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Automated Air Quality Monitoring Using Sentinel-5P Data and Google Earth Engine: Case Study of Dnipropetrovsk and Zaporizhzhia Regions

*__A. Andreiev__ (*State Institution "Scientific Centre for Aerospace Research of the Earth of the Institute of Geological Sciences of the National Academy of Sciences of Ukraine"*), **T. Dudar, D. Malyi** (*State University "Kyiv Aviation Institute"),* **O. Titarenko, A. Kozlova** (*State Institution "Scientific Centre for Aerospace Research of the Earth of the Institute of Geological Sciences of the National Academy of Sciences of Ukraine"*)

SUMMARY

Air pollution represents a critical environmental challenge with significant negative impacts on human health, livestock, and vegetation. To mitigate these risks, consistent air quality monitoring is recognized as an actual and important task due to such international standards and regulations, as the EU Air Quality Directive (2008/50/EC) and World Health Organization (WHO) guidelines. For this monitoring, the most effective tool is remote sensing, since it provides means for regular and large-scale analysis with almost open-source and freely available data. Specifically, the Sentinel-5P dataset provides the necessary spatial (approximately 1 km) and temporal (2 days) resolution for effective regional monitoring. Also, it enables the analysis of multiple pollutant, including nitrogen dioxide (NO_2), sulfur dioxide (SO_2), methane (CH_4), and carbon monoxide (CO). Given the large data volumes involved, the Google Earth Engine (GEE) platform serves as a highly effective environment for automated processing. Thus, the aim of this study is to develop an automated air quality monitoring application based on Google Earth Engine and Sentinel-5P data The developed application was applied to the Dnipropetrovsk and Zaporizhzhia regions to conduct a comparative analysis between the pre-war (2019–2021) and wartime (2022–2024) periods. The obtained results revealed that the combined area of "High" and "Very High" NO_2 concentration classes decreased from 37.9% to 29.3%, while the combined area of "Medium" and "Low" classes increased from 62.1% to 70.7%. The observed improvement in air quality is driven by military actions in these regions, which caused a decrease in industrial activity.

Keywords: Air quality monitoring; Air pollution; Sentinel-5P; Google Earth Engine; Remote sensing; Nitrogen dioxide; Spatial analysis; Industrial regions; Automated monitoring; Environmental security.

Corresponding Author: artem.a.andreev@gmail.com

Introduction

Air pollution is one of the key environmental challenges that significantly affects human health, livestock, and vegetation. The importance of air quality monitoring is recognized by international standards and regulations, including the EU Air Quality Directive (2008/50/EC) (European Parliament and Council of the European Union, 2008) and World Health Organization (WHO) guidelines (World Health Organization, 2021). Accordingly, continuous air quality monitoring supports effective environmental management and sustainable development and contributes to the achievement of the Sustainable Development Goals (SDGs), particularly SDG 3 (Good Health and Well-being) and SDG 11 (Sustainable Cities and Communities) (United Nations, 2015).

For the task of air quality monitoring, remote sensing has proven to be an effective tool (Stankevich et al., 2016; Savenets & Osadchyi, 2024). Among its main advantages are the ability to analyze large-scale areas, perform regular monitoring, and the fact that most remote sensing products are freely available. In addition, unlike ground-based observations, remote sensing can be applied to areas where ongoing military operations are taking place (Ievsiukov et al., 2018; Savenets et al., 2023). Among the available remote sensing products, Sentinel-5P is the most widely used, providing a spatial resolution of approximately 1 km, which is sufficient for regional-scale analysis. Furthermore, its temporal resolution of 2 days enables regular monitoring of air quality (Halder et al., 2023).

However, effective air quality monitoring requires the processing of large volumes of remote sensing data. This is mainly due to two reasons. First, environmental monitoring often relies on the analysis of long-term satellite data time series (Popov et al., 2021). Therefore, temporal analysis requires the construction of time series based on frequent satellite observations. Second, regional-scale analysis involves large spatial extents, which further increases the volume of data to be processed. Accordingly, cloud-based geospatial analysis platforms are well-suited for this task. One of the most widely used platforms is Google Earth Engine (GEE) (Gorelick et al., 2017). It enables the processing of large volumes of geospatial data using Google's cloud computing infrastructure, eliminating the need for high-performance local hardware and data storage. Another advantage of GEE is the ability to develop custom applications with a graphical user interface (GUI), allowing users to create tools for their specific tasks.

Thus, the aim of this study is to develop an automated air quality monitoring application based on Google Earth Engine and Sentinel-5P data. The developed application enables automated processing, visualization, and analysis of satellite-derived air quality data.

Method and Theory

The presented web-based application for automated air quality monitoring is developed on the Google Earth Engine (GEE) cloud platform and is accessible via the following link: https://ee-artemaandreev.projects.earthengine.app/view/sentinel-5p-air-quality-monitoring-global. The functional flowchart of the application's architecture is presented in Figure 1. This architecture is based on such functional blocks as Sentinel-5P products, study area assignment, aggregation over the study period, classification into ranges, and generation of aggregated maps of air quality.

This application provides the assessment based on key atmospheric products, including Nitrogen Dioxide (NO_2), Sulfur Dioxide (SO_2), Methane (CH_4), and Carbon Monoxide (CO). The source of input data is the Copernicus Sentinel-5P satellite mission. This dataset provides high revisit frequency, namely every 2 days. The spatial resolution of these products is 1113.2 meters, which is suitable for regional analysis. The measurement units for the selected products are expressed as vertical column density (mol/m2).

The study area can be assigned using four options: 1) selecting from administrative regions of Ukraine, 2) drawing on the GEE interactive map, 3) using a preset asset path, or 4) entering a custom asset path. Users can select administrative regions, an option realized through the FAO/GAUL datasets, which provide the boundaries of global administrative level units. Another option is to draw the polygons, rectangles, or lines using the GEE interactive map. Another two options imply selecting a preset path to existing GEE assets or providing a custom path to the user's own data. Along with the study area, the user should also assign the study period. This parameter includes both the months and the years over which the analysis will be performed.

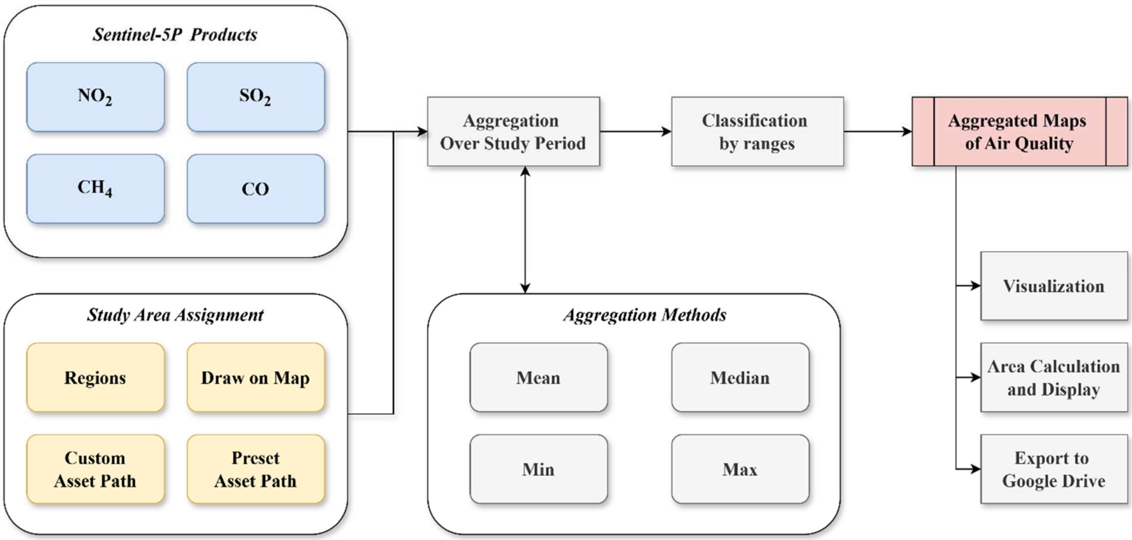


Figure 1. *Functional flowchart of the developed web application for air quality monitoring based on the Sentinel-5P dataset*

The data processing stage includes data aggregation over the study period and its further classification. The aggregation could be performed by one of the following methods: Mean, Median, Min, or Max. Following the aggregation, the obtained aggregated maps could be divided into several classes based on user-defined value ranges.

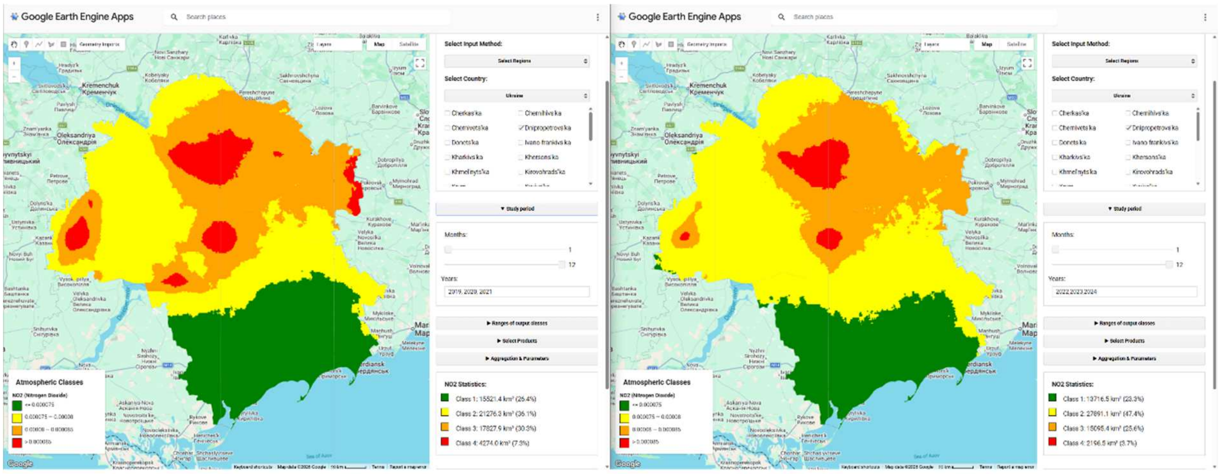
As a result, the developed application generates the aggregated maps of air quality based on user-selected Sentinel-5P products. These maps could be visualized using user-defined range classification in the GEE interactive map. Also, the application provides area statistics for each class of the obtained maps. These stats could be displayed via the application GUI. Finally, both the processed map layers (as GeoTIFFs) and the calculated statistical data (as CSV files) can be exported directly to the user's Google Drive for further external analysis. However, it should be noted that direct export is not available through the published application, so it can only be performed using the GEE code editor.

Results

For the practical application of the developed tool, the Dnipropetrovsk and Zaporizhzhia regions of Ukraine were selected as the study area. These regions were selected due to their high industrial activity, which causes significant atmospheric pollution. Given their proximity to the frontline, industrial activity has shifted significantly, making a comparative pre-war and wartime analysis essential.

The conducted experiment implied a comparison between two study periods, namely the first one represents pre-war years (2019–2021), while the second represents wartime years (2022–2024). Both study periods include all months of the year

For the visual interpretation and further analysis, the obtained maps were classified into five classes based on the NO_2 concentration values (mol/m²): Very Low (0–0.00007), Low (0.00007–0.000075), Medium (0.000075–0.00008), High (0.00008–0.000085), and Very High (>0.000085). The GUI of the developed application and the obtained maps of NO_2 concentration distributions for the pre-war (2019–2021) and wartime (2022–2024) periods are presented in Figure 2.



a) b)

Figure 2. *Interface of the developed application displaying NO_2 concentration maps for the Dnipropetrovsk and Zaporizhzhia regions: (a) pre-war period (2019–2021) and (b) wartime period (2022–2024)*

Based on the obtained maps, the area distribution of each was calculated for both study periods. The corresponding statistics are presented in Table 1.

Table 1. *Distribution of NO_2 concentration classes by area (km^2 and %) for the two study periods*

Class	***Range, mol/m^2***	***Area (2019 – 2021), km^2 (%)***	***Area (2022 – 2024), km^2 (%)***
Low	*0 – 0.000075*	*15428.3 (26.2%)*	*13716.5 (23.3%)*
Medium	*0.000075 – 0.00008*	*21173.3 (35.9%)*	*27891.1 (47.4%)*
High	*0.00008 – 0.000085*	*18182.3 (30.9%)*	*15095.4 (25.6%)*
Very High	*>0.000085*	*4115.6 (7.0%)*	*2196.5 (3.7%)*

The obtained area distribution indicates that NO_2 concentrations decreased in the study regions during the wartime years (2022-2024) compared to the pre-war years (2019-2021).

Conclusions

In this paper, we presented a web-based application developed on the Google Earth Engine platform for automated air quality monitoring using Sentinel-5P satellite data. This application provides analysis of such gas concentrations as NO_2, SO_2, CH_4, and CO. To meet the terms of the user's task, the developed GUI allows assigning input parameters such as the study area, study period, required atmospheric products, and aggregation method. The outputs are generated as a map of gas concentrations and stats, reflecting the spatial distribution of gases. These maps can be visualized directly within the GEE interactive map. Also, both maps and statistical data can be exported to Google Drive for further analysis.

The developed application was applied to the Dnipropetrovsk and Zaporizhzhia industrial regions of Ukraine. The study conducted a comparative analysis between two periods: the pre-war years (2019–2021) and the wartime years (2022–2024). As a result, it was revealed that air quality improved during the wartime period, as industrial activity decreased. Specifically, the combined area of “High” and “Very High” NO_2 concentration classes decreased from 37.9% to 29.3%, while the combined area of “Medium” and “Low” classes increased from 62.1% to 70.7%.

Future research may focus on extending the application to support near-real-time detection and monitoring of local air pollution events caused by industrial accidents, accidental releases of hazardous substances, and wildfires (Stankevich et al., 2023; Yan et al., 2025).

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