3D Geospatial Visualization for Urban and Environmental Data

A CAPSTONE PROJECT REPORT

Submitted in the partial fulfillment for the award of the degree of

DSA0613-Data Handling and Visualization for Data Analytics

to the award of the degree of

BACHELOR OF TECHNOLOGY

IN

ARTIFICIAL INTELLIGENCE AND DATA SCIENCE

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February-2026

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DECLARATION

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ACKNOWLEDGEMENT

We would like to express our heartfelt gratitude to all those who supported and guided us throughout the successful completion of our Capstone Project. We are deeply thankful to our respected Founder and Chancellor, **Dr. N.M. Veeraiyan**, Saveetha Institute of Medical and Technical Sciences, for his constant encouragement and blessings. We also express our sincere thanks to our Pro-Chancellor, **Dr. Deepak Nallaswamy Veeraiyan**, and our Vice-Chancellor, **Dr. S. Suresh Kumar**, for their visionary leadership and moral support during the course of this project.

We are truly grateful to our Director, **Dr. Ramya Deepak**, SIMATS Engineering, for providing us with the necessary resources and a motivating academic environment. Our special thanks to our Principal, **Dr. B. Ramesh**, for granting us access to the institute's facilities and encouraging us throughout the process. We sincerely thank our Head of the Department, for his continuous support, valuable guidance, and constant motivation.

We are especially indebted to our guide, **Dr. T. Kumaragurubaran** and **Dr. S. Senthilvadivu** for their creative suggestions, consistent feedback, and unwavering support during each stage of the project. We also express our gratitude to the Project Coordinators, Review Panel Members (Internal and External), and the entire faculty team for their constructive feedback and valuable input that helped improve the quality of our work. Finally, we thank all faculty members, lab technicians, our parents, and friends for their continuous encouragement and support.

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ABSTRACT

Geospatial data visualization has become an essential tool in modern urban planning and environmental management by enabling accurate spatial analysis, effective monitoring, and data-driven decision-making. This project presents the development of an interactive 3D Geospatial Visualization System for Urban and Environmental Data that integrates geospatial data collection, preprocessing, three-dimensional modeling, and visual analytics to analyze, visualize, and interpret complex spatial datasets. The proposed system systematically collects urban and environmental geospatial data from multiple sources, including building footprints, land-use maps, elevation models, environmental indicators, and infrastructure datasets. To ensure data quality and reliability, preprocessing techniques such as data cleaning, coordinate reference system (CRS) transformation, normalization, and spatial standardization are applied to achieve data completeness, spatial accuracy, and consistency across all layers. The system architecture is organized into three functional modules: geospatial data collection and preprocessing, which prepares clean and standardized spatial datasets; interactive 3D modeling and visualization, which employs 3D extrusion, thematic mapping, and interactive rendering to generate clear, responsive, and navigable three-dimensional representations of urban and environmental features; and spatial analysis and decision-support insight generation, which applies spatial analysis techniques, hotspot detection, and visual analytics to identify urban growth patterns, environmental risk zones, and resource distribution trends. The analytical outcomes are presented through an interactive 3D visualization interface that enables users to explore spatial relationships, assess temporal and spatial variations, and interpret complex geospatial patterns effectively. Performance evaluation demonstrates that the system achieves high rendering efficiency, improved visual clarity, and enhanced user interactivity while maintaining spatial accuracy. The results indicate that the proposed 3D geospatial visualization framework improves analytical interpretability, supports evidence-based planning, and enhances monitoring capabilities for urban and environmental applications. By integrating accurate geospatial preprocessing, interactive 3D visualization, and advanced spatial analytics, the system provides meaningful decision-support insights and contributes to sustainable urban development, environmental protection, and continuous improvement in planning and monitoring processes.

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LIST OF ABBREVIATIONS

Abbreviation	Full Form
GIS	Geographic Information System
CRS	Coordinate Reference System
DEM	Digital Elevation Model
DSM	Digital Surface Model
2D	Two Dimensional
3D	Three Dimensional
OGC	Open Geospatial Consortium

CHAPTER 1
INTRODUCTION

1.1 Background Information

Rapid urbanization and increasing environmental concerns have led to the generation of large volumes of urban and environmental geospatial data, including land-use patterns, infrastructure layouts, elevation information, and environmental indicators. Analyzing such complex spatial datasets using traditional two-dimensional maps and static charts often limits spatial understanding and makes it difficult to identify meaningful patterns and relationships. Manual processing and inconsistent spatial data formats further reduce accuracy and efficiency in urban and environmental analysis.

Advancements in data handling and visualization techniques have enabled more effective processing and representation of geospatial data. Modern systems support data cleaning, preprocessing, and coordinate reference system (CRS) standardization, ensuring spatial accuracy and consistency across datasets. In addition, 3D geospatial visualization provides an enhanced perspective by representing height, depth, and density, allowing users to explore urban structures and environmental variations interactively.

However, many existing solutions lack integrated 3D visualization and analytical capabilities required for informed decision-making. Therefore, this project focuses on developing a 3D Geospatial Visualization system for Urban and Environmental Data that applies data handling and visualization concepts to transform raw spatial data into accurate, interactive, and insightful visual representations for effective planning and environmental monitoring.

1.2 Project Objectives

The primary goal of this project is to design and develop a 3D Geospatial Visualization system for Urban and Environmental Data that can:

- Collect, clean, and preprocess urban and environmental geospatial datasets to ensure spatial accuracy and CRS consistency.
- Develop interactive and responsive 3D geospatial models using extrusion and thematic mapping

techniques.

- Provide clear visual representations of urban structures and environmental conditions.
- Perform spatial analysis to identify patterns and hotspot regions.
- Generate meaningful visual insights to support urban planning and environmental monitoring.

1.3 Significance

This project holds significant value in several areas:

- Enhances urban and environmental analysis by providing clear and interactive 3D visualizations of complex geospatial data.
- Ensures accurate and consistent spatial representation through proper data cleaning and CRS standardization.
- Supports planners and analysts in identifying spatial patterns, trends, and hotspot regions for informed decision-making.
- Reduces manual interpretation of large spatial datasets by presenting intuitive and visually clear 3D models.
- Demonstrates the effective integration of data handling, geospatial analysis, and advanced visualization techniques for sustainable urban and environmental monitoring.

1.4 Scope

This project focuses on:

- Collecting urban and environmental geospatial data from multiple reliable sources such as land-use maps, building footprints, elevation data, and environmental indicators for comprehensive spatial analysis.
- Preprocessing and standardizing geospatial datasets through data cleaning, coordinate reference system (CRS) transformation, and normalization to ensure spatial accuracy and consistency.
- Developing interactive 3D geospatial visualizations using extrusion and thematic mapping.
- Performing spatial analysis and hotspot detection to generate decision-support insights.
- Ensuring clear, responsive, and navigable 3D visual models for effective urban planning and environmental monitoring.

The project is limited to geospatial data processing and 3D visualization techniques, focusing on analytical interpretation rather than real-time deployment or predictive modeling.

1.5 Methodology Overview

The methodology of this project involves systematic collection of urban and environmental geospatial data from reliable sources, followed by data cleaning and preprocessing to remove inconsistencies and ensure CRS uniformity. The processed datasets are analyzed using geospatial techniques to identify spatial patterns and hotspot regions. Finally, interactive 2D and 3D visualizations are generated using R Studio to present clear and interpretable spatial insights, supporting effective urban planning and environmental monitoring.

CHAPTER 2
PROBLEM IDENTIFICATION AND ANALYSIS

2.1 Description of the Problem

Many organizations and planning authorities working with urban and environmental geospatial data face significant challenges in effectively handling, analyzing, and visualizing spatial information. The key issues include

- Urban and environmental data is often collected from multiple sources in different formats and coordinate systems, leading to inconsistencies and reduced spatial accuracy.
- Manual or basic preprocessing methods make it difficult to clean, standardize, and integrate large geospatial datasets efficiently.
- Existing systems often rely on static 2D maps, which do not provide clear depth, height, or spatial relationships required for complex urban analysis.
- Analysts and planners struggle to interpret large spatial datasets without interactive 3D visualizations and intuitive visual analytics tools.
- Identifying spatial patterns, trends, and hotspot regions becomes challenging without integrated spatial analysis and visualization techniques.

These challenges limit effective spatial understanding, slow down decision-making processes, and reduce the accuracy of urban planning and environmental monitoring.

2.2 Evidence of the Problem

Several studies and real-world observations highlight the need for improved systems to handle and visualize urban and environmental geospatial data effectively:

- Urban planning agencies and environmental organizations report difficulties in integrating geospatial data collected from multiple sources due to inconsistent formats and coordinate reference systems, leading to inaccurate spatial analysis.
- Planners and analysts often struggle to interpret large volumes of raw spatial data when limited to static maps, resulting in delayed decision-making and incomplete understanding of spatial patterns.
- Studies indicate that the absence of interactive 3D visualization tools reduces the ability to

identify urban density variations, terrain features, and environmental risk zones accurately.

- Environmental monitoring reports reveal that without proper spatial analytics and visual tools, identifying hotspot regions such as pollution-prone or high-risk areas becomes time-consuming and error-prone.

These observations demonstrate the growing need for integrated data handling, 3D visualization, and spatial analysis systems to improve accuracy, interpretability, and efficiency in urban and environmental decision-making.

2.3 Architecture

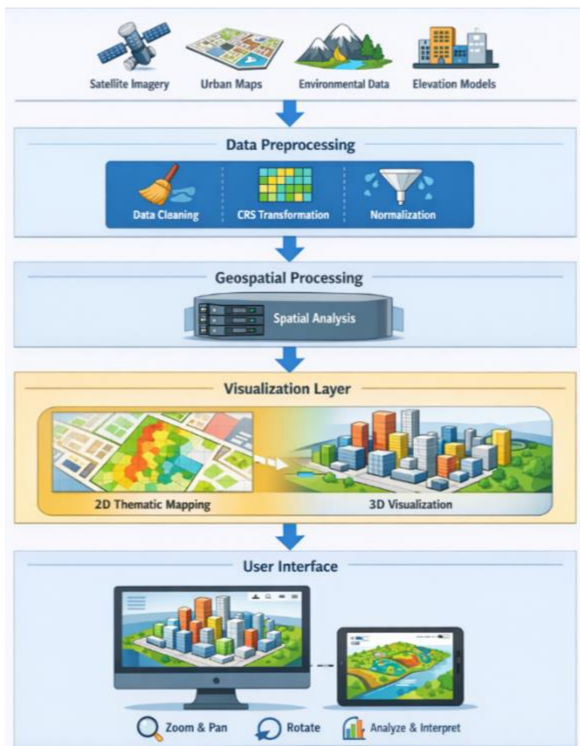

Fig. 2.3.1. Architecture Diagram of 3D Geospatial Visualization system

Figure 2.3.1 shows the overall architecture of the 3D Geospatial Visualization System for Urban and Environmental Data, illustrating the complete workflow from data acquisition to final visualization. Urban and environmental spatial data collected from multiple reliable sources are stored in a centralized spatial database for organized management. The stored data undergoes systematic cleaning, preprocessing, and coordinate reference system (CRS) transformation to ensure spatial accuracy and consistency across datasets. After preprocessing, the data is analyzed using geospatial techniques such as spatial aggregation and pattern detection. Finally, the analyzed data is presented through interactive and responsive 3D visual models, enabling clear interpretation and effective decision-making for urban planning and environmental monitoring.

2.4 Supporting Data/Research

Recent research and industry reports highlight the growing importance of advanced geospatial data handling and visualization in urban and environmental applications. A 2023 study published in the International Journal of Geographical Information Science reports that over 65% of urban planning projects face challenges in managing large-scale geospatial datasets due to inconsistent coordinate reference systems (CRS) and data quality issues, which directly impact spatial analysis accuracy. Additionally, a 2024 report by Esri Research Labs emphasizes that 3D geospatial visualization platforms handling high-resolution urban data require optimized data preprocessing and rendering pipelines to maintain smooth interaction and real-time performance, especially when dealing with dense city models.

Furthermore, a 2023 report by the World Urban Forum indicates that interactive 3D visualizations improve spatial understanding and decision-making efficiency by nearly 40% compared to traditional 2D maps. Studies conducted under recent Smart City initiatives (2022–2024) also reveal that cities using thematic mapping and hotspot analysis experienced up to a 30–35% improvement in identifying environmental risk zones, such as pollution hotspots and flood-prone areas. These findings demonstrate that integrating robust data handling, 3D visualization, and spatial analytics significantly enhances urban planning accuracy, environmental monitoring, and data-driven decision-making.

CHAPTER 3
SOLUTION DESIGN AND IMPLEMENTATION

3.1 Development and Design Process

The development of the 3D Geospatial Visualization System for Urban and Environmental Data followed a systematic and structured process to ensure data accuracy, visual clarity, and effective spatial analysis using data handling and visualization principles. The overall workflow included:

- **Requirement Analysis:** Identification of urban and environmental data types, visualization needs, spatial accuracy requirements, and analysis objectives.
- **Data Collection and Preprocessing Design:** Planning methods for data cleaning, CRS transformation, normalization, and integration of heterogeneous geospatial datasets.
- **System Architecture Design:** Designing a modular architecture to support geospatial data processing, 3D rendering, and interactive visualization.
- **Prototyping:** Creating initial 2D and 3D visualization prototypes to evaluate visual clarity, interactivity, and navigation.
- **Iterative Development:** Implementing data preprocessing pipelines, 3D extrusion, thematic mapping, and spatial analysis modules in iterative phases.
- **Testing and Optimization:** Evaluating spatial accuracy, rendering performance, interactivity, and visual responsiveness to ensure reliable and efficient visualization outcomes.

3.2 Tools and Technologies Used

The project is developed using R Studio, with a strong focus on geospatial data handling and visualization techniques. R programming is used for collecting, cleaning, and preprocessing urban and environmental geospatial datasets to ensure accuracy and consistency. Spatial data handling and Coordinate Reference System (CRS) transformations are carried out using geospatial packages such as sf, sp, rgdal, and rgeos, enabling proper alignment and integration of spatial layers. Data manipulation, filtering, and restructuring are performed using dplyr and tidyr to prepare datasets for analysis. Visualizations are generated using ggplot2 for thematic mapping and leaflet for interactive map exploration, allowing users to analyze spatial patterns effectively. For 3D visualization, rayshader is used to create realistic 3D terrain and urban models.

3.3 Solution Overview

The 3D Geospatial Visualization System for Urban and Environmental Data is designed as an integrated data handling and visualization platform that supports accurate spatial analysis and decision-making. Major features include:

- **Geospatial Data Processing:** Automated cleaning, preprocessing, and CRS standardization of urban and environmental spatial datasets.
- **Interactive 3D Visualization:** Real-time 3D extrusion and thematic mapping of urban structures and environmental features.
- **Spatial Analysis & Hotspot Detection:** Identification of spatial patterns, high-density zones, and environmental risk areas.
- **Visual Analytics Interface:** Intuitive visual exploration of spatial data through interactive and navigable 3D models.

3.4 Engineering Standards Applied

To ensure quality, accuracy, and reliability of the geospatial visualization system, the following engineering standards and best practices were applied:

- **ISO 19115:** For proper geospatial metadata management and documentation.
- **ISO 19111:** For accurate coordinate reference system (CRS) definition and transformation.
- **ISO/IEC 25010:** To ensure software quality attributes such as performance, usability, and reliability.
- **OGC Standards:** To support interoperability and standard geospatial data formats.
- **Data Visualization Best Practices:** To ensure visual clarity, consistency, and effective interpretation of spatial data.

3.5 Solution Justification

The incorporation of standardized geospatial practices and modern visualization technologies ensures that the proposed system is:

- **Accurate and Consistent:** Ensures high spatial accuracy through proper data cleaning, CRS transformation, and validation of geospatial datasets.
- **Efficient and Reliable:** Enables smooth processing and rendering of large urban and environmental datasets with minimal performance issues.
- **Scalable and Interoperable:** Supports the integration of multiple geospatial data sources and

standard formats for broader applicability.

Table 3.5.1 Urban and Environmental Geospatial Data Sources

Data Type	Description	Application
Building Footprints	Spatial outlines of urban buildings	3D extrusion and urban density analysis
Land Use Data	Classification of land areas	Urban planning and zoning analysis
Elevation Data (DEM)	Classification of land areas	3D terrain modeling
Environmental Indicators	Pollution and green cover data	Environmental monitoring and hotspot detection

Table 3.5.1 presents the key urban and environmental geospatial datasets used in the project. This structured representation helps in organizing spatial data systematically and supports accurate visualization and spatial analysis across different urban and environmental layers.

3.5 Solution Justification

The proposed 3D Geospatial Visualization System is justified by its ability to effectively handle, analyze, and visually represent complex urban and environmental datasets using data handling and visualization principles. By applying systematic data cleaning, CRS transformation, and spatial standardization, the system ensures high accuracy and reliability of geospatial data. The use of interactive 3D visualization techniques such as extrusion and thematic mapping enhances spatial understanding and interpretability compared to traditional 2D maps.

CHAPTER 4
RESULTS AND RECOMMENDATIONS

4.1 Evaluation of Results

The performance of the 3D Geospatial Visualization System for Urban and Environmental Data was evaluated using key data handling and visualization metrics. Notable outcomes include:

- **Data Accuracy:** Preprocessed datasets achieved high spatial accuracy and CRS consistency, reducing alignment errors across geospatial layers.
- **Visualization Performance:** The 3D models rendered smoothly with minimal lag, ensuring responsive interaction during zooming, panning, and rotation.
- **Analytical Effectiveness:** Spatial analysis and hotspot detection successfully identified urban density patterns and environmental risk zones with improved clarity.
- **User Interpretability:** Interactive 3D visualizations enhanced spatial understanding, enabling faster interpretation of complex urban and environmental patterns and supporting informed decision-making.

4.2 Challenges Encountered

The development of the 3D Geospatial Visualization System faced several technical and analytical challenges:

- **Large Geospatial Dataset Handling:** Processing high-resolution spatial data initially caused performance delays, which were addressed through data optimization and efficient preprocessing techniques.
- **CRS Inconsistencies:** Datasets from different sources used varying coordinate systems, requiring careful CRS transformation and validation.
- **Rendering Performance:** Ensuring smooth 3D visualization for dense urban models required optimization of rendering parameters.
- **Data Integration:** Integrating heterogeneous urban and environmental datasets demanded consistent data formats and structured preprocessing workflows.
- **Data Quality Issues:** Incomplete or missing spatial attributes required additional data cleaning and validation to maintain analytical accuracy.
- **Visualization Interpretability:** Designing 3D visualizations that were both visually clear and

easy to interpret required careful selection of color schemes, scales, and thematic representations.

4.3 Possible Improvements

Future enhancements for the system include:

- **AI-Based Spatial Prediction:** Applying machine learning models to predict urban growth and environmental risk trends.
- **Real-Time Data Integration:** Incorporating live sensor and satellite data for dynamic updates.
- **Enhanced 3D Interactivity:** Adding advanced navigation and animation features for better exploration.
- **Scalability Improvements:** Optimizing the system to handle larger geographic regions and higher data volumes.

4.4 Recommendations

For further development and wider practical adoption:

- **Phase-Wise Implementation:** Deploy the system across different urban regions to gather feedback and improve functionality.
- **Improved Data Quality Controls:** Strengthen validation and error-checking mechanisms for geospatial datasets.
- **Advanced Spatial Analytics:** Integrate predictive and simulation-based spatial models to support long-term planning decisions.
- **Standards Compliance:** Ensure alignment with national and international geospatial data standards for broader interoperability and usability.

CHAPTER 5
REFLECTION ON LEARNING AND PERSONAL DEVELOPMENT

5.1 Key Learning Outcomes

The development of the 3D Geospatial Visualization System for Urban and Environmental Data provided valuable academic, technical, and analytical learning experiences. The project strengthened the understanding of geospatial data handling, spatial preprocessing, and visualization techniques, and demonstrated their practical application in analyzing complex urban and environmental datasets through interactive 3D visual models.

5.1.1 Academic Knowledge

Through this project, a strong understanding of geospatial data structures, spatial reference systems, and urban–environmental datasets were gained. Concepts such as coordinate reference system (CRS), spatial data layers, thematic mapping, and hotspot analysis were studied and applied. The project also enhanced knowledge of data handling principles, spatial accuracy, and geospatial analytics used in urban planning and environmental monitoring.

5.1.2 Technical Skills

The project helped in developing technical skills related to geospatial data collection, cleaning, preprocessing, and visualization using R Studio. Practical experience was gained in handling spatial datasets, performing CRS transformations, and creating 2D and 3D visualizations.

5.1.3 Problem-Solving and Critical Thinking

Various challenges such as inconsistent spatial data formats, missing spatial attributes, and visualization performance issues were addressed during the project. Analytical thinking was applied to design efficient preprocessing workflows and clear 3D visual representations. The project enhanced the ability to analyze spatial data critically and derive actionable insights for decision-making.

5.2 Challenges Encountered and Overcome

During the development process, several challenges related to geospatial data quality, CRS inconsistencies, and visualization performance were encountered. These challenges were resolved through systematic data cleaning, spatial standardization, and iterative improvement of visualization techniques.

5.2.1 Personal and Professional Growth

Working on this project improved time management, self-learning, and adaptability. Independently designing and implementing a geospatial visualization system contributed to professional confidence and technical maturity.

5.2.2 Collaboration and Communication

The project involved discussions with peers and mentors to understand geospatial concepts, visualization requirements, and evaluation criteria. Effective communication helped in refining design choices and improving the overall quality of the visual outputs.

5.3 Application of Engineering Standards

Engineering principles such as modular design, systematic problem analysis, data accuracy, and documentation were applied throughout the project. The system was developed using structured design practices to ensure reliability, scalability, and clarity in geospatial visualization and analysis.

5.4 Insights into the Industry

The project provided insight into how urban planners, environmental agencies, and smart city initiatives use geospatial data analytics and visualization for planning and monitoring. It highlighted the growing importance of 3D visualization and data-driven decision-making in real-world urban and environmental management systems.

5.5 Conclusion on Personal Development

In conclusion, this project contributed significantly to both technical and personal development. It enhanced analytical skills, geospatial data handling expertise, and visualization proficiency. The experience gained will be valuable for future academic and professional endeavours in geospatial analytics, data visualization, and urban and environmental planning.

CHAPTER 6
PROBLEM-SOLVING AND CRITICAL THINKING

Developing a system that accurately handles large-scale urban and environmental geospatial data and presents meaningful 3D visual insights required strong analytical and problem-solving abilities. The project involved addressing challenges related to spatial data preprocessing, coordinate reference system (CRS) inconsistencies, large dataset handling, and 3D rendering performance. These challenges were managed through systematic data analysis, iterative refinement, optimization techniques, and careful visualization design.

6.1 Challenges Encountered and Overcome

6.1.1 Personal and Professional Growth

Managing large geospatial datasets, CRS transformations, and 3D visualization performance issues improved analytical thinking, patience, and problem-solving skills. The project helped in learning advanced techniques such as spatial data optimization, modular preprocessing workflows, and efficient 3D rendering strategies, contributing to overall professional growth.

6.1.2 Collaboration and Communication

Effective collaboration and communication were essential to understand geospatial requirements, visualization goals, and evaluation criteria. Regular discussions with peers and mentors helped in clarifying spatial concepts, improving visualization clarity, and refining analytical outputs, ensuring smooth project execution.

6.1.3 Application of Engineering Standards

The project followed structured engineering principles such as modular design, systematic problem analysis, and data accuracy assurance. Geospatial standards for CRS handling and visualization best practices were applied to ensure reliable, scalable, and interpretable visual outputs throughout the system.

6.1.4 Insights into the Industry

This project provided real-world exposure to how urban planners, environmental agencies, and smart city initiatives use geospatial analytics and 3D visualization for monitoring, planning, and decision-making. It highlighted the growing demand for data-driven spatial analysis in urban and environmental management.

6.1.5 Conclusion of Personal Development

The project significantly enhanced technical expertise in geospatial data handling, visualization, and spatial analysis. It strengthened confidence in working with complex datasets and pursuing future opportunities in geospatial analytics, data visualization, and urban and environmental planning.

6.1.6 Performance Table for 3D Geospatial Visualization System

To evaluate the effectiveness and efficiency of the 3D Geospatial Visualization System, several key performance indicators (KPIs) were analyzed. These KPIs measure data processing accuracy, visualization performance, system responsiveness, and user experience.

Table 6.1.6.1 Performance Metrics for 3D Geospatial Visualization System

Performance Metric	Description	Optimal Value / Target
Spatial Data Volume Handling	Ability to process large urban and environmental datasets	High-volume datasets without errors
CRS Accuracy	Correct alignment of spatial layers after CRS transformation	100% spatial consistency
3D Rendering Time	Time taken to render 3D visual models	≤ 3 seconds
Visualization Responsiveness	Smooth interaction during zoom, pan, and rotation	No noticeable lag
Spatial Analysis Accuracy	Precision in identifying spatial patterns and hotspots	High analytical accuracy

System Scalability	Ability to handle larger geographic regions	Linear scalability
Memory Utilization	Efficient use of system memory during processing	≤ 75% usage
Data Preprocessing Time	Time taken for cleaning and standardization	Optimized and stable
Visual Clarity	Readability of thematic and 3D maps	High clarity
System Stability	Stability during continuous visualization tasks	No crashes

Table 6.1.6.1 shows the key performance metrics used to evaluate the 3D Geospatial Visualization System for Urban and Environmental Data. The system effectively handles large volumes of urban and environmental spatial data while maintaining high accuracy and stability. Proper CRS transformation ensures complete spatial consistency across datasets. The 3D models are rendered within acceptable time limits, providing smooth and responsive interaction during zooming, panning, and rotation. Spatial analysis achieves high precision in identifying patterns and hotspot regions. Optimized memory usage and preprocessing time contribute to overall system stability. These results indicate that the system delivers scalable, visually clear, and reliable performance for effective geospatial analysis and decision-making.

CHAPTER 7
CONCLUSION

7.1 Key Findings and Impact

The development of the 3D Geospatial Visualization System for Urban and Environmental Data successfully addressed a critical need in urban planning and environmental monitoring: accurate, interactive, and interpretable representation of complex geospatial data. The system achieved

- Effective cleaning, preprocessing, and standardization of urban and environmental geospatial datasets.
- Accurate CRS transformation ensuring spatial consistency across data layers.
- Interactive and responsive 3D visualizations using extrusion and thematic mapping.
- Clear identification of spatial patterns and hotspot regions through spatial analysis.
- Improved decision-making support through visually intuitive geospatial insights.

Overall, the system demonstrated its effectiveness as a reliable tool for enhancing spatial understanding, analytical accuracy, and data-driven planning.

7.2 Value and Significance

This project highlighted the growing importance of data handling and visualization in urban and environmental applications. By applying structured preprocessing methods, geospatial standards, and advanced 3D visualization techniques, the solution establishes a strong foundation for future enhancements such as real-time data integration, predictive spatial modeling, and smart city applications.

Beyond technical contributions, the project significantly enriched personal and professional development by strengthening skills in geospatial analytics, problem-solving, visualization design, and systematic project implementation, making it highly relevant for future academic and professional work in geospatial and data visualization domains.

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APPENDICES

Appendix I

Sample Code

```
install.packages(c("shiny", "leaflet", "jsonlite"))
library(shiny)
library(leaflet)
library(jsonlite)
get_weather <- function(lat, lon) {
  url <- paste0(
    "https://api.open-meteo.com/v1/forecast?",
    "latitude=", lat,
    "&longitude=", lon,
    "&current=temperature_2m,relative_humidity_2m,wind_speed_10m"
  )
  data <- fromJSON(url)
  data$current
}
ui <- fluidPage(
  titlePanel("Global Urban & Environmental Data Viewer"),
  leafletOutput("map", height = "600px")
)
server <- function(input, output, session) {
  output$map <- renderLeaflet({
    leaflet() %>%
      addTiles() %>%
```

```
    setView(lng = 0, lat = 20, zoom = 2)
})
observeEvent(input$map_click, {
  lat <- input$map_click$lat
  lon <- input$map_click$lng
  weather <- get_weather(lat, lon)
  air <- get_air_quality(lat, lon)
  col <- aqi_color(air$pm2_5)
  popup_text <- paste0(
    "<b>Location</b><br>",
    "Latitude: ", round(lat, 4), "<br>",
    "Longitude: ", round(lon, 4), "<br><br>",
    "<b>Weather</b><br>",
    "Temperature: ", weather$temperature_2m, " °C<br>",
    "Humidity: ", weather$relative_humidity_2m, " %<br>",
    "Wind Speed: ", weather$wind_speed_10m, " km/h<br><br>",
    "<b>Air Quality</b><br>",
    "PM2.5: ", air$pm2_5, " µg/m³<br>",
    "PM10: ", air$pm10, " µg/m³"
  )
  leafletProxy("map") %>%
    clearMarkers() %>%
    addCircleMarkers(
      lng = lon,
      lat = lat,
```

```
        radius = 12,
        color = col,
        fillOpacity = 0.8,
        popup = popup_text
      )
 })
}
shinyApp(ui = ui, server = server)
get_air_quality <- function(lat, lon) {
  url <- paste0(
    "https://air-quality-api.open-meteo.com/v1/air-quality?",
    "latitude=", lat,
    "&longitude=", lon,
    "&current=pm2_5,pm10" )
  data <- fromJSON(url)
  data$current }
aqi_color <- function(pm25) {
  if (pm25 < 30) {
    "green"
  } else if (pm25 < 60) {
    "orange"
  } else {
    "red"
  }
}
```

Appendix II

Sample Output

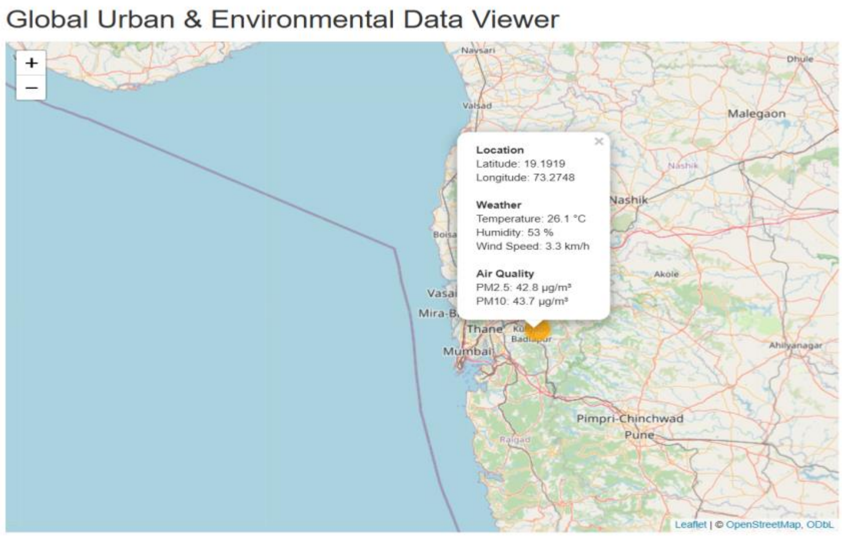

Fig. A.1. Interactive Urban and Environmental Geospatial Visualization Dashboard

Figure A.1 illustrates an interactive geospatial visualization dashboard displaying urban and environmental data for a selected location. The map shows geographic position along with real-time information such as latitude and longitude, weather conditions, and air quality indicators including PM2.5 and PM10 levels. This visualization supports effective spatial analysis, environmental monitoring, and data-driven decision-making through an intuitive map-based interface.

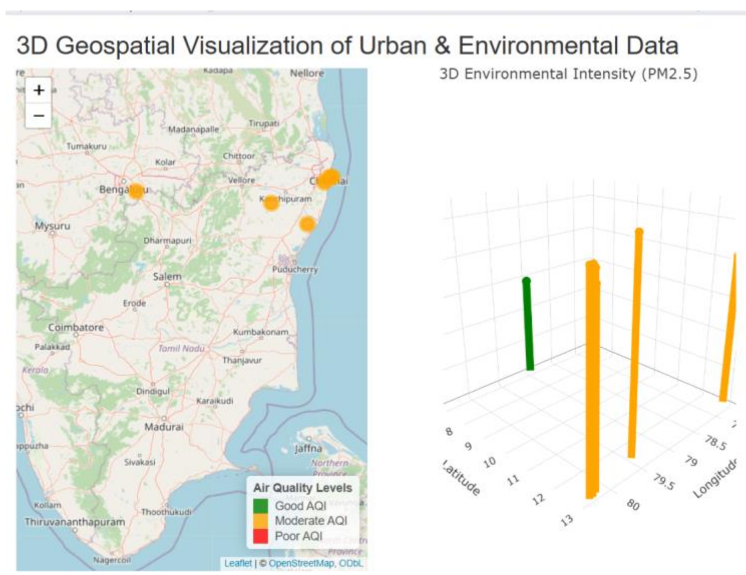

Fig. A.2. 3D Urban Air Quality Visualization Output

The figure A.2 presents the final output of the project, combining interactive 2D maps and 3D visualization to represent urban and environmental air quality data. Geographic locations are mapped with corresponding PM2.5 intensity levels, displayed as vertical 3D bars, enabling clear comparison, spatial analysis, and effective interpretation of environmental conditions.

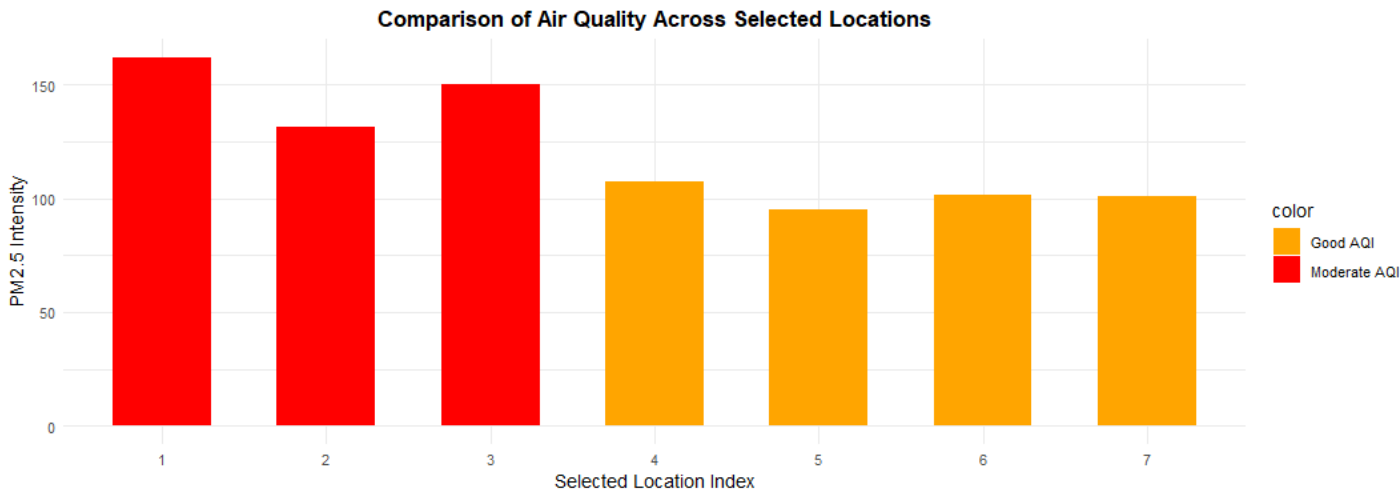

Fig. A.3. Comparison of Air Quality Across Selected Locations

The figure A.3 illustrates a bar chart comparing PM2.5 air quality intensity across selected locations. Each bar represents a location index, with color coding used to distinguish air quality categories such as moderate and good AQI levels. The chart enables easy comparison of pollution intensity across different urban locations, supporting environmental analysis and decision-making.