in the "Contents" section after uploading. The files also contain data from rural, suburban, and urban stations after merging.

Picture 7. Attribute table



	OBJECTID *	EoICode	AirQuality	AQStationN	Longitude	Latitude	Altitude	StationTyp	StationAre	POINT_X	POINT_Y	PM25_avg
237	237	AT52000	STA.05.2000	Hallein B159 Kreisverk...	13,1	47,6831	440	Background	urban	4553819,88396	2734821,14486	10,679
238	238	AT60107	STA.06.107	Voitsberg Mühlgasse	15,1528	47,0447	390	Background	suburban	4712542,96143	2672631,2601	10,14
239	239	AT60138	STA.06.138	Graz Nord Gösting	15,4151	47,0944	355	Background	suburban	4732044,85811	2679561,05338	12,376
240	240	AT60170	STA.06.170	Graz Süd Tiergartenweg	15,4331	47,0417	345	Background	urban	4733823,03047	2673819,57938	15,554
241	241	AT60178	STA.06.178	Weiz Bahnhofstraße	15,6284	47,2157	459	Background	suburban	4747211,26877	2694211,25154	11,655
242	242	AT72110	STA.07.2110	Innsbruck Zentrum - F...	11,3924	47,2626	577	Background	urban	4426453,90652	2684214,80887	9,025
243	243	AT80706	STA.08.0706	Lustenau Wiesenrain	9,6537	47,4102	410	Background	suburban	4294845,47596	2699682,75832	10,765
244	244	AT80807	STA.08.0807	Dornbirn Stadtstraße	9,7434	47,41	440	Background	suburban	4301620,01343	2699632,96356	9,283
245	245	AT900KE	STA.09.KE	Kaiser-Ebersdorf	16,4761	48,1567	158	Background	suburban	4802343,56925	2803694,60289	12,717
246	246	AT90AKC	STA.09.AKC	AKH	16,3456	48,2195	184	Background	urban	4792087,398	2809811,16565	12,507
247	247	AT90FLO	STA.09.FLO	Floridsdorf	16,397	48,2611	164	Background	urban	4795501,926	2814750,16701	13,209
248	248	AT90LAA	STA.09.LAA	Laaer Berg	16,3929	48,161	251	Background	suburban	4796137,192	2803632,03957	12,367
249	249	AT90LOB	STA.09.LOB	Lobau	16,5256	48,1621	155	Background	suburban	4805960,11249	2804616,86731	10,93
250	250	AT9BELG	STA.09.BELG	Belgradplatz	16,3614	48,1744	218	Background	urban	4793677,737	2804914,62461	12,817
251	251	AT9GAUD	STA.09.GAUD	Gaudenzdorf	16,3393	48,1871	179	Background	urban	4791922,22162	2806180,65931	12,163
252	252	AT9KEND	STA.09.KEND	Kendlerstraße	16,3098	48,205	230	Background	urban	4789571,29808	2807976,48004	13,069
253	253	AT9LIES	STA.09.LIES	Liesing - Carlberger-G...	16,3013	48,1412	211	Background	suburban	4789531,20747	2800852,56891	11,399
254	254	AT9SCHA	STA.09.SCHA	Schafberg	16,3016	48,2354	319	Background	suburban	4788683,07017	2811293,28864	11,654
255	255	AT9STAD	STA.09.STAD	Stadlau	16,4583	48,2264	155	Background	urban	4800364,42004	2811301,40344	12,593
256	256	BA0041A	STA-BA0041A	GORAZDE - RASADNIK	18,9775	43,6616	361	Background	suburban	5044968,38057	2327016,59002	32,535
257	257	BEGBB15	STA-BEGBB15	26BB15 - BRUGGE	3,2341	51,2135	5	Background	urban	3849007,68339	3144364,89903	12,403

0 of 1 367 selected

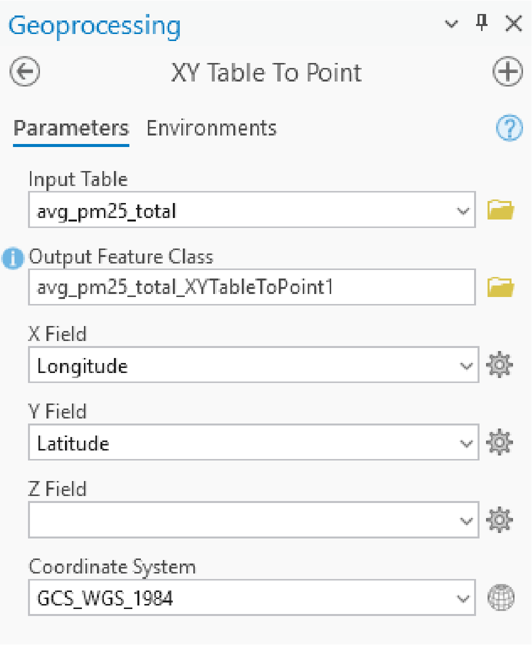
Source: own processing

As the datasets include information from stations across the whole of Europe, it is important to add a shapefile of the Czech Republic to perform analysis only inside this country. To upload the shapefile, the same process was used as for the data upload. After that, the data processing and spatial analysis could be performed inside this area.

4.3.2 Data visualization

To begin the visualization of the data, the points from the table should be transferred to the map. For this, the "*XY Table to Point*" tool was used. To make the points for PM$_{2.5}$ measurements visible, it is needed to mark such fields as *X Field, Y Field, and coordinate system*. As the database contains longitude and latitude, the input was made automatically, while the World Geodetic System 1984 (WGS 1984) is used by default in GIS applications.

Picture 8. Transferring table data to map layer



Input Table
avg_pm25_total

Output Feature Class
avg_pm25_total_XYTableToPoint1

X Field
Longitude

Y Field
Latitude

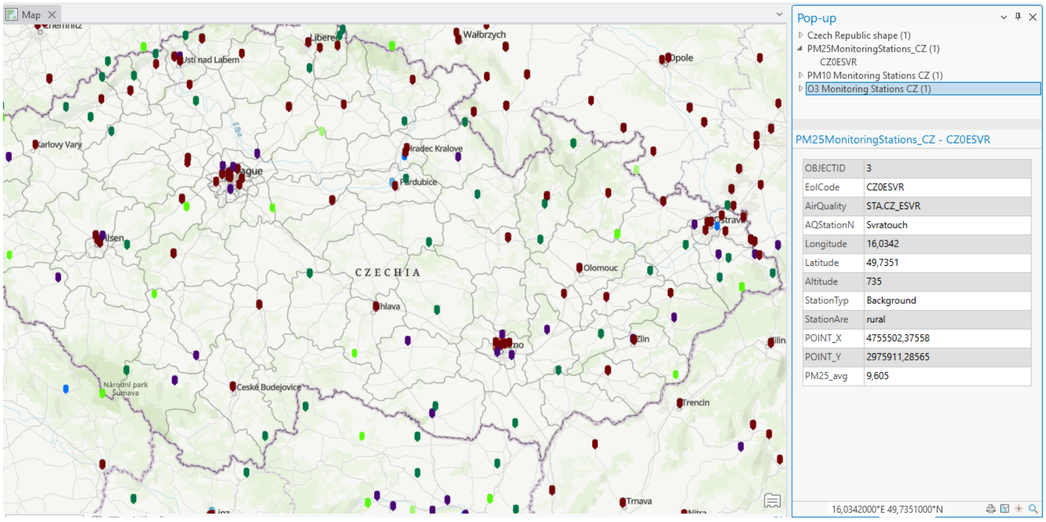
Z Field

Coordinate System
GCS_WGS_1984

Source: own processing

The same steps were performed for all other pollutants databases, including PM10, NO_2, and O_3. After that, the points appear on the map. Each of the pollutants now has its own layer and could be modified independently. The data, which is stored in points, may be accessible by clicking on it.

Picture 9. Transferred table values



PM25MonitoringStations_CZ - CZ0ESVR

OBJECTID	3
EoICode	CZ0ESVR
AirQuality	STA.CZ_ESVR
AQStationN	Svratouch
Longitude	16,0342
Latitude	49,7351
Altitude	735
StationTyp	Background
StationAre	rural
POINT_X	4755502,37558
POINT_Y	2975911,28565
PM25_avg	9,605

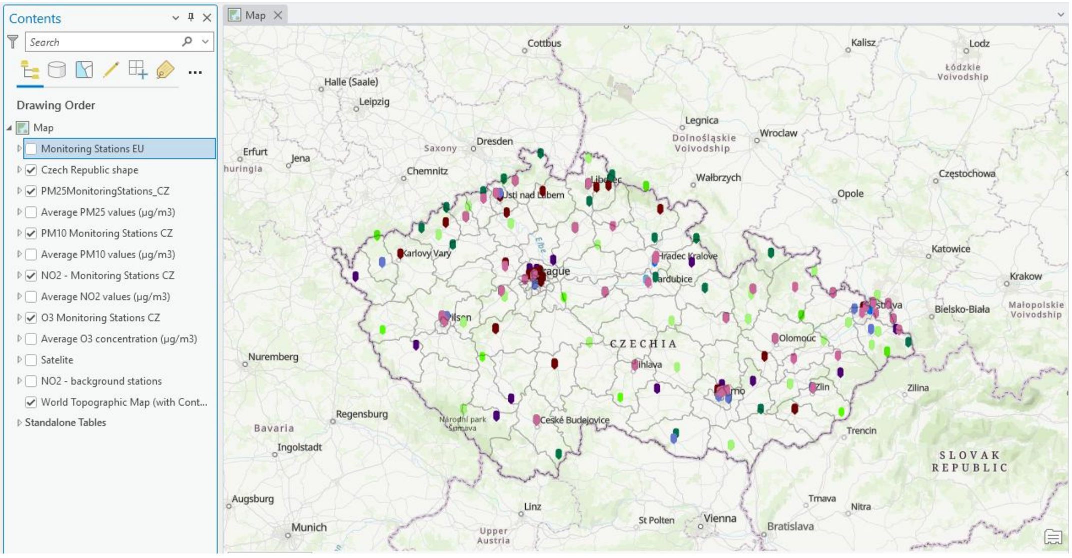
16,0342000°E 49,7351000°N

Source: own processing

4.3.3 Clipping data

Since the original air pollution datasets contained monitoring stations across all of Europe, it was necessary to extract only the data points that fall within the Czech Republic for more precise analysis. This was achieved using the "*Clip*" tool in ArcGIS Pro, which allows extracting features that intersect with a defined boundary. After clipping, the new layers were created, while the old layers still could be accessible in the "*Contents*" section.

Picture 10. Clipped data layer



Contents

Drawing Order

Map
- ☐ Monitoring Stations EU
- ☑ Czech Republic shape
- ☑ PM25MonitoringStations_CZ
- ☐ Average PM25 values (μg/m3)
- ☑ PM10 Monitoring Stations CZ
- ☐ Average PM10 values (μg/m3)
- ☑ NO2 - Monitoring Stations CZ
- ☐ Average NO2 values (μg/m3)
- ☑ O3 Monitoring Stations CZ
- ☐ Average O3 concentration (μg/m3)
- ☐ Satelite
- ☐ NO2 - background stations
- ☑ World Topographic Map (with Cont...

Standalone Tables

Source: own processing

The clipped dataset provided a more accurate representation, allowing for better visualization. This also improved the efficiency and precision of further geospatial analyses by limiting the workload to the specific region of interest.

4.3.4 IDW Analysis for $PM_{2.5}$

Burrough and McDonnell (1998) describe Inverse Distance Weighted (IDW) interpolation as a widely used deterministic spatial interpolation technique that assumes that the influence of a known data point diminishes with distance. IDW assigns higher weights to nearby points while reducing the impact of those further away, making it particularly effective for continuous environmental variables like air pollution. It is based on a mathematical formula that estimates the value of an unknown point using weighted averages of known data points.

Picture 11. IDW concept formula

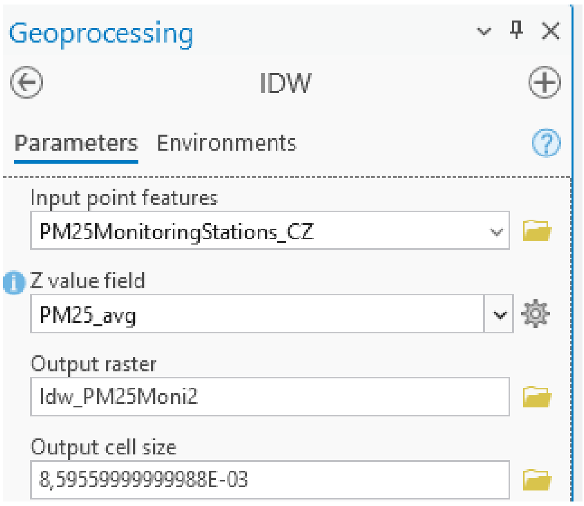
$$z_p = \frac{\sum_{i=1}^{n} \left(\frac{z_i}{d_i^p} \right)}{\sum_{i=1}^{n} \left(\frac{1}{d_i^p} \right)}$$

Source: (GISGeography, 2025)

This formula represents the Inverse Distance Weighted (IDW) interpolation method used to estimate an unknown value at a given location based on nearby known values. The estimated value at a point (Zp) is calculated as a weighted average of surrounding known values. Each known value (Zi) is inversely weighted by its distance (di) to the unknown point. The power parameter (p) determines how strongly distance influences the weighting. The numerator sums the weighted values of all known points. The denominator ensures that the weights sum to 1, normalizing the result. This mathematical approach makes IDW effective in air pollution analysis where data is collected at quality monitoring stations.

To perform this analysis in ArcGIS Pro, it is necessary to identify input point features, the value that will be analyzed, the coordinate system, and the extent. The IDW was also selected because it is perfect for our case of local study. Other interpolation methods, like Kriging, are suitable for global research.

Picture 12. Data input for IDW analysis



Input point features
PM25MonitoringStations_CZ

Z value field
PM25_avg

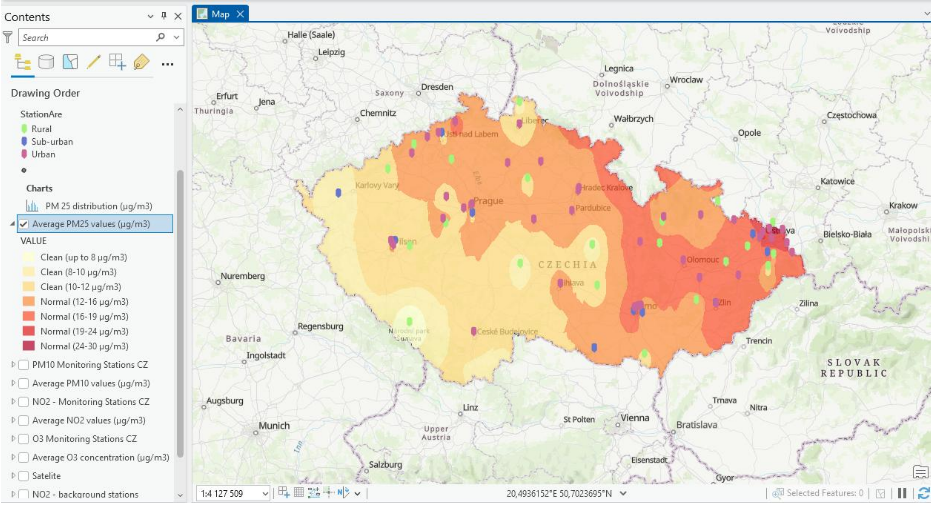
Output raster
Idw_PM25Moni2

Output cell size
8,59559999999988E-03

Source: own processing

After spatial analysis, a labeling should be done to enhance the interpretability and readability of the $PM_{2.5}$. Labeling allows for the automatic display of attribute values from the dataset directly on the map. The station type (rural, urban, or suburban) was chosen as the primary label for the point-based layer of monitoring stations. To classify $PM_{2.5}$ concentration, the 7 classes were chosen. As a result, the new raster layer appeared after using the IDW tool.

Picture 13. $PM_{2.5}$ pollution visualisation

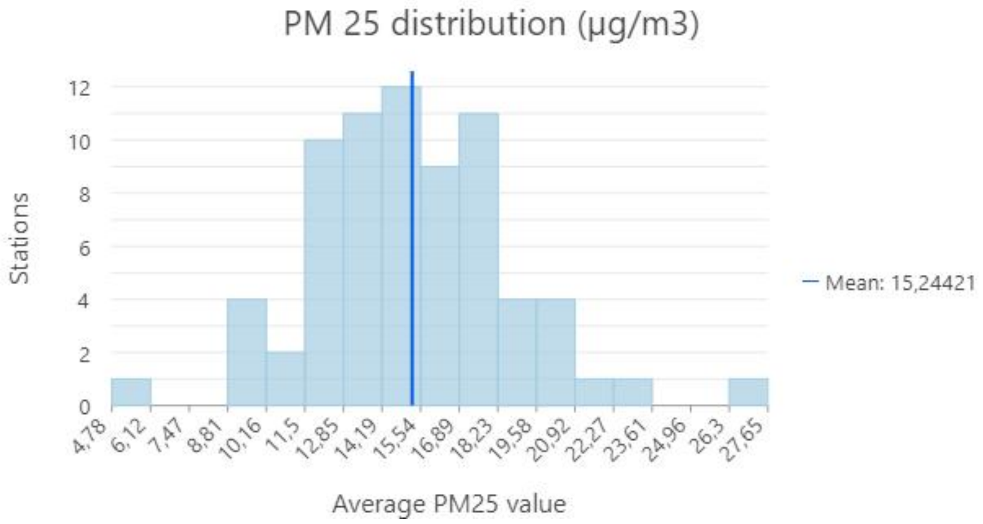


Source: own processing

The interpolated map (Picture 13) indicates that central and eastern regions, including cities like Prague, Brno, and Ostrava, experience higher $PM_{2.5}$ concentrations, exceeding 16-24 µg/m³ in some areas. However, western and southern parts of the country, such as Karlovy Vary and parts of South Bohemia, exhibit lower $PM_{2.5}$ levels, generally falling within the "clean" range of below 12 µg/m³.

The created histogram (Picture 14) using ArcGIS Pro shows the average $PM_{2.5}$ value across the country. The World Health Organization (WHO) revised its air quality guidelines in 2021, recommending an annual mean $PM_{2.5}$ concentration of no more than 5 µg/m³ to minimize health risks (WHO, 2021).

Picture 14. PM$_{2.5}$ distribution



Source: own processing

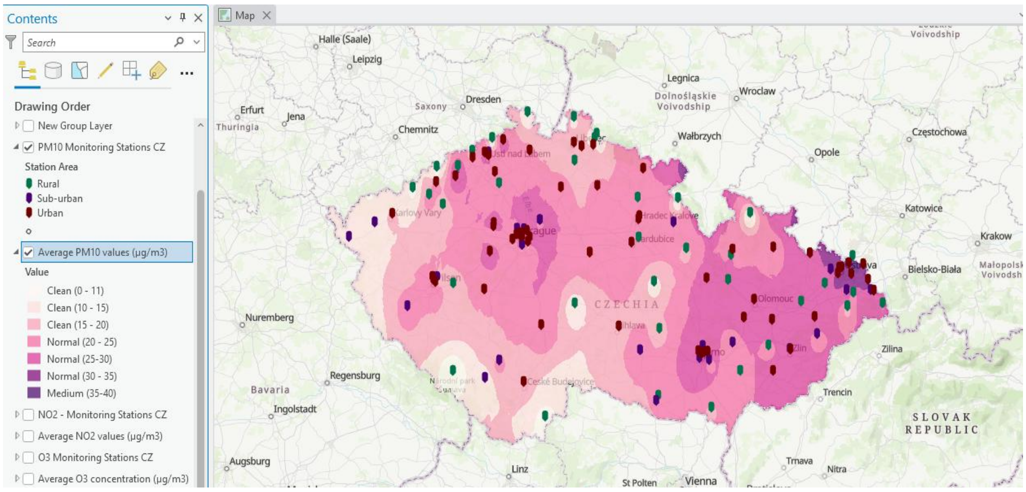
The EU's current legal threshold is more lenient, allowing up to 25 µg/m^3 annually. Based on this analysis, large areas of the Czech Republic surpass WHO recommendations, indicating potential health concerns, particularly for vulnerable populations.

However, most regions remain within EU limits, suggesting compliance with European regulations. Continued mitigation efforts, including stricter emission controls, a transition to cleaner energy sources, and the promotion of sustainable transport, could help reduce PM$_{2.5}$ pollution levels further (EEA, 2023). Western European countries, such as Sweden, Norway, and Finland, maintain significantly lower PM$_{2.5}$ concentrations, often below 10 µg/m^3, due to stricter emissions regulations, a lower density of heavy industry, and meteorological conditions (EEA, 2023). In contrast, Central and Eastern European countries, including Poland, Slovakia, and parts of Hungary, exhibit similar or even higher PM$_{2.5}$ concentrations, often exceeding 20 µg/m^3, due to coal-based energy production and industrial emissions.

4.3.5 IDW Analysis for PM$_{10}$

For the analysis of PM$_{10}$ concentration, the same processes were used. The PM$_{10}$ concentration analysis in the Czech Republic, which was done using Inverse Distance Weighting (IDW) interpolation, indicates that pollution levels vary significantly across the country (Picture 15).

Picture 15. PM_{10} pollution visualisation



Source: own processing

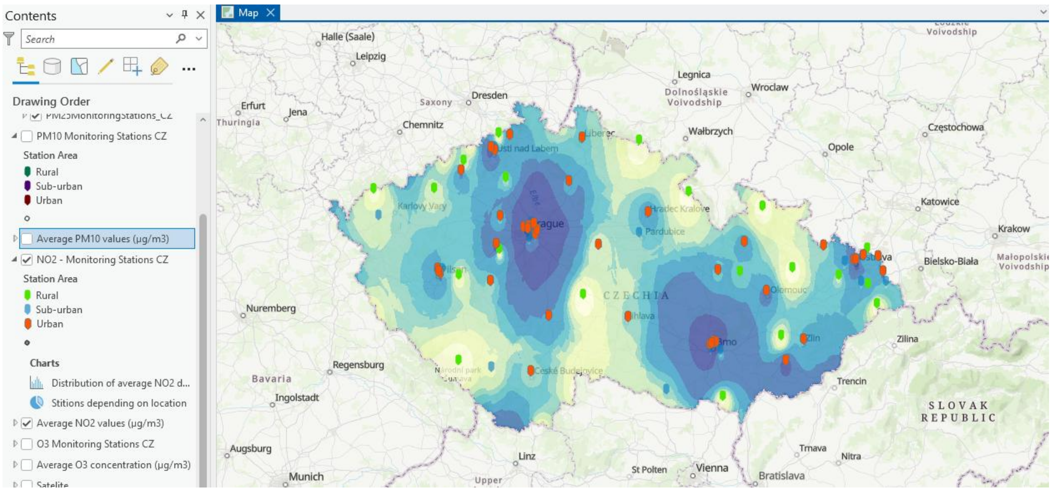
Higher PM_{10} values, above 30 µg/m^3, are found in urban and industrial areas like Prague, Brno, and Ostrava. The overall mean PM_{10} concentration for the Czech Republic, which was found using ArcGIS statistical tools, is 19.92 µg/m^3. The trend for PM10 is similar to $PM_{2.5}$. Compared to Western and Northern Europe, where PM_{10} levels are often below 15 µg/m^3, the Czech Republic has slightly higher concentrations, while it is a pretty good concentration compared to the closest neighbors, Poland and Slovakia.

PM_{10} levels are also influenced by seasonal changes; higher concentrations typically appear during the winter months as a result of increased emissions from heating systems in homes and unfavorable climate conditions that trap pollutants closer to the surface. In contrast, PM_{10} concentrations are often lower during the summer months because of better air dispersion and lower emissions from heating sources.

4.3.6 IDW Analysis for NO_2

Nitrogen dioxide (NO_2) is a key air pollutant emitted from vehicle exhaust, industrial processes, and combustion sources. The spatial analysis shows that NO_2 pollution in the Czech Republic is mainly an urban issue, linked to traffic and industry.

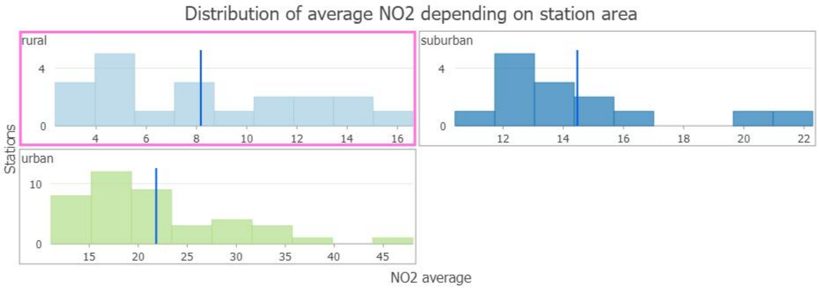
Picture 16. NO_2 pollution visualization



Source: own processing

While rural and suburban areas have good levels, cities require further improvements, where emissions from older vehicles and industrial sources contribute to air quality concerns. It is the visible trend in Central and Eastern Europe, while Western European cities often have stricter regulations, resulting in lower NO_2 levels. The histogram below shows how distribution differs depending on station area.

Picture 17. NO_2 distribution in different areas



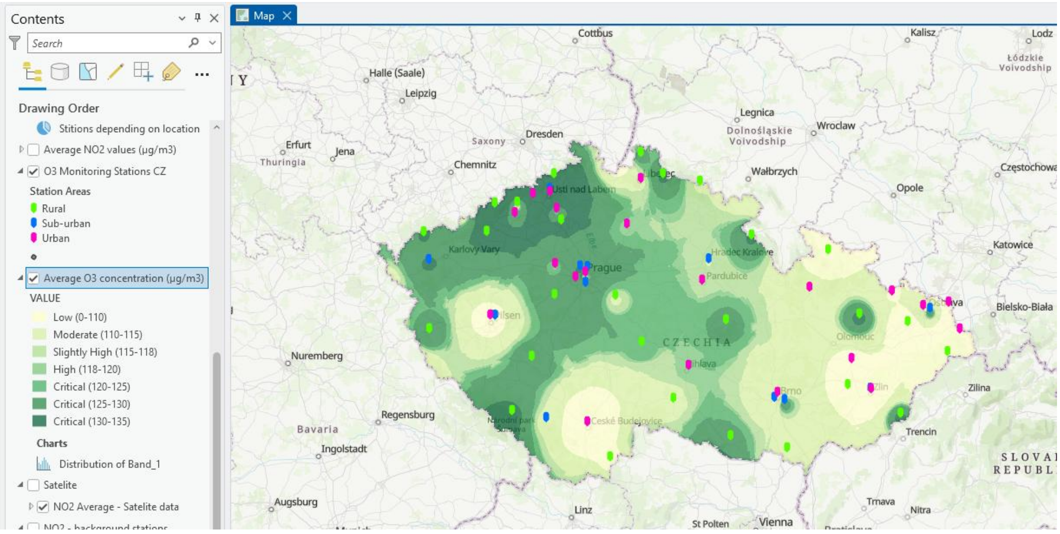
Source: own processing

It shows the levels of nitrogen oxide in different areas and confirms the huge difference between NO_2 values in urban and rural areas, where people do not have as much influence on the environment.

4.3.7 IDW Analysis for ozone (O3)

While the EU limit is 120 µg/m^3 (maximum daily 8-hour average), the created map shows that some regions exceed this limit.

Picture 18. O3 pollution visualisation



Source: own processing

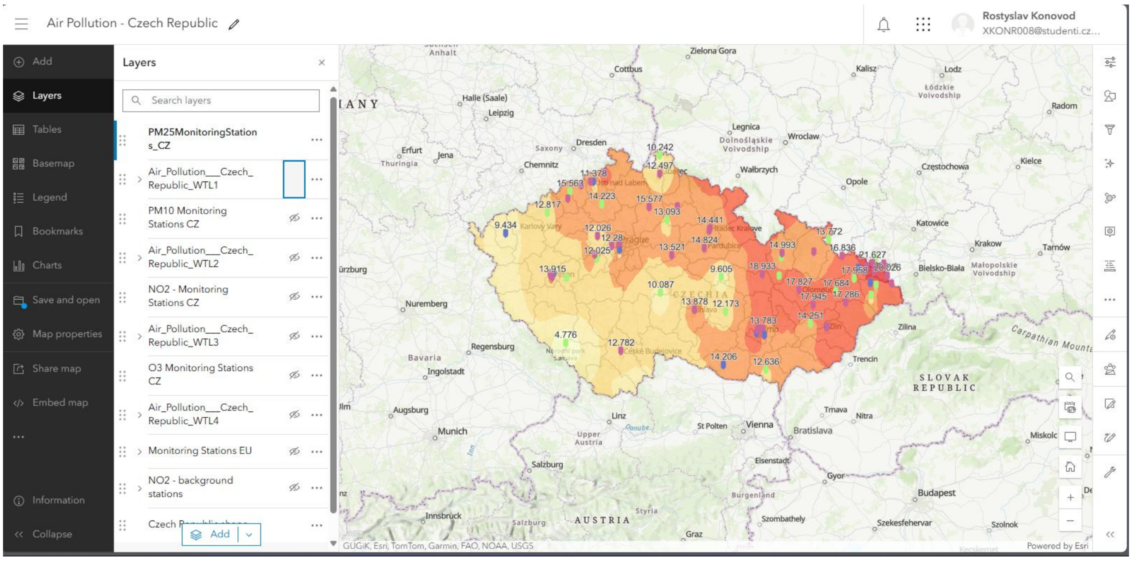
Ozone pollution follows a different pattern than NO_2 and PM. While nitrogen dioxide (NO_2) and particulate matter (PM) concentrations tend to be highest in urban areas due to direct emissions from traffic and industry, ozone levels are typically **lower in urban regions**. This is because NO_x emissions in cities react with O_3, reducing its concentration (EEA, 2021).

The average concentration of ozone for this case study was calculated as 118 $\mu g/m^3$ using ArcGIS, which is under the EU limit. It also confirms that the Czech Republic's ozone levels are in line with other Central European countries, where pollution transport and meteorological conditions contribute to high rural concentrations (European Commission, 2022).

4.4 Publishing map to ArcGIS Online

After all analysis is done, the map should be published to ArcGIS Online to allow the use of this map in web application building. Before publishing, it is necessary to make sure that all layers, symbology, and settings are finalized in ArcGIS Pro. To publish the map into ArcGIS Online, such steps were performed: **Share** → **Web Map**. After assigning the name to the map and creating a folder for it in ArcGIS Online and pressing the "Publish" button, the map is accessible in ArcGIS Online.

Picture 19. Opening map in MapViewer



Source: own processing

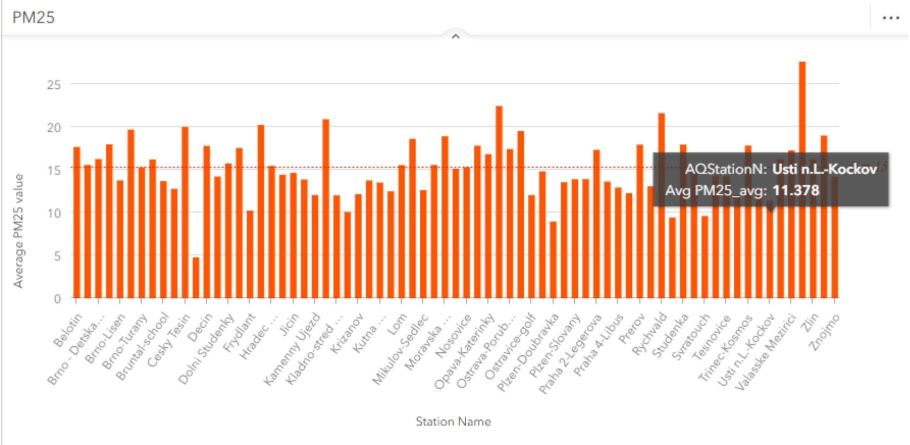
To open this map for web application creation, it should have "Shared" status. For this, all layers of the map were selected and shared through the "My Content" section. Now, it is ready for use in ArcGIS Insights and StoryMaps to add interactive charts and statistics and create a web application.

4.5 Creating interactive graphs with ArcGIS Insights

The ArcGIS Insights tool was used in the project to create histograms and heatmaps, which will be used in the final StoryMap. By integrating these graphs and maps, I made my StoryMap more interactive and accessible, allowing users to explore data and interact not only with the map layers but also with graphs and data in this project.

To begin, I transferred my datasets for pollutant concentration levels from my ArcGIS online maps to ArcGIS Insights. Then I selected the pollutant dataset, which I would like to add to my StoryMap. The histogram, which represents average PM2.5 values across all of the monitoring stations in the Czech Republic, was created using the "Column chart" visualization type.

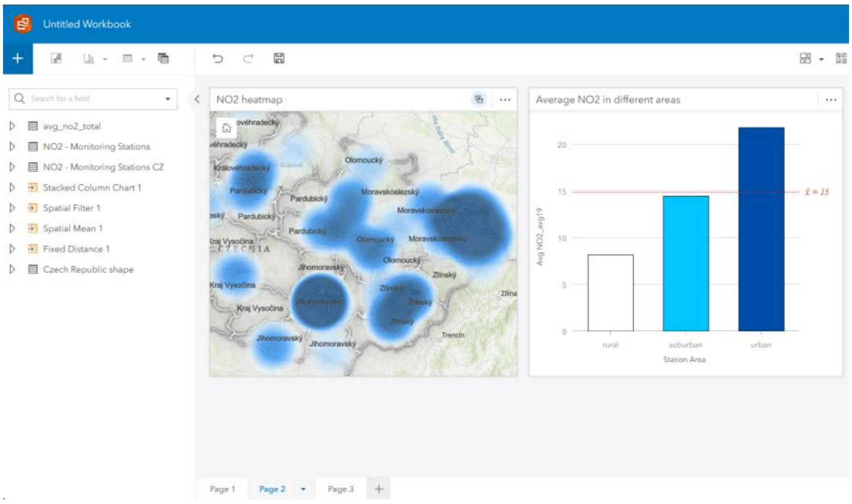
Picture 20. Creating a column chart in ArcGIS Insights



Source: own processing

For NO₂, the heatmap was also created. The chart on the right shows concentration levels based on different area types—rural, suburban, and urban. It also allows users to interact with the map through this chart—by clicking on different bars. The map highlights impact zones of NO₂ pollution across different regions of the Czech Republic.

Picture 21. Heatmap and interactive chart for NO₂



Source: own processing

The highest NO₂ concentrations appear around Prague, Ústecký, Moravskoslezský, and Jihomoravský regions, which are known for dense urbanization and industrial activity. It also confirms an association with major transport routes, particularly around Prague and key industrial cities. After assigning labels and choosing colors and filters, the pages were ready to be published. It is necessary to retrieve the link for this report, which will be used in ArcGIS StoryMaps.

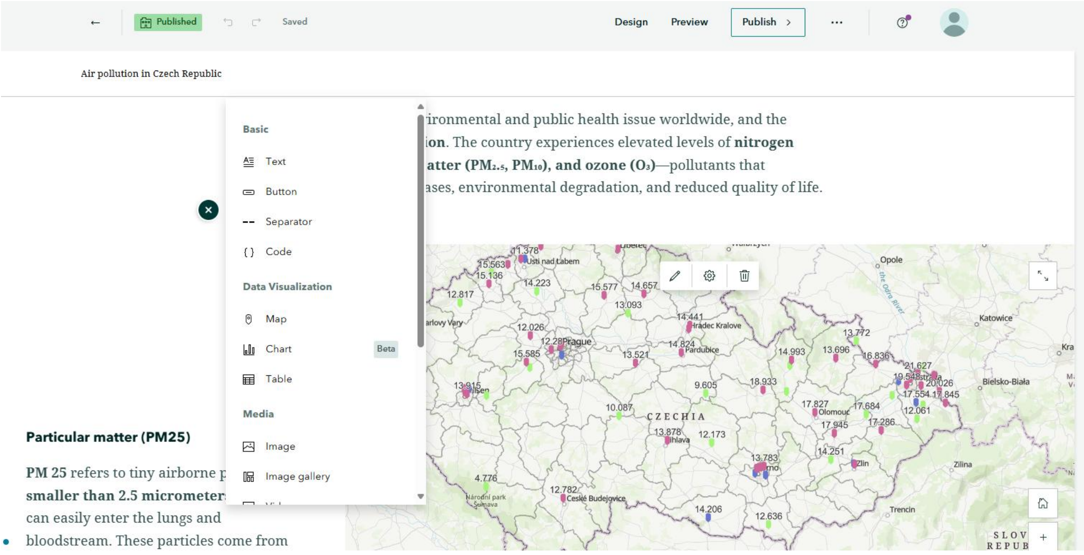
4.6 Creating a StoryMap

The StoryMaps was selected from other web application building tools by ArcGIS. It’s flexible, easy to use, and the key advantage is that this software allows you to use any multimedia, such as audio, video, and images. StoryMaps also support transferring maps and interactive data from ArcGIS Insights.

This is the final step of the practical part. After logging in to the StoryMaps portal, the application allows you to immediately create a StoryMap from a template or scratch. This step includes the uploading of text, ArcGIS Insights graphs, and maps from ArcGIS online.

When everything is uploaded, the map may be published to all internet users or users across your organization. To publish the map, the “Publish” button was used. When all these actions are done, the StoryMap is finally available on the internet.

Picture 22. StoryMap creation



Air pollution in Czech Republic

ironmental and public health issue worldwide, and the ion. The country experiences elevated levels of **nitrogen** **atter (PM$_{2.5}$, PM$_{10}$), and ozone (O$_3$)**—pollutants that ases, environmental degradation, and reduced quality of life.

Particular matter (PM25)

PM 25 refers to tiny airborne p **smaller than 2.5 micrometer** can easily enter the lungs and

- bloodstream. These particles come from

Source: own processing

Now, this presentation allows users to access the data about air pollution in the Czech Republic, interact with maps, and see the key insights about pollutant measurements across the country. The web page also contains information about pollution levels in some other European countries. In the end of the StoryMap, there are recommendations, which could be used to improve air quality in the Czech Republic.

5. Results and Discussion

Created map layers and published a StoryMap that represents air pollution in the Czech Republic and could be accessed by this link: https://arcg.is/11Geyu0.

It shows the key trends for pollutants, such as that major urban centers, industrial regions, and transportation hubs exhibit the highest concentrations of $PM_{2.5}$ and NO_2. The heatmap created with ArcGIS Insights shows the most critical areas in the Ostrava-Karviná Industrial Region, Prague city center, and Northern Bohemia.

The statistics that were retrieved using IDW and statistical tools in ArcGIS Pro were compared with WHO and EU air quality limits. For example, the recommended annual limit of PM10 is 15 $\mu g/m^3$, while research shows 19.92 $\mu g/m^3$. All other pollutant concentrations are higher than the limits of the World Health Organization, but still in the range of European Union rules. Overall, the average concentrations of pollutants in the Czech Republic remain moderate, but western countries, such as Germany or Denmark, have a better situation because of stricter environmental policies for public transport and factories.

Improvements that could be done to improve air quality include industrial and transport emission control, underground ventilation, and green corridors. For example, in Ostrava-Karviná, where pollution spikes at certain hours, factories could be required to shift operations to off-peak times or adjust production levels based on live pollution readings.

The chosen toolset performed well in analyzing and visualizing air pollution trends in the Czech Republic. ArcGIS Pro provided powerful spatial analysis for ground-based data from monitoring stations. ArcGIS Online provided data sharing of the layers to the Internet. ArcGIS Insights enabled advanced data exploration and interactive analytics, allowing the inclusion of these statistics into the final web application. Finally, ArcGIS StoryMaps effectively helped in web application building. Together, these tools created a great technical environment for the study.

6. Conclusion

This bachelor thesis examined the functions of different GIS tools and their application in analyzing air pollution in the Czech Republic. The theoretical part provided an overview of GIS technologies, including ArcGIS, QGIS, and Google Earth Engine, and discussed various data sources and spatial analysis methods. The practical part involved using ArcGIS Pro, ArcGIS Online, ArcGIS Insights, and ArcGIS StoryMaps to visualize and analyze air pollution data. These tools helped in effective data processing and visualization, resulting in a user-friendly web application.

The findings highlight key pollution trends across the Czech Republic, main emission sources, and regions with critical pollution levels, such as the Ostrava-Karviná Industrial Region, Prague city center, and Northern Bohemia. The insights help to create strategies to reduce air pollution levels in the country.

The study confirms that GIS tools are necessary for environmental research and policy planning. In addition, with the development of artificial intelligence, these tools will become irreplaceable in the future, as they have the potential to not only analyze but also predict future events exactly. Future research could expand this work by integrating real-time sensor data and predictive modeling to enhance air quality assessments further.

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8. List of pictures, tables, graphs and abbreviations

8.1 List of pictures

8.2 List of tables

8.3 List of abbreviations

GIS	Geographic Information System
QGIS	Quantum Geographic Information System
AI	Artificial Intelligence

EEA	European Environment Agency
EPA	Environmental Protection Agency
ESA	European Space Agency
IoT	Internet of Things
PM	Particulate Matter
WHO	World Health Organization
IDW	Inverse distance weighting

9. Appendix

Link to the StoryMap in ArcGIS Online - https://arcg.is/11Geyu0

Duplicate posted on the university server - https://gis.czu.cz/portal/apps/storymaps/stories/53edf53d46ca4ac7bd771fcf113e468c