ASSESSING AND MODERNIZING INFRASTRUCTURE INVENTORY AND ASSET MANAGEMENT WITH OPEN-SOURCE GIS TOOLS IN ADAMA CITY

Borena Hundesa Angasa

A Thesis Submitted to The Department of Geomatics Engineering

College of Civil Engineering and Architecture

Presented in Partial Fulfillment of the Requirement for the Degree ofMasters of Science

in Geo-informatics Engineering

Office of Graduate Studies

Adama Science and Technology University

September, 2024

Adama, Ethiopia

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Declaration

I declare hereby this research thesis entitled "Assessing and modernizing Infrastructure Inventory and Asset Management with Open-Source GIS Tools in Adama City**"** 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 proposal have been duly acknowledged through citation.

Borena Hundesa ____________________ ________________

Recommendation

I/we, the advisor(s) of this thesis, hereby certify that I/we have read the revised version of the thesis entitled "Assessing and modernizing Infrastructure Inventory and Asset Management with Open-Source GIS Tools in Adama City" by Borena Hundesa submitted in partial fulfillment of the requirements for the degree of Mater's of Science in Geo-informatics Engineering Therefore, I/we recommend the submission of revised version of the thesis to the departmentfollowing the applicable procedures.

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Major Advisor/supervisor Signature Date

Approval page

We, the advisors of the thesis entitled "Assessing and modernizing Infrastructure Inventory and Asset Management with Open-Source GIS Tools in Adama City" and developed by Borena Hundesa hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

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Major Advisor/supervisor	Signature	Date

We, the undersigned, members of the Board of Examiners of the thesis by Borena Hundesa have read and evaluated the thesis entitled "Assessing and modernizing Infrastructure Inventory and Asset Management with Open-Source GIS Tools in Adama City" 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 Geoinformatics Engineering.

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Final approval and acceptance of the thesis proposal is contingent upon submission of its final copy to the Office of Postgraduate Studies (OPGS) through the Department Graduate Council (DGC) and School Graduate Committee (SGC).

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List of Acronyms

CSS	Cascade Style Sheet
GIS	Geographic Information System
HTML	Hypertext markup language
JS	Java Script
OSS	Open-source software
RS	Remote Sensing
USGS	United States Geological Survey
WEBGIS	Web based Geographic Information System

ABSTRACT

Infrastructure asset management stands as a vital cornerstone within the operational framework of any thriving enterprise, demanding meticulous planning and execution to preserve the durability and operational efficiency of the organization's assets. The primary aim of this study revolves around evaluating the efficacy of open-source Geographic Information System (GIS) solutions in enhancing infrastructure inventory and asset management within Adama City. The research methodology employed encompasses indicator selection, requirements analysis, spatial database design, and the development of web mapping applications. Data sources utilized comprise Asset Management Plan (AMP) reports, existing geodatabases, infrastructure and utility data. Field data collection was facilitated through the utilization of QField, a mobile data collection application seamlessly integrated with QGIS tailored for Android devices. Furthermore, the adoption of Open Data Kit (ODK), a versatile suite of open-source tools designed to assist organizations in crafting, deploying, and managing mobile data collection solutions effectively, was advocated. The research delved into an assessment of Adama City's infrastructure asset management system, focusing on road condition evaluations, information system analyses, and the development of logical and physical database models for infrastructure asset management alongside the creation and testing of web mapping applications using the QGIS2 web plugin. This application empowered users to interact with infrastructure data via a user-friendly web-based interface. Ultimately, the research culminated in the establishment of a GIS-based asset management database and a web GIS-based infrastructure asset management system as tangible outcomes. The study concludes by emphasizing the necessity of conducting a comprehensive assessment to bolster understanding regarding Adama City's asset management framework.

Keywords: Infrastructure, Asset management, Database models, web GIS

CHAPTER I: INTRODUCTION

1.1. Background of the study

Infrastructure asset management is an essential component of any successful business. It requires planning and thoughtful execution in order to ensure the longevity and efficiency of the organization's assets. This article will discuss the best practices in infrastructure asset management and how they can help businesses achieve their operational goals. We will also cover the different components of an asset management system, the importance of proper asset tracking, and the benefits of implementing a cost-effective asset management strategy. Infrastructure asset management is the process of managing the lifecycle of infrastructure assets, such as buildings, computers, networks, and other physical assets. It involves planning, budgeting, designing, constructing, operating, maintaining, and eventually decommissioning infrastructure assets. The goal of infrastructure asset management is to ensure that infrastructure assets are available when and where they are needed while also providing value for money and maximizing their longevity. This is done by using a systematic approach to identify, assess, and manage the risks associated with the asset and its environment, such as financial, environmental, and social risks (Mohammadi, et al. 2020).

The management of assets encompasses a multifaceted process that includes evaluating the present state of the asset, forecasting its future requirements, and formulating a comprehensive strategy for overseeing and utilizing the asset throughout its lifespan. This strategy must encompass measures aimed at reducing risks, optimizing performance, and guaranteeing cost efficiency. Moreover, it should take into account sustainable long-term goals and the most effective approaches to achieve them. The overall approach to infrastructure asset management should also consider the economic, social, and environmental factors affecting the asset. It includes understanding the asset's impact on the local community, the environment, and the economy. It also requires understanding the costs and benefits of different management strategies and how they might affect the asset's performance.

Furthermore, infrastructure asset management should also consider how best to leverage technology to improve the management of the asset. This includes using data analytics to improve decision-making and using information systems to coordinate activities across departments and agencies (Hastings, 2015).

The management of infrastructure inventory and assets is pivotal for the sustainable and efficient operation of various systems and services (Li et al., 2018; Smith et al., 2020). With the rapid evolution of technology, Geographic Information Systems (GIS) have emerged as integral tools for monitoring and maintaining infrastructure assets, providing spatially explicit data for informed decision-making (Chen et al., 2019). However, there exists a pressing need to reassess and modernize current asset management practices by embracing the potential of open-source GIS tools.

Open-source GIS tools offer a cost-effective and flexible alternative to proprietary software, enabling organizations to customize and integrate solutions tailored to their specific needs (Jones and Smith, 2017). By leveraging the collaborative nature of open-source communities, infrastructure managers can access a diverse range of tools and resources for enhancing asset inventory and management processes (Brown and Green, 2021).

Adama City, like many urban areas, encounters difficulties in maintaining an up-to-date inventory and effectively managing its infrastructure assets (Addisu et al., 2019). With the escalating population and ongoing urbanization, there is a mounting demand for infrastructure services, intensifying the strain on existing assets (UN, 2014). Consequently, there is a pressing need to investigate innovative solutions to enhance infrastructure inventory and asset management in Adama City.

This thesis seeks to delve into the advantages and challenges associated with the integration of open-source GIS tools into infrastructure asset management strategies, aiming to optimize operational efficiency and resource allocation. By exploring the potential synergies between open-source GIS technologies and asset management practices, this research endeavors to contribute valuable insights to the ongoing discourse on sustainable infrastructure management of Adama City.

1.2. Statement of the Problem

Research in the past has predominantly concentrated on the management of both spatial and non-spatial data within GIS software systems concerning infrastructure. However, these studies have often neglected to integrate efficient geodatabase design principles, which are rooted in relational database management concepts. These principles play a critical role in ensuring the efficient storage and retrieval of large volumes of infrastructure and utility data, which are essential for urban development and management (Smith, 2019).

Moreover, there exists a noticeable gap in the current body of literature regarding the evaluation of the infrastructure asset management system utilized by the Adama Municipality. Understanding the strengths and weaknesses of the current practices is vital for identifying areas of enhancement and improving overall performance in infrastructure management (Jones et al., 2020).

Furthermore, minimal research has been conducted to investigate the data sharing mechanisms among various agencies and organizations operating within Adama city. Establishing effective data sharing protocols is crucial for enhancing coordination, ensuring the dissemination of up-to-date information, and optimizing processes such as scheduling and budgeting for infrastructure projects (Brown & White, 2018).

Adama City, like many other urban centers, encounters challenges in efficiently managing its infrastructure inventory and assets, which are crucial for the city's effective operation and maintenance. Previous studies have pointed out deficiencies in Adama City's infrastructure management system, including inaccurate and incomplete data, limited integration of technological tools, and a lack of systematic frameworks (Merga & Behulu, 2019). The absence of a comprehensive and current inventory of infrastructure assets hampers the prioritization of maintenance, repair, and replacement activities in Adama City. Additionally, the city lacks advanced tools such as open-source Geographic Information System (GIS) applications, which are essential for efficient data analysis and visualization (Admasu et al., 2019). The integration of open-source GIS tools into the existing infrastructure management system is hindered by the lack of an integration framework, limiting data sharing, synchronization, and analysis (Alok, 2016).

Furthermore, the deficiency in a GIS-based asset management system obstructs the optimization of infrastructure management practices and cost-effective solutions (Richard

& Iguisi, 2016). The primary issue lies in the inadequate integration of infrastructure management and data sharing among different entities in the city. Various organizations, including water agencies, electric utilities, and telecommunication providers, independently operate and manage their infrastructures, leading to fragmentation and a lack of coordination, resulting in inefficiencies, redundancies, and suboptimal decision-making in infrastructure management (Alok, 2016).

A significant challenge arises from the lack of integration between agencies responsible for managing critical infrastructure systems. Considering potential interdependencies and conflicts between different systems is crucial when planning new infrastructure projects or maintaining existing ones. However, the absence of a coordinated approach often causes agencies to overlook these interconnections, resulting in suboptimal infrastructure planning and utilization (Bazilian et al., 2011).

Additionally, data sharing poses a significant challenge in the city as each agency tends to collect and maintain data separately, leading to data silos and limited accessibility, inhibiting informed decision-making based on comprehensive and up-to-date information. Effective coordination and collaboration among agencies are hindered, especially when responding to emergencies or planning infrastructure upgrades, due to the absence of shared data (Amos et al., 2020).

The implications of these challenges can be far-reaching. Inefficient infrastructure management can lead to increased costs, service disruptions, and delays in delivering essential services to residents and businesses (Bazilian et al., 2011). Inadequate data sharing impedes the ability to identify and address systemic issues, optimize resource allocation, and plan for future infrastructure needs.

To address these challenges, this research aims to develop a comprehensive approach to infrastructure inventory and asset management in Adama City. This study involves several steps, including evaluating the current state of infrastructure inventory and asset management practices, exploring and assessing customized open-source GIS tools, customizing an existing open-source framework, and implementing and evaluating a GIS-based asset management system. The ultimate objective is to enhance infrastructure management practices, enable evidence-based decision-making, optimize resource allocation, and contribute to the sustainable development of Adama City. By leveraging advanced GIS technologies and implementing an integrated system, Adama City can overcome its infrastructure management challenges and improve the effectiveness of urban infrastructure management (Merga & Behulu, 2019).

1.3. Research Objective

1.3.1. General Objective

The general objective of this research is to assess the effectiveness of open-source GIS-based solutions in improving infrastructure inventory and asset management in Adama City.

1.3.2. Specific Objectives.

1. Assess the current state of infrastructure inventory and asset management practices in Adama City.
2. Develop a spatial database model to enhance the management of infrastructure data.
3. Explore and evaluate open-source applications for data inventory, sharing and visualization capabilities for efficient infrastructure management.

1.4. Research Questions

1. What are the existing infrastructure inventory and asset management practices in Adama City, including data collection, storage, maintenance, and utilization?
2. How can a spatial database model be designed and implemented to effectively manage infrastructure data in Adama City?
3. What open-source applications are available for data inventory, sharing, and Storage for managing infrastructure data in Adama City?

1.5. Significance of the study

This study carries significant implications for both Adama city and the broader domain of infrastructure asset management. Through a thorough assessment of current practices, the creation of a tailored spatial database model, and the utilization of open-source tools for data dissemination, this research endeavors to address critical gaps and obstacles in infrastructure asset management within Adama city. The importance of this study can be understood through several key dimensions.

Primarily, the research findings offer crucial insights into the strengths and weaknesses of Adama city's existing infrastructure asset management strategies. By pinpointing areas for enhancement, the results of this study will contribute to boosting asset performance, streamlining maintenance operations, and optimizing resource allocation. These enhancements will ultimately promote the sustainability and resilience of the city's infrastructure networks.

Secondly, the development of a customized spatial database model crafted specifically for Adama city is poised to revolutionize data management practices. This model is expected to enhance the organization, integration, visualization, and analysis of data, empowering decision-makers with precise and timely information for strategic infrastructure planning and upkeep. Moreover, the use of open-source tools to publish infrastructure data online will significantly enhance data accessibility, transparency, and stakeholder involvement, fostering collaborative decision-making processes.

Moreover, the outcomes of this research will serve as a valuable resource for other cities facing similar challenges in infrastructure asset management. The methodologies, spatial database model, and open-source tools employed in this study can be adapted and replicated to meet the distinct requirements of different urban areas, promoting the wider adoption of effective asset management practices and advancing sustainable urban development initiatives on a larger scale. This study contributes to the body of knowledge in infrastructure asset management by addressing specific research gaps, broadening the understanding of contextual factors, challenges, and strategies involved in optimizing asset performance and maintenance in urban settings. The practical insights, best practices, and innovative approaches derived from this research will enrich the field and offer guidance for managing infrastructure assets in diverse contexts. Ultimately, the improved asset performance resulting from this research will lead to more efficient transportation systems, reliable utilities, and safer urban environments in Adama city, consequently enhancing productivity, attracting investments, and enhancing the overall quality of life for its residents.

1.6. Scope of the study

This thesis aims to evaluate the existing infrastructure inventory and asset management system within Adama City, focusing on key aspects such as asset inventory methods and database management systems. The research scope involves the development of a spatial database tailored to infrastructure and utility assets like roads, walkways, drainage systems, electric poles, and water distribution lines.

By concentrating on fundamental indicators, such as asset inventory techniques and database management, the assessment seeks to provide a comprehensive understanding of the current state of infrastructure management practices in Adama City.

Furthermore, the design of the spatial database is intended to optimize the storage and retrieval of essential asset information, enhancing data accessibility and management efficiency. Specifically, the database design will be tailored to accommodate various infrastructure and utility assets critical for the city's operations and planning.

In addition, a web mapping application will be implemented to facilitate improved decision-making processes and resource allocation. This application, developed using open-source tools and QGIS plugins, aims to provide stakeholders with an intuitive platform for visualizing and analyzing spatial data related to infrastructure assets. Through testing and validation, the efficacy and usability of the web mapping application will be assessed to ensure its practicality in enhancing infrastructure management practices within Adama City.

CHAPTER II: LITRATURE REVIEW

2.1. Evolution of Infrastructure Inventory and Asset Management

This literature review delves into the historical progression of infrastructure inventory and asset management practices, elucidating key advancements and shifts that have shaped the field over time. Initially, infrastructure management predominantly focused on reactive maintenance strategies with minimal long-term planning considerations.

Modern societies are built around and served by physical infrastructure networks, with the ultimate purpose of facilitating the wellbeing of individuals. Infrastructure plays a central role in our lives; it provides us with clean water, energy, and telecommunications; it allows us to travel; and it gives us the means to make food available. Well-managed infrastructure is vital to make nations competitive and has the potential to support social development and economic growth (Frischmann, 2012).

The transition to preventive maintenance strategies in the mid-20th century marked a pivotal shift towards proactive asset management to extend infrastructure lifespan and reduce lifecycle costs. The introduction of Computerized Maintenance Management Systems (CMMS) in the 1980s revolutionized asset management by enabling streamlined tracking of maintenance activities and work orders. Subsequently, the integration of Geographic Information Systems (GIS) technology in the 1990s facilitated spatial analysis, visualization, and enhanced data management capabilities for infrastructure assets. More recently, the emphasis has shifted towards asset performance management, leveraging data-driven insights to optimize asset performance, enhance risk management, and streamline decision-making processes. The integration of Building Information Modeling (BIM) and predictive analytics has further modernized asset management practices, enabling stakeholders to collaborate efficiently, visualize assets in 3D models, and forecast asset performance for informed decision-making (Tang & Gao, 2019).

Looking ahead, the convergence of emerging technologies such as IoT, AI, and blockchain is poised to revolutionize infrastructure asset management, offering new avenues for improved asset monitoring, decision support, and performance optimization. The review also underscores the increasing focus on sustainability and resilience in asset management practices, with considerations for environmental impact, climate change resilience, and adherence to circular economy principles shaping infrastructure decision-making processes. Regulatory standards like ISO 55000 have played a pivotal role in standardizing asset management practices globally, while industry trends continue to evolve, paving the way for a future where technology-driven innovations will continue to redefine how infrastructure assets are managed and maintained (Jain, 2024).

2.2. Importance and Challenges of Infrastructure Inventory and Asset Management

Infrastructure inventory and asset management play a pivotal role in ensuring the efficient operation, maintenance, and sustainability of critical infrastructure systems. Effective asset management practices are crucial for optimizing the performance and longevity of infrastructure assets while minimizing lifecycle costs and maximizing return on investment. Asset management encompasses a systematic approach to identifying, acquiring, operating, maintaining, and disposing of assets, thereby enabling organizations to make informed decisions regarding resource allocation, risk mitigation, and long-term planning (Brown et al., 2017). By maintaining an accurate inventory of infrastructure assets and implementing robust asset management strategies, organizations can enhance operational efficiency, improve service delivery, and enhance the resilience of infrastructure systems against natural disasters and other unforeseen events.

Despite its significance, infrastructure inventory and asset management pose several challenges that organizations must address to ensure effective implementation. One primary challenge is the vast and diverse nature of infrastructure assets, including roads, bridges, utilities, buildings, and transportation networks, among others. Managing this wide array of assets requires comprehensive data collection, analysis, and monitoring processes to track asset condition, performance, and maintenance histories accurately (Feng et al., 2014). Moreover, infrastructure assets are subject to various environmental, operational, and regulatory risks that can impact their performance and lifespan. Balancing competing priorities such as budget constraints, evolving technology, and changing user demands further complicates asset management decision-making, requiring organizations to adopt adaptive and forward-thinking strategies to address these challenges effectively.

Another critical challenge in infrastructure asset management is the integration of disparate data sources and systems to ensure data accuracy, consistency, and accessibility. The lack of standardized data formats, siloed information, and limited interoperability between asset management software platforms can hinder the efficiency of asset management processes and impede informed decision-making (Li et al., 2018). Additionally, inadequate investment in technology, training, and capacity building can pose barriers to implementing advanced asset management practices, limiting organizations' ability to leverage data-driven insights and predictive analytics to optimize asset performance and maintenance activities. Overcoming these challenges requires a holistic approach that combines technology, data integration, stakeholder collaboration, and continuous improvement to enhance the effectiveness and efficiency of infrastructure inventory and asset management practices.

Moreover, challenges of infrastructure inventory and asset management are: (1) Available data might not represent the real deterioration mechanism and might be of different qualities and quantities for different infrastructures. (2) Uncertainties in performance prediction obviously exist in all asset types. On top of that, the level or extent of uncertainties can be different for different asset types. (3) Flexibility in interventions may vary from asset type to asset type. Other challenges of IMAM are scattered in literature and addressed in a quite limited way. Consequently, this article reviews and classifies the existing approaches and highlights the challenges of IMAM in a structured way. It further outlines future research opportunities and knowledge gaps. The focus of this study is mainly on pavements, sewer pipes and drinking water distribution pipes (water pipes). One reason for this is that available IMAM literature is mostly focusing on these three asset types. Second, they can represent the other asset types in the urban fabric (e.g. gas pipes, electric and ICT cables) due to their similarities in layout and behavior from an asset management point of view (Keilhauer, et al. , 2017).

2.3. Role of GIS in Infrastructure Management

Developing countries face unique challenges with the design, construction and operations of new infrastructure. Nations with mature infrastructure have followed traditional technology models for planning, design, construction and operation of facilities. With GIS technology, the development of new infrastructure will follow new technology models eliminating data redundancy, miscommunication, and costly conversion when moving through the planning, design, construction, and operation of infrastructure data. Specific site data requirements for the design and construction of infrastructure are developed for quality engineering design and to minimize and accurately predict construction costs. GIS provides the central data system for the process of developing and constructing infrastructure gives the engineers a common means to communicate geospatial data, maintain current data, and allow iterative design/data collection procedures without exchanging data files of differing format, version, and content. Due to superior spatial data handling capabilities, Geographic Information System (GIS) technology is increasingly being considered for implementation in many infrastructure projects.

Geographic Information Systems (GIS) have revolutionized infrastructure management by providing spatial data analysis, visualization, and decision support tools for effectively managing and maintaining complex infrastructure assets. GIS technology enables organizations to capture, store, analyze, and display geographic information, allowing stakeholders to gain valuable insights into asset location, condition, and performance. By integrating GIS into infrastructure management practices, organizations can optimize asset planning, maintenance scheduling, and resource allocation based on spatial data analysis (Huang et al., 2008). GIS facilitates the creation of detailed asset inventories, mapping infrastructure networks, and identifying spatial relationships among assets, enabling stakeholders to make informed decisions for enhancing infrastructure resilience and operational efficiency.

The application of GIS in infrastructure management extends beyond asset inventory and spatial analysis to encompass a wide range of functions, including asset tracking, risk assessment, and emergency response planning. GIS technology enables real-time monitoring of infrastructure assets, facilitating proactive maintenance activities and minimizing downtime through predictive maintenance strategies (Kumar et al., 2016). By integrating GIS with asset management systems, organizations can streamline data management processes, improve data accuracy, and enhance collaboration among various departments involved in infrastructure planning and maintenance. GIS also plays a crucial role in assessing infrastructure vulnerabilities, identifying potential risks, and developing mitigation strategies to enhance infrastructure resilience in the face of natural disasters, climate change, and other disruptive events.

Moreover, the integration of GIS with emerging technologies such as IoT, remote sensing, and big data analytics offers new opportunities for enhancing infrastructure management practices. By leveraging real-time data from IoT sensors and satellite imagery, GIS can provide valuable insights into asset performance, environmental conditions, and infrastructure health, enabling organizations to optimize maintenance activities, improve asset utilization, and enhance decision-making processes (Wu et al., 2020). The combination of GIS with advanced analytics tools allows for predictive modeling, scenario planning, and risk analysis, empowering organizations to proactively manage infrastructure assets, prioritize maintenance tasks, and allocate resources effectively for ensuring the long-term sustainability and resilience of critical infrastructure systems.

Infrastructure planning involves the design and development of essential facilities and services such as roads, bridges, water supply, and energy distribution. With growing urban populations and the need for sustainable development, planners must make data-driven decisions. This is where GIS plays a vital role.

Site Selection and Analysis

When selecting sites for new infrastructure, GIS helps planners assess the suitability of different locations by analyzing factors like topography, land use, and proximity to existing facilities. For instance, when planning a new highway, GIS can help identify the most efficient route that minimizes environmental impact while considering factors like population density and natural obstacles.

Urban Growth Management

Cities are expanding rapidly, and managing this growth is a significant challenge. GIS assists in mapping current land use and projecting future growth patterns. This information is crucial in developing urban areas that are both functional and sustainable. For example, planners can use GIS to ensure that new developments are located in areas that can support additional population density without overburdening existing infrastructure.

Environmental Impact Assessment

Before any large-scale infrastructure project begins, an environmental impact assessment is usually required. GIS can map sensitive environmental areas, helping planners avoid locations that might lead to significant ecological disruption. This tool aids in balancing development with environmental conservation.

2.4. Review of Open-Source GIS Tools for Asset Management

Open-source Geographic Information System (GIS) tools have gained popularity in asset management practices due to their cost-effectiveness, flexibility, and collaborative features, offering organizations access to a wide range of capabilities for managing infrastructure assets. Open-source GIS tools such as QGIS, GRASS GIS, and GeoServer provide robust functionalities for asset inventory, spatial analysis, and visualization, enabling organizations to streamline asset management processes without the constraints of proprietary software licenses (Haklay, 2010). These tools empower organizations to create interactive maps, analyze spatial data, and share geospatial information across departments, enhancing collaboration and decision-making for asset management tasks.

One key advantage of open-source GIS tools in asset management is the vibrant user community and extensive plugin libraries that offer additional functionalities and customization options to meet specific asset management requirements. Tools like QGIS, with its user-friendly interface and diverse plugin ecosystem, enable organizations to tailor asset management workflows to their unique needs, integrating spatial data from various sources and formats for comprehensive asset monitoring and analysis (Neteler et al., 2012). The open nature of these tools promotes knowledge sharing, innovation, and continuous improvement within the asset management domain, fostering a collaborative environment where users can contribute to the development of new features and tools to enhance asset management capabilities.

Despite the benefits of open-source GIS tools for asset management, challenges such as data interoperability, technical support, and training requirements need to be addressed to maximize their effectiveness in real-world applications. Ensuring data consistency, quality, and security when integrating open-source GIS tools with existing asset management systems is crucial for maintaining accurate asset information and facilitating informed decision-making processes (Sinha et al., 2017). Organizations also need to invest in training programs and technical support to build internal capacity and expertise in utilizing open-source GIS tools effectively for asset management tasks, ensuring that staff members can leverage the full potential of these tools to optimize asset performance, maintenance activities, and infrastructure planning.

2.5. Case Studies of Successful Implementation of GIS in Infrastructure Inventory and Asset Management

Good project planning, at the initial stage, is a key to its successful implementation. Majority of the GIS-based projects are challenging as they need substantial efforts on building the capacity at both ends (user and implementing agencies) for suitably designing the application, considering the constraints in terms of quality and quantity of spatial data. The experience of executing projects involving implementation of GIS suggests that the spiral model of project management is more suited than the waterfall model. Data format and data interoperability are major concerns of the geomatics community. Project scheduling, time management and building a buffer to absorb unforeseen reasons for delays are important components of managing the GIS-based projects. This article discusses the project management approach for the implementation of GIS, with special reference to monitoring projects in infrastructure development.

Several case studies have demonstrated the successful integration of Geographic Information System (GIS) technologies in infrastructure inventory and asset management, showcasing how organizations have leveraged spatial data analysis, visualization, and decision support tools to enhance operational efficiency and optimize asset performance. One notable case study is the implementation of GIS in the City of Riverside, California, where the city's Public Works Department utilized GIS to create a comprehensive inventory of infrastructure assets, including roads, utilities, and facilities. By centralizing asset data in a GIS database, the city improved asset tracking, maintenance planning, and emergency response capabilities, leading to more effective resource allocation and enhanced service delivery to residents (Haklay, 2010). The Riverside case study highlights how GIS can streamline asset management processes, improve data accessibility, and support informed decision-making for sustainable infrastructure management.

Another compelling case study is the application of GIS in asset management by the Tennessee Department of Transportation (TDOT), where GIS technology was employed to monitor and maintain the state's transportation infrastructure network. TDOT integrated GIS with asset management systems to track asset condition, prioritize maintenance activities, and optimize resource allocation for infrastructure maintenance and rehabilitation projects. By leveraging GIS for asset inventory and spatial analysis, TDOT improved asset performance, reduced maintenance costs, and extended the lifespan of critical infrastructure assets, demonstrating the value of GIS in enhancing infrastructure resilience and operational efficiency (Kumar et al., 2016). The TDOT case study underscores the importance of integrating GIS into asset management practices to enhance data-driven decision-making, optimize maintenance strategies, and ensure the long-term sustainability of infrastructure assets.

Furthermore, the successful implementation of GIS in infrastructure inventory and asset management is exemplified by the case study of Singapore's Land Transport Authority (LTA), where GIS technology was utilized to manage the country's transportation infrastructure assets. LTA employed GIS for asset mapping, condition assessment, and predictive maintenance planning, enabling the agency to optimize asset performance, minimize disruptions to transportation services, and enhance public safety. By utilizing GIS for asset management, LTA improved asset monitoring, streamlined maintenance operations, and implemented proactive strategies to address infrastructure vulnerabilities, showcasing how GIS can support comprehensive asset management practices in a complex urban environment (Huang et al., 2008). The LTA case study highlights the transformative impact of GIS in infrastructure asset management, illustrating how spatial data analysis and visualization tools can drive operational efficiency, cost savings, and infrastructure resilience for sustainable urban development.

2.6. Comparison of Open-Source vs. Proprietary GIS Tools for Asset Management

The debate between open-source and proprietary Geographic Information System (GIS) tools for asset management has been a topic of interest in the geospatial community, with studies highlighting the advantages and limitations of each approach. Open-source GIS tools, such as QGIS and GRASS GIS, offer cost-effective solutions for asset management, enabling organizations to access a wide range of functionalities without licensing fees. These tools provide flexibility, customization options, and community support, allowing users to tailor asset management workflows to their specific needs and integrate spatial data from diverse sources for comprehensive asset monitoring and analysis (Neteler et al., 2012). In contrast, proprietary GIS software like ArcGIS by Esri offers advanced features, technical support, and seamless integration with other Esri products, catering to the needs of large organizations with complex asset management requirements.

Open-source software is that kind of software that can be freely used, changed, and shared (in modified or unmodified form) by anyone. Generally, the open-source software is made by many people, and distributed under licenses that comply with the Open-Source Definition. There are currently several open-source GIS software solutions that imposed themselves in GIS environments and gained ground against proprietary GIS branded solutions. The purpose of the present article is to highlight the characteristics of these freeware solutions and some advantages of using them. It's important, however, to distinguish between open-source systems and 'free' systems. For example, quite a lot of software and services today provide some sort of 'free' layer, but in exchange, you are not permitted to do anything with the underlying code (or data), and in most cases, you are effectively giving up your personal information for that company to use for profit. Google Maps, for example, is widely perceived to be 'free' in that way - it doesn't technically take money from you directly to use it, but your interactions with the service are captured and re-used to derive profits for Google. It's also definitely not Open Source - you have no ability to access the source code or to modify and/or re-use their maps beyond what they explicitly permit.

Research comparing open-source and proprietary GIS tools for asset management has shown that the choice between the two often depends on factors such as budget constraints, IT infrastructure, user expertise, and data security requirements. Open-source GIS tools are favored for their affordability and collaborative features, making them accessible to organizations with limited financial resources or those seeking customizable solutions for asset management tasks. However, challenges such as data interoperability, technical support, and training needs may pose obstacles to the widespread adoption of open-source GIS tools in asset management workflows (Sinha et al., 2017). In contrast, proprietary GIS tools provide a comprehensive suite of functionalities, user-friendly interfaces, and dedicated technical support, appealing to organizations that prioritize seamless integration, data security, and reliability in asset management operations.

Case studies comparing the implementation of open-source and proprietary GIS tools in asset management have highlighted the strengths and limitations of each approach in real-world applications. For example, the City of Portland, Oregon, successfully leveraged open-source GIS tools to develop a comprehensive asset management system for tracking and maintaining public infrastructure assets, showcasing the versatility and cost-effectiveness of open-source solutions in municipal asset management (Haklay, 2010). In contrast, multinational corporations and government agencies often opt for proprietary GIS software like ArcGIS for its advanced spatial analysis capabilities, enterprise-level support, and compatibility with industry standards, demonstrating the value of proprietary solutions in managing complex asset portfolios across diverse geographic regions (Kumar et al., 2016). The comparison of open-source and proprietary GIS tools for asset management underscores the importance of evaluating organizational needs, technical requirements, and long-term sustainability goals to determine the most suitable GIS solution for optimizing asset performance, maintenance activities, and decision-making processes.

2.7. Best 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.

2.8. 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.

2.9. 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).

2.10. Land asset management Modeling

The topic of asset management has grown in importance and scope over the last decade. According to the international Organization for Standardization (ISO 55000, 2014), asset management and planning is defined as an integrated activity to realise a value from a system of assets. This definition encompasses a wide range of decision problems related to the whole-life-cycle of the asset to deliver value to the asset owners and stakeholders. Asset management touches and intersects with many areas and functions within the oranimation, such as workforce planning, maintenance, and supply chain management. Both the public and private sectors have various degrees of asset management responsibilities, forming an essential component of good governance. Organizations with large asset holdings require an asset management framework which is both well-structured and practical to assist them in providing stakeholders with clarity regarding the relationship between asset levels and the expected outcomes, and ultimately improve decisions on asset management. Understanding how assets can be better aligned with expected outcomes will also benefit organizations with smaller asset holdings. In short, organisations must ensure that their investment in assets is matched to program requirements, and where applicable, to take a strategic approach to asset replacement in accordance with the Government's capital budgeting framework. (Commonwealth of Australia, 2010).

There are numerous benefits associated with good management of assets. Informed investment decision, improved services and demonstrated compliance represent only a few of these benefits. Both business and government alike are recognizing these benefits more than ever before and this recognition has been reflected in several factors such as the publication of numerous reports regarding the management of public assets, and the emergence of the international standard on asset management (Asset Management Council). Asset planning and management can be viewed as a complex and dynamic problem, as it exhibits several challenging features for decision making (Sterman, 2000).

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Path-dependence: decisions are long-term and largely irreversible. The decision to buy a particular asset often involves a large investment with long-term operational and economic impacts. Dynamic complexity: the performance of any selected strategy is influenced by feedback interactions among decisions made by dispersed functions and divisions, including acquisition policies, resourcing decisions, workforce planning decisions, and supply-chain management.Characterized by delays and trade-offs: planners are faced with the challenge to make decisions now whose outcomes can vary at different temporal scales and performance dimensions.

Tightly coupled subsystems: sharing resources among different entities (e.g. spatial regions, assets) and activities creates tightly coupled relationships among assets and their constituent systems. Reductionist thinking that fails to account for these interdependencies may lead to suboptimal outcomes of improving the performance of one asset or a function on the expense of another.

Conceptual modeling:

Conceptual models serve as abstract, psychological representations of how tasks should be carried out. People often use these models subconsciously and intuitively to systematize processes. Let's delve into the world of conceptual models:

Conceptual models are abstractions that help us understand how things work. They provide a mental framework for interpreting and interacting with systems. For instance, when creating appointments, our mental model might involve calendars and diaries.

Design Implications: Designers leverage conceptual models to tailor software that aligns with users' mental models. By echoing these models in interfaces and apps, designers build on existing knowledge, making it easier for users to learn new products.

Development Process: Conceptual models are identified early in the design process and serve as a constant reference for direction and inspiration. They guide designers in creating intuitive applications.

Creating Conceptual Models:

- User Research: Designers gather information from user research (interviews, surveys, observations).
- Visual Representation: Using this data, they create visual representations of how users perceive and interact with a system. These representations can take various forms, such as flowcharts, diagrams, wireframes, or prototypes.
- Benefits of Conceptual Modeling:

Conceptual models – What are they and how can you use them?

This 2017 post by Andrew Powell-Morse provides a good introduction to these models. He explores what conceptual models are, how they are most commonly implemented, and touches on a few advantages and disadvantages of using conceptual models in the realm of software development. The process of determining what to model is known as conceptual modeling. He acknowledges a balance in getting the right level of detail – make it too complex and it may not be possible to complete the model with the time and knowledge available, make it too simple and the results may not be sufficiently accurate. In this paper we explore conceptual modeling first with an illustrative example from a healthcare setting. Conceptual modeling, its artefacts and requirements are then defined. Finally, a framework for helping a modeler to determine the conceptual model is briefly outlined.

The conceptual modelling stage in a simulation project is very important and yet is still generally regarded as more of an art than a science. In this paper Roger Brooks sets out some of his views on conceptual modelling. The meaning and nature of conceptual modelling are discussed and a framework set out. The overall aim should be to choose the best model for the project and conceptual modelling can be viewed as a difficult optimization problem that can be tackled effectively using a creative search process that develops alternative models and predicts their performance throughout the project. Based on advice from the literature and personal experience principles of conceptual modelling are suggested.

Developing conceptual models is also a key step in developing indicators for sustainable and performance-based management. Another related page in this section provides a number of links outlining how to develop programmed-based outcomes models, also called intervention logic models. A number of pages cover related approaches to problem structuring and framing, especially systems thinking, systemic design and systems thinking tools.

Logical modeling:

The international society has formulated demands on the cadastral organizations, among others the Voluntarily Guidelines on the Responsible Governance of Tenure of land, fisheries and forest in the context of national food security (FAO 2012) which includes the following principles for implementation of land reforms and the services that an efficient land administration organization should be able to deliver:

− Human dignity; Non-discrimination; Equity and justice; Gender equality; Holistic and sustainable approach; Consultation and participation; Rule of law; Transparency; Accountability; Continuous development; Responsible Governance of Tenure of organizational development (Land Fisheries and Forests,2012).

− Management capacity and structure (Management in control of its human, technical and financial resources)

− Appropriate financing of the services, directly from the client and/or indirectly through the national treasury.

− Clear responsibilities and follow-up/reporting systems, incl. finance and time management

Risk management

− Professional staff (in-house and/or sourced) for core and support tasks Continuous improvements of work processes

− Proper technology, incl. ICT, based on a realistic strategy for information management

− Communication inside the organization as well as with external stakeholders and the general public

Physical modeling:

Physical modeling is an established tool in geotechnical engineering for studying complex interaction problems involving soils. This chapter provides an overarching narrative of different aspects of such physical modeling include the challenging issue of designing meaningful (useful) tests and interpretation of the results for predicting prototype consequences. There are mainly two types of scaled physical modeling: (a) geotechnical centrifuge modeling under enhanced pseudo-gravity and (b) scaled modeling under 1-g, i.e., (Earth's gravity). Both approaches are briefly described together with the advantages and disadvantages. Furthermore, this chapter also discusses the two types of methods for designing and scaling model tests: (a) use of standard scaling laws available in textbooks which is "*Black-box*"-type modeling and (b) mechanics-based scaling. Few physical modeling examples (such as buckling instability of piles in liquefied soils, behavior of buried pipelines crossing faults and landslides, response of foundations for offshore wind turbines) are considered to show the mechanics-based scaling method. It has been shown that none of the techniques is perfect, and one needs the right tool for the right job. Black-box type modeling is suitable for simple interaction problems. However, for an unknown-unknown problem (typical of a multiple interaction problem), mechanics-based scaling method is appropriate. Do's and Don'ts in physical modeling are discussed.

The physical design involved structuring all geospatial and non-spatial data in a format acceptable by the implementing software and hardware. For this project, relational (table) structuring method was used due to its easy implementation and management. Point, line, and polygon layers were created for spatial objects on the digital cadastral map, and attribute data needs of the database were also structured in tables to enable information storage, retrieval, and updates, as well as analytical functions to be performed (Nwaka et al., 2021).

2.11. Empirical Research Review

Numerous studies have showcased the successful implementation of open-source GIS tools in infrastructure management, emphasizing the benefits of integrating GIS with asset management systems. This integration has been shown to enhance maintenance planning, resource allocation, data accuracy, and decision-making processes (Zhang et al., 2020). For instance, Zhang et al. (2020) integrated GIS technology with asset management systems in a Chinese city, improving infrastructure maintenance planning and resource allocation by visualizing and analyzing asset condition and performance.

Similarly, Xu et al. (2018) focused on open-source GIS tools for water infrastructure management, enhancing data accuracy and decision-making processes through spatial data integration. These studies underscore the advantages of open-source GIS tools in infrastructure management, offering customizable solutions for various sectors, including transportation, water, energy, and telecommunications.

While existing literature has concentrated on managing specific assets like roads or water distribution lines using open-source tools, there is a noticeable research gap in integrated infrastructure and utility management with these tools. The absence of frameworks compounds this gap, hindering the implementation of integrated management strategies effectively.

Integrated infrastructure and utility management are pivotal due to the interconnected nature of assets and utilities, impacting overall system performance. Leveraging open-source tools for integrated management remains largely untapped, particularly in developing countries like Ethiopia. Addressing this gap through further research that explores interdependencies between assets and utilities, evaluates the benefits and challenges of open-source tools, and develops structured frameworks is crucial for optimizing infrastructure and utility management.

By bridging this research gap, practitioners and policymakers can harness the potential of open-source tools for integrated infrastructure and utility management, leading to enhanced performance, cost-effectiveness, and sustainability

CHAPTER III: RESEARCH MATERIAL AND METHODOLOGY

3.1. Description of the Study Area

The study area (**Fig.3.1**) viz. Adama City is extending between geographic coordinates of at 8° 30′ 52.1172″N latitude and 39° 16′ 9.3252″ E longitude at some 80 Kilometers away from Addis Ababa City. The maximum elevation of the city is 1712 meters above mean sea level. Owing to its geographical proximity to international port of Djibouti within the distance of about 777 Kilometers, the city is one of the preferred destinations for trade and industry.

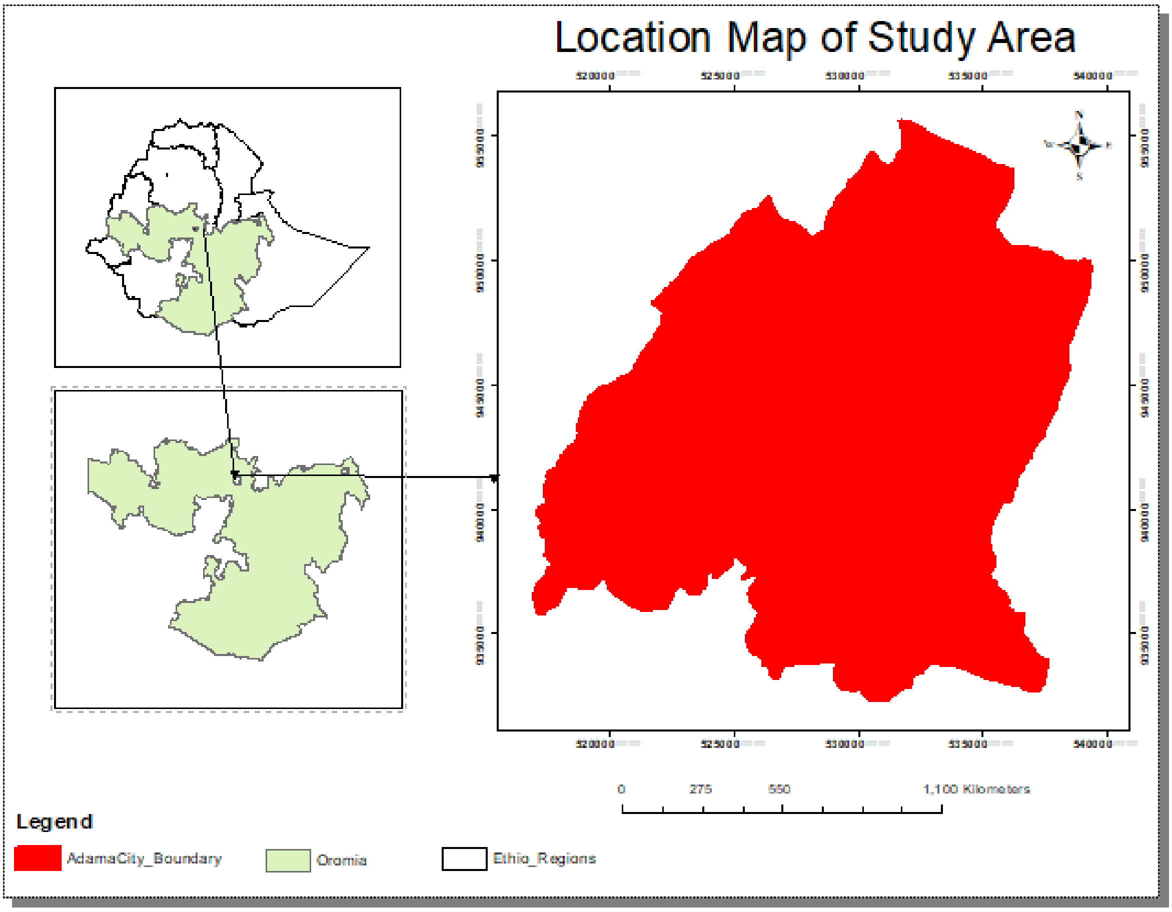

Figure 3.1. Location map Adama city

3.2. Required data and software

The primary focus of this research was on gathering and analyzing data pertaining to infrastructure and utilities, along with assessing the current state of assets and developing spatial database and publishes on the web. To accomplish this, various software tools was utilized, including ArcGIS, QGIS, and additional plugins like QGIS WEB2 and Qui map services GITHAB account. These tools aid to effectively examine and understand the infrastructure and utility systems, as well as the condition of assets.

3.2.1. DATA SOURCE

The studies were mainly supported by 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 Data	Adama municipality
4	Utility Data	Adama municipality

3.2.2. REQUIRED SOFTWARE

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, Geodatabase Creation
2	Postgresql /PostGIS	Spatial database management system
3	QGIS Plug-in /qgis2web, Quick Map services	For web GIS application
4	Notepad++	For organizing and running the codes

5	HTML, CSS, Java Script and Open layers	For customizing the web mapping applications

3.3. Description of Methodology

The methodology comprises several key steps to enhance infrastructure asset management practices in Adama city. To begin, a comprehensive literature review is conducted, focusing on existing studies, ISO 55000 standard, frameworks, and best practices in infrastructure asset management. Data is then collected from various sources, including the infrastructure Geodatabase, maintenance records, financial reports, and Asset management plan from Adama city's infrastructure departments. Additionally, interviews are conducted with key stakeholders to gather their valuable perspectives. Assessment indicators are developed based on ISO 55000 standard. The collected data is analyzed to identify patterns, trends, strengths, weaknesses, and areas for improvement in infrastructure asset management practices. Based on these findings, recommendations are provided to improve infrastructure asset management practices in Adama city.

Furthermore, the methodology involves requirement analysis to identify specific needs for infrastructure asset management. A spatial database model is designed to efficiently store, organize, and retrieve infrastructure data, incorporating the identified requirements. Data integration is carried out, integrating various data sources such as GIS data, asset inventories, maintenance records, and spatial information into the spatial database model. The spatial database model is then tested and validated using sample data to ensure its functionality, performance, and usability.

To devise an efficient spatial database model that can adeptly store, organize, and retrieve infrastructure data while aligning with the specified requirements, a systematic research methodology can be employed. This methodology encompasses three key stages: conceptual, logical, and physical database modeling. In the conceptual stage, entities relevant to infrastructure asset management, such as roads, bridges, buildings, and utilities, are identified and their relationships and attributes defined. The logical stage involves translating the conceptual model into a relational database design, including mapping entities, relationships, and attributes to tables, establishing primary and foreign keys, and ensuring data normalization. Finally, in the physical stage, the logical design is transformed into a physical implementation, considering the target database management system and optimizing storage structures, access methods, spatial indexing techniques, and performance optimization strategies. By following this research methodology, an effective spatial database model can be crafted to proficiently handle infrastructure data management needs.

In addition, the methodology includes the selection of open-source tools suitable for publishing infrastructure data on the web. Factors such as data formats, visualization capabilities, scalability, and user-friendliness are considered during the tool selection process. The infrastructure data is prepared to ensure data quality, consistency, and compatibility with the selected tools. The chosen open-source tools are implemented to create a web-based platform for publishing infrastructure data. Finally, the web-based platform is thoroughly tested for functionality, performance, and compatibility across different browsers, with optimization measures implemented as necessary.

In this research the proposed research methodology are as follows:

1. Literature review

The literature review is a crucial first step in the proposed research methodology to enhance infrastructure asset management practices in Adama City. This comprehensive review serves several key purposes. Firstly, it helps the researcher identify the current state of knowledge by examining existing academic and industry studies related to infrastructure asset management. This exploration of the latest developments, theories, and standards like ISO 55000 in the field provides a solid understanding of the current understanding and best practices in infrastructure asset management in this research. Secondly, the literature review analyzes successful approaches by investigating frameworks, strategies, and case studies of effective infrastructure asset management practices implemented by other cities, municipalities, or organizations. Understanding these successful approaches can aid in identifying potential solutions and adaptable strategies for Adama City.

Thirdly, the literature review recognizes emerging trends in the field, exploring the latest technologies, data management techniques, and innovative practices that are shaping infrastructure asset management. Identifying these emerging trends can help the researcher anticipate future challenges and develop forward-looking solutions for Adama City. Fourthly, the literature review establishes a strong theoretical foundation for the research project by providing an understanding of the underlying principles, concepts, and frameworks that guide effective infrastructure asset management. This theoretical grounding ensures that the research is rooted in established knowledge and best practices. Finally, the literature review helps the researcher identify gaps in the existing knowledge and research, pinpointing areas where further exploration or empirical investigation is needed, particularly in the context of Adama City. Identifying these gaps guides the researcher in focusing their efforts on addressing the specific needs and challenges of the city.

2. Data Collection

The data collection phase of the research methodology was a comprehensive approach that involved gathering information from multiple sources to develop a deep understanding of Adama City's infrastructure asset management practices. The researcher accessed and analyzed the city's infrastructure Geodatabase, which contained detailed spatial and attribute data on the location, type, condition, and performance of the various infrastructure assets. By combining data from these diverse sources, the researcher developed a holistic understanding of Adama City's infrastructure asset management practices, which informed the subsequent steps of the research methodology.

3. Indicator selection

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

4. Data Analysis

The data collected during the comprehensive research process was meticulously analyzed to gain a deep understanding of Adama City's infrastructure asset management practices. The researcher employed a rigorous analytical approach, 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 enabled 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.

5. Requirement Analysis

Recognizing the importance of tailoring the proposed solutions to the unique context and needs of Adama City, the researcher conducted a thorough requirement analysis. This crucial step involved a deep dive into the specific challenges, pain points, and priorities faced by the city in managing its infrastructure assets. By engaging with city officials, infrastructure managers, and experts, the researchers gained valuable insights into the operational, managerial, and organizational constraints that hindered the city's ability to effectively maintain and optimize its infrastructure. The requirement analysis ensured that the recommended solutions would be closely aligned with Adama City's unique circumstances, addressing the most pressing issues and delivering tangible improvements to the city's infrastructure asset management.

6. Spatial Database Design

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

7. Web Mapping Applications

The researcher recognized 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 would best meet the city's requirements.

The selection process considered 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 ensured that the chosen tools would seamlessly integrate with Adama City's existing infrastructure data and provide a seamless, intuitive experience for end-users.

3.4. General workflow

The research approach is illustrated in the accompanying figure.

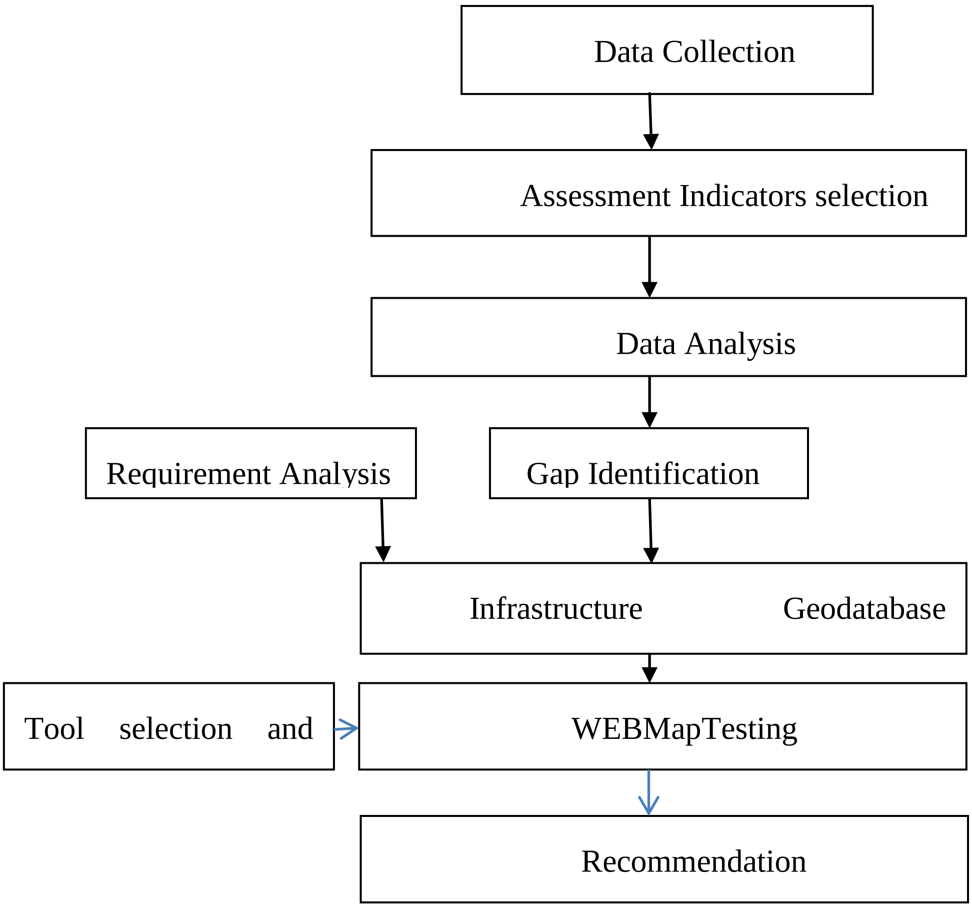

Figure 3.2 Research Methodological Flowchart

By employing this methodology, the research aims to not only assess the current state of infrastructure asset management in Adama City but also to enhance data sharing, improve system efficiency, and optimize infrastructure management practices. The utilization of geodatabases, GIS software, and web applications allows for a comprehensive approach to infrastructure management that can lead to better decision-making and resource allocation within the municipality.

The research methodology begins with the comprehensive collection of all available resources and infrastructure data from the municipality of Adama City. This initial step involves gathering both spatial and non-spatial information related to the infrastructure and utilities present in the city. Subsequently, a thorough literature review is conducted to identify relevant assessment indicators that will be used to evaluate the current infrastructure asset management system. These indicators are carefully selected based on existing literature, ensuring that they align with the collected infrastructure and utility data.

Following the indicator selection, an assessment is carried out to determine the strengths and weaknesses of the current infrastructure asset management system in Adama City. This evaluation process aims to provide insights into the effectiveness and efficiency of the existing system, highlighting areas that require improvement. Based on the nature of the infrastructure data and the specific requirements of the municipality, a suitable relational geodatabase is designed and implemented. This geodatabase is created using ArcGIS and Postgreql with the PostGIS extension, enabling efficient management of spatial data within the infrastructure asset management system.

To facilitate the sharing of infrastructure data among different organizations and within the municipality, a web GIS application is customized. Leveraging open-source opportunities, tools like QGIS and OpenLayers are utilized to develop this application. QGIS, as an open-source desktop geographic information system, enables the manipulation and analysis of geospatial data, while OpenLayers, an open-source JavaScript library, is employed for displaying dynamic maps in web browsers. By customizing a web GIS application, the research aims to streamline the exchange of infrastructure data, promoting collaboration and enhancing decision-making processes within and between organizations in Adama City.

4. CHAPTER IV. RESULTS AND DISCUSSIONS

4.1. Assessment of Adama City's Asset Management System

The evaluation of Adama City's asset management system is detailed in this section, with a focus on the Inventory dimension, which centers on capturing comprehensive data regarding the physical attributes, utilization, maintenance history, planned work, costs, and resources related to assets. The data collection process is tailored to meet the agency's decision-making needs and resource availability. Three key indicators are used to assess the inventory methods: Reference System, Inventory Methods and Frequency of Data Collection, and Technology/Instrument. The primary data for this dimension is gathered through semi-structured interviews with management officials and subject matter experts, providing valuable insights into the employed inventory methods.

The assessment results for each dimension in the framework are presented based on their efficiency or maturity level, enabling a thorough analysis of the road asset management system in Adama City. The study delves into the Reference System aspect, emphasizing the significance of assigning a Unique Reference Identifier to each road asset element for a systematic road inventory. While the intended method involved a structured approach for assigning IDs, the study revealed a deviation from the original plan towards an incremental approach. The importance of adhering to the designated reference system for assigning IDs to road assets is underscored, as it enhances data organization, analysis, and decision-making within the city’s asset management system.

Furthermore, the study addresses the Inventory Methods, Frequency of Data Collection, and Technology/Instrument aspects. It outlines the current manual data collection process and suggests advancements such as incorporating GPS-enabled mobile applications and small laser scanners for more detailed data collection on asphalt pavement structures. By highlighting the limitations of existing inventory methods and instruments, the study advocates for modernization and upgrade to ensure efficient data collection processes for improved asset management in Adama City.

The importance of Data Storage and Management is also emphasized, evaluating aspects such as Database Performance/Technology, Level of Detail, and Simplicity and Security. The study identifies shortcomings in the current data storage practices, including issues related to data consistency, integrity, redundancy, and data sharing mechanisms.

Recommendations are provided to explore alternative database solutions for better performance and to establish systematic processes for updating data regularly. By emphasizing the need for comprehensive and accurate representation of road assets, the study stresses the significance of maintaining updated databases and capturing detailed information for informed decision-making and effective asset management strategies in Adama City.

4.2. Road Condition Assessment Methods

The assessment of road asset conditions is a critical component in determining appropriate management strategies and evaluating the current state of these assets. Typically, this evaluation involves utilizing performance measures aligned with the agency's objectives, which can include condition indices, the percentage of the network in good condition, and the remaining lifespan of assets. Within the domain of road condition assessment methods, two key indicators stand out: Condition Assessment Techniques and Technology.

Condition Assessment Techniques presently involve evaluating road conditions at the route level through methods like visual inspection performed by experienced staff members. The results are then classified using simple Excel formulas based on factors like remaining useful life or deterioration percentage. However, there is a growing preference for segment-level assessments leveraging modern approaches that employ advanced methods and technologies to collect detailed and precise data about individual road segments.

By adopting modern technologies such as laser scanners and sensor technologies, organizations can gather precise measurements of parameters like pavement distress and structural integrity. These advanced tools enable a thorough understanding of each road segment's condition, facilitating targeted maintenance interventions. Additionally, incorporating data analysis techniques such as machine learning algorithms enhances the efficiency and accuracy of condition assessments, offering valuable insights into deterioration trends and future performance expectations.

The research underscores the recommendation to transition from traditional assessment methods towards segment-level evaluations using contemporary technologies for improved accuracy, efficiency, and speed. Embracing tools like laser scanners, ground-penetrating radar, and advanced data analysis algorithms can revolutionize the road condition assessment process, leading to more informed decision-making, efficient resource allocation, and enhanced maintenance strategies. Integrating open-source tools like QField and QGIS can further streamline field data collection and analysis, empowering organizations to make data-driven decisions and optimize road asset management in Adama city.

4.3. Information system

The discussion surrounding Information Systems in the research focuses on three primary aspects: ICT infrastructure/Technology, Performance Evaluation and Costing, and Planning and Scheduling.

In terms of ICT infrastructure/Technology, the study uncovers that the agency lacks a dedicated Information and Communication Technology (ICT) infrastructure and an asset register. Instead, individual experts within the agency utilize personal computers to document core attributes of road assets, indicating a decentralized approach without centralized systems for effective asset management and tracking.

The agency heavily relies on manual systems and Excel spreadsheets for generating valuation and renewal forecasting reports, implying that these critical tasks are primarily conducted manually without specialized software support. This reliance on manual processes poses challenges such as difficulty in maintaining accurate and up-to-date records, scattered information across devices leading to inefficiencies, inconsistencies, and data duplication, jeopardizing effective asset management.

Furthermore, the research reveals that the manual systems and spreadsheet-based methods employed for valuation and renewal forecasting reports expose the agency to risks of errors and inconsistencies in data. Human errors in manual data entry and the limitations of spreadsheet solutions without robust validation mechanisms can compromise the reliability and accuracy of reports, potentially impacting decision-making related to asset management, budgeting, and planning for asset renewals.

To address these challenges, the research recommends investing in establishing an ICT infrastructure and an asset register, centralizing data management through a database or asset management system to enhance data accuracy, sharing, and collaboration. Transitioning from manual processes to dedicated software solutions for valuation and renewal forecasting is advised to improve efficiency, reduce errors, and enhance data analysis capabilities, enabling informed decision-making for asset valuation and renewal planning.

4.4. Developed Database models

In this phase of the study, a structured approach was employed to design and establish an infrastructure geodatabase. This process was primarily driven by the need to address deficiencies in infrastructure asset management practices, which were identified through a detailed analysis of requirements. The subsequent sections will elaborate on the specific methodologies utilized to craft and implement the infrastructure geodatabase, shedding light on the critical factors that guided the decision-making process. The outcomes derived from this phase will also be meticulously expounded upon.

Within the domain of the conceptual database model, the central focus revolves around identifying and delineating the entities crucial for effective asset management within a designated infrastructure and utility data framework. These entities function as fundamental elements within the system, serving as the foundational units for structuring and representing the data. Examples of such entities encompass Road, Median, Drainage, Electric Pole, Electric Line, Water Distribution Line, Water Transmission Line, Reservoir, Walkway Line, Transformer, Bridge, and Administrative Building.

The conceptual model further delves into establishing the relationships and connections between these entities. For instance, the Road entity may exhibit relationships with other entities like Median, Drainage, and Bridge, underscoring their interrelatedness within the system. These relational links play a pivotal role in defining the logical interconnections and dependencies among the various entities, thereby enhancing the overall coherence of the system.

Additionally, attributes or characteristics are assigned to each entity to capture pertinent information accurately. These attributes furnish specific details about each entity, encompassing aspects such as its geographical location, condition assessments, capacity, and other pertinent data points. Through the delineation of these attributes, the conceptual model ensures that requisite information is meticulously stored and associated with each entity, facilitating comprehensive data management practices.

In essence, the conceptual database model serves as a top-level representation of the spatial database model, delineating the entities, relationships, and attributes essential for fostering efficient asset management practices within the specified context. This model not only provides a structured framework for organizing and managing data but also lays the foundation for streamlined asset management processes within the infrastructure and utility domain.

4.4.1. The logical database model of land asset management:

The logical database model represents the transition of the conceptual model into a relational database design tailored for implementation within the ArcGIS and PostgreSQL/PostGIS software environments. This phase is dedicated to crafting a well-defined framework capable of effectively storing and managing data associated with 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 a structured system that streamlines data storage and manipulation processes.

Within the logical model, each entity outlined in the conceptual model is translated into a corresponding table, with the attributes linked to these entities transforming into columns within the respective tables. This mapping procedure ensures that data is systematically organized, promoting efficient data retrieval and manipulation. The assignment of primary keys to each table is crucial for maintaining data integrity, as these keys guarantee the uniqueness of each record within a table, simplifying the identification and referencing of specific data entries.

The establishment of relationships between tables is facilitated through the utilization of foreign keys, which encapsulate the connections between associated entities. By interlinking tables via foreign keys, the logical model solidifies the relationships between different entities within the database, enabling the seamless retrieval of interconnected information. To enhance data consistency and integrity, normalization techniques are applied to the tables, streamlining data storage by eliminating redundancy and reducing the likelihood of database inconsistencies or anomalies.

Moreover, the logical model enforces the specification of appropriate data types and constraints for each column in the tables. Data types define the format and nature of data permissible in a given column, ensuring uniformity and accuracy. Constraints, such as unique constraints and data validation rules, are implemented to enforce specific regulations or conditions on the data stored in the columns, thereby upholding data quality and validity standards. In essence, the logical database model refines the conceptual model into a methodical and structured relational database design, fostering data integrity and facilitating efficient data retrieval and management within the context of ArcGIS and PostgreSQL/PostGIS software platforms.

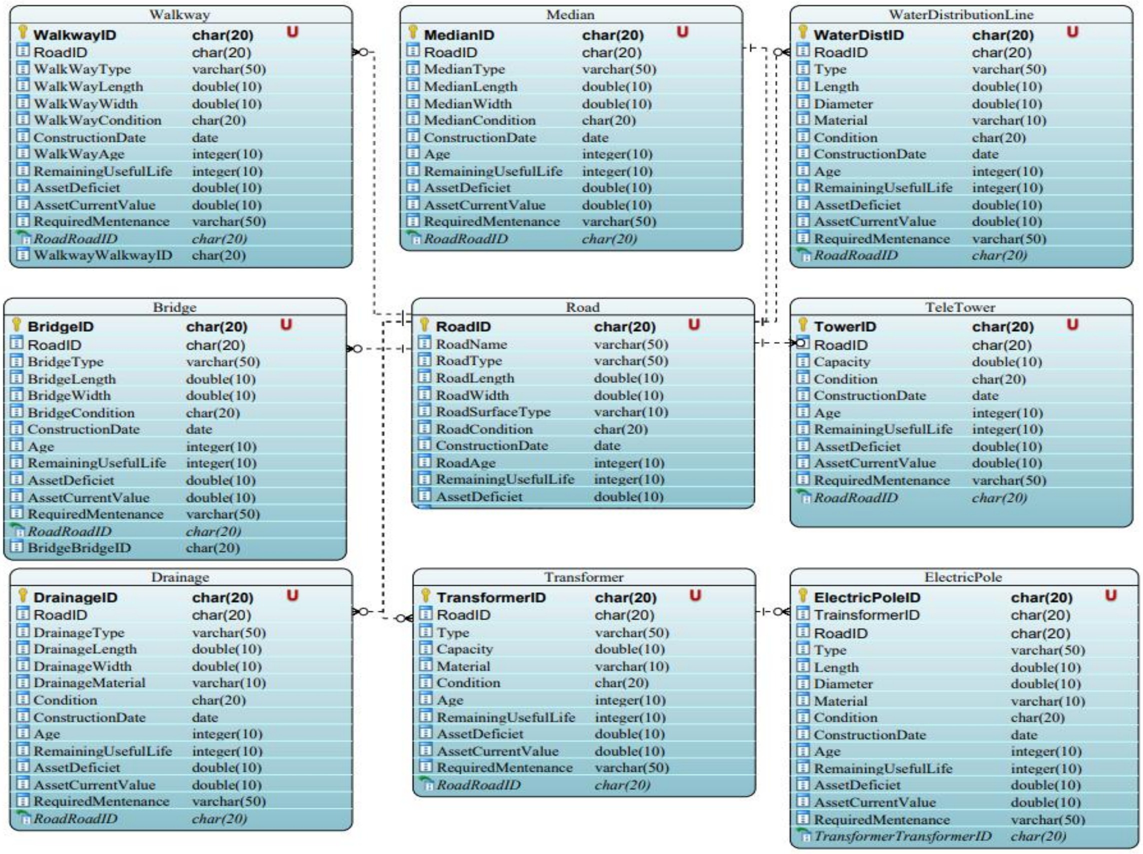

Figure 4.1 Logical database Model

The logical diagram presented offers a visual depiction of the interconnections among multiple tables in the realm of road infrastructure management, emphasizing the relationships between the road table and other pertinent tables in the database. Specifically, the road table showcases a one-to-many relationship with the water distribution table, indicating that a single road can be linked to numerous water distribution records, while each water distribution entry corresponds to only one road. This linkage is facilitated by the road ID, serving as a unique identifier for each road and enabling a seamless association between the two tables.

Likewise, the road table exhibits one-to-many relationships with the walkway, drainage line, and transformer tables, signifying that a road can have multiple associated records in these tables, whereas each record in the walkway, drainage line, and transformer tables is connected to a single road. These relationships are established based on the road ID, acting as a common denominator that effectively links the tables.

Furthermore, a one-to-one relationship is observed between the road table and the median table, implying that each road record corresponds to a single median record, and vice versa. The road ID functions as the pivotal identifier aligning the road and median tables, ensuring the accuracy and uniqueness of this relationship. In essence, the logical diagram offers a comprehensive overview of how the road table intertwines with various tables in the database, showcasing diverse 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, streamline data retrieval and management processes within the road infrastructure management framework.

4.4.2. The physical database model of land asset management:

The implementation of the physical database model on both the ArcGIS geodatabase and the PostgreSQL/PostGIS spatial database was a strategic decision aimed at harnessing the strengths of both platforms. By leveraging the capabilities of ArcGIS geodatabase, the research aimed to capitalize on functionalities such as relationship attachment and topology management, which are integral for maintaining complex spatial relationships within the database. This choice allowed for the establishment of robust spatial relationships and attachments, thereby enhancing the overall integrity and coherence of the data stored in the system.

Simultaneously, the integration of the physical database model with PostgreSQL/PostGIS spatial database was motivated by the desire to directly link the web mapping application to the database, facilitating seamless data access and interaction. By connecting the web mapping application directly to the PostgreSQL database, the research sought to streamline data retrieval and dissemination processes, enabling real-time access to spatial data for end-users. This direct connection not only enhanced the efficiency of data retrieval but also fostered a more interactive and dynamic user experience within the web mapping application.

The implementation on both platforms also catered to the diverse requirements of the research project, ensuring a comprehensive approach to spatial data management and accessibility. While ArcGIS provided specialized functionalities for spatial data management and analysis, PostgreSQL/PostGIS offered a robust foundation for storing and querying spatial data efficiently. This dual implementation strategy enabled the research project to benefit from the strengths of each platform, creating a synergistic environment that maximized the utility and effectiveness of the physical database model for infrastructure asset management.

In essence, the integration of the physical database model on ArcGIS geodatabase and PostgreSQL/PostGIS spatial database represents a strategic fusion of capabilities to enhance spatial data management and accessibility. By combining the functionalities of ArcGIS for spatial relationships and attachments with the direct connectivity of PostgreSQL for web mapping applications, the research project aimed to optimize data integrity, accessibility, and user experience. This dual implementation approach underscored a commitment to leveraging the strengths of both platforms to create a robust and versatile spatial data management system tailored to the specific needs of infrastructure asset management.

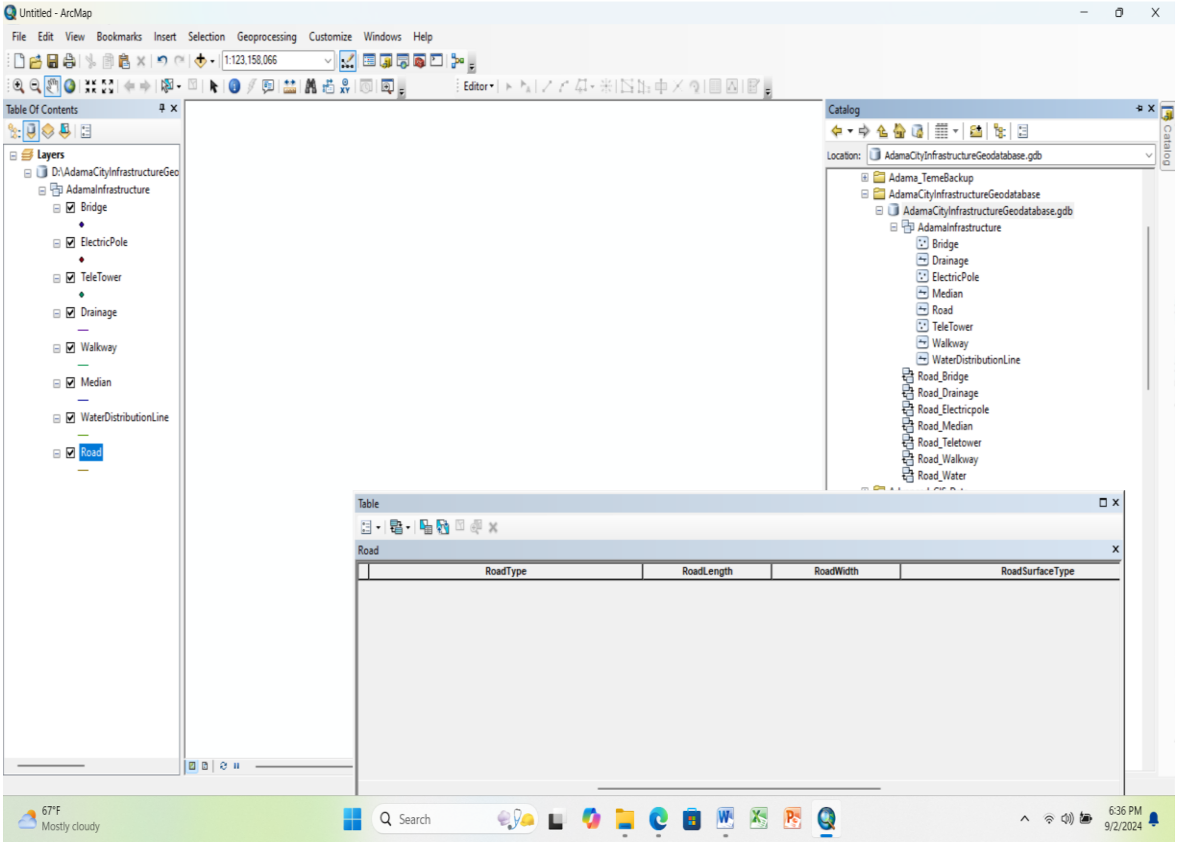

Figure 4.2 Empty Schema of the model on ArcGIS

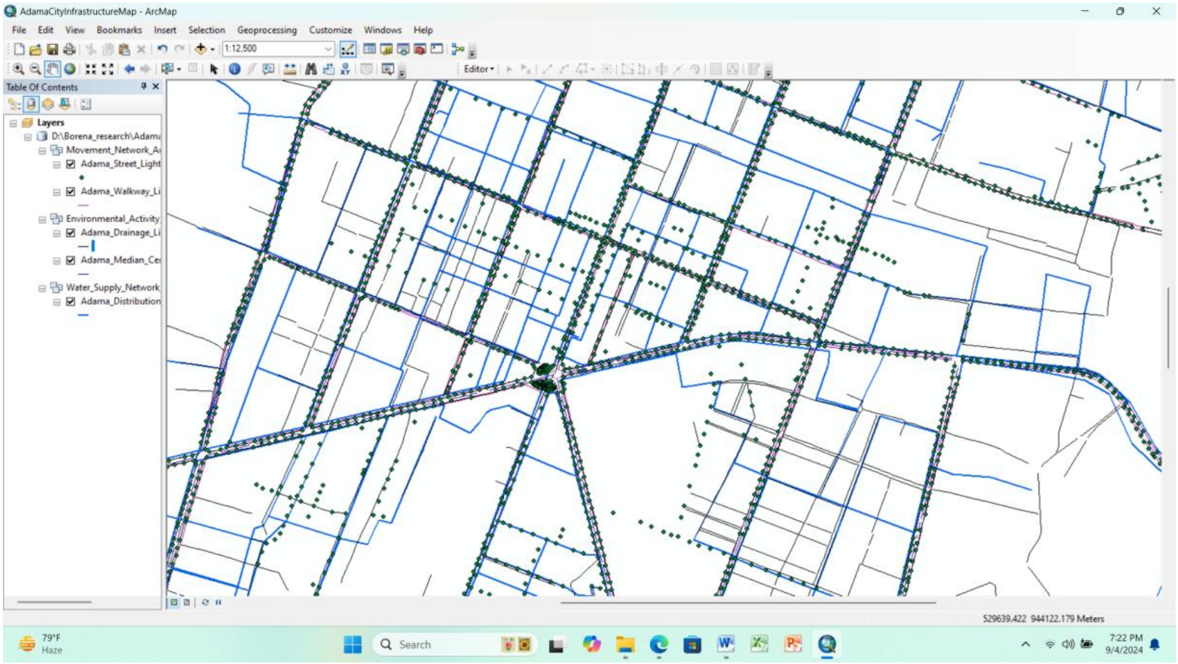

Figure 4.3 Physical implementation of the model on ArcGIS

4.5. 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.

Subsequent to the map preparation phase, the researchers perform parameter setting in QGIS Web 2. Configuring the requisite settings and options in QGIS Web 2, a web mapping platform, facilitates the seamless transfer and display of the prepared map on the web. This step ensures compatibility with web-based environments, enabling user access through a web browser.

After the map is prepared and parameters are set, the subsequent stage involves readying the web map for publication. Various techniques and tools are employed by the researchers to optimize the web map's performance and user experience.

Ultimately, the research outcome accentuates the process of publishing the web map on the GITHUB server. GITHUB, a widely utilized web-based hosting service, facilitates seamless sharing and dissemination of the prepared web map. By making the map accessible on the GITHUB server, the researchers extend its reach to a broader audience, thereby facilitating easy exploration and utilization of the infrastructure asset information.

In essence, this research outcome furnishes a comprehensive overview of the step-by-step process involved in disseminating infrastructure asset information on the web. The amalgamation of map preparation in QGIS, parameter setting in QGIS Web 2, web map preparation, and publication on the GITHUB server ensures the effective dissemination and accessibility of infrastructure asset data.

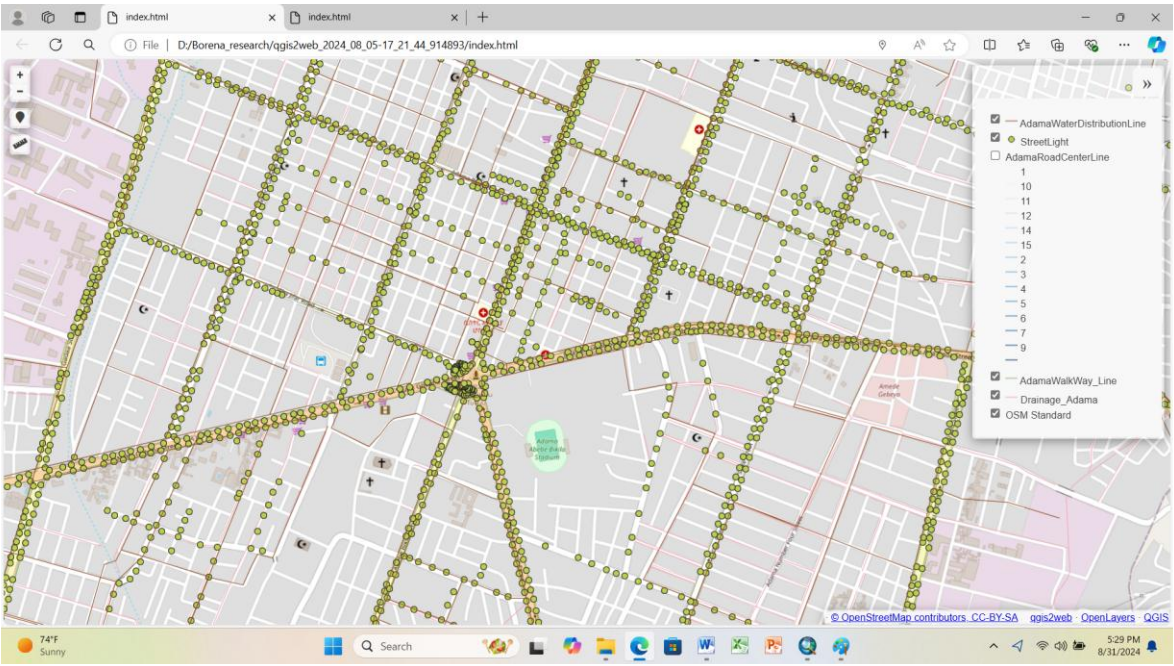

Figure 4.4 Web mapping application map

In Figure 4.4, 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.

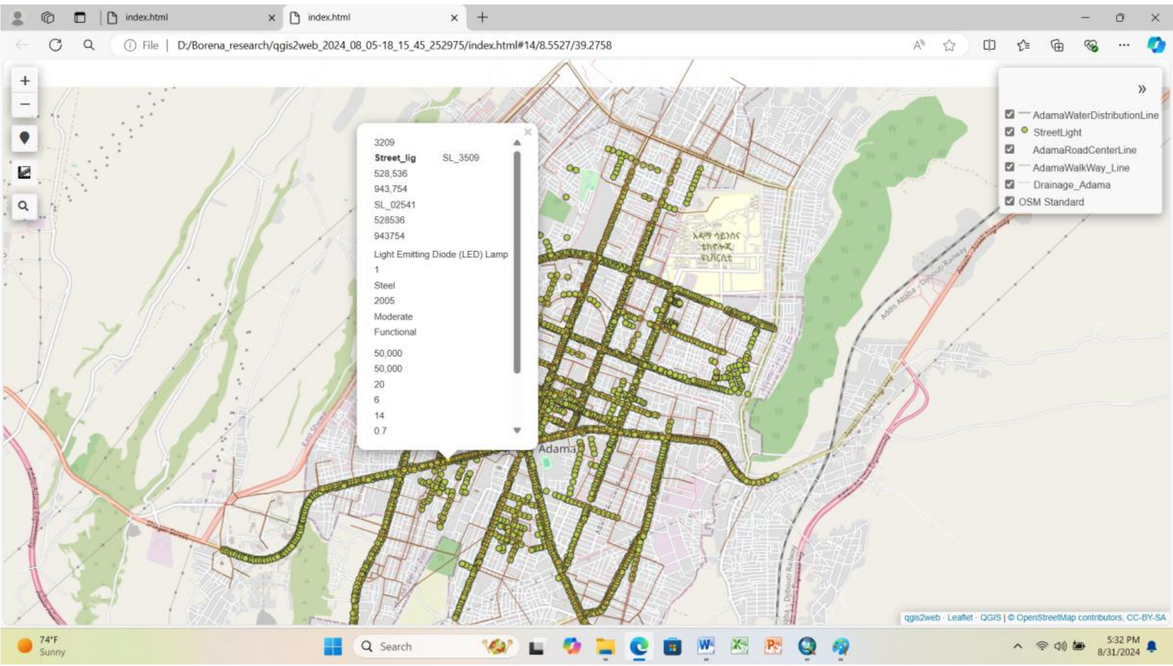

Figure 4.5 Web mapping application for attribute information display

As depicted in Figure 4.5, 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.

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.

For field data collection purposes, the researcher identified and advocated for the utilization of QField, a mobile data collection application integrated with QGIS, tailored for Android devices. Additionally, the researcher endorsed the use of ODK (Open Data Kit), a versatile set of open-source tools aiding organizations in authoring, fielding, and managing mobile data collection solutions effectively.

In terms of data storage and management, PostgreSQL/PostGIS emerged as a robust combination, with PostgreSQL offering a potent open-source object-relational database system and PostGIS extending support for geographical objects within PostgreSQL, transforming it into a spatial database. For Web GIS applications, the researcher highlighted the significance of QGIS Server, a WMS implementation enabling the sharing of QGIS projects and data online, alongside advocating for the implementation of Leaflet and Open Layers, two open-source JavaScript libraries renowned for their interactive mapping capabilities and mobile-friendly interfaces. These tools, when synergistically employed, contributed to the development of a comprehensive infrastructure asset inventory management system, encompassing data collection, storage, management, and visualization functionalities. Leveraging the extensive capabilities of QGIS as a robust open-source GIS platform in constructing an infrastructure asset management system was emphasized, underscoring the manifold benefits such an approach brings, including heightened asset visibility, streamlined maintenance operations, informed decision-making processes, and the fostering of long-term sustainability for critical infrastructure networks.

4.6. 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 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).

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 (Alok, 2016). 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).

In conclusion, the research findings underscore the importance of enhancing infrastructure asset management practices in Adama City through improved data storage, management, sharing, and valuation methods. The implemented geodatabase model in ArcGIS and PostgreSQL shows promise in addressing these challenges, while the customized web GIS applications offer a valuable platform for promoting data sharing and collaboration. By incorporating feedback from previous studies and continuing to refine these systems, Adama City can make significant strides towards optimizing its infrastructure asset management practices and supporting sustainable urban development.

CONCLUSION AND RECOMMENDATION

Conclusion

The research findings indicate areas within the infrastructure asset management system that necessitate enhancement. Specific aspects such as the inventory system, data storage and management, road condition assessment, and information systems have been underscored for improved system performance.

Addressing these identified areas for enhancement, a geodatabase model was conceived as a remedial measure. This model was meticulously crafted to efficiently manage and organize infrastructure and utility data. Through rigorous testing using ArcGIS software, the model demonstrated its efficacy in handling information pertinent to infrastructure assets.

Moreover, to bolster accessibility and foster collaboration, a web mapping application underwent testing utilizing the QGIS2, web plugin from QGIS. This application empowered users to engage with infrastructure data via a web-based interface. Nevertheless, further customization is warranted to enable dynamic interaction with user input and enhance the application's functionality.

While the application was initially made accessible on GitHub pages for broader reach, it necessitates thorough testing and deployment on a server for optimal performance.

In essence, the development of the geodatabase model and the deployment of the web GIS application present invaluable tools for enhancing the infrastructure asset management system. These tools not only streamline data management and visualization but also facilitate informed decision-making and strategic planning. The availability of the web GIS application on GitHub pages not only ensures wider accessibility but also fosters collaboration among stakeholder’s keen on advancing infrastructure asset management practices.

Recommendations

Drawing from the research outcomes, several recommendations are proposed to elevate the infrastructure asset management system. Firstly, conducting a comprehensive assessment is advised to gain a thorough understanding of Adama City's asset management framework. Secondly, delving into advanced database solutions and technologies is encouraged to enhance data storage and management. Exploring cloud-based storage alternatives, instituting robust data backup protocols, and ensuring data integrity and security stand out as crucial measures in this context.

Moreover, optimizing the road condition assessment process can be achieved by integrating cutting-edge technologies like remote sensing, machine learning, or predictive analytics. These innovative tools offer real-time insights into road conditions, enabling proactive maintenance strategies and informed decision-making. It is also recommended to embed data-driven decision-making and operational planning into the infrastructure asset management system. This can be realized through the deployment of analytical models or decision support systems that factor in aspects such as asset condition, budgetary constraints, and performance metrics.

The stakeholders and experts of Adama Municipality are encouraged to leverage the developed geodatabase model and open-source tools like Qfield, QGIS, and PostgreSQL database.

By implementing these recommendations, it is anticipated that the infrastructure asset management system will witness heightened efficiency, precision, and efficacy in bolstering informed decision-making processes and fostering sustainable long-term planning initiatives.

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Appendix

```
<!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="css/leaflet.css">
        <link rel="stylesheet" href="css/L.Control.Layers.Tree.css">
        <link rel="stylesheet" href="css/L.Control.Locate.min.css">
        <link rel="stylesheet" href="css/qgis2web.css">
        <link rel="stylesheet" href="css/fontawesome-all.min.css">
                     <link    rel="stylesheet"    href="css/leaflet-control-geocoder.Geocoder.css">
        <link rel="stylesheet" href="css/leaflet-measure.css">
        <style>
        html, body, #map {
            width: 100%;
            height: 100%;
            padding: 0;
            margin: 0;
        }
        </style>
        <title></title>
    </head>
    <body>
        <div id="map">
        </div>
        <script src="js/qgis2web_expressions.js"></script>
```

```
        <script src="js/leaflet.js"></script>
        <script src="js/L.Control.Layers.Tree.min.js"></script>
        <script src="js/L.Control.Locate.min.js"></script>
        <script src="js/leaflet.rotatedMarker.js"></script>
        <script src="js/leaflet.pattern.js"></script>
        <script src="js/leaflet-hash.js"></script>
        <script src="js/Autolinker.min.js"></script>
        <script src="js/rbush.min.js"></script>
        <script src="js/labelgun.min.js"></script>
        <script src="js/labels.js"></script>
        <script src="js/leaflet-control-geocoder.Geocoder.js"></script>
        <script src="js/leaflet-measure.js"></script>
        <script src="data/Drainage_Adama_1.js"></script>
        <script src="data/AdamaWalkWay_Line_2.js"></script>
        <script src="data/AdamaRoadCenterLine_3.js"></script>
        <script src="data/StreetLight_4.js"></script>
        <script src="data/AdamaWaterDistributionLine_5.js"></script>
        <script>
        var highlightLayer;
        function highlightFeature(e) {
            highlightLayer = e.target;

                  if  (e.target.feature.geometry.type  ===  'LineString'  ||
e.target.feature.geometry.type === 'MultiLineString') {
              highlightLayer.setStyle({
                color: '#ffff00',
              });
            } else {
              highlightLayer.setStyle({
                fillColor: '#ffff00',
                fillOpacity: 1
              });
            }
```

```
        highlightLayer.openPopup();
    }
    var map = L.map('map', {
        zoomControl:false, maxZoom:28, minZoom:1
    }).fitBounds([[8.540250956679596,39.26728266947185],[8.541823758305974,39.270254416395666]]);
    var hash = new L.Hash(map);
    map.attributionControl.setPrefix('<a href="https://github.com/tomchadwin/qgis2web" target="_blank">qgis2web</a> &middot; <a href="https://leafletjs.com" title="A JS library for interactive maps">Leaflet</a> &middot; <a href="https://qgis.org">QGIS</a>');
    var autolinker = new Autolinker({truncate: {length: 30, location: 'smart'}});
    // remove popup's row if "visible-with-data"
    function removeEmptyRowsFromPopupContent(content, feature) {
     var tempDiv = document.createElement('div');
     tempDiv.innerHTML = content;
     var rows = tempDiv.querySelectorAll('tr');
     for (var i = 0; i < rows.length; i++) {
         var td = rows[i].querySelector('td.visible-with-data');
         var key = td ? td.id : '';
         if (td && td.classList.contains('visible-with-data') && feature.properties[key] == null) {
             rows[i].parentNode.removeChild(rows[i]);
         }
     }
     return tempDiv.innerHTML;
    }
    // add class to format popup if it contains media
    function addClassToPopupIfMedia(content, popup) {
        var tempDiv = document.createElement('div');
        tempDiv.innerHTML = content;
        if (tempDiv.querySelector('td img')) {
            popup._contentNode.classList.add('media');
                // Delay to force the redraw
```

```
                    setTimeout(function() {
                        popup.update();
                    }, 10);
                } else {
                    popup._contentNode.classList.remove('media');
                }
            }
        var zoomControl = L.control.zoom({
            position: 'topleft'
        }).addTo(map);
        L.control.locate({locateOptions: {maxZoom: 19}}).addTo(map);
        var measureControl = new L.Control.Measure({
            position: 'topleft',
            primaryLengthUnit: 'meters',
            secondaryLengthUnit: 'kilometers',
            primaryAreaUnit: 'sqmeters',
            secondaryAreaUnit: 'hectares'
        });
        measureControl.addTo(map);
                   document.getElementsByClassName('leaflet-control-measure-
toggle')[0].innerHTML = '';
                   document.getElementsByClassName('leaflet-control-measure-
toggle')[0].className += ' fas fa-ruler';
        var bounds_group = new L.featureGroup([]);
        function setBounds() {
        }
        map.createPane('pane_OSMStandard_0');
        map.getPane('pane_OSMStandard_0').style.zIndex = 400;
                                     var        layer_OSMStandard_0        =
L.tileLayer('http://tile.openstreetmap.org/{z}/{x}/{y}.png', {
            pane: 'pane_OSMStandard_0',
            opacity: 1.0,
                                                       attribution:        '<a
href="https://www.openstreetmap.org/copyright">© OpenStreetMap contributors,
CC-BY-SA</a>',
```

```
            minZoom: 1,
            maxZoom: 28,
            minNativeZoom: 0,
            maxNativeZoom: 19
        });
        layer_OSMStandard_0;
        map.addLayer(layer_OSMStandard_0);
        function pop_Drainage_Adama_1(feature, layer) {
            layer.on({
                mouseout: function(e) {
                    for (var i in e.target._eventParents) {
                        if (typeof e.target._eventParents[i].resetStyle ===
'function') {
                            e.target._eventParents[i].resetStyle(e.target);
                        }
                    }
                    if (typeof layer.closePopup == 'function') {
                        layer.closePopup();
                    } else {
                        layer.eachLayer(function(feature){
                            feature.closePopup()
                        });
                    }
                },
                mouseover: highlightFeature,
            });
            var popupContent = '<table>\
                    <tr>\
                        <td colspan="2">' + (feature.properties['OBJECTID']
!== null ? autolinker.link(feature.properties['OBJECTID'].toLocaleString())
: '') + '</td>\
                    </tr>\
                    <tr>\
```

```
                                                    <td colspan="2">' + (feature.properties['OBJECTID__'] !== null ? autolinker.link(feature.properties['OBJECTID__'].toLocaleString()) : '') + '</td>\
                    </tr>\
                    <tr>\
                                                    <td colspan="2">' + (feature.properties['Drainage_I'] !== null ? autolinker.link(feature.properties['Drainage_I'].toLocaleString()) : '') + '</td>\
                    </tr>\
                    <tr>\
                                                    <td colspan="2">' + (feature.properties['Drainage_N'] !== null ? autolinker.link(feature.properties['Drainage_N'].toLocaleString()) : '') + '</td>\
                    </tr>\
                    <tr>\
                        <td colspan="2">' + (feature.properties['Node_From'] !== null ? autolinker.link(feature.properties['Node_From'].toLocaleString()) : '') + '</td>\
                    </tr>\
                    <tr>\
                        <td colspan="2">' + (feature.properties['Node_To'] !== null ? autolinker.link(feature.properties['Node_To'].toLocaleString()) : '') + '</td>\
                    </tr>\
                    <tr>\
                                                    <td colspan="2">' + (feature.properties['Length_Fro'] !== null ? autolinker.link(feature.properties['Length_Fro'].toLocaleString()) : '') + '</td>\
                    </tr>\
                    <tr>\
                        <td colspan="2">' + (feature.properties['Length_To'] !== null ? autolinker.link(feature.properties['Length_To'].toLocaleString()) : '') + '</td>\
                    </tr>\
```

```
                    <tr>\
                                                                <td colspan="2">' + (feature.properties['Actual_Len'] !== null ? autolinker.link(feature.properties['Actual_Len'].toLocaleString()) : '') + '</td>\
                    </tr>\
                    <tr>\
                                                                <td colspan="2">' + (feature.properties['Draiange_C'] !== null ? autolinker.link(feature.properties['Draiange_C'].toLocaleString()) : '') + '</td>\
                    </tr>\
                    <tr>\
                        <td colspan="2">' + (feature.properties['Avg_Width'] !== null ? autolinker.link(feature.properties['Avg_Width'].toLocaleString()) : '') + '</td>\
                    </tr>\
                    <tr>\
                        <td colspan="2">' + (feature.properties['Depth'] !== null ? autolinker.link(feature.properties['Depth'].toLocaleString()) : '') + '</td>\
                    </tr>\
                    <tr>\
                                                                <td colspan="2">' + (feature.properties['Drainage_S'] !== null ? autolinker.link(feature.properties['Drainage_S'].toLocaleString()) : '') + '</td>\
                    </tr>\
                    <tr>\
                         <td colspan="2">' + (feature.properties['Diameter'] !== null ? autolinker.link(feature.properties['Diameter'].toLocaleString()) : '') + '</td>\
                    </tr>\
                    <tr>\
                         <td colspan="2">' + (feature.properties['Area'] !== null ? autolinker.link(feature.properties['Area'].toLocaleString()) : '') + '</td>\
                    </tr>\
```

```
                    <tr>\
                                                        <td    colspan="2">'    +
(feature.properties['Deteriorat']            !==            null            ?
autolinker.link(feature.properties['Deteriorat'].toLocaleString())  :  '')  +
'</td>\
                    </tr>\
                    <tr>\
                          <td colspan="2">' + (feature.properties['Volume']
!== null ? autolinker.link(feature.properties['Volume'].toLocaleString()) :
'') + '</td>\
                    </tr>\
                    <tr>\
                                                        <td    colspan="2">'    +
(feature.properties['Deterior_1']            !==            null            ?
autolinker.link(feature.properties['Deterior_1'].toLocaleString())  :  '')  +
'</td>\
                    </tr>\
                    <tr>\
                                                        <td    colspan="2">'    +
(feature.properties['Deto_Perce']            !==            null            ?
autolinker.link(feature.properties['Deto_Perce'].toLocaleString())  :  '')  +
'</td>\
                    </tr>\
                    <tr>\
                                                        <td    colspan="2">'    +
(feature.properties['Drainage_o']            !==            null            ?
autolinker.link(feature.properties['Drainage_o'].toLocaleString())  :  '')  +
'</td>\
                    </tr>\
                    <tr>\
                                                        <td    colspan="2">'    +
(feature.properties['Deterior_2']            !==            null            ?
autolinker.link(feature.properties['Deterior_2'].toLocaleString())  :  '')  +
'</td>\
                    </tr>\
                    <tr>\
                        <th scope="row">Condition</th>\
```

```
                         <td>' + (feature.properties['Condition'] !== null ?
autolinker.link(feature.properties['Condition'].toLocaleString())  :  '')  +
'</td>\

                    </tr>\

                    <tr>\

                                                 <td    colspan="2">'    +
(feature.properties['Constructi']            !==            null           ?
autolinker.link(feature.properties['Constructi'].toLocaleString())  :  '')  +
'</td>\

                    </tr>\

                    <tr>\

                                                 <td    colspan="2">'    +
(feature.properties['Maintenanc']            !==            null           ?
autolinker.link(feature.properties['Maintenanc'].toLocaleString())  :  '')  +
'</td>\

                    </tr>\

                    <tr>\

                        <td colspan="2">' + (feature.properties['Owner'] !==
null ? autolinker.link(feature.properties['Owner'].toLocaleString()) : '') +
'</td>\

                    </tr>\

                    <tr>\

                                                 <td    colspan="2">'    +
(feature.properties['Actual_L_1']            !==            null           ?
autolinker.link(feature.properties['Actual_L_1'].toLocaleString())  :  '')  +
'</td>\

                    </tr>\

                    <tr>\

                                                 <td    colspan="2">'    +
(feature.properties['Maintena_1']            !==            null           ?
autolinker.link(feature.properties['Maintena_1'].toLocaleString())  :  '')  +
'</td>\

                    </tr>\

                    <tr>\

                                                 <td    colspan="2">'    +
(feature.properties['Maintena_2']            !==            null           ?
autolinker.link(feature.properties['Maintena_2'].toLocaleString())  :  '')  +
'</td>\

                    </tr>\
```

```
                    <tr>\
                          <td colspan="2">' + (feature.properties['EQL'] !==
null ? autolinker.link(feature.properties['EQL'].toLocaleString()) : '') +
'</td>\
                    </tr>\
                    <tr>\
                                                        <td    colspan="2">'    +
(feature.properties['URReplacem']            !==            null             ?
autolinker.link(feature.properties['URReplacem'].toLocaleString())  :  '')  +
'</td>\
                    </tr>\
                    <tr>\
                                                        <td    colspan="2">'    +
(feature.properties['EstimatedR']            !==            null             ?
autolinker.link(feature.properties['EstimatedR'].toLocaleString())  :  '')  +
'</td>\
                    </tr>\
                    <tr>\
                                                        <td    colspan="2">'    +
(feature.properties['EstimatedU']            !==            null             ?
autolinker.link(feature.properties['EstimatedU'].toLocaleString())  :  '')  +
'</td>\
                    </tr>\
                    <tr>\
                          <td colspan="2">' + (feature.properties['Age'] !==
null ? autolinker.link(feature.properties['Age'].toLocaleString()) : '') +
'</td>\
                    </tr>\
                    <tr>\
                                                        <td    colspan="2">'    +
(feature.properties['RemainingU']            !==            null             ?
autolinker.link(feature.properties['RemainingU'].toLocaleString())  :  '')  +
'</td>\
                    </tr>\
                    <tr>\
                                                        <td    colspan="2">'    +
(feature.properties['PercentRUL']            !==            null             ?
autolinker.link(feature.properties['PercentRUL'].toLocaleString())  :  '')  +
'</td>\
```

```
                    </tr>\
                    <tr>\
                                                                <td    colspan="2">'    +
(feature.properties['Depreciate']            !==             null            ?
autolinker.link(feature.properties['Depreciate'].toLocaleString())  :  '')  +
'</td>\
                    </tr>\
                    <tr>\
                                                                <td    colspan="2">'    +
(feature.properties['Maintena_3']            !==             null            ?
autolinker.link(feature.properties['Maintena_3'].toLocaleString())  :  '')  +
'</td>\
                    </tr>\
                    <tr>\
                                                                <td    colspan="2">'    +
(feature.properties['EstimatedC']            !==             null            ?
autolinker.link(feature.properties['EstimatedC'].toLocaleString())  :  '')  +
'</td>\
                    </tr>\
                    <tr>\
                                                                <td    colspan="2">'    +
(feature.properties['AssetDefic']            !==             null            ?
autolinker.link(feature.properties['AssetDefic'].toLocaleString())  :  '')  +
'</td>\
                    </tr>\
                    <tr>\
                                                                <td    colspan="2">'    +
(feature.properties['Shape_Leng']            !==             null            ?
autolinker.link(feature.properties['Shape_Leng'].toLocaleString())  :  '')  +
'</td>\
                    </tr>\
                </table>';
                var  content  =  removeEmptyRowsFromPopupContent(popupContent,
feature);
            layer.on('popupopen', function(e) {
                addClassToPopupIfMedia(content, e.popup);
            });
            layer.bindPopup(content, { maxHeight: 400 });
```

```
        }

        function style_Drainage_Adama_1_0() {
            return {
                pane: 'pane_Drainage_Adama_1',
                opacity: 1,
                color: 'rgba(243,166,178,1.0)',
                dashArray: '',
                lineCap: 'square',
                lineJoin: 'bevel',
                weight: 1.0,
                fillOpacity: 0,
                interactive: true,
            }
        }
        map.createPane('pane_Drainage_Adama_1');
        map.getPane('pane_Drainage_Adama_1').style.zIndex = 401;
             map.getPane('pane_Drainage_Adama_1').style['mix-blend-mode']   =
'normal';
        var layer_Drainage_Adama_1 = new L.geoJson(json_Drainage_Adama_1, {
            attribution: '',
            interactive: true,
            dataVar: 'json_Drainage_Adama_1',
            layerName: 'layer_Drainage_Adama_1',
            pane: 'pane_Drainage_Adama_1',
            onEachFeature: pop_Drainage_Adama_1,
            style: style_Drainage_Adama_1_0,
        });
        bounds_group.addLayer(layer_Drainage_Adama_1);
        map.addLayer(layer_Drainage_Adama_1);
        function pop_AdamaWalkWay_Line_2(feature, layer) {
            layer.on({
                mouseout: function(e) {
```

```
                    for (var i in e.target._eventParents) {
                         if (typeof e.target._eventParents[i].resetStyle ===
'function') {
                            e.target._eventParents[i].resetStyle(e.target);
                        }
                    }
                    if (typeof layer.closePopup == 'function') {
                        layer.closePopup();
                    } else {
                        layer.eachLayer(function(feature){
                            feature.closePopup()
                        });
                    }
                },
                mouseover: highlightFeature,
            });
            var popupContent = '<table>\
                    <tr>\
                         <td colspan="2">' + (feature.properties['OBJECTID']
!== null ? autolinker.link(feature.properties['OBJECTID'].toLocaleString())
: '') + '</td>\
                    </tr>\
                    <tr>\
                        <th scope="row">Road_ID</th>\
                          <td>' + (feature.properties['Road_ID'] !== null ?
autolinker.link(feature.properties['Road_ID'].toLocaleString()) : '') +
'</td>\
                    </tr>\
                    <tr>\
                                                       <td colspan="2">' +
(feature.properties['Walkway_ID'] !== null ?
autolinker.link(feature.properties['Walkway_ID'].toLocaleString()) : '') +
'</td>\
                    </tr>\
                    <tr>\
```

```
                                                    <td    colspan="2">'    +
(feature.properties['Shape_Leng']            !==          null            ?
autolinker.link(feature.properties['Shape_Leng'].toLocaleString())  :  '')  +
'</td>\
                    </tr>\
                </table>';
                var  content  =  removeEmptyRowsFromPopupContent(popupContent,
feature);
            layer.on('popupopen', function(e) {
                addClassToPopupIfMedia(content, e.popup);
            });
            layer.bindPopup(content, { maxHeight: 400 });
        }

        function style_AdamaWalkWay_Line_2_0() {
            return {
                pane: 'pane_AdamaWalkWay_Line_2',
                opacity: 1,
                color: 'rgba(133,182,111,1.0)',
                dashArray: '',
                lineCap: 'square',
                lineJoin: 'bevel',
                weight: 1.0,
                fillOpacity: 0,
                interactive: true,
            }
        }
        map.createPane('pane_AdamaWalkWay_Line_2');
        map.getPane('pane_AdamaWalkWay_Line_2').style.zIndex = 402;
          map.getPane('pane_AdamaWalkWay_Line_2').style['mix-blend-mode']  =
'normal';
                            var      layer_AdamaWalkWay_Line_2      =      new
L.geoJson(json_AdamaWalkWay_Line_2, {
            attribution: '',
            interactive: true,
```

```
            dataVar: 'json_AdamaWalkWay_Line_2',
            layerName: 'layer_AdamaWalkWay_Line_2',
            pane: 'pane_AdamaWalkWay_Line_2',
            onEachFeature: pop_AdamaWalkWay_Line_2,
            style: style_AdamaWalkWay_Line_2_0,
        });
        bounds_group.addLayer(layer_AdamaWalkWay_Line_2);
        map.addLayer(layer_AdamaWalkWay_Line_2);
        function pop_AdamaRoadCenterLine_3(feature, layer) {
            layer.on({
                mouseout: function(e) {
                    for (var i in e.target._eventParents) {
                         if (typeof e.target._eventParents[i].resetStyle ===
'function') {
                            e.target._eventParents[i].resetStyle(e.target);
                        }
                    }
                    if (typeof layer.closePopup == 'function') {
                        layer.closePopup();
                    } else {
                        layer.eachLayer(function(feature){
                            feature.closePopup()
                        });
                    }
                },
                mouseover: highlightFeature,
            });
            var popupContent = '<table>\
                    <tr>\
                                                              <td    colspan="2">'    +
(feature.properties['OBJECTID_1']              !==              null              ?
autolinker.link(feature.properties['OBJECTID_1'].toLocaleString())  :  '')  +
'</td>\
                    </tr>\
```

```
                    <tr>\
                          <td colspan="2">' + (feature.properties['Road_ID']
!== null ? autolinker.link(feature.properties['Road_ID'].toLocaleString()) :
'') + '</td>\
                    </tr>\
                    <tr>\
                                                            <td    colspan="2">'    +
(feature.properties['Shape_Leng']            !==            null            ?
autolinker.link(feature.properties['Shape_Leng'].toLocaleString())  :  '')  +
'</td>\
                    </tr>\
                    <tr>\
                         <td colspan="2">' + (feature.properties['OBJECTID']
!==  null  ?  autolinker.link(feature.properties['OBJECTID'].toLocaleString())
: '') + '</td>\
                    </tr>\
                    <tr>\
                          <td colspan="2">' + (feature.properties['RouteID']
!== null ? autolinker.link(feature.properties['RouteID'].toLocaleString()) :
'') + '</td>\
                    </tr>\
                    <tr>\
                                                            <td    colspan="2">'    +
(feature.properties['Road_Bridg']            !==            null            ?
autolinker.link(feature.properties['Road_Bridg'].toLocaleString())  :  '')  +
'</td>\
                    </tr>\
                    <tr>\
                                                            <td    colspan="2">'    +
(feature.properties['Left_kerbi']            !==            null            ?
autolinker.link(feature.properties['Left_kerbi'].toLocaleString())  :  '')  +
'</td>\
                    </tr>\
                    <tr>\
                                                            <td    colspan="2">'    +
(feature.properties['Right_Kerb']            !==            null            ?
autolinker.link(feature.properties['Right_Kerb'].toLocaleString())  :  '')  +
'</td>\
```

```
                    </tr>\
                    <tr>\
                                                     <td    colspan="2">'    +
(feature.properties['Road_ID_Ne']            !==            null            ?
autolinker.link(feature.properties['Road_ID_Ne'].toLocaleString())  :  '')  +
'</td>\
                    </tr>\
                    <tr>\
                         <td colspan="2">' + (feature.properties['NodeFrom']
!== null ? autolinker.link(feature.properties['NodeFrom'].toLocaleString())
: '') + '</td>\
                    </tr>\
                    <tr>\
                          <td colspan="2">' + (feature.properties['NodeTo']
!== null ? autolinker.link(feature.properties['NodeTo'].toLocaleString()) :
'') + '</td>\
                    </tr>\
                    <tr>\
                                                     <td    colspan="2">'    +
(feature.properties['LengthFrom']            !==            null            ?
autolinker.link(feature.properties['LengthFrom'].toLocaleString())  :  '')  +
'</td>\
                    </tr>\
                    <tr>\
                         <td colspan="2">' + (feature.properties['LengthTo']
!== null ? autolinker.link(feature.properties['LengthTo'].toLocaleString())
: '') + '</td>\
                    </tr>\
                    <tr>\
                                                     <td    colspan="2">'    +
(feature.properties['Actual_Len']            !==            null            ?
autolinker.link(feature.properties['Actual_Len'].toLocaleString())  :  '')  +
'</td>\
                    </tr>\
                    <tr>\
                                                     <td    colspan="2">'    +
(feature.properties['Deteriorat']            !==            null            ?
```

```
autolinker.link(feature.properties['Deteriorat'].toLocaleString())  :  '')  +
'</td>\
                    </tr>\
                    <tr>\
                        <td colspan="2">' + (feature.properties['Deto_Area']
!== null ? autolinker.link(feature.properties['Deto_Area'].toLocaleString())
: '') + '</td>\
                    </tr>\
                    <tr>\
                                                        <td    colspan="2">'    +
(feature.properties['Deto_Perce']             !==             null             ?
autolinker.link(feature.properties['Deto_Perce'].toLocaleString())  :  '')  +
'</td>\
                    </tr>\
                    <tr>\
                        <th scope="row">Condition_</th>\
                        <td>' + (feature.properties['Condition_'] !== null ?
autolinker.link(feature.properties['Condition_'].toLocaleString())  :  '')  +
'</td>\
                    </tr>\
                    <tr>\
                                                        <td    colspan="2">'    +
(feature.properties['Carriage_w']             !==             null             ?
autolinker.link(feature.properties['Carriage_w'].toLocaleString())  :  '')  +
'</td>\
                    </tr>\
                    <tr>\
                                                        <td    colspan="2">'    +
(feature.properties['Left_Carri']             !==             null             ?
autolinker.link(feature.properties['Left_Carri'].toLocaleString())  :  '')  +
'</td>\
                    </tr>\
                    <tr>\
                                                        <td    colspan="2">'    +
(feature.properties['Right_Carr']             !==             null             ?
autolinker.link(feature.properties['Right_Carr'].toLocaleString())  :  '')  +
'</td>\
                    </tr>\
```

```
                    <tr>\
                                                     <td    colspan="2">'    +
(feature.properties['Constructi']            !==            null            ?
autolinker.link(feature.properties['Constructi'].toLocaleString())  :  '')  +
'</td>\
                    </tr>\
                    <tr>\
                                                     <td    colspan="2">'    +
(feature.properties['Maintenanc']            !==            null            ?
autolinker.link(feature.properties['Maintenanc'].toLocaleString())  :  '')  +
'</td>\
                    </tr>\
                    <tr>\
                                                     <td    colspan="2">'    +
(feature.properties['Maintena_1']            !==            null            ?
autolinker.link(feature.properties['Maintena_1'].toLocaleString())  :  '')  +
'</td>\
                    </tr>\
                    <tr>\
                                                     <td    colspan="2">'    +
(feature.properties['Maintena_2']            !==            null            ?
autolinker.link(feature.properties['Maintena_2'].toLocaleString())  :  '')  +
'</td>\
                    </tr>\
                    <tr>\
                          <td colspan="2">' + (feature.properties['Owner_1']
!== null ? autolinker.link(feature.properties['Owner_1'].toLocaleString()) :
'') + '</td>\
                    </tr>\
                    <tr>\
                         <td colspan="2">' + (feature.properties['Area_SQM']
!==  null  ?  autolinker.link(feature.properties['Area_SQM'].toLocaleString())
: '') + '</td>\
                    </tr>\
                    <tr>\
                          <td colspan="2">' + (feature.properties['EQL'] !==
null  ?  autolinker.link(feature.properties['EQL'].toLocaleString())  :  '')  +
'</td>\
```

```
                    </tr>\
                    <tr>\
                                                     <td    colspan="2">'    +
(feature.properties['URReplacem']            !==            null            ?
autolinker.link(feature.properties['URReplacem'].toLocaleString())  :  '')  +
'</td>\
                    </tr>\
                    <tr>\
                                                     <td    colspan="2">'    +
(feature.properties['EstimatedR']            !==            null            ?
autolinker.link(feature.properties['EstimatedR'].toLocaleString())  :  '')  +
'</td>\
                    </tr>\
                    <tr>\
                                                     <td    colspan="2">'    +
(feature.properties['EstimatedU']            !==            null            ?
autolinker.link(feature.properties['EstimatedU'].toLocaleString())  :  '')  +
'</td>\
                    </tr>\
                    <tr>\
                          <td colspan="2">' + (feature.properties['Age'] !==
null  ?  autolinker.link(feature.properties['Age'].toLocaleString())  :  '')  +
'</td>\
                    </tr>\
                    <tr>\
                                                     <td    colspan="2">'    +
(feature.properties['RemainingU']            !==            null            ?
autolinker.link(feature.properties['RemainingU'].toLocaleString())  :  '')  +
'</td>\
                    </tr>\
                    <tr>\
                                                     <td    colspan="2">'    +
(feature.properties['PercentRUL']            !==            null            ?
autolinker.link(feature.properties['PercentRUL'].toLocaleString())  :  '')  +
'</td>\
                    </tr>\
                    <tr>\
```

```
                                                    <td    colspan="2">'    +
(feature.properties['Depreciate']            !==            null            ?
autolinker.link(feature.properties['Depreciate'].toLocaleString())  :  '')  +
'</td>\
                    </tr>\
                    <tr>\
                                                    <td    colspan="2">'    +
(feature.properties['Maintena_3']            !==            null            ?
autolinker.link(feature.properties['Maintena_3'].toLocaleString())  :  '')  +
'</td>\
                    </tr>\
                    <tr>\
                                                    <td    colspan="2">'    +
(feature.properties['EstimatedC']            !==            null            ?
autolinker.link(feature.properties['EstimatedC'].toLocaleString())  :  '')  +
'</td>\
                    </tr>\
                    <tr>\
```