Air pollution in Georgia as seen from Space

Study based on satellite imagery & Copernicus data

Prague – Tbilisi
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Air pollution in Georgia as seen from Space

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Contents

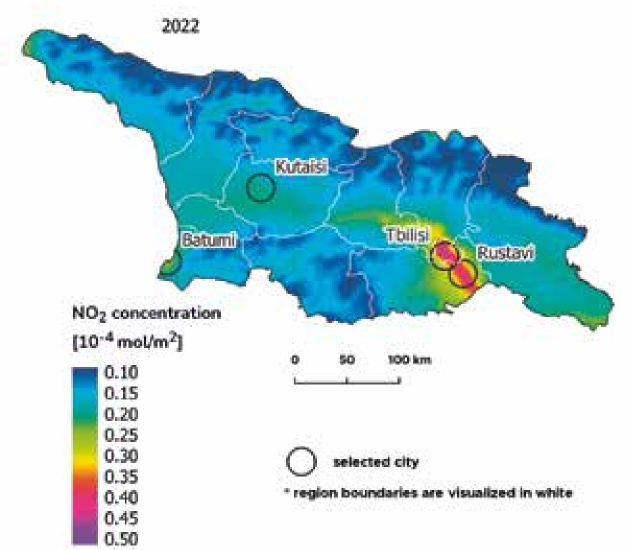
Abbreviations and acronyms

CAMS - Copernicus Atmosphere Monitoring Service
CO - carbon monoxide
ECMWF - European Centre for Medium-Range Weather Forecasts
EEA - European Environment Agency
EPA - U. S. Environmental Protection Agency
EU - European Union
GIS - geographic information system
L2 - Sentinel-5P Level-2 product
MEPA - Ministry of Environmental Protection and Agriculture of Georgia
NO_2 - nitrogen dioxide
PM_{10} - particulate matter under 10 μm
S5P - Sentinel 5P
SH - Sentinel Hub
TROPOMI - TROPOspheric Monitoring Instrument
WHO - World Health Organization

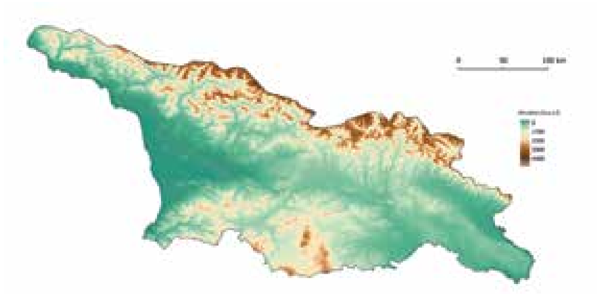
Key findings

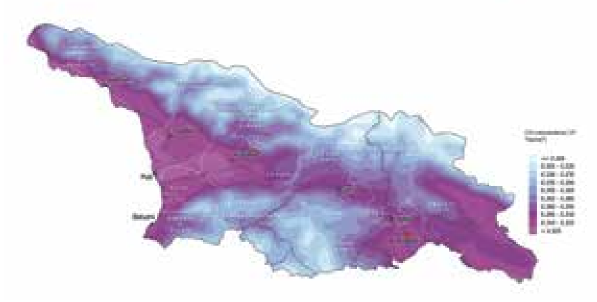
Good air quality is one of the essential factors in public health, societal well-being, and stable natural ecosystems. Producing lower emissions of pollutants and greenhouse gases helps prevent climate change accelerating. Polluted air remains one of the most serious threats to human health, contributing to nearly 7 million deaths worldwide each year. In 2018, air pollution in Georgia was responsible for around 4000 premature deaths and the economic costs were estimated at $560 million, as much as 3% of GDP (World Bank, 2021). Georgia belongs among the countries very vulnerable to climate change, while concerns remain in the country about compliance with air quality standards in transport or compliance with the environmental responsibility of industries. This study aims at analysing and interpreting geographic and temporal patterns and the causes of three major pollutants – nitrogen dioxide, carbon monoxide, and PM_{10} particulate matter. These initial steps in a country-wide air pollution analysis suggest several possible improvements and recommendations for air quality management.

Nitrogen dioxide (NO_2) in Georgia is most concentrated **in places with a high population density**, namely the capital, **Tbilisi** (see picture below), and the major industrial centre of Rustavi or cities such as Kutaisi, Batumi, and Gori. They function as transport hubs and feature most industrial facilities. **NO_2 levels in the rest of the country are evenly distributed with respect to the ruggedness of the surface**. The lowest concentrations are found in the mountains, where there is little human activity. Depending on the weather, NO_2 is dispersed with the prevailing airflow. In the Colchis Lowland, pollutants are blocked from escaping by mountain ranges. **Significantly higher concentrations of NO_2 occur in winter because of heating.** When compared with the **road network density, NO_2 concentrations** show a **strong pattern.** As much as 44% of the variability of NO_2 pollution is explained by the presence of traffic at the given location (R2 = 0.44).



The greatest influence on the amount of carbon monoxide (CO) in the air is **elevation**. High concentrations remain at the lowest elevations, with mountains at the boundaries preventing dispersion (see picture below). The spatial distribution of the pollutant coincides with the natural pattern,





so the influence of natural CO emissions is more significant than that of human-made sources. It is thus impossible to determine specific anthropogenic sources of CO pollution in the basic data analysis, and nor does the study detect clear contributions of anthropogenic origin after filtering out the natural sources. Climate change can, never-

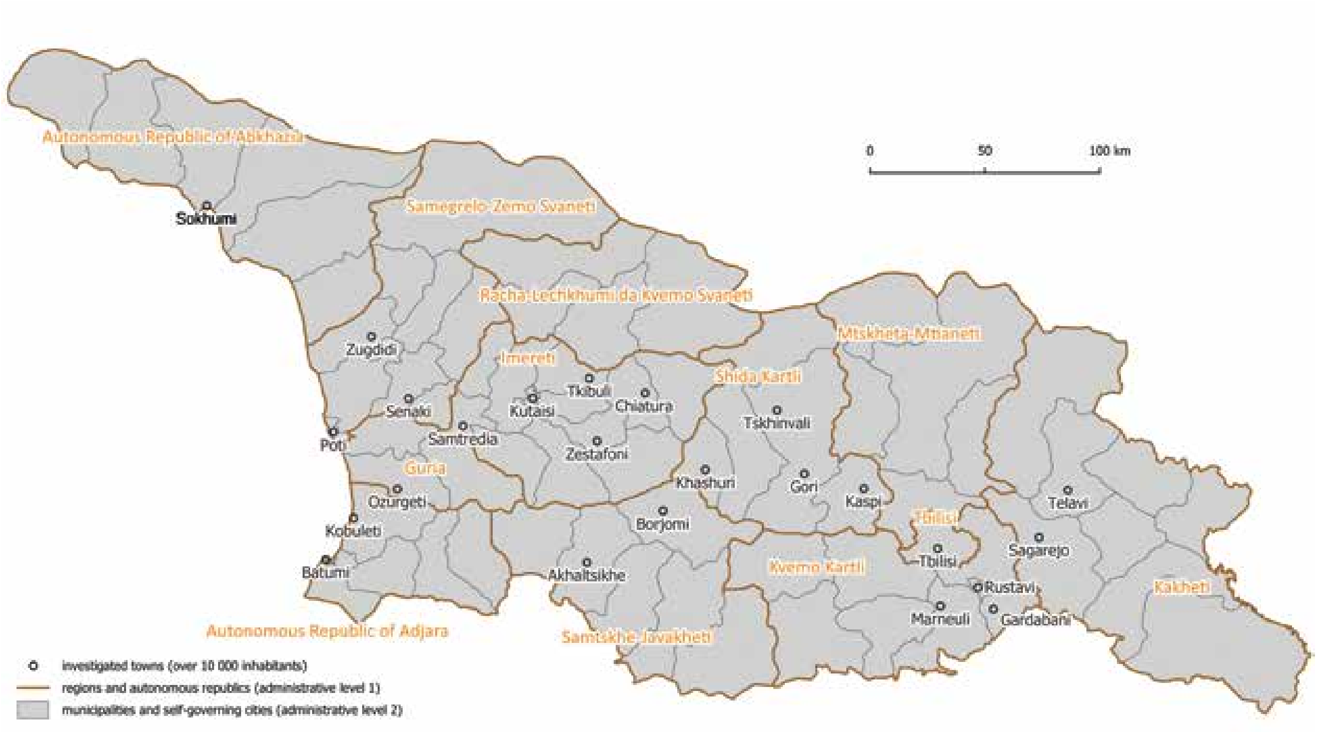


Fig. 1: Cities and towns in Georgia with over 10,000 inhabitants specifically investigated for air pollution. Sources: administrative units (HDX, 2022; Runfola et al., 2023 [geoBoundaries]; modified), cities (OpenStreetMap Contributors, 2023).

theless, indirectly accelerate the uptake of CO to the country by chemical processes in the atmosphere.

Particulate matter over 10 µm (PM_{10}) was assessed on the basis of two models because of data availability. The global model shows **elevated concentrations primarily in the south-east because of dust picked up by the wind**. The finer European model highlights **high concentrations around cities and their main highway connectors**, with Tbilisi and Rustavi having the highest averages. **The yearly variation** in PM_{10} showed **no strong correlation with COVID-19** lockdown measures, with concentrations decreasing steadily towards 2022. **The seasonality of PM_{10} distribution is caused by natural processes**, with **summer and spring** affecting Tbilisi and Rustavi because of **particles spreading westwards from the drier east**, and **winter and autumn peaks around cities as a result of household heating**; however, the impact of forest fires should be investigated further.

Introduction

Georgia, a transcontinental country in the Caucasus region, has to deal with a number of environmental difficulties, including air pollution, deforestation, water pollution, and invasive species. The purpose of this study is to examine several pollutants in the air and their causes and impacts. According to the Georgian Law on Ambient Air Protection, “the pollution of the ambient air with harmful substances means the dispersion (emission) of any substance in the ambient air as a result of human activities, which affects or may adversely affect human health and the natural environment” (Legislative Herald of Georgia, 1999).

Georgia has a population of approximately 3.7 million; its capital, Tbilisi, is the most populous city, with more than 1.5 million inhabitants. The rapid growth of the country’s industrial and transport sectors, along with the lack of proper regulations and enforcement, has resulted in decreasing air quality in many parts of Georgia (Worldometers, 2023). The main sources of air pollution in the country include traffic emissions, industrial activities, and household heating. This has caused a variety of negative health effects, including respiratory and cardiovascular problems. According to the WHO (WHO, 2023), air pollution is assumed to be responsible for around one-third of global lung cancer deaths, ischemic heart disease deaths, and stroke deaths. In 2019, 5220 deaths in Georgia were caused by air pollution.

There are several factories in and around the capital, Tbilisi, and Rustavi that discharge pollutants such as sulphur dioxide, nitrogen oxide, and particulate matter. Many factories use outdated technologies that cause excessive pollution.

Georgia’s geographical location is a factor that contributes to increased air pollution. The varied topography and mountainous border areas prevent smog and other pollutants from dispersing into the surroundings, which leads to higher concentrations in the lowlands in the central part of the country.

The monitoring of air quality in Georgia began in the 1960s. In 2013, the government started modernising the obsolete monitoring equipment and in 2020, an air quality monitoring system was built according to the European indicator measurement standards and harmonised with the EU atmospheric air quality indices (MEPA, 2020 and 2023). Eight automatic monitoring stations were installed in Tbilisi, Kutaisi, Batumi, and Chiatura and air samples are taken every three months from various municipalities (MEPA, 2023).

Air pollution from transport

The increasing traffic load and the technological status of transportation in Georgia present a threat to air quality. According to the Information-Analytical Department of the Ministry of Internal Affairs, emissions from transport vehicles are the major source of emissions in the country, contributing to overall emissions by up to 71%.

37% of these emissions are concentrated in the capital city, Tbilisi, with the largest population, with induced transit of residential cars, cargo, and commuters from the vast hinterland (National Statistics Office of Georgia, 2023). The report on air quality in Tbilisi states that in 2019, more than 90% of the vehicles in Georgia were older than ten years, which was caused by the tariffs on the export of outdated personal vehicles being lowered in 2004. Buses have recently started to fail technical inspections because of problems caused by ageing and outdated technology or safety systems, including car emissions tests (Government of Georgia, 2018). New buses to be purchased in 2024 could partly solve this problem.

Personal car ownership is growing rapidly by around 70,000-80,000 cars each year. Many of the cars are older models, which are less efficient and produce more emissions (National Statistics Office of Georgia, 2023).

According to the 2017 statistics, only 40% of car owners had undergone a technical inspection. Since 2019, regular technical inspections have become compulsory and fines have been introduced for driving without an inspection pass. This may have improved the situation slightly (Ministry of Economy and Sustainable Development, 2019), but controls are still seldom enforced.

Nitrogen dioxide (NO_2)

Nitrogen dioxide (NO_2) is an important trace gas present both in the troposphere and stratosphere, while it is also a key atmospheric pollutant produced by anthropogenic activities. According to the WHO (WHO, 2000), higher nitrogen dioxide levels can lead to respiratory infections and reduced lung function and growth; it is also linked with increased symptoms of bronchitis and asthma. The interaction of NO_2 with water and other chemicals in the atmosphere leads to the formation of acid rain, causing changes in forests and aquatic ecosystems.

According to the European Environment Agency 2020 Air Quality report (EEA, 2022), **road transport** was the principal source of nitrogen oxides and was responsible for 37% of emissions. Other sources of NO_2 are **petrol and metal refining**, electricity generation from **coal-fired power plants**, manufacturing industries, and food processing. The natural source of the gas comes from **microbiological processes in soils, wildfires, and lightning**.

Carbon monoxide (CO)

Carbon monoxide (CO) is a colourless, tasteless, and odourless poisonous gas. CO is generally considered an important indirect greenhouse gas as it enhances the lifetime of greenhouse gases such as methane, halocarbons, and tropospheric ozone. It is a product

Main human sources of NO_2

- motor vehicle exhaust
- coal-fired power stations
- petrol and metal refining

of incomplete combustion as encountered in the operation of vehicles, heating, coal power generation, the coke and steel industry, and biomass burning. Approximately 40% of CO comes from natural sources such as **volcanic eruptions, emissions of natural gases, degradation of vegetation and animals, and forest fires**, and 60% comes from **fossil fuel consumption, waste incineration, tobacco smoke, and charcoal fires** (EEA, 2019).

In equatorial regions the oxidation of isoprene and biomass burning play the most important role in CO production, while at higher latitudes fossil fuel combustion is the main source.

The dominant sink of CO is oxidation by the hydroxyl radical (OH), the key reactive species of the troposphere:

$$CO + OH \rightarrow H + CO_2$$

Approximately 90% of CO (and 70% of OH) in the atmosphere on a global basis is consumed by this reaction, which is responsible for one-sixth of the atmospheric CO_2 (Feilberg, 2002). This process leads to an important feature of CO in extratropical latitudes, which is its seasonal cycle. While CO accumulates in the atmosphere during winter when OH concentrations are low, in spring it is depleted rapidly as a result of reaction (1), as the warmer air carries more moisture, which produces more OH. Thus, in the northern hemisphere, CO concentrations are generally at their lowest in June, July, and August.

There is a clear causal link between human systemic diseases and the effects of elevated concentrations of carbon monoxide in the air. CO has a toxic effect on the organs of tissues with high oxygen consumption – the

Main human sources of CO

- fossil fuel consumption
- waste incineration
- fires, e. g. biomass burning

brain, heart, and a developing foetus. There are proven toxic effects of carbon monoxide on the health of the mother during pregnancy and the development of congenital heart defects in infants (EPA, 2022). High concentrations of carbon monoxide enhance the combined action of other pollutants (O_3, SO_2, PM, NO_2) and increase the risk of all respiratory diseases.

While CO accumulates in the atmosphere during winter, it is depleted rapidly because of natural reactions in spring. Thus, in the northern hemisphere, CO concentrations are generally lowest in June, July, and August (NOAA 2015).

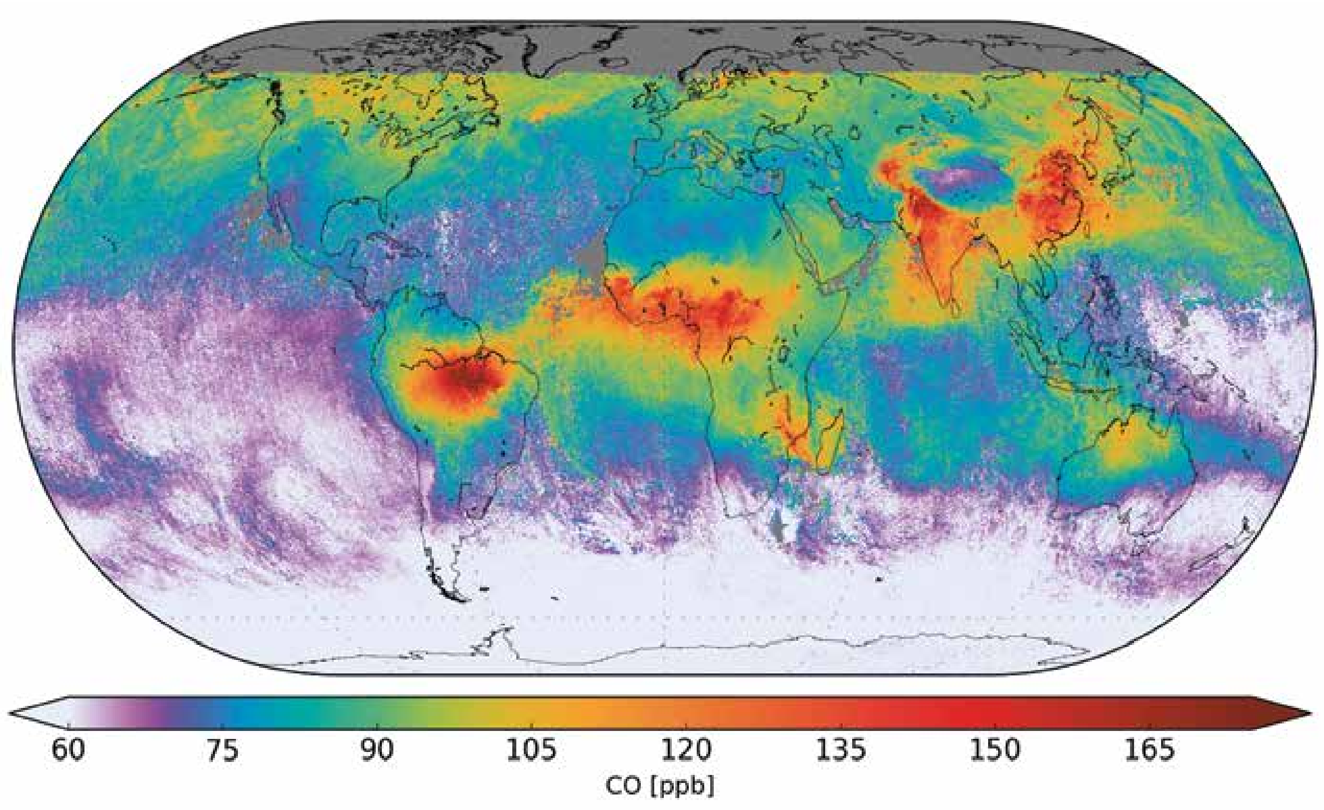


Fig. 2: The global CO total column mixing ratio average concentration created with TROPOMI L2 data (November 13th-19th 2017), The data clearly shows CO enhancement by wildfires in Brazil, Africa, Madagascar, and Australia as well as anthropogenic air pollution in India and China). Source: TROPOMI, 2023.

Particulate matter (PM_{10})

Main human sources of PM_{10}

- construction activities
- transport
- domestic heating
- industrial processes
- power plants

Particulate matter or atmospheric aerosols are solid or liquid particles suspended in the air and capable of free movement in the atmosphere. They are classified by size, rather than their chemical properties. The coarse fraction of PM_{10} contains larger particles ranging from 2.5 to 10 µm. Particles smaller than 2.5 µm ($PM_{2.5}$) are primarily produced by mechanical processes such as **construction activities**, **road dust** re-suspension, and wind, whereas PM_{10} originates primarily from combustion sources, including **domestic heating** and **transport**. Other significant sources include **industrial processes** and **power plants**. Naturally, particles are released into the atmosphere during **volcanic activities, fires, erosion,** and from **seawater** (WHO, 2013). **Dust storms coming from bare land cover** can also contribute to the presence of PM_{10} in the atmosphere.

There is a direct negative effect of high particulate matter concentrations on human health (WHO, 2005). The effect depends on the size, chemical composition, and shape, but generally concerns the respiratory and cardiovascular systems. PMs have toxic and genotoxic effects; they increase the carcinogenic risk (Karlsson et al., 2004), affect the structure and integrity of endoepithelial cells, increase the potential for vascular thrombosis (Gilmour et al., 2005), and increase blood coagulation and the risk of stroke, myocardial infarction, and atherosclerosis (Künzli et al., 2005).

Particulate matter (PM) can act as catalysts for chemical reactions on their surface. Thus, the toxic effect of PM is enhanced by the content of other pollutants in the air. All these features make it impossible to clearly define the "safe" concentration of PM in the air. Therefore, WHO experts have recommended values that determine the minimum risk to public health.

The WHO offers a **guideline of annual mean values** for particulate matter concentrations in the air designed to offer guidance in reducing the health impacts of air pollution. In the case of PM_{10} particulate matter the value is **20 µg/m_3**. Short-term levels of pollution should not exceed a 24-hour mean of 50 µg/m^3 (PM_{10}) (WHO, 2023b).

Data and methodology

Sentinel-5P

The Sentinel-5P mission (S5P) involves a satellite devoted to atmospheric monitoring, launched in October 2017 as a part of the EU Copernicus Programme. It carries a TROPOMI spectrometer (TROPOspheric Monitoring Instrument) covering wavelength bands between the ultraviolet and the shortwave infrared. S5P measures gases such as NO_2, ozone, formaldehyde, SO_2, methane, carbon monoxide, and aerosols daily with a spatial resolution of about 5.5 km x 3.5 km (~7 km to ~5.5 km until August 2019).

Sentinel-5P Level-2 (L2) products were used with “quality assurance value” pixels below the 0.5 threshold filtered out. The quality assurance value is an important parameter that reduces the seamless coverage of the areas of interest by S5P data and the proposed methodology takes it into account. NO_2 and CO products (from May 2018 to December 2022) are obtained via SH.

Copernicus Atmosphere Monitoring Service Data (CAMS)

The monitoring of particulate matter (PM_{10}) concentrations was obtained through the Copernicus Atmosphere Monitoring Service (CAMS). CAMS, a part of the Copernicus Programme implemented by the European Centre for Medium-Range Weather Forecasts (ECMWF), provides global, quality-controlled information related to air pollution, solar energy, greenhouse gases, and climate forcing.

For Georgia, two types of datasets were used: the European and the global model. This was because the European model does not cover the entire territory of Georgia. The European CAMS model produces specific daily air quality analyses and forecasts at a spatial resolution of 0.1 degrees (approx. 10 km). Nine European air quality forecasting systems are utilised in the production, using a median ensemble from individual outputs. Furthermore, the analysis combines model data with real ground observations provided by the European Environment Agency (EEA) into a complete and consistent dataset using various data assimilation techniques. In parallel, air quality forecasts are produced once a day for the next four days.

The Global CAMS atmospheric composition forecast (at a spatial resolution of 0.4 x 0.4°) consists of more than 50 chemical substances (e.g. ozone, nitrogen dioxide, carbon dioxide) and seven different types of aerosols (desert dust, sea salt, organic matter, black carbon, sulphate, nitrate, and ammonium aerosol). The analysis, which is the best estimate of the state of the atmosphere at the beginning of the forecast period, is derived from combining the latest satellite observations with a previous forecast, using a technique known as data assimilation. This method is used to establish the initial conditions for each forecast. Both the analysis and the forecast are available at hourly time steps at various pressure levels (CAMS, 2022).

Outline of processing

All the data was automatically downloaded and preprocessed using our proprietary Python scripts and the SH service for **the study period, May 2018-December 2022.** The final processing steps were executed on a desktop GIS. **In maps and graphs, PM_{10} concentrations were given in μg/m³, while NO_2 and CO were given in the original 10^{-4} mol/m² units.**

The Sentinel-5 revisit time for Georgia is once a day with scanning overlaps at higher latitudes because of the near-polar, sun-synchronous orbit of the satellite. The processed data thus comprises all the available satellite measurements. Using all available data meant combining data from several satellite orbits with varying grid sizes and orientations. To address this, all the S5P satellite observations were downscaled to obtain a regular grid with a resolution of 1×1 km. It is important to understand that the quality of accessible pixels is highly dependent on weather conditions, sensor errors, and other parameters such as cloud cover.

CAMS provides daily estimates of pollutant concentrations calculated using a combination of satellite data, ground-based observations, and numerical models. The global version of the model estimates pollutant concentrations for two timestamps each day: at 0:00 and at 12:00. The European version provides hourly estimates. In both cases, daily averages were calculated by taking the mean of all daily pollutant concentration values.

Daily values were used to calculate various statistics to gain deeper insights into the data. These included all-time averages and medians from all the values measured between 2018 and 2022, yearly averages and medians, seasonal averages and medians, and monthly averages and medians. Averages for each month were calculated by taking the mean of all values measured during that month between 2018 and 2022. In the case of seasonality assessment, seasons were defined as three-month periods of winter (December-February), spring (March-May), summer (June-August), and autumn (September-November) to simplify the air quality caused by weather conditions.

Rasters representing per-pixel statistics were then used to calculate the average concentrations of pollutants within different zones of Georgia. These zones included administrative units such as regions and municipalities, as well as selected cities and towns with a population of over 10,000 inhabitants if the analysis focused on households and transport.

To assess the impact of transportation on air quality, the road density was compared to concentrations of NO_2. Road data was obtained from the OpenStreetMap database, specifically selecting motorways, trunk roads, primary, secondary, and tertiary roads, bus routes, service roads, and residential and unclassified roads. To account for the varying importance of road classes, different weights were assigned: motorways were given a weight of four, trunk roads three, primary and secondary roads two, and the rest of the classes a weight of one. Using a radius of 7 kilometres, the weighted road density was calculated for each point. The result was a raster with a 1-km resolution.

Results

The results of the air pollution analysis include overview maps and graphs with individual pollutants and the interpretation of their distribution for the study period between May 2018 and December 2022. Fig. 3 shows the administrative units of Georgia for which analyses were conducted. Three administrative levels of spatial data were compiled using geoBoundaries (Runfola et al., 2023) and the Humanitarian Data Exchange data (HDX, 2022) to account for the officially recognised Georgian borders and the inclusion of self-governing cities (see https://newnala.nala.ge/Cities). In the report, the administrative divisions are referred to as the following: admin. level 0 – country, admin. level 1 – region, admin. level 2 – municipality (or self-governing city where applicable).

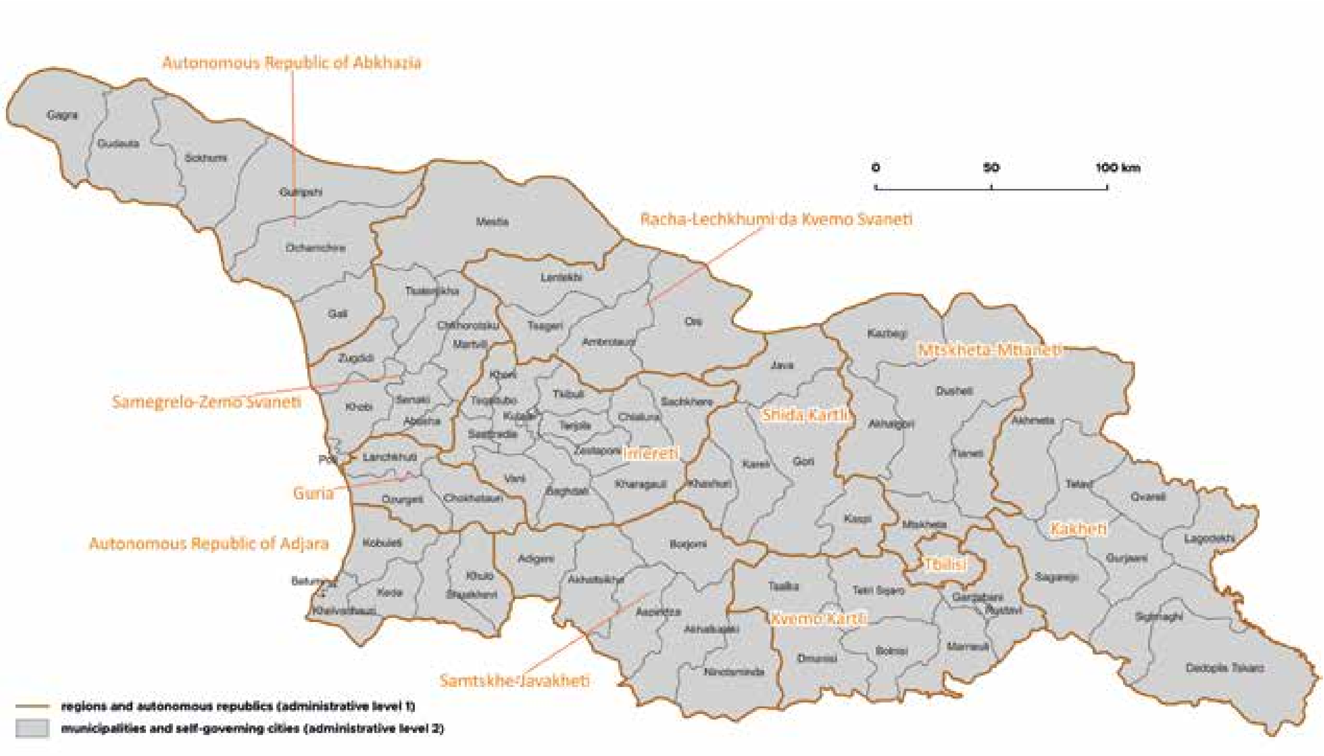


Fig. 3: Administrative divisions of Georgia. Sources: HDX, 2022 and Runfola et al. [geoBoundaries], 2023; modified.

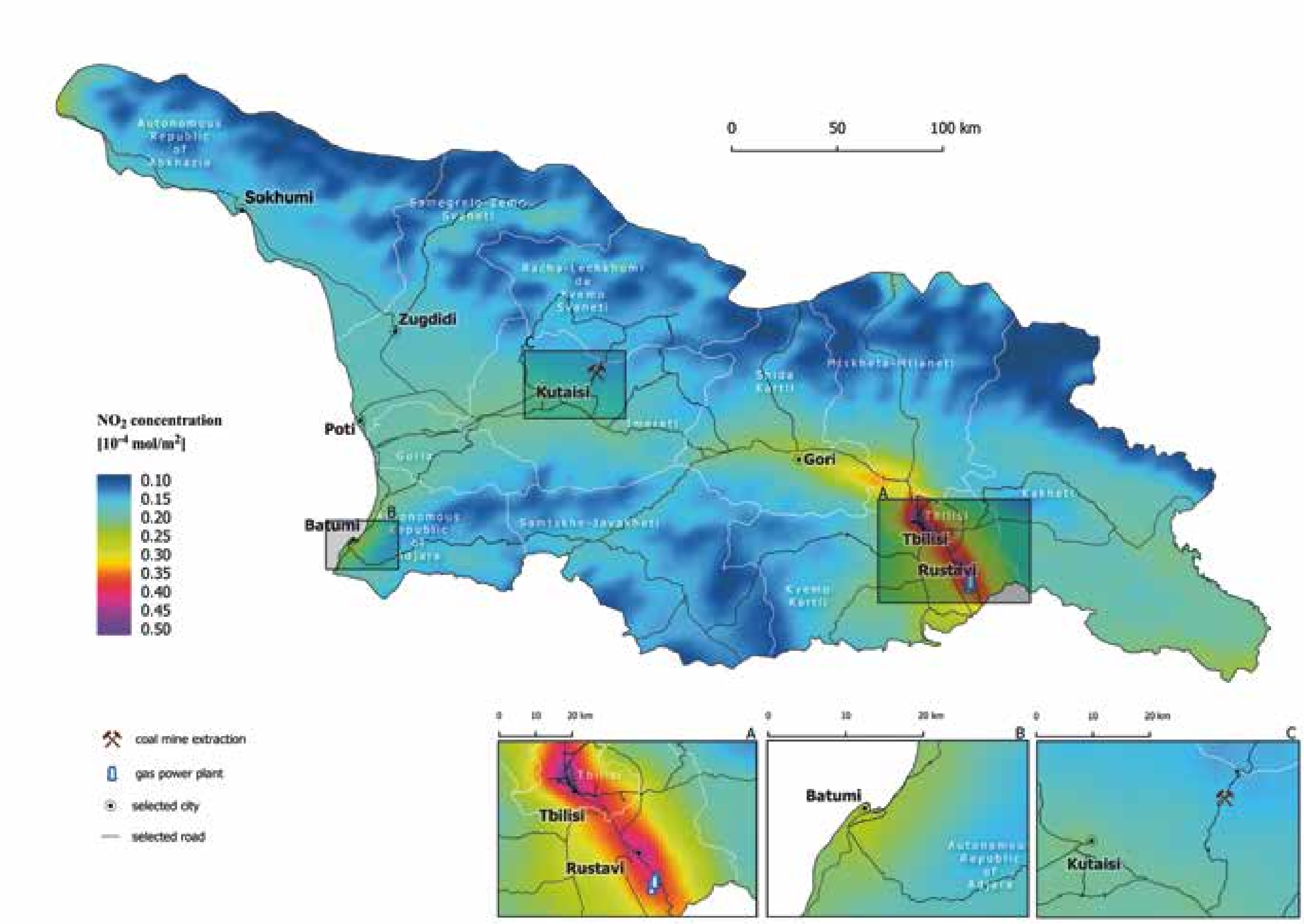


Fig. 4: Average NO_2 concentrations in Georgia between May 2018 and December 2022, obtained from the Sentinel-5P satellite. Sources: imagery (ESA, 2018-2022; modified), roads and cities (OpenStreetMap Contributors, 2022), coal and gas (Global Energy Monitor, 2023).

Nitrogen dioxide (NO_2)

Basic analysis

Fig. 4 shows the average distribution of NO_2 concentrations in Georgia. The terrain can influence nitrogen dioxide concentrations by affecting the dispersion and transport of pollutants. The geography of the regions with mountains and valleys can influence the distribution of NO_2. The highest concentrations of NO_2 are typically found in urban areas, where emissions from transport and industry are most concentrated. However, the topography of the region can create localised pockets of higher concentrations, especially in valleys where pollutants become trapped as a result of thermal inversions or wind patterns. Additionally, the terrain can also affect the transport of pollutants between regions, with some areas being more susceptible to pollution from nearby industrial or transportation sources. According to higher NO_2, there is also a correlation between air pollution, industry, and population density. It can be observed that the highest concentrations are tied to the vicinity of the capital, Tbilisi, and the vicinity of Rustavi and Gardabani (the Kvemo Kartli region), where major industrial enterprises are located.

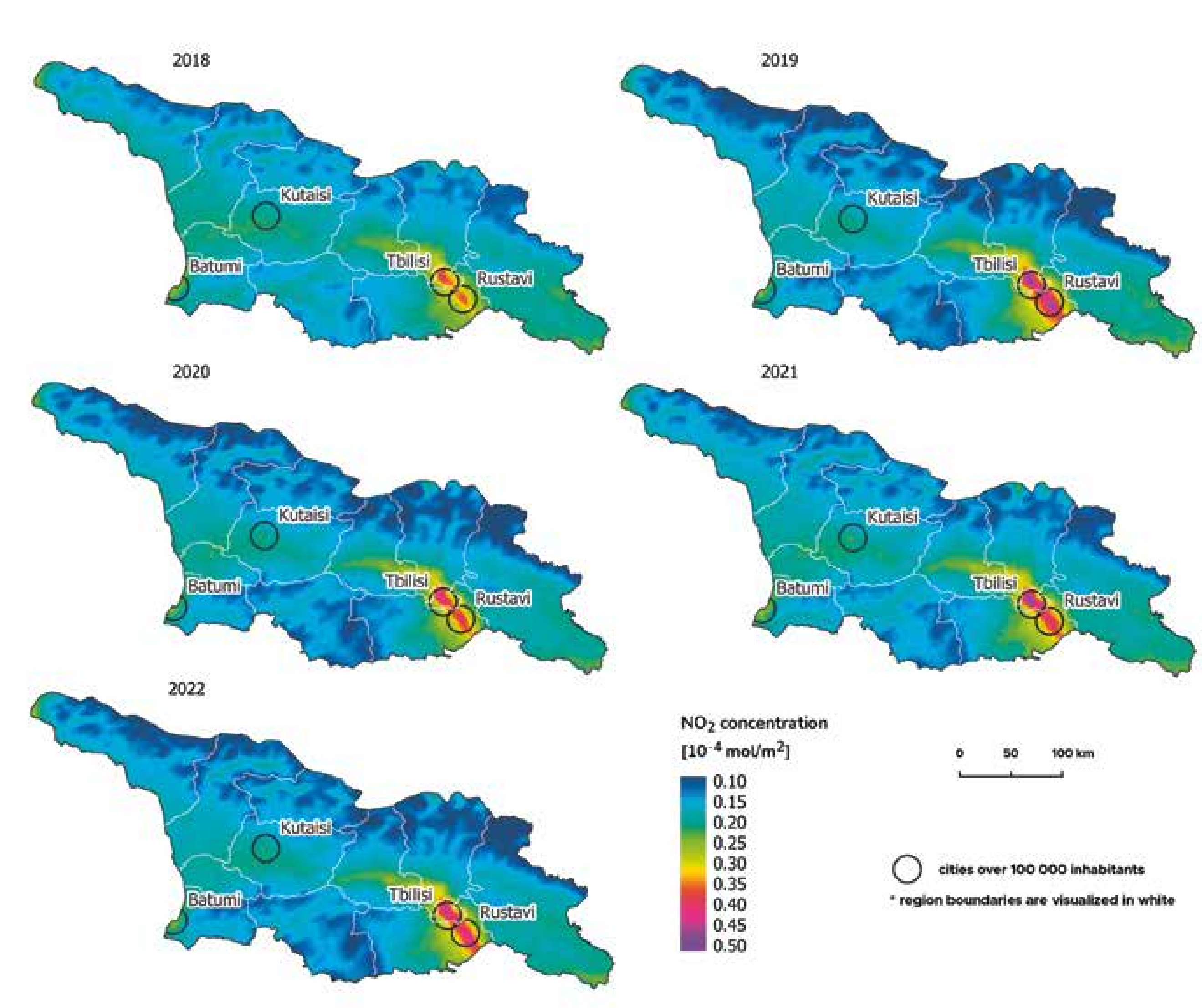


Fig. 5: Average yearly NO_2 concentrations in Georgia between May 2018 and December 2022, obtained from the Sentinel-5P satellite. Sources: ESA, 2018-2020; modified.

The maps in Fig. 5 show the dispersion of NO_2 over Georgia from May 2018 to December 2022. The distribution of the pollutant varies in the same locations over the five years, mainly in the axial valley between the northern and southern mountain ranges. The highest values are found in the capital city, Tbilisi, and its surrounding regions, Kvemo Kartli and Shida Kartli, which are the areas with the largest population density and high-density traffic. There is a noticeable rise in values between 2018 and 2019, which could have been caused by the absence of data from the early months of 2018, when domestic heating increased NO_2 concentrations.

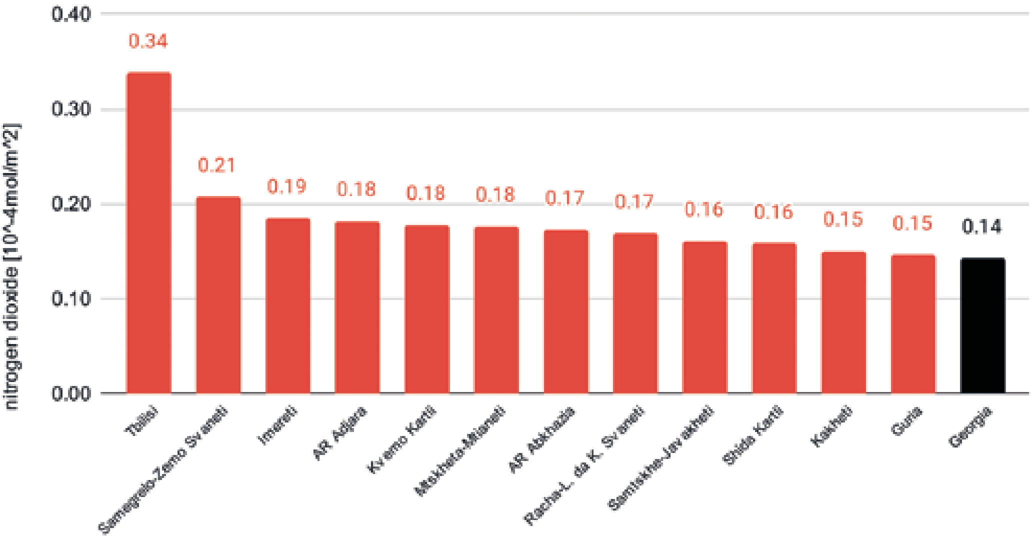


Fig. 6: Average NO_2 concentrations in the regions of Georgia between May 2018 and December 2022, obtained from the Sentinel-5P satellite. Source: ESA, 2018–2020; modified.

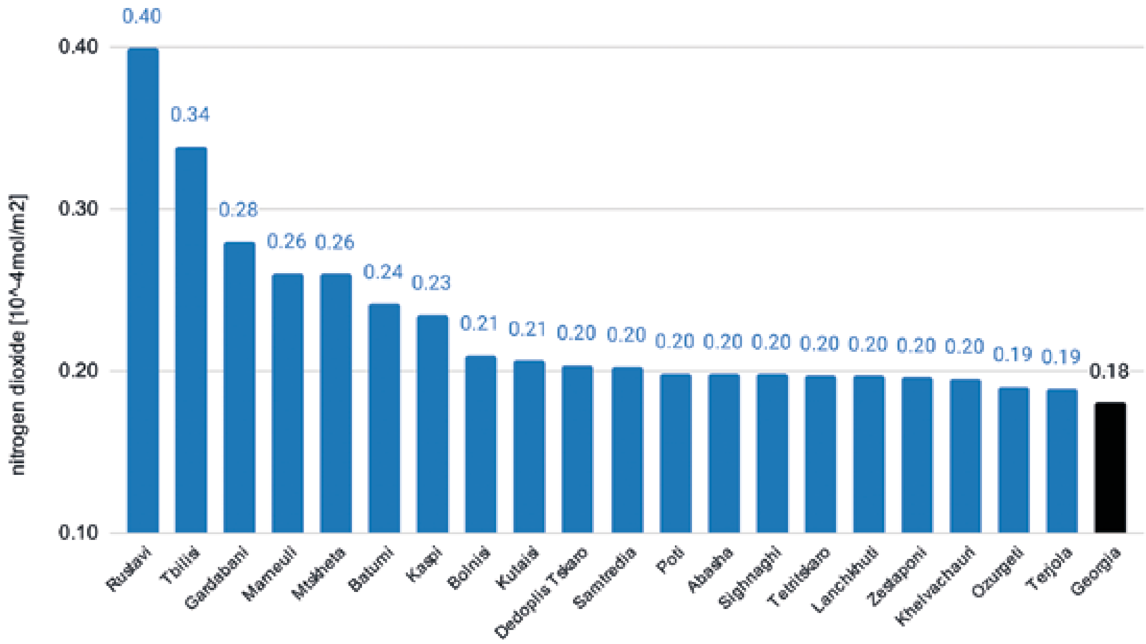


Fig. 7: 20 highest average NO_2 concentrations in municipalities and self-governing cities of Georgia between May 2018 and December 2022, obtained from the Sentinel-5P satellite. Source: ESA, 2018-2020; modified.

Fig. 6 shows a comparison of the average NO_2 values in the regions of Georgia between 2018 and 2022. A significant maximum is found in the Tbilisi region and slightly higher values occur in the neighbouring regions of Kvemo Kartli and Shida Kartli, with higher urbanisation levels and more industrial towns.

A comparison of the average values of 20 municipalities and self-governing cities for the selected period can be seen in Fig 7. The city of Rustavi has the highest levels of NO_2. Rustavi is an industrial city in Georgia that is known for its steel production and other heavy industries, which can be a significant source of NO_2 emissions. Many people driving to work in the capital participate in increasing NO_2 levels by using cars instead of public transport.

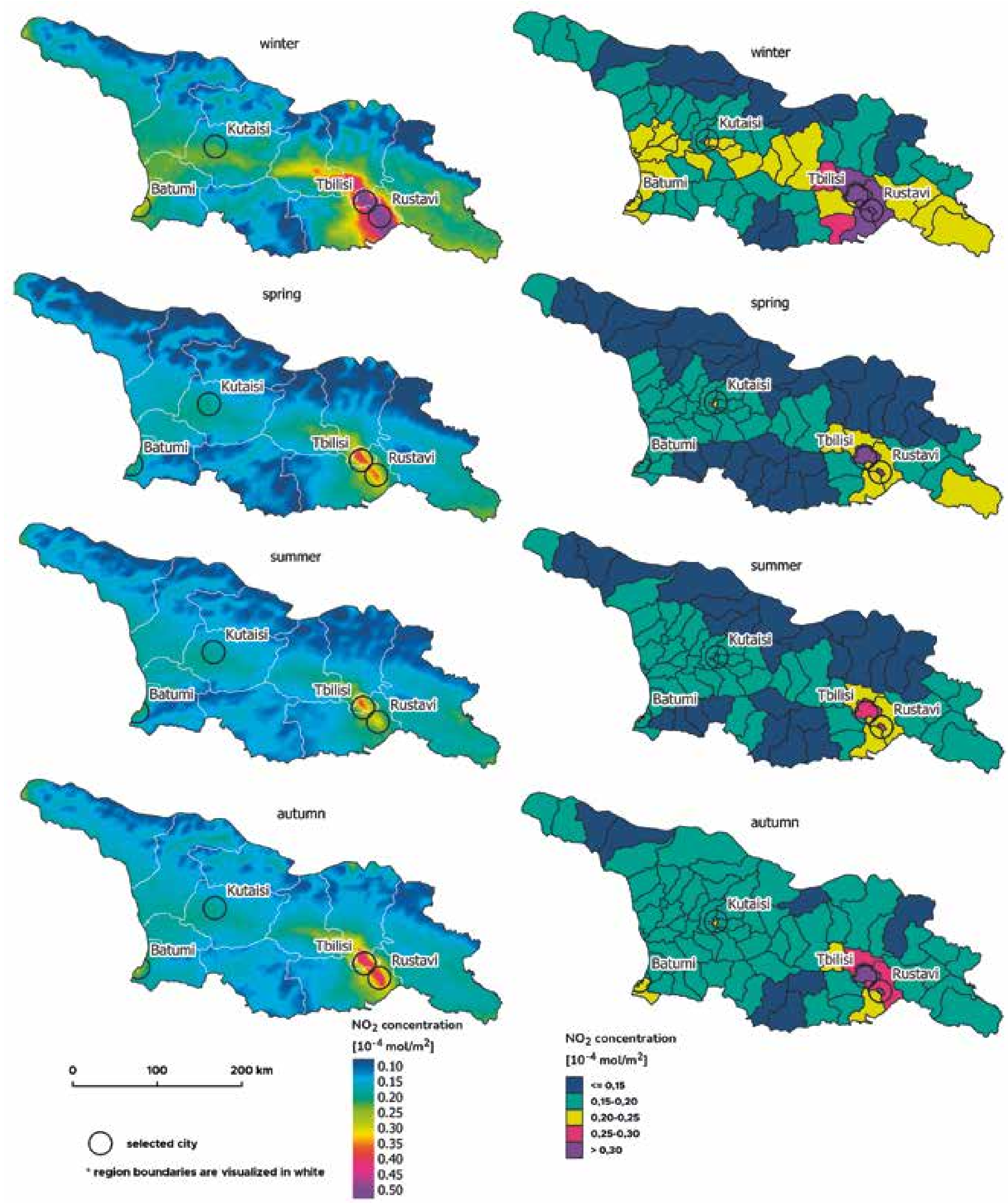


Fig. 8: Average seasonal NO_2 concentrations in the regions of Georgia between May 2018 and December 2022, obtained from the Sentinel-5P satellite. Source: ESA, 2018-2020; modified.

Seasonality of air pollution

NO_2 pollution in Georgia shows seasonal changes (Fig. 8), with the maximum in winter, when there is a greater need for heating. The distribution of pollution remains consistent during the seasons; the highest values occur in the south-east of the country, where the large cities of Tbilisi and Rustavi are located. Higher values are also found in the Colchis Lowland, bordered by mountains that hinder the diffusion of air. Levels of NO_2 can also increase because of different causes, such as increasing industrial activity,

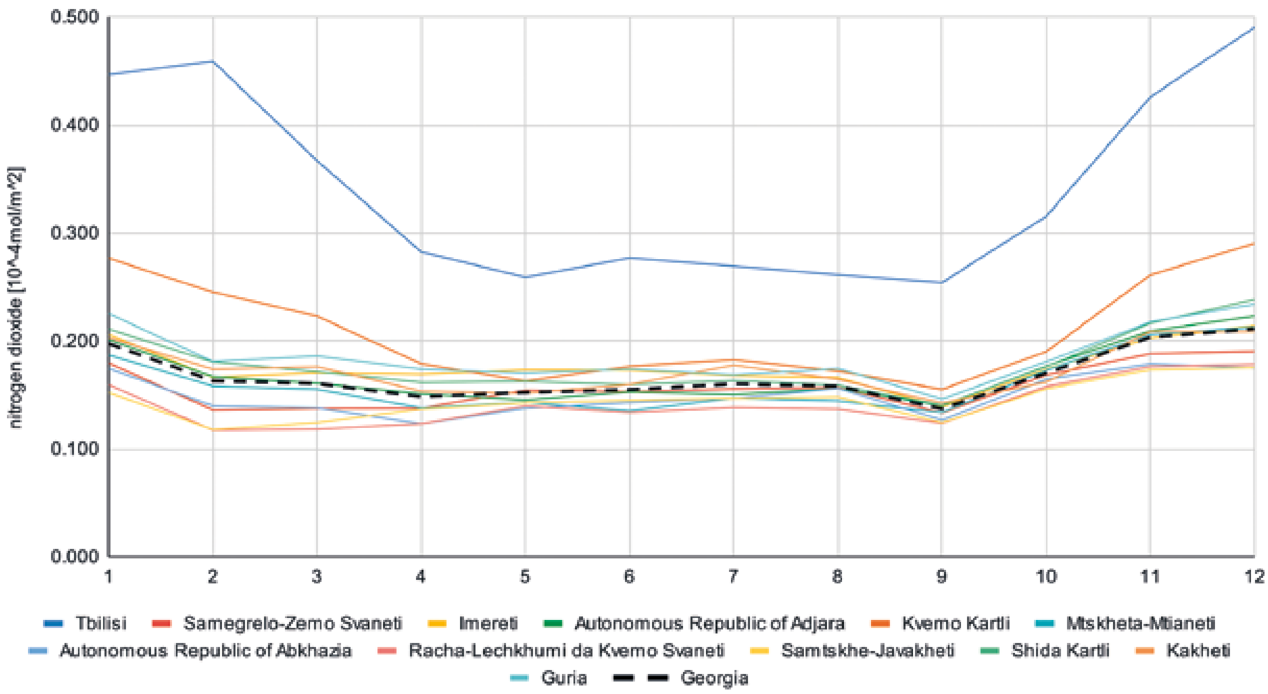


Fig. 9: Average monthly NO_2 concentrations in the regions of Georgia between May 2018 and December 2022, obtained from the Sentinel-5P satellite. Source: ESA, 2018-2020; modified.

traffic emissions, and wildfires. Unfavourable weather conditions and wind direction can contribute to worsening the situation.

Fig. 9 shows the comparison of the average NO_2 concentrations for each region. Concentrations rise in winter months, which is probably caused by domestic heating and generally increased energy production.

Air pollution in cities

The relationship between population density and NO_2 concentrations in Georgia may be influenced by several factors, including the location of major cities, the types of industries that are present, and the prevalence of transportation networks. Georgia has particularly rugged terrain, which affects air circulation patterns and can trap pollutants in certain areas. Seasonal factors, such as temperature and precipitation, can additionally affect nitrogen dioxide concentrations.

Fig. 10 shows the average concentrations of nitrogen dioxide for cities with a population of more than 10,000 inhabitants. In general, it can be assumed that as the population decreases, the level of pollution also decreases. However, in several cities with average populations, concentrations of NO_2 that were multiple times higher were detected. These are Kaspi (0.27 10^{-4} mol/m^2), Marneuli (0.27 10^{-4} mol/m^2), and Gardabani (0.34 10^{-4} mol/m^2). Conversely, NO_2 concentrations in Kutaisi (0.22 10^{-4} mol/m^2) and Batumi (0.20 10^{-4} mol/m^2) reach concentrations at the level of cities with three times less inhabitants. This fact can be observed in Fig. 11, which shows the relationship between the concentration of nitrogen dioxide with the number of inhabitants; some of the above-mentioned cities are located at the extreme limits of the graph.

A detailed view of nitrogen dioxide concentrations in and around the capital city, Tbilisi, can be seen in Fig. 12. The increased concentrations are mainly related to the city centre and the "sleeping districts" with blocks of flats in the valley. It can be observed that pollution continues from the city

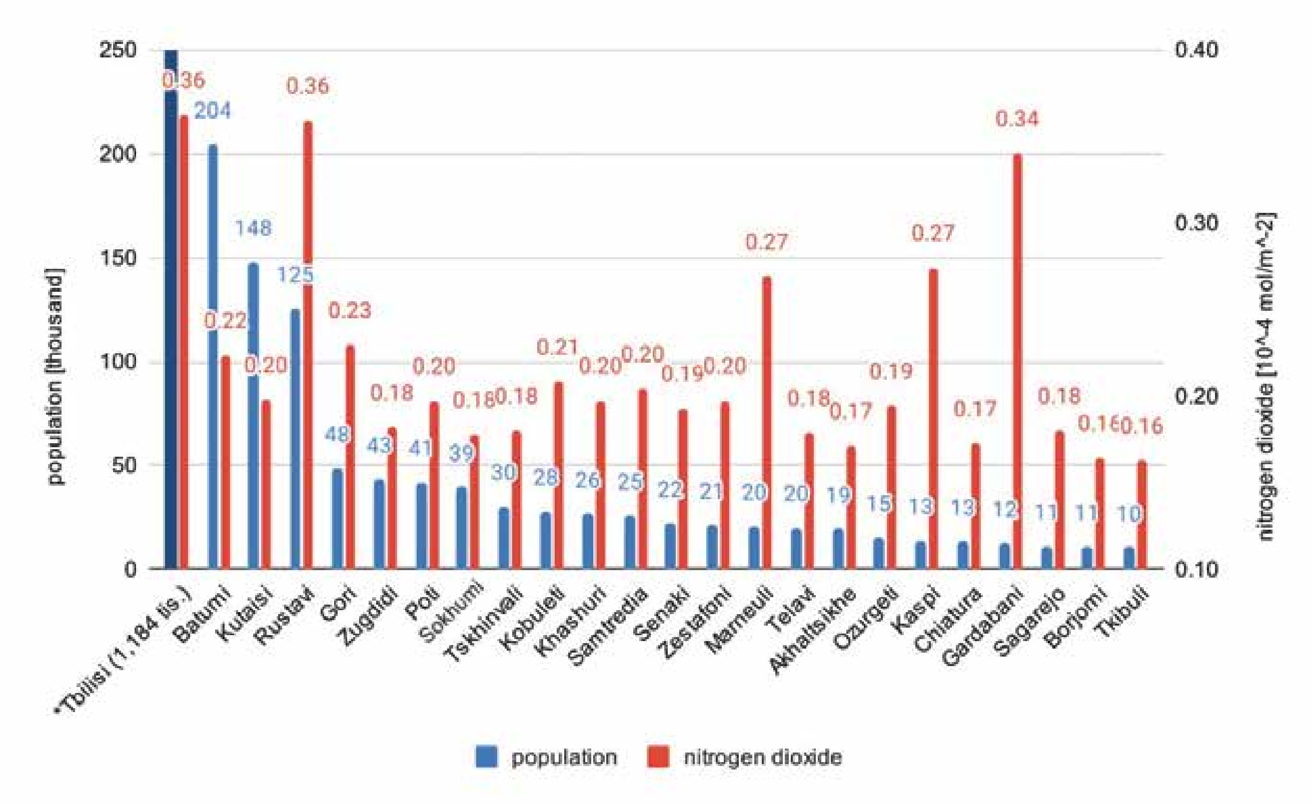


Fig. 10: Average NO_2 concentrations between May 2018 and December 2022 in the cities of Georgia with a population over 10,000, obtained from the Sentinel-5P satellite. Source: ESA, 2018–2020; modified.

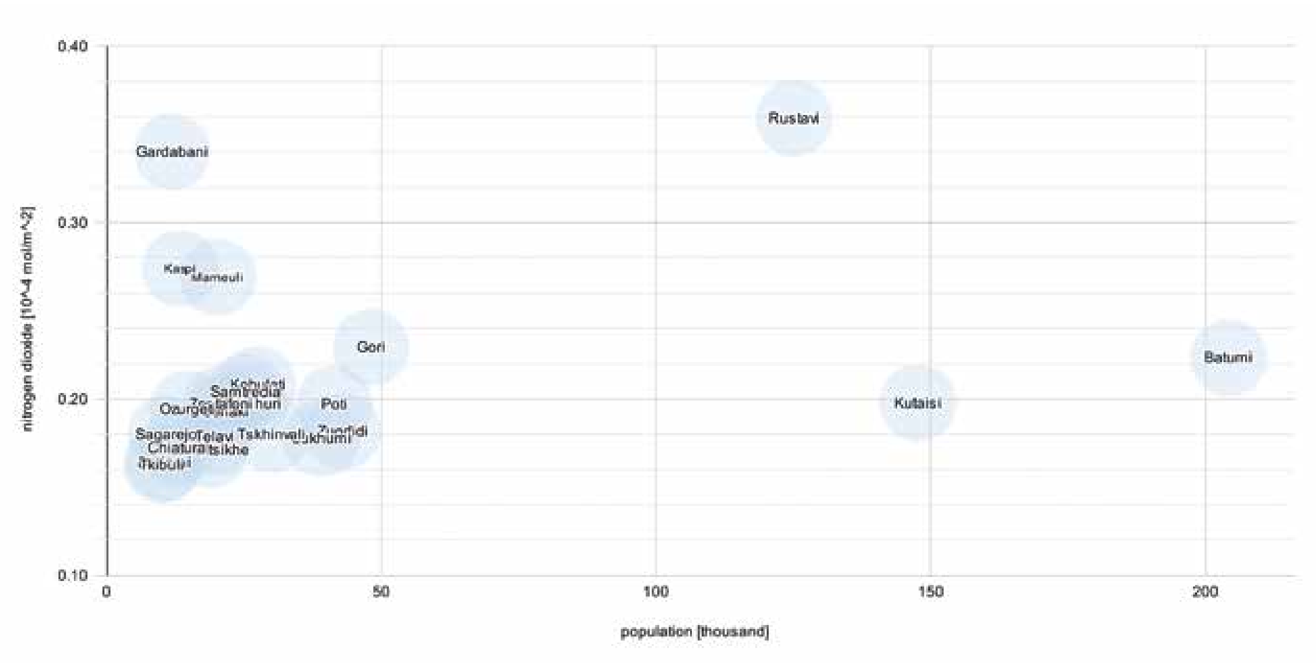


Fig. 11: Average NO_2 concentrations between May 2018 and December 2022 in the cities in Georgia with a population over 10,000, obtained from the Sentinel-5P satellite. Source: ESA, 2018–2020; modified. Note: Tbilisi is not included in the graph.

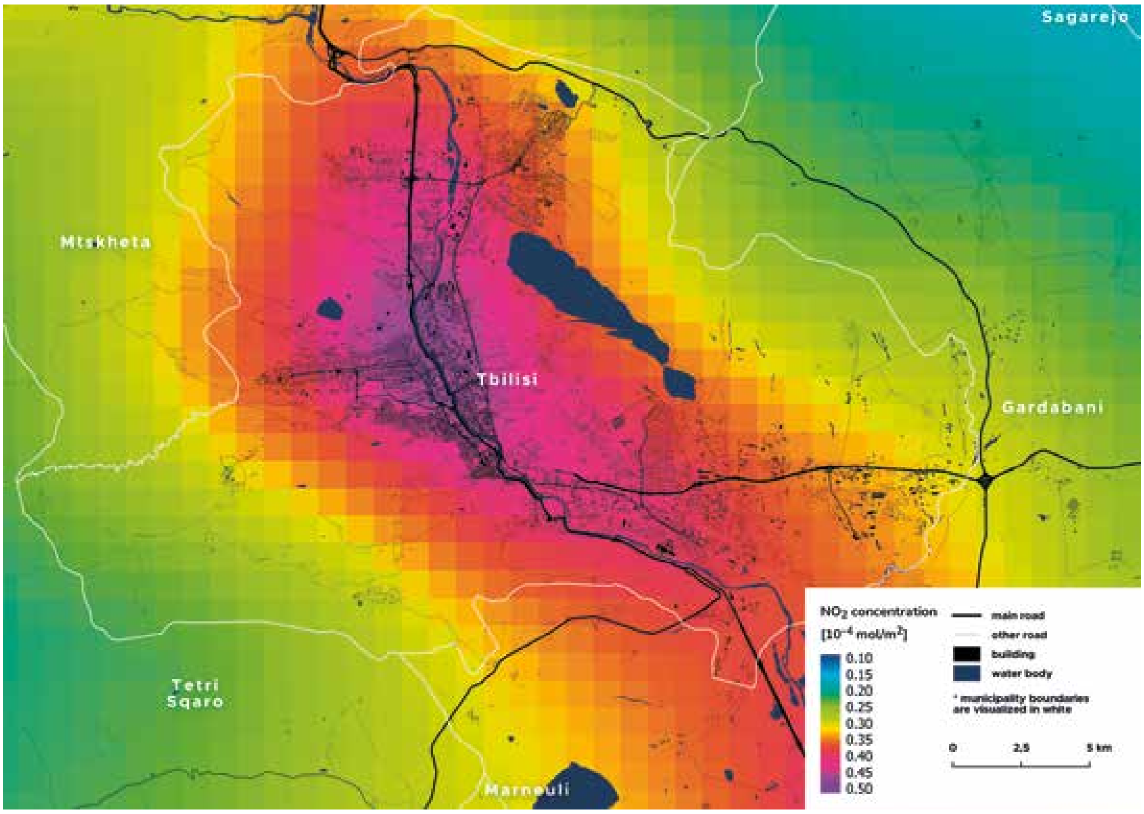


Fig. 12: Average NO_2 concentrations in Tbilisi between May 2018 and December 2022, obtained from the Sentinel-5P satellite. Sources: imagery (ESA, 2018–2022; modified), topography (OpenStreetMap Contributors, 2022).

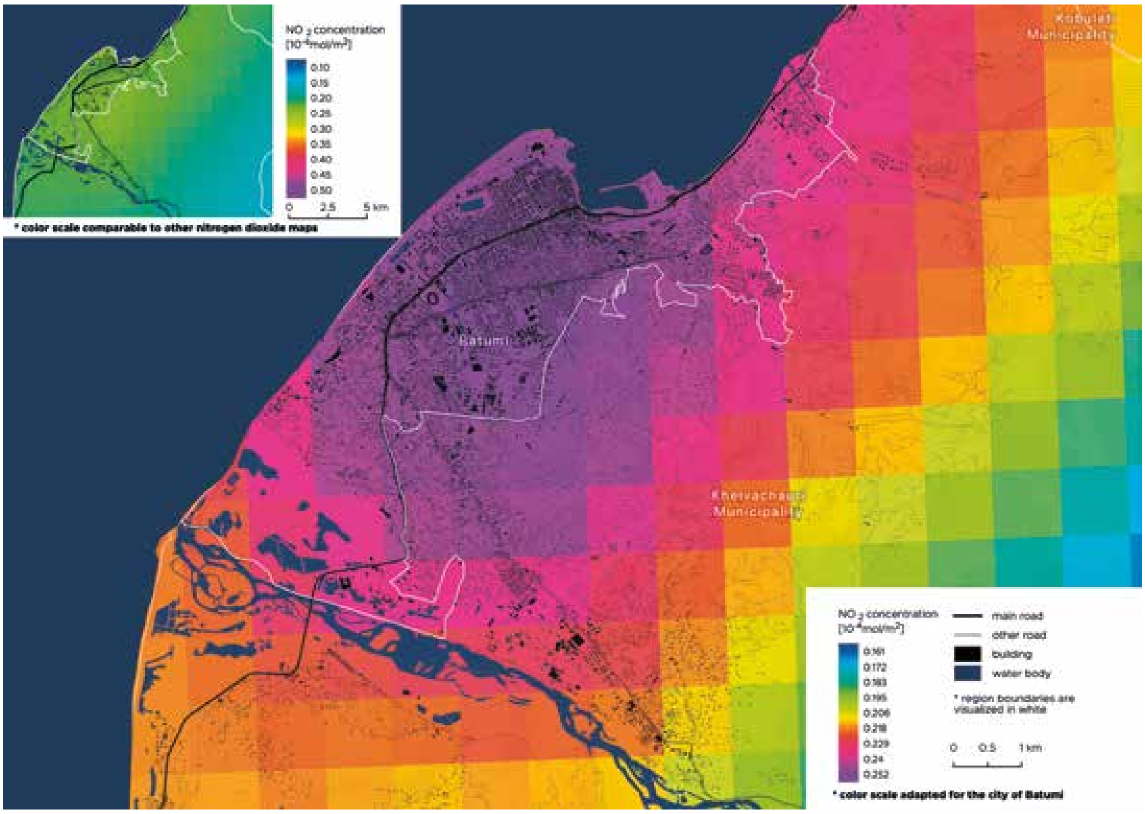


Fig. 13: Average NO_2 concentrations in Batumi between May 2018 and December 2022, obtained from the Sentinel-5P satellite. Sources: imagery (ESA, 2018–2022; modified), topography (OpenStreetMap Contributors, 2022). Note: Colour scale in the main map adapted to the city of Batumi.

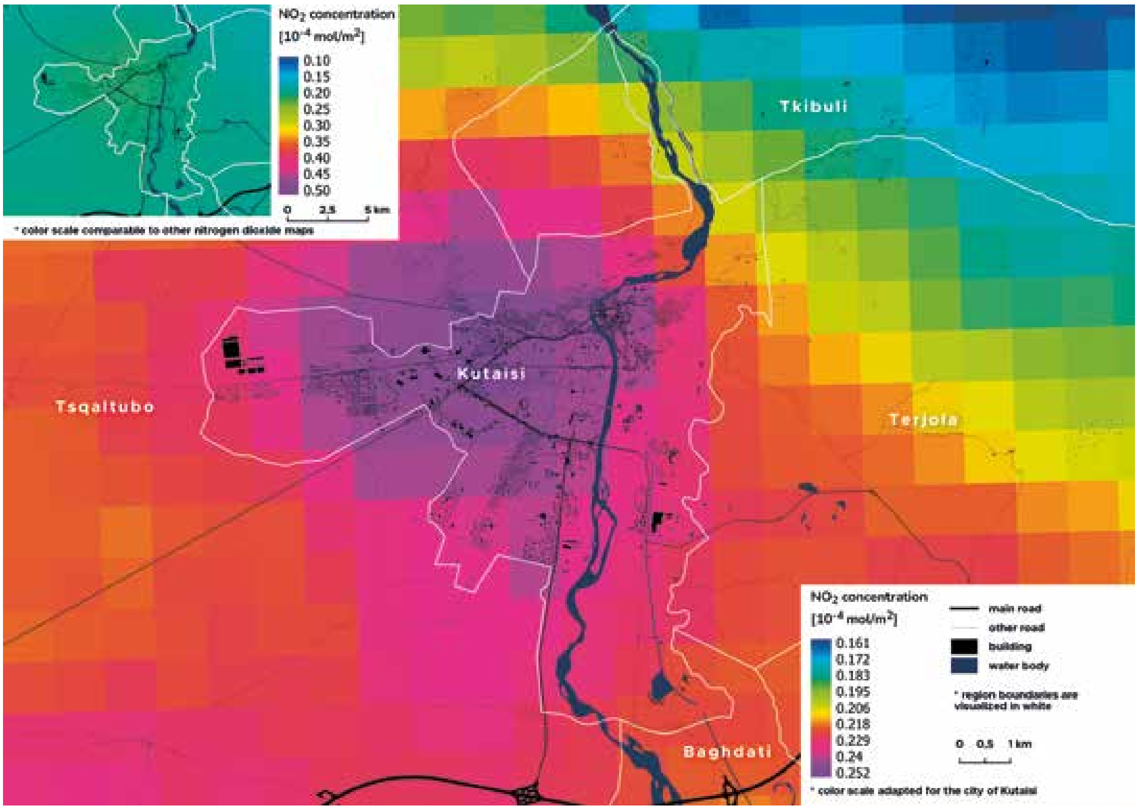


Fig. 14: Average NO_2 concentrations in Kutaisi between May 2018 and December 2022, obtained from the Sentinel-5P satellite. Sources: imagery (ESA, 2018–2022; modified), topography (OpenStreetMap Contributors, 2022). Note: Colour scale in the main map adapted to the city of Kutaisi.

towards the south-east. This may be due to the elevated terrain that surrounds the city on the opposite side, keeping the pollution in one place as there is not as much air circulation. The industrial cities of Gardabani and Rustavi, where elevated NO_2 levels were also detected, are also located in the south-eastern direction.

The distribution of NO_2 air pollution in the territory of the city of Batumi is shown in Fig. 13. On the main map, it can be seen that the highest concentration is found in the city centre. However, it is important to mention that the colour scale for the main map was adjusted to highlight the differences within the city, and it does not correspond to the scale used in other maps in this study. The smaller map in the top left corner is used for comparison within the whole territory of Georgia. NO_2 concentrations in Batumi are lower than in the capital or some industrial cities. There is no heavy industry located in Batumi and its coastal character is dominated by windier weather conditions than inland cities. For example, a sea breeze has been found to have helped reduce NO_2 concentrations (Geddes et al., 2021).

A detailed view of NO_2 concentrations in and around the city of Kutaisi can be seen in Fig. 14. The highest concentration is again found in the city centre. As with Tbilisi, the influence of the terrain on the distribution of pollution can be observed. The city is situated to the south-west of the Greater Caucasus, where pollution increases. On the other hand, to the north-east of the city, lower pollution levels are detected. The comparison map shows that NO_2 concentrations are lower than in other cities, where the average NO_2 concentration within a 10-km radius of the city route reaches 0.22 10^{-4} mol/m^2 (see Fig 11 – graph of the pollution in cities at the beginning of this chapter).

Rustavi, Gardabani, and Marneuli together have around 321 thousand inhabitants and are part of the industrial hinterland

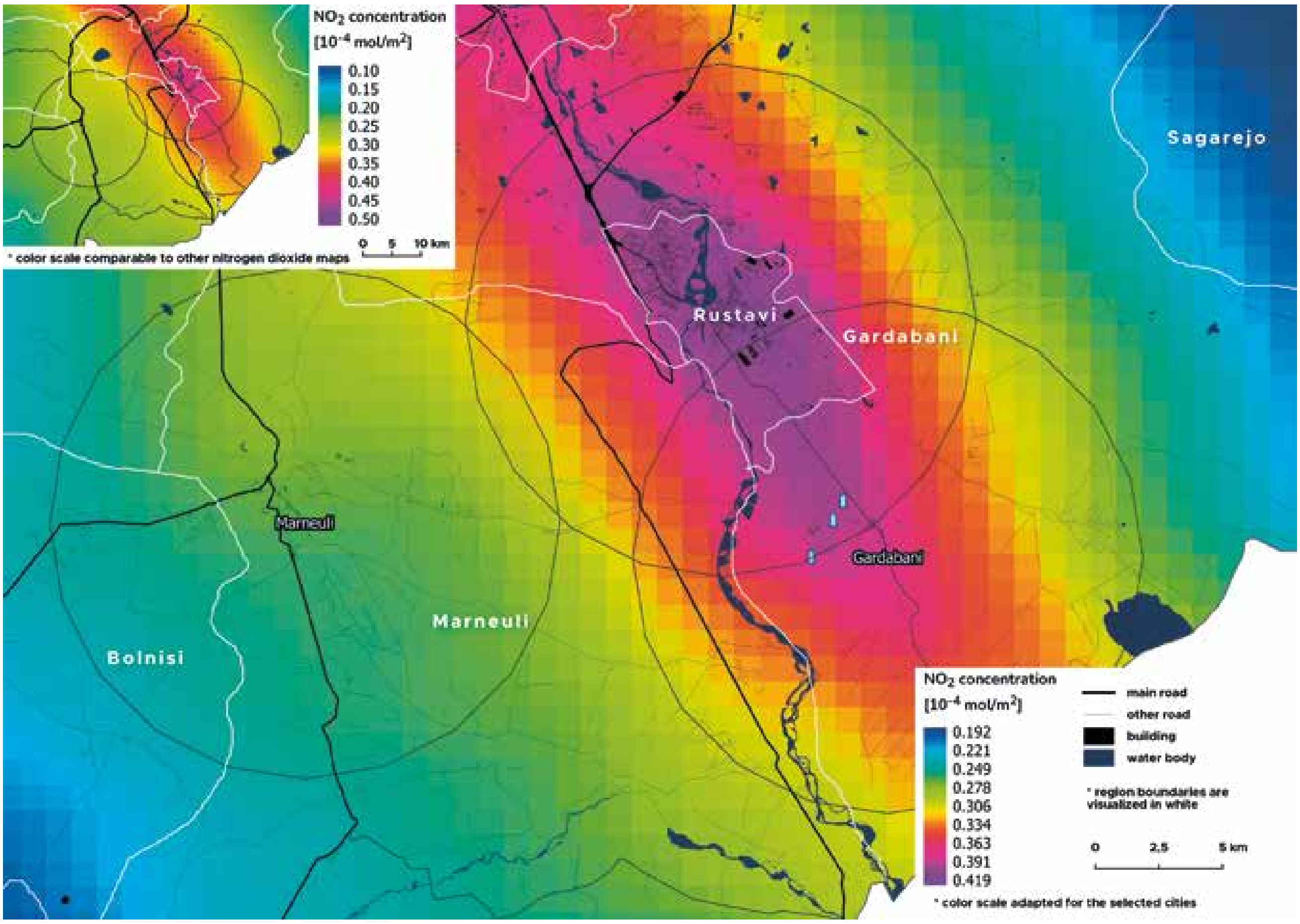


Fig. 15: Average NO_2 concentrations in the agglomeration of Rustavi, Gardabani, and Marneuli between May 2018 and December 2022, obtained from the Sentinel-5P satellite. Sources: imagery (ESA, 2018–2022; modified), topography (OpenStreetMap Contributors, 2022). Note: Colour scale in the main map adapted to the cities of Rustavi, Gardabani, and Marneuli.

south of the capital, Tbilisi. Here, the NO_2 concentrations are significantly higher than in other cities with similar populations. The area plays a vital role in Georgia's economy. Rustavi has an extensive industrial sector and the city's industrial zone is one of the largest in the country. The Rustavi Metallurgical Plant is one of the largest producers of steel and metal products in Georgia; the local cement plant is one of the two large facilities in the country (Heidelberg Materials, 2023) and *Rustavi Azot* is one of the largest producers of fertilisers and industrial chemical products in the Caucasus region. There are around 22 further factories that have been contributing to high levels of air pollution. While they play a crucial role in the city's development, their environmental impact has been raising public health concerns. Many are owned by private companies with foreign investment, which have failed to go beyond planting trees to meet their social responsibilities (Chkareuli, 2019). Gardabani faces high levels of air pollution from various sources, including cement factories and transport emissions. The town is located on a major transportation route between Georgia and Azerbaijan, which means that a large number of heavy trucks and other vehicles pass through the town every day. The gas-fired thermal power plant in Gardabani is not a significant source of the emissions analysed in this study. Because of the close proximity of Rustavi and Gardabani, weather conditions drive the transfer of pollution between the two cities. A similar influence can also be observed in the town of Marneuli, which is located to the west of Rustavi and Gardabani, although there are no polluting industries in Marneuli.

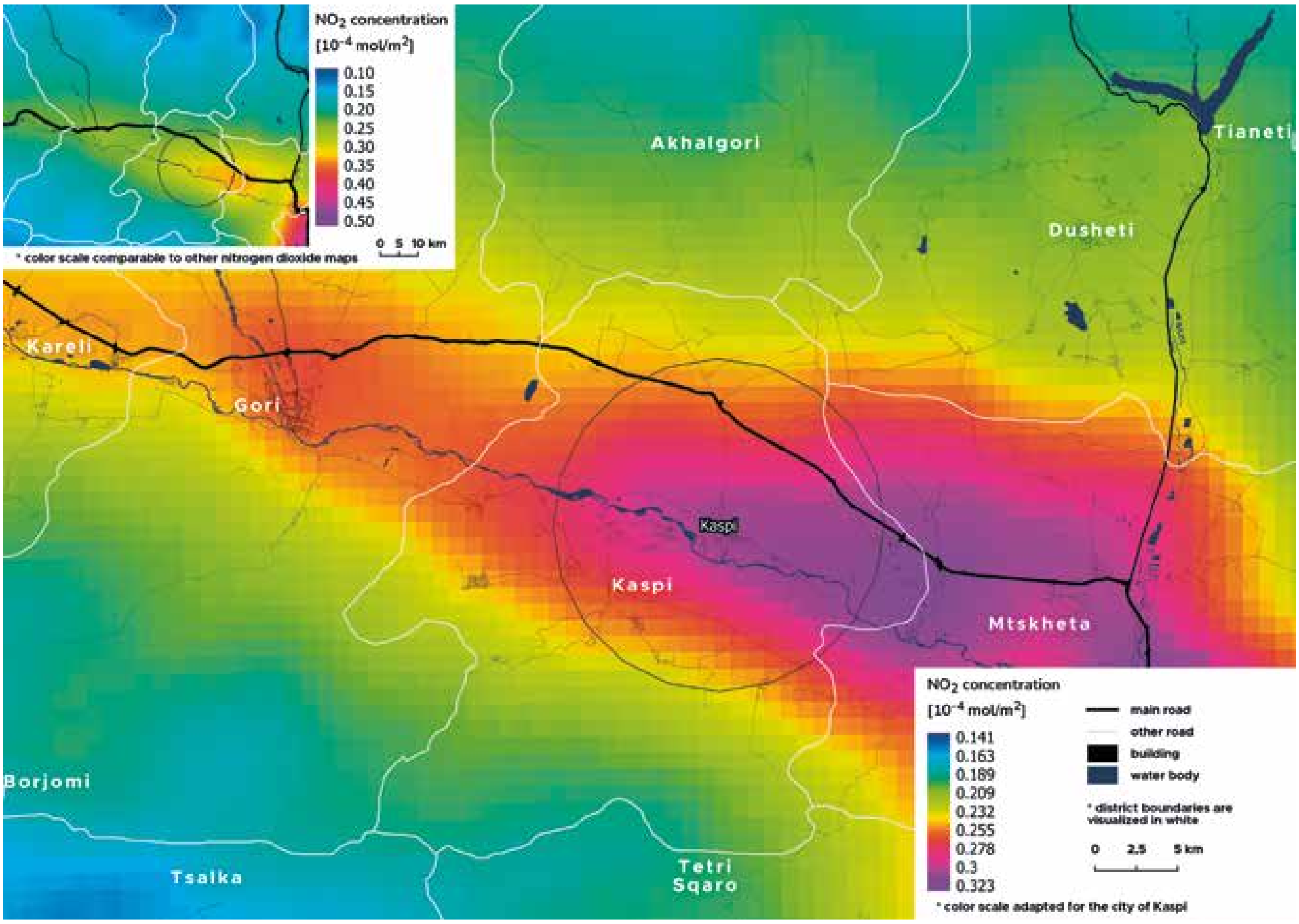


Fig. 16: Average NO_2 concentrations in Kaspi between May 2018 and December 2022, obtained from the Sentinel-5P satellite. Sources: imagery (ESA, 2018–2022; modified), topography (OpenStreetMap Contributors, 2022). Note: Colour scale adapted for the city of Kaspi.

Elevated nitrogen dioxide concentrations were also observed within a 10-km radius of the town of Kaspi (Shida Kartli region) (Fig. 16), where one of the largest cement plants is located (Heidelberg Materials, 2023). Even higher concentrations occur further east of the town, where the large Ksani Glass Factory is located. Another reason for the higher levels can be the relief, which forms a pocket-like shape around Kaspi and Ksani, which can prevent air circulation and trap more pollution in the area.

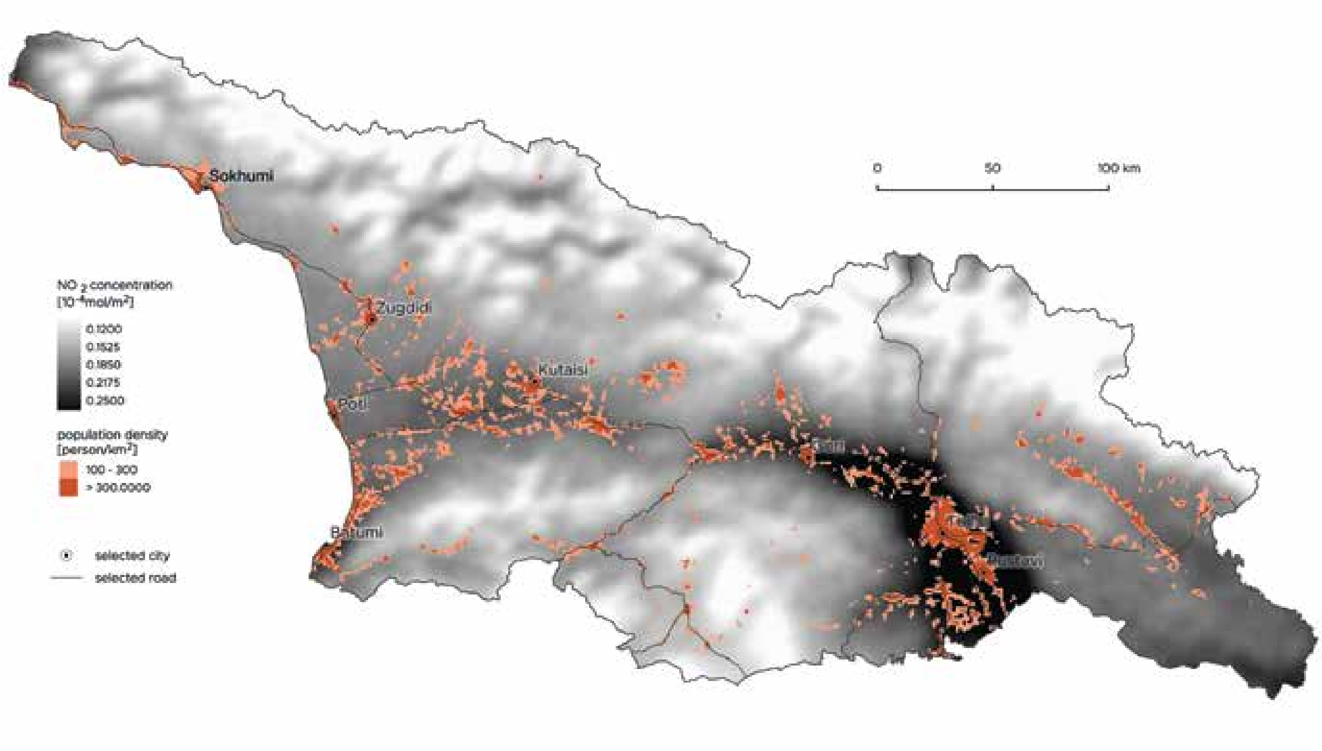


Fig. 17: Average NO_2 concentrations in Georgia between May 2018 and July 2020, obtained from the Sentinel-5P satellite in context with the 2019 population density data. Sources: imagery (ESA, 2018-2020; modified), topography (OpenStreetMap Contributors, 2022), population (WorldPop, 2020).

Because of human activities, most pollution is found in the densely inhabited cities (Fig. 17). Higher population density is connected to more vehicles and greater economic activity. It can be observed that in the less populated mountainous areas, the concentrations do not reach such values. Elevated values are found in the central lowlands of Georgia, where the majority of the population lives.

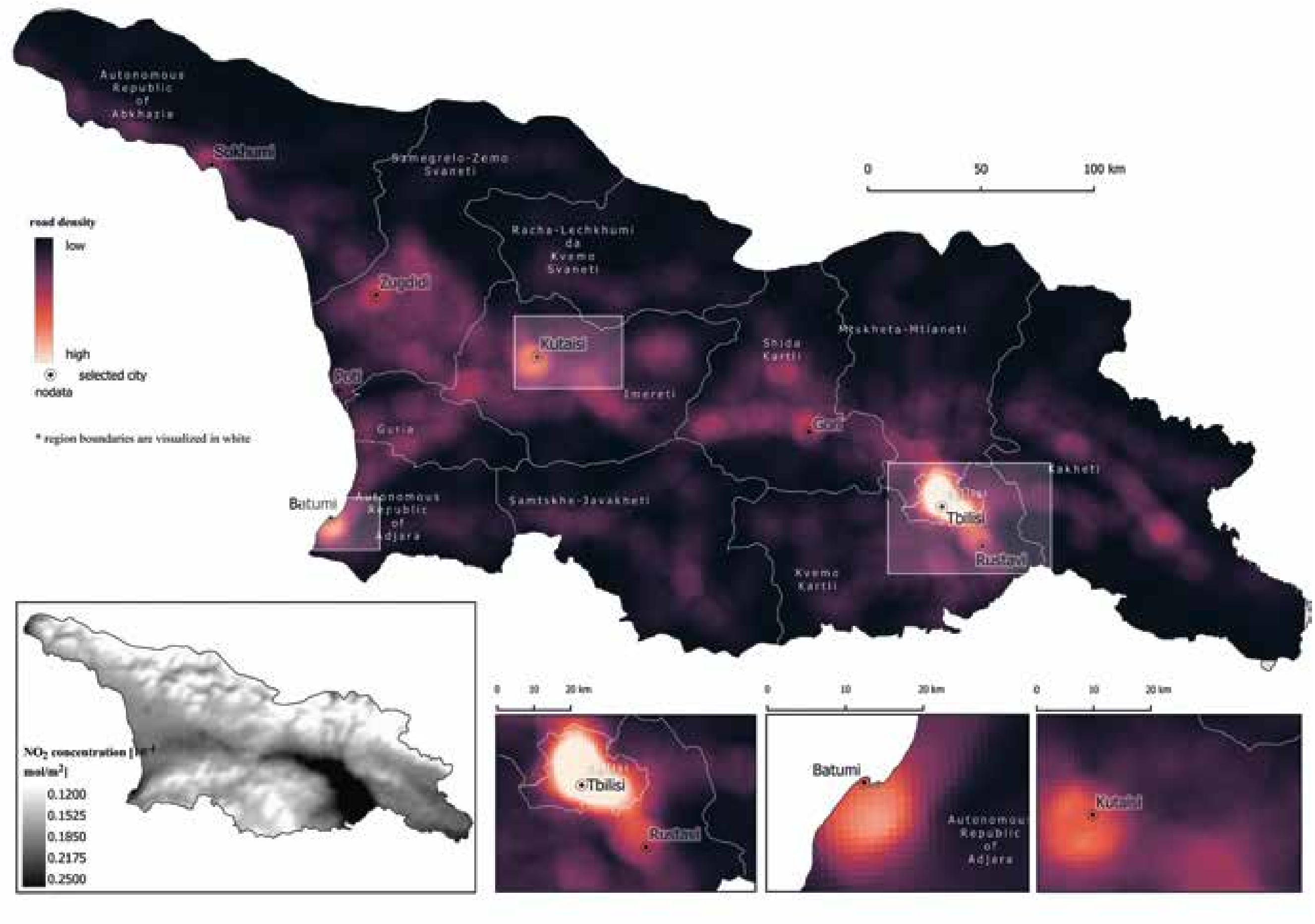


Fig. 18: Average NO_2 concentrations in Georgia between May 2018 and July 2020 (bottom left corner) in context with road density (main map). Sources: imagery (ESA, 2018-2020; modified), roads (OpenStreetMap Contributors, 2022; modified).

Air pollution from transportation

The relationship between road density and NO_2 concentrations can be observed in Fig. 18. Transportation, particularly road transport, is a significant contributor to air pollution in Georgia. The number of cars in the country has been increasing, with a corresponding rise in traffic congestion and emissions. Additionally, as mentioned in the introduction, many vehicles in Georgia are old and poorly maintained, which contributes to higher levels of pollution. The main map presents the density of the road network weighted by road class within a radius of 7 km from the given road. When the road network density is compared with NO_2 concentrations, there is a strong correlation (0.67), and 44% of the pollution variability is explained by the presence of traffic at the given location (R2 = 0.44).

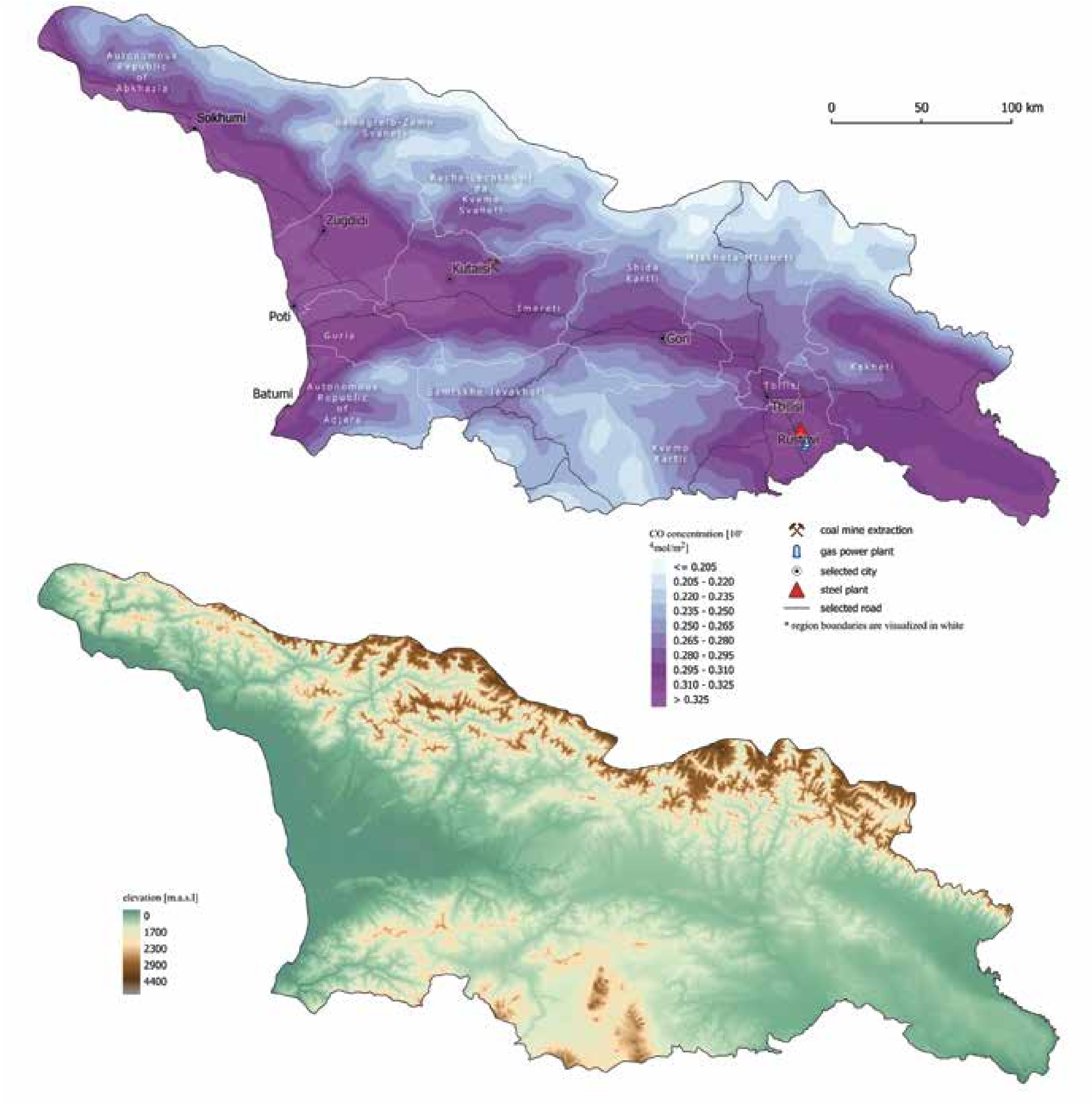


Fig. 19: Average CO concentrations in Georgia between May 2018 and December 2022, obtained from the Sentinel-5P satellite in context with a digital elevation model. Sources: imagery (ESA, 2018-2020; modified), roads (OpenStreetMap Contributors, 2022; modified), elevation (USGS, 2023).

Carbon monoxide (CO)

Basic analysis

The average CO concentration correlates negatively with elevation, as shown in Fig. 19. This is mostly caused by the natural cycle of CO in the air. The lowest concentrations are found at higher altitudes in mountainous areas, while the highest concentrations occur in the lowlands between the Greater Caucasus and Lesser Caucasus, orographically closed areas with potentially reduced air circulation and dispersion. Regarding anthropogenic factors, probably the only potential cause of elevated CO values can be found around the S1 arterial highway from

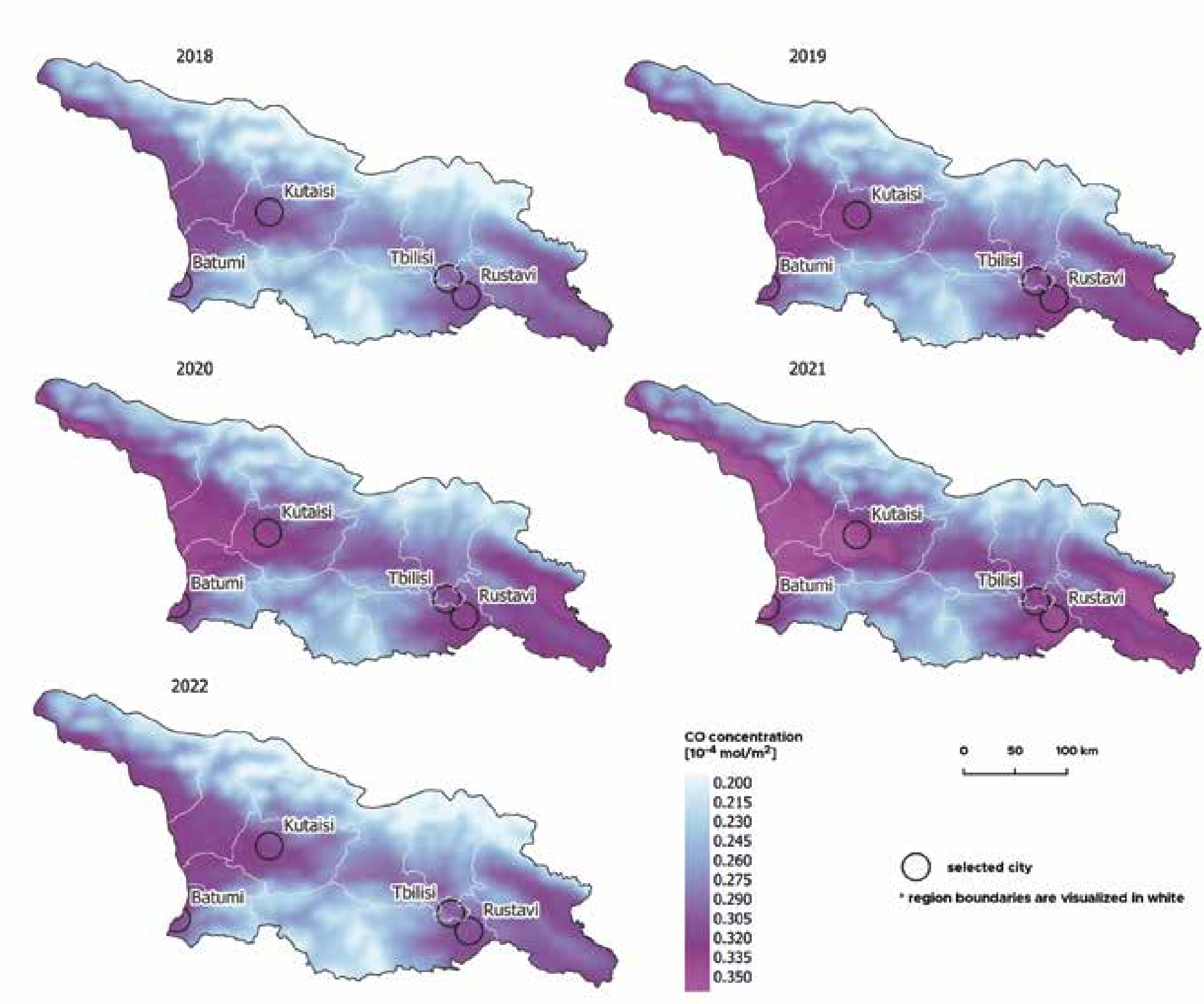


Fig. 20: Average yearly CO concentrations in Georgia between May 2018 and December 2022, obtained from the Sentinel-5P satellite. Sources: ESA, 2018-2020; modified.

Tbilisi to Kutaisi. While fossil fuel burning is a dominant contribution to CO in the atmosphere, the distribution pattern in Georgia fails to clearly point to industrial centres, such as Rustavi. Higher CO levels could also be caused by forest fires, which have been increasing over the last two decades with advancing climate change (Balashvili and Neidze, 2022; MEPA, 2021). Nonetheless, the displayed CO averages rather dissolve such immediate events.

In Fig. 20, it can be seen that average yearly concentrations of CO in Georgia have remained similarly distributed over the study period. The concentrations are lowest in 2018 and highest in 2021. In 2018, data before April is non-existent, which can have a diminishing effect on the year average.

In the given resolution and pattern, it is difficult to attribute the 2021 peak to extraordinary anthropogenic activities such as accelerated industrial activity. Natural conditions could provide an explanation; CO concentrations tend to rise after longer periods of drought because of the lack of moist air carrying the hydroxyl radical (•OH) that destroys CO (NOAA, 2015). Warm summer air usually brings moisture to Georgia from the Black Sea, which helps reduce the CO in the atmosphere. This situation could have changed in 2021 as August recorded unexpectedly high CO concentrations. While 2021 was not an exceptionally drier year than others investigated, extreme droughts occurred in the wider region in July and August: in Turkey (the worst in two decades; Bianet,

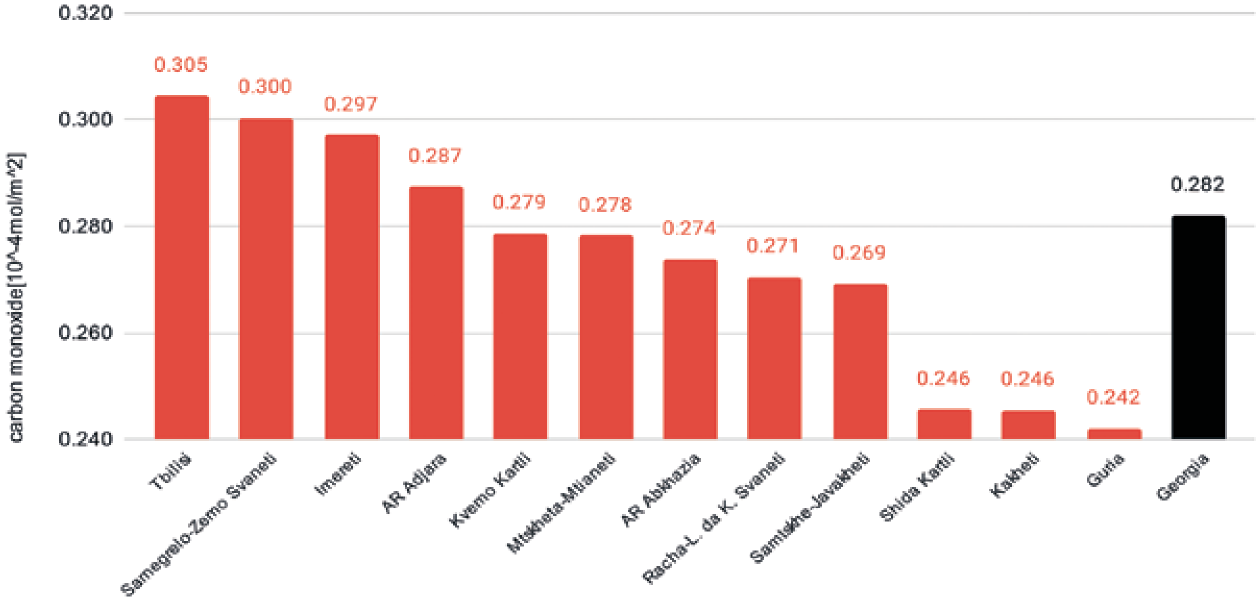


Fig. 21: Average CO concentrations in the regions of Georgia between May 2018 and December 2022, obtained from the Sentinel-5P satellite. Source: ESA, 2018-2020; modified.

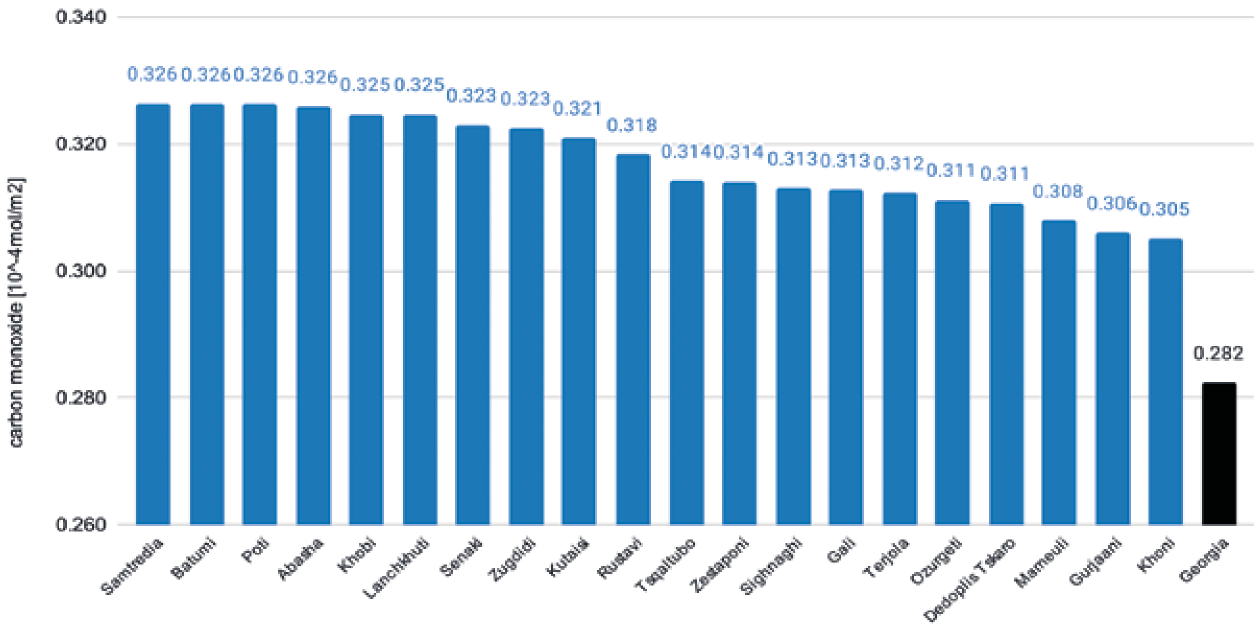


Fig. 22: 20 highest average CO concentrations in municipalities and self-governing cities of Georgia between May 2018 and December 2022, obtained from the Sentinel-5P satellite. Source: ESA, 2018-2020; modified.

2023), Armenia (the hottest June in history and a subsequent drought; Zargarian, 2021) and Central Asia (one of the most severe droughts in decades; Jiang and Zhou, 2023). This suggests a theory that a significant portion of CO could have been transferred towards Georgia with the dominant westerly air flow or with dry air from the south-east from Azerbaijan, thus preventing the usual CO depletion and increasing the overall average.

The average CO concentrations within each region can be seen in Fig. 21. The highest concentrations were detected in the regions of Tbilisi (0.301 10^{-4} mol/m^2), Guria (0.298 10^{-4} mol/m^2), and Imereti (0.296 10^{-4} mol/m^2). No significant anthropogenic pollution sources were detected. The influence of natural CO

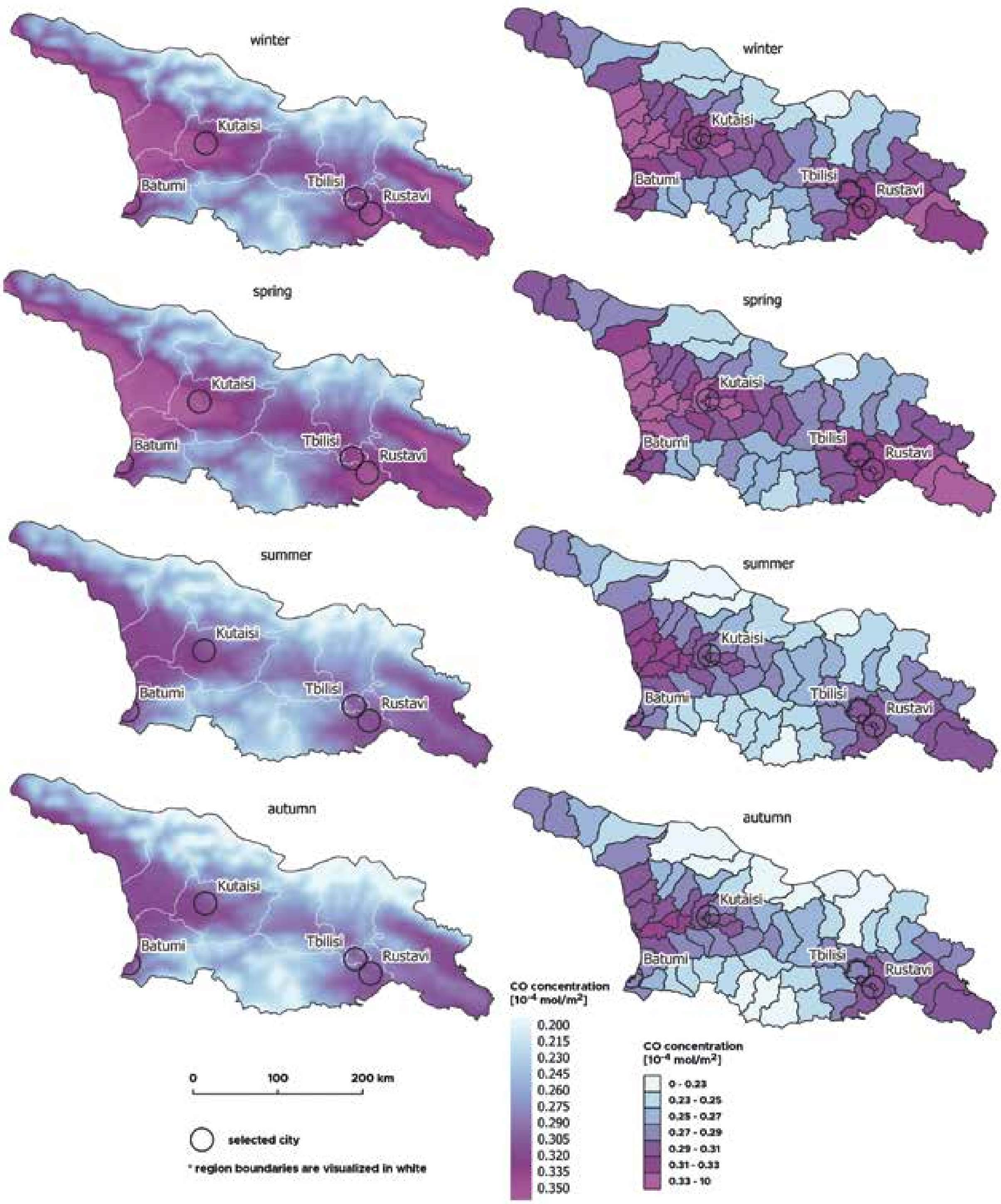


Fig. 23: Average seasonal CO concentrations in the regions of Georgia between May 2018 and December 2022, obtained from the Sentinel-5P satellite. Source: ESA, 2018-2020; modified.

distribution is higher than the concentrations resulting from anthropogenic sources.

In Fig. 22, the highest concentrations in 20 municipalities and self-governing cities of Georgia can be observed, with the values being rather balanced. All the municipalities that are displayed tend to be located in lowland terrain or at the edge of the mountains.

Seasonality of air pollution

Because of the natural cycle of CO, in the comparison of seasonal levels of CO in Fig. 23, there is a visible decrease in CO concentrations in the summer. The highest concentration of carbon monoxide in all seasons is in the Colchis Lowland. This trend follows

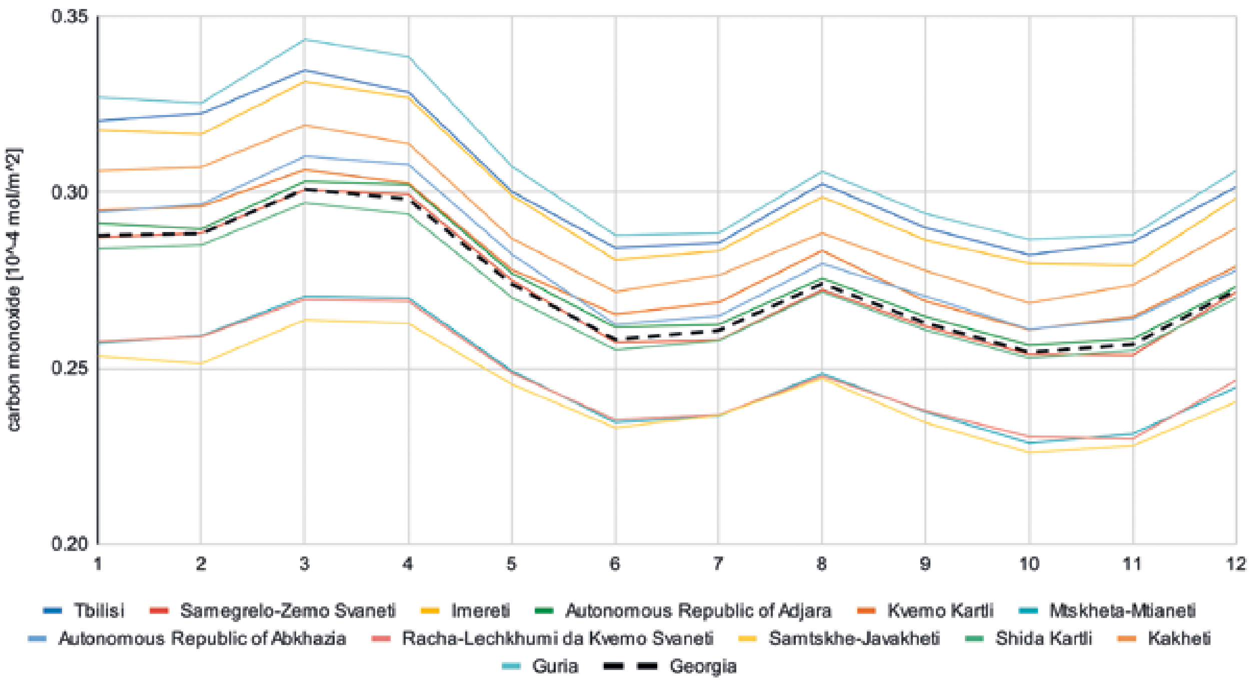


Fig. 24: Average monthly CO concentrations in the regions of Georgia between May 2018 and December 2022, obtained from the Sentinel-5P satellite. Source: ESA, 2018-2020; modified.

a general yearly cycle of CO concentrations in the atmosphere of the Northern Hemisphere.

Fig. 24 shows the CO values in each month averaged over 2018-2022. The concentrations rise in winter and the early spring months, reaching their highest values in April, followed by a sharp decline. There is a visible link between the winter months and higher CO levels, as well as a smaller peak in August. The winter months may be due to more cloudy days, causing CO to settle and not dissipate in the Colchis Lowland area. Increased use of heating systems using wood and fires can be responsible for the higher values. The peak in August may be due to high temperatures and more frequent fires.

In examining the influence of anthropogenic and natural factors affecting CO concentrations in Georgia, an analysis was also conducted to filter out the effect of elevation on the distribution of CO values in order to detect anthropogenic sources of this pollutant. In particular, the impact of the major polluters in Rustavi (the Rustavi Metallurgical Plant, Heidelberg Cement Rustavi, and Rustavi Azot) was sought, as this type of industrial activity is a significant contributor of CO to the air. However, this anthropogenic source did not appear in the filtered data from Sentinel-5P, nor were high values found in the vicinity of other industrial cities.

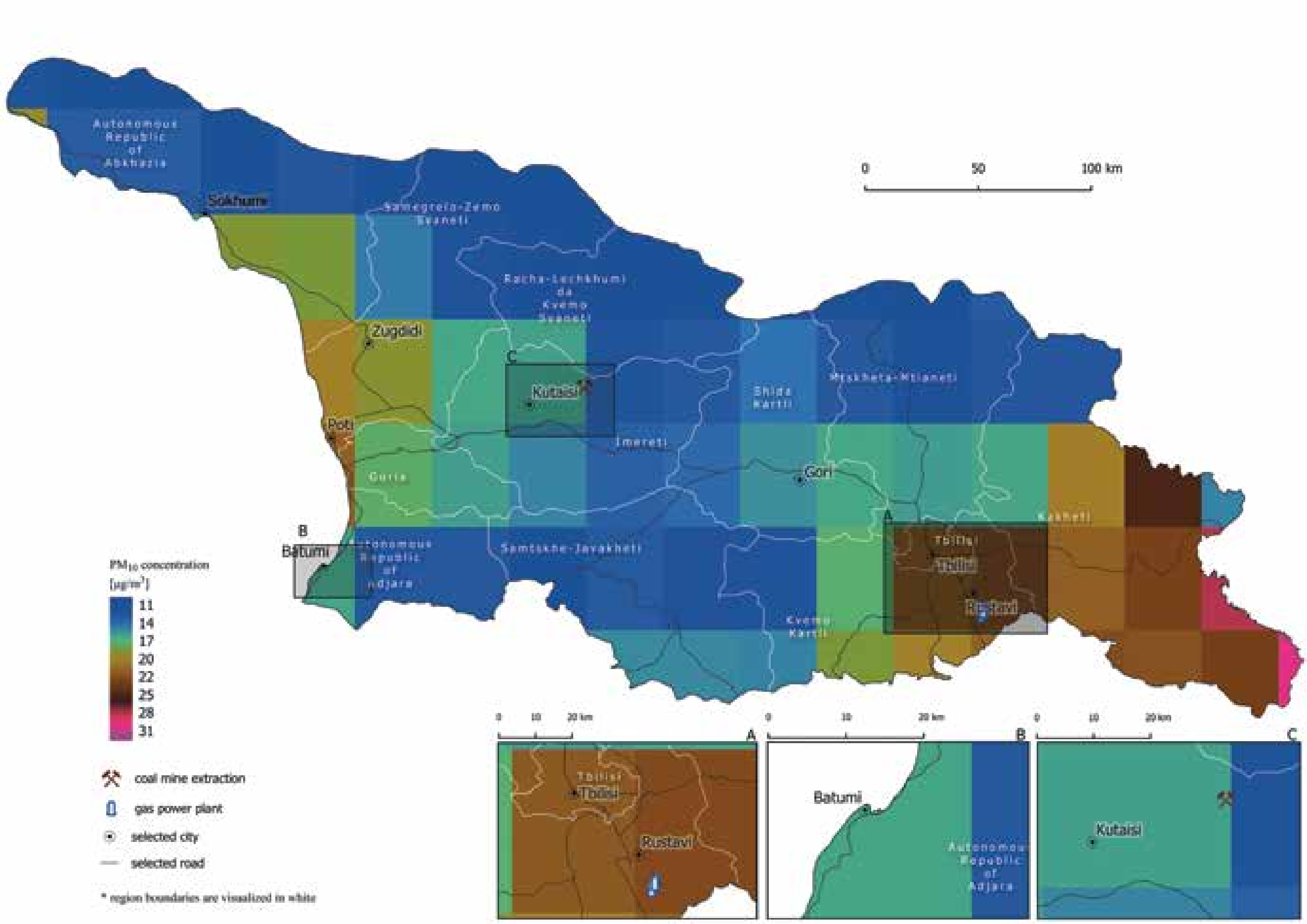


Fig. 25: Average PM_{10} concentrations in Georgia (global model) between May 2018 and December 2022, obtained from the Copernicus Atmosphere Monitoring Service data. Sources: CAMS, 2018-2022; topography (OpenStreetMap Contributors, 2022), coal and gas (Global Energy Monitor, 2023).

Particulate matter (PM_{10})

Basic analysis

According to the global model (Fig. 25), the increased PM_{10} levels are generally pronounced in the south-east of the country, primarily from Tbilisi towards the Kakheti region. This is bound to the changing land cover from continental through subtropical and semi-arid landscapes, such as steppes or semi-deserts (Balashvili and Neidze, 2022). The sparser vegetation cover in areas such as the Iori Plateau enables dust particles to be picked up by the wind and spread to the air more easily. Easterly and westerly airflows in Georgia are a significant natural factor in transporting dust particles (Davitashvili, 2019); in the case of the Kakheti region, particles are transported primarily from Central Asia and the Middle East. This can overshadow any potential PM_{10} microvariability in the region. Similarly, elevated PM_{10} concentrations along the country's west coast in the global model can be related to the coastline (sand) or sea water.

A similar trend can be seen in the European model (Fig. 26), which, however, highlights increases around the cities. The highest average PM_{10} concentrations build up circularly around the capital, Tbilisi, and the city of Rustavi. Increased concentrations are also found around the S1 arterial high-

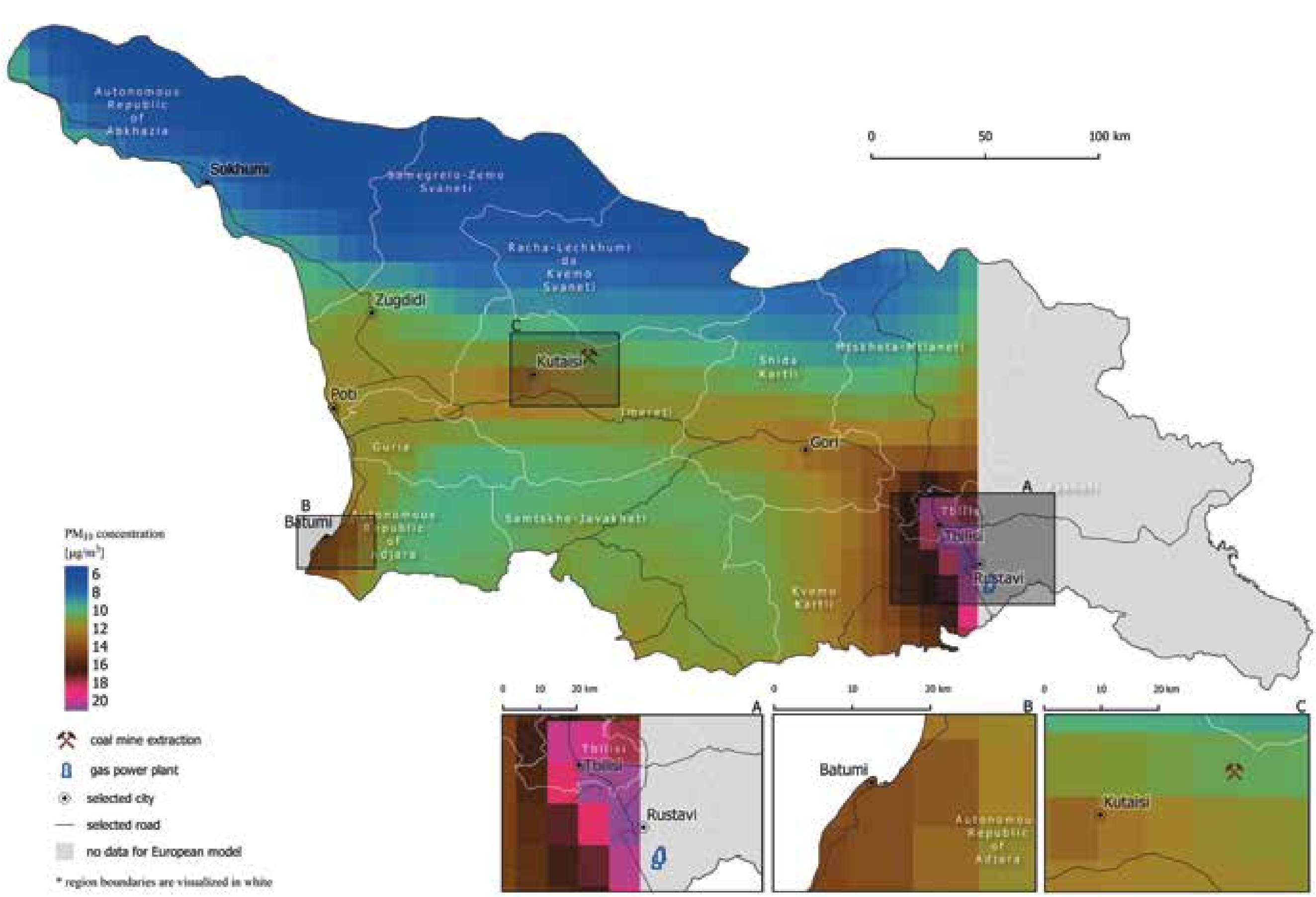


Fig. 26: Average PM_{10} concentrations in Georgia (European model) between May 2018 and December 2022, obtained from the Copernicus Atmosphere Monitoring Service data. Sources: CAMS, 2018-2022; topography (OpenStreetMap Contributors, 2022), coal and gas (Global Energy Monitor, 2023).

way from Tbilisi to Kutaisi and further to the west, where they keep higher along the coast between the cities of Poti and Batumi.

The distribution of PM_{10} in the Georgian regions (Fig. 27) shows that the concentrations in the Tbilisi and Kakheti regions only slightly exceed the WHO's recommended limit and the rest of the regions remain well below the limit. Trend differences between the models in the Guria region and the regions along the northern border with Russia are probably caused by averaging of the global model over the sudden elevation rise towards the north-east, where PM_{10} concentrations plummet rapidly. The country's average in the global model is unevenly shifted up by high levels in the mountainous regions and the Kakheti region, for which data is missing in the European model.

The highest average PM_{10} levels are found in Rustavi and Tbilisi (Fig. 26), which are cities to one another and with adjacent metropolitan areas. There is a slight increase towards the industrial centre of Rustavi. The Marneuli and Mtskheta municipalities, with high average PM_{10} concentrations, are adjacent to the Tbilisi metropolitan area.

According to the global model (Fig. 28), Dedoplis Tskaro town (located in the Kakheti region, missing in the European model) has the highest PM_{10} concentrations among municipalities. This is caused by the enhanced diffusion of particles, which stems from the arid climate and sparsely vegetated land cover. The situation is similar for other municipalities in the Kakheti region, such as Singhnaghi, Lagodekhi, and Qvareli.

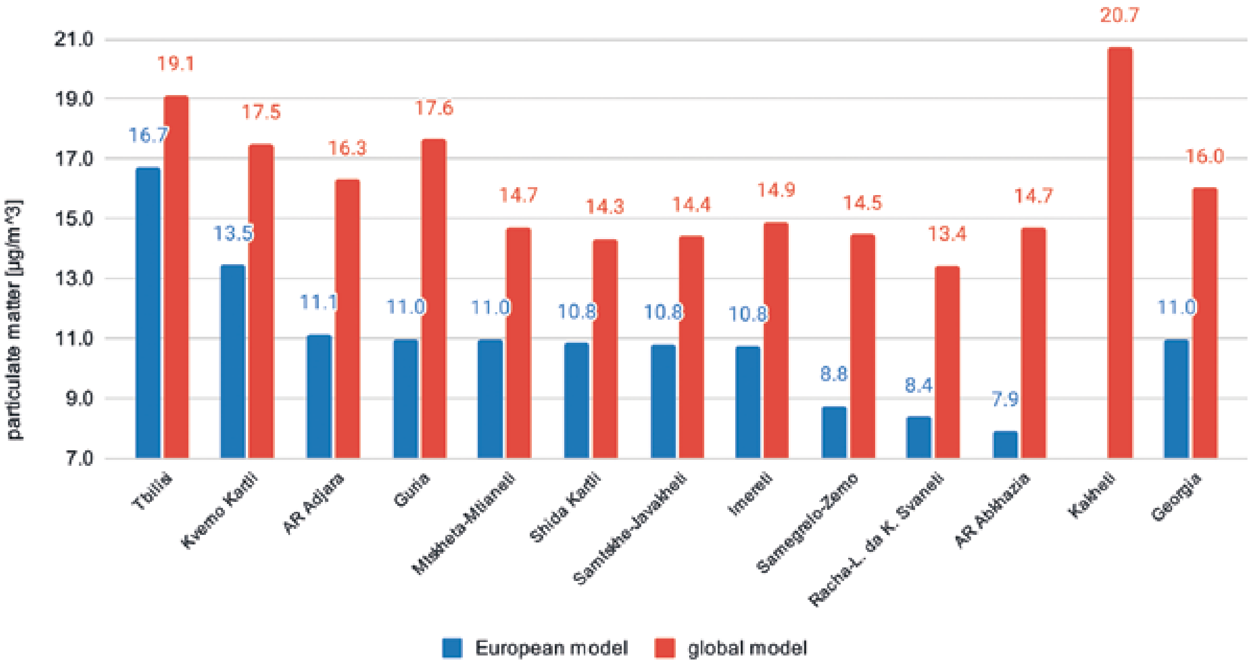


Fig. 27: Average PM_{10} concentrations in the regions of Georgia between May 2018 and December 2022, obtained from the Copernicus Atmosphere Monitoring Service data. Source: CAMS, 2018-2022.

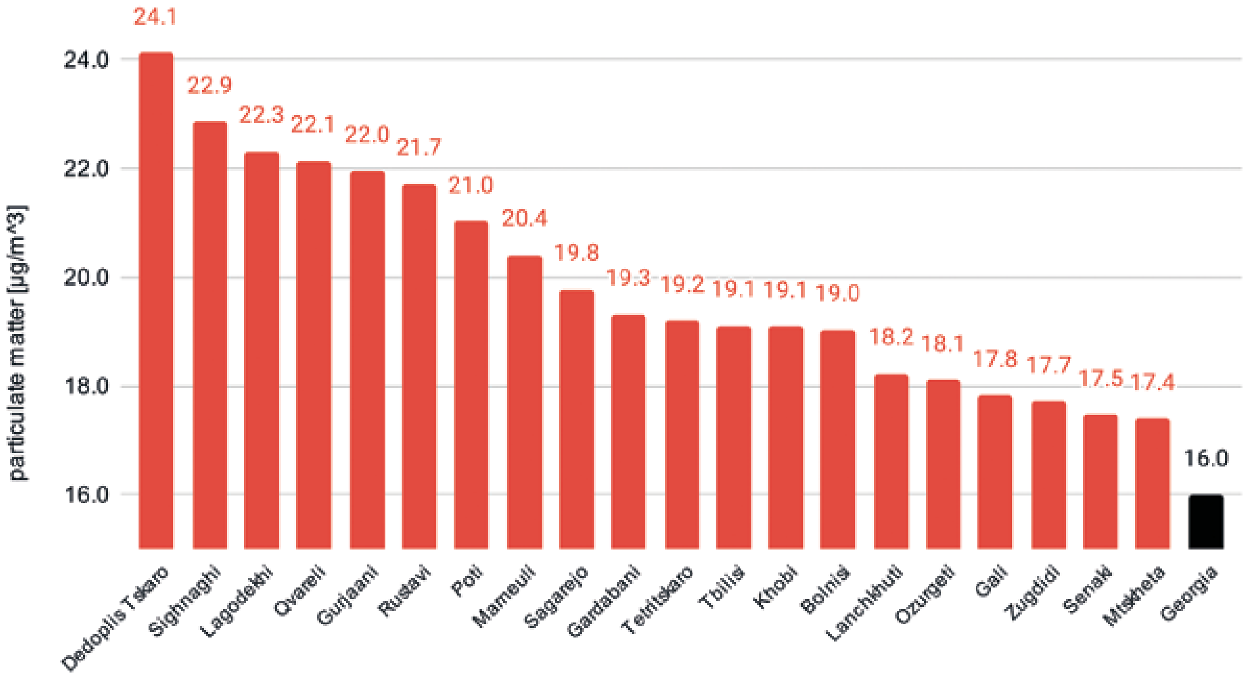


Fig. 28: 20 highest average PM_{10} concentrations in municipalities and self-governing cities of Georgia (using the global model) between May 2018 and December 2022, obtained from Copernicus Atmosphere Monitoring Service data. Source: CAMS, 2018-2022.

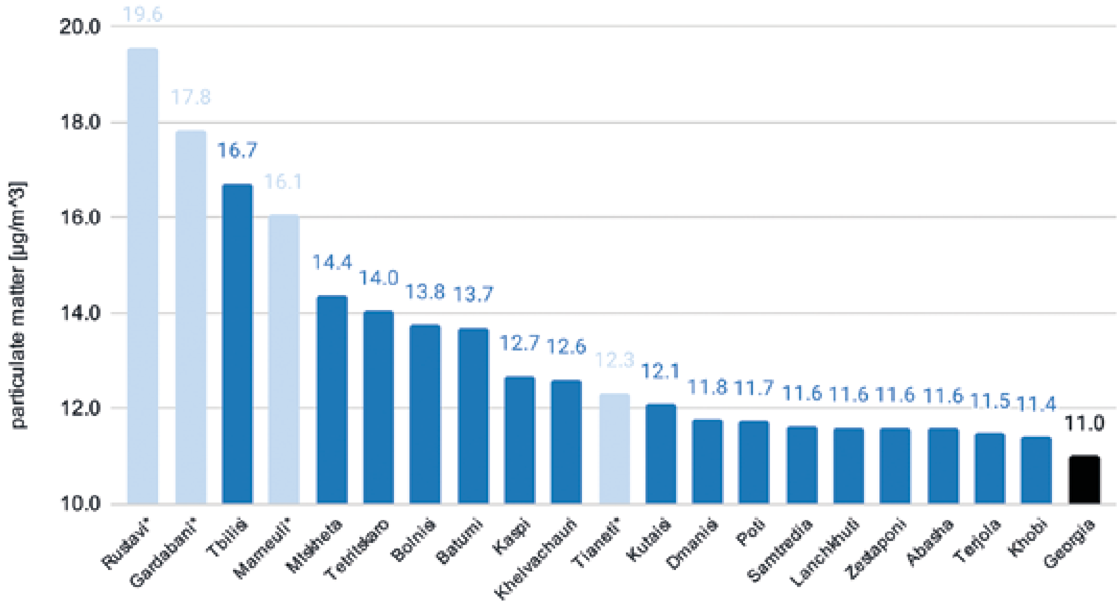


Fig. 29: 20 highest average PM_{10} concentrations in municipalities and self-governing cities of Georgia (using the European model) between May 2018 and December 2022, obtained from Copernicus Atmosphere Monitoring Service data. Source: CAMS, 2018-2022. Note (*): The values for the self-governing city of Rustavi and the Gardabani, Tianeti, and Marneuli municipalities do not cover their entire areas.

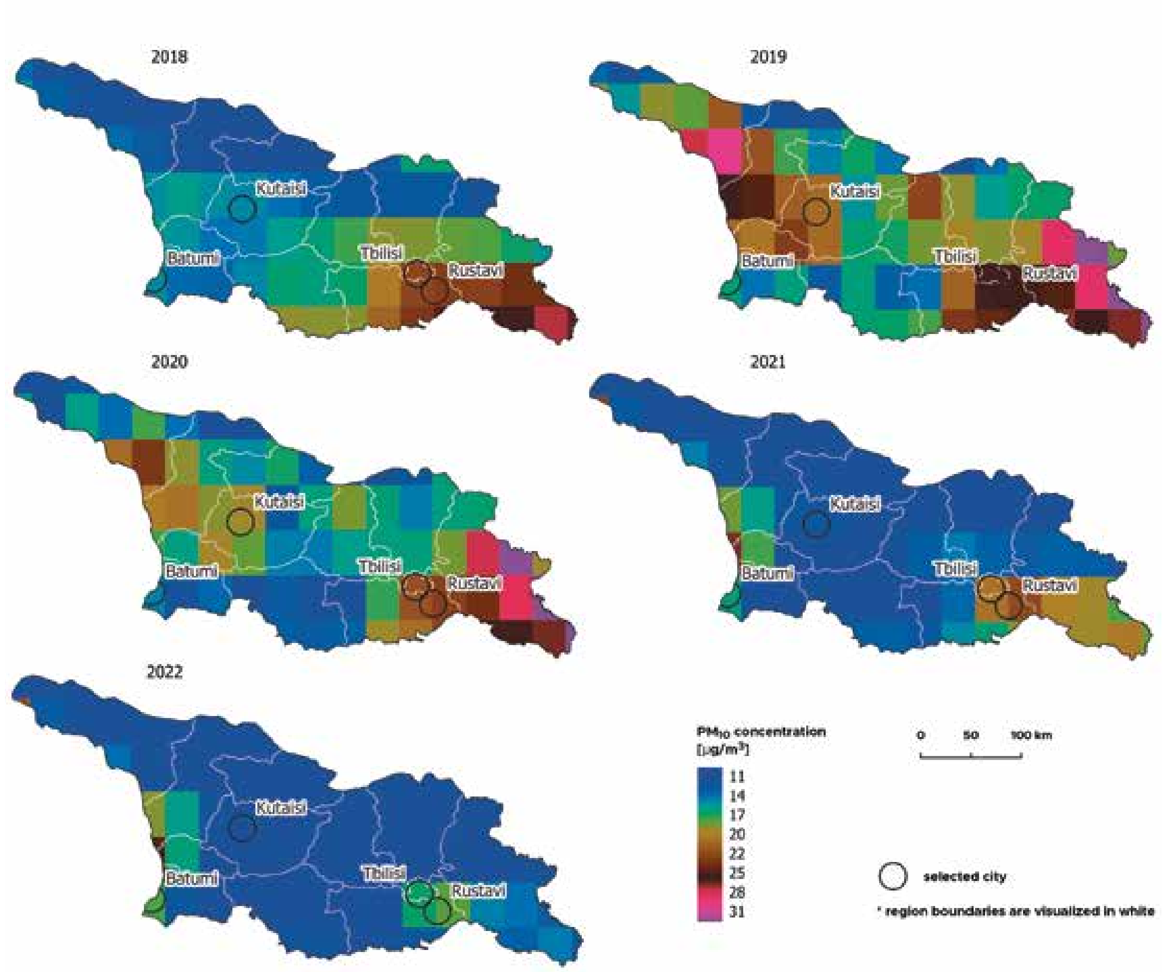


Fig. 30: Average yearly PM_{10} concentrations in Georgia (using the global model) between May 2018 and December 2022, obtained from the Copernicus Atmosphere Monitoring Service data. Source: CAMS, 2018-2022.

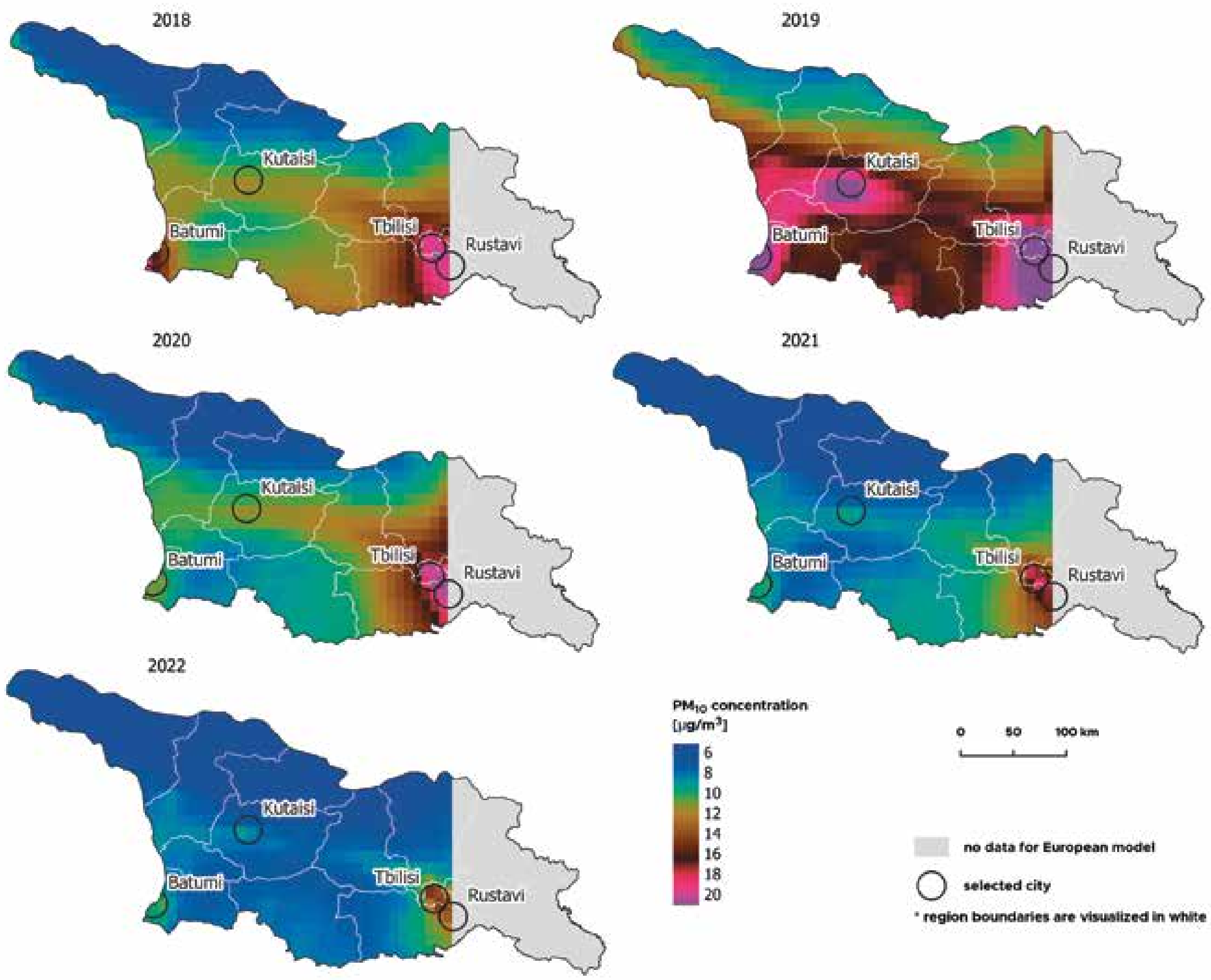


Fig. 31: Average yearly PM_{10} concentrations in Georgia (using the European model) between May 2018 and December 2022, as obtained from the Copernicus Atmosphere Monitoring Service data. Source: CAMS, 2018-2022.

The yearly variation in PM_{10} (Fig 30) surprisingly shows a low dependency on introducing a COVID-19 lockdown, although drastic preemptive measures were implemented in the country. A form of lockdown was introduced from mid-April to June 2020, with another lockdown following from October 2020 to February 2021, with public transport suspended in November 2020 and re-opened in February 2021 (Nadareishvili et al., 2022). Several returns of the measures, such as a curfew and suspension of public transport, occurred during 2021 (A3M Global Monitoring GmbH, 2023). The PM_{10} pollution was higher in the pre-COVID years, with the maximum concentrations in 2019. The concentrations in 2020 saw a decrease; however, they were comparable with the 2018 values, and the decrease continued steadily until 2022. Similar overall temporal trends can be seen in both models.

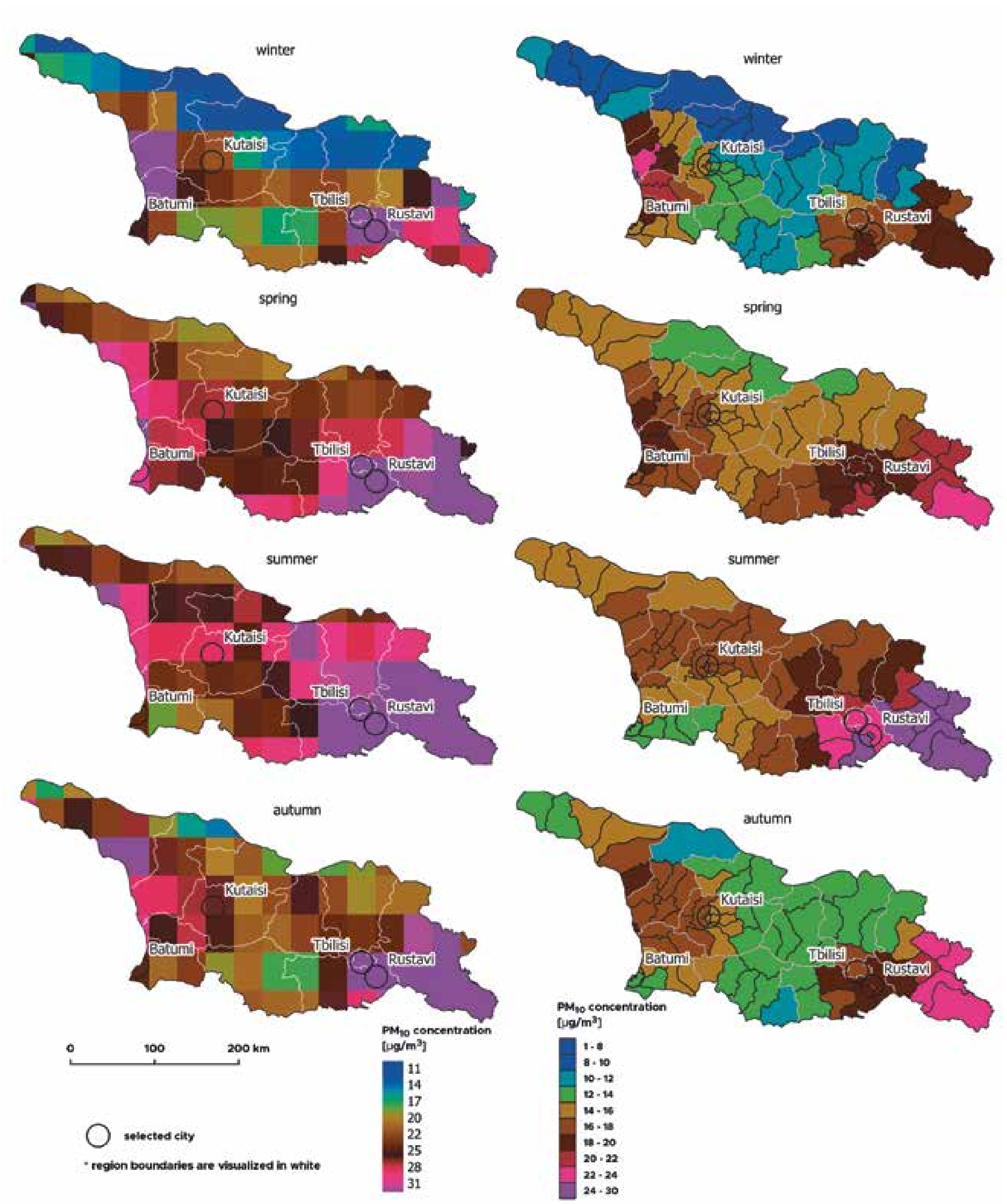


Fig. 32: Average seasonal PM_{10} concentrations in Georgia (using the global model) between May 2018 and December 2022, obtained from the Copernicus Atmosphere Monitoring Service data. Source: CAMS, 2018-2022.

Seasonality of air pollution

The seasonality of PM_{10} distribution (Fig. 33) supports the previously described reasoning for the pollution. In summer and partly spring, the particles from the drier eastern part of the country spread towards the west and thus, the area of Tbilisi, Rustavi, and the surrounding municipalities is strongly affected. In winter and autumn, the peaks are more distinctive around larger cities, probably caused by intensified household heating

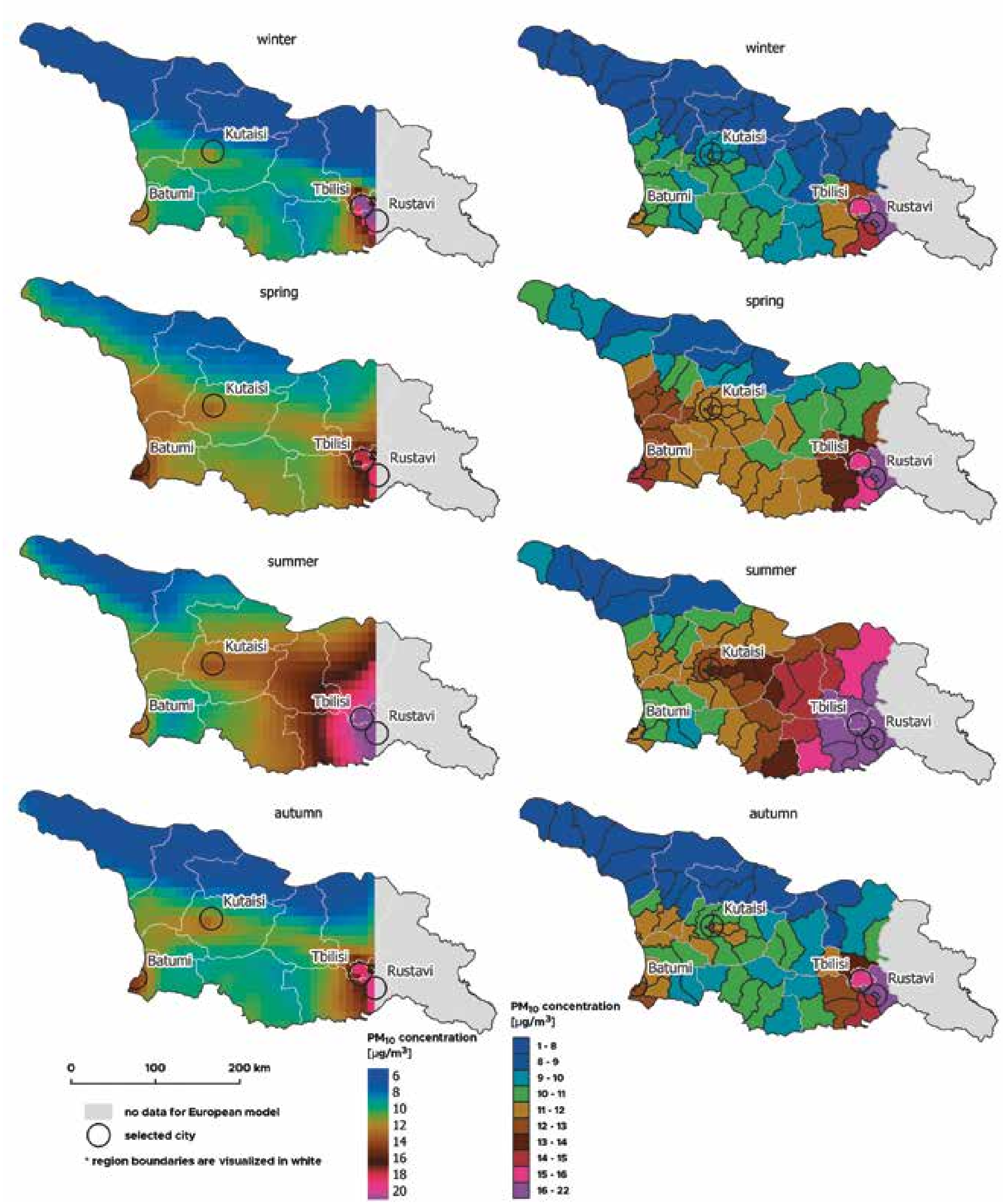


Fig. 33: Average seasonal PM_{10} concentrations in the regions of Georgia (using the European model) between May 2018 and December 2022, as obtained from the Copernicus Atmosphere Monitoring Service data. Source: CAMS, 2018-2022.

using solid fuels, such as wood and coal.

The global model (Fig. 32) fails to observe more subtle changes and the temporal trend seems to adhere predominantly to the natural processes of dust and aerosol distribution throughout the year. Concentrations are thus elevated in spring and summer, when drier and windier periods cause re-suspension of the particles, primarily in the east of the country and on the west coast.

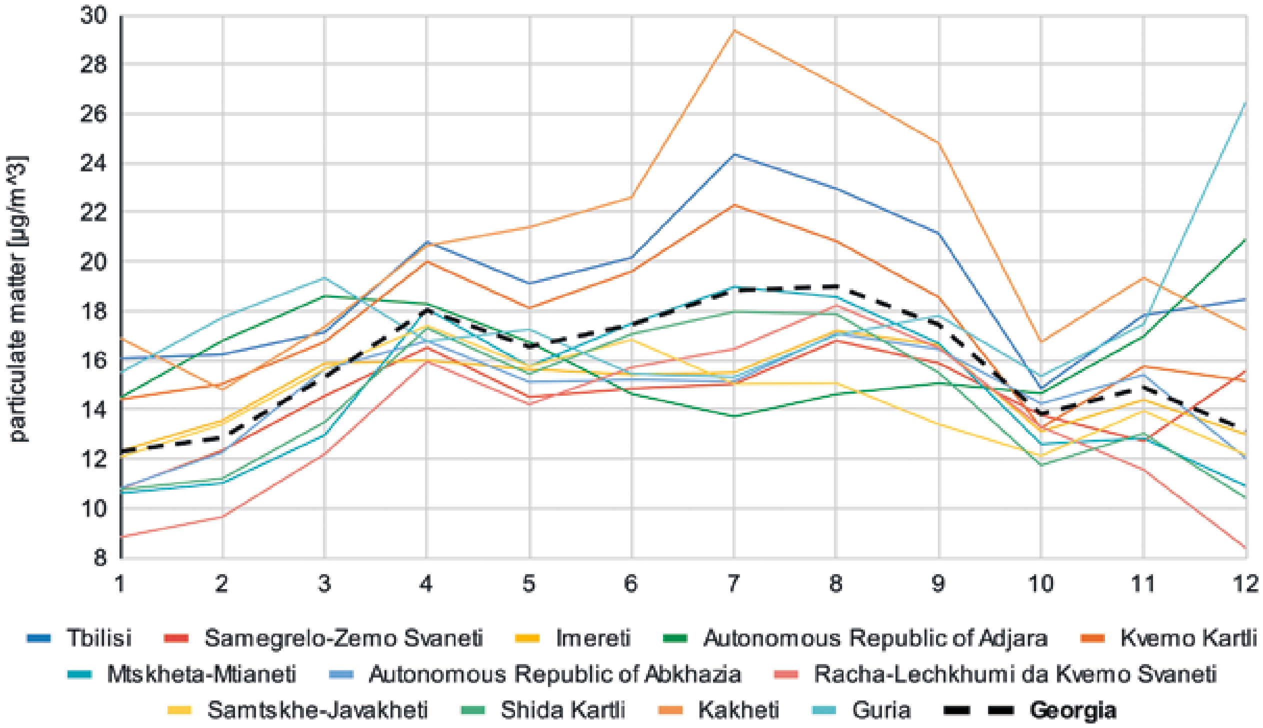


Fig. 34: Seasonality of PM_{10} in the regions of Georgia (using the global model) between May 2018 and December 2022, obtained from the Copernicus Atmosphere Monitoring Service data. Source: CAMS, 2018–2022.

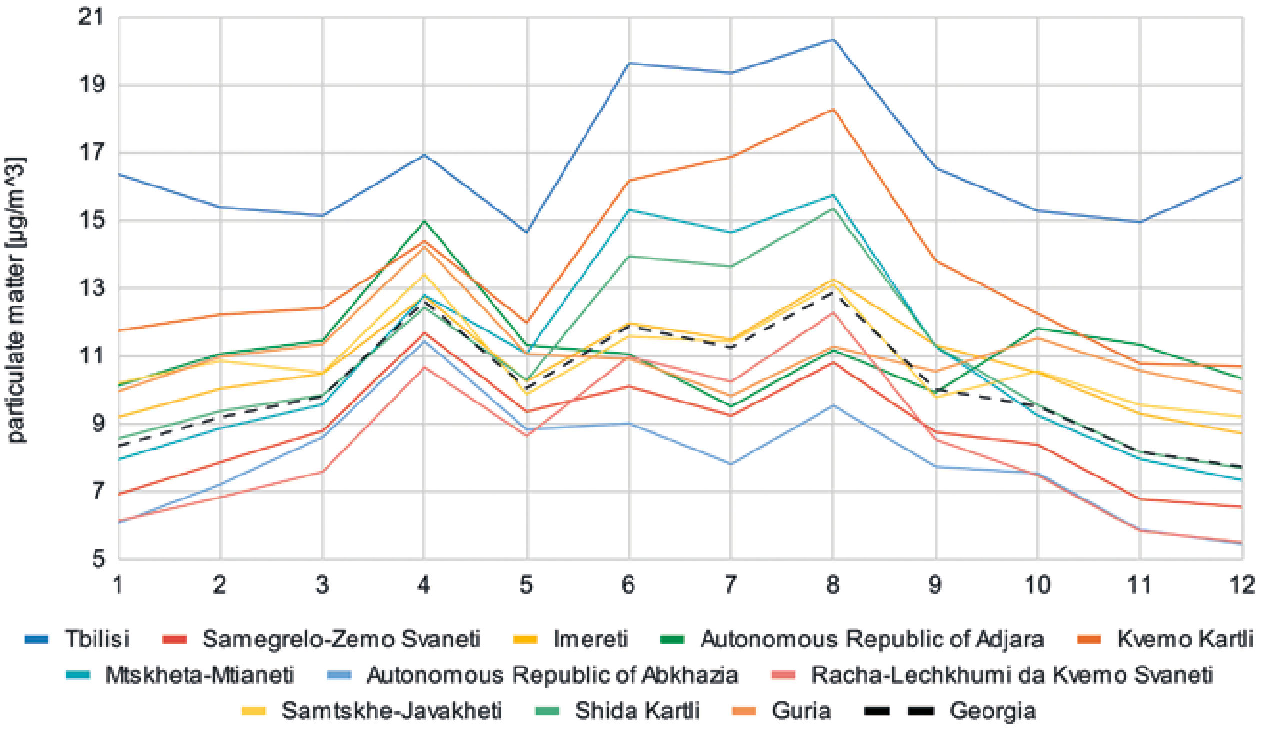


Fig. 35: Seasonality of PM_{10} in the regions of Georgia (using the European model) between May 2018 and December 2022, obtained from the Copernicus Atmosphere Monitoring Service data. Source: CAMS, 2018–2022.

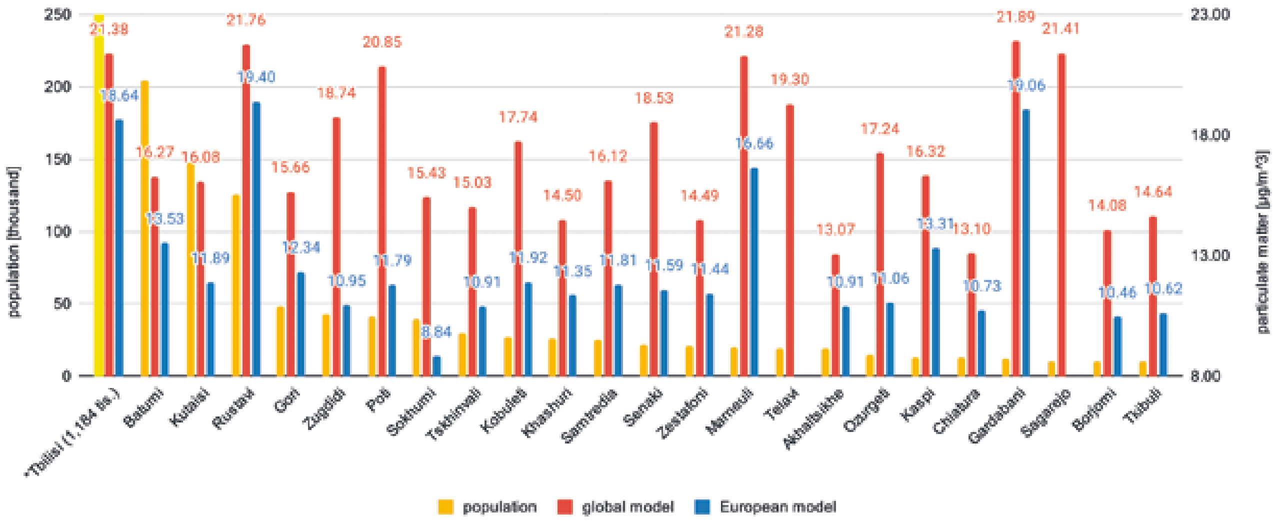


Fig. 36: Average PM_{10} concentrations in cities with a population over 10,000 in Georgia between May 2018 and December 2022, obtained from the Copernicus Atmosphere Monitoring Service data. Source: CAMS, 2018-2022.

Figs. 34 and 35 show the PM_{10} values in each month averaged over 2018-2022. The concentrations rise in the summer months in both models. The European model does not include the Kakheti region, which scores highest in the global model. In contrast, the European model is dominated in all months by the Tbilisi region, which is generally the second highest in the global model. As with maps referring to seasonality, natural conditions cause the re-suspension of particles in the east and west of the country, leading to elevated concentrations.

Air pollution in cities

Fig. 36 shows the average concentrations of PM_{10} for cities with more than 10,000 inhabitants. It can be observed that the model values for both the European and global models are not vastly dependent on the population of a given city. In general, the values for cities measured using the global model are higher and significantly generalised. The European model achieves similarly high values as the global model for industrial cities such as Gardabani and Rustavi.

Recommendations

Air pollution presents a threat to human health and the environment and can cause non-negligible economic losses. Georgia is on a well-established track to improve and maintain air quality and has been adopting many of the EU environmental standards and legislation. It is necessary to follow up in several areas of improvement, such as transport and transit, industry accountability, enforced regulatory frameworks, energy diversification, and public involvement. The following activities are recommended to support the objective.

Energy efficiency measures

Implementing financial instruments backed by strong energy efficiency rules and obligations based on EU policies can significantly reduce energy consumption and the associated emissions. This regards areas such as the renovation of buildings, industry, and transport. It also includes promoting energy-efficient equipment, retrofitting buildings, and implementing smart transportation solutions, all of which contribute to a reduction of air pollution. Policy instruments such as audit obligations, technical competence requirements, and the implementation of energy management systems need to be used, with a specific focus on efficient district heating and cooling to support a clean and decarbonised heat and cooling supply.

Modernisation of transport

In terms of transport, it is further required to strengthen the authority of regular emission and technical checks for cars, trucks, and motorised means of public transport. The public transport in Tbilisi and its metropolitan area is at a fairly good level and old diesel buses are being replaced with new CNG vehicles. However, the capacity, convenience, and reliability of public transport should be developed further. A daily commute regime and the busiest road sections to Tbilisi should be carefully analysed for a proper reinforcement of public transport from the hinterland. Other larger cities, such as Kutaisi, Batumi, or Rustavi, would benefit from a similar public transport renewal.

Emission control measures for industries

The heavy industry present in Georgia has been raising concerns regarding its impact on the environment and human health. One example may be the numerous factories with questionable pollution management in the industrial zone of the city of Rustavi (Chkareuli, 2019). It is recommended to implement regular pollution control technologies, require cleaner production methods, and enforce strict emission standards for such industries (it is recommended to follow the Best Available Techniques (BAT) defined within the EU Integrated Pollution Prevention and Control (IPPC) Directive). Financial support in the form of subsidies, low-interest loans, or tax incentives helps significantly in the introduction of better technologies and reducing emissions. Nevertheless, many of the larger facilities are driven by foreign capital, for example, the GeoSteel plant in Rustavi by the Indian company JSW or the Kaspi Cement Plant by the German company Heidelberg Cement. As Georgia's economy has been stable and transparent over the past decade (World Bank 2022), being the easternmost member of the European Union's Free Trade Area, the country is in an ever-stronger position to show that no concessions are to be made to large multinational corporations with regard to the unsustainable exploitation of the environment and workers' health.

In the cities, stricter regulations should be implemented and enforced to reduce dust from construction sites (e.g. a ban on dry cutting of construction stone), which are frequently reported as a significant contributor to air pollution.

Sector-specific roadmaps for emission reduction should outline key steps, milestones, and targets for transitioning to more sustainable production. Proper support and technology transfer from international institutions or the EU can provide guidance and technical support in the development of these roadmaps and monitoring progress. Support for research and development initiatives focused on developing innovative solutions for the reduction of emissions in industries will also foster international competition and provide new business opportunities.

Regulatory frameworks and environmental liability

In recent years, Georgia has taken various steps to unify its legislation on environmental protection with the EU. An air quality monitoring framework based on the EU indicative measurement standards was launched in 2020 (UNDP, 2020) and Georgia's 2030 Climate Change Strategy with the Action Plan was introduced in 2021 (Government of Georgia, 2021). It is now vital also to strengthen the capacity of the regulatory agencies responsible for environmental protection to enforce the proposed air quality standards and regulations effectively. This requires the allocation of adequate resources, including funding, staffing, and training. An emphasis should also be placed on enforcing the legislation, which is bound to advances against lobbying activities and corruption. Regular inspections and audits of industries, power plants, and other sources of pollution should be conducted to verify compliance with environmental regulations. Stringent but proportional penalties for non-compliance with air quality standards and regulations should raise awareness among industries and the public about the consequences of non-compliance. Because of the political situation in the region and its strategic position, Georgia has a big transit potential. When the S1 arterial highway is finished, appropriate tolls for personal and especially cargo transport should be introduced to help gain a return on investment and to balance the environmental burden. A similar process could apply to the Baku-Tbilisi-Kars railway; however, the process should be careful because of the multinational nature of the project.

Renewable energy deployment

The geographic distribution patterns of air pollution do not always convincingly expose the notorious anthropogenic sources (except maybe transport). This partly points to the country's current energy sector, with more than 80% of electricity generated from hydropower sources. The emphasis must be placed on preventing the building of new fossil fuel power plants, gradual reduction of the share of fossil fuels, and the diversification of energy production among renewable sources. Climate change is a threat to water as an energy resource and its sudden lack could bring about regression to quickly deployable but polluting fossil resources. To attract business interest in the renewable energy sector, it is recommended to establish supportive policies, feed-in tariffs, and investment incentives to attract private sector involvement in renewable energy projects.

Monitoring and open data

An automated nationwide system of air pollution monitoring should be introduced, providing data on concentrations of individual pollutants to the public authorities and the public continuously. Other open information systems should also be built to contribute to better understanding of air pollution and its sources, such as a PRTR (Pollution Release and Transfer Register), presenting the annual volume of emissions from major industrial sources.

Public awareness and participation

Living standards are projected to improve significantly in Georgia in the coming years, and this should be closely tied to responsibility and environmental awareness. It is thus recommended to foster activities focused on raising awareness among the public about the health impacts of air pollution and the importance of individual actions in reducing emissions. To encourage public participation in decision-making processes and involve stakeholders in the development and implementation of air pollution control measures, user-friendly platforms and tools for accessing and understanding environmental data are crucial. One well-executed example is the operational public air quality monitoring portal (https://www.air.gov.ge). The public should be invited much more actively by the public authorities to participate in the preparation of spatial plans, regional air quality control plans, and other strategies with crucial importance for the quality of life, as well as decision making on major industrial and infrastructural projects.

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ARNIKA

Arnika is uniting people seeking a better environment. We believe that natural wealth is not only a gift, but also an obligation to save it for the future. Since its foundation, Arnika has become one of the most important environmental organisations in the Czech Republic. It bases its activities on three pillars: engaging the public, arguments based on expertise, and communication. Since the beginning, Arnika has led public campaigns both in the Czech Republic and internationally. The organisation focuses on nature conservation, toxics and waste, and environmental democracy.

WORLD FROM SPACE

World from Space is a Czech deep-tech company that utilises satellite and geospatial data to create positive impacts in agriculture, NewSpace, and beyond. The company's data-driven analytics are pivotal for informed decision making, enabling organisations to derive actionable insights from vast amounts of information and drive strategic outcomes. WFS is working on commercial contracts, R&D projects with the European Space Agency (ESA), the EU Agency for Space Programmes (EUSPA), and in international consortia on Horizon, LIFE, and other research projects.

MY CITY KILLS ME

The civic movement **"My City Kills"** was first established in 2018 on Facebook with the sole purpose of emphasising and discussing the existing environmental and social problems of Georgia. Since then, the team of volunteers has been working to safeguard the rights of all people to clean air and water, safe food, and to live in a healthy environment. Our mission is to protect the land, the air, and the waters on which all life depends. Our vision is a place where people act consciously to conserve nature for its own sake and for future generations.

More information:
http://arnika.org/en/countries/georgia
http://greenpole.org

Rustavi Metallurgial plant is one of the largest metallurgical industry in the entire Caucasus. Pollution from Rustavi is most likely transmitted also to nearby capital, Tbilisi. Photo: Majda Slamova / Arnika

Although remote sensing has not identified certain industrial cities amont the most polluted locations, outdated technologies may pose a risk to the local population. The authorities should consistently monitor the air condition, for example, in Zestaponi, where the smelters are located. Photo: Majda Slamova / Arnika

You can download the study: