JOURNAL OF APPLIED GEOSPATIAL INFORMATION

Vol 9 No 2 2025

http://jurnal.polibatam.ac.id/index.php/JAGI
ISSN Online: 2579-3608

Optimization of Spatial Disaster Profile Database for Spatial Disaster Risk Analysis

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Received: September, 19 2025
Accepted: November 28, 2025
Published: December 26, 2025

Abstract

This study developed a dynamic, web-based integrated spatial disaster profile database system that is highly vulnerable to various types of natural hazards, using Lebak Regency as a case study. The reference for each profile displayed is the Indonesian Disaster Risk (RBI). The output of this study is a web performance overview consisting of an interactive HTML-based frontend integrated with the backend spatial data management using MongoDB, Python, and JavaScript. This system provides district-level statistical summaries, visualizations with thematic classifications, and an automatic update feature via API simulation. In addition, this system integrates spatial and non-spatial data. Based on the evaluation, this system improves the effectiveness of data collection and utilization, supports evidence-based decision making, and strengthens cross-sector collaboration. The use of a non-relational database architecture optimized for dynamic spatial data with synchronous updates and web-based distribution is a major innovation with the hope of creating a standardized and adaptive disaster information system that can be replicated in other regions with similar risks.

Keywords: *geographic information system, disaster management, non-relational database, data integration*

1. Introduction

Indonesia's geographical location, geological conditions, and complex climatic factors make it one of the countries with the highest vulnerability to natural disasters in the world (Hutchings and Mooney, 2021; Wibowo et al., 2024). This archipelagic country is located at the meeting point of three major tectonic plates, has many active volcanoes, and is prone to hydrometeorological disasters such as floods, landslides, droughts, and forest fires. Data from the National Disaster Management Agency (BNPB) shows that the number of disasters in Indonesia has never been less than 3,500 incidents per year in the last four years (Paskalis, 2025).

One of the areas with high vulnerability is Lebak Regency, Banten Province. This location is close to the Sunda Strait Subduction Zone, which has the potential for megathrust earthquakes, as evidenced by the tsunami that occurred in 2018. In addition, the Lebak Regional Disaster Management Agency (BPBD) recorded 392 disasters throughout 2024, including floods, landslides, fires, and coastal erosion, which caused damage to thousands of homes and infrastructure and resulted in fatalities (Suryana, 2025). The complexity of these geological and hydrometeorological threats makes Lebak a representative study area for disaster risk management research.

Disaster risk management is a comprehensive effort based on actual conditions using a number of resources in the form of data. A set of data is used to describe the conditions of an area, which are then linked to various types of disasters. This is referred to as a profile. When visualized in spatial dimensions, the profile is referred to as the spatial profile of an area. The existence of spatial data containing information on the profile of an area aims to support exposure analysis in the disaster risk assessment process. These profiles include social, physical, economic, and environmental profiles. All of these profiles can change over a certain period of time and cover various sectors, so that they are dynamic in nature and require a multidisciplinary approach.

The provision of profile data can be done through a spatial data infrastructure (SDI) system. Asante et al. (2006) highlight the crucial role of SDI in supporting natural disaster management through the integration of geospatial technology. This study suggests that the development of hazard and vulnerability baselines using historical data through SDI enables more effective planning efforts in dealing with various disaster scenarios. Therefore, this system needs to pay attention to design principles and data conditions which, in this context, support the dynamic nature of data. The form of SDI that can be implemented is a spatial database containing the profile of an area.

Various studies show that database technology plays an important role in disaster information management. Databases can include models that spatially simulate the resilience of a region from various dimensions (Narieswari et al., 2022). Databases can also store measurement data from various sensors in real time or synchronized with other features (Nur Laily et al., 2023). A number of findings have proven that databases not only meet current needs but can also be used as a foundation for the development of more comprehensive disaster risk assessments based on future scenarios (Ward et al., 2022).

Despite these studies, data availability remains a major obstacle in disaster management in Indonesia. The current situation shows that spatial data is still fragmented and static. Disaster data is scattered across various agencies (BPS, BIG, PUPR, Disdukcapil, and local governments) and is not integrated (Barai et al., 2025). This condition is exacerbated by other problems, such as the incompleteness of directly accessible data, which necessitates the supplementation of one data set with another (Han and Liu, 2025), the lack of interoperability between data and communication media, and issues related to quality and scalability (Jailani, 2019). This hinders quick and accurate decision-making and creates an information gap. On the other hand, the need for improved quality, dynamic nature, and completeness of data is increasingly urgent to support early warning systems, resource planning, and infrastructure strengthening.

Relational databases have long been used in Geographic Information Systems (GIS). However, their limitations in handling large, heterogeneous, and dynamic data pose challenges (Sveen, 2019). In contrast, non-relational database approaches (NoSQL), such as MongoDB, offer schema flexibility, scalability, and efficiency in spatial data storage, especially in GeoJSON format (Maia et al., 2018). The data structure, especially the spaghetti structure without topology, allows for simple yet effective storage for spatial integration needs, although it requires additional strategies for complex spatial analysis. Recent research has examined a conceptual design of a dynamic database for specific disaster cases, namely a multilevel dynamic database model specifically designed to support data management in remote sensing-based geological disaster emergency monitoring (Zhang et al., 2021). Database development can also be carried out with flexible adjustments while maintaining the clarity of the existing structure and standardization (Faiella et al., 2022). This supports the importance of multi-source Jdata integration in a data warehouse with practical interpretations in the form of interactive dashboards to support rapid decision-making in disasters (Jailani, 2019). This integration not only enables comprehensive spatial data representation but also provides synchronized access to users, thereby improving preparedness and mitigation. However, studies combining MongoDB as a dynamic spatial database with interactive WebGIS implementation for disaster profiles at the local level are still very limited.

Based on these issues, this study focuses on optimizing dynamic spatial databases to support disaster studies. This approach is expected to improve the efficiency of data storage, updating, and cross-sector integration, thereby providing more adaptive and relevant risk profiles for policy makers and the community.

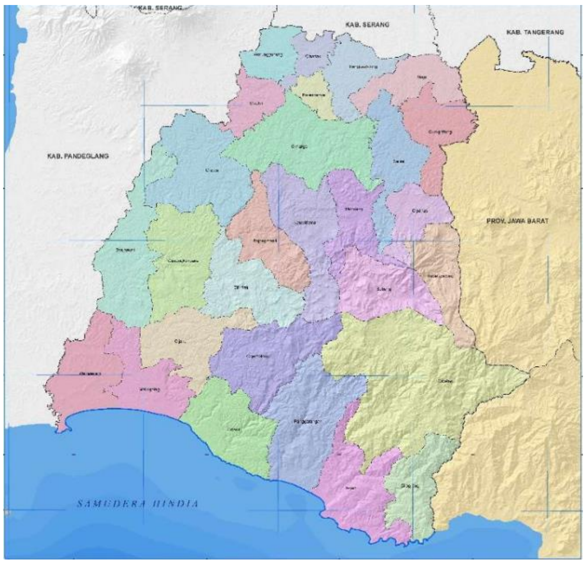


Fig. 1. Map of Lebak Regency

2. Material and Methods

2.1 Study Area

As shown in Fig.1, this study focuses on Lebak Regency, Banten Province, with an area of 3,426 km². This regency was chosen because it has a high level of vulnerability to geological and hydrometeorological disasters. Based on the BPBD (2025) report, throughout 2024 there were 392 disaster events in Lebak, including floods, landslides, extreme weather, and coastal erosion, which had a significant impact on the community and infrastructure. It has 28 districts which each of them will be shown its spatial profile.

No.	Data yang Digunakan	Tipe Data	Sumber	Tujuan Profil	Keterangan
1	Batas Administrasi (per Kecamatan)	Data vektor (GeoJSON)	RBI	Profil Topografi	
2	Kontur	Data vektor (GeoJSON)	RBI	Profil Topografi	
3	Sebaran Permukiman	Data vektor (GeoJSON)	RBI	Profil Fisik	
4	Sebaran Fasilitas	Data vektor (GeoJSON)	RBI	Profil Fisik	
5	Tutupan Lahan	Data vektor (GeoJSON)	RBI	Profil Ekonomi Profil Lingkungan	
6	Data Penduduk	Data tabel	BPS	Profil Sosial	Dispasialkan dengan data batas administrasi

Fig. 2. List of data used as test object

2.2 Data

The data used is in the form of vector data representing the profile of the Lebak Regency area. This data serves as a test object for the research results. The data will be used to assess the performance of the results and control the algorithms running on the output.

The data used was obtained from a number of sources. Geospatial data, which is vector data, was obtained from Indonesian Earth Appearance (RBI) data published by the Geospatial Information Agency. However, the semantic structure (attributes) of this data was simplified to include only the information necessary for spatial analysis of disaster risk as applied by the National Disaster Management Agency (BNPB) in the Indonesian Disaster Risk (RBI) document and the resulting technical modules for disaster risk assessment for various categories

2.3 Method

The research process began with identifying the needs for spatial analysis of disaster risk. The data was adjusted in terms of format and attributes. The data format used was GeoJSON, which is an encrypted and compressed vector spatial data format. Attribute adjustments were made roughly by replacing all attribute names according to the conceptual design that had been developed.

In addition to data preparation, a database schema was also created using MongoDB. The database creation process was not carried out directly on MongoDB, but using a programming script in Python (the definition script is shown in the Appendix). After the definition was made, when all data had been adjusted, the data was entered into the MongoDB database using Python programming. This method is categorized as optional because it can be done directly by entering the data one by one. However, the process of entering with Python is done for efficiency in the data entry process.

The database will be displayed in the form of a web-based data warehouse. The web design process consists of two parts: frontend design, which is the part that is directly used by users, and backend design, which is a series of processes that work behind the frontend. The frontend is designed using HTML for the main web framework, CSS for interface decoration, and JavaScript to run the functionality of all features on the frontend by connecting them to the backend. The backend is designed using Python, which contains algorithms for database definition, data entry, data display on the frontend, synchronized data updates, and downloading the latest data. The connection between the frontend and backend is made using an API defined in one of the main scripts located in the backend. The frontend features are activated using a server called Uvicorn, while the backend is activated in various ways, namely with Python or with the Live Server feature, an extension found in Visual Studio Code.

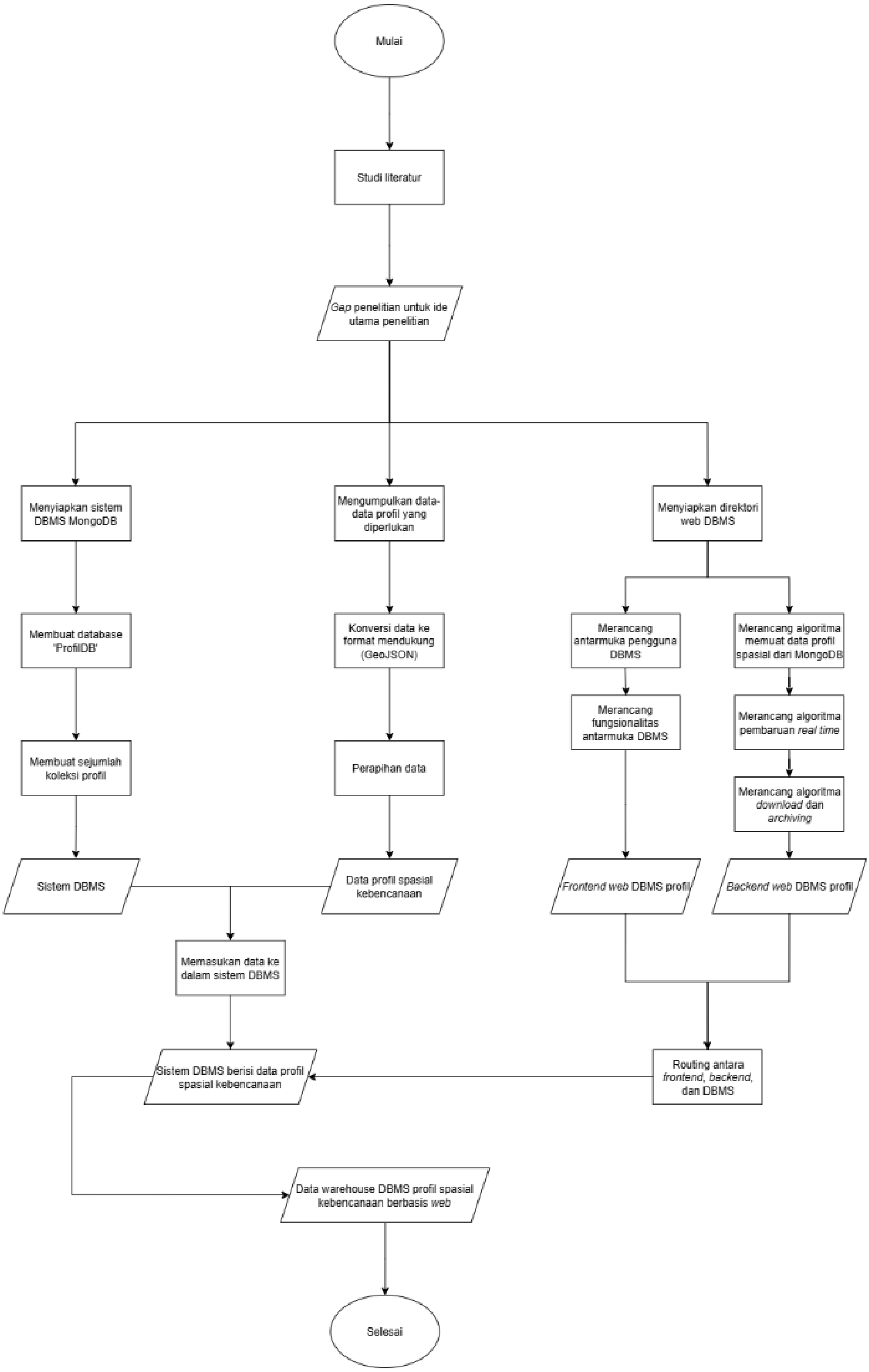


Fig. 3. Research flowchart

3. Results and Discussion

3.1 Database Structure

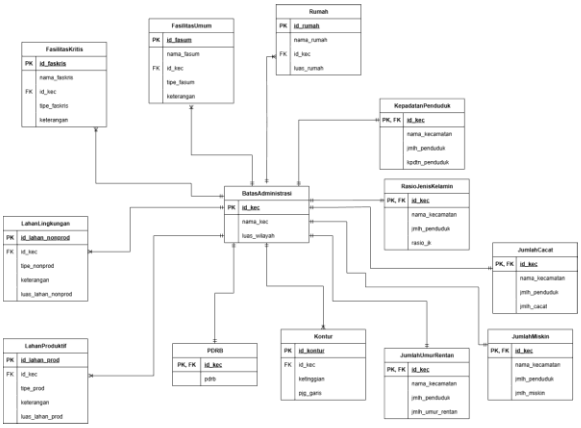


Fig. 4. Entity relationship diagram of relational database structure

Fig. 4 illustrates the data structure relationship depicted in an entity relationship diagram (ERD), focusing on the “AdministrativeBoundary” entity as the main entity whose profile is derived through relationships with other entities. The “AdministrativeBoundary” entity has attributes in the form of a subdistrict identity code (‘id_kec’), which is the entity's primary key, and additional information, namely the subdistrict name (‘nama_kec’) and subdistrict area (‘luas_wilayah’). The ‘id_kec’ attribute will be a foreign key for most other related entities.

The profiles displayed refer to BNPB Regulation Number 2 of 2012, which is further elaborated in the Indonesian Disaster Risk (RBI) document and a number of technical modules on Indonesian disaster risk assessment. The profiles displayed include social, physical, economic, environmental, and topographical profiles. A number of these profiles can be used to define a region's exposure and vulnerability to disasters.

The topography profile consists of contours and administrative boundaries per subdistrict so that the database can provide three-dimensional data and information related to the spatial aspects of Lebak Regency. The social profile consists of population density and the number of vulnerable groups. The physical profile is the distribution of infrastructure objects in a region, namely infrastructure and facilities. The economic profile is defined as the economic conditions of the region, focusing on the productivity of an area in relation to regional progress and development. The environmental profile consists of a number of non-productive lands.

The Lebak Regency spatial disaster profile database was designed with reference to the Indonesian Disaster Risk module framework (BNPB). The main entity is the subdistrict administrative boundary, which is connected to derivative entities in the form of social, physical, economic, and environmental profiles. The referencing model in MongoDB was chosen because it is efficient for one-to-many relationships with large data volumes and independent access.

The social profile includes population density and vulnerable groups (age, disability, poverty, gender ratio). The physical profile consists of settlements, public facilities (education, health, worship), and critical facilities (telecommunications networks and resource infrastructure). Economic profiles display GRDP and the distribution of productive land (rice fields, gardens, ponds), while environmental profiles highlight non-productive land such as forests and swamps. This structure makes the database flexible to support multi-dimensional disaster analysis.

3.2 Web Architecture Design

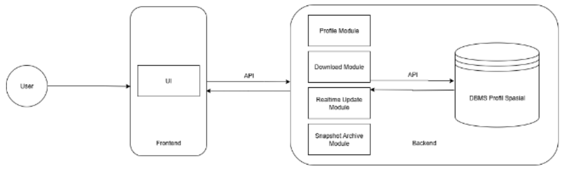


Fig. 5. DBMS web architecture design

The system architecture consists of a backend (FastAPI–Python) that manages the MongoDB database and API services, as well as a LeafletJS-based frontend for interactive spatial visualization. The web dashboard allows users to display spatial profiles per subdistrict, classify numerical data (Natural Breaks/Jenks), view profile summaries, and access historical data archives. Data upload–download features are provided to facilitate further utilization.

The backend is the backbone of the system which is responsible for data management, algorithms, and interactions with the database. For data management, a non-relational database MongoDB was chosen for this research. MongoDB was selected based on its ability to handle spatial data efficiently, its flexible schema that allows for dynamic data adjustments, and its good scalability to accommodate future data growth. The use of MongoDB specifically supports the storage and analysis of spatial data through its geospatial features. The scripts for the backend were developed using Python so they utilize various relevant libraries for data manipulation, routing, and other supporting services. Functions handled by the backend are database management, routing requests from the frontend, data processing utilities, and API services for data interaction.

The frontend consists of a web-based user interface that allows users to interact directly with the system. Using HTML, CSS, and JavaScript, this frontend presents information visually and interactively. The interface design focuses on ease of use with an intuitive map dashboard display and an organized spatial disaster profile data warehouse.

3.3 DBMS Overview

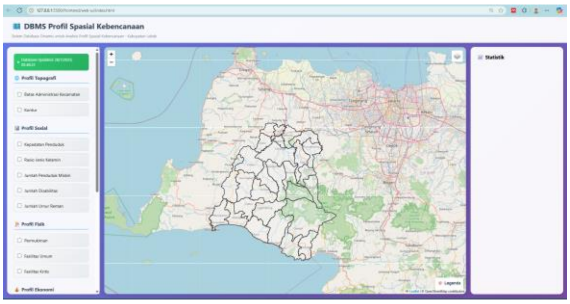


Fig. 6. Interface of Spatial Disaster Profile DBMS

The tangible manifestation of the database structure and web architecture design is a real website titled “Spatial Disaster Profile DBMS.” As a data warehouse, this system functions as a centralized repository for various types of profile data that determine disaster factors. It is important to emphasize that profile data, both spatial and tabular, has automatic updating capabilities (synchronized updating). This is a fundamental feature that makes this database “dynamic.” This updating mechanism will be explained further in data management. This capability eliminates the need for time-consuming and error-prone manual updates and ensures that analyses are always based on the latest data. In addition, the system is designed to allow users to download spatial data and profile table data. This feature is very important because it makes it easier for interested parties to conduct disaster analysis without the need for scraping from various sources. This reduces duplication of effort and increases the efficiency of the analysis process.

Fig. 7. Demonstration of subdistrict’s profile brief summary

The DBMS has a number of interface features that can be accessed by users. These features help users easily and quickly view the spatial profile details of an area. In this case, the area is each subdistrict in Lebak Regency, Banten. Figure 6 shows a map and two sidebars: the main sidebar on the left side of the map and the statistics sidebar on the right side of the map. By default, the administrative boundaries of subdistricts in Lebak Regency are displayed with no fill and a black outline. Users can click on one of the administrative boundaries of the subdistricts in Lebak Regency to see a brief summary of the subdistrict profile at the bottom of the left sidebar, as seen in Figure 7. This maximizes the effectiveness and efficiency of viewing a subdistrict profile, but it is not possible to view everything at once, so to view the profile of a regency, further analysis using the data provided in the DBMS is required.

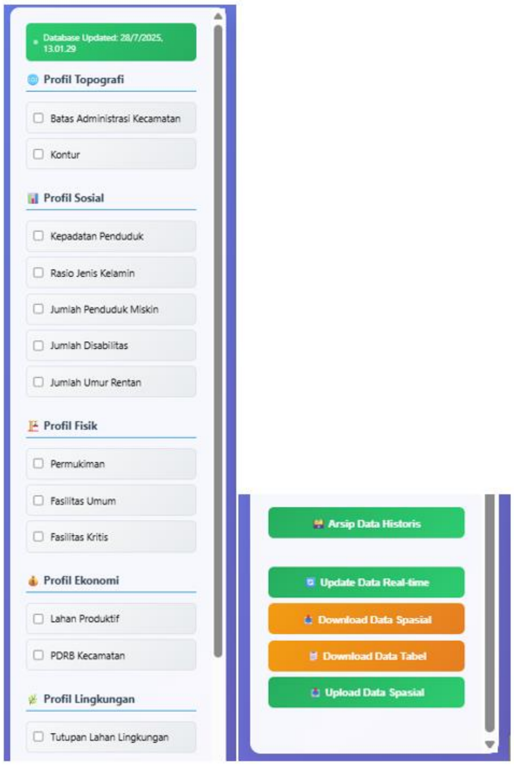


Fig. 8. Layer selection and other menu (data upload and download)

In addition to viewing a summary of a subdistrict's profile, the left sidebar contains a number of tools for viewing simultaneous data updates (synchronized data updating), options for displaying the spatial profile layer of a regency, and a number of tools for downloading and uploading data. The profile viewing feature is a tick button that displays the profile spatially with its classifications. When users display the profile, the frontend functionality also classifies the data. The classification performed is numerical classification. Additional information on the classification results can be seen in the legend, which dynamically adjusts to the profile displayed. For numerical classification, the classification method used is natural break (Jenks) because it is able to adjust to various types of data. The legend is located at the bottom right of the map.

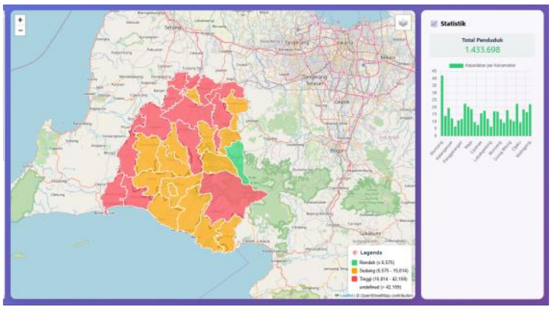


Fig. 9. Statistic summary

In this DBMS, there is a special page that allows users to access historical data. On the left sidebar, there is a menu to access the ‘Historical Data Archive’ page. Users will be redirected to the Historical Data Archive page, where they can specify the desired data date. A set of historical data is stored in a snapshot, which is a collection of data for each spatial and non-spatial profile.

The Spatial Disaster Profile DBMS was developed as a dynamic system that provides raw data and visualizations of disaster-determining factors without performing direct risk calculations, thus giving users the flexibility to apply risk analysis methodologies as needed. The core of this system is an automatic update mechanism through API integration simulation from primary data sources (e.g., BPS or local government agencies), which enables continuous data updates without manual intervention. MongoDB was chosen as the main engine due to its schema flexibility, which allows for the addition or modification of new data without complex migration, as well as its support for horizontal scalability through sharding, ensuring stable performance even as data volume and users increase. The flexible database design allows for gradual cross-sector integration, while support for GeoJSON spatial data storage and 2dsphere geospatial indexes enables fast execution of spatial queries such as proximity search, geoWithin, and intersection. Tests show that MongoDB is capable of handling periodic profile data updates without a significant decrease in dashboard response time, making this system not only adaptive and efficient, but also has the potential to be adopted on a regional and national scale.

3.4 Spatial Query Performance

Profil	Kecamatan	Query	Waktu Kueri (ms)	
			MongoDB	PostGIS
Fasilitas Umum	LB01	pip	51.33	44.9
		radius	1.82	40.4
		bbox	11.22	12.67
	LB05	pip	45.7	43.32
		radius	1.11	11.37
		bbox	13.73	11.2
	LB21	pip	38.3	36.78
		radius	1.24	10.07
		bbox	11.3	11.4
Fasilitas Kritis	LB01	pip	45.82	2.57
		radius	1.08	0.48
		bbox	3.03	0.41
	LB05	pip	29.94	0.5
		radius	1.04	0.4
		bbox	0.65	0.42
	LB21	pip	34.49	0.66
		radius	1.31	0.45
		bbox	0.74	0.52
Permukiman	LB01	pip	68.86	66.74
		bbox	123.77	63.05
	LB05	pip	47.29	82.11
		bbox	105.67	54.26
	LB21	pip	58.79	74.75
		bbox	106.41	55.02
Lahan Produktif	LB01	pip	328.96	144.67
		bbox	7226.22	313.93
	LB05	pip	906.92	87.73
		bbox	6436.59	239.47
	LB21	pip	3602.58	81.4
		bbox	6503	370.98
Lahan Lingkungan	LB01	pip	90.77	25.54
		bbox	160.78	23.36
	LB05	pip	106.61	31.7
		bbox	158.97	19.51
	LB21	pip	39.07	7.85
		bbox	111.12	18.02

Fig. 10. Spatial query speed results between MongoDB and PostGIS

Performance testing of spatial queries on identical datasets in MongoDB and PostgreSQL/PostGIS shows that the two have different characteristics. In the point-in-polygon test, both are relatively equal with an execution time of 78.07 ms in MongoDB and 79.95 ms in PostGIS, while in the radius search test, MongoDB is much faster, at 1.96 ms compared to 154.75 ms in PostGIS, thanks to efficient 2dsphere index optimization for proximity searches. Because of these findings, MongoDB is better suited for emergency response scenarios involving disasters that call for a prompt reaction, like looking for vital facilities or weak spots nearby an incident. In the bounding box search test, MongoDB also outperformed PostGIS (18.50 ms vs. 25.85 ms), supporting the loading of map view-based data on interactive dashboards.

3.5 Flexibility Performance

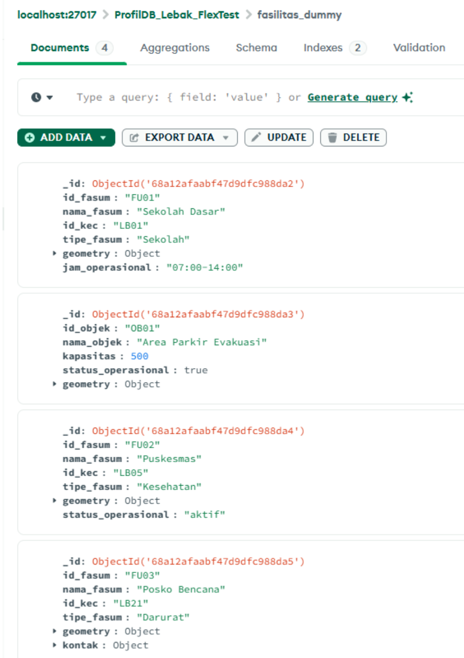
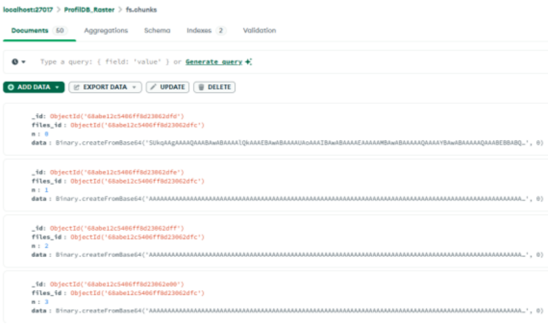
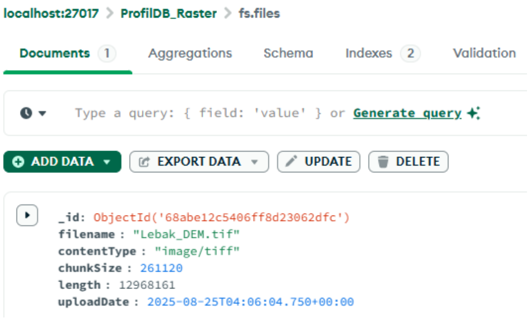


Fig. 11. Example of data with different attributes in a single data collection in MongoDB

This study highlights data integrity management through thorough backend validation before data is entered or updated, covering structure, format, completeness, and value suitability, despite MongoDB's reputation as a flexible non-relational database. This feature prevents data corruption and inconsistency. In addition, MongoDB also supports 2dsphere spatial indexes to ensure the accuracy of spatial queries such as geoWithin, near, and intersect, while maintaining geographic data integrity. However, to demonstrate MongoDB's adaptability to changing standards or new data types, a dummy collection comprising documents with different attributes such as operational hour time (jam_operasional) as a string or capacity as an integer was created. Although PostGIS is still better for complex spatial analysis like buffering, overlay, and network analysis, MongoDB's role in supporting dynamic disaster spatial profiling systems is strengthened by this flexibility and quick spatial query performance. Consequently, a hybrid strategy that uses PostGIS for sophisticated spatial analysis and MongoDB for dynamic queries may be the best course of action.



(a)



(b)

Fig. 12. Structures of raster data storage in MongoDB: (a) in chunks and (b) in a single file

In order to evaluate frontend access and storage capacity, raster data was converted from vector contour data to MongoDB. The results of the study show that although Digital Elevation Model (DEM) rasters can be stored well using the GridFS mechanism and integrated with the backend, the process of direct visualization to a web-based map (Leaflet) is unable to display an accurate representation of the Earth's surface due to fundamental differences between the raster storage structure in the database and the spatial visualization requirements on the frontend. Rasters from GridFS can only be converted into simple images in the form of 256×256 pixel PNG tiles through resampling, which reduces the resolution and eliminates topographical details. Thus, MongoDB is effective as a raster storage repository, but it is not designed to support direct visualization, so DEM raster presentation is more appropriately done through a dedicated tile server such as GeoServer or Cloud Optimized GeoTIFF (COG).

3.6 Implementation

Spatial Disaster Profile DBMS in Lebak Regency is expected to have a significant impact on disaster risk management and response through improved analysis efficiency, strengthened data-driven decision making, and resource optimization. The system that integrates various up-to-date spatial and non-spatial data into a single platform might help stakeholders reducing data collection time, avoiding duplication, and focusing more on evidence-based mitigation strategies. Interactive visualizations in the form of dynamic maps and attribute tables enable a better understanding of exposure patterns for vulnerability assessment, while the availability of valid data encourages cross-sector collaboration between local governments, academics, communities, and non-governmental organizations.

In terms of performance, MongoDB with 2dsphere spatial index support has been proven to improve the performance of spatial query processing such as point-in-polygon and proximity search, enabling the system to respond quickly to large data volumes and intensive updates. However, the system still has limitations: the implemented profile only complies with BNPB Head Regulation No. 2/2012, without an automatic risk analysis module; dependence on public APIs that are not yet uniform; and the need for manual supervision when data integration is not fully available. This system is therefore positioned as a valid and dynamic data repository, while risk analysis is still carried out externally.

Going forward, development can be directed towards integrating an automatic risk analysis module, adding advanced spatial analysis features (overlay, clustering, temporal modeling), and integrating real-time data from IoT sensors to enrich monitoring functions. From an infrastructure perspective, implementation on a public cloud server will expand accessibility and support the principle of open data, while mobile applications can strengthen field monitoring and rapid response in limited areas. The use of managed database services such as AWS or Alibaba Cloud is also recommended to ensure system scalability, security, and reliability. Thus, the Spatial Disaster Profile DBMS has a strong foundation as an adaptive, collaborative, and sustainable digital ecosystem in supporting data-based disaster risk management in Indonesia.

4. Conclusion

This research successfully developed a web-based dynamic spatial disaster profile database system with a case study in Lebak Regency, which integrates spatial and non-spatial data (topography, social, physical, economic, and environmental) into a centralized platform with automatic updates through API integration. By utilizing MongoDB as a flexible, scalable, and efficient non-relational database for geospatial processing, this system is designed based on the “AdministrativeBoundary” entity to support visualization, structured storage, and comprehensive spatial disaster analysis. Performance tests reveal that MongoDB outperforms PostgreSQL/PostGIS in a number of spatial queries; however, PostGIS is generally more potent, and MongoDB's adaptability to handling a variety of data types is still a benefit. Through a combination of automation and manual supervision, this system overcomes the limitations of the API, exhibiting flexibility in real-world scenarios while enhancing data accessibility, analysis efficiency, and cross-sector collaboration. It is advised that future development incorporate automated risk analysis modules, advanced spatial features (overlay, clustering), IoT sensor integration, and integration with public cloud infrastructure to guarantee data security, availability, and openness. The system's scalability, dependability, and sustainability as a long-term spatial disaster data infrastructure will also be strengthened by technical training, institutional cooperation with data providers, and the use of managed database services

Acknowledgements

The authors would like to express their gratitude to the Badan Pusat Statistik (BPS) and the Badan Informasi Geospasial (BIG) for providing open-source datasets that were essential for this research. Their support in data provision greatly facilitated the establishment of the research design and the analysis of spatial and non-spatial profiles. The authors also acknowledge the valuable insights and constructive feedback from colleagues and academic supervisors, which contributed significantly to the refinement of the research framework and the preparation of this manuscript..

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