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APPLICATION OF OPEN SOURCE SOFTWARE IN DEVELOPING WEBGIS FOR MONITORING AIR QUALITY IN BINH DUONG

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ABSTRACT

This study applies open-source software including GeoServer, OpenLayer, and QGIS2Web in conjunction with QGIS to build a database, along with Visual Studio Code to develop a WebGIS for monitoring air quality in Binh Duong province in 2024. The authors utilized Sentinel-5P satellite data to extract concentrations of air pollutants (NO_2, SO_2, CO, and O_3) through a scripting interface on the Google Earth Engine platform. They also incorporated ground-based data from 29 monitoring stations, provided by the Binh Duong Environmental Monitoring Center. The WebGIS was developed to display information on air pollution parameters (NO_2, SO_2, CO, and O_3) in the Binh Duong area, featuring monthly averages for the year 2024. It includes maps of pollutant distributions and statistical summaries by month and monitoring location. Through the WebGIS application, users can access and query air quality data, enabling policymakers and managers to develop effective strategies for air pollution control and environmental management in the study area.

Keywords: Open source, air pollution, Sentinel-5P, WebGIS, QGIS2Web, GeoServer, GEE.

1. INTRODUCTION

Air pollution is the condition that alters the physical, chemical, and biological properties of the air, adversely affecting human health, living organisms, and the environment [1]. Air pollution poses a danger to health, and this is also bad news for the community, society, and the economy of Vietnam. Air pollution reduces labor productivity, negatively impacts crop and livestock yields, decreases domestic and international tourism revenue, as well as international investment, causes damage to heritage sites due to acid rain, and leads to the degradation of ecosystems and

biodiversity. According to the World Bank, air pollution causes social and economic losses for Vietnam, including premature deaths and illnesses, amounting to over 13 billion USD each year, not including future cleanup costs. This number is equivalent to 4% of the country's gross domestic product (GDP) [2].

Binh Duong province is located in the Southeast region, with the highest economic development rate in the area and the highest average income per capita in the country [3]. However, this has also led to some environmental consequences, with pollution levels rising significantly in recent years, especially air pollution. According to the Binh Duong Province Center for Natural Resources and Environment Monitoring and Engineering, the Air Quality Index (AQI) in Binh Duong in November 2024 showed that 48% of the air quality was good, 14% was moderate, 31% was poor, and 7% was bad [4]. Compared to the same period in 2023, air quality has decreased. Compared to October 2024, air quality has shown a downward trend, with an increase of 08 positions in the poor category and 2 positions in the bad category [4]. In the Southeast region in general, and Binh Duong in particular, during the transitional period between the rainy and dry seasons, it is easy to notice that the atmosphere is covered by a layer of fog in the early morning, a phenomenon known as "photochemical smog," which describes a type of air pollution occurring in the troposphere, reducing visibility. Meteorological and atmospheric conditions cause pollutants to accumulate, limiting their dispersion, and remaining suspended at low levels, leading to an increase in pollutant concentrations.

WebGIS (Web-based Geographic Information System) is widely applied in many fields, especially in environmental quality management, thanks to its ability to share spatial data online, allowing users to easily access and quickly grasp information as WebGIS continuously updates in real-time [5]. GIS applications are now developed not only on desktop computers but also on the web. WebGIS is considered a geographic information system distributed over computer networks to integrate, distribute, and transmit geographic information online to users. Users everywhere can access the WebGIS site and utilize GIS applications without having to purchase software. The database through WebGIS technology has the advantage of allowing multiple users to access it simultaneously, managing data over time with large capacity, consistency, and no duplication [6].

Remote sensing technology has become a powerful tool for long-term air quality monitoring across various spatial and temporal scales [7]. Its capabilities in real-time observation and spatial data distribution offer a robust framework for assessing air quality, delivering detailed insights into pollutants such as CO_2, NO_2, SO_2, and other atmospheric contaminants. The integration of remote sensing has greatly enhanced the precision of pollutant concentration mapping, thereby contributing significantly to environmental protection and public health initiatives [8-9]. The emergence of the

Copernicus Sentinel-5P satellite has introduced significant advantages in atmospheric monitoring, particularly through its ability to detect a wide range of pollutants, including carbon monoxide, nitrogen dioxide, methane, and formaldehyde. Equipped with high-precision measurement capabilities and frequent temporal resolution, Sentinel-5P enables consistent and reliable monitoring of atmospheric gases over time. These features have made it a widely adopted tool in air quality monitoring efforts around the world [9-10].

Taken the advantages of remote sensing and WebGIS technologies, the research on "Applying Open Source Software in Building and Designing WebGIS Monitoring Air Quality in Binh Duong Province" has been conducted to provide information and data related to air quality in Binh Duong province to specialists and local managers for a comprehensive overview of the air environment and air quality. The study has taken advantages of remote sensing and Geographical Information System (GIS) in generation of database for the WebGIS. In addition, the free and open source software have been utilized in generation of WebGIS monitoring the air quality in Binh Duong Province. Results from this study provide useful applications for local government as well as citizen in updating information about local air quality and proposing appropriate strategies to enhance air quality in such urbanized and industrialized areas as Binh Duong Province.

2. METHODOLOGY

2.1. Data Sources and Preprocessing

The data for building WebGIS is Sentinel-5P data from the provider of European Space Agency (ESA) [11]. The data is received by default in the WGS-84 coordinate system and includes air quality parameters (NO_2, SO_2, CO, O_3) extracted directly from the online application Google Earth Engine. Google Earth Engine (GEE) is a highly advanced platform for assessing current air pollution levels. Through its robust data processing capabilities and integration of various analytical algorithms, GEE enables researchers to generate detailed maps illustrating air pollution distribution and to identify regions experiencing high concentrations of pollutants [12]. The specific implementation process of Sentinel-5P data is shown in Figure 1.

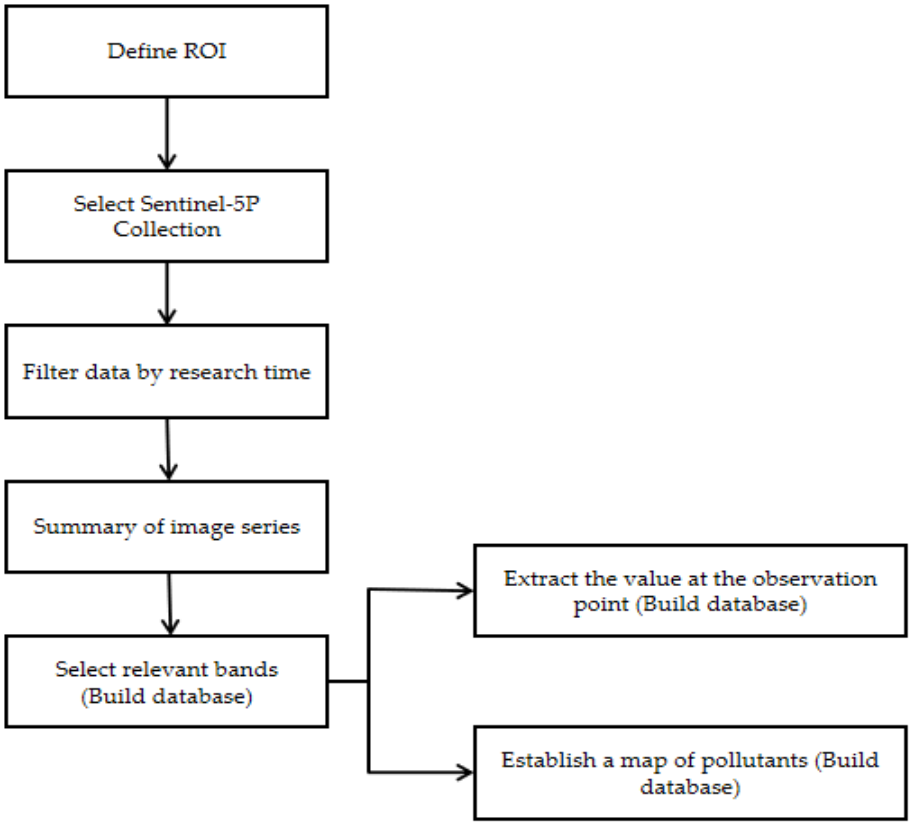

Figure 1: Sentinel-5P Data Processing Workflow.

Table 1. The input data used for generation of WebGIS

Data type	**Temporal resolution**	**Spatial resolution (km²)**	**Bandwidth used**
Sentinel-5P Surphur Dioxide (SO_2)	Daily	5.5 x 3.5	SO_2_column_number_density
Sentinel-5P Cacbon Monoxide (CO)	Daily	5.5 x 3.5	CO_column_number_density
Sentinel-5P Nitrogen Dioxide (NO_2)	Daily	5.5 x 3.5	tropospheric_NO_2_column_number_density
Sentinel-5P Ozon (O_3)	Daily	5.5 x 3.5	O_3_column_number_density
Binh Duong GIS database	NA	NA	Administrative boundary
29 air-quality monitoring stations	Monthly	Point locations	Coordinate locations

Table 1 presents the detailed information of the input data used in generation of the WEBGIS. The extraction of Sentinel 5P images from Google Earth Engine involves several key steps that ensure the data aligns with research objectives. Initially, satellite images are

collected, focusing on the specific bands required for analysis. The data is then filtered to encompass the time frame from January to December 2024, ensuring relevance to the study.

To enhance clarity and facilitate interpretation, unit conversions are performed, allowing for easier observation of air quality changes. Given the frequent satellite captures, images are aggregated to create a composite that improves classification accuracy.

However, due to the wide coverage of each image, substantial data volumes are generated. To refine the analysis, the images are clipped to the boundaries of Binh Duong province, which helps focus the research. Finally, the processed concentration data of pollution indicators is exported in TIF format, allowing for efficient storage in Google Drive and accessibility for future analyses (Figure 2).

In this study, the coordinate data of monitoring locations provided by the Center for Monitoring - Technical Resources & Environment. However, the concentration data of the indicators NO_2, SO_2, CO, and O_3 at 29 monitoring locations are only collected once a month at each location and are used to represent the entire month. This leads to low data accuracy as it does not reflect temporal fluctuations. To improve the accuracy and continuity of the data, it is necessary to propose extracting the concentrations of the air pollutants at monitoring locations from Sentinel-5P satellite data, which is recorded daily, thereby providing a more comprehensive and updated view of the air quality situation.

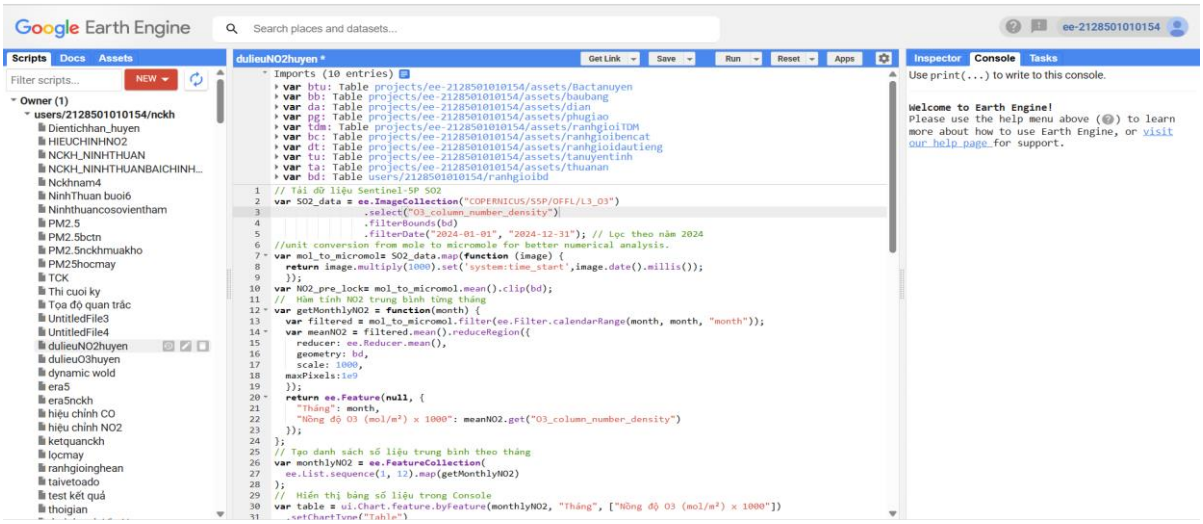

Figure 2. Extracting air pollution information in the Binh Duong area on the GEE platform.

2.2. Developing WebGIS for monitoring air quality in Binh Duong Area

During the development of a WebGIS platform for displaying and retrieving spatial map information related to parameters such as NO_2, SO_2, CO, and O_3, the open-source software that is easy to deploy and fits practical conditions has been used.

Specifically, QGIS software serves as the primary tool for editing and processing the initial map data. This is a powerful open-source software that supports various data formats and has the ability to integrate many useful plugins. QGIS2Web is a plugin integrated directly into QGIS, allowing users to publish designed maps in interactive web format (based on OpenLayers or Leaflet) [13]. This QGIS2Web software supports automatic generation of HTML, JavaScript, and CSS code, helping to minimize programming time for administrators. GeoServer is chosen as the platform to publish spatial raster data to the web according to OGC standards such as WMS, WFS [14]. Visual Studio Code is used as the main programming environment to build the interface for WebGIS using HTML, JavaScript, and CSS tags [15]. Finally, easy web access and online information retrieval are facilitated through popular web browsers such as Chrome, Internet Explorer, Opera.

Figure 3 is a methodological illustration of building WebGIS for air quality monitoring in Binh Duong. The framework includes collecting data on air pollution parameters (NO_2, SO_2, CO, O_3) directly from Google Earth Engine, overlaying with GIS data (boundaries and maps of Binh Duong province), and integrating information related to air quality.

After generation of database for WebGIS, the study uploaded raster spatial data of parameters (NO_2, SO_2, CO, O_3) to the GeoServer system and created styles for data layers using QGIS software. Subsequently, the research focused on building WebGIS for air quality at monitoring locations using data from Sentinel 5P satellites: Using Visual Studio Code to design the interface and QGIS2Web tool to provide functions for retrieving concentrations of parameters (NO_2, SO_2, CO, O_3) at monitoring locations. Then, registering to create a project name on the GitHub platform and establishing the WebGIS page. Finally, the study completed by finalizing the database, standardizing, designing the interface and functions for the website, conducting usability testing, interaction, and fixing any missing components.

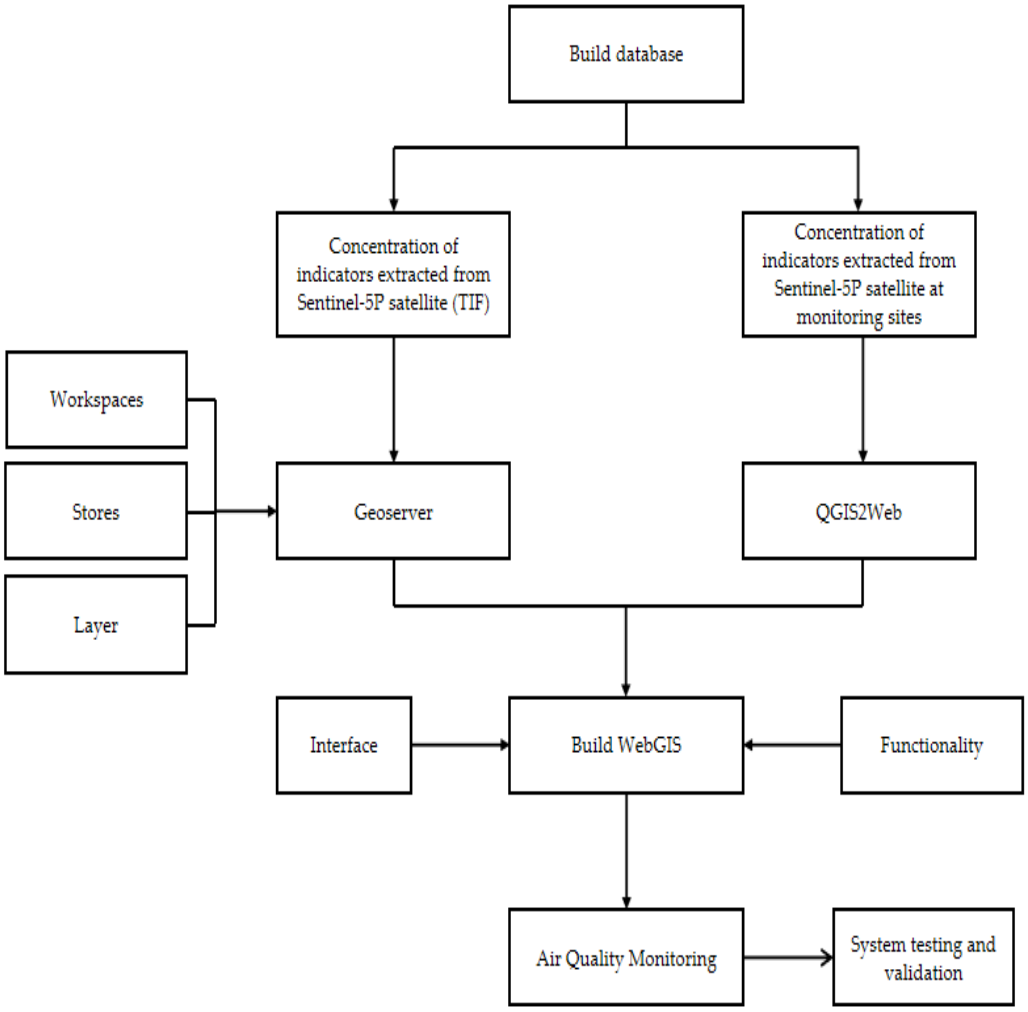

Figure 3: The process of building WebGIS to monitor air quality in Binh Duong Province.

3. RESULTS AND DISCUSSIONS

3.1. Functions of the WebGIS

The WebGIS is designed with functions for two groups of users as follows:

Functions for administrators

Administrators have the authority to update the interface of the WebGIS and update necessary information such as: they can control, monitor, and manage all activities of adding, deleting, and supplementing new information related to the WebGIS, including content, images, and texts that have been published and displayed on the WebGIS.

User Functions

Map Viewing: Users can view maps displaying parameters (NO_2, SO_2, CO, O_3). They have the ability to zoom in and out by either moving the map with the mouse or pressing and holding the mouse wheel.

Concentration Information: Users can access concentration data for these parameters at various monitoring locations, featuring average monthly data for the year 2024. The interface allows users to select specific locations, search for monitoring sites, and zoom in and out as needed.

Provincial Data Overview: Users can view the average monthly concentrations of parameters (NO_2, SO_2, CO, O_3) for the entire Binh Duong province, along with statistical charts. Users can select the parameter they wish to examine and view monthly and daily charts as images.

3.2. WebGIS Interface for Air Quality in Binh Duong Province

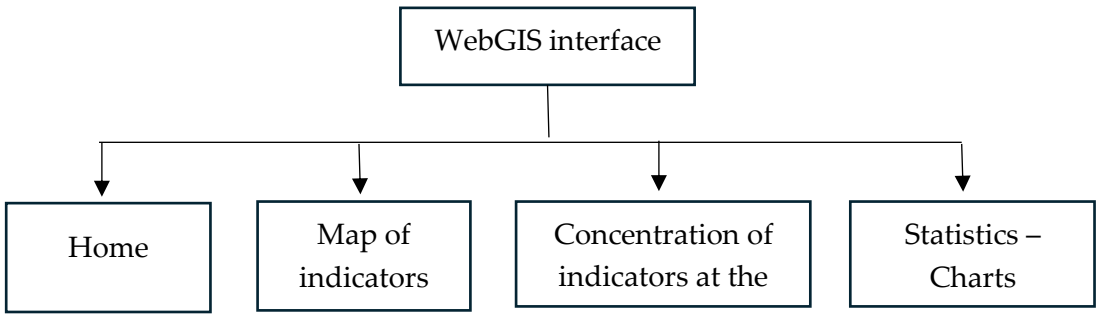

Figure 4. WebGIS interface diagram

The user interface includes a homepage with a menu bar consisting of sections such as general introduction, statistics, map, concentration of indicators at the monitoring location and charts.

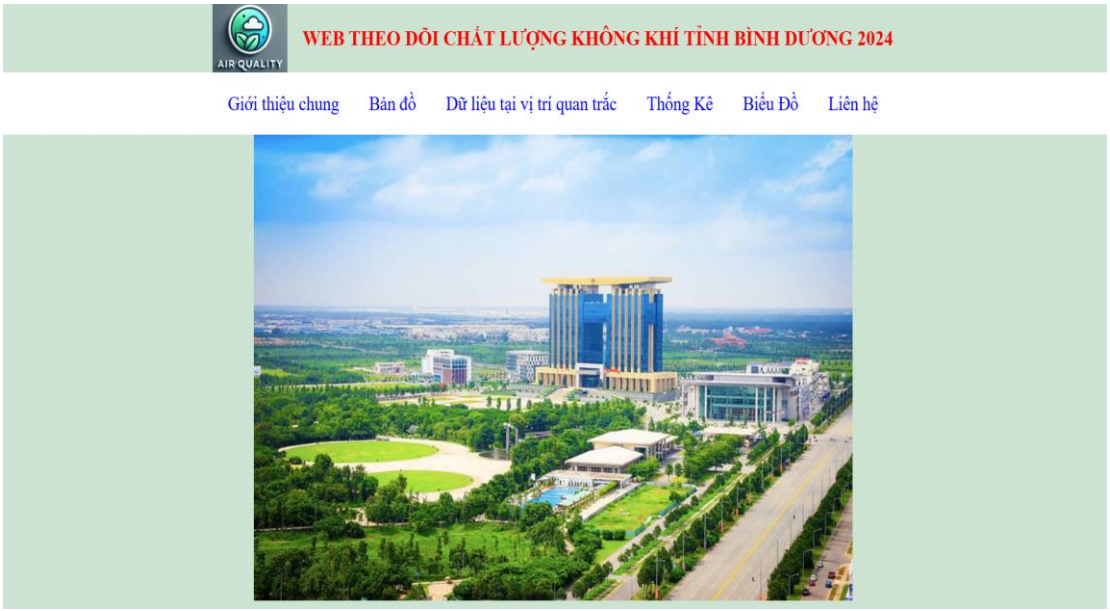

Figure 5. Homepage interface

On the general introduction page, the interface is specifically shown as in Figure 4, displaying some general information about Binh Duong province to users, such as geographical location, topography, land, climate, hydrology, transportation, and forest resources.

Figure 6. General introduction interface.

The map page provides users with information about satellite images from Sentinel 5P; NO_2 parameters (with options for monthly averages in 2024); SO_2 parameters (with options for monthly averages in 2024); CO parameters (with options

for monthly averages in 2024); O_3 parameters (with options for monthly averages in 2024).

The map page displays several main components such as: zooming in and out of the map; toggling views by month; on the top left is a menu bar for users to select.

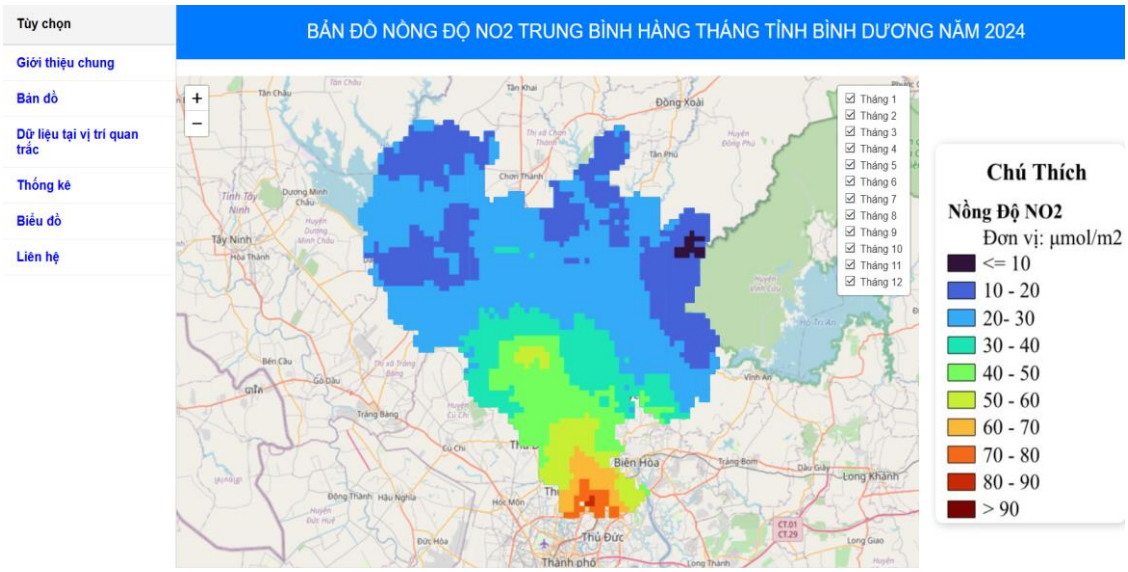

Figure 7. The map interface displays according to each index

The interface of the data page at the monitoring station: users can perform basic operations such as measuring distance and calculating area, zooming in and out, and viewing attribute information. The query feature is also integrated into the WebGIS system so that users can query concentration data of the indicators at the monitoring location.

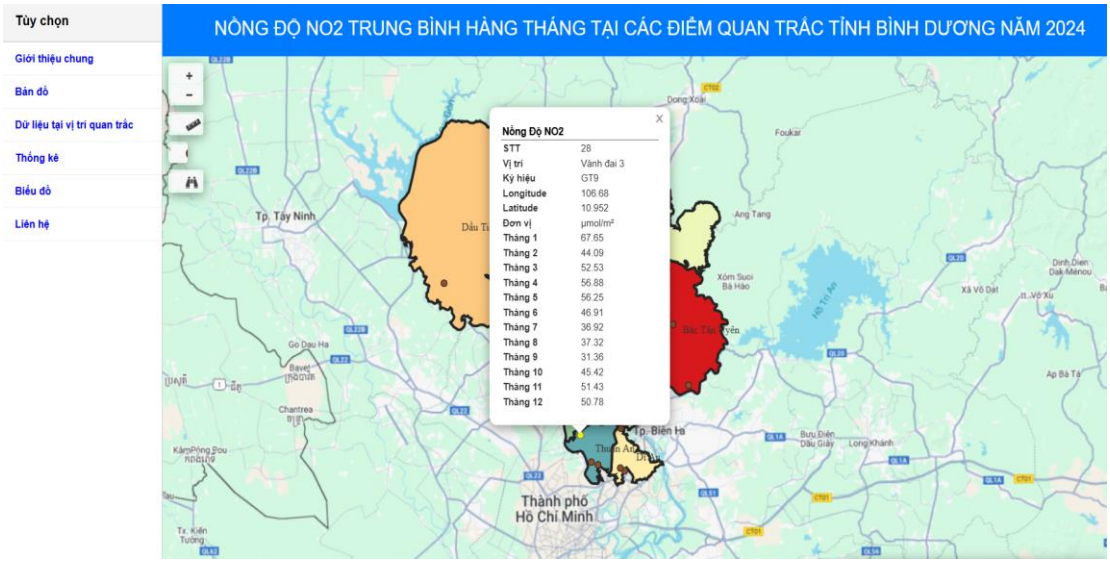

Figure 8. Concentration interface at the monitoring location according to each indicator

Statistics page interface – chart: This page represents statistics on the concentration of parameters according to the monthly average, the monthly average chart, and the average monthly statistics of indicators by district for the year 2024, designed simply by the author.

ID	Tháng	NO_2 (µmol/m²)
1	Tháng 1	38.1
2	Tháng 2	27.5
3	Tháng 3	32.9
4	Tháng 4	37.3
5	Tháng 5	39.7
6	Tháng 6	25.8
7	Tháng 7	25.5
8	Tháng 8	26.4
9	Tháng 9	25.8
10	Tháng 10	27.4
11	Tháng 11	28.5
12	Tháng 12	28.3

Figure 9. Statistical interface – chart by each indicator.

Contact page interface: The contact page contains some information about the administrator as well as the designer of the WebGIS and some data uploaded by the author to the WebGIS for users to download and reference.

3.3. System Performance and Validation

To analyze the effectiveness of the system, the study used an online survey through Google Forms to collect user opinions about the WebGIS. A total of 30 people, including 20 students and 10 lecturers have participated in the survey and provided feedback. The results obtained are presented in Figure 10.

The survey results indicate that the initial WebGIS system has effectively met the needs for accessing and exploiting spatial information. The majority of users rated the system as having a friendly interface, easy to operate, and allowing for quick data retrieval, with 80% finding it very easy or easy to use (Figure 10). This reflects the effectiveness of optimizing the map processing workflow on the Web platform.

In terms of functionality, core features such as displaying data layers, querying information, exporting data, and viewing maps of pollutants were rated relatively well (Figure 10). Many users reported that the operations were smooth, with no errors or interruptions during use. This indicates that the system has high stability and reliability, suitable for general needs in spatial data exploitation (Figure 10).

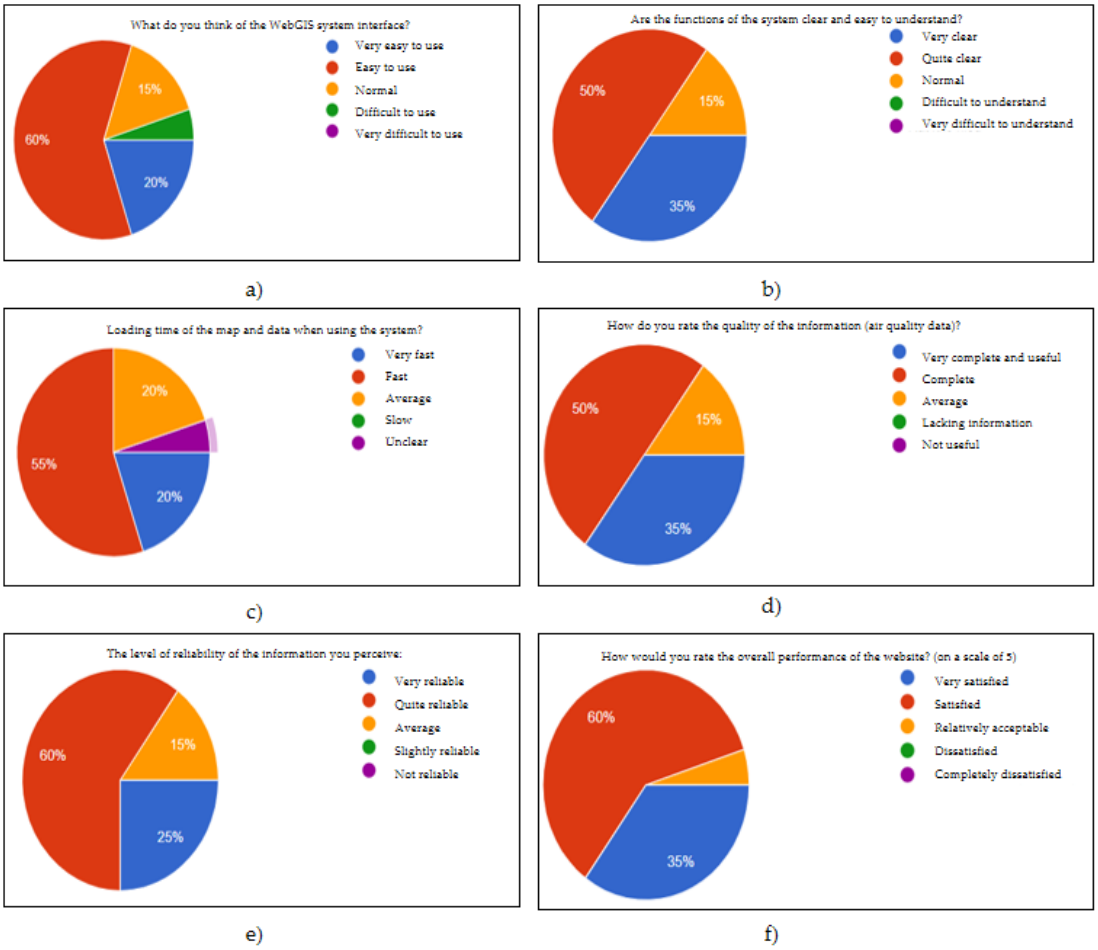

Figure 10. User survey on WebGIS for monitoring air quality

Additionally, while there are some positive evaluations from users, the website still has some limitations that have been noted and need to be improved by the authors in the future. Notably, the interface design is not yet optimized for mobile devices. Some survey participants reported that the interface when accessed on smartphones lacks compatibility, making it difficult to zoom in/out and select data layers. This is an aspect that the research team needs to improve in future versions to enhance the user experience across multiple platforms.

3.4. Interpretation of Air Quality Data

From the visual interface, it is clear that the concentration of NO_2 varies significantly between months, peaking in January and May during the dry season, and reaching its lowest levels in July and September during the rainy season. The highest concentrations were recorded in Di An and Thuan An, with levels of 56.5 µmol/m² and 52.1 µmol/m² respectively, indicating a correlation between urbanization and the increase in pollution in the study area (Figure 7).

From the results displayed on the map from the web, it is visually apparent that the average CO concentration in the study area fluctuates significantly over time. During the dry months, particularly from January to March, many areas recorded CO concentrations at high levels ranging from 38 to 47 mmol/m². In contrast, from June to August, CO concentrations decreased markedly in most areas. Similar to NO_2, the highest CO concentrations in most months were also found in the two cities of Thuan An and Di An. This indicates a characteristic seasonal pattern and a potential link to meteorological conditions and emission sources.

SO_2 levels are generally below the threshold but show a slight increase near industrial areas such as Tan Uyen Industrial Park, Viet Huong Industrial Park, Viet Huong 2 Industrial Park, An Tay Industrial Park, Rach Bap Industrial Park, Mai Trung Industrial Park, Binh An Industrial Park, Tan Đong Hiep A Industrial Park, and Tan Đong Hiep B Industrial Park. This suggests a correlation between the industrialization process and elevated SO_2 levels.

O_3 concentrations increased sharply from 121.2 mmol/m² in April, peaking at 124.6 mmol/m² in September. O_3 levels began to decline from 123.7 mmol/m² in October to 111.9 mmol/m² in December. Di An and Thuan An have the highest average O_3 concentrations at 118.6 mmol/m², significantly exceeding the provincial average. These are highly urbanized areas with dense population and traffic.

3.5. Benchmarking and Future Prospects

Through the research results, the authors have observed some advantages and disadvantages of the WebGIS monitoring air quality in Binh Duong Province as follows:

The advantage is that users can easily access the interface of the website, and the map information and data are updated frequently in real-time. The author designed the WebGIS to be simple, interactive, and easy to use, effectively conveying information. GIS data can be shared with many people and organizations simultaneously, facilitating teamwork and quick decision-making.

However, there are still some disadvantages of the WebGIS that remain and are not yet perfected in the design process. The interface is sometimes too simple, not user-friendly for the general public, and lacks professionalism in building the WebGIS. The displayed map still has many limitations in functions such as attribute querying, and online attribute input and deletion. Complex analytical functions such as spatial analysis and advanced statistics have not yet been integrated into the WebGIS.

Compared to the WebGIS of Air Pollution Warning System developed by Le Thi Thu Ha et al., 2021 [6], the WebGIS system in this study has not integrated a real-time data update mechanism, leading to information delays and reducing the effectiveness of timely warnings. Additionally, the feature for alerting when air pollution exceeds

thresholds is lacking, and it does not support sending direct notifications to users when pollution levels rise. The current map system is limited to static display, not allowing users to interact more deeply or extract detailed data by area. Furthermore, the website lacks a function for storing and retrieving historical data, which restricts trend analysis and supports environmental management decision-making. To ensure that WebGIS is widely implemented and achieves higher effectiveness in management, the research team needs to continue addressing the aforementioned shortcomings.

4. CONCLUSIONS

The research has successfully established a WebGIS system for monitoring air quality, presenting several notable advantages that contribute to environmental management. This innovative system introduces a new deployment solution utilizing open-source tools, specifically designed for developing a WebGIS tailored for air quality monitoring in an industrial province of Vietnam. By integrating remote sensing data from the Sentinel-5P satellite with an interactive web-based GIS platform, the study provides users with visual representations of air quality across various spatial regions, making complex data accessible and understandable.

This method not only enhances public awareness of air quality issues but also serve as a foundation for intelligent environmental management systems that could be adapted for application in similar urbanized areas. By enabling real-time monitoring and analysis, the system can assist policymakers and environmental agencies in making informed decisions to mitigate pollution and protect public health.

However, despite these advancements, the WebGIS currently faces several challenges due to limited resources. Issues such as data accuracy, system scalability, and user engagement need to be addressed. Therefore, further research is essential to develop in-depth analysis features that can provide more comprehensive insights into air quality trends and effects. Additionally, enhancing system security is essential to ensure the safety and privacy of users and their data, thereby encouraging greater trust and wider adoption of the platform. By tackling these limitations, the project aims to evolve into a more robust tool for environmental monitoring and management.

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ỨNG DỤNG CÁC PHẦN MỀM MÃ NGUỒN MỞ XÂY DỰNG VÀ THIẾT KẾ WEBGIS THEO DÕI CHẤT LƯỢNG KHÔNG KHÍ TỈNH BÌNH DƯƠNG

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TÓM TẮT

Nghiên cứu này ứng dụng các phần mềm mã nguồn mở GeoServer, OpenLayer và QGIS2Web kết hợp với phần mềm QGIS để xây dựng cơ sở dữ liệu, kết hợp với công cụ Visual Studio Code để xây dựng WebGIS theo dõi chất lượng không khí tại tỉnh Bình Dương năm 2024. Dữ liệu vệ tinh Sentinel-5P được tác giả sử dụng để trích xuất nồng độ các thông số ô nhiễm không khí (NO_2, SO_2, CO, O_3), thực hiện trực tiếp thông qua lập trình trên nền tảng Google Earth Engine và dữ liệu thu thập từ quan trắc tại 29 vị trí quan trắc lấy mẫu, được cung cấp bởi Trung tâm Quan trắc môi trường tỉnh Bình Dương. WebGIS được xây dựng với các chức năng xem thông tin các thông số chất lượng không khí (NO_2, SO_2, CO, O_3), tại địa bàn tỉnh Bình Dương, trung bình hàng tháng năm 2024 bao gồm bản đồ các thông số ô nhiễm không khí, thống kê các thông số này theo từng tháng và theo từng vị trí quan trắc. Thông qua ứng dụng WebGIS, người dùng có thể truy cập và truy vấn các dữ liệu về chất lượng không khí, từ đó các nhà quản lý có thể đưa ra các chính sách kiểm soát và quản lý môi trường một cách hiệu quả nhằm cải thiện chất lượng không khí tại địa phương.

Từ khóa: Mã nguồn mở, ô nhiễm không khí, Sentinel-5P, WebGIS, QGIS2Web, GeoServer, GEE.

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