ENHANCING INFRASTRUCTURE ASSET MANAGEMENT IN ADAMA CITY THROUGH GEOSPATIAL TECHNOLOGY

Nafilet Demisse

A Thesis Submitted to the department of Architecture

College of Civil Engineering and Architecture (CoCEA),

Presented in Partial Fulfillment of the Requirement for the Degree of
Master's in Geoinformatics Engineering

Office of Graduate Studies
Adama Science and Technology University

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Enhancing Infrastructure Asset Management in Adama City through Geospatial technology

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DECLARATION

I declare hereby that this Master Thesis entitled" Enhancing Infrastructure Asset Management in Adama City through Geospatial technology" is my original work. That is, it has not been submitted for the award of any academic degree, diploma or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation.

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Name of Candidate	Signature	Date

RECOMMENDATION

We, the advisor(s) of this thesis, hereby certify that we have read and revised version of thesis entitled" Enhancing Infrastructure Asset Management in Adama City through Geospatial technology". Prepared under our guidance by Nafilet Demisse submitted in partial fulfillment of the requirements for the degree of Masters of Science in Geo-informatics Engineering. Therefore, we recommend the submission of revised version of the thesis to department following the applicable procedures.

Major Advisor	Signature	Date

APPROVAL SHEET

We, the advisors of the thesis entitled "Enhancing Infrastructure Asset Management in Adama City through Geospatial technology". And developed by Nafilet Demisse by certify that the recommendation and suggestions made by the board of examiners are appropriate incorporated into the final version of the thesis.

Major Advisor	Signature	Date
Co-advisor	Signature	Date

We, the undersigned, members of the Board of Examiners of the thesis by Nafilet Demisse have read and evaluated the thesis entitled "Enhancing Infrastructure Asset Management in Adama City through Geospatial technology".And examined the candidate during open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in Geo-informatics Engineering.

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Finally, approval and acceptance of thesis is contingent upon submission of its final copy to the Office of Postgraduate Studies (OPGS) through the Department Graduate Council (DGC) and College Graduate Committee (CGC).

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LIST OF ACRONYMS

ISO	International Organization for Standardization
IMA	Infrastructure Asset Management
GIS	Geographic Information System
GPS	Global Positioning System
OSS	Open-source software
OSM	Open street map
QGIS	Quantum GIS
RS	Remote Sensing
USGS	United States Geological Survey
UN	United Nation
WEBGIS	Web based Geographic Information System

ABSTRACT

Effective infrastructure asset management is crucial for sustainable urban development, especially in rapidly expanding cities like Adama, Ethiopia. Conventional methods for managing infrastructure assets often fall short in terms of accuracy, efficiency, and real-time data integration. Adama City, similar to many urban environments, confronts significant challenges in managing its infrastructure inventory and assets, which are essential for the city's operational efficiency and maintenance. Recent evaluations show that over 40% of the city's infrastructure data is outdated or inaccurate, hindering effective management and decision-making processes. The primary aim of this research is to enhance infrastructure asset management in Adama City through the development and implementation of a geospatial technology-based approach for data collection, integration, analysis, and decision-making. The methodology involves collecting both primary and secondary data, selecting assessment indicators, identifying gaps, analyzing requirements, and developing a spatial database for data integration and sharing. The findings of the research identify specific areas within the infrastructure asset management system that require enhancement. Key components such as the inventory system, data storage and management, road condition assessments, and infrastructure asset information systems are highlighted for improved performance. A spatial database model was created and tested specifically for Adama City's infrastructure asset management system. Additionally, to enhance accessibility and foster collaboration, a web mapping application was developed using the QGIS2 web plugin. The implementation of these technologies can empower city administrators to shift from reactive to proactive asset management, optimize resource allocation, and support sustainable urban development. The study concludes with recommendations for the institutional adoption of geospatial systems, capacity building, and policy integration to ensure long-term infrastructure resilience in Adama City.

Keywords: Infrastructure, Asset Management, Geospatial technology, Web Mapping

CHAPTER I: INTRODUCTION

1.1. BACKGROUND OF THE STUDY

Infrastructure is crucial for the economic and social development of urban areas, serving as the backbone for essential services such as transportation, water supply, and energy distribution. Effective infrastructure asset management (IAM) is vital for ensuring the sustainability and efficiency of these systems, especially in rapidly growing cities. IAM involves the planning, acquisition, operation, maintenance, and disposal of infrastructure assets, which are essential for optimizing resource allocation and enhancing service delivery (Mao et al., 2019).

Advancements in geospatial technologies, data analytics, and real-time monitoring systems have significantly transformed traditional IAM practices. These modern tools enable improved data collection, integration, and analysis, facilitating informed decision-making and proactive management strategies (Zhang et al., 2021). As urban populations continue to grow, the adoption of these technologies in IAM becomes increasingly critical, allowing cities to better manage their infrastructure and adapt to changing demands (Kumar & Kumar, 2020). Integrating innovative technologies is not simply a trend; it is necessary for achieving long-term infrastructure resilience and sustainability.

In the context of developing cities like Adama, Ethiopia, this research aims to explore the implications of current technological advancements in IAM and their potential to address urban challenges. The efficient management of infrastructure assets is essential for sustainable growth and the effective operation of urban areas (World Bank, 2016). Adama City faces significant difficulties in maintaining an up-to-date inventory and managing its infrastructure resources effectively (Addisu et al., 2019). Examples of infrastructure management failures include frequent road maintenance delays that lead to poor road conditions and increased traffic congestion, as well as inadequate drainage systems resulting in flooding during rainstorms. These challenges highlight the urgent need for a systematic approach to infrastructure management.

With ongoing urbanization and population growth, the demand for infrastructure services continues to rise, placing additional strain on existing assets (UN, 2014). Therefore, exploring innovative approaches to enhance infrastructure inventory and asset management practices in Adama City is critical.

This research thesis investigates the potential of using open-source Geographic Information System (GIS) tools to tackle the infrastructure inventory and asset management challenges faced by Adama City. GIS is a powerful technology that combines spatial data with attribute information, providing a comprehensive platform for analyzing, visualizing, and managing infrastructure assets (Longley et al., 2015). Open-source GIS tools like QGIS and OpenStreetMap have gained popularity due to their cost-effectiveness, adaptability, and community-driven development (Kitchin & McArdle, 2016).

Cities such as Kigali, Rwanda, and Medellín, Colombia, have successfully implemented GIS technologies to enhance their infrastructure management, demonstrating improved data accuracy and effective urban planning, which leads to better-maintained infrastructure and increased public satisfaction. By learning from these examples, Adama City can adopt similar strategies to address its infrastructure challenges.

By leveraging open-source GIS tools, this study aims to enhance decision-making processes, optimize resource distribution, and ensure the long-term sustainability of infrastructure assets in Adama City. The use of GIS can streamline data integration, allowing city authorities to maintain an updated inventory and ensure precise asset management (Yuan et al., 2019). Additionally, GIS analysis can provide spatial insights into infrastructure conditions and future requirements (Jia et al., 2021), assisting in prioritizing maintenance and investment decisions for more efficient resource allocation.

Furthermore, adopting open-source GIS tools can promote collaboration and knowledge sharing among various stakeholders, including city officials, planners, engineers, and the public (Chen et al., 2020). These tools facilitate the creation of shared platforms and the integration of diverse datasets, enhancing transparency and engagement in infrastructure management processes (Kitchin & McArdle, 2016). Public involvement in infrastructure decision-making leads to more informed choices that align with community needs (Goodchild, 2007).

Traditional IAM techniques often fail to provide the spatial insights necessary to understand the geographic distribution, connectivity, and performance of infrastructure networks. This can result in premature deterioration of systems, unreliable public services, and planning decisions made without a comprehensive understanding of existing assets and service gaps.

1.2. STATEMENT OF THE PROBLEM

Adama City, like many urban areas, faces significant challenges in effectively managing its infrastructure inventory and assets, which are vital for the city’s efficient operation and maintenance. Recent assessments indicate that over 40% of the city's infrastructure data is outdated or inaccurate, hampering effective management and decision-making (Merga & Behulu, 2019). The geodatabase was not updated frequently even once in a year. The existing infrastructure management system is plagued by deficiencies, including incomplete data, limited technological integration, and a lack of systematic frameworks. For instance, a recent report highlighted that the city lacks a comprehensive inventory, which directly impedes the prioritization of maintenance, repair, and replacement activities.

Moreover, Adama City currently lacks essential geospatial tools, such as open-source Geographic Information System (GIS) applications, which are crucial for efficient data analysis and visualization (Admasu et al., 2019). The absence of an integration framework for these tools restricts data sharing, synchronization, and analysis, leading to fragmented infrastructure management (Alok, 2016). This fragmentation is exacerbated by the lack of a GIS-based asset management system, which limits the city’s ability to implement effective and cost-efficient infrastructure management practices (Richard & Iguisi, 2016).

The core problem lies in the inadequate integration of infrastructure management and data sharing among various agencies, including water, electricity, and telecommunications providers. Each agency operates independently, resulting in a lack of coordination and increased inefficiencies. For example, the failure to consider interdependencies between these systems often leads to redundant efforts and suboptimal decision-making in infrastructure planning (Bazilian et al., 2011).

Data sharing remains a significant challenge as agencies tend to maintain their data in silos, which restricts accessibility and inhibits informed decision-making. This disconnection becomes particularly problematic during emergencies or when planning infrastructure upgrades, as effective coordination relies on shared, up-to-date information

(Amos et al., 2020). Consequently, these issues contribute to increased costs, service disruptions, and delays in delivering essential services to residents and businesses.

There is a pressing need to transition from conventional asset management practices to a more data-driven, spatially aware approach. Geospatial technologies such as Geographic Information Systems and remote sensing, tools to map, monitor, and analyze infrastructure assets in real time. Despite their proven effectiveness, these technologies remain underutilized in Adama City's urban planning and infrastructure management processes.

This study seeks to address exploring how geospatial technology can enhance infrastructure asset management, support proactive maintenance planning, and improve service delivery in Adama City. This research is timely and necessary, as no prior studies have focused on enhancing Adama City's infrastructure asset management system using modern frameworks and open-source software solutions. The adoption of GIS technology can address existing gaps, streamline operations, and foster collaboration among agencies, ultimately leading to more efficient and effective management of the city's infrastructure assets.

1.3 Objective

General Objective.

The general objective of this research is to improve infrastructure asset management in Adama City by developing and implementing a Geospatial technology-based approach for data collection, integration, analysis, and decision-making.

Specific Objective

1. To assess the current practices, challenges, and limitations of infrastructure asset Management in Adama City.
2. To design a spatial database model for managing infrastructure asset data using Geospatial technology
3. To develop a prototype GIS-based asset management system tailored to the needs of Adama City.
4. To demonstrate how geospatial technology can enhance data integration, sharing, and decision-making among infrastructure-related agencies

1.4 RESEARCH QUESTIONS

1. What are the current practices, challenge and limitation of infrastructure inventory and asset management practices in Adama City?
2. How can a spatial database model be designed to enhance the efficiency of infrastructure data management in Adama City?
3. How can a prototype GIS-based asset management system be developed to meet the specific needs of Adama City.
4. Which open-source geospatial applications can be utilized to increase data inventory, sharing efficiency and decision making among infrastructure-related agencies

1.5 SIGNIFICANCE OF THE STUDY

This research is of great importance to Adama City and other urban areas grappling with infrastructure inventory and asset management challenges. By tackling the shortcomings of existing systems and incorporating open-source Geographic Information System (GIS) tools, the study aims to provide substantial benefits. Primarily, it seeks to enhance decision-making in infrastructure management by offering accurate and current information on the city’s assets. This will empower infrastructure managers and city officials to prioritize maintenance, repair, and replacement activities based on reliable data, leading to more effective resource allocation and improved infrastructure performance. Additionally, the implementation of a GIS-based asset management system will optimize resource utilization by efficiently monitoring infrastructure assets and identifying areas that require immediate attention, thus ensuring that limited resources are directed toward critical needs.

Moreover, the integration of open-source GIS tools will support better planning and development strategies, facilitating evidence-based decision-making for future infrastructure projects aligned with the city’s growth patterns. This approach promotes sustainable urban development practices and enhances local infrastructure management, which can inform broader national strategies and policies. The research also highlights the significance of data sharing and collaboration among stakeholders, as the integration of GIS tools fosters better coordination and knowledge exchange, ultimately improving overall management practices. Furthermore, a GIS-based asset management system can yield cost savings and operational efficiencies by enabling proactive maintenance, reducing infrastructure downtime, and ensuring that investments are used effectively. The findings and recommendations from this research will not only benefit Adama City but also provide transferable knowledge and best practices for other municipalities facing similar challenges, thereby contributing to overall urban development and influencing national infrastructure planning and policy formulation

1.6 SCOPE OF THE STUDY

This research thesis focuses on evaluating and enhancing infrastructure inventory and asset management practices in Adama City. It specifically addresses the challenges the city faces in maintaining an accurate and up-to-date inventory of its infrastructure assets. The study emphasizes the integration of open-source Geographic Information System (GIS) tools to improve decision-making and optimize resource allocation within this context.

The scope is confined to the practices of infrastructure inventory and asset management within Adama City and does not extend to broader urban planning or policy issues that are not directly related to infrastructure management. By concentrating on these specific areas, the research aims to provide targeted insights and solutions that can significantly improve the city's infrastructure management practices.

CHAPTER II: LITERATURE REVIEW

2.1. GIS Applications in Infrastructure Management

GIS (Geographic Information System) has gained widespread recognition as a valuable tool for infrastructure management. Li et al. (2018) emphasize that GIS enables the integration of spatial data with other relevant information, which in turn facilitates various aspects of infrastructure management, including analysis, monitoring, and decision-making processes. By incorporating spatial data, GIS provides a comprehensive and visual representation of infrastructure assets and their associated attributes.

The successful implementation of GIS-based systems in various cities globally has demonstrated their effectiveness in improving infrastructure management practices. Albrecht et al. (2016) conducted a study that showcased the benefits of GIS in enhancing infrastructure management. These systems have been utilized to streamline data collection, analysis, and visualization processes, leading to more informed decision-making and improved operational efficiency.

One of the key advantages of GIS in infrastructure management is its ability to integrate spatial data from different sources. Spatial data includes information such as geographical boundaries, locations of infrastructure assets, and associated attributes like condition, age, and maintenance history. By incorporating this spatial information into a GIS-based system, infrastructure managers can gain a holistic view of their assets and effectively analyze their current state. Moreover, GIS allows for real-time monitoring of infrastructure assets. By integrating sensor data, remote sensing technologies, and other monitoring tools, GIS-based systems enable infrastructure managers to track the condition and performance of assets. This real-time monitoring capability helps identify potential issues or anomalies promptly, allowing for proactive maintenance and minimizing the risk of failures or disruptions (Jia et al 2021).

Additionally, GIS provides a platform for data-driven decision-making in infrastructure management. By analyzing spatial data and generating visualizations, GIS enables infrastructure managers to identify patterns, trends, and correlations that may not be apparent in tabular data alone. This information can support informed decision-making processes regarding maintenance prioritization, resource allocation, and long-term planning.

In conclusion, GIS has been widely recognized as a valuable tool for infrastructure management. It allows for the integration of spatial data with other relevant information, facilitating analysis, monitoring, and decision-making processes. The successful implementation of GIS-based systems in various cities globally has demonstrated their effectiveness in improving infrastructure management practices. By harnessing the power of GIS, infrastructure managers can make more informed decisions, optimize resource allocation, and enhance the overall efficiency of infrastructure management (Ettouney et al 2019).

In Kenya, GIS has been effectively used to create detailed inventories of urban infrastructure, such as roads, water supply systems, and public facilities. For instance, the Nairobi City County has implemented GIS to map its infrastructure assets, which has improved the management and maintenance of these assets by providing accurate spatial data for decision-making). This approach allows city planners to prioritize maintenance activities based on the condition and usage of infrastructure, leading to more efficient resource allocation(Bazilian et al., 2011).

Similarly, in Uganda, GIS applications have been employed to manage infrastructure in cities like Kampala. The Kampala Capital City Authority has utilized GIS to develop a comprehensive database of urban infrastructure, which aids in planning and monitoring urban development projects. This system enables the identification of infrastructure gaps and facilitates better planning for future expansions (Jia et al 2021).

One of the significant challenges in infrastructure management in developing countries is the fragmentation of data across various agencies. GIS promotes data sharing and collaboration among stakeholders. In Kenya, initiatives have been launched to create centralized GIS databases that integrate information from different government departments, enhancing coordination and reducing duplication of efforts in infrastructure management(Peng & Tsou, 2003)..

In Uganda, the establishment of a national GIS platform has facilitated the sharing of infrastructure data among various stakeholders, including government agencies, NGOs, and the private sector. This collaborative approach has improved the overall efficiency of urban infrastructure management.

2.2. Data Collection Techniques for Infrastructure Inventory and Asset Management

Efficient data collection techniques are essential for establishing accurate and up-to-date infrastructure inventories and asset management systems. Research by Li et al. (2017) emphasizes the significance of integrating remote sensing technologies, such as LiDAR (Light Detection and Ranging) and aerial imagery, in infrastructure data collection processes. LiDAR enables high-resolution 3D mapping of infrastructure assets, allowing organizations to accurately survey and inventory assets like roads, bridges, and utilities. By combining LiDAR data with aerial imagery and Geographic Information System (GIS) technologies, organizations can enhance asset visibility, streamline data collection workflows, and improve decision-making processes for infrastructure maintenance and asset management.

In addition to remote sensing technologies, mobile mapping systems have emerged as valuable tools for collecting real-time spatial data for infrastructure inventory and asset management purposes. Research by Fan et al. (2019) highlights the benefits of using mobile mapping platforms equipped with GPS, cameras, and sensors to capture geospatial information while on the move. Mobile mapping systems enable field personnel to collect asset data, assess asset conditions, and update inventory databases directly from the field, reducing manual data entry errors and improving data accuracy. By leveraging mobile mapping technologies, organizations can increase operational efficiency, enhance data quality, and expedite asset management workflows for timely maintenance interventions and informed decision-making.

Furthermore, the integration of Internet of Things (IoT) devices and sensors in data collection processes offers opportunities for real-time asset monitoring and condition assessment in infrastructure asset management. Research by Zhang et al. (2020) explores the use of IoT devices embedded in infrastructure assets to collect performance data, monitor asset health, and detect anomalies that may indicate potential failures. By deploying IoT sensors for structural health monitoring, vibration analysis, and environmental sensing, organizations can gather real-time data on asset conditions, predict maintenance needs, and prioritize interventions to ensure the longevity and reliability of critical infrastructure assets. The utilization of IoT devices in data collection enhances asset visibility, enables predictive maintenance strategies, and supports proactive asset management practices for sustainable infrastructure performance. The feasibility of using technologies such as LiDAR for data collection for cities like Adama depends on their cost and the requirement for training on their operation.

2.3. Database Design, Spatial Databases, Database Management Systems and Web Mapping

The effective management and utilization of data are pivotal in infrastructure asset management and decision-making processes. Database design, spatial databases, and database management systems (DBMS) are critical components for organizing, storing, and retrieving the vast amounts of data generated by infrastructure assets and associated systems. Database design, as outlined by Elmasri & Navathe (2016), involves creating a structured system for data storage and management by identifying data entities, relationships, and appropriate data models. Spatial databases, specialized systems for geospatial data storage, as emphasized by Worboys & Duckham (2004), are crucial for managing spatial characteristics like location and shape. The choice of DBMS, such as relational or object-oriented systems (Date, 2006), is essential for effective data storage, querying, and transaction management. Integrating these elements is vital for infrastructure asset management, combining spatial data storage with efficient data organization and analysis capabilities (Worboys & Duckham, 2004; Rigaux et al., 2002).

The integration of advanced database technologies like cloud-based DBMS and NoSQL databases can enhance scalability and analytical capabilities in infrastructure asset management systems (Silberschatz et al., 2020; Elmasri & Navathe, 2016). These technologies enable the integration of diverse data sources, handling large data volumes and facilitating sophisticated decision-support tools. Web GIS, an amalgamation of GIS capabilities with web-based technologies, is a powerful tool for infrastructure asset management, allowing centralized storage and dissemination of asset data (Peng & Tsou, 2003). Web GIS, by integrating various data sources and offering advanced analytical tools, enables spatially-enabled views of assets, aiding in informed decision-making and optimized asset management strategies. The web-based nature of Web GIS supports real-time data updates, remote access, and collaborative decision-making, enhancing transparency and public engagement in decision processes (Peng & Tsou, 2003).

The amalgamation of web mapping technologies with infrastructure asset management systems, particularly through open-source tools and frameworks, has garnered attention for enhancing data visualization, accessibility, and decision-making processes (Smith et al., 2020). Incorporating web mapping facilitates spatial data visualization concerning asset locations, conditions, and performance indicators, improving monitoring and maintenance planning strategies (Jones & Brown, 2019). Open-source tools like OpenLayers and Leaflet offer flexibility for constructing interactive maps, while frameworks such as GeoServer provide advanced geospatial functionalities for data visualization and analysis (Johnson, 2021). By integrating spatial data with asset management systems through web mapping, stakeholders gain a spatial context for asset data, aiding in pattern recognition, trend analysis, and maintenance issue identification (Brown & Clark, 2017). While challenges like data interoperability and user training may arise, leveraging open-source solutions can offer cost-effective, customizable solutions aligned with specific asset management needs (Garcia et al., 2019).

Web Geographic Information Systems (Web GIS) are increasingly recognized as effective tools for enhancing public engagement and fostering collaboration among non-governmental organizations (NGOs) in areas such as urban planning and disaster management. By allowing users to visualize and interact with spatial data, Web GIS empowers citizens to participate actively in decision-making processes. This participatory approach not only increases transparency but also cultivates a sense of community ownership over local issues, enabling residents to provide valuable feedback on proposed developments(Peng & Tsou, 2003)..

In addition to enhancing public participation, Web GIS serves as a collaborative platform for various stakeholders, including government agencies and NGOs. By integrating diverse datasets, these platforms facilitate the sharing of information and coordination of efforts, particularly in crisis situations like natural disasters. The ability to create shared situational awareness among responders and NGOs allows for more effective and timely interventions, highlighting the importance of collaboration in addressing complex challenges (Peng & Tsou, 2003).

While the benefits of Web GIS are significant, challenges such as data privacy concerns, the digital divide, and the need for ongoing training must be addressed to maximize its effectiveness. Ensuring the accuracy and reliability of the data presented is also crucial, as misinformation can lead to public distrust. Overall, the continued development of Web GIS technologies holds great potential for fostering inclusive stakeholder engagement, ultimately leading to more informed and sustainable decision-making in various sectors (Johnson, 2021).

2.4. OPEN-SOURCE GIS TOOLS

Open-source GIS tools have emerged as valuable resources for infrastructure management, offering cost-effective and customizable solutions. Kuo et al. (2017) highlight several advantages of open-source GIS tools, including their flexibility, interoperability, and community-driven development. One of the key advantages of open-source GIS tools is their flexibility. Unlike proprietary software, open-source tools can be customized and tailored to meet specific needs and requirements of infrastructure management projects.

This flexibility allows infrastructure managers to adapt the tools to their unique workflows and integrate them seamlessly into existing systems.

Interoperability is another significant advantage of open-source GIS tools. These tools are designed to support various data formats and standards, enabling the integration of diverse datasets from different sources. This interoperability promotes data sharing and collaboration among stakeholders involved in infrastructure management. It also facilitates the integration of spatial data with non-spatial data, enhancing the overall analysis and decision-making processes (Karas et al 2019).

Community-driven development is a distinguishing characteristic of open-source GIS tools. Developers and users from around the world contribute to the improvement and enhancement of these tools through collaborative efforts. This collective input leads to continuous updates, bug fixes, and the development of new features. The active community support ensures that open-source GIS tools remain up-to-date, reliable, and responsive to the evolving needs of infrastructure management.

Open-source platforms such as QGIS and OpenLayers have gained popularity in the field of infrastructure management. QGIS, for example, offers a user-friendly interface and a wide range of functionalities, making it accessible to users with varying levels of GIS expertise. It provides tools for data visualization, spatial analysis, and data editing, empowering infrastructure managers to efficiently work with their geospatial data. Similarly, Open Layers is an open-source JavaScript library that enables the integration of interactive maps into web applications. It provides a versatile platform for displaying and interacting with geospatial data online, making it a valuable tool for sharing infrastructure information and engaging stakeholders (Jiang et al, 2020).

The adoption of open-source tools for infrastructure asset management systems offers numerous advantages, including cost-effectiveness and flexibility. However, several barriers can hinder their effective implementation. One significant challenge is the lack of technical expertise among users, which can limit the ability to fully leverage these tools. Research indicates that insufficient training and knowledge gaps often result in underutilization of open-source technologies, leading to suboptimal asset management outcomes(Johnson, 2021). . Additionally, organizational resistance to change and a lack of institutional support can further exacerbate these challenges, making it difficult for stakeholders to transition from traditional systems to open-source alternatives.

To overcome these barriers, targeted capacity-building strategies are essential. One effective approach is the development of tailored training programs that focus on both technical skills and practical applications of open-source tools. By providing hands-on workshops and access to learning resources, organizations can empower users to gain confidence in utilizing these technologies. Furthermore, fostering a culture of collaboration among stakeholders—from government agencies to local communities—can enhance knowledge sharing and collective problem-solving. Research suggests that community-driven initiatives, where users actively contribute to the development and improvement of open-source tools, can significantly enhance engagement and ownership, leading to more sustainable usage(Karas et al 2019).

Moreover, ensuring ongoing support and mentorship is crucial for maintaining momentum in capacity building. Establishing partnerships with educational institutions or technology experts can provide users with continuous access to resources and guidance. Additionally, creating user communities or forums can facilitate peer-to-peer learning and encourage the exchange of best practices. By addressing the technical, organizational, and social dimensions of capacity building, stakeholders can better harness the potential of open-source tools for effective infrastructure asset management, ultimately leading to improved service delivery and resource optimization (Peng & Tsou, 2003).

In conclusion, open-source GIS tools offer cost-effective and customizable solutions for infrastructure management. Their flexibility, interoperability, and community-driven development make them attractive options for infrastructure managers seeking efficient and tailored solutions. Platforms such as QGIS and Open Layers have gained popularity due to their user-friendly interfaces and extensive functionality. By leveraging these open-source tools, infrastructure managers can enhance their data analysis, visualization, and decision-making capabilities.

2.5. Infrastructure Inventory and Asset Management

Efficient inventory and asset management practices are crucial for maintaining infrastructure systems. Moeckel and Wilson (2016) emphasize the importance of accurate and up-to-date inventory data in enabling effective decision-making in infrastructure management.

GIS-based asset management systems have proven to be valuable tools for monitoring, evaluating, and prioritizing maintenance and repair activities. Kamp et al. (2017) highlight the benefits of using GIS in asset management, particularly in the context of infrastructure systems.

One of the key advantages of GIS-based asset management systems is their ability to provide a comprehensive and visual representation of infrastructure assets. By integrating spatial data with other relevant information, such as asset attributes, condition assessments, and maintenance history, GIS enables infrastructure managers to have a complete overview of their assets. This holistic view helps in identifying critical assets, assessing their performance, and making informed decisions regarding maintenance and repair activities.

GIS-based asset management systems also support better monitoring of infrastructure assets. By utilizing real-time data feeds, sensor networks, and remote sensing technologies, these systems enable infrastructure managers to track the condition and performance of assets continuously. This real-time monitoring capability helps detect anomalies or potential issues promptly, allowing for proactive maintenance interventions and minimizing the risk of failures or disruptions (Kuo et al , 2017).

Furthermore, GIS facilitates the evaluation and prioritization of maintenance and repair activities. By analyzing spatial data and generating visualizations, GIS-based asset management systems enable infrastructure managers to identify patterns, trends, and correlations related to asset performance, deterioration, and usage. This information helps prioritize maintenance activities based on asset criticality, condition, and anticipated future demands. Moreover, GIS-based asset management systems support data integration and interoperability. They can integrate data from various sources, including internal databases, external datasets, and real-time monitoring systems. This integration enhances the accuracy and completeness of inventory data, enabling more robust decision-making processes(Longley et al 2015).

Effective inter-agency coordination is essential for successful infrastructure asset management, particularly in complex urban environments. Geographic Information Systems (GIS) have emerged as vital tools for facilitating communication and collaboration among various stakeholders, including government agencies, NGOs, and private sector entities. GIS enables the integration of diverse datasets, providing a comprehensive view of infrastructure assets that enhances decision-making processes. Studies have shown that GIS can significantly improve inter-agency coordination by fostering data sharing and reducing redundancy in infrastructure planning and management efforts(Peng & Tsou, 2003) . For instance, in the context of urban planning, GIS platforms allow different agencies to visualize and analyze the spatial relationships of various infrastructure components, leading to more coherent and coordinated development strategies.

In addition to enhancing data sharing, GIS supports real-time communication among agencies involved in infrastructure management. By providing a common platform for monitoring asset conditions and maintenance needs, GIS enhances situational awareness and facilitates timely responses to emerging issues. Research highlights the effectiveness of GIS in disaster management scenarios, where multiple agencies must collaborate to respond to emergencies. For example, during natural disasters, GIS tools enable agencies to assess damage, allocate resources efficiently, and coordinate relief efforts, ultimately improving the effectiveness of response initiatives . This capability underscores the importance of GIS in creating a unified approach to infrastructure asset management, ensuring that all stakeholders are informed and aligned in their efforts(Kuo et al , 2017)..

Despite the benefits, implementing GIS-supported inter-agency coordination frameworks is not without challenges. Barriers such as data privacy concerns, varying levels of technical expertise among agencies, and institutional resistance to change can hinder effective collaboration. To address these challenges, strategic initiatives are needed to promote training and capacity building, as well as to establish protocols for data sharing and integration. Research suggests that creating formal inter-agency partnerships and developing standardized GIS practices can facilitate smoother collaboration and enhance the overall effectiveness of infrastructure asset management systems . By leveraging GIS as a central tool for inter-agency coordination, stakeholders can optimize resource management and improve service delivery in urban infrastructure systems(Longley et al 2015).

In conclusion, efficient inventory and asset management practices are essential for maintaining infrastructure systems. Accurate and up-to-date inventory data is crucial for effective decision-making. GIS-based asset management systems provide a comprehensive and visual representation of infrastructure assets, supporting better monitoring, evaluation, and prioritization of maintenance and repair activities. By leveraging GIS technology, infrastructure managers can optimize their asset management practices, leading to improved operational efficiency and resource allocation

2.6. Practices in Infrastructure Inventory and Asset Management

Infrastructure inventory and asset management play crucial roles in ensuring the sustainability and efficiency of public and private infrastructure systems. Best practices in this domain encompass a range of strategies, methodologies, and technologies aimed at optimizing the performance, maintenance, and decision-making processes associated with infrastructure assets. Research by Kumar et al. (2016) emphasizes the importance of adopting a data-driven approach to infrastructure asset management, where organizations leverage Geographic Information System (GIS) technologies for asset inventory, condition assessment, and predictive maintenance planning. By integrating GIS with asset management systems, organizations can enhance asset monitoring, optimize maintenance strategies, and prioritize resource allocation to extend the lifespan of critical infrastructure assets, promoting cost savings and operational efficiency.

Effective infrastructure inventory and asset management practices also involve the implementation of risk-based asset management strategies to proactively address asset vulnerabilities and ensure the resilience of infrastructure systems. According to Smith et al. (2018), risk-based asset management frameworks enable organizations to assess asset risks, prioritize maintenance interventions, and allocate resources based on asset criticality and potential failure consequences. By conducting risk assessments and developing asset management plans that account for varying levels of risk exposure, organizations can enhance asset performance, reduce downtime, and improve public safety, demonstrating the significance of risk-informed decision-making in infrastructure asset management.

Moreover, the adoption of asset performance management (APM) frameworks and advanced analytics tools has emerged as a best practice in infrastructure asset management, enabling organizations to monitor asset health, predict failures, and optimize maintenance schedules to maximize asset reliability and operational efficiency. Research by Wang et al. (2019) highlights the benefits of integrating predictive analytics and machine learning algorithms with asset management systems to forecast asset performance, detect anomalies, and recommend proactive maintenance actions. By harnessing the power of data analytics and real-time monitoring technologies, organizations can move towards predictive maintenance strategies, minimize asset downtime, and enhance the overall lifecycle management of infrastructure assets, illustrating the transformative impact of APM practices on infrastructure sustainability and operational excellence.

Infrastructure management practices globally have evolved through the adoption of innovative strategies and technologies that address various challenges. Best practices, such as integrated asset management frameworks, data-driven decision-making, and stakeholder engagement, have been effectively implemented in developed countries. For instance, the use of Geographic Information Systems (GIS) for asset management has been widely adopted in cities like Singapore and Amsterdam, where real-time data and analytics support proactive maintenance and efficient resource allocation. However, these practices often face unique local challenges when applied in developing contexts, such as limited financial resources, varying levels of technical expertise, and inadequate institutional frameworks (Longley et al 2015).

To effectively adapt global best practices to local realities, it is crucial to consider the specific socio-economic and cultural contexts of each region. Local challenges, such as insufficient infrastructure funding and lack of skilled personnel, necessitate customized solutions that may involve scaling down certain practices or modifying their implementation. For example, while advanced GIS tools may be effective in developed nations, developing countries might benefit from simpler, cost-effective alternatives that still allow for data collection and analysis. Additionally, fostering community involvement in infrastructure management can enhance accountability and ensure that local needs are met, as evidenced by participatory budgeting initiatives in cities like Porto Alegre, Brazil . This approach not only empowers residents but also builds trust in local governance(Kuo et al , 2017)..

Furthermore, successful adaptations of global best practices often involve collaborative approaches that engage multiple stakeholders, including government agencies, private sector partners, and civil society organizations. Establishing multi-stakeholder platforms can facilitate knowledge sharing and co-create solutions that are sensitive to local contexts. For instance, public-private partnerships (PPPs) have been effective in various regions, enabling resource sharing and innovation to tackle infrastructure deficits . By integrating local insights with global knowledge, infrastructure management practices can be transformed to address specific challenges while leveraging the strengths of established methodologies, ultimately leading to more sustainable and resilient infrastructure systems(Kuo et al , 2017)..

2.7. EMPIRICAL LITERATURE REVIEW

The successful implementation of open-source GIS tools in infrastructure management has been demonstrated through various case studies. These studies highlight the benefits of integrating GIS with asset management systems and showcase the positive impact on maintenance planning, resource allocation, data accuracy, and decision-making processes.

One example is the study conducted by Zhang et al. (2020) in a Chinese city. The researchers integrated GIS technology with asset management systems to improve infrastructure maintenance planning and resource allocation. By incorporating spatial data and asset information into the GIS platform, they were able to visualize and analyze the condition and performance of infrastructure assets. This integration facilitated better decision-making in terms of identifying critical assets, prioritizing maintenance activities, and allocating resources effectively.

Another research study by Xu et al. (2018) focused specifically on the application of open-source GIS tools for water infrastructure management. By utilizing GIS technology, they enhanced data accuracy and decision-making processes related to water infrastructure systems. The researchers integrated spatial data, such as water network layouts and asset attributes, into the open-source GIS platform. This integration allowed for improved visualization, analysis, and modeling of the water infrastructure, enabling infrastructure managers to make informed decisions regarding maintenance, repair, and system upgrades.

These case studies highlight the advantages of open-source GIS tools in infrastructure management. By leveraging the flexibility and functionality of open-source platforms, infrastructure managers can tailor the tools to their specific needs and workflows. The integration of spatial data with asset management systems provides a comprehensive and visual representation of infrastructure assets, leading to more accurate assessments of asset condition and performance.

Moreover, open-source GIS tools facilitate data accuracy and decision-making processes. The ability to integrate diverse datasets, such as asset attributes, maintenance records, and geographical information, improves the overall accuracy of inventory data. This, in turn, enables more informed decision-making regarding maintenance planning, resource allocation, and infrastructure upgrades.

The successful implementation of open-source GIS tools in infrastructure management demonstrates their potential for improving operational efficiency, cost-effectiveness, and overall infrastructure performance. These tools offer customizable solutions that can be adapted to various infrastructure sectors, including transportation, water, energy, and telecommunications.

In General, several case studies have showcased the successful implementation of open-source GIS tools in infrastructure management. These studies emphasize the benefits of integrating GIS with asset management systems, leading to improved maintenance planning, resource allocation, data accuracy, and decision-making. The flexibility and functionality of open-source platforms make them valuable tools for infrastructure managers seeking cost-effective and customizable solutions

However, the existing literature primarily focuses on studying the management of specific assets, such as roads or water distribution lines, using open-source tools. However, there is a significant research gap when it comes to integrated infrastructure and utility management using open-source tools. Additionally, there is a lack of frameworks available to effectively handle this integrated management approach.

Research Gaps

Previous studies have predominantly examined the management of individual assets within infrastructure systems. For instance, researchers have explored how open-source tools can be utilized to enhance the maintenance and monitoring of road networks or water distribution lines. While these studies have provided valuable insights into asset-specific management strategies, they have overlooked the broader perspective of integrating multiple assets and utilities within a comprehensive management framework. The integration of infrastructure and utility management is crucial because various assets and utilities, such as transportation networks, water supply systems, and energy grids, are interconnected and influence each other's performance. By considering the interdependencies and interactions between these components, a more holistic approach to management can be achieved, leading to optimized resource allocation, improved resilience, and enhanced overall system performance.

However, despite the significance of integrated management, there is a research gap in the literature concerning the application of open-source tools in this context. Open-source tools offer numerous advantages, including cost-effectiveness, flexibility, and the potential for collaborative development. Yet, their potential remains largely untapped for integrated infrastructure and utility management purposes especially for developing countries like Ethiopia. Furthermore, the lack of frameworks compounds this research gap. A comprehensive framework serves as a guiding structure that outlines the methodologies, processes, and decision-making mechanisms required for integrated management. It helps in organizing and streamlining the management approach, ensuring consistency and efficiency throughout the system. However, the absence of such frameworks hinders the implementation of integrated management strategies using open-source tools.

Therefore, there is a critical need for further research that focuses on integrated infrastructure and utility management using open-source tools. This research should address the interdependencies between different assets and utilities, explore the potential benefits and challenges of using open-source tools, and develop frameworks that provide a systematic and structured approach to integrated management. By bridging this research gap, practitioners and policymakers can effectively leverage open-source tools to optimize the management of complex infrastructure systems and utilities.

CHAPTER III: METHODOLOGY

3.1. Description of the Study Area

Adama City, located in the Oromia Region of Ethiopia, is a rapidly growing urban center known for its strategic location along the Addis Ababa-Djibouti Railway. Economically, Adama is a key hub for trade and commerce in Ethiopia. The city has seen substantial investment in various sectors, including agriculture, manufacturing, and services. Adama is particularly known for its agricultural activities, with surrounding areas engaged in the production of cash crops such as fruits and vegetables. The establishment of industrial parks has also attracted businesses, fostering job creation and economic diversification. The city's economy benefits from its proximity to the capital, Addis Ababa, facilitating trade and access to larger markets.

Moreover, the local government has prioritized infrastructure development to support economic growth. Initiatives aimed at improving transportation, utilities, and public services are underway, enhancing the overall quality of life for residents and attracting further investment. As a result, Adama City is emerging as a significant economic player in the region, with ongoing efforts to promote sustainable development and improve living standards for its growing population.

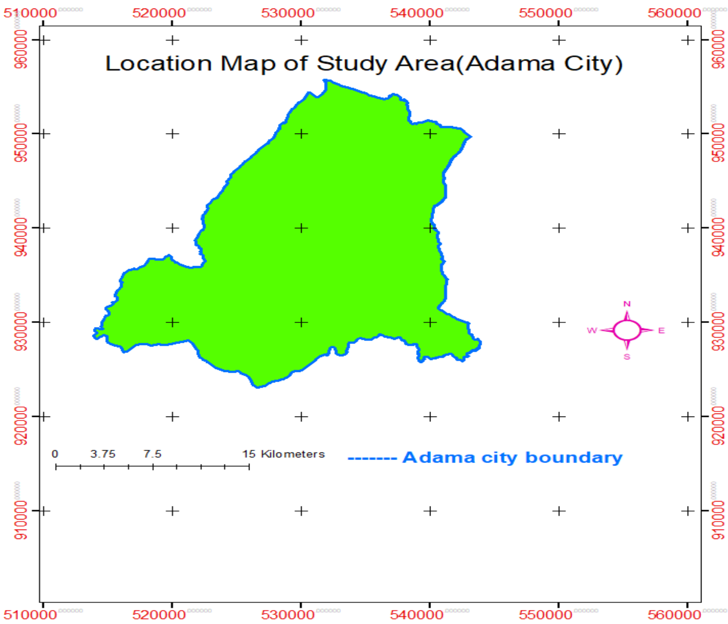


Figure 3.1. Location map Adama city

3.2. DESCRIPTION OF METHODOLOGY

The research methodology involved a comprehensive data collection process utilizing various methods. A structured survey was developed to gather quantitative data on the current state of infrastructure inventory and asset management practices. This survey was distributed to infrastructure managers, city officials, and relevant stakeholders, focusing on aspects such as data accuracy, completeness, and the use of technological tools. Additionally, in-depth semi-structured interviews with key informants, including GIS specialists and city officials, provided qualitative insights into existing practices and challenges. Document analysis was also performed, examining existing geodatabases, reports, and records related to infrastructure management, which helped identify deficiencies and enhance understanding of current practices.

Following data collection, critical steps were undertaken, including the selection of assessment indicators based on literature review and ISO 15000 standards to evaluate Adama City's infrastructure management effectiveness. The collected data was rigorously analyzed to identify patterns, strengths, and areas for improvement, enabling a comparative analysis against the selected indicators. A thorough requirement analysis was conducted to align proposed solutions with the city's unique challenges and priorities. This led to the design of a comprehensive spatial database model aimed at centralizing infrastructure data. Finally, the researcher developed a user-friendly web-based platform, selecting appropriate open-source tools to facilitate data management and visualization, ensuring compatibility with existing infrastructure systems and enhancing user experience.

3.3. RESEARCH DESIGN

3.3.1. DATA COLLECTION

Data collection is conducted through a variety of methods. Firstly, a structured survey was developed to collect quantitative data on the current state of infrastructure inventory and asset management practices. This survey was administered to infrastructure managers, city officials, and relevant stakeholders involved in infrastructure asset management. The survey was including questions regarding data accuracy, completeness, and the utilization of technological tools (GIS, GPS, DBMS, and QField). open-ended questions was used to gather both quantitative and qualitative responses.

In addition to surveys, in-depth interviews were conducted with key informants such as infrastructure managers, GIS specialists, and city officials. These interviews are providing valuable insights into current practices, challenges, and deficiencies related to data accuracy, completeness, and the integration of technological tools. The interviews was be semi-structured, allowing for flexibility in exploring specific areas of interest and probing for detailed information.

Furthermore, document analysis was conducted by examining existing Geodatabases, reports, documents, and records pertaining to infrastructure inventory and asset management in Adama City. This analysis offer a deeper understanding of current practices and identify any existing deficiencies in data accuracy, completeness, and the integration of technological tools. The documents include asset inventories, maintenance logs, inspection reports, and relevant policies and procedures.

3.3.2. INDICATOR SELECTION

The selection of assessment indicators was a critical step in the research methodology, providing a structured framework to evaluate the effectiveness of Adama City's infrastructure asset management practices. Drawing from the insights gained during the literature review and the ISO 15000 standard, the researcher is carefully craft a set of indicators that can capture the multifaceted dimensions of the city's infrastructure management.

3.3.3. DATA ANALYSIS

The data collected throughout the research process underwent a thorough analysis to develop a comprehensive understanding of infrastructure asset management practices in Adama City. This analysis focused on several critical aspects of the infrastructure geodatabase, including its data structure, integrity, and relationships among various data entities. By examining the database's layout and organization, the research identified how effectively the data was arranged and whether it supported efficient data retrieval and management. Additionally, the integrity of the data was assessed to ensure that it maintained accuracy and reliability over time, which was essential for making informed decisions based on the data. Furthermore, the analysis evaluated the geodatabase's query capabilities, ensuring that users could efficiently extract relevant information to support their decision-making processes. Data consistency was examined to verify that similar data points were presented uniformly throughout the database, reducing confusion and errors in interpretation. The completeness of the data was also scrutinized to identify any gaps that might hinder effective asset management. Lastly, interoperability was assessed to determine how well the geodatabase could integrate with other systems and

The researcher was employed a rigorous analytical approach using GI, identifying patterns, trends, strengths, weaknesses, and areas for improvement within the city's asset management strategies. A comparative analysis was performed, benchmarking Adama City's practices against the assessment indicators selected in the research methodology. This comparative evaluation would enable the identification of critical gaps and opportunities for enhancing the city's infrastructure management, laying the foundation for the subsequent requirement analysis and solution design phases.

3.3.4. SPATIAL DATABASE DESIGN

Building upon the insights gained from the data analysis and requirement assessment, the researcher was embarking on the design of a comprehensive spatial database model. This model is envisioned to serve as a centralized and efficient platform for storing, organizing, and retrieving Adama City's infrastructure data. The database design process involve a multi-stage approach, starting with conceptual modeling to establish the overall structure and relationships within the database. This would be followed by logical modeling, where the researcher was refine the data entities, attributes, and integrity constraints to ensure the database's functionality and performance. Finally, the physical database modeling stage was focus on the implementation-level details.

3.3.5. DATA SHARING AND MAPPING APPLICATIONS

The researcher recognize the paramount importance of developing a robust and user-friendly web-based platform to facilitate Adama City's infrastructure data management and visualization. After a careful evaluation of various open-source tools and technologies, the researchers selected the most appropriate solutions that is best meet the city's requirements. The selection process considers a range of factors, including the ability to handle diverse data formats, the availability of sophisticated visualization capabilities, the potential for scalability to accommodate growing data volumes, and the overall user-friendliness of the platform. By thoroughly assessing these crucial criteria, the researcher ensures that the chosen tools seamlessly integrate with Adama City's existing infrastructure data and provide a seamless, intuitive experience for end-users.

3.4. DATA AND SOFTWARE

The data and software utilized in this research are presented in the following tables.

3.4.1. DATA SOURCE

The studies were mainly used geospatial datasets gathered from Adama municipality Construction office.

Table 3.1: Data and their sources

No	Data	Source
1	AMP Reports	Adama municipality
2	Existing Geodatabase	Adama municipality
3	Infrastructure and Utility Data	Adama municipality
4	Orth photo	Adama municipality

3.1.1. SOFTWARE USED

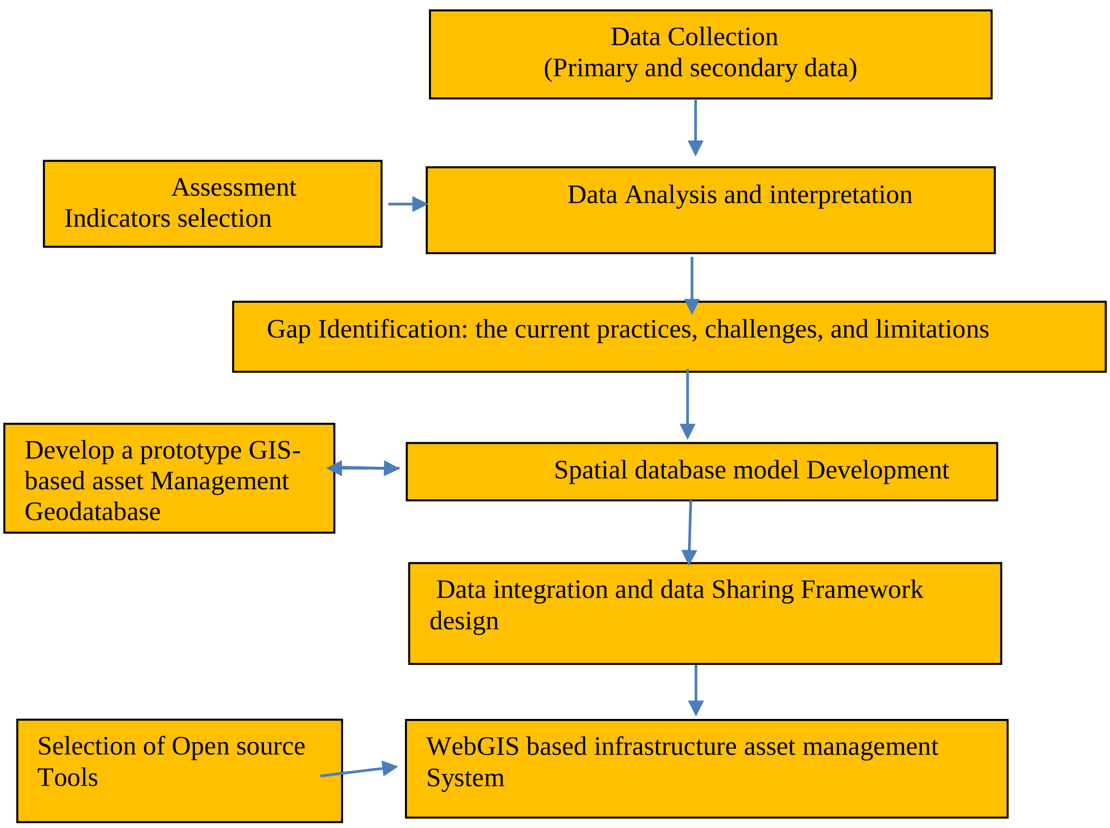
The following software applications were utilized in this research

Table 3.2: Software and programming language used

No.	Software	Purpose
1	ArcGIS 10.8	For mapping, Creating Graphs, Geodatabase Creation
2	PostgreSQL /PostGIS	For Spatial database management system
3	QGIS Plug-in /qgis2web, Quick Map services, HTML, CSS, Java Script and Open layers	For web GIS application
4	Visual Studio Code	For organizing and running the codes
5	QField	For online data inventory

The software tools selected for this research—PostgreSQL/PostGIS, QGIS, QField, and OpenLayers were chosen primarily for their open-source nature and high interoperability. These tools offer significant advantages in terms of cost-effectiveness and flexibility, allowing for extensive customization to meet the specific needs of the research. PostgreSQL, combined with PostGIS, provides a robust database management system capable of handling complex geospatial data, making it ideal for infrastructure asset management. QGIS serves as a powerful desktop GIS application that enables detailed data visualization and analysis, while QField facilitates field data collection through mobile devices, ensuring real-time updates and accuracy. OpenLayers enhances web mapping capabilities, allowing for seamless integration of geospatial data into web applications. The ability of these tools to connect and work together effectively ensures a cohesive workflow, promoting efficient data management and analysis throughout the research process.

Research Methodological Flow Chart



3.2 Research Methodological Flowchart

The flowchart above illustrates the process beginning with the selection of assessment indicators based on the ISO 15000 standard. Primary data was then gathered through questionnaires and interviews with selected professionals and decision-makers. Following this, secondary data was collected, including the infrastructure geodatabase and AMP reports. Data analysis was conducted to identify gaps in current practices, challenges, and limitations. Subsequently, a spatial database model was developed and implemented using GIS and PostgreSQL/PostGIS. Finally, a web-based GIS infrastructure asset management system was created.

CHAPTER IV. RESULTS AND DISCUSSIONS

4.1 Assessment of Adama City's Asset Management System

This section provides a comprehensive evaluation of Adama City's asset management system, focusing specifically on the Inventory dimension. This dimension is concerned with gathering extensive data on the physical characteristics, usage, maintenance history, planned work, costs, and resources associated with the assets. The data collection process is customized to align with the agency's decision-making requirements and available resources. To assess the inventory methods, three key indicators are employed: Reference System, Inventory Methods and Frequency of Data Collection, and Technology/Instrument. Primary data for this dimension is collected through semi-structured interviews with management officials and subject matter experts, which offer valuable insights into the inventory methods in practice.

The assessment results for each dimension within the framework are presented based on their efficiency or maturity levels, facilitating a comprehensive analysis of the road asset management system in Adama City. The study explores the Reference System aspect, highlighting the importance of assigning a Unique Reference Identifier to each road asset for effective inventory management. Although the original plan called for a structured process to assign IDs, the findings indicated a shift towards a more incremental approach. The necessity of following the established reference system for ID assignment is emphasized, as it improves data organization, analysis, and decision-making in the city's asset management framework. Additionally, the study reviews the Inventory Methods, Frequency of Data Collection, and Technology/Instrument aspects, noting the current manual data collection process. It recommends enhancements such as the use of GPS-enabled mobile applications and small laser scanners for more precise data gathering on asphalt pavement structures. By identifying the limitations of existing inventory methods and tools, the study advocates for modernization to enhance data collection efficiency for better asset management in Adama City.

The significance of Data Storage and Management is also highlighted, assessing factors such as Database Performance/Technology, Level of Detail, and Simplicity and Security. The study points out deficiencies in current data storage practices, including challenges related to data consistency, integrity, redundancy, and sharing mechanisms. Recommendations are made to explore alternative database solutions for improved performance and to implement systematic processes for regular data updates. By stressing the need for a comprehensive and accurate representation of road assets, the study underscores the importance of maintaining updated databases and capturing detailed information for informed decision-making and effective asset management strategies in Adama City.

4.1. Evaluation of Road Condition assessment Methods of Adama city

Evaluating the condition of road assets is essential for formulating effective management strategies and assessing their current status. This evaluation typically employs performance measures that align with the agency's goals, such as condition indices, the percentage of the network in good condition, and the remaining lifespan of the assets. Within the realm of road condition assessment, two primary indicators emerge: Condition Assessment Techniques and Technology.

Currently, Condition Assessment Techniques involve evaluating road conditions at the route level through methods like visual inspections conducted by trained personnel. The findings are classified using basic Excel formulas based on criteria such as remaining useful life or deterioration percentage. However, there is an increasing shift towards segment-level assessments that utilize modern approaches and technologies to gather detailed and accurate data on individual road segments. By leveraging advanced technologies like machine learning and deep learning, the condition of infrastructure can be assessed more accurately and efficiently. These sophisticated tools provide a comprehensive understanding of each road segment's condition, enabling targeted maintenance actions. Furthermore, the application of data analysis techniques, including machine learning algorithms, enhances the precision of condition assessments and yields valuable insights into deterioration patterns and future performance predictions.

The research emphasizes the need to move from traditional assessment methods to segment-level evaluations using contemporary technologies for better accuracy, efficiency, and speed. The integration of open-source tools like QField and QGIS can further optimize field data collection and analysis, enabling organizations to make data-informed decisions and enhance road asset management in Adama City.

4.2. Assessment of adama city asset management Information system

The discussion on Information Systems in this research centers on three key areas: ICT infrastructure/Technology, Performance Evaluation and Costing, and Planning and Scheduling.

Regarding ICT infrastructure/Technology, the study finds that the agency lacks a dedicated Information and Communication Technology (ICT) framework and an asset register. Instead, individual staff members rely on personal computers to record essential details about road assets, indicating a decentralized approach without a centralized system for effective asset management and tracking. The agency primarily depends on manual processes and Excel spreadsheets to generate valuation and renewal forecasting reports, suggesting that these important functions are largely carried out without specialized software support. This reliance on manual methods leads to challenges such as difficulties in maintaining accurate and current records, dispersed information across various devices, and issues with inefficiencies, inconsistencies, and data duplication, all of which threaten effective asset management.

Additionally, the research highlights that the manual and spreadsheet-based approaches for valuation and renewal forecasting expose the agency to potential errors and inconsistencies in data. Human mistakes in manual data entry and the limitations of spreadsheets without strong validation processes can undermine the reliability and accuracy of reports, which may negatively affect decision-making related to asset management, budgeting, and planning for renewals. To tackle these issues, the study recommends investing in the development of an ICT infrastructure and an asset register, centralizing data management through a dedicated database or asset management system to improve data accuracy, sharing, and collaboration. It also advises transitioning from manual processes to specialized software solutions for valuation and renewal forecasting to enhance efficiency, minimize errors, and improve data analysis capabilities, thereby facilitating informed decision-making for asset valuation and renewal planning.

4.3. Database models

In this phase of the study, a systematic approach was adopted to design and create an infrastructure geodatabase. This initiative was primarily motivated by the need to rectify deficiencies in infrastructure asset management practices identified through a thorough analysis of requirements. The following sections will detail the specific methodologies employed in the development and implementation of the infrastructure geodatabase, highlighting the key factors that influenced the decision-making process. The results from this phase will also be thoroughly discussed.

The focus within the conceptual database model is on identifying and defining the essential entities for effective asset management within an infrastructure and utility data framework. These entities serve as fundamental components of the system, acting as the building blocks for organizing and representing data. Examples of these entities include Road, Median, Drainage, Electric Pole, Electric Line, Water Distribution Line, Water Transmission Line, Reservoir, Walkway Line, Transformer, Bridge, and Administrative Building.

The conceptual model also explores the relationships and connections between these entities. For example, the Road entity may relate to other entities such as Median, Drainage, and Bridge, highlighting their interconnectedness within the system. These relational links are critical for defining the logical associations and dependencies among the various entities, thus enhancing the overall coherence of the system.

Moreover, each entity is assigned attributes or characteristics to accurately capture relevant information. These attributes provide specific details about each entity, including its geographical location, condition assessments, capacity, and other important data points. By outlining these attributes, the conceptual model ensures that essential information is carefully stored and linked to each entity, facilitating comprehensive data management practices.

Overall, the conceptual database model acts as a high-level representation of the spatial database model, outlining the entities, relationships, and attributes necessary for promoting efficient asset management practices within the specified context. This model not only establishes a structured framework for organizing and managing data but also lays the groundwork for streamlined asset management processes within the infrastructure and utility sector.

4.3.1. The logical database model of infrastructure asset management:

The logical database model marks the evolution of the conceptual model into a relational database design specifically suited for implementation in the ArcGIS and PostgreSQL/PostGIS software environments. This phase focuses on creating a clear framework capable of effectively storing and managing data related to infrastructure and utility assets. By aligning the entities, relationships, and attributes identified in the conceptual model with tables, columns, and relationships in the relational database, the logical model establishes an organized system that simplifies data storage and manipulation processes.

In the logical model, each entity from the conceptual model is converted into an equivalent table, while the attributes linked to these entities become columns within their respective tables. This mapping process ensures that data is systematically organized, enhancing efficient data retrieval and manipulation. Assigning primary keys to each table is vital for maintaining data integrity, as these keys ensure the uniqueness of each record, making it easier to identify and reference specific data entries.

Relationships between tables are established using foreign keys, which represent the connections between related entities. By linking tables through foreign keys, the logical model reinforces the relationships among different entities within the database, allowing for the smooth retrieval of interconnected information. To improve data consistency and integrity, normalization techniques are applied to the tables, optimizing data storage by eliminating redundancy and minimizing the risk of inconsistencies or anomalies.

Additionally, the logical model requires the specification of appropriate data types and constraints for each column in the tables. Data types determine the format and nature of the data allowed in a given column, ensuring uniformity and accuracy. Constraints, such as unique constraints and data validation rules, are implemented to enforce specific conditions on the data stored in the columns, thereby maintaining data quality and validity standards. Overall, the logical database model refines the conceptual model into a systematic and structured relational database design, promoting data integrity and facilitating efficient data retrieval and management within the ArcGIS and PostgreSQL/PostGIS software platforms.

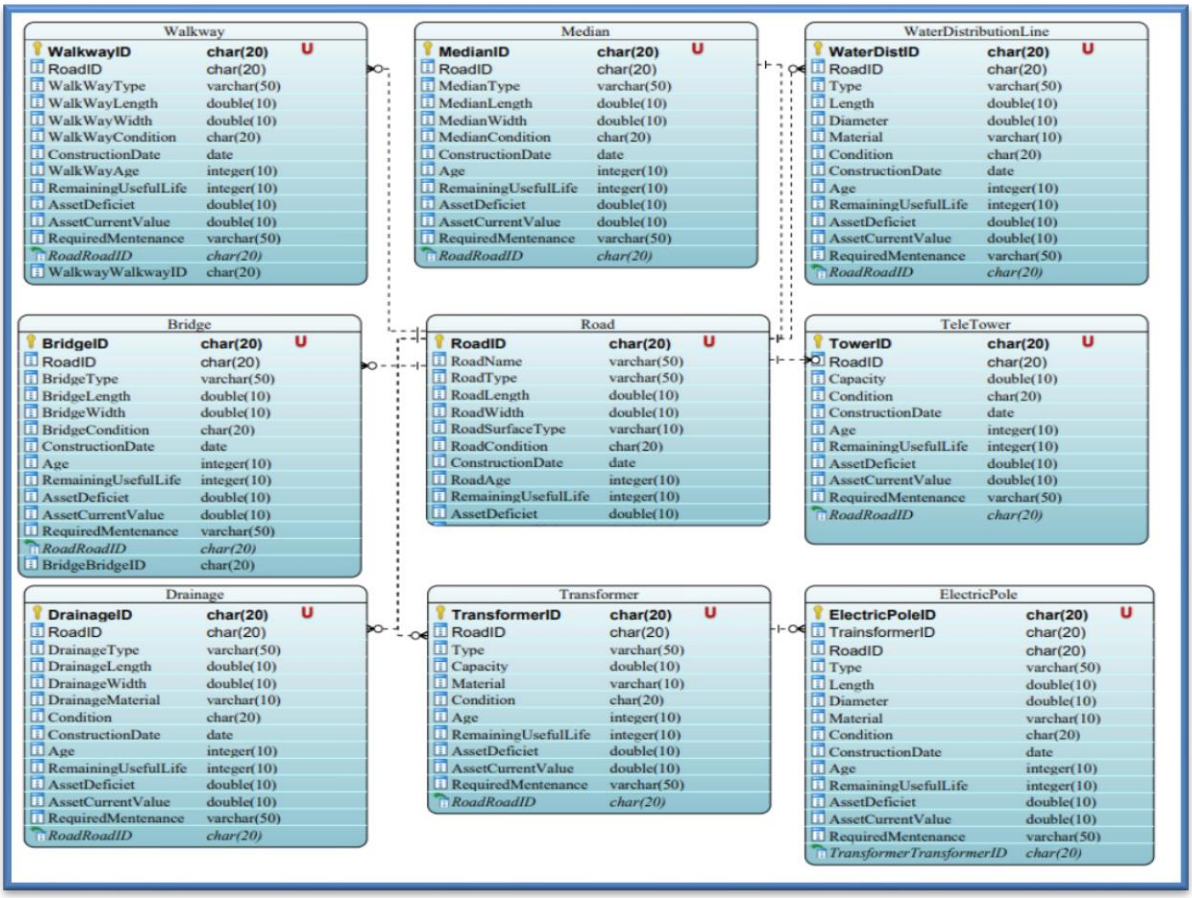


Figure 4.1 Logical database Model (source: researcher).

The logical diagram provided visually illustrates the connections between various tables within the context of road infrastructure management, highlighting the relationships between the road table and other relevant tables in the database. Notably, the road table displays a one-to-many relationship with the water distribution table, indicating that a single road can be associated with multiple water distribution records, while each water distribution entry relates to only one road. This connection is facilitated by the road ID, which serves as a unique identifier for each road and enables a smooth association between the two tables.

Similarly, the road table has one-to-many relationships with the walkway, drainage line, and transformer tables, meaning that a road can have multiple related records in these tables, while each record in the walkway, drainage line, and transformer tables corresponds to a single road. These relationships are based on the road ID, which acts as a common link between the tables.

Additionally, a one-to-one relationship is found between the road table and the median table, indicating that each road record corresponds to a single median record, and vice versa. The road ID serves as the key identifier that connects the road and median tables, ensuring the accuracy and uniqueness of this relationship. Overall, the logical diagram provides a detailed overview of how the road table interacts with various tables in the database, illustrating different relationship types, such as one-to-many and one-to-one, with the water distribution, walkway, drainage line, transformer, and median tables. These relationships, established through the road ID, enhance data retrieval and management processes within the road infrastructure management framework.

Water Infrastructure Logical database model

In a logical database model for a water infrastructure asset management system, various entities represent the critical components of the water distribution network. Key entities include Distribution Line, Transmission Line, Pumps, Reservoir, Valves, Junction Valves, and Boreholes. Each entity is designed to capture relevant attributes that define its characteristics and operational parameters. For instance, the Distribution Line entity might include attributes such as line ID, length, diameter, material type, and installation date, while the Pumps entity may contain pump ID, capacity, power rating, and maintenance history. This structured approach ensures comprehensive data management, allowing for efficient monitoring and decision-making regarding water infrastructure assets.

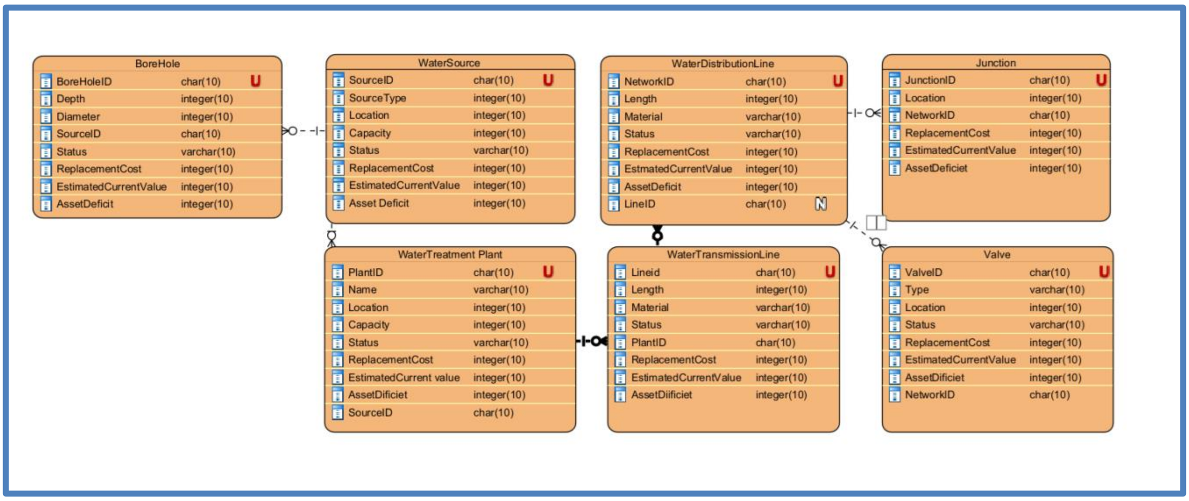


Figure 4.2 Logical database Model for water infrastructure (source: researcher).

Relationships among Entities

The relationships between these entities are crucial for understanding the interconnectivity of the water infrastructure system. The Distribution Line entity exhibits a one-to-many relationship with Junction Valves and Valves, indicating that each distribution line can have multiple valves associated with it to manage flow and pressure. Similarly, the Transmission Line may also be linked to multiple Reservoirs, reflecting the need for water storage points along the transmission route. Furthermore, the Pumps entity can have a one-to-many relationship with both Distribution Lines and Reservoirs, as a single pump may serve multiple distribution lines or supply water to various reservoirs, ensuring efficient water delivery across the network.

Comprehensive Data Integration

To facilitate effective asset management, the logical model integrates these relationships with foreign keys that link entities together. For example, the Distribution Line might include a foreign key referencing the Reservoir it draws from, while the Pumps entity includes foreign keys linking to both the Distribution Line and the Reservoir it services. This design allows for seamless data retrieval and analysis, enabling stakeholders to assess the overall health of the water infrastructure, identify maintenance needs, and plan for future expansions. By establishing these clear relationships and a well-defined logical model, the water infrastructure asset management system can operate efficiently, ensuring reliable water services for the community.

4.3.2. The physical database model of infrastructure asset management:

The implementation of the physical database model on both ArcGIS geodatabase and PostgreSQL/PostGIS spatial database was a strategic choice designed to leverage the strengths of each platform. By utilizing the capabilities of the ArcGIS geodatabase, the research aimed to take advantage of features like relationship attachment and topology management, which are essential for maintaining complex spatial relationships within the database. This approach allowed for the creation of strong spatial links and attachments, thereby improving the overall integrity and coherence of the data within the system.

At the same time, integrating the physical database model with the PostgreSQL/PostGIS spatial database was driven by the goal of directly connecting the web mapping application to the database, facilitating smooth data access and interaction. By linking the web mapping application to the PostgreSQL database, the research aimed to streamline data retrieval and sharing processes, providing real-time access to spatial data for users. This direct connection not only improved the efficiency of data retrieval but also created a more interactive and dynamic user experience within the web mapping application.

The implementation on both platforms addressed the varied needs of the research project, ensuring a comprehensive approach to spatial data management and accessibility. While ArcGIS offered specialized functionalities for spatial data management and analysis, PostgreSQL/PostGIS provided a solid foundation for efficiently storing and querying spatial data. This dual implementation strategy allowed the research project to capitalize on the advantages of each platform, fostering a synergistic environment that maximized the effectiveness of the physical database model for infrastructure asset management.

In summary, integrating the physical database model on both ArcGIS geodatabase and PostgreSQL/PostGIS spatial database represents a strategic combination of capabilities to improve spatial data management and accessibility. By merging ArcGIS's functionalities for spatial relationships and attachments with PostgreSQL's direct connectivity for web mapping applications, the research project aimed to enhance data integrity, accessibility, and user experience. This dual implementation approach highlighted a commitment to utilizing the strengths of both platforms to create a robust and adaptable spatial data management system tailored to the specific needs of infrastructure asset management.

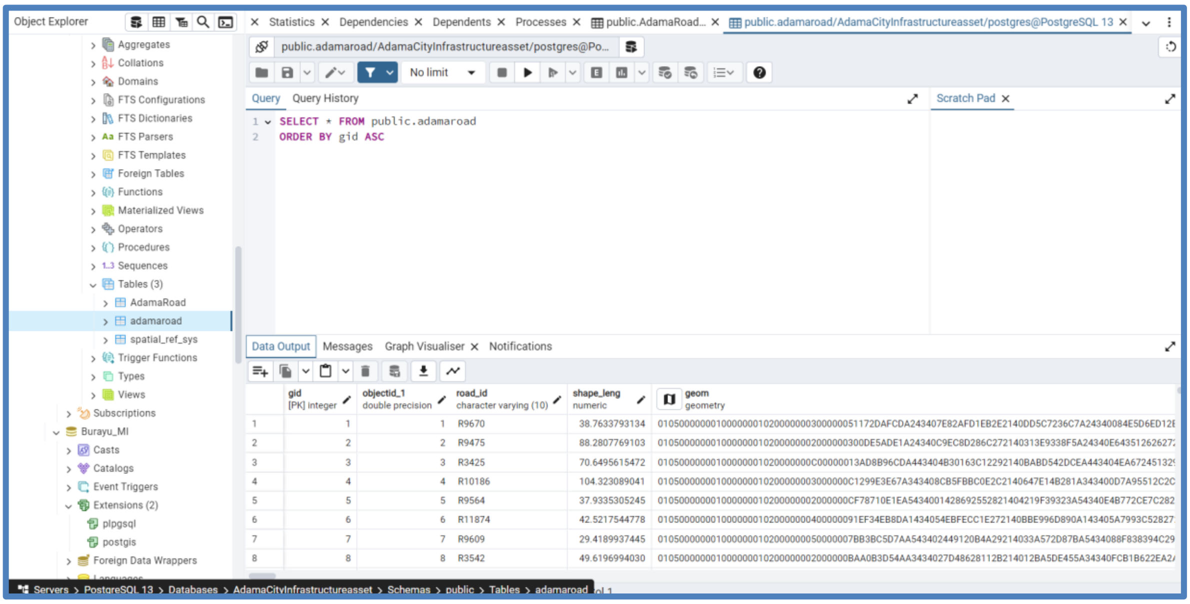


Figure 4.3 Physical implementation of the model on Postgresql/PostGIS

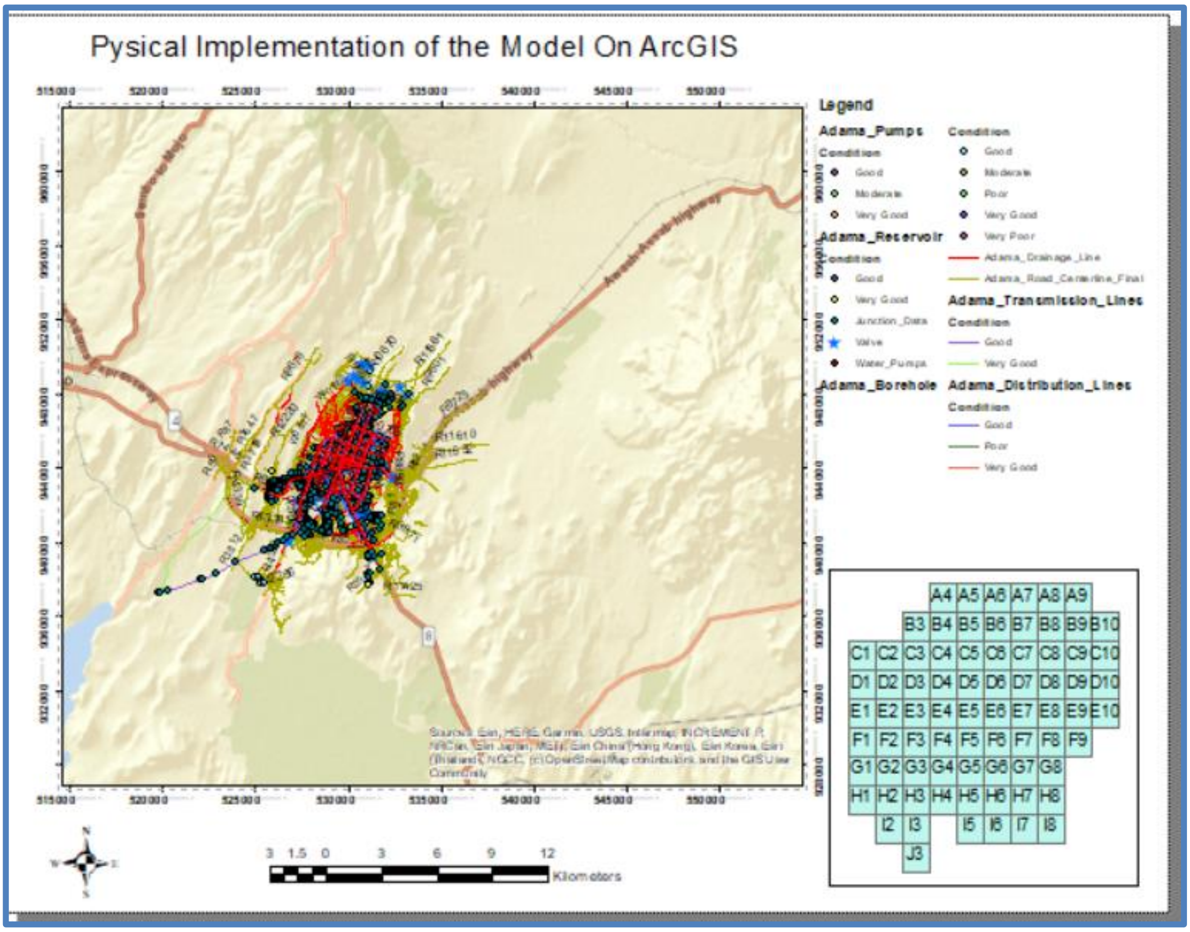


Figure 4.4 Physical implementation of the model on ArcGIS

Road Infrastructure Analysis

The road infrastructure in Adama City is characterized by a diverse composition, with a total length of 1,124,084.3592 meters of various road types. Predominantly, asphalt roads dominate the landscape, comprising 246,018.1092 meters, which reflects a significant investment in durable and modern road surfaces that can support heavy traffic. In contrast, earthen roads dominate with a substantial 720,123.1875 meters, indicating a reliance on less developed infrastructure that may affect accessibility and maintenance challenges. The presence of concrete (4,190.954833 meters), cobble (151,241.1673 meters), gravel (53,546.61203 meters), redash (51,015.24232 meters), and large block stone (9,364.980965 meters) further highlights the variety of materials utilized, each presenting unique maintenance and management considerations.

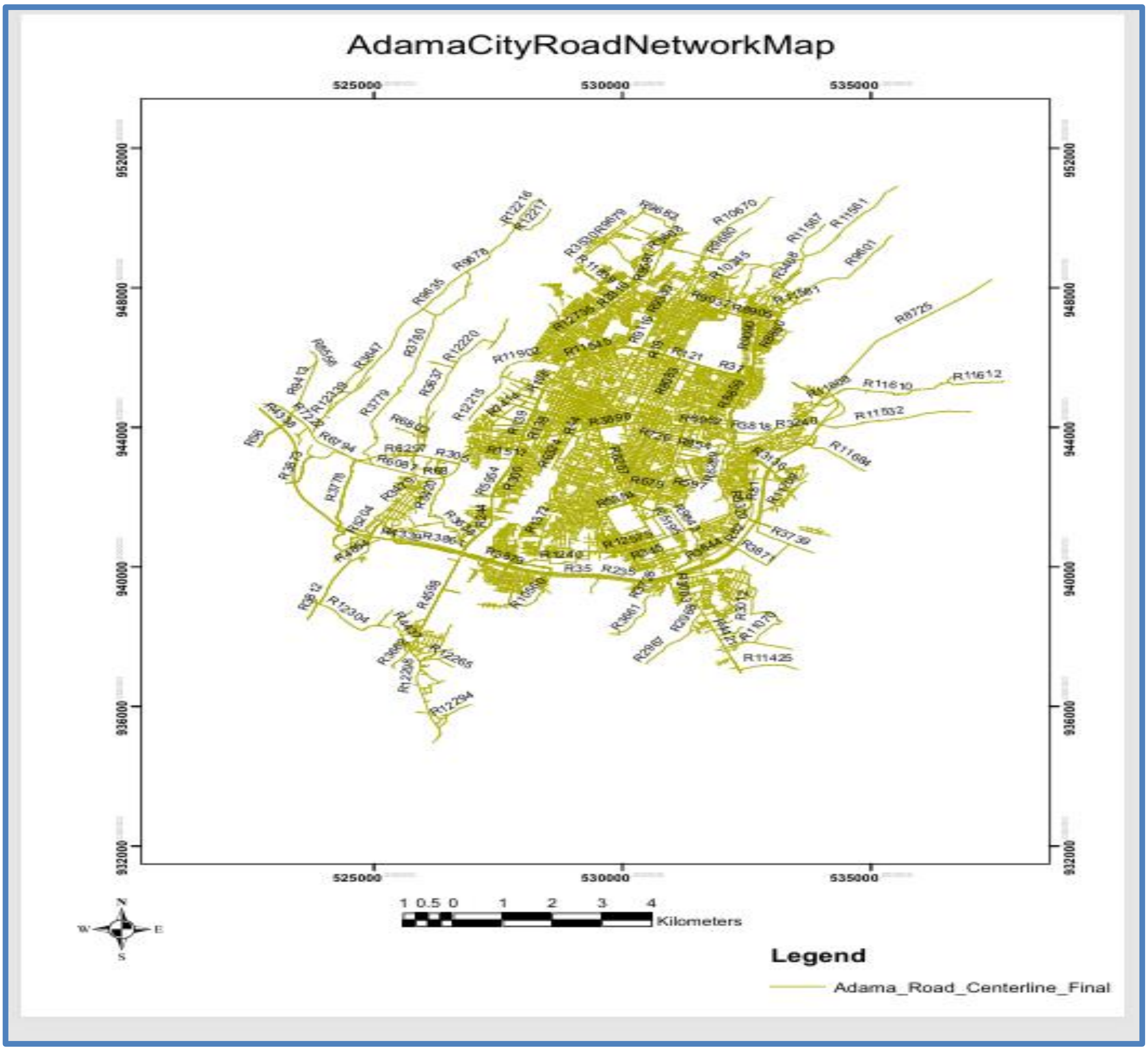


Figure 4.5 Adama city road network map

This diverse array of road types necessitates a comprehensive asset management system that can effectively monitor, evaluate, and prioritize maintenance efforts. The significant length of earthen roads suggests a potential area for improvement, as these roads may require more frequent upkeep to ensure safety and usability. Additionally, the asphalt roads, while well-suited for heavy traffic, will also need regular assessments to prolong their lifespan and optimize performance. Implementing a robust road infrastructure asset management system will enable Adama City to allocate resources efficiently, track the condition of each road type, and make informed decisions that enhance the overall quality of the transportation network.

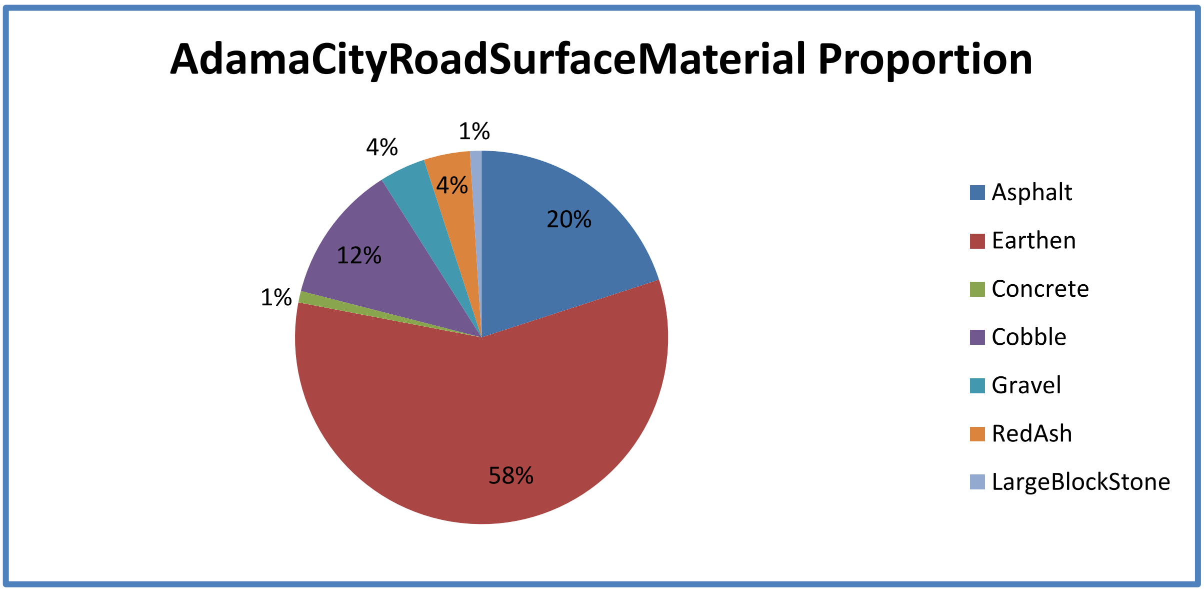


Figure 4.6 Proportion of Road Surface Materials in Adama City

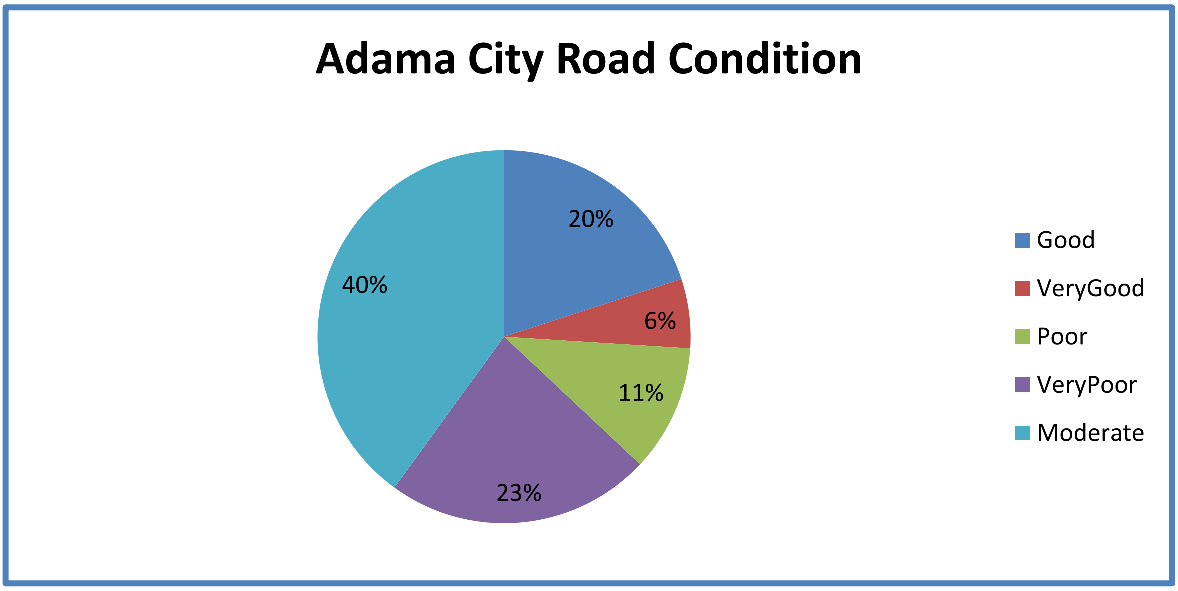


Figure 4.7 Proportion of Road condition in Adama City

The analysis of the road conditions in Adama City reveals a mixed landscape in terms of infrastructure quality. Out of the total road length, approximately 276,962.95 meters are classified as being in good condition, which constitutes a significant portion of the overall network. Additionally, 68,695.09 meters are categorized as very good, indicating that nearly 16% of the roads are in optimal condition. However, the findings also highlight areas of concern, with 148,738.12 meters marked as poor and 317,288.50 meters identified as very poor. These figures suggest that almost 70% of the road network requires urgent attention, as they do not meet acceptable standards of usability and safety.

Furthermore, the moderate condition of 530,058.28 meters of the total road length indicates that while these roads are not in dire disrepair, they are also not performing optimally. This substantial length of moderate roads reflects a need for maintenance and improvement to enhance overall accessibility and infrastructure reliability in the city. The data underscores the importance of targeted asset management strategies that prioritize the rehabilitation of poor and very poor roads, ensuring that the urban road network can support the growth and mobility needs of Adama City's residents. Addressing these critical infrastructure issues is vital for promoting economic development and enhancing the quality of life for its inhabitants.

Walkway infrastructure analysis

The walkway infrastructure within the studied area exhibits a rich diversity in materials, with a total length of 169,677.0898 meters. Cobble stone is the most prevalent material, measuring 52,240.60434 meters, which suggests a traditional aesthetic and durability suitable for pedestrian traffic. Clay tiles also contribute significantly to the total, accounting for 46,931.76471 meters, indicating a preference for visually appealing and sustainable materials. Other materials such as precast paving blocks (10,536.60709 meters) and large block stone (29,909.01017 meters) highlight a commitment to varied design choices, while the presence of asphalt (2,159.111145 meters) and gravel (5,872.103799 meters) suggests areas where functionality and cost-effectiveness are prioritized.

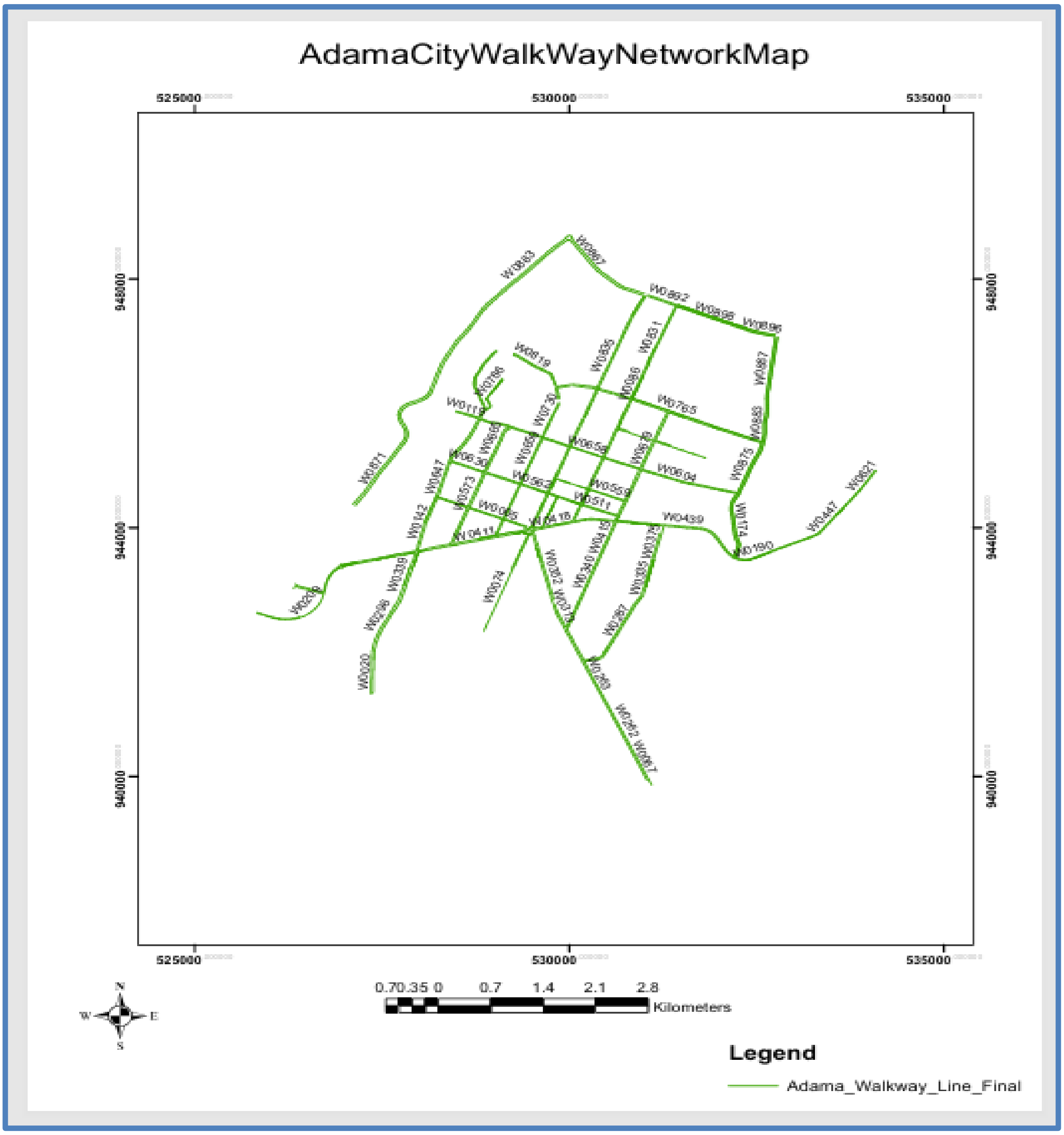


Figure 4.8 Map of the Walkway Network in Adama City

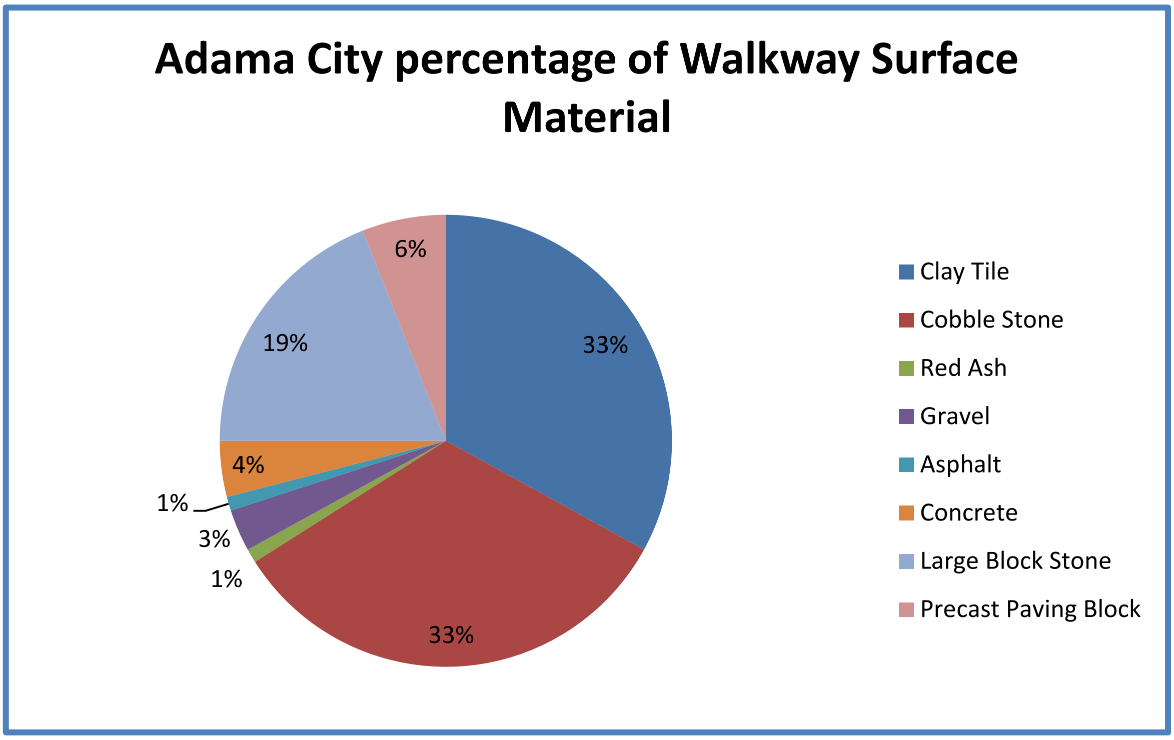


Figure 4.9 Proportion of walkway Surface Materials in Adama City

This diverse composition of walkway materials necessitates a strategic asset management approach to ensure optimal maintenance and usability. The prominence of cobble stone and clay tile, while aesthetically pleasing, may require specialized maintenance practices to ensure longevity and safety. In contrast, the smaller lengths of asphalt and gravel walkways may indicate a need for improved infrastructure in these areas to enhance accessibility. A comprehensive walkway infrastructure asset management system will be crucial in assessing the condition of these materials, prioritizing repairs, and ensuring that the walkways meet the needs of the community. This system will facilitate informed decision-making, ultimately enhancing pedestrian safety and the overall quality of the urban environment.

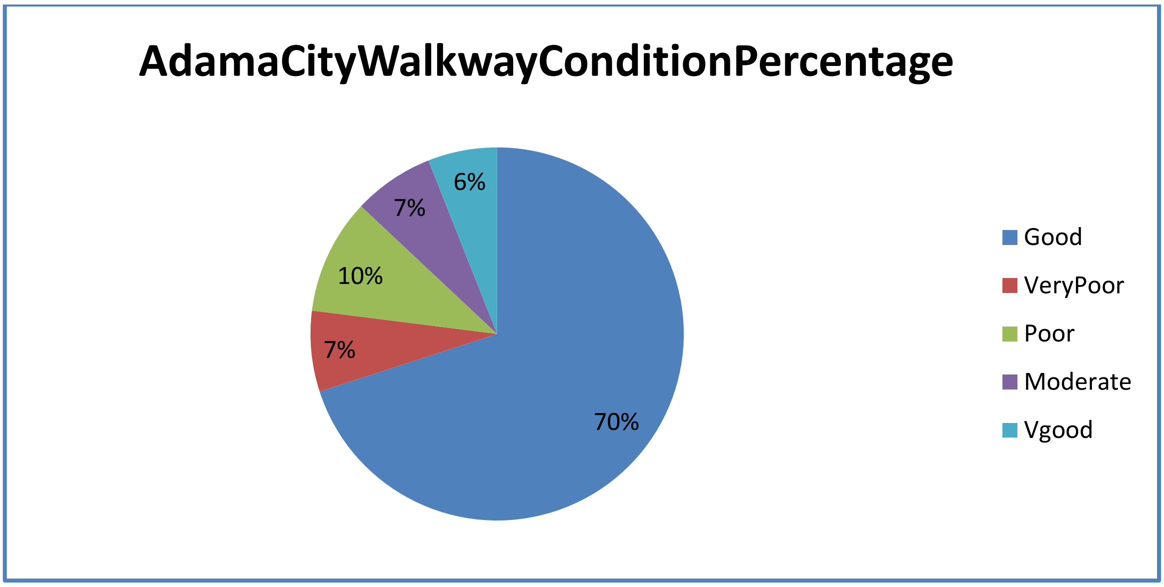


Figure 4.10 Proportion of walkway condition in Adama City

The assessment of walkway infrastructure in Adama City reveals a varied condition across the total length of 112,074.2448 meters. Notably, a significant portion of the walkways is classified as "good," suggesting that the majority of the infrastructure is functional and meets the needs of pedestrians. However, the presence of 11,687.01394 meters designated as "very poor" and 16,294.90782 meters as "poor" indicates critical areas requiring immediate attention and investment. The moderate classification, encompassing 12,220.77654 meters, signifies sections that may benefit from targeted improvements to enhance safety and usability.

The overall distribution of walkway conditions highlights the necessity for a comprehensive asset management system to prioritize maintenance and upgrades effectively. The substantial lengths of "very poor" and "poor" walkways pose risks to pedestrian safety and accessibility, emphasizing the urgency for remedial action. By implementing a structured management system, Adama City can systematically evaluate these conditions, allocate resources efficiently, and develop targeted interventions. This proactive approach will not only improve the safety and functionality of walkways but also enhance the overall quality of urban mobility, fostering a more pedestrian-friendly environment.

Water infrastructure analysis

The analysis of the water distribution infrastructure in Adama City reveals significant financial insights regarding its current status and future needs. The estimated replacement cost of the infrastructure is approximately 557,840,000.6 birr, indicating the total investment required to replace the existing system entirely. In contrast, the estimated current value stands at 400,670,644.2 birr, highlighting a substantial difference that underscores the depreciation and potential inefficiencies within the existing water distribution network. This disparity suggests that the current infrastructure may not be adequately maintained or upgraded, posing risks to service delivery and reliability.

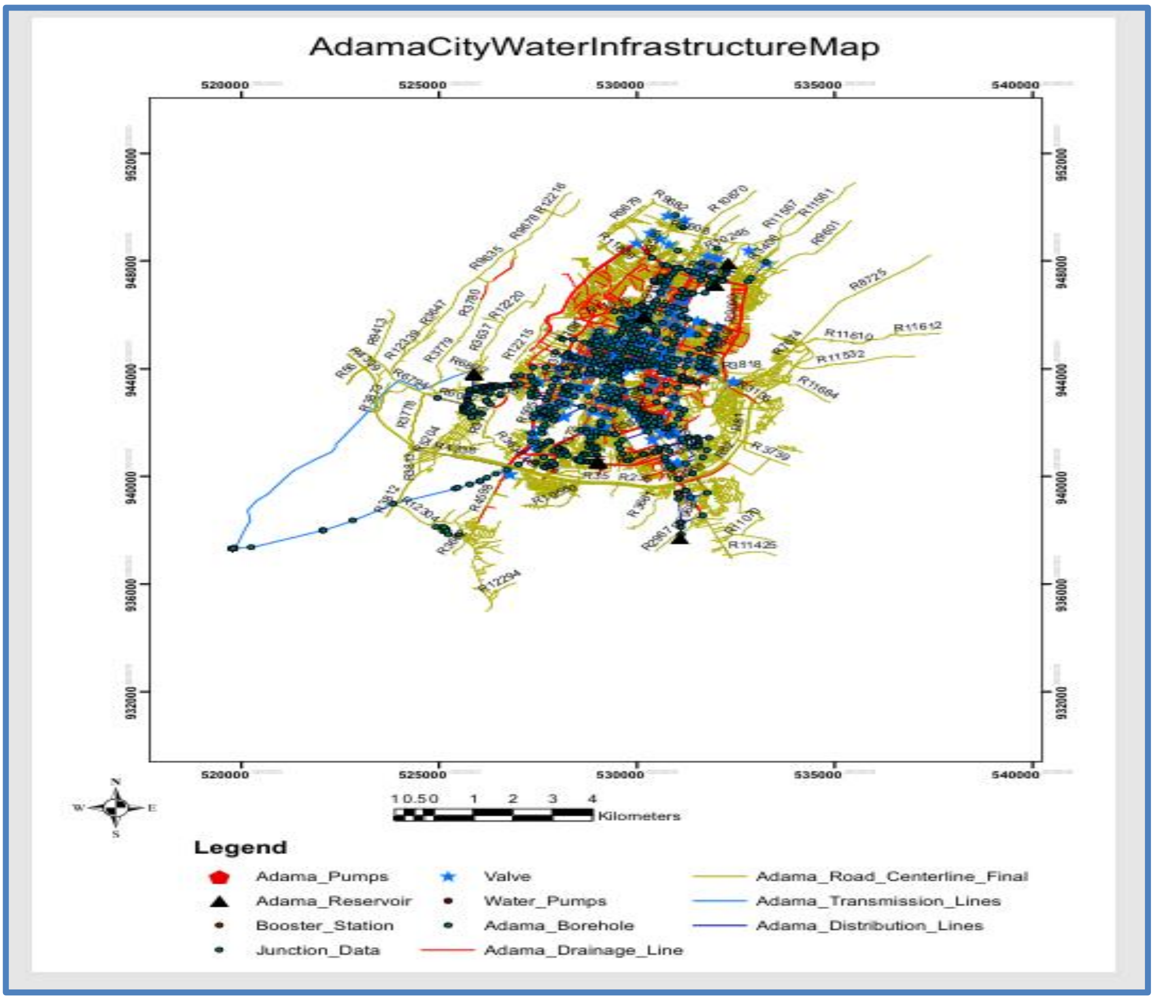


Figure 4.11 Map of water infrastructure Network in Adama City

Furthermore, the identified asset deficit of approximately 157,169,357.2 birr emphasizes the urgent need for investment in the water distribution system. This deficit indicates that the current assets are falling short in value relative to the replacement cost, which may hinder the city's ability to provide consistent and quality water services to its residents. A proactive asset management strategy is essential to address this gap, enabling Adama City to prioritize funding and resource allocation for necessary upgrades and repairs. By doing so, the city can improve its water distribution infrastructure's efficiency and sustainability, ultimately enhancing the quality of life for its citizens and ensuring reliable access to essential water services.

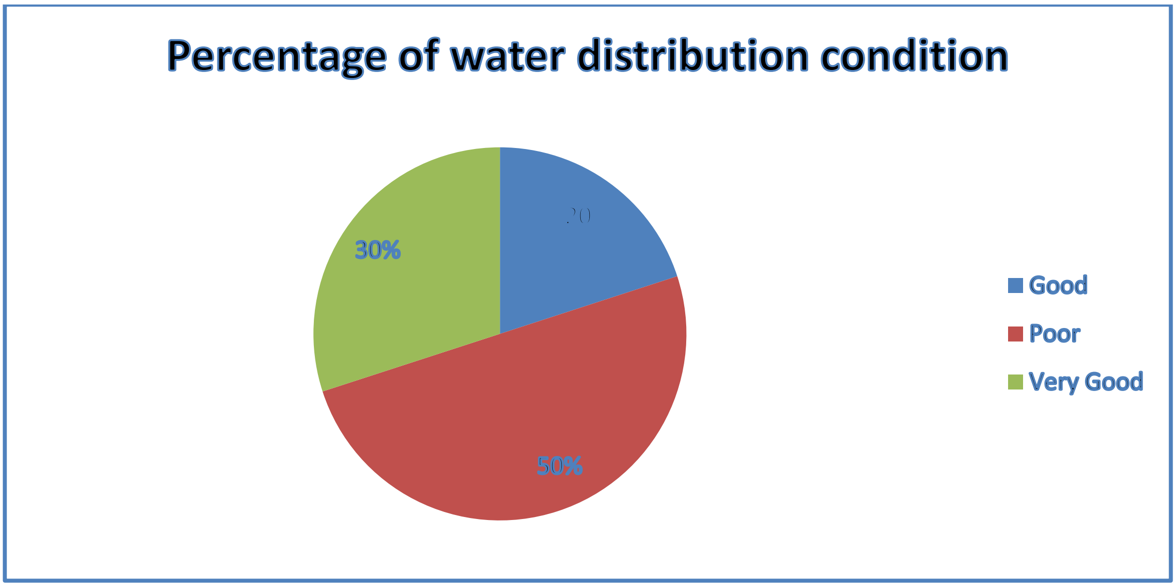


Figure 4.12 Proportion of water distribution line condition in Adama City

The assessment of the total water distribution line reveals a concerning distribution of conditions among the infrastructure. With only 20% classified as being in good condition, the data indicates that a significant portion of the system is potentially at risk of failure or inefficiency. This limited percentage raises alarms about the reliability and sustainability of the water supply, suggesting that the infrastructure may not adequately support the community's needs. Furthermore, the 50% of the system that is deemed to be in poor condition underscores an urgent need for maintenance and investment to prevent further deterioration and to ensure continued access to safe water.

In contrast, the 30% of the water distribution line that is rated as being in very good condition offers a glimpse of hope and a foundation for future improvements. This segment of the infrastructure can serve as a benchmark for best practices in maintenance and upgrades. However, the overall analysis emphasizes the need for a strategic approach to address the vast proportion of the system that is either in poor or good condition. Prioritizing repairs and enhancements in these areas will be essential to bolster the integrity of the water distribution system, ultimately leading to improved service reliability and public health outcomes.

Street Light Infrastructure Analysis

The analysis of the street lighting infrastructure in Adama reveals significant financial insights regarding its current state and future needs. The estimated current value of the street lighting assets stands at approximately 93,554,004.86 birr. This valuation indicates the worth of the existing infrastructure as it currently functions. However, the asset deficit of around 67,745,995.14 birr highlights a concerning gap between the current value and the replacement cost, which is estimated at 161,300,000 birr. This disparity underscores that the existing street lighting system has depreciated significantly, potentially due to inadequate maintenance and upgrades over time.

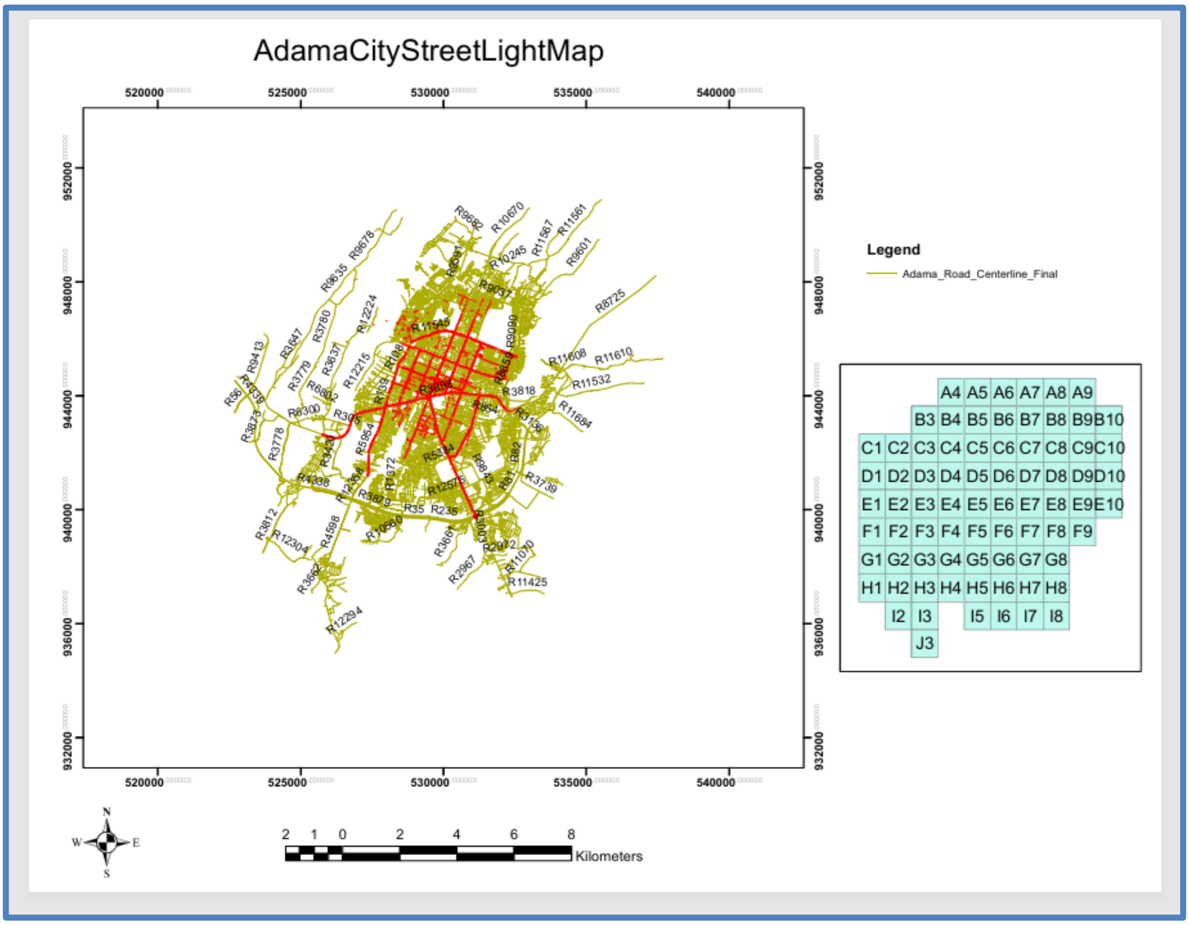


Figure 4.13 Map illustrating the locations of streetlights in Adama City.

The substantial asset deficit suggests that the current street lighting infrastructure may not meet the city’s operational and safety standards, posing risks to public safety and overall service quality. With the replacement cost being significantly higher than the current value, it is evident that investment in the street lighting system is critical. The findings highlight an urgent need for financial planning and resource allocation to address this gap, ensuring that the infrastructure can be maintained and upgraded effectively.

In conclusion, the financial analysis of Adama's street lighting assets indicates a pressing requirement for investment to bridge the asset deficit and enhance the overall quality of the infrastructure. A proactive asset management strategy should be implemented to prioritize funding for necessary upgrades and repairs, thereby improving the efficiency and reliability of street lighting services. This approach will not only enhance public safety but also contribute to the city's overall urban development and sustainability goals.

Table 4.1 summarizing the status of Street light in adama city

Table

Adama_Street_Light

Pole_Material	Installation_Year	Pole_Material_Condition	Street_Light_Operation	MaintenanceRate	MaintenanceCost	URReplacementCost	EstimatedRep
Wood	2005	Moderate	Functional	<Null>	<Null>	50000	
Wood	2005	Moderate	Functional	<Null>	<Null>	50000	
Wood	2005	Moderate	Functional	<Null>	<Null>	50000	
Wood	2005	Moderate	Functional	<Null>	<Null>	50000	
Wood	2007	Good	Functional	<Null>	<Null>	50000	
Wood	2007	Good	Functional	<Null>	<Null>	50000	
Wood	2007	Good	Functional	<Null>	<Null>	50000	
Wood	2007	Good	Functional	<Null>	<Null>	50000	
Wood	2007	Moderate	Functional	<Null>	<Null>	50000	
Wood	2007	Moderate	Functional	<Null>	<Null>	50000	
Wood	2007	Moderate	Functional	<Null>	<Null>	50000	
Wood	2007	Moderate	Functional	<Null>	<Null>	50000	
Wood	2007	Moderate	Functional	<Null>	<Null>	50000	
Wood	2007	Moderate	Functional	<Null>	<Null>	50000	
Wood	2007	Moderate	Functional	<Null>	<Null>	50000	
Wood	2008	Good	Functional	<Null>	<Null>	50000	
Wood	2008	Good	Functional	<Null>	<Null>	50000	
Wood	2008	Good	Functional	<Null>	<Null>	50000	
Wood	2008	Good	Functional	<Null>	<Null>	50000	
Wood	2005	Good	Functional	<Null>	<Null>	50000	
Steel	2005	Very Good	Functional	<Null>	<Null>	50000	
Steel	2005	Very Good	Functional	<Null>	<Null>	50000	
Steel	2005	Moderate	Functional	<Null>	<Null>	50000	
Steel	2005	Very Good	Functional	<Null>	<Null>	50000	
Steel	2005	Very Good	Functional	<Null>	<Null>	50000	
Steel	2005	Very Good	Functional	<Null>	<Null>	50000	
Steel	2005	Poor	Functional	<Null>	<Null>	50000	
Steel	2005	Very Good	Functional	<Null>	<Null>	50000	
Steel	2005	Very Good	Functional	<Null>	<Null>	50000	

The findings indicate that out of 3,326 street lights in Adama, only 649 are currently functional. This stark discrepancy highlights a significant operational challenge within the city's street lighting infrastructure. With a functionality rate of approximately 19.5%, the vast majority of street lights are either non-operational or in disrepair, potentially compromising public safety and urban livability. The limited number of functional lights may lead to inadequate illumination in various areas, increasing the risks of accidents and crime, which can have detrimental effects on community well-being and trust in local governance.

This situation calls for urgent intervention and strategic planning from city officials and urban planners. The low functionality of street lights suggests that maintenance practices may be insufficient or that resources have not been effectively allocated to address infrastructure needs. Consequently, there is an implication for the city to prioritize investments in the maintenance and repair of existing street lights, as well as consider the installation of new units to restore adequate lighting levels. Furthermore, this analysis underscores the necessity for a comprehensive asset management strategy that includes regular inspections, timely repairs, and a sustainable funding model to ensure the long-term functionality of essential infrastructure. Addressing these issues will not only enhance public safety but also improve the overall quality of life for residents in Adama.

Table 4.2 Summarizing the replacement cost, estimated current value, and asset deficit valuation of the water distribution lines in Adama City.

AdamaRoadsfinal

ReplacRate	CurrYear	EUL	STotArea	RoadAge	RUL	IndicRUL	Condition	MentenCost	Replac_cos	DepRepCost	MentenDifi	EstCurrVal	AssDeficit
2500	2/12/2016	15	1800	8	7	44.444444	Poor	258400	4500000	2500000	258400	2241600	2258400
2500	2/12/2016	15	5400	8	7	44.444444	Poor	775200	13500000	7500000.00001	775200	6724800.00001	6775199.99999
2500	2/12/2016	15	9000	8	7	22.222222	Good	646000	22500000	17500000	646000	16854000	5646000
2500	2/12/2016	15	9000	8	7	44.444444	Poor	1292000	22500000	12500000	1292000	11208000	11292000
2500	2/12/2016	15	9000	8	7	4.444444	VGOOD	0	22500000	21500000	0	21500000	1000000
2500	2/12/2016	15	9000	8	7	17.777778	Good	0	22500000	18500000	0	18500000	4000000
2500	2/12/2016	15	9000	8	7	26.666667	Good	775200	22500000	16500000	775200	15724800	6775200
2500	2/12/2016	15	9000	8	7	13.333333	Good	0	22500000	19500000	0	19500000	3000000
2500	2/12/2016	15	12600	8	7	12.698413	Good	0	31500000	27500000	0	27500000	4000000
2500	2/12/2016	15	6300	8	7	25.396825	Good	516800	15750000	11750000	516800	11233200	4516800
2500	2/12/2016	15	6300	8	7	6.349206	VGOOD	0	15750000	14750000	0	14750000	1000000
2500	2/12/2016	15	9000	8	7	44.444444	Vpoor	1292000	22500000	12500000	1292000	11208000	11292000
2500	2/12/2016	15	9000	8	7	8.888889	VGOOD	0	22500000	20500000	0	20500000	2000000
2500	2/12/2016	15	9000	8	7	26.666667	Good	775200	22500000	16500000	775200	15724800	6775200
2500	2/12/2016	15	9000	8	7	31.111111	Poor	904400	22500000	15500000	904400	14595600	7904400
2500	2/12/2016	15	10800	8	7	14.814815	Good	0	27000000	23000000	0	23000000	4000000
2500	2/12/2016	15	5400	8	7	7.407407	VGOOD	0	13500000	12500000	0	12500000	1000000
2500	2/12/2016	15	4500	8	7	17.777778	Good	0	11250000	9250000	0	9250000	2000000
2500	2/12/2016	15	9000	8	7	13.333333	Good	0	22500000	19500000	0	19500000	3000000
2500	2/12/2016	15	4500	8	7	26.666667	Good	387600	11250000	8250000	387600	7862400	3387600
2500	2/12/2016	15	9000	8	7	8.888889	VGOOD	0	22500000	20500000	0	20500000	2000000
2500	2/12/2016	15	4500	8	7	26.666667	Good	387600	11250000	8250000	387600	7862400	3387600
2500	2/12/2016	15	4500	8	7	88.888889	Poor	1292000	22500000	2500000	1292000	1208000	21292000
500	2/12/2013	10	1400	5	5	71.428571	VPoor	500000	700000	200000	500000	0	700000
2500	2/12/2016	15	4500	8	7	88.888889	Poor	1292000	22500000	2500000	1292000	1208000	21292000
2500	2/12/2016	15	9000	8	7	44.444444	Poor	1292000	22500000	12500000	1292000	11208000	11292000
2500	2/12/2016	15	9000	8	7	44.444444	Poor	1292000	22500000	12500000	1292000	11208000	11292000
2500	2/12/2016	15	9000	8	7	44.444444	Poor	1292000	22500000	12500000	1292000	11208000	11292000
2500	2/12/2016	15	4500	8	7	88.888889	Poor	1292000	22500000	2500000	1292000	1208000	21292000
2500	2/12/2016	15	9000	8	7	44.444444	Poor	1292000	22500000	12500000	1292000	11208000	11292000
2500	2/12/2016	15	5400	8	7	74.074074	Poor	1292000	13500000	3500000	1292000	2208000	11292000

The condition of the water distribution infrastructure in Adama City is a critical factor influencing its operational efficiency and reliability. Regular assessments of asset condition help identify areas that require maintenance or upgrades, allowing for timely interventions to prevent service disruptions. A well-maintained infrastructure not only ensures the effective delivery of water services but also mitigates the risks associated with aging components, such as leaks or system failures. In Adama City, the current condition may reflect a lack of adequate maintenance, thereby contributing to the observed depreciation in asset value. Understanding the infrastructure's condition allows city planners and decision-makers to prioritize repairs and allocate resources effectively. When evaluating the financial health of the water distribution system. These costs encompass routine upkeep, repairs, and preventive measures to ensure the infrastructure remains functional and efficient. In contrast, the estimated replacement cost of approximately 557,840,000.6 birr indicates the funding needed to completely overhaul the existing system. The significant difference between replacement and current values highlights the financial burden on the city, as outdated infrastructure may require more frequent repairs, increasing overall maintenance costs. A strategic approach to asset management involves balancing these costs by investing in preventive maintenance to prolong the life of existing assets while also planning for future upgrades. By doing so, Adama City can optimize its financial resources, improving service delivery and minimizing long-term expenditures.

The estimated current value of the water distribution infrastructure, at 400,670,644.2 birr, reveals the extent of depreciation that has occurred over time. This value reflects not only market conditions but also the effectiveness of maintenance practices. The asset deficit of approximately 157,169,357.2 birr indicates a significant gap between what the assets are currently worth and what it would cost to replace them. This deficit raises concerns regarding the city's capacity to provide reliable water services, as it suggests that the infrastructure is not keeping pace with the growing demands of the population. To address this deficit, Adama City must adopt a proactive asset management strategy that prioritizes investment in upgrades and repairs. By addressing these financial challenges, the city can enhance the efficiency and sustainability of its water distribution system, ultimately improving the quality of life for residents and ensuring equitable access to essential water services.

4.4. WebGIS based Infrastructure Asset Management

In this section, the research outcome delineates the procedure for disseminating infrastructure asset information on the web. The entire process, commencing from map preparation in QGIS to parameter configuration in QGIS Web 2 and culminating in publishing the web map on the GITHUB server, is meticulously elucidated and deliberated upon.

The initial step entails map preparation in QGIS, where the researchers meticulously organize and structure the infrastructure asset information. This includes selecting and configuring relevant layers, applying suitable symbology, and ensuring the accuracy and completeness of the data.

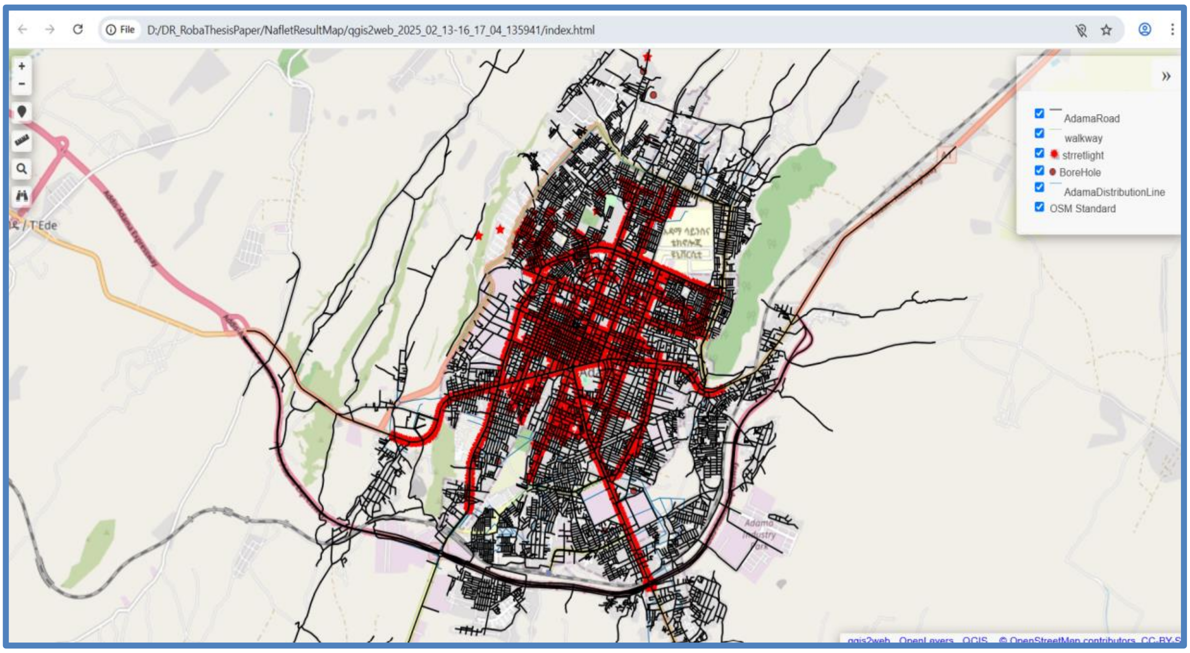


Figure 4.14 Web mapping application map

In Figure 4.14, a web mapping application was evaluated on a local server where a computer served as the hosting platform. The application visibly displays various infrastructure layers, enabling users to toggle these layers on and off as needed. Moreover, the application exhibits functionalities such as zooming in and out to explore detailed map sections, as well as a feature to measure distances on the map interface. These interactive capabilities enhance the user experience and provide essential tools for navigating and analyzing spatial data effectively within the web mapping application.

As depicted in Figure 4.15, the user interface of the mapping application is streamlined, featuring a concise layout comprising essential components such as a table of contents, zoom controls, measurement tools, and a search function. While these core functionalities provide a solid foundation for the application's utility, there is room for improvement in enhancing the user experience. Future research endeavors should focus on refining the user interface through code customization and integrating supplementary features to enrich the functionality of the web mapping application. By augmenting the interface with tailored enhancements and additional tools, the application can offer a more comprehensive and user-friendly experience, catering to a wider range of user needs and preferences.

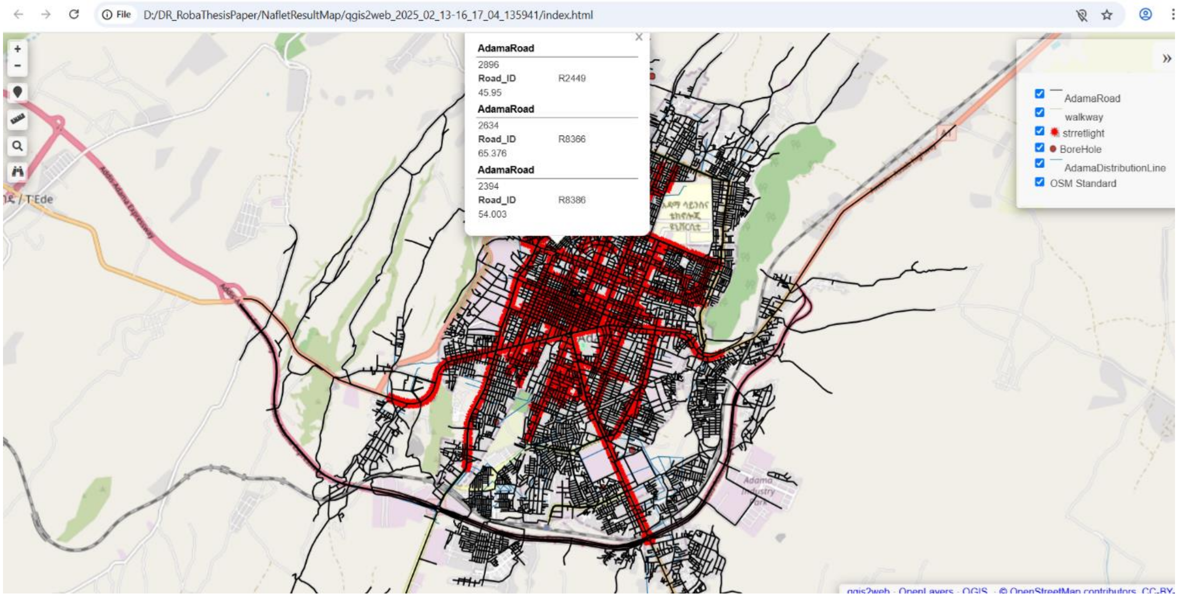


Figure 4.15 Web mapping application for attribute information display

In the realm of web mapping, a variety of open-source software and frameworks are available to facilitate the creation and management of geospatial data. For this research, PostgreSQL with PostGIS, QGIS, OpenLayers, and the Qgisweb2 Plugin were selected due to their robust features and interoperability. PostgreSQL serves as a powerful relational database management system, while PostGIS adds spatial capabilities, allowing for efficient storage and querying of geospatial data. QGIS provides a comprehensive desktop environment for data visualization and analysis, which is essential for preparing the data before deployment on the web.

The integration of these tools creates a seamless workflow for infrastructure asset management. QGIS can be used to perform initial data processing and visualization, enabling users to analyze various infrastructure assets effectively. Once the data is ready, the Qgisweb2 Plugin simplifies the process of converting QGIS projects into interactive web maps. This plugin allows users to publish their maps online with minimal effort, making it easier for stakeholders to access and interact with the data. The interoperability of these tools ensures that data flows smoothly between them, enhancing the overall efficiency of the asset management process.

Furthermore, the developed web maps can be customized using HTML, CSS, and JavaScript, allowing for a more functional and visually appealing user interface. This customization capability enables developers to tailor the web mapping applications to meet specific user needs and preferences, improving the user experience significantly. By leveraging these web technologies, stakeholders can create intuitive interfaces that facilitate better data interaction, enhance decision-making, and ultimately lead to more effective infrastructure management practices. The combination of these open-source tools provides a powerful framework for building and maintaining a comprehensive web mapping solution.

4.5. Discussion

The research findings on the infrastructure asset management practices in Adama City reveals several key areas that require improvement, including data storage, management, sharing, and asset valuation methods. These findings align with previous research highlighting the challenges faced by municipalities in effectively managing their infrastructure assets (Smith et al., 2019; Brown & White, 2018). The need for enhanced data storage and management systems is crucial for ensuring the accuracy and accessibility of infrastructure information, which is essential for informed decision-making and resource allocation (Jones et al., 2020; Merga & Behulu, 2019).

The design and implementation of a geodatabase model in ArcGIS and PostgreSQL represents a significant step towards addressing these challenges. The results indicate that this model offers improved data management and query capabilities, highlighting its potential to streamline infrastructure data handling (Richard & Iguisi, 2016). The scalability of the geodatabase model is particularly noteworthy, as it suggests that the system can accommodate growing volumes of data and evolving infrastructure needs over time (Admasu et al., 2019).

The analysis of road, walkway, water distribution, and street lighting infrastructures in Adama City reveals significant insights into the current state and future needs of the urban landscape. The city’s road infrastructure, with a total length of 1,124,084.3592 meters, showcases a diverse composition dominated by asphalt (246,018.11 meters) and earthen roads (720,123.19 meters). This substantial reliance on earthen roads raises concerns regarding accessibility and maintenance, as supported by the findings of Kadir et al. (2020), who emphasize that poor road conditions can significantly hinder economic activities and mobility in urban settings.

The need for a comprehensive asset management system is underscored by the finding that approximately 70% of the road network is classified as poor or very poor. This aligns with the work of Odeck (2018), which advocates for strategic asset management to prioritize infrastructure rehabilitation and ensure safety. Moreover, the presence of 530,058.28 meters of moderate-condition roads indicates a pressing need for targeted maintenance efforts to enhance overall usability and safety.

In terms of walkway infrastructure, the total length of 169,677.0898 meters, primarily composed of cobblestone and clay tiles, suggests a focus on aesthetics and durability. However, as highlighted by Shafique et al. (2021), the maintenance of such materials requires specialized practices to ensure longevity, further emphasizing the necessity of a strategic asset management approach. The identification of critical areas within the walkway network that are classified as very poor or poor indicates a risk to pedestrian safety, necessitating immediate attention and investment.

The analysis of water distribution infrastructure reveals a concerning discrepancy between the estimated replacement cost (557,840,000.6 birr) and the current value (400,670,644.2 birr), highlighting significant depreciation and inefficiencies. The findings correlate with the work of Akinyemi et al. (2019), who argue that inadequate maintenance of water infrastructure can lead to service delivery challenges. The identified asset deficit of 157,169,357.2 birr underscores the urgency for investment in the water distribution system to enhance service reliability.

Similarly, the street lighting infrastructure presents alarming findings, with only 649 out of 3,326 street lights functional, leading to a functionality rate of approximately 19.5%. This low rate poses serious risks to public safety, echoing the concerns raised by Poon et al. (2019) regarding the implications of inadequate lighting on crime rates and community well-being. The substantial asset deficit of around 67,745,995.14 birr indicates an urgent need for financial planning and resource allocation to address both maintenance and new installations.

In conclusion, the findings from Adama City’s infrastructure analysis highlight critical areas requiring immediate intervention and strategic planning. Implementing a robust asset management strategy across all infrastructure types will not only enhance safety and accessibility but also contribute to the city’s overall economic development and quality of life for its residents. Addressing these infrastructure challenges is vital for promoting sustainable urban growth and improving the well-being of the community.

Moreover, the development of customized web GIS applications presents a promising approach to facilitating data sharing among different stakeholders. While the initial results demonstrate the potential of these applications as a starting point for enhancing collaboration and information dissemination, further customization and development are necessary to maximize their effectiveness. Enhancements in web forms, user authentication mechanisms, and search capabilities within the web GIS applications are essential for improving usability and ensuring that stakeholders can easily access and utilize the shared infrastructure data (Bazilian et al., 2011; Amos et al., 2020).

Generally, in the realm of infrastructure asset inventory management, a multitude of open-source tools and applications were explored by the researcher, who meticulously tested and selected specific tools deemed suitable for the infrastructure asset management system of Adama City. The chosen tools were recommended based on their functionality and applicability to the city's infrastructure management requirements.

CHAPTR V: CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The research findings reveal specific areas within the infrastructure asset management system that require improvement. Key elements such as the inventory system, data storage and management, road condition assessments, and infrastructure asset information systems have been highlighted for better system performance.

Traditional techniques, on manual records and reactive maintenance practices, are no longer adequate to meet the complex and evolving needs of urban infrastructure systems. This study highlights the transformative potential of geospatial technologies—particularly Geographic Information Systems (GIS) and remote sensing in enhancing the planning, monitoring, and management of infrastructure assets address these identified areas, a geodatabase model was developed as a corrective solution. This model was carefully designed to efficiently organize and manage infrastructure and utility data. Through rigorous testing with ArcGIS software, the model proved effective in handling information related to infrastructure assets.

The thorough analysis of Adama City's infrastructure—including roads, walkways, water distribution, and street lighting—reveals significant challenges and opportunities for enhancement. The diverse range of road types, particularly the high number of earthen roads, underscores the urgent need for focused maintenance and the establishment of a robust asset management system. With around 70% of the road network rated as poor or very poor, prioritizing rehabilitation efforts is crucial for improving safety and accessibility for residents.

Similarly, the walkway infrastructure highlights critical areas that need immediate intervention, particularly those categorized as very poor, which pose risks to pedestrian safety. The variety of materials used necessitates specialized maintenance practices to ensure both functionality and aesthetic appeal.

The financial assessment of the water distribution infrastructure reveals a significant asset deficit, indicating a pressing need for increased investment to guarantee reliable service delivery. Additionally, the concerning state of street lighting, with only 19.5% of lights operational, emphasizes the need for strategic planning and resource allocation to enhance public safety and community welfare.

In summary, tackling these infrastructure challenges through a comprehensive asset management strategy will not only enhance the quality and reliability of essential services but also support the sustainable development of Adama City. By prioritizing maintenance and upgrade investments, the city can stimulate economic growth and improve residents' overall quality of life.

Furthermore, to improve accessibility and promote collaboration, a web mapping application was tested using the QGIS2 web plugin. This application allows users to interact with infrastructure data through a web-based interface. However, further customization is needed to enable dynamic user interactions and enhance functionality.

While the application was initially made available on GitHub pages to reach a broader audience, it requires thorough testing and deployment on a server for optimal performance.

In essence, the creation of the geodatabase model and the implementation of the web GIS application are invaluable tools for improving the infrastructure asset management system. These tools not only streamline data management and visualization but also support informed decision-making and strategic planning. The availability of the web GIS application on GitHub fosters wider accessibility and encourages collaboration among stakeholders interested in advancing infrastructure asset management practices.

5.2 Recommendations

To improve the infrastructure asset management system in Adama City, a comprehensive assessment of the current framework, including financial aspects, is essential. This foundational step will uncover existing challenges and opportunities for enhancement. It is also recommended to adopt advanced database solutions, such as cloud-based storage and robust data backup protocols, to strengthen data management practices and ensure data integrity and security.

Stakeholders and experts in Adama Municipality should actively utilize the developed geodatabase model along with open-source tools like QField and QGIS. By prioritizing targeted rehabilitation of poor infrastructure and increasing investments in water distribution and street lighting, the city can significantly enhance service reliability. Engaging the community in planning and maintenance efforts, along with conducting regular condition assessments, will create a collaborative environment that supports sustainable long-term infrastructure planning.

Future research should investigate the integration of machine learning algorithms within the asset management system to improve predictive maintenance capabilities. By analyzing historical data, machine learning can detect patterns and predict potential infrastructure failures, enabling proactive interventions. Additionally, exploring the implementation of smart infrastructure technologies, such as IoT sensors, will allow for real-time data collection on asset conditions, facilitating better-informed decision-making and enhancing overall efficiency.

It is also important for future studies to focus on developing advanced web-based platforms with user-friendly interfaces and robust data visualization tools. These platforms should enable stakeholders to easily access, analyze, and share infrastructure data, fostering collaboration and improving asset management outcomes. Furthermore, research should aim to establish interoperability standards for various software tools used in infrastructure management, ensuring seamless data exchange between systems and enhancing overall operational efficiency.

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Appendix

Questionnaire for Research on "Enhancing Infrastructure Asset Management in Adama City through Geospatial Technology"

Section 1: Participant Information

1. Name (Optional):
2. Position/Title:
3. Department/Organization:
4. Years of Experience in Infrastructure Management:

Section 2: Current Practices in Infrastructure Asset Management

5. How would you describe the current practices of infrastructure asset management in Adama City?
   - Very Effective
   - Effective
   - Neutral
   - Ineffective
   - Very Ineffective
   - Comments:
6. What methods are currently used for road condition assessments in Adama City? (Please specify all that apply)
   - Visual inspections
   - Mobile surveys
   - Automated data collection
   - Other (please specify):
7. How frequently are road condition assessments conducted?
   - Monthly
   - Quarterly
   - Annually
   - Other (please specify):

Section 3: Challenges and Limitations

8. What are the main challenges faced in the current infrastructure asset management practices?
   (Please rank the following from 1 to 5, with 1 being the most significant challenge)
   - Lack of data integration
   - Insufficient funding
   - Limited technical skills
   - Outdated data management systems
   - Other (please specify):
9. What limitations do you encounter in the data inventory methods used for assessing road conditions?
   - Inaccurate data
   - Inconsistent data collection
   - Lack of real-time data
   - Other (please specify):

Section 4: Assessment of Asset Management Information System

10. Does Adama City currently have an Asset Management Information System (AMIS)?

- Yes
- No

11. If yes, how effective is the current AMIS in supporting infrastructure management?

- Very Effective
- Effective
- Neutral
- Ineffective
- Very Ineffective
- Comments:

12. What features are most useful in the current AMIS?
    (Please specify all that apply)

- Data visualization
- Reporting tools
- Real-time monitoring
- Other (please specify):

Section 5: Current Geodatabase Assessment

13. Is there an existing geodatabase for infrastructure asset management in Adama City?

- Yes

- No

14. If yes, how would you rate the quality of the current geodatabase?

- Excellent
- Good
- Fair
- Poor
- Very Poor
- Comments:

15. What improvements would you suggest for the current geodatabase?

- Enhanced data accuracy
- Improved user interface
- Increased data accessibility
- Other (please specify):

Section 6: Additional Comments

16. Please provide any additional comments or suggestions regarding infrastructure asset management in Adama City:
    (Open-ended response)

Thank you for your participation! Your insights are valuable for enhancing infrastructure asset management in Adama City through geospatial technology.

Semi-Structured Interview Questions

Section 1: Current Practices in Infrastructure Asset Management

1. Can you describe the current practices in infrastructure asset management in Adama City?
   - What specific methods do you use for assessing road conditions?
2. How do you collect and manage data related to infrastructure assets?
   - What data inventory methods are currently implemented?
3. How frequently are road condition assessments conducted, and who is responsible for these assessments?

Section 2: Challenges and Limitations

4. What are the main challenges you face in managing infrastructure assets?
   - Can you provide specific examples of these challenges?
5. What limitations have you encountered in the data inventory methods used for road assessments?
   - How do these limitations affect your work?
6. In your opinion, what prevents effective coordination among different sector offices regarding asset management?

Section 3: Asset Management Information System Assessment

7. Is there an Asset Management Information System (AMIS) currently in use?
   - If so, how effective do you find it in supporting infrastructure management?
8. What features of the AMIS do you find most beneficial?
   - Are there any features that you feel are missing?
9. How is the data from the AMIS used in decision-making processes?

Section 4: Geodatabase Assessment

10. Is there a geodatabase in place for infrastructure asset management?
    - If yes, how would you describe its quality and functionality?
11. What challenges do you face with the current geodatabase?
    - How do these challenges impact your ability to manage infrastructure effectively?
12. What improvements would you suggest for the existing geodatabase to enhance its utility?

Section 5: Future Directions

13. How do you envision the role of geospatial technology in enhancing infrastructure asset management in Adama City?
    - What specific technologies or tools do you think could be beneficial?
14. What steps do you believe should be taken to improve infrastructure asset management practices in the city?
15. Do you have any additional comments or insights that you believe are important for this research?

Thank you for your time and insights. Your contributions are invaluable for understanding and enhancing infrastructure asset management in Adama City through geospatial technology.

Appendix2 Sample HTML code

```
<!doctype html>
<html lang="en">
    <head>
        <meta charset="utf-8">
        <meta http-equiv="X-UA-Compatible" content="IE=edge">
        <meta name="viewport" content="initial-scale=1,user-
scalable=no,maximum-scale=1,width=device-width">
        <meta name="mobile-web-app-capable" content="yes">
        <meta name="apple-mobile-web-app-capable" content="yes">
        <link rel="stylesheet" href="./resources/ol.css">
        <link rel="stylesheet" href="resources/fontawesome-all.min.css">
        <link rel="stylesheet" type="text/css"
href="resources/horsey.min.css">
        <link rel="stylesheet" type="text/css" href="resources/ol3-search-
layer.min.css">
        <link href="resources/ol-geocoder.min.css" rel="stylesheet">
        <link rel="stylesheet" href="./resources/ol-layerswitcher.css">
        <link rel="stylesheet" href="./resources/qgis2web.css">
        <style>
        html, body {
            background-color: #ffffff;
        }
        .ol-control > * {
            background-color: #f8f8f8!important;
            color: #444444!important;
            border-radius: 0px;
        }
        .ol-attribution a, .gcd-gl-input::placeholder, .search-layer-input-
search::placeholder {
            color: #444444!important;
        }
        .search-layer-input-search {
            background-color: #f8f8f8!important;
        }
        .ol-control > *:focus, .ol-control >*:hover {
            background-color: rgba(248, 248, 248, 0.7)!important;
        }
        .ol-control {
            background-color: rgba(255,255,255,.4) !important;
            padding: 2px !important;
        }
```

```html
        </style>

        <style>
        html, body, #map {
            width: 100%;
            height: 100%;
            padding: 0;
            margin: 0;
        }
        </style>
        <title></title>
    </head>
    <body>
        <div id="map">
            <div id="popup" class="ol-popup">
                <a href="#" id="popup-closer" class="ol-popup-closer"></a>
                <div id="popup-content"></div>
            </div>
        </div>
        <script src="resources/qgis2web_expressions.js"></script>
        <script src="./resources/functions.js"></script>
        <script src="./resources/ol.js"></script>
        <script src="resources/horsey.min.js"></script>
        <script src="resources/ol3-search-layer.js"></script>
        <script src="./resources/ol-layerswitcher.js"></script>
        <script src="resources/ol-geocoder.js"></script>
        <script src="layers/AdamaDistributionLine_1.js"></script><script
src="layers/BoreHole_2.js"></script><script
src="layers/strretlight_3.js"></script><script
src="layers/walkway_4.js"></script><script
src="layers/AdamaRoad_5.js"></script>
        <script
src="styles/AdamaDistributionLine_1_style.js"></script><script
src="styles/BoreHole_2_style.js"></script><script
src="styles/strretlight_3_style.js"></script><script
src="styles/walkway_4_style.js"></script><script
src="styles/AdamaRoad_5_style.js"></script>
        <script src="./layers/layers.js" type="text/javascript"></script>
        <script src="./resources/Autolinker.min.js"></script>
        <script src="./resources/qgis2web.js"></script>
    </body>
</html>
```