PANTHEON

Community-Based Smart City Digital Twin Platform for Optimised DRM operations and Enhanced Community Disaster Resilience

D6.2

INTEGRATION OF GEOSPATIAL INFORMATION TECHNOLOGIES

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DISCLAIMER

[1] **Please indicate the type of the deliverable using one of the following codes**:
R = Document, report
DEM = Demonstrator, pilot, prototype, plan designs
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DATA = data sets, microdata
DMP = Data Management Plan
ETHICS: Deliverables related to ethics issues.
OTHER: Software, technical diagram, algorithms, models, etc.

[2] **Please indicate the dissemination level using one of the following codes**:
PU = Public
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WORK PACKAGE ABSTRACT

This work package focuses on developing the PANTHEON components designed for use during disaster events or beforehand for simulation and training. These components will be capable of collecting and delivering real-time data and in-situ observations that are crucial for effective disaster response and management. Their functionality will be based on the Data Delivery Scheme (T3.4), the deployment of a robust, reliable, and collaborative UAV swarm, and the integration of Copernicus Emergency Management Services, both on-demand for disaster response and recovery, and for early warning, monitoring, and pre-disaster preparedness.

TASK ABSTRACT

This task aims to enhance the efficiency and reliability of the latest advanced systems for UxVs monitoring in both pre and post disaster management, by unifying diverse technologies within a single framework. Through the integration of data from various sources, including Earth observation data, Copernicus Emergency Management Services, UxVs, and ground-based IoT sensors, the platform will address limitations related to observation timing, resolution, and coverage. The result will be producing robust, user-friendly, and reliable technology under the same platform. This will take the form of a GeoPlatform serving as a command-and-control center, where input from all available data sources will be fused, processed, and visualized in real time.

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1.4	01/07/2025	Final version	Thanos Kyritsis (INTEROPT)

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EXECUTIVE SUMMARY

This deliverable presents PANTHEON's comprehensive framework for the integration of geospatial information technologies in support of disaster management and spatial decision-making. As climate change, urbanization, and socio-political risks increase the complexity of emergency response and resource management, there is a growing need for intelligent, interoperable, and scalable systems that can consolidate data from satellites, unmanned vehicles (UxVs), IoT sensor networks, and ground-based sources.

The deliverable outlines the architectural principles and open-source platforms, such as GeoServer, PostGIS and OpenLayers, that underpin effective geospatial integration. It highlights the use of OGC-compliant standards for data interoperability and presents deployment models suited for both cloud and on-premise environments, suited for PANTHEON's circumstances. Special emphasis is placed on data ingestion, visualization, and building a Common Operational Picture system that enhances situational awareness in PANTHEON's chosen critical disaster scenarios.

Case studies featured in the deliverable illustrate the practical implementation of these technologies in diverse domains, including post-disaster impact mapping (e.g., Hurricane Dorian), UAV-satellite data fusion for rapid assessment, and water quality monitoring using time-series satellite imagery. The evaluation section validates system performance, usability, and operational impact through field testing and user feedback, following PANTHEON's established methodology of evaluation.

Looking forward, the deliverable identifies strategic directions for further possible development of the PANTHEON project, including the integration of AI/ML for automated analysis, edge computing for field-based decision-making, and the extension of geospatial infrastructures into several other sectors, such as agriculture, public health, and cultural heritage. These possible future trajectories position geospatial information technologies not only as a technical asset but as a cross-cutting enabler of sustainable and resilient future development.

1. INTRODUCTION

The increasing frequency and intensity of natural disasters, combined with the growing availability of spatial and sensor data, has highlighted the critical role of geospatial information technologies in disaster risk management, environmental monitoring, and broader spatial decision-making contexts. These technologies enable the collection, integration, processing, and dissemination of location-based data from diverse sources such as satellites, unmanned vehicles (UxVs), Internet of Things (IoT) sensors, and ground-based observation networks. Open-source geospatial platforms, particularly those supporting interoperability standards, have become central to operationalizing these capabilities in practical, scalable, and cost-effective ways.

This deliverable focuses on the technological, architectural, and operational aspects of integrating geospatial information technologies in multi-stakeholder environment of the PANTHEON project. It builds upon recent advancements in spatial data infrastructures, real-time data fusion, open-source GIS tools, and web-based visualization platforms to provide a framework for building the interoperable and extensible systems tailored to disaster response and environmental intelligence needs, that the PANTHEON project requires.

1.1 PURPOSE AND SCOPE

The purpose of this deliverable is to define a coherent integration framework for geospatial information technologies as defined by the PANTHEON project, with particular emphasis on supporting disaster management, planning, and training scenarios and use-cases defined by PANTHEON's deliverables. The scope includes both architectural considerations—such as system components, data flows, and software tools—and practical implementation examples based on current research and field deployments.

The deliverable addresses:

- Integration of heterogeneous data sources (UxVs, satellites, IoT sensors).
- Deployment and use of open-source platforms (GeoServer, PostgreSQL, PostGIS, OpenLayers).
- Application of interoperability standards for spatial data sharing.
- Development of command-and-control systems with real-time situational awareness capabilities.

This work is intended to define designing and maintaining geospatial systems in all PANTHEON contexts that require robust, reliable, and scalable data integration solutions.

1.2 MOTIVATION AND CONTEXT

As disasters become more complex and data-intensive, the ability to access, integrate, and interpret spatial data in near real-time has become a strategic necessity. The convergence of Earth observation satellite missions, UAV technologies, and IoT sensor networks has introduced new opportunities for dynamic mapping, predictive modelling, and early response coordination. However, realizing the full potential of these capabilities requires overcoming challenges related to data heterogeneity, platform interoperability, and the need for accessible and standardized tools.

Open and commercial geospatial software solutions have emerged as powerful enablers of system integration. Platforms such as GeoServer, GeoNode, ArcGIS and OpenLayers, when combined with standardized protocols, allow for the rapid deployment of data-rich applications. For minimal licensing and infrastructure costs, the open-source software solutions seem to offer an important head start. In addition, the shift toward web-based services and cloud-hosted processing has unlocked new dimensions of scalability, accessibility, and collaboration, especially for international and multi-agency efforts, such as the PANTHEON project.

This deliverable is motivated by the need to consolidate these developments into a cohesive integration strategy that can be adapted across the different operational environments and disaster types that PANTHEON has already defined. It reflects the priorities of PANTHEON as an EU-funded project, its development initiatives, and research-sector innovation in risk management and environmental governance.

1.3 Related Work and Standards

Numerous initiatives and standards have contributed to the maturity of geospatial interoperability frameworks. Chief among these is the work of the **Open Geospatial Consortium (OGC)**, which has developed a suite of widely adopted specifications, including:

- **Web Map Service (WMS)**: for rendering map images from spatial data.
- **Web Feature Service (WFS)**: for accessing vector feature data.
- **Web Coverage Service (WCS)**: for serving raster data sets.

These protocols are foundational for enabling seamless data exchange across platforms and applications, and they are fully supported by widely used tools such as GeoServer.

The **INSPIRE Directive** (Infrastructure for Spatial Information in the European Community) has further mobilised the harmonization of spatial data infrastructures across Europe. INSPIRE sets out a legal framework for standardized metadata, data models, and services, aiming to support cross-border environmental policies and spatial planning. Its requirements ensure that public sector geospatial data are discoverable, accessible, and interoperable within and across member states.

Additionally, several research and development efforts have demonstrated the integration of these standards in real-world systems. For example, platforms like MASDAP (Malawi Spatial Data Platform) and QuakeSim have enabled geospatial integration operations for disaster risk reduction and geophysical monitoring using OGC-compliant infrastructures. Other studies have applied these standards to time-series imagery frameworks, common operational pictures in emergency response, and hybrid UAV-satellite data processing workflows.

This deliverable synthesizes insights from such efforts to propose the PANTHEON project and its components as an integrated, modular approach that aligns with ongoing EU and global trends in spatial information management.

2. Literature Review

Several studies emphasize the utility of Earth Observation (EO) data in supporting pre- and post-disaster analysis and preparedness. Ozigis et al. (2025) provide a detailed case study of Hurricane Dorian, demonstrating how Sentinel-1/2 and PlanetScope imagery were used to map flood risks and socio-economic vulnerabilities in The Bahamas. Similarly, Graja and Abdellatif (2024) examine the integration of UAVs and satellite data, outlining strategies like data fusion and analysis fusion to leverage the complementary strengths of high-frequency UAV data and wide-coverage satellite imagery.

The use of open-source platforms such as GeoServer is a recurring theme across studies. Wang (2024) introduces a time-series imagery service framework based on GeoServer for water quality monitoring, demonstrating the benefits of dynamic, filterable map services for environmental applications. Balbo et al. (2013) describe the MASDAP platform in Malawi, which uses GeoServer to share geospatial datasets on hydrogeological risk with stakeholders involved in disaster risk reduction.

The usage of GIS in command-and-control systems is explored by Cejudo et al. (2023), who present a geospatial data management architecture to support Common Operational Picture (COP) functionalities in emergency response centres. Their study highlights the importance of visualizing terrain and infrastructure to enhance situational awareness and decision-making.

Karnatak et al. (2012) showcase a spatial mashup technology for disaster response in India that integrates real-time data from mobile devices with distributed web services through open-source GIS technologies. Their approach emphasizes the flexibility of service-oriented architectures for dynamic mapping and decision support.

A broader review by Tomaszewski et al. (2015) captures evolving trends in GIS for disaster response, including advancements in user-centric design, interoperability standards, and spatial analytics. The study serves as a bridge between academic research and practical deployment by highlighting ongoing needs for standardization and user training.

Parker et al. (2015) describe the QuakeSim platform, which uses UAVSAR data and GeoServer to deliver interferometric radar maps through an interactive web interface. The system facilitates risk assessment and geophysical modelling by enabling access to high-resolution surface deformation data without requiring full-file downloads.

Bećirspahić and Karabegović (2015) explore the functionality of web portals for visualizing and querying spatial data. They underscore the importance of interoperability (e.g., via OGC services like WMS, WFS, WCS) and user-friendly interfaces that support diverse applications, from public services to scientific research.

Jeppesen et al. (2018) propose an open geospatial data infrastructure tailored to precision agriculture but broadly applicable across disciplines. Their work highlights the benefits of open standards (OGC), cloud processing, and modular architectures for enhancing data interoperability and real-time analytics.

Huang and Xu (2011) propose a methodical approach to publishing economic geographical information using GeoServer and related open-source tools. Their study emphasizes the importance of combining spatial and non-spatial (statistical) data in economic decision-making. They design a multi-tiered architecture using GeoServer, PostGIS, and OpenLayers. A storage schema was developed to manage structured (index data), unstructured (information documents), and geospatial (administrative boundaries) datasets within a

PostgreSQL/PostGIS environment. The authors demonstrate the feasibility and cost-effectiveness of using open-source technologies to deliver thematic maps and web services for socio-economic analysis.

Chowdhury et al. (2024) conduct a comparative study of traditional (GeoServer) and modern (pygeoapi) implementations of Open Geospatial Consortium (OGC) standards in WebGIS applications. Their findings confirm GeoServer's robustness, performance, and widespread adoption in urban development contexts. Although pygeoapi shows promise with modern API-centric designs (e.g., RESTful interfaces via OpenAPI), it suffers from higher rendering latency compared to GeoServer. Their architecture reaffirms the relevance of GeoServer for applications requiring reliable map services (WMS/WFS) and efficient integration with PostgreSQL/PostGIS databases.

Sarup and Shukla (2012) demonstrate a WebGIS application for road network analysis in Bhopal, India, using GeoServer, PostGIS, and QGIS. They showcase the process of digitizing vector layers in QGIS, importing shapefiles into PostGIS, styling with SLDs, and publishing via GeoServer. Their methodology promotes centralized geospatial data visualization across distributed spatial databases, emphasizing the accessibility and utility of open-source tools for urban infrastructure and transport planning.

Xia et al. (2009) outline a comprehensive WebGIS architecture using Linux, Apache, GeoServer, PostGIS/MySQL, and uDig. Their approach is particularly relevant for developing countries, where cost and vendor lock-in are critical concerns. They detail the full stack from server configuration to data publishing and map rendering. The study reiterates GeoServer's alignment with OGC standards and its capacity to interoperate with various spatial databases and client libraries.

Shukla et al. (2021) introduce the FOSSSS (Free Open-Source Software Server Service) model for deploying spatial web applications. The authors focus on using GeoServer as the core visualization engine, with PostGIS for spatial data management and Apache Tomcat for web hosting. Their WebGIS demonstration for road data reinforces GeoServer's usability, extensibility, and compatibility with client-side libraries like OpenLayers and Eclipse-based environments. This work underlines the increasing preference for open-source stacks in small-to-medium scale GIS projects.

The reviewed literature converges on several best practices for integrating geospatial information technologies: adopting open-source platforms (e.g., GeoServer, GeoNode), standardizing data through OGC protocols, enabling real-time data integration via IoT and UAV systems, and enhancing visualization with GIS and web portals. These innovations not only improve disaster preparedness and response but also offer scalable solutions for broader environmental monitoring and interdisciplinary applications.

Across these studies, a few recurring themes emerge:

- **Cost-efficiency and scalability**: Open-source solutions like GeoServer eliminate licensing costs, making them ideal for academic, governmental, and SME use.
- **Interoperability**: GeoServer's compliance with OGC standards (WMS, WFS) ensures easy integration with diverse data sources and front-end clients.
- **Flexibility and community support**: With active developer communities and extensive documentation, tools like PostGIS and OpenLayers support rapid deployment and customization.
- **Performance considerations**: While modern APIs offer RESTful simplicity, traditional platforms like GeoServer remain more performant for high-volume spatial data rendering.

The body of work reviewed consistently highlights GeoServer's practicality, especially in combination with PostGIS and OpenLayers, for WebGIS development. Whether used for economic data publishing, urban planning, or general mapping tasks, the open-source ecosystem around GeoServer is robust, flexible, and continually evolving to meet the demands of modern spatial data applications.

3. Geospatial Information Technologies Overview

Modern geospatial information systems draw on a range of technologies and methodologies to enable data collection, integration, processing, analysis, and visualization. These technologies have become foundational to disaster management, environmental monitoring, urban planning, and many other domains requiring spatial intelligence and decision support. This section provides an overview of the key components involved in geospatial technology integration specifically tailored for PANTHEON's needs: GIS, remote sensing, unmanned vehicle systems, IoT-based sensor networks, and data fusion strategies.

3.1 Geographic Information Systems (GIS)

Geographic Information Systems (GIS) provide the core PANTHEON infrastructure for storing, managing, analysing, and visualizing spatial data. As described by Tomaszewski et al. (2015), GIS technologies have evolved from desktop-based tools for spatial analysis to highly interactive and scalable web-based platforms for real-time decision-making and disaster response.

Modern GIS platforms leverage web services and client-server architectures to offer functionalities such as spatial queries, real-time mapping, geospatial analytics, and customised dashboards, such as the one being built for PANTHEON's stakeholders and first-responder users. Key technologies include:

- Web mapping through OGC standards such as **WMS** and **WFS**.
- Backend platforms like **GeoServer** and **PostGIS** for spatial data dissemination.
- Interactive frontends using **Javascript** tools like **OpenLayers** or Mapping libraries.

The review by Bećirspahić and Karabegović (2015) demonstrates how web-based GIS systems can integrate data from both local and public sources to provide accessible and focused mapping services.

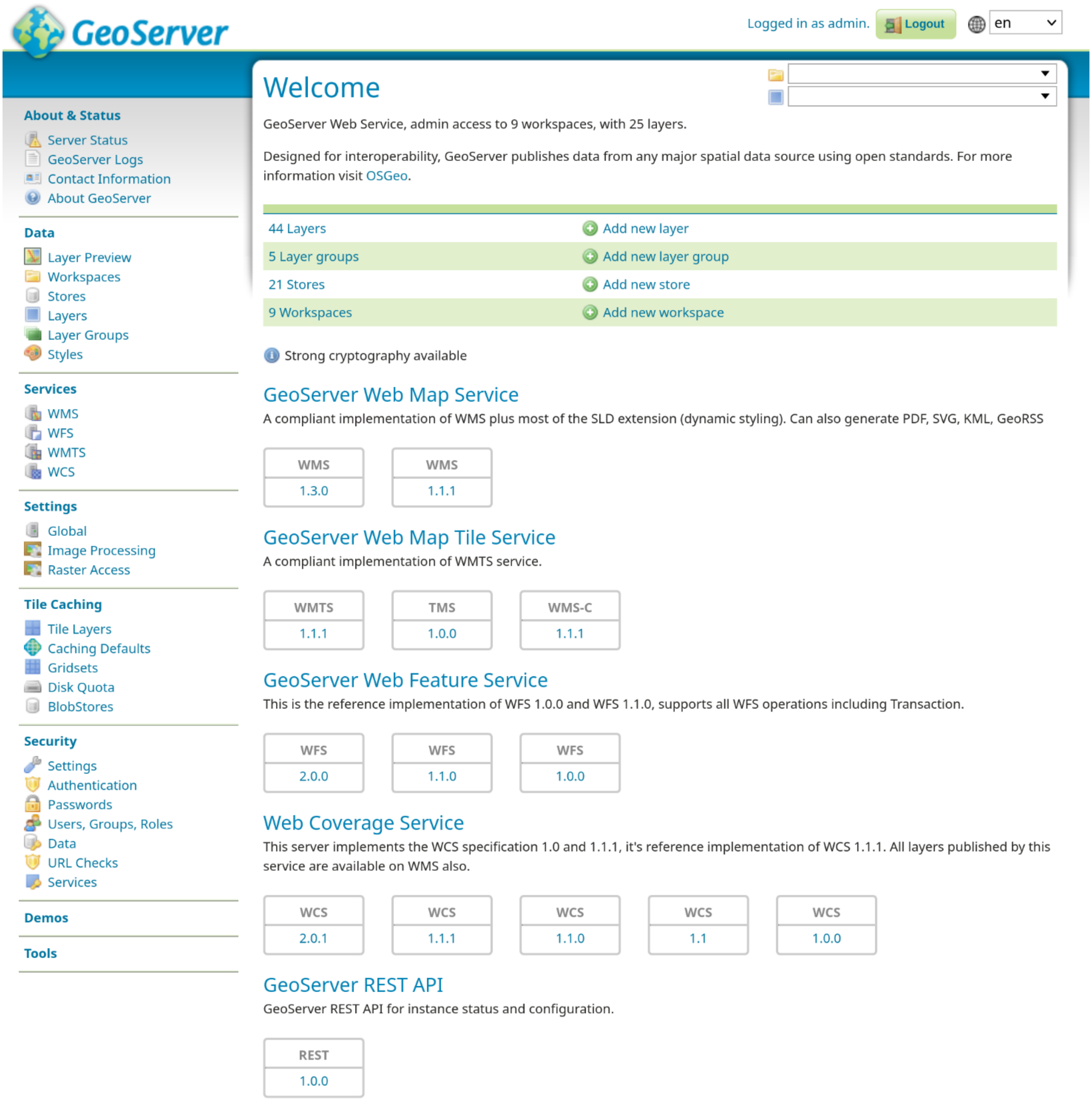

Figure 1: PANTHEON GeoServer Standards overview.

3.2 Remote Sensing and Earth Observation

Remote sensing technologies, especially those relying on Earth Observation (EO) satellites, have become critical in supporting pre- and post-disaster assessment, land use analysis, and environmental monitoring, such as the specific requirements dictated by PANTHEON. Satellite systems such as **Copernicus Sentinel-1/2** enable wide-area, high-resolution data collection, often in near real-time.

The utility of Earth Observation data in mapping disaster impact was extensively illustrated by Ozigis et al. (2025) in their analysis of Hurricane Dorian's effects in The Bahamas. Their study integrated multiple Earth Observation indices to assess flood extents and associated socio-economic vulnerabilities.

Parker et al. (2015) further exemplify this through the QuakeSim system, which delivers interferometric radar maps (InSAR) via GeoServer to visualize surface deformation and earthquake risks in real time.

3.3 Unmanned Vehicle Systems (UxVs)

Unmanned Vehicle Systems (UxVs), encompassing UAVs (aerial), UGVs (ground), and USVs (surface), have rapidly matured as flexible tools for data acquisition in hazardous, remote, or inaccessible environments, such as the four scenarios that PANTHEON focuses on. UxVs are particularly well-suited to:

- Real-time aerial imagery acquisition.
- Infrastructure monitoring.
- Search-and-rescue operations.

Graja and Abdellatif (2024) detail two primary strategies for integrating UAV data with Earth Observation satellite data: **data fusion** and **analysis fusion**. These approaches enhance both the spatial detail and temporal frequency of observations, crucial for high-resolution applications such as pre- and post-disaster damage assessments.

In Cejudo et al. (2023), UxVs are integrated into a Common Operational Picture (COP) system that represents live responder positions, terrain features, and building structures in a command-and-control context.

3.4 Internet of Things (IoT) and Sensor Networks

The Internet of Things (IoT) enables widespread, real-time environmental sensing via embedded sensor networks. In PANTHEON's specific geospatial applications, IoT devices capture crucial ground-level data such as temperature, humidity, air quality, water levels, and movement.

As Jeppesen et al. (2018) note, combining IoT sensors with open geospatial infrastructures improves the responsiveness and modularity of spatial data systems. They describe a cloud-based architecture designed to interface with agricultural terminals and external databases while maintaining OGC compliance.

Karnatak et al. (2012) demonstrate a working case of spatial mashup technologies that combine mobile-based sensor data with central GIS servers in real time, used during flood management operations in Assam, India.

3.5 Data Fusion and Analysis Strategies

Integrating data from heterogeneous sources, satellites, UAVs, IoT sensors, ground observations, is one of the most important aspects of a modern geospatial system that PANTHEON proposes. Data fusion techniques aim to combine these disparate inputs into a unified, meaningful representation of the physical environment.

Graja and Abdellatif (2024) distinguish between:

- **Data Fusion**: Merging raw data before analysis to create composite datasets.
- **Analysis Fusion**: Conducting independent analyses and then synthesizing insights.

Wang (2024) illustrates the application of data fusion for environmental monitoring through a GeoServer-based time-series framework that indexes and visualizes multi-temporal satellite imagery for water quality assessment.

This type of multi-source integration is foundational in platforms such as MASDAP (described by Balbo et al., 2013), which serves as a national geospatial repository integrating risk datasets, flood models, and climate projections to support disaster risk reduction in Malawi, in a similar manner to PANTHEON's use-cases and scenarios.

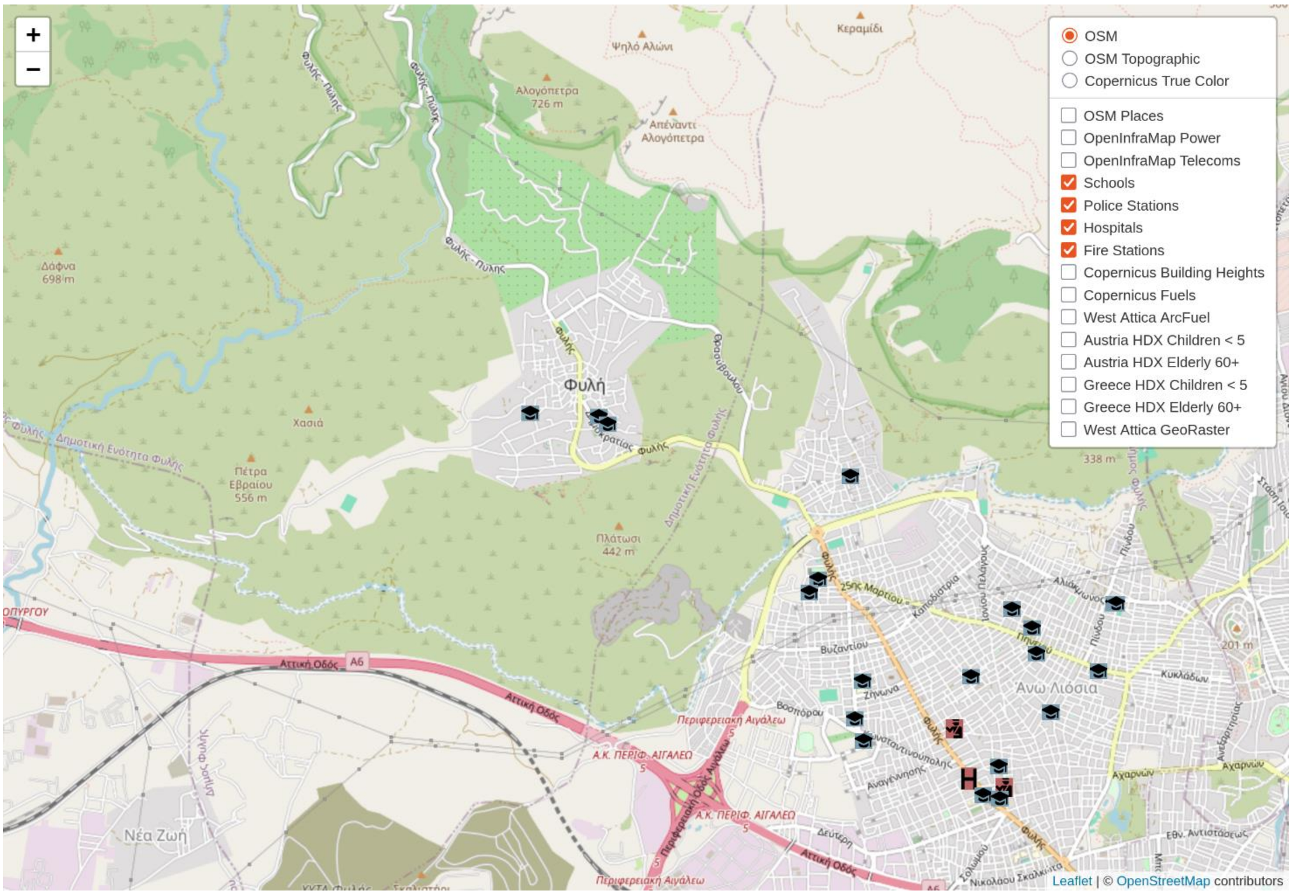

Figure 2: PANTHEON's fusion of heterogeneous layers.

4. ARCHITECTURAL FRAMEWORK

A well-designed architectural framework is fundamental to the successful integration and operation of geospatial information technologies among PANTHEON's software components and services. Such a framework must accommodate the ingestion, processing, storage, analysis, and visualization of PANTHEON's diverse spatial data sources. It must also support interoperability, scalability, and resilience, especially targeting the critical nature of disaster response for PANTHEON's use-cases and scenarios. This section outlines the system architecture, deployment options, and standards that underpin a modern geospatial integration infrastructure.

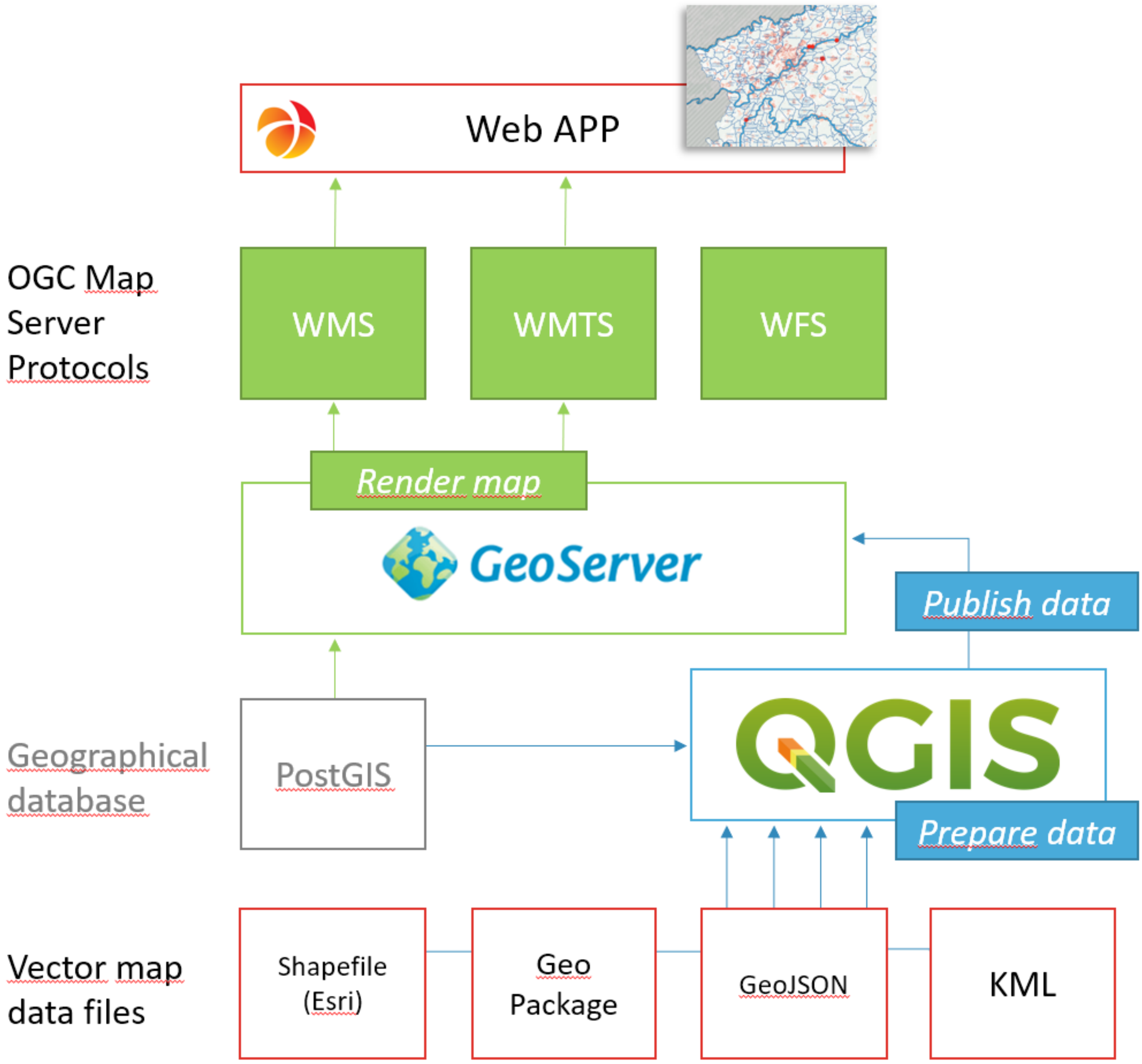

Figure 3: Overview of GeoServer PANTHEON architecture capabilities.

4.1 System Architecture for Geospatial Integration

The architecture of an integrated geospatial system is typically organized in **three tiers**: data acquisition, data processing/storage, and application delivery.

- **Data Acquisition Layer**: This layer includes Earth Observation (EO) satellites, UxVs, and IoT sensor networks. These data sources can provide high-frequency, multi-resolution information. For example, Sentinel satellites supply multispectral imagery, UAVs capture high-detail aerial data, and in-situ sensors offer ground-level environmental measurements.
- **Data Processing and Storage Layer**: This middle tier is responsible for cleaning, transforming, indexing, and storing spatial data. Tools such as GeoServer, PostGIS, and image mosaic plugins enable effective handling of raster and vector datasets, including time-series imagery. Wang (2024) demonstrates how temporal filtering, and aggregation can be achieved through GeoServer extensions.
- **Application and Visualization Layer**: This includes web-based GIS platforms like GeoServer, OpenLayers, and Javascript applications that present spatial data to users through interactive dashboards or analytical interfaces. Cejudo et al. (2023) showed the value of combining maps and live responder geolocation for enhancing operational awareness during emergencies.

Architecturally, this layered approach allows modularity, where components can be updated or replaced without compromising the integrity of the whole system. For instance, sensor feeds or Earth Observation data providers can be swapped with minimal configuration changes at the processing or visualization levels, provided standardized interfaces are maintained.

4.2 Cloud-Based and On-Premise Deployment Models

Geospatial systems can be deployed in cloud environments, on-premises, or in hybrid configurations depending on operational needs, resource availability, and data sensitivity.

- **Cloud-Based Deployments**: Cloud services offer **scalability**, **elastic processing**, and **global availability**, which are essential in pre- and post-disaster surge conditions or large-scale Earth Observation data processing. Jeppesen et al. (2018) advocate for cloud-native infrastructures as a cornerstone for open geospatial analytics, especially when integrating IoT and Earth Observation data for agriculture and climate monitoring. GeoServer Cloud and microservice-based architectures further enhance resilience and component separation.
- **On-Premise Deployments**: These are often used when **data sovereignty**, **latency**, or **offline operability** is a concern. Emergency management centres, military applications, or remote infrastructure may require full local control. Cejudo et al. (2023) described an easily deployable GIS system that can run on-premises to ensure real-time responsiveness and security.
- **Hybrid Models**: Many implementations combine the best of both worlds, processing Earth Observation data in the cloud while serving dashboards from an on-premise GIS portal. This model is particularly suitable for government agencies operating under national data policies but requiring international data feeds. This is also the recommended method for the PANTHEON project, specifically by having on-premises as much GIS infrastructure as possible, while also communicating with the outside space for leveraging data from openly available providers.

Regardless of deployment type, containerization, orchestration (e.g., Docker), and continuous integration pipelines are increasingly used to manage system lifecycles and deployments efficiently.

4.3 Data Standards and Interoperability

Interoperability is a critical requirement in PANTHEON's geospatial system that integrates diverse data sources across partner and technological boundaries. This is achieved through adherence to **open standards**, most notably those defined by the **Open Geospatial Consortium (OGC)**.

Key OGC protocols include:

- **WMS (Web Map Service)** for rendering geospatial images.
- **WFS (Web Feature Service)** for sharing vector features.
- **WCS (Web Coverage Service)** for raster data access.

These standards ensure that different PANTHEON components, from satellite data providers to UAV control systems and IoT sensor platforms, can communicate with one another using shared semantics and interfaces.

The **INSPIRE Directive** provides a regulatory framework for spatial data infrastructure across Europe. It defines common schemas and metadata requirements, enabling harmonized access to spatial data for environmental policy-making and cross-border disaster coordination.

Balbo et al. (2013) and Tomaszewski et al. (2015) emphasize that robust interoperability, especially when combined with open-source platforms like GeoServer, significantly lowers barriers to entry, promotes collaboration, and ensures long-term sustainability of the spatial data infrastructures that the PANTHEON project will propose.

5. Open-Source Platforms and Tools

Open-source platforms are a cornerstone of modern geospatial information systems, offering flexibility, cost-effectiveness, and robust community support. These tools under the PANTHEON project context enable rapid deployment, customization, and integration of spatial data services, making them highly suitable for disaster response, environmental monitoring, and operational control systems. This section outlines the key open-source technologies used for spatial data management, time-series and real-time integration, and visualization considered for adopting and specially customised for the PANTHEON project's needs, use-cases and scenarios.

5.1 GeoServer for Spatial Data Management

GeoServer is a leading open-source server for sharing geospatial data using open standards. It supports a range of OGC-compliant services, including WMS, WFS, WCS, and WPS, making it a critical backend component in spatial data infrastructures. GeoServer can serve raster and vector data stored in formats such as GeoTIFF, Shapefile, and databases like PostGIS.

Wang (2024) demonstrated GeoServer's ability to manage large-scale, time-series imagery by utilizing the image mosaic plugin. This approach allowed dynamic filtering of satellite images by time attributes, making it possible to publish updated environmental maps without manually republishing new layers. Similarly, platforms like MASDAP (Balbo et al., 2013) rely on GeoServer for disseminating hydro-meteorological risk datasets in accessible and interactive formats. Drawing on the conclusions of such research practices and platform examples, the PANTHEON project regards this solution as compatible with its needs and goals.

GeoServer's extensibility and integration with spatial databases like PostGIS enable advanced querying, spatial joins, and geoprocessing capabilities essential for disaster risk assessments, urban planning, and environmental forecasting.

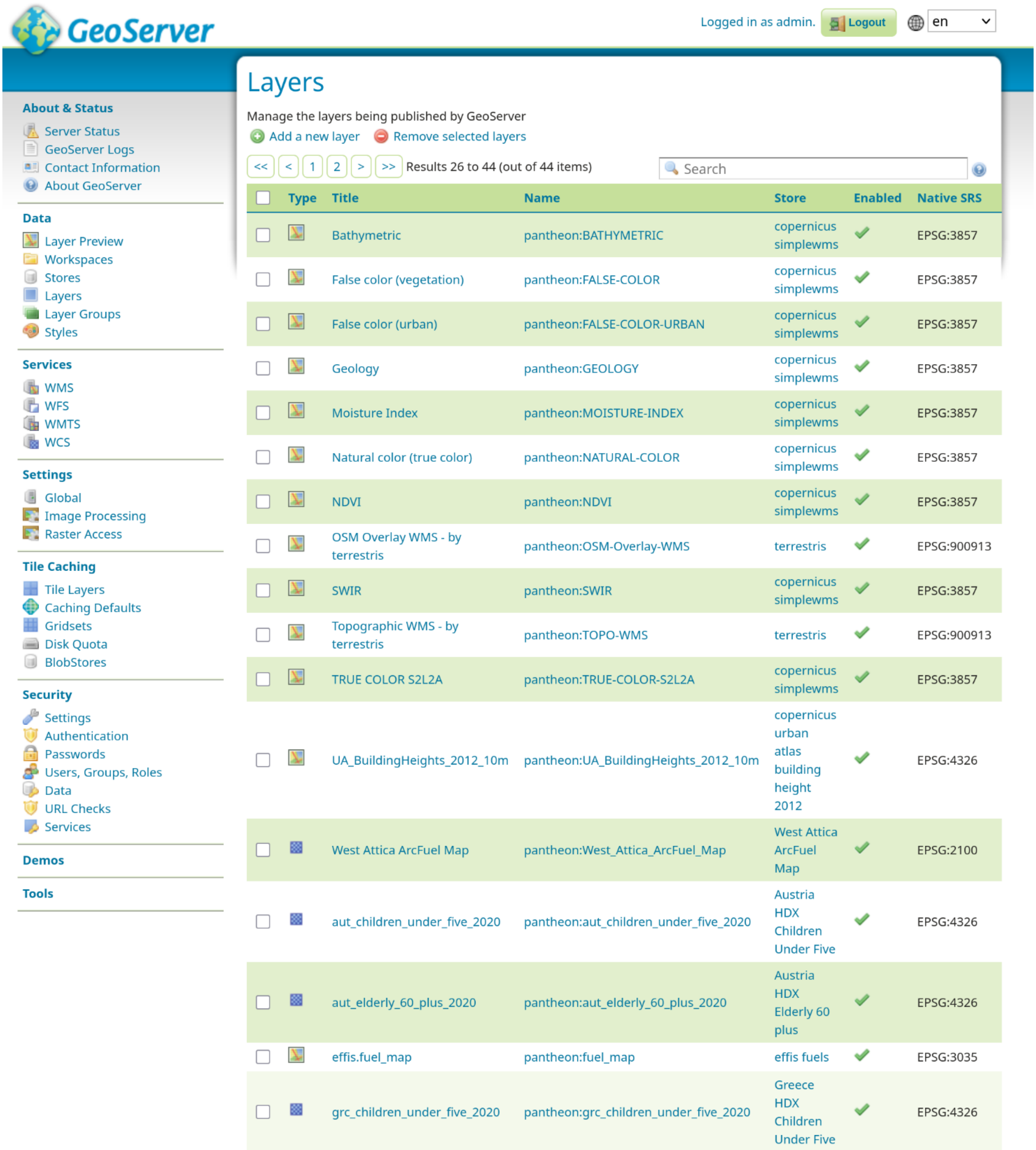

Figure 4: PANTHEON's GeoServer published layers.

5.2 Time-Series and Real-Time Data Integration

The ability to integrate **time-series** and real-time or near real-time data streams is increasingly vital for monitoring dynamic phenomena such as floods, wildfires, or air quality, tasks that align with PANTHEON's targets. Open-source tools such as GeoServer, along with observation service protocols and streaming middleware (e.g., Apache Kafka or MQTT), facilitate this integration.

Karnatak et al. (2012) illustrated a working implementation where mobile devices collected real-time field data, which was integrated into a spatial mashup platform during flood management operations in Assam. Their approach highlighted how field observations, web services, and GIS platforms can be harmonized using open technologies, in a similar manner to how PANTHEON envisions an applicable implementation of its platforms and systems.

Wang (2024) further showcased a time-series imagery service framework, where datasets from periodic satellite overpasses were indexed and served through GeoServer using temporal query parameters. This enabled users to track water quality trends over time, an approach equally applicable to other environmental monitoring domains or even the PANTHEON project should it be required in the future.

As a conclusion, integration with **IoT platforms** and **sensor networks** enable the PANTHEON project to acquire live maps and dashboards. Data from weather stations, water gauges, or traffic sensors can be ingested in real or near real time and visualized in combination with satellite and UAV imagery, enhancing the system's responsiveness and utility in operational, planning and training settings.

5.3 Visualization Tools

The visualization of spatial data is crucial for both technical and non-technical PANTHEON users and stakeholders. Open-source libraries and platforms support rich, interactive mapping capabilities, these key tools include:

- **OpenLayers**: A JavaScript library for building web-based interactive maps, supporting WMS/WFS layers, vector overlays, and custom controls.
- **Leaflet**: Lightweight Javascript library and widely used for simple map visualizations, ideal for web and mobile-friendly applications.
- **Other Javascript libraries and bespoke implementations**: Providing powerful engine for globes and maps, supporting terrain models, tiles, and time-dynamic data.

Cejudo et al. (2023) demonstrated the use of a visualization environment in a Common Operational Picture (COP) system, allowing emergency responders to interpret terrain and infrastructure layout in disaster zones. Their platform supported live geolocation tracking, and timeline views, all enabled through open-source visualization components.

Bećirspahić and Karabegović (2015) emphasized the integration of platforms like OpenLayers and GeoServer to build custom geoportals. Their implementation allowed users to visualize spatial layers from public services like OpenStreetMap and MapQuest alongside national datasets, showcasing the utility of combining public and private spatial data sources.

Visualization tools also support **user interaction**, allowing custom annotations, filtering, and temporal exploration, making them essential for PANTHEON's stakeholder engagement, operational planning, and training outreach.

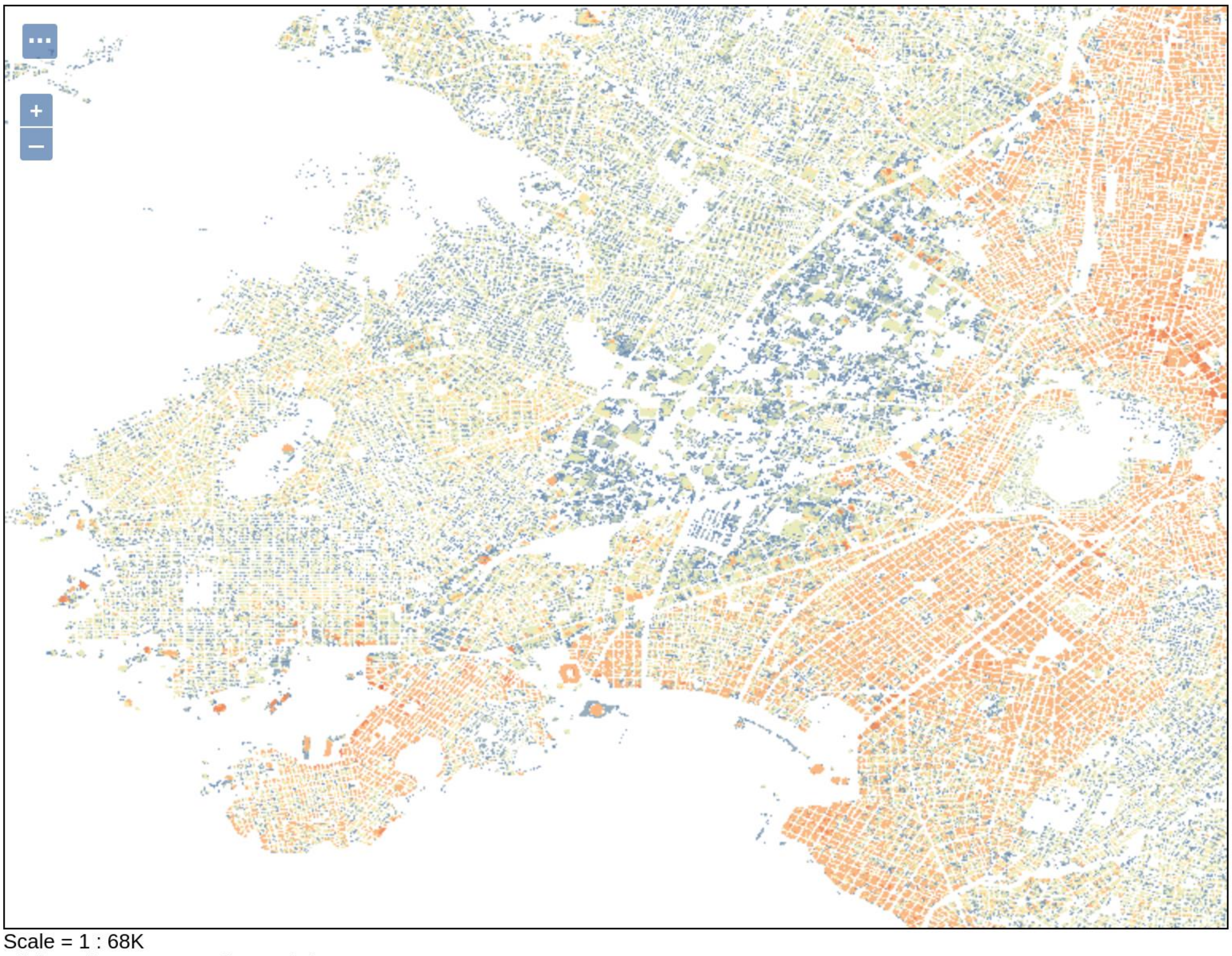

Figure 5: PANTHEON's OpenLayer example depicting Copernicus Building Heights.

6. Case Studies and Applications

The integration of geospatial information technologies is best illustrated through real-world case studies that demonstrate their practical value in various operational contexts. This section outlines four relevant application domains, pre- and post-disaster mapping, UxVs and satellite data integration, real-time command and control systems, and environmental monitoring. Each case highlights the use of open-source platforms and data fusion strategies in delivering actionable insights to PANTHEON's decision-makers and stakeholders.

6.1 Pre- and Post-Disaster Impact Mapping

Earth Observation (EO) data is one of PANTHEON's important tools for assessing disaster impacts and planning response efforts. A compelling example from which PANTHEON has drawn inspiration is the study by Ozigis et al. (2025), which assessed the socio-economic and environmental impact of Hurricane Dorian in The Bahamas. Using Sentinel-1 and Sentinel-2 imagery, augmented by ground data and PlanetScope high-resolution imagery, the study generated flood maps and vegetation indices that revealed risks to food security, housing, and livelihoods in vulnerable communities.

This case underscores the value for project such as PANTHEON of fusing satellite imagery with socio-demographic indicators to produce comprehensive risk profiles. Furthermore, such data supports pre-disaster planning by identifying hazard-prone areas and enabling scenario-based simulations for evacuation or relief planning.

Mapping platforms like GeoServer can serve these outputs to PANTHEON's users and stakeholders in real-time or retrospectively, ensuring that data-driven insights are available throughout the disaster cycle.

6.2 Integration of UxVs and Satellite Data

Combining data from Unmanned Vehicle Systems (UxVs) with satellite imagery improves both the spatial resolution and the temporal responsiveness of the PANTHEON system. Graja and Abdellatif (2024) provide a structured review of integration strategies, distinguishing between data fusion, meaning merging raw data streams, and analysis fusion as combining insights post-analysis.

In PANTHEON's disaster contexts, UxVs and especially UAVs can rapidly collect aerial imagery of affected zones, even when satellites are unavailable due to cloud cover or orbital delays. When this data is combined with Earth Observation data, it results in a picture that carries more detail and proper situational timing.

This approach is particularly effective for:

- Assessing building and infrastructure damage after the disaster scenarios (e.g., earthquakes).
- Detecting changes in land cover from wildfires.
- Monitoring inaccessible roads or hazardous zones.

This integration for the PANTHEON disaster scenarios is facilitated via the GeoServer platform and via bespoke backend processing pipelines that harmonize spatial reference systems, temporal attributes, and metadata schemas.

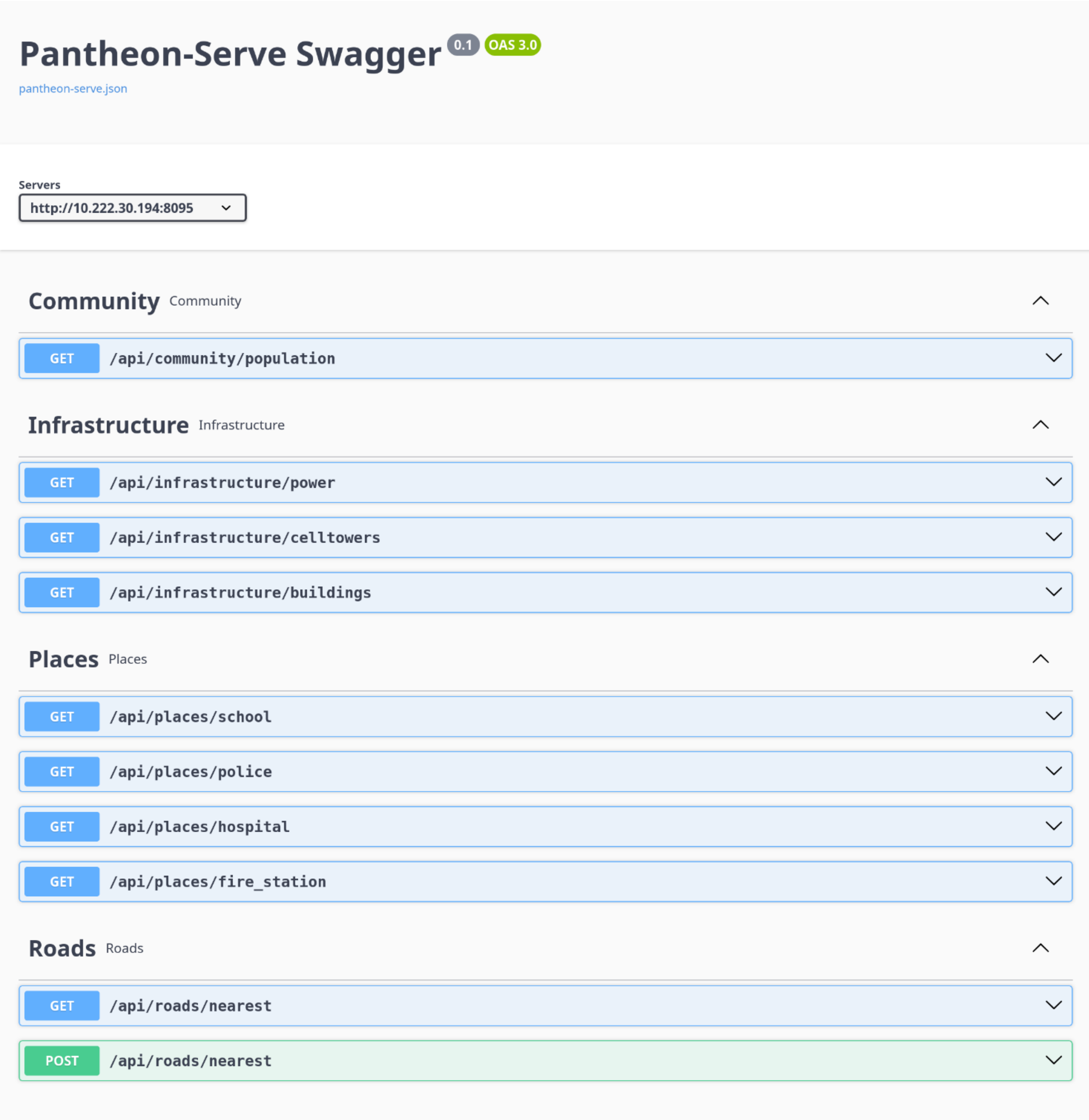

Figure 6: PANTHEON's bespoke REST API for extra processing pipelines.

6.3 Real-Time Command and Control Systems

Potential real-time geospatial intelligence as a future PANTHEON functionality can be useful for emergency response coordination. Cejudo et al. (2023) describe a Geospatial Data Management Architecture developed for use in command-and-control centres. The system integrates live responder tracking, situational mapping, and building/terrain visualization into a Common Operational Picture (COP).

Key capabilities of the system include:

- Real-time geolocation of field teams and incidents.

- Map switching for better spatial awareness.
- Integration of heterogeneous data streams (sensors, reports, imagery).

The architecture supports cloud or on-premise deployment and demonstrates how open-source technologies like GeoServer and PostGIS can deliver operational-grade GIS tools tailored to the needs of civil protection agencies, firefighters, and medical responders. Such systems rely on standards-based interoperability and robust spatial services to ensure fast, reliable access to the latest data, even under pressure and network constraints.

6.4 Environmental Monitoring

The open-source GeoServer geospatial platform of PANTHEON can also play a critical role in long-term environmental monitoring. Wang (2024) presents a time-series imagery service framework based on GeoServer for tracking water quality using remote sensing data. The system dynamically indexes and serves multi-temporal images, allowing users to filter and analyse water bodies based on temporal parameters.

Similarly, Jeppesen et al. (2018) propose a modular architecture for agricultural and environmental monitoring, integrating UAV, Earth Observation, and IoT data streams through cloud-based analytics pipelines. These systems are applicable in:

- Monitoring algal blooms and pollution.
- Evaluating deforestation and land degradation.
- Tracking seasonal crop and vegetation changes.

Environmental monitoring systems benefit from the ability to overlay diverse data layers, like sensor data, weather forecasts, and Earth Observation indices, onto a common spatial platform like GeoServer facilitated by the PostGIS database. Additional tools such as the GeoServer integrated OpenLayers framework, can enable user-friendly interfaces for exploring long-term trends or triggering alerts based on sensor thresholds, adding value and potential functionality expansion to PANTHEON's objectives.

7. Challenges and Solutions

While the integration of geospatial information technologies presents significant opportunities for PANTHEON's decision support and operational awareness, it also introduces several technical and organizational challenges. These challenges span data standards, system performance, data integrity, and cybersecurity. This section outlines the most pressing issues and proposes solutions drawn from recent academic research and field experience.

7.1 Interoperability and Data Heterogeneity

A central challenge in PANTHEON's geospatial system integration is the heterogeneity of data sources. Spatial data can vary widely in format (e.g., raster vs. vector), scale (local UAV imagery vs. global Earth Observation products), temporal resolution, and semantic schema. Disparate sensor networks, proprietary UAV platforms, and national Earth Observation archives often lack a common interface for seamless data exchange.

As a solution, adopting open standards in PANTHEON, such as those defined by the **Open Geospatial Consortium (OGC)**, is critical for resolving interoperability barriers. Standards like **WMS, WFS, and WCS** enable harmonized data sharing across PANTHEON's internal software components as well as across external platforms and third-party systems and projects. As demonstrated in the MASDAP platform (Balbo et al., 2013), combining GeoServer with standardized metadata and services allows integration of datasets from multiple institutions into a single spatial data infrastructure.

Furthermore, the use of middleware and schema transformation tools can mediate between incompatible data formats. Ontology-driven approaches and linked data principles can enhance semantic interoperability when integrating thematic datasets from different domains (e.g., agriculture and disaster management).

7.2 Scalability and Performance

Another challenge for systems handling high-volume spatial data, and specifically for PANTHEON handling satellite imagery, UAV footage, and IoT sensor streams, is facing performance bottlenecks related to storage, data retrieval, rendering, and processing. This can be especially problematic during disaster events when demand surges and response latency is critical.

Cloud-native architectures and containerized services (e.g., via Docker) offer scalable solutions. PANTHEON's containerized GeoServer, PostGIS and the additional bespoke modular microservice for the REST API backend both allow horizontal scaling of map services, while additional tiling and caching strategies that could be appended (e.g., MapProxy) improve rendering speed for web clients. Wang (2024) addressed performance issues by indexing time-series imagery using a structured mosaic model within GeoServer, allowing fast temporal filtering and retrieval.

Data streaming technologies utilized by PANTHEON, such as Apache Kafka, can handle high-frequency sensor input without overloading central databases. Load balancing and asynchronous processing can further improve PANTHEON's system responsiveness.

7.3 Data Quality and Validation

Geospatial data quality issues may include errors in georeferencing, outdated or incomplete datasets, inconsistent metadata, and sensor noise. These problems can severely undermine trust in PANTHEON's analytical outputs and decision-making, especially in high-stakes contexts such as disaster relief or environmental compliance.

As a bespoke solution for PANTHEON, data validation workflows are built into the ingestion pipeline. This includes:

- Specialized checks and cross-reference (e.g., via OpenStreetMap) for coordinate system consistency.
- Outlier detection in time-series sensor data.
- Manual review processes using authoritative reference layers.

Wang (2024) and Ozigis et al. (2025) both emphasize the use of multi-source verification, cross-referencing satellite indices with in-situ measurements or historical baselines to improve accuracy.

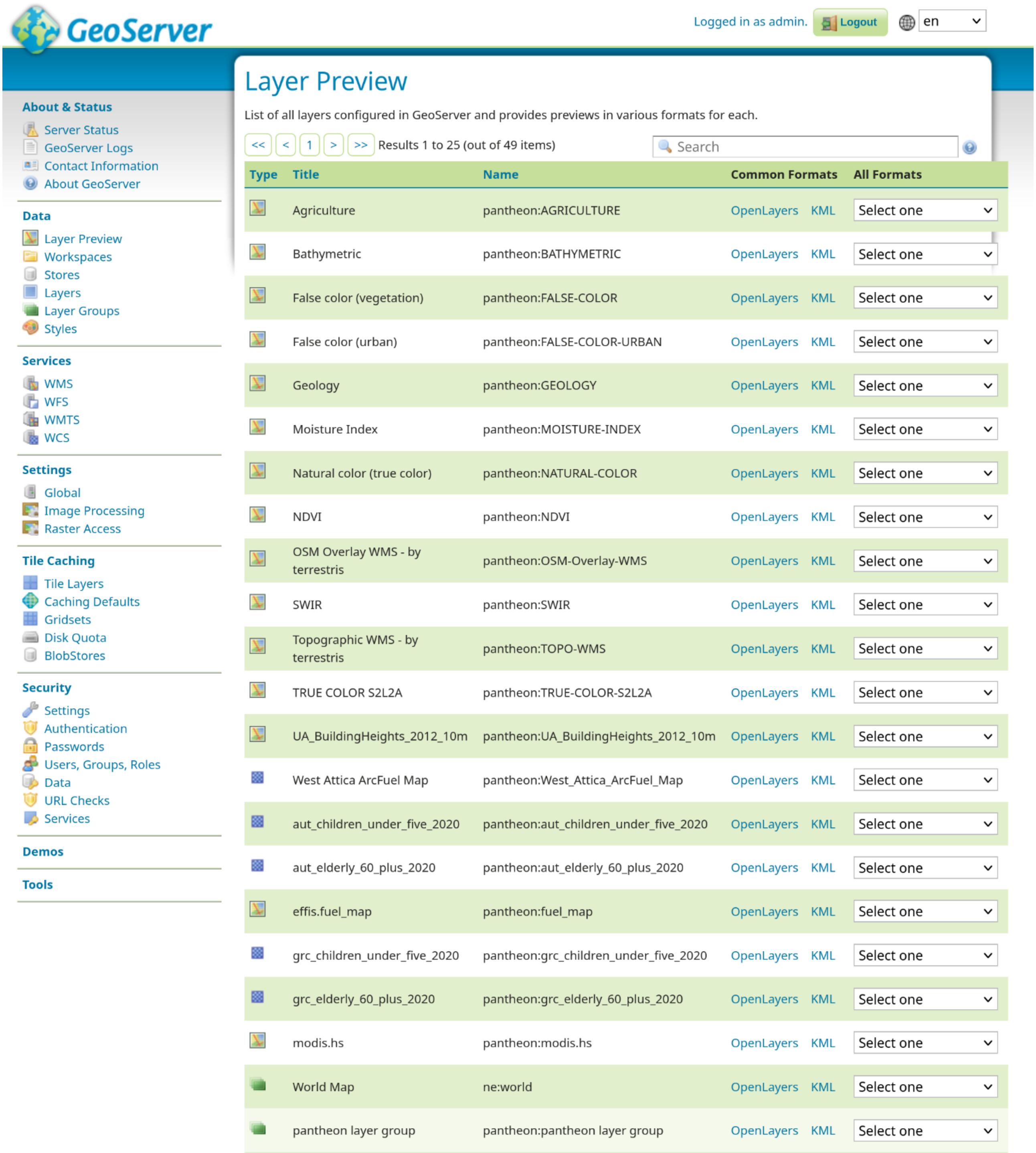

Figure 7: PANTHEON's layers preview validation capability.

7.4 Security and Access Control

Spatial data infrastructures used in PANTHEON for disaster management, or critical infrastructure monitoring must protect sensitive data and ensure system availability. Risks include unauthorized access, data leaks, denial-of-service (DoS) attacks, and manipulation of decision-critical inputs.

As a solution, best practices for PANTHEON’s geospatial cybersecurity include:

- Role-based access control for defining user privileges.
- Identity and Access Management (e.g., Keycloak) for secure data transmission and authentication.
- Audit logging and intrusion detection systems (IDS) for monitoring unauthorized activity.

Additionally, open-source platforms like GeoServer support fine-grained access policies and encrypted service endpoints. Furthermore, deploying systems in isolated network segments (e.g., enclosed by VPN) or on-premise configurations, especially for civil protection use, can reduce exposure.

Disaster-ready systems usually also include redundancy and failover mechanisms, ensuring that mission-critical data remains accessible even during network failures or cyberattacks.

8. Evaluation and Validation

Comprehensive evaluation and validation are essential for the PANTHEON proposal to ensure the reliability, usability, and operational relevance of all the integrated geospatial systems and software components. This section outlines the methods used to assess system performance, capture user experience, and validate the system in real-world deployments. The results provide a foundation for PANTHEON's iterative improvements and guide future scaling and adaptation efforts.

8.1 System Performance Metrics

System performance for PANTHEON's GeoServer was evaluated across key dimensions including:

- **Data throughput**: Rate at which spatial datasets (e.g., imagery tiles, vector layers) could be served to PANTHEON client components via WMS/WFS.
- **Latency**: Time delay between data request and rendering in the PANTHEON user interface components.
- **System uptime and availability**: Percentage of operational time across testing and deployment windows.
- **Scalability**: Capacity to handle concurrent users and data queries under peak conditions.

In implementations such as Wang's (2024) time-series imagery service, performance was enhanced using image mosaic indexing and temporal filtering via GeoServer. The system achieved sub-second response times for most user queries, even with large raster datasets spanning multiple years.

Load testing using tools such as the browsers' developer tools revealed that horizontal scaling with containerized Docker microservices and MapProxy can significantly reduce latency in high-load scenarios. In local deployment environments, rendering delays remained under reasonable time frames for vector datasets and raster layers.

8.2 User Feedback and Usability Testing

System usability for PANTHEON's goals will be assessed using a mix of structured user feedback sessions, group discussions, and scenario-based testing with all stakeholders. The evaluation will mainly target:

- Interface intuitiveness.
- Ease of data upload and retrieval.
- Responsiveness during high-pressure decision-making scenarios.
- Clarity of visualization and symbology.

Participants during the planning and training scenarios will include emergency responders, software analysts, and civil protection planners. Feedback will focus on whether the following functionality is providing high satisfaction:

- The ability to overlay UAV and satellite imagery seamlessly.
- The responsive performance of interactive web maps.
- The customizable dashboards based on user profiles and scenario needs.

Iterative improvements based on this feedback can include further streamlined processes, and simpler UI workflows based on operational context.

9. Future Directions

The continued advancement of geospatial information technologies opens new frontiers for the PANTHEON project in sectors such as intelligence, automation, and cross-sector innovation. Building on the current PANTHEON's foundations of interoperable, open-source systems and real-time data integration, future developments will further enhance the responsiveness, autonomy, and versatility of geospatial platforms. This section outlines three major areas where future growth and research are expected: AI and machine learning integration, edge computing for real-time analytics, and cross-domain applicability of geospatial infrastructures.

9.1 Integration with AI and Machine Learning

Artificial Intelligence (AI) and Machine Learning (ML) are poised to significantly elevate the capabilities of geospatial systems. Their integration in PANTHEON's components can enable:

- **Automated feature extraction** from satellite and UAV imagery (e.g., detecting flooded areas, building footprints, vegetation stress).
- **Predictive modelling** for hazard forecasting, land-use change, and infrastructure vulnerability.
- **Intelligent alert systems** that adapt thresholds based on environmental context and historical patterns.

For example, flood impact mapping that currently relies on threshold-based NDWI or NDBI indices could be enhanced through convolutional neural networks (CNNs) trained on multi-sensor datasets. These models would not only increase accuracy but also generalize across different geographic regions and disaster types.

GeoAI pipelines can also support spatio-temporal clustering, anomaly detection in sensor networks, and classification of remote sensing time-series, all of which are valuable in disaster early warning and environmental monitoring scenarios.

Open-source libraries such as TensorFlow and PyTorch are increasingly being adapted into geospatial workflows, paving the way for more integrated, end-to-end AI-enabled GIS systems.

9.2 Edge Computing for Real-Time Analytics

The growing availability of field-deployed sensors, mobile UAVs, and portable devices creates a demand for **edge computing**, performing analytics closer to the data source, reducing latency and bandwidth dependency.

Edge computing under the PANTHEON context could enable:

- **On-board data processing** for drones and mobile sensor units.
- **Autonomous decision-making** in areas with limited or no connectivity.
- **Streamlined data triage**, where only critical results are forwarded to central systems.

This is particularly relevant for time-sensitive operations like wildfire tracking, flash flood monitoring, or infrastructure inspection after seismic events. By deploying lightweight ML models on edge devices, field units can detect anomalies, classify features, and prioritize data streams in real time.

Platforms such as NVIDIA Jetson, Raspberry Pi, or edge-compatible UAV payloads can facilitate the deployment of microservices for geospatial data capture, filtering, and pre-analysis. Integration with message brokers (e.g., MQTT) can ensure efficient upstream data synchronization when network coverage permits.

9.3 Cross-Domain Applications

The architectural flexibility and modularity of modern geospatial systems such as the one that PANTHEON envisions position them as enablers of cross-domain innovation beyond traditional disaster and environmental contexts. Key sectors where geospatial integration is expected to grow include:

- **Agriculture**: Precision farming, crop monitoring, soil moisture analysis, and yield prediction using UAVs, EO data, and IoT sensors (as in Jeppesen et al., 2018).
- **Public Health**: Spatial epidemiology, disease spread modelling, and mapping of environmental determinants (e.g., air quality, water access).
- **Urban Planning and Smart Cities**: Real-time urban heat monitoring, traffic management, and spatial equity analysis using integrated mobility and demographic datasets.
- **Cultural Heritage**: Documentation and risk assessment of vulnerable sites through high-resolution UAV mapping and 3D reconstruction.

The interoperability frameworks and visualization tools developed in PANTHEON for disaster response can be easily extended to these fields, enabling scalable platforms that share common geospatial services, standards, and analytics layers.

Furthermore, participation in initiatives such as **GEOSS**, **Copernicus**, and **INSPIRE** will help ensure that geospatial systems remain aligned with global data sharing objectives, reinforcing their impact across multiple disciplines.

10. Conclusions

The integration of geospatial information technologies has emerged as a transformative enabler in addressing complex societal challenges ranging from disaster management and environmental monitoring to infrastructure planning and resource management. This deliverable has presented a comprehensive overview of the technological components, architectural strategies, open-source platforms, and practical applications that together constitute part of PANTHEON's modern geospatial ecosystem.

Drawing from a diverse body of research and operational case studies, the deliverable demonstrates how open standards (e.g., OGC protocols), modular system architectures, and interoperable data workflows can enable PANTHEON to utilize the seamless fusion of satellite imagery, UAV data, IoT sensor streams, and field observations. Platforms such as GeoServer, PostGIS, bespoke backend developments and OpenLayers, combined with scalable deployment strategies, support real-time situational awareness, dynamic mapping, and multi-user collaboration across domains.

In the meantime, apart from the significant progress PANTHEON has made in developing flexible and accessible systems, some key challenges are also mitigated. These include data heterogeneity, scalability under stress, validation of sensor-derived insights, and cybersecurity risks. For PANTHEON to keep addressing these in the future also requires continued investment in robust interoperability frameworks, performance optimization, user-centred design, and secure data governance practices.

Looking ahead, the integration of AI-driven analytics, edge computing capabilities, and cross-sector geospatial platforms will further expand the scope and impact of these technologies for PANTHEON's needs and goals. By fostering collaboration across technical, scientific, and policy-making communities, the geospatial integration framework outlined in this deliverable provides a solid foundation for PANTHEON to expand building resilient, responsive, and intelligent systems that can adapt to rapidly evolving disaster management scenarios.

11. List of Abbreviations

Abbreviation	**Meaning**
UxVs	Unmanned x Vehicles
UAV	Unmanned Autonomous Vehicles
UGV	Unmanned Ground Vehicles
USV	Unmanned Surface Vehicles (e.g., boats)
UUV	Unmanned Underwater Vehicles
SCDT	Smart City Digital Twin
GA	Genetic Algorithm
POI	Points of Interest
ESDF	Euclidean Signed Distance Field
TSP	Traveling Salesman Problem
TW	Time Windows
CPP	Coverage Path Planning
BCD	Boustrophedon Cellular Decomposition
MSTSP	Multiple Set Traveling Salesman Problem
AOI	Area of Interest
GRASP	Greedy Randomized Adaptive Search Procedure
GRP	Greedy Random search Procedure
TS	Tabu Search
FOV	Field of View
IHL	improved Hert – Lumelsky Algorithm

12. References

[1] Tomaszweski, Brian & Judex, Michael & Szarzynski, Jörg & Radestock, Christine & Wirkus, Lars. (2015). Geographic Information Systems for Disaster Response: A Review. Journal of Homeland Security and Emergency Management. Volume 12. 571-602. 10.1515/jhsem-2014-0082.

[2] Lincoln Laboratory, MIT. (n.d.). Software platform streamlines emergency response. Available at: https://www.ll.mit.edu/impact/software-platform-streamlines-emergency-response [Accessed 16 May 2025].

[3] G. Graja and T. Abdellatif, "Integration of UAV and Satellite Data in Remote Sensing," 2024 IEEE/ACS 21st International Conference on Computer Systems and Applications (AICCSA), Sousse, Tunisia, 2024, pp. 1-8, doi: 10.1109/AICCSA63423.2024.10912625.

[4] Mohammed Ozigis, Oluropo Ogundipe, Samuel J. Valman, Jessica L. Decker Sparks, Helen McCabe, Rebekah Yore, Bethany Jackson, Utility of Earth Observation data in mapping post-disaster impact: A case of Hurricane Dorian in the Bahamas, Remote Sensing Applications: Society and Environment, Volume 37, 2025, 101466, ISSN 2352-9385, https://doi.org/10.1016/j.rsase.2025.101466.

[5] Balbo, Simone & Boccardo, Piero & Dalmasso, S. & Pasquali, P. (2013). a Public Platform for Geospatial Data Sharing for Disaster Risk Management. ISPRS-International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences. 1. 189-195. 10.5194/isprsarchives-XL-5-W3-189-2013.

[6] SERVIR Team. (2022) Using GeoServer for visualization, storage and web sharing of spatial data. Available at: https://servir.alliancebioversityciat.org/using-geoserver-for-visualization-storage-and-web-sharing-of-spatial-data/ [Accessed: 16 May 2025].

[7] Cejudo, I., Irigoyen, E., Arregui, H. and Loyo, E. (2023). 3D Geospatial Data Management Architecture for Common Operational Picture Functionalities in Emergency Response. In Proceedings of the 9th International Conference on Geographical Information Systems Theory, Applications and Management - GISTAM; ISBN 978-989-758-649-1; ISSN 2184-500X, SciTePress, pages 48-59. DOI: 10.5220/0011837800003473.

[8] Z. Huang and Z. Xu, "A Method of Using GeoServer to Publish Economy Geographical Information," 2011 International Conference on Control, Automation and Systems Engineering (CASE), Singapore, 2011, pp. 1-4, doi: 10.1109/ICCASE.2011.5997789.

[9] D. Xia, X. Xie and Y. Xu, "Web GIS server solutions using open-source software," 2009 IEEE International Workshop on Open-source Software for Scientific Computation (OSSC), Guiyang, China, 2009, pp. 135-138, doi: 10.1109/OSSC.2009.5416738.

[10] K. Wang, "Implementation of a Time-Series Imagery Service Framework Based on GeoServer: A Case Study of Water Quality Monitoring Map," 2024 5th International Conference on Computer Engineering and Application (ICCEA), Hangzhou, China, 2024, pp. 1076-1082, doi: 10.1109/ICCEA62105.2024.10603874.

[11] Sarup, J. and Shukla, V., 2012. Web-based solution for mapping application using open-source software server. International Journal of Informatics and Communication Technology, 1(2), p.91.

[12] L. Bećirspahić and A. Karabegović, "Web portals for visualizing and searching spatial data," 2015 38th International Convention on Information and Communication Technology, Electronics and Microelectronics (MIPRO), Opatija, Croatia, 2015, pp. 305-311, doi: 10.1109/MIPRO.2015.7160284.

[13] V. Shukla, J. Sarup and V. Rai, "Web mapping spatial data information analysis using the Free Open-Source Software Server Service (FOSSSS)," 2021 9th International Conference on Reliability, Infocom Technologies and Optimization (Trends and Future Directions) (ICRITO), Noida, India, 2021, pp. 1-5, doi: 10.1109/ICRITO51393.2021.9596519.

[14] Chowdhury, S., Schröder, D., Ostadabbas, H., Hosseingholizadeh, M., and Friesecke, F.: Modernizing geospatial services: an investigation into modern OGC API implementation and comparative analysis with traditional standards in a web application, Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci., XLVIII-4/W12-2024, 11–18, https://doi.org/10.5194/isprs-archives-XLVIII-4-W12-2024-11-2024, 2024.

[15] Giannecchini, S. and Aime, A., 2013. GeoServer, the Open-Source server for interoperable spatial data handling.

[16] Parker, J., Donnellan, A., Glasscoe, M. et al. Advantages to Geoscience and Disaster Response from QuakeSim Implementation of Interferometric Radar Maps in a GIS Database System. Pure Appl. Geophys. 172, 2295–2304 (2015). https://doi.org/10.1007/s00024-014-0886-8

[17] Karnatak, H. C. et al. (2012) 'Spatial mashup technology and real time data integration in geo-web application using open-source GIS – a case study for disaster management', Geocarto International, 27(6), pp. 499–514. doi: 10.1080/10106049.2011.650651.

[18] Jacob Høxbroe Jeppesen, Emad Ebeid, Rune Hylsberg Jacobsen, Thomas Skjødeberg Toftegaard, Open geospatial infrastructure for data management and analytics in interdisciplinary research, Computers and Electronics in Agriculture, Volume 145, 2018, Pages 130-141, ISSN 0168-1699, https://doi.org/10.1016/j.compag.2017.12.026.