

Impact Of GIS-Based Spatial Decision Support Systems on Urban Water Supply Network Optimization: A Qualitative Evaluation

Taufiqur Rahaman¹; Kazi Mohammad Khalid Ahsan²;

- [1]. Master of Science (Planning Group) in Geography & Environment, Jahangirnagar University; Dhaka, Bangladesh; Email: khalid.grid@gmail.com
- [2]. Department of Civil Engineering, Rajshahi University of Engineering & Technology, Rajshahi, Bangladesh; Email: rueconomy@gmail.com

Doi: [10.63125/2hqejb24](https://doi.org/10.63125/2hqejb24)

Received: 19 September 2022; **Revised:** 22 October 2022; **Accepted:** 25 November 2022; **Published:** 29 December 2022

Abstract

This study examined the impact of GIS-based Spatial Decision Support Systems on the optimization of urban water supply networks using a quantitative cross-sectional case study design. Data were collected from 120 professionals, including engineers, GIS analysts, planners, and maintenance supervisors, alongside operational and spatial data from 15 urban water network zones. Descriptive and inferential statistical analyses were conducted to evaluate relationships between SDSS utilization and key performance indicators such as network efficiency, pressure stability, leakage detection, service coverage, and maintenance prioritization. The findings revealed strong positive correlations between SDSS usage and network optimization outcomes, with correlation coefficients ranging from 0.55 to 0.72, all statistically significant at $p < 0.05$. Regression analysis indicated that GIS-based SDSS variables explained 62% of the variance in network performance ($R^2 = 0.62$), demonstrating substantial predictive power. Leakage rates were significantly lower in high SDSS integration zones (17.9%) compared to low integration zones (27.1%), while pressure stability scores improved from 3.42 to 4.25 on a five-point scale. Sub-group analysis showed that GIS analysts reported higher effectiveness scores (mean = 4.32) compared to maintenance personnel (mean = 3.61), highlighting the influence of user expertise. Reliability testing confirmed strong internal consistency (Cronbach's alpha = 0.82). The results demonstrated that GIS-based SDSS significantly enhanced decision-making accuracy and operational efficiency, particularly in complex and high-demand network environments. Overall, the study provided empirical evidence supporting the effectiveness of GIS-based spatial decision tools in improving urban water supply system performance and infrastructure management.

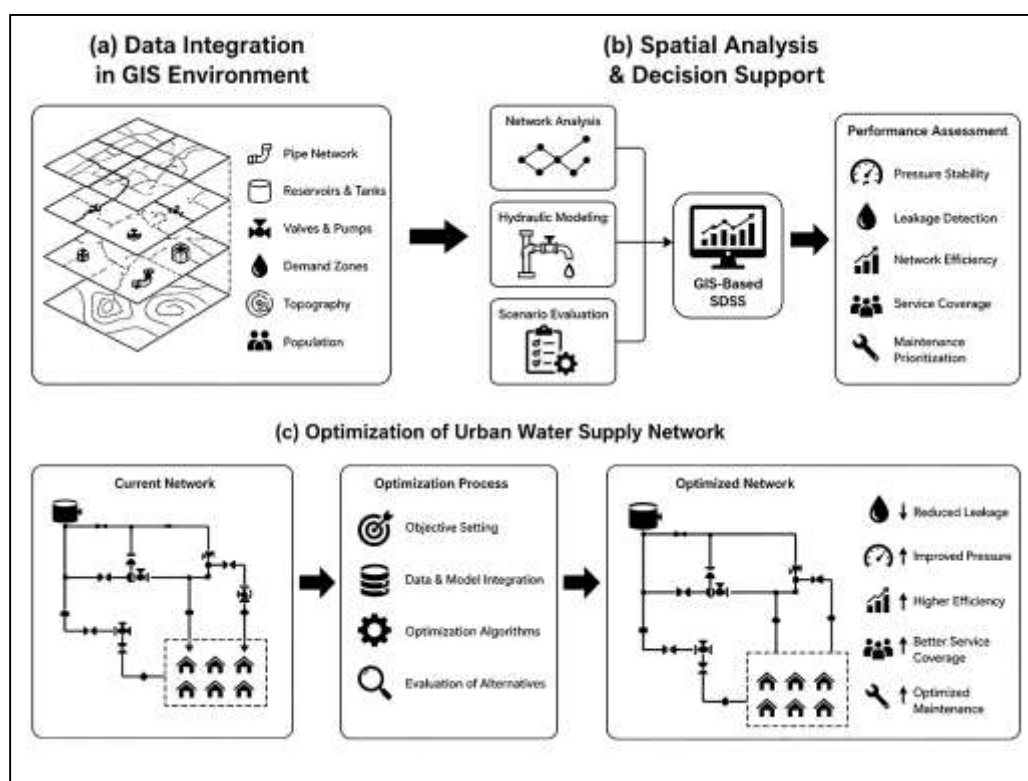
Keywords

GIS, SDSS, Water Networks, Optimization, Spatial Analysis.

INTRODUCTION

Geographic Information Systems (GIS) are defined as computer-based frameworks designed to capture, store, manage, analyze, and visualize spatially referenced data within an integrated digital environment (Kirby et al., 2017). These systems enable the organization of geographic information into structured layers that can be manipulated and analyzed to support complex problem-solving activities across multiple domains. Spatial Decision Support Systems (SDSS) represent an extension of conventional decision support systems, integrating spatial data handling, analytical modeling, and interactive visualization tools to assist decision-makers in addressing geographically complex challenges. SDSS incorporates database management systems, analytical models, and user interfaces to facilitate the evaluation of alternative scenarios and improve decision outcomes in environments where spatial relationships are fundamental (Yang & Han, 2020). Within the context of urban water supply networks, these systems provide a structured mechanism for integrating geospatial data with hydraulic and operational parameters. Urban water supply networks are defined as interconnected infrastructures that transport potable water from sources such as reservoirs or treatment facilities to consumers through a system of pipes, pumps, valves, and storage units. Optimization in this domain refers to the application of systematic and computational approaches to improve efficiency, reliability, and resource allocation within the network (Blaschke et al., 2018). The integration of GIS with SDSS forms a multidisciplinary analytical framework that enables engineers and planners to simulate, analyze, and optimize water distribution systems, establishing a foundation for addressing complex infrastructure challenges in urban environments.

Figure 1: GIS-Based SDSS Water Optimization



Urban water supply systems hold global significance as essential components of public health, economic development, and environmental sustainability. Access to safe and reliable water remains a critical determinant of quality of life and socio-economic stability across both developed and developing regions (Monteiro et al., 2018). Rapid urbanization, population growth, and industrial expansion have intensified the demand for efficient and resilient water distribution systems worldwide. In many urban centers, water supply networks are subject to increasing stress due to aging

infrastructure, rising consumption patterns, and environmental variability. These pressures have amplified the need for advanced management approaches capable of addressing inefficiencies and ensuring equitable distribution of water resources (Arcuri et al., 2020). Urban water systems are inherently complex due to their spatial extent, interconnected components, and dynamic operational conditions. Conventional management approaches often lack the capacity to fully capture the spatial variability and interdependencies within these systems, resulting in inefficiencies such as water loss, pressure imbalances, and service disruptions. The global emphasis on sustainable development has reinforced the necessity for integrated and intelligent solutions that enhance the performance of urban water infrastructure (Kumar et al., 2019a). GIS-based Spatial Decision Support Systems have gained international relevance by offering the ability to analyze spatial patterns, model system behavior, and support informed decision-making processes. Their adoption across diverse regions reflects their effectiveness in improving water distribution efficiency, reducing operational costs, and enhancing system resilience.

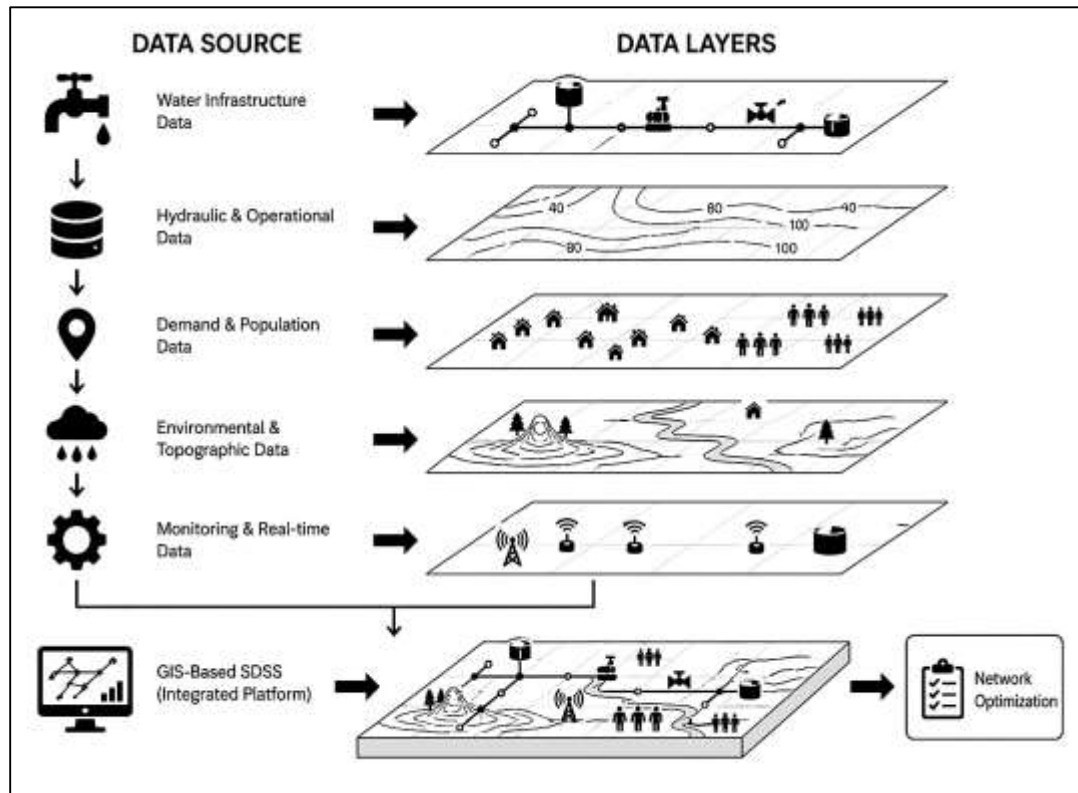
GIS technology plays a central role in the management and analysis of urban water supply networks by enabling the integration of spatial and non-spatial data into a cohesive analytical environment. The ability to map and visualize infrastructure components such as pipelines, reservoirs, valves, and pumping stations provides a comprehensive representation of the network, facilitating improved understanding and management of system operations (Banerjee et al., 2020). GIS allows for the layering of multiple datasets, including topographical features, land use patterns, and population distribution, which enhances the ability to analyze spatial relationships and identify critical areas within the network. This capability supports the detection of inefficiencies such as leakage zones, pressure inconsistencies, and areas with high demand. By providing a spatial context to water distribution systems, GIS enables detailed analyses that inform decision-making processes (Kucera, 2020). The integration of real-time data from monitoring systems further enhances GIS functionality, allowing for continuous assessment of network performance and enabling proactive maintenance strategies. GIS-based tools also support infrastructure planning and design by enabling the simulation of alternative scenarios and evaluating their potential impacts on system performance (Reddy et al., 2018). These capabilities contribute to improved operational efficiency, reduced water losses, and enhanced service delivery, highlighting the importance of GIS in modern water supply management.

The integration of GIS with hydraulic modeling systems represents a significant advancement in the optimization of urban water supply networks (Bansal, 2020). Hydraulic models are used to simulate the behavior of water within distribution systems, providing insights into parameters such as flow rates, pressure distribution, and system dynamics. When combined with GIS, these models benefit from enhanced spatial accuracy and the ability to incorporate detailed geographic information into simulations. This integration enables the development of georeferenced models that accurately represent the physical and operational characteristics of the network, allowing for more precise analysis and prediction of system performance (Zhou et al., 2019). GIS facilitates the visualization of model outputs, making complex data more accessible and easier to interpret for decision-makers. The ability to simulate various operational scenarios, including changes in demand or infrastructure modifications, provides valuable insights that support strategic planning. Integrated systems also enable the identification of critical points within the network, such as areas susceptible to low pressure or high-water loss, allowing for targeted interventions (Gilfoyle & Thorpe, 2016). The combination of spatial analysis and hydraulic modeling enhances the reliability and efficiency of water supply networks by enabling data-driven decision-making and comprehensive system evaluation.

GIS-based Spatial Decision Support Systems extend the capabilities of traditional GIS by incorporating advanced analytical tools and structured decision-making frameworks that support the optimization of urban water supply networks. These systems are designed to address complex problems that involve spatial variability and require the evaluation of multiple criteria (Petrişor, 2016). SDSS integrates spatial data with optimization techniques, simulation models, and user-defined parameters to facilitate comprehensive analysis. In the context of water supply networks, these systems enable the assessment of alternative design and operational strategies, allowing decision-makers to identify solutions that balance efficiency, cost, and sustainability (Abdalla, 2016). The interactive nature of SDSS allows users to explore different scenarios, visualize outcomes, and refine parameters to achieve specific objectives.

This enhances the decision-making process by providing deeper insights into the potential impacts of different strategies. GIS-based SDSS also supports collaboration among stakeholders by offering intuitive visualization tools that make complex data more understandable (Kumar et al., 2019b). The integration of diverse data sources and analytical methods makes these systems highly effective in addressing challenges associated with urban water supply network optimization, contributing to improved system performance and resource management.

Figure 2: Spatial Decision Systems Water Networks



The optimization of urban water supply networks involves the application of advanced computational and analytical techniques aimed at improving efficiency, reducing operational costs, and ensuring reliable service delivery (Silva & Fernandes, 2020). GIS-based systems contribute significantly to this process by providing accurate spatial data and analytical capabilities that support the identification of optimal solutions. Various optimization approaches, including simulation-based methods and algorithmic techniques, are integrated with GIS to analyze complex network configurations and operational conditions. These approaches enable the evaluation of multiple alternatives, allowing decision-makers to select strategies that maximize system performance while minimizing resource use (Johnson, 2016). GIS facilitates the identification of inefficiencies such as high-water loss areas and inadequate pressure zones, enabling targeted interventions that improve overall system functionality. The ability to analyze spatial patterns enhances the effectiveness of optimization processes, providing insights that extend beyond traditional analytical methods. GIS-based optimization frameworks also allow for the incorporation of environmental and socio-economic considerations, ensuring that solutions are contextually appropriate and sustainable (Hong, 2017). These capabilities contribute to the development of more efficient and resilient water supply systems, emphasizing the importance of GIS-based approaches in infrastructure optimization.

The evaluation of GIS-based Spatial Decision Support Systems in urban water supply network optimization involves a comprehensive examination of their technical capabilities, usability, and influence on decision-making processes (Wegener & Masser, 2019). These systems are assessed based on their ability to integrate diverse datasets, support complex analyses, and generate actionable insights

that improve system performance. Qualitative evaluation approaches focus on understanding how these systems enhance decision-making, improve system comprehension, and facilitate coordination among stakeholders. The effectiveness of GIS-based SDSS is reflected in their capacity to provide accurate and timely information, enabling informed responses to changing network conditions (Çöltekin et al., 2020). The integration of spatial data with analytical models allows for a deeper understanding of system dynamics, supporting the identification of patterns and trends that influence performance. These systems also enhance transparency by presenting data and analytical outcomes in a clear and visual format. The increasing complexity of urban water supply networks requires advanced tools capable of managing large datasets and delivering meaningful insights (Pal, 2019). GIS-based SDSS fulfills this requirement by offering a comprehensive platform for analyzing and optimizing water distribution systems, reinforcing their significance in contemporary urban infrastructure management.

The primary objective of this study is to systematically evaluate the impact of GIS-based Spatial Decision Support Systems on the optimization of urban water supply networks through a qualitative analytical framework. This objective is centered on examining how the integration of geospatial technologies with decision support mechanisms contributes to improved understanding, management, and operational efficiency of complex water distribution systems. The study aims to explore the role of GIS-based SDSS in enhancing the visualization, analysis, and interpretation of spatial data related to water infrastructure, including pipelines, reservoirs, demand zones, and pressure systems. A key focus is placed on understanding how these systems support decision-making processes by enabling the assessment of multiple scenarios, facilitating the identification of inefficiencies such as leakage, pressure imbalance, and uneven distribution, and supporting strategic planning for infrastructure development and maintenance. The objective further includes evaluating how GIS-based SDSS integrates with hydraulic models and optimization techniques to provide a comprehensive platform for analyzing network performance under varying operational conditions. Attention is also given to the ability of these systems to incorporate real-time and historical data, thereby improving the responsiveness and adaptability of water management strategies. In addition, the study seeks to investigate how the use of GIS-based SDSS influences stakeholder engagement, collaboration, and transparency in decision-making processes by providing accessible and visually intuitive representations of complex data. The qualitative nature of the evaluation emphasizes the exploration of system capabilities, user interactions, and contextual factors that shape the effectiveness of these technologies in real-world applications. This objective reflects a comprehensive approach to understanding the contribution of GIS-based Spatial Decision Support Systems to the optimization of urban water supply networks, focusing on their capacity to enhance system performance, support informed decision-making, and address the spatial complexity inherent in urban water management.

LITERATURE REVIEW

The literature review section aims to critically examine and synthesize existing scholarly contributions related to the integration of Geographic Information Systems and Spatial Decision Support Systems in the context of urban water supply network optimization. This section establishes a structured foundation for understanding how spatial technologies, analytical frameworks, and decision-support mechanisms have evolved to address the complexity of water distribution systems in urban environments (Keenan & Jankowski, 2019; Binte & Sazzadul, 2022). The review focuses on identifying key theoretical constructs, methodological approaches, and empirical findings that explain the role of GIS-based SDSS in improving system efficiency, reliability, and operational decision-making. It explores how prior studies have conceptualized spatial intelligence, network modeling, and optimization techniques, and how these elements have been applied to water infrastructure challenges. Emphasis is placed on understanding the interaction between geospatial data integration and hydraulic modeling, as well as the effectiveness of decision support tools in handling multi-criteria and spatially dependent problems (Erskine et al., 2019; Manam & Ashfaq, 2022).

The section also investigates how qualitative evaluations have been used to assess system usability, stakeholder engagement, and decision-making enhancement. Through a comprehensive synthesis of interdisciplinary research, the literature review provides a detailed understanding of the current state of knowledge, identifies prevailing research patterns, and highlights conceptual and methodological gaps relevant to the study (Jung et al., 2020; Khaled, 2021).

GIS and Spatial Decision Support Systems

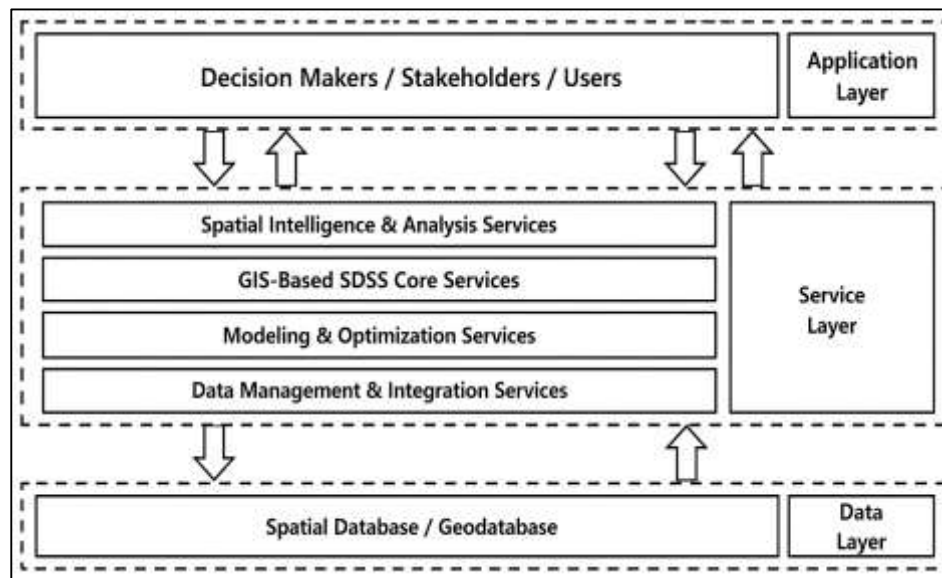
Geographic Information Systems are widely understood as integrated technological frameworks designed to capture, store, manage, analyze, and visualize spatially referenced data within a unified environment. The conceptual foundation of GIS lies in its ability to organize geographic information into structured layers that represent real-world entities such as infrastructure networks, environmental features, and demographic distributions (Cerreta & Poli, 2017). Core components of GIS include spatial databases for storing georeferenced information, data acquisition tools for collecting both primary and secondary data, analytical engines for processing spatial relationships, and visualization interfaces for presenting results in map-based formats. These components function collectively to transform raw data into meaningful insights that support decision-making in complex environments. In the context of urban water supply systems, GIS enables the detailed representation of network components such as pipelines, reservoirs, valves, and pumping stations, facilitating comprehensive system analysis (Rikalovic et al., 2017). The layered architecture of GIS allows for the integration of diverse datasets, including topography, land use, and population density, which enhances the understanding of spatial interactions within infrastructure systems. This capability is essential for identifying inefficiencies, monitoring system performance, and supporting planning activities. The literature emphasizes that GIS improves data accuracy, reduces redundancy, and enables collaborative data management across multiple stakeholders. Its ability to handle large volumes of spatial and non-spatial data makes it a critical tool in modern engineering and planning contexts (Yusianto & Hardjomidjojo, 2020). The conceptualization of GIS as a data-driven and spatially oriented system underscores its significance in addressing the complexities associated with urban infrastructure management, particularly in water supply networks where spatial relationships directly influence system performance and operational outcomes.

Spatial Decision Support Systems have emerged as an evolution of traditional decision support systems, reflecting the growing need to address problems characterized by spatial complexity and uncertainty. Traditional decision support systems were primarily designed to process structured numerical data and generate analytical outputs to aid decision-making (Nyimbili & Erden, 2018). The increasing recognition of the importance of spatial factors in infrastructure planning and management led to the development of SDSS, which integrates geographic information capabilities with decision-making frameworks. This evolution represents a shift from purely computational tools to systems that emphasize spatial reasoning, visualization, and interactive analysis. SDSS combines spatial databases, analytical models, and user interfaces to enable decision-makers to explore multiple scenarios and evaluate alternative solutions in a dynamic and flexible manner (Jayarathna et al., 2017). In urban water supply systems, this functionality is particularly valuable due to the interconnected nature of infrastructure components and the spatial variability of demand and supply conditions. SDSS allows users to modify parameters, simulate different operational conditions, and assess the potential impacts of various strategies, thereby enhancing the quality of decision-making. The development of SDSS reflects an increasing emphasis on integrating data, models, and human judgment into a cohesive framework that supports complex problem-solving. This transformation has expanded the applicability of decision support systems to a wide range of engineering and planning challenges, including the optimization of urban water networks (Pérez et al., 2018). The integration of spatial intelligence into decision-making processes has significantly improved the ability to address issues that involve multiple criteria, spatial dependencies, and dynamic conditions, making SDSS an essential tool in contemporary infrastructure management.

The integration of spatial databases, analytical models, and user interfaces within GIS-based SDSS forms a comprehensive and interactive framework for managing and optimizing urban water supply networks. Spatial databases act as the foundational layer, storing detailed georeferenced information about infrastructure components, environmental conditions, and demand patterns. Analytical models,

including simulation and optimization tools, are used to evaluate system performance under various scenarios, providing insights into factors such as flow dynamics, pressure distribution, and system reliability (Jafary et al., 2018). The combination of these elements enables the development of georeferenced models that accurately represent the physical and operational characteristics of water distribution systems. User interfaces play a critical role in facilitating interaction with the system, allowing decision-makers to visualize data, interpret analytical results, and explore alternative scenarios. This integration enhances the accessibility and usability of complex datasets, making it easier for stakeholders to understand system behavior and make informed decisions (Jeong & Ramírez-Gómez, 2018). The literature indicates that such integrated systems enable the identification of inefficiencies within the network, including leakage points, pressure imbalances, and suboptimal design configurations. By providing a unified platform for data management and analysis, GIS-based SDSS supports more effective planning, design, and operation of water supply systems (Kazak et al., 2017). The ability to align spatial data with analytical models improves the accuracy of system evaluations and enhances the effectiveness of optimization strategies. This integrated approach represents a significant advancement in infrastructure management, enabling decision-makers to address complex challenges through data-driven and spatially informed methodologies.

Figure 3: GIS SDSS Water System Architecture



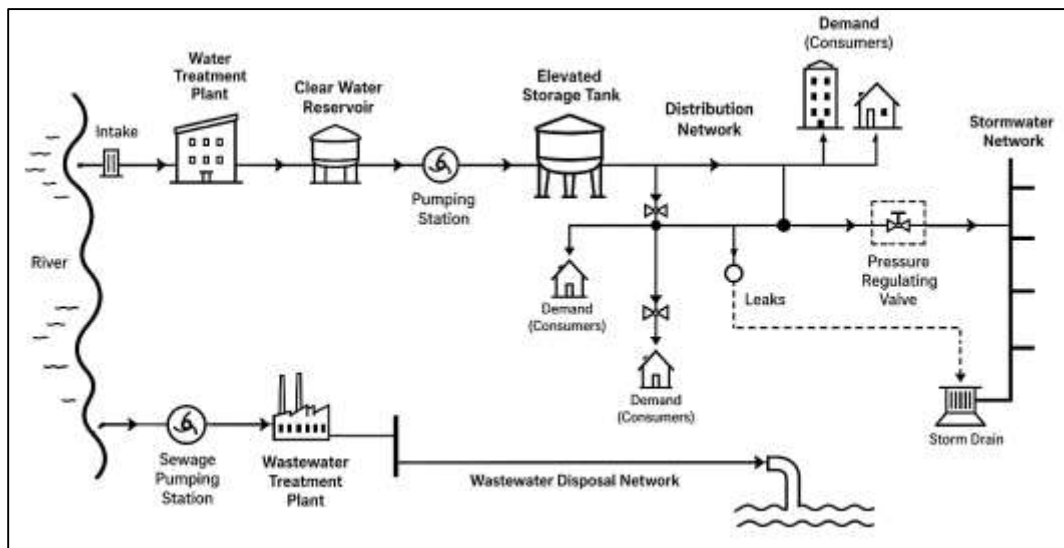
Spatial intelligence serves as a fundamental component of GIS-based SDSS, enabling the analysis of geographic patterns, relationships, and trends that influence infrastructure performance and decision-making processes. In urban water supply networks, spatial intelligence involves the use of geospatial data and analytical tools to understand how factors such as terrain, population distribution, and infrastructure layout affect water distribution and system efficiency (Gheshlaghi & Feizizadeh, 2017). Theoretical frameworks underpinning SDSS are grounded in principles of spatial analysis, systems thinking, and multi-criteria evaluation, which provide a structured approach to addressing complex engineering problems. These frameworks emphasize the integration of diverse data sources and analytical methods to support comprehensive decision-making. Spatial intelligence allows decision-makers to identify patterns and relationships that are not easily discernible through traditional analytical approaches, enabling more accurate and context-specific solutions. In water supply systems, this includes the identification of high-demand areas, critical infrastructure components, and potential points of failure (Noorollahi et al., 2016). The application of multi-criteria evaluation within SDSS frameworks further enhances decision-making by allowing the consideration of various factors such as cost, efficiency, and sustainability. The literature highlights that the use of spatial intelligence improves the quality of decisions by providing a deeper understanding of system dynamics and enabling the

evaluation of multiple alternatives. This analytical capability is essential for optimizing urban water supply networks, where spatial variability and interdependencies play a significant role in system performance (Beard et al., 2018). The theoretical foundations of GIS-based SDSS thus provide a robust framework for integrating spatial data and decision-making processes, reinforcing their importance in modern engineering and planning contexts.

Urban Water Supply Networks

Urban water supply networks are structured as highly interconnected systems composed of multiple physical and functional components that collectively ensure the reliable delivery of potable water across urban environments (Monte & Morais, 2019). These systems typically include pipelines that act as conduits for water transport, nodes that function as junctions or consumption points, reservoirs and storage tanks that regulate supply and maintain pressure stability, and pumping stations that provide the necessary energy to move water across varying elevations. The configuration of these components is designed to ensure continuous service while maintaining efficiency and reliability under varying demand conditions (McPhearson et al., 2016). The structural arrangement of water distribution systems often follows looped, branched, or hybrid configurations, each designed to balance cost, redundancy, and operational resilience. Looped systems provide multiple pathways for water flow, enhancing reliability and reducing vulnerability to localized failures, while branched systems are simpler and more cost-effective but may lack redundancy. The integration of these components within a unified network creates a complex infrastructure that requires careful coordination and management (Hoang & Fenner, 2016). The literature consistently emphasizes that the performance of urban water supply networks depends on the effective interaction of these components, where inefficiencies or failures in one part of the system can significantly impact overall functionality. This structural complexity forms the foundation for understanding the operational dynamics of water distribution systems and highlights the importance of systematic design and management approaches in ensuring optimal performance.

Figure 4: Urban Water Supply Network Framework



The spatial characteristics and network topology of urban water supply systems play a critical role in determining their efficiency, reliability, and adaptability. These systems are inherently spatial, with the arrangement and connectivity of infrastructure components influencing the flow of water and the distribution of pressure throughout the network. The topology of a water distribution system is often conceptualized as a network of interconnected nodes and links, where nodes represent junctions or demand points and links represent pipes that carry water between them (Nguyen et al., 2019). This network structure is influenced by various spatial factors, including topography, land use patterns, and population distribution, all of which affect the design and operation of the system. Elevation differences, for example, can significantly impact pressure levels, requiring the use of pumps or

pressure-regulating devices to maintain consistent service (Boeing, 2017). The spatial distribution of demand also influences network design, as areas with higher population density require greater capacity and more robust infrastructure. The literature highlights that understanding the spatial configuration of water networks is essential for optimizing their performance, as it allows for the identification of critical nodes, vulnerable links, and areas of inefficiency. The complexity of network topology is further increased by the need to balance competing objectives such as cost efficiency, service reliability, and coverage (Dubey & Gunasekaran, 2016). This spatial dimension introduces additional challenges in system analysis and optimization, necessitating the use of advanced tools and methodologies to effectively manage and improve network performance.

Operational challenges within urban water supply networks are diverse and arise from the interplay of technical, environmental, and demand-related factors that influence system performance. One of the most significant challenges is water leakage, which results in substantial losses and reduces overall system efficiency (McGrane, 2016). Leakage can occur due to aging infrastructure, material degradation, or external disturbances, and its detection and management require continuous monitoring and analysis. Pressure imbalance is another critical issue, as variations in pressure across the network can lead to inadequate water supply in certain areas while causing excessive stress on infrastructure in others. Maintaining optimal pressure levels is essential for ensuring consistent service delivery and prolonging the lifespan of system components (Bai et al., 2016). Demand variability further complicates network operations, as water consumption patterns fluctuate based on time of day, seasonal changes, and socio-economic factors. These fluctuations require adaptive management strategies to ensure that supply meets demand without compromising system stability. The literature indicates that these operational challenges are interrelated, with issues such as pressure imbalance contributing to increased leakage and reduced system efficiency (Xia et al., 2017). Addressing these challenges requires a comprehensive understanding of system dynamics and the implementation of strategies that can effectively manage the complex interactions between different components of the network.

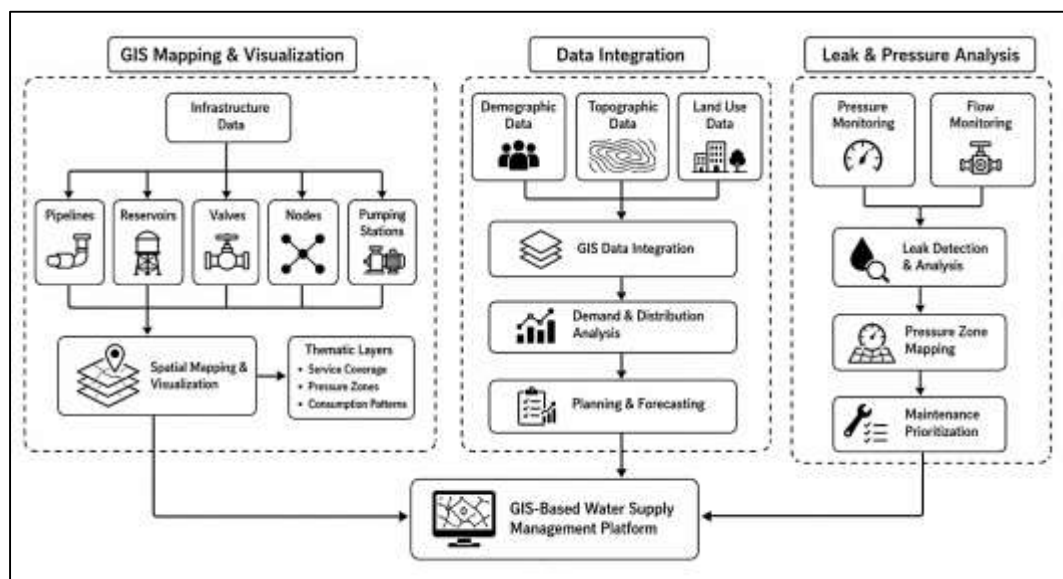
Urban growth and infrastructure aging introduce additional layers of complexity to the management and optimization of water supply networks. Rapid urbanization leads to increased demand for water services, often exceeding the capacity of existing infrastructure and necessitating the expansion and modification of distribution systems (Fuenfschilling & Truffer, 2016). This expansion increases the complexity of the network, as new components must be integrated with existing structures while maintaining system efficiency and reliability. At the same time, aging infrastructure presents a significant challenge, as older pipes and components are more susceptible to corrosion, leakage, and failure. The deterioration of infrastructure not only reduces system performance but also increases maintenance costs and the risk of service disruptions (Mahdianpari et al., 2018). The interaction between urban growth and infrastructure aging creates a dynamic environment in which system conditions are constantly evolving. This dynamic nature is further influenced by spatial interdependencies within the network, where changes in one part of the system can have cascading effects on other components. For example, increased demand in one area may alter pressure conditions elsewhere, affecting overall system stability. The literature emphasizes that understanding these interdependencies is essential for effective system management, as it allows for the identification of potential vulnerabilities and the development of targeted interventions (Nagendra et al., 2018). The complexity arising from these factors underscores the need for integrated and adaptive approaches to managing urban water supply networks, ensuring their continued functionality in the face of evolving challenges.

GIS Applications in Urban Water Supply Management

The application of Geographic Information Systems in urban water supply management has been widely recognized as a transformative approach for spatial mapping and visualization of infrastructure systems. GIS enables the digital representation of water distribution networks by converting physical components such as pipelines, reservoirs, valves, and nodes into structured geospatial layers that can be analyzed and visualized within an integrated platform (Moniz et al., 2020). This capability significantly enhances the understanding of system structure and operational dynamics by allowing decision-makers to observe spatial relationships and identify patterns that are not easily detectable

through conventional analytical methods. The literature consistently highlights that GIS-based mapping improves infrastructure transparency, supports asset inventory management, and facilitates more efficient monitoring of system conditions (Wang & Xie, 2018). The visualization functions of GIS extend beyond simple mapping, incorporating multiple thematic layers that represent variables such as service coverage, pressure zones, and consumption patterns. This multi-layered approach allows for detailed analysis of system performance and enables the identification of inefficiencies or critical areas within the network. Furthermore, GIS visualization enhances communication among engineers, planners, and stakeholders by presenting complex datasets in an intuitive and accessible format (Sharvelle et al., 2017). The integration of mapping and visualization capabilities within GIS platforms has therefore become a fundamental component of urban water supply management, supporting more accurate interpretation of data and enabling informed decision-making in complex infrastructure environments.

Figure 5: GIS Water Network Analysis Framework



The integration of demographic, topographic, and land use data within GIS frameworks has further strengthened the analytical capabilities of water supply management systems by providing a comprehensive understanding of the factors influencing water demand and distribution (Singh et al., 2017). GIS allows for the seamless combination of diverse datasets, enabling the analysis of how population density, terrain characteristics, and patterns of urban development impact water consumption and infrastructure performance. Demographic data contributes to the estimation of demand patterns and consumption variability, while topographic data is essential for understanding elevation-related influences on pressure distribution and flow dynamics (Jeihooni et al., 2020). Land use data provides insights into the spatial organization of residential, commercial, and industrial zones, which directly affect water usage patterns and infrastructure requirements. The integration of these datasets within a unified system enables more accurate modeling and forecasting, supporting the design of efficient and sustainable water distribution networks. The literature emphasizes that this holistic approach to data integration improves planning accuracy by aligning infrastructure development with population growth and urban expansion. It also allows for the identification of underserved areas and supports the development of targeted interventions to improve service delivery (Singh, 2019). This comprehensive analytical capability represents a significant advancement in water supply management, as it enables decision-makers to consider multiple interrelated factors in their assessments and strategies.

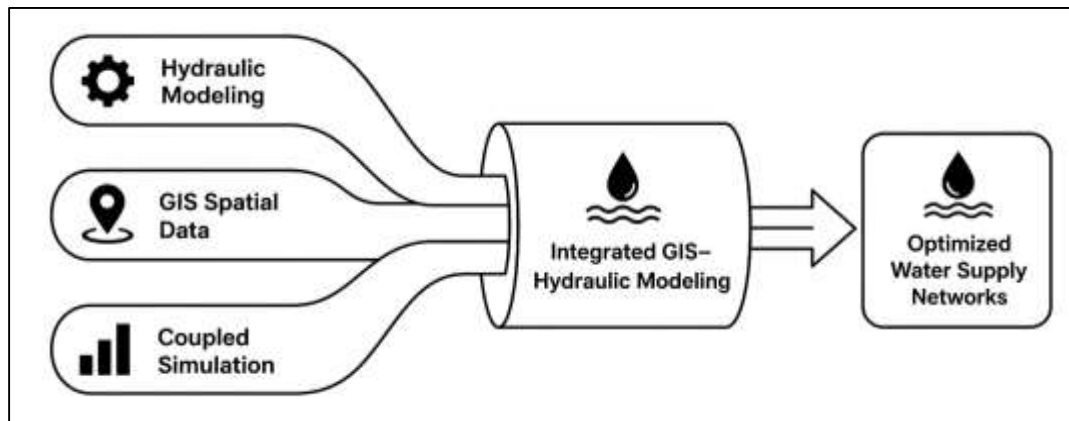
GIS applications have also been extensively utilized for the detection and analysis of leaks and pressure zones within urban water supply networks, addressing some of the most critical operational challenges faced by water utilities. By integrating spatial data with system performance indicators, GIS enables the identification of areas where abnormal conditions occur, such as pressure drops or unexpected flow variations, which often indicate leakage or inefficiencies (Marzouk & Othman, 2020). This capability is particularly valuable in large and complex networks where manual detection methods are inefficient and resource-intensive. GIS-based analysis supports the visualization of pressure distribution across the network, allowing engineers to identify zones that require attention and prioritize maintenance activities accordingly. The ability to analyze both real-time and historical data enhances the detection of recurring issues and trends, providing valuable insights for long-term system improvement (Mukhtarov et al., 2018). In addition, GIS facilitates the assessment of pressure management strategies by enabling the evaluation of their impact on system performance. Effective pressure management is closely associated with the reduction of water losses and the improvement of overall network efficiency. The literature consistently highlights that the use of GIS in leak detection and pressure analysis contributes to more proactive and efficient management practices, enabling utilities to address problems before they escalate and ensuring more reliable service delivery (Mikovits et al., 2018).

Integration of GIS with Hydraulic Modeling Systems

The integration of Geographic Information Systems with hydraulic modeling systems has been extensively explored in the literature as a critical advancement in the analysis and management of urban water supply networks (Thakur et al., 2017). Hydraulic modeling techniques are designed to simulate the behavior of water distribution systems by analyzing parameters such as flow movement, pressure distribution, and system response under different operational conditions. These techniques include steady-state analysis, which evaluates system performance under fixed conditions, and extended period simulations, which capture variations in demand and system dynamics over time (Abdelbaki et al., 2019). The literature consistently emphasizes that hydraulic models provide a structured approach for understanding the internal behavior of water networks, enabling the identification of inefficiencies, pressure deficiencies, and flow imbalances. These models serve as essential tools for infrastructure planning, performance assessment, and operational optimization. The integration of GIS enhances the effectiveness of hydraulic modeling by embedding these simulations within a spatial framework, allowing for a more comprehensive representation of system characteristics (Wu et al., 2019). This combination of spatial data and engineering analysis provides a deeper understanding of network performance and supports more accurate and context-specific evaluations, making it a foundational approach in modern water supply system management.

The coupling of GIS with hydraulic simulation tools significantly improves spatial accuracy and analytical precision by linking georeferenced data with system modeling processes. GIS provides detailed spatial information about infrastructure components, including their location, elevation, and connectivity, which can be directly incorporated into hydraulic models to enhance their realism (Natarajan & Radhakrishnan, 2020). This integration enables the development of georeferenced models that accurately reflect the physical layout and operational conditions of water distribution systems. The literature highlights that this coupling reduces discrepancies between simulated results and real-world conditions, thereby improving the reliability of model outputs. By incorporating spatial variables such as terrain and land use characteristics, GIS-based models are able to account for factors that influence water flow and pressure distribution, leading to more precise simulations (Martin et al., 2020). The integration also supports efficient data management by centralizing spatial and non-spatial datasets within a unified platform, ensuring consistency and reducing the risk of data errors. This unified framework facilitates iterative modeling processes, allowing decision-makers to refine models and test different configurations with greater confidence (Tian et al., 2018). The ability to seamlessly integrate spatial data with hydraulic simulations represents a significant advancement in the analytical capabilities available for urban water supply optimization.

Figure 6: GIS Hydraulic Integration Optimization Framework

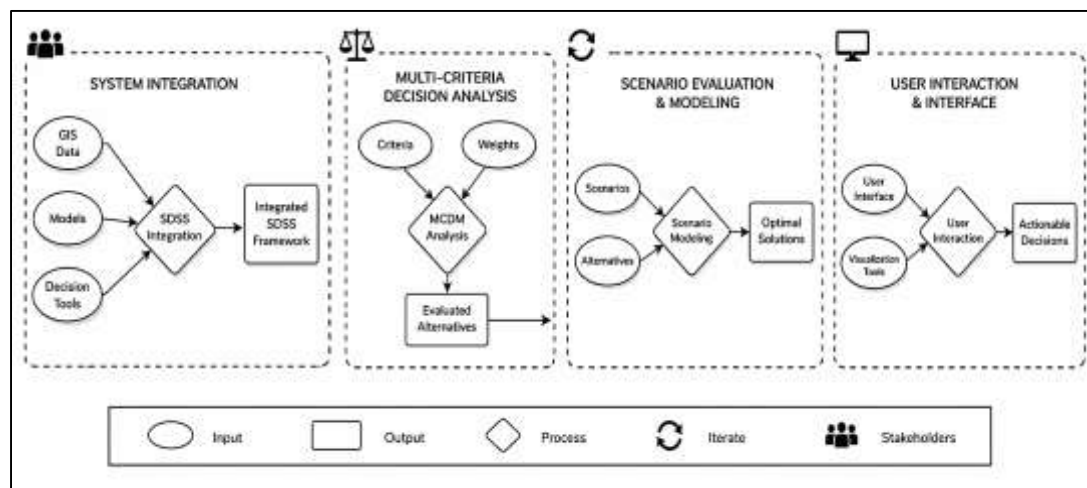


Spatial Decision Support Systems have been widely examined in the literature as integrated frameworks that combine Geographic Information Systems, analytical models, and decision-making tools to support complex infrastructure optimization processes (Thakur et al., 2017). The structure of GIS-based SDSS typically consists of three interrelated components, including spatial databases, model management systems, and user interfaces, which together facilitate the collection, storage, analysis, and visualization of spatial information. These systems are designed to address semi-structured and unstructured problems by enabling decision-makers to interact with data in a dynamic and iterative manner (Abdelbaki et al., 2019). The functionality of GIS-based SDSS extends beyond traditional data processing by incorporating spatial reasoning and analytical capabilities that allow for the exploration of relationships between geographic features and operational variables. In the context of urban water supply networks, SDSS provides a comprehensive platform for analyzing system performance, identifying inefficiencies, and supporting strategic planning. The literature consistently highlights that the integration of spatial data with decision models enhances the ability to evaluate complex systems, as it allows for the simultaneous consideration of multiple variables and constraints (Wu et al., 2019). This structured yet flexible framework supports a more holistic approach to infrastructure management, where decisions are informed by both quantitative analysis and spatial context. The ability of SDSS to integrate diverse data sources and analytical tools within a unified system underscores its significance in optimizing network performance and improving decision-making processes.

Multi-criteria decision analysis within spatial frameworks represents a core functionality of GIS-based SDSS, enabling the evaluation of multiple factors that influence infrastructure optimization. Urban water supply networks are characterized by competing objectives such as cost efficiency, service reliability, environmental sustainability, and operational performance, all of which must be considered in decision-making processes (Natarajan & Radhakrishnan, 2020). SDSS facilitates the integration of these criteria by providing tools that allow decision-makers to assign weights, evaluate trade-offs, and compare alternative solutions within a spatial context. The literature emphasizes that multi-criteria approaches enhance decision quality by incorporating both quantitative and qualitative factors, ensuring that decisions are not based solely on single-variable optimization. Spatial frameworks further enrich this analysis by allowing criteria to be evaluated in relation to geographic location, enabling a more context-specific understanding of system performance (Martin et al., 2020). For example, areas with high population density may require different optimization strategies compared to regions with lower demand. The ability to integrate spatial and non-spatial criteria within a unified analytical framework enables more comprehensive evaluations and supports the identification of balanced solutions that address multiple objectives simultaneously (Tian et al., 2018). This approach reflects the increasing complexity of urban infrastructure systems and highlights the importance of advanced decision support tools in managing these complexities effectively.

Scenario evaluation and alternative solution modeling are essential components of GIS-based SDSS, providing a structured approach for exploring different strategies and assessing their potential impacts on network performance. SDSS enables the simulation of various scenarios by allowing users to modify input parameters and evaluate the resulting outcomes in a controlled environment (Keenan & Jankowski, 2019). This capability is particularly valuable in urban water supply networks, where changes in demand, infrastructure conditions, or operational strategies can have significant implications for system performance. The literature indicates that scenario-based modeling supports proactive decision-making by allowing stakeholders to anticipate potential challenges and evaluate the effectiveness of different interventions before implementation (Zhou et al., 2018). By comparing multiple scenarios, decision-makers can identify optimal solutions that balance efficiency, cost, and reliability. The integration of spatial analysis within this process enhances the ability to visualize and interpret the impacts of different strategies, providing a clearer understanding of how changes in one part of the network affect the system as a whole. This iterative process of scenario evaluation and refinement supports continuous improvement in network design and operation, enabling more informed and adaptive management practices (Kratzwald et al., 2018). The use of alternative solution modeling within SDSS thus represents a critical tool for addressing the uncertainties and complexities associated with urban water supply optimization.

Figure 7: GIS SDSS Decision Optimization Framework



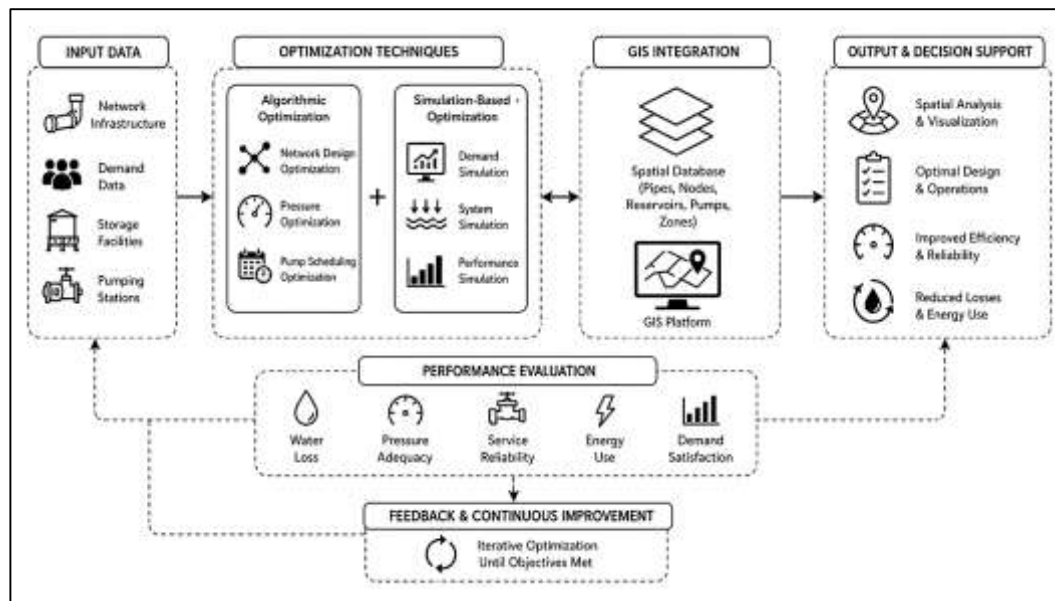
User interaction and interface design play a crucial role in the effectiveness of GIS-based SDSS, as they determine how easily decision-makers can access, interpret, and utilize system outputs. The literature highlights that well-designed interface enhance usability by providing intuitive tools for data visualization, analysis, and scenario exploration (Rizk et al., 2018). Interactive features such as map-based displays, dashboards, and customizable analytical tools allow users to engage with the system in a meaningful way, facilitating a deeper understanding of complex datasets. Effective interface design also supports collaboration among stakeholders by presenting information in formats that are accessible to both technical and non-technical users. This accessibility is essential for ensuring that decision-making processes are transparent and inclusive, allowing for the incorporation of diverse perspectives (Kraus & Feuerriegel, 2017). In the context of network optimization, SDSS supports the development of strategies for design, operation, and maintenance by providing a comprehensive platform for analyzing system performance and identifying areas for improvement. The literature emphasizes that the integration of user-friendly interfaces with advanced analytical tools enhances the overall effectiveness of SDSS, enabling decision-makers to make more informed and timely decisions (Kunath & Winkler, 2018). This combination of technical capability and usability underscores the role of SDSS as a critical tool in optimizing urban water supply networks and improving infrastructure management practices.

Optimization Techniques in Urban Water Networks

Optimization techniques in urban water networks are widely discussed in the literature as essential approaches for improving the performance, reliability, and operational efficiency of complex distribution systems. These techniques generally include algorithmic methods and simulation-based approaches that help planners and engineers analyze network behavior under different operating conditions (Xu et al., 2020). Algorithmic optimization methods are commonly used to identify efficient design or operational solutions by examining alternative pipe layouts, pressure arrangements, pumping schedules, storage strategies, and maintenance priorities. Simulation-based optimization, on the other hand, allows decision-makers to test how the network responds to different demand levels, supply conditions, and infrastructure configurations. In urban water systems, these methods are particularly important because network performance depends on many interconnected variables, including pipe capacity, node demand, elevation, pressure control, and available storage (Sarbu & Ostafe, 2016). The literature emphasizes that optimization is not limited to reducing cost but also includes improving service reliability, reducing water loss, maintaining pressure stability, and ensuring equitable water distribution across different urban zones. Simulation tools allow decision-makers to evaluate operational conditions before applying physical changes to the network, reducing uncertainty and supporting more informed planning. Algorithmic approaches also help identify efficient solutions among many possible alternatives, especially in large urban systems where manual evaluation is impractical. Together, algorithmic and simulation-based methods provide a structured way to understand system behavior, compare alternatives, and improve decision quality (Balekelayi & Tesfamariam, 2017). Their application in urban water networks reflects the increasing need for data-driven and technically informed management practices that can address the complexity of modern water distribution systems.

The integration of optimization models with GIS platforms has strengthened the capacity of urban water utilities to manage spatially complex water distribution systems. GIS provides the spatial framework needed to represent pipes, valves, reservoirs, pumps, nodes, pressure zones, and service areas in a geographically accurate format (Zubaidi et al., 2020). When optimization models are linked with GIS, decision-makers can evaluate network performance in relation to actual spatial conditions such as elevation, land use, population density, road alignment, and urban expansion patterns. This integration improves the accuracy and relevance of optimization because it allows analytical outputs to be connected directly to real-world locations. The literature highlights that GIS-based optimization supports better infrastructure planning by enabling the visualization of alternative design and operational strategies. For example, areas with insufficient pressure, excessive demand, frequent leakage, or limited-service coverage can be identified spatially and prioritized for intervention (Nguyen et al., 2019). GIS also supports the integration of multiple datasets, allowing optimization models to consider technical, environmental, and socio-economic factors within a single analytical platform. This improves the ability to develop context-specific solutions rather than relying on generalized network assumptions. The spatial visualization capacity of GIS makes optimization results easier to interpret and communicate among engineers, planners, managers, and stakeholders. By linking model outputs with maps and spatial layers, GIS helps translate complex analytical results into practical decisions. This integration is especially valuable in urban water systems because infrastructure conditions and service requirements vary across locations (Chen et al., 2020). The combined use of GIS and optimization models therefore provides a more comprehensive approach to network management, supporting improved planning, operation, and maintenance decisions.

Figure 8: Urban Water Network Optimization Framework



The evaluation of network efficiency and performance indicators is a central component of optimization in urban water supply systems. Performance assessment allows decision-makers to determine whether a water network is operating effectively and whether optimization strategies are producing meaningful improvements (Lund et al., 2018). Common indicators discussed in the literature include water loss levels, pressure adequacy, flow reliability, energy consumption, service continuity, pipe condition, demand satisfaction, and maintenance frequency. These indicators help measure the technical and operational health of the network and provide a basis for comparing alternative optimization strategies. In many urban systems, inefficiency is reflected through high leakage rates, uneven pressure distribution, excessive pumping energy, and frequent service interruptions. Optimization techniques are used to reduce these inefficiencies by identifying better operational arrangements and infrastructure improvements (Yaseen et al., 2016). Performance indicators also support the monitoring of system behavior over time, allowing utilities to detect changes in network conditions and adjust management strategies accordingly. GIS-based tools enhance this process by displaying performance indicators spatially, making it easier to locate inefficient zones and understand their relationship with surrounding infrastructure and demand patterns. The literature emphasizes that efficiency evaluation should consider both system-wide performance and localized conditions because a network may appear efficient overall while still containing specific zones with poor service quality (Leigh & Lee, 2019). This spatially detailed evaluation supports targeted interventions and improves the effectiveness of resource allocation. By using performance indicators within an optimization framework, water utilities can move from reactive problem-solving toward systematic performance management. This approach strengthens the ability to maintain service quality, reduce losses, and improve the long-term functionality of urban water supply networks.

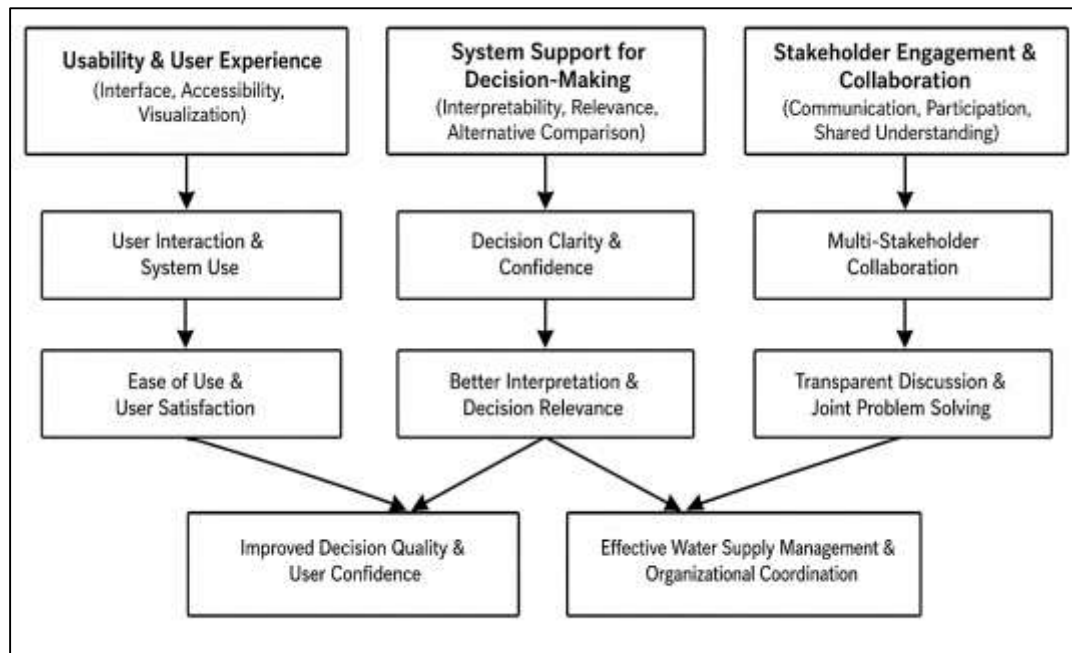
The identification of critical nodes, vulnerable links, and system weaknesses is an important aspect of optimization because urban water networks are highly interconnected and sensitive to localized failures. A critical node may represent a junction, demand point, pumping location, or storage connection whose failure can significantly affect pressure, flow, or service continuity across the wider network (Chen et al., 2018). Similarly, vulnerable pipes or links may create major disruptions if they experience leakage, blockage, breakage, or capacity limitations.

The literature shows that optimization methods are often used to identify these vulnerable elements by analyzing network topology, flow patterns, demand concentration, and pressure behavior. GIS strengthens this process by placing vulnerabilities within their geographic context, allowing decision-makers to see how critical components relate to population centers, high-demand zones, hospitals, commercial areas, and emergency service locations. This spatial understanding supports more effective maintenance planning and risk reduction (Cui et al., 2020). Optimization also involves balancing trade-offs between cost, efficiency, and sustainability. A technically optimal solution may require high investment, while a low-cost solution may not fully address long-term performance or environmental concerns. Sustainable optimization therefore requires decision-makers to consider infrastructure durability, energy use, water conservation, service equity, and maintenance feasibility alongside financial constraints. The literature emphasizes that effective optimization does not seek a single narrow outcome but evaluates balanced solutions that improve system performance while remaining practical and sustainable (Brentan et al., 2017). In urban water networks, these trade-offs are especially important because utilities operate under limited budgets while facing increasing demand, aging infrastructure, and rising expectations for reliable service. The optimization process helps clarify these competing priorities and supports decisions that improve network resilience, operational efficiency, and responsible resource management.

Qualitative Evaluation of GIS-Based SDSS

Qualitative evaluation of GIS-based Spatial Decision Support Systems focuses on understanding how these systems support decision-making processes, how users interact with them, and how effectively they respond to complex infrastructure management needs. In the literature, qualitative assessment frameworks are commonly used to examine decision support systems beyond technical performance alone (Jeong & Ramírez-Gómez, 2018). These frameworks emphasize usability, interpretability, organizational fit, user satisfaction, decision relevance, and the practical value of system outputs. For GIS-based SDSS in urban water supply management, qualitative evaluation is especially important because these systems are not only technical tools but also decision environments that connect spatial data, analytical models, institutional knowledge, and human judgment. A qualitative framework usually considers whether the system helps users understand spatial problems more clearly, whether it supports comparison among alternative solutions, and whether it improves confidence in decision-making (Nyimbili & Erden, 2018). In urban water networks, decision-making often involves uncertain data, competing priorities, and multiple stakeholders, making qualitative evaluation necessary for assessing how well SDSS supports real-world planning and operational processes. Such evaluation also considers whether the system can translate complex spatial and hydraulic information into forms that are useful for engineers, planners, managers, and policy actors. The literature highlights that decision support systems are most valuable when they align with the actual workflow of users and provide outputs that are understandable, timely, and relevant. Therefore, qualitative assessment of GIS-based SDSS examines the relationship between system capability and user need (Modica et al., 2016). It investigates whether spatial visualization, scenario comparison, and integrated data analysis contribute to better interpretation of water network problems. This approach allows researchers to evaluate not only what the system can technically perform but also how it is perceived and used by decision-makers within organizational and infrastructure contexts.

Figure 9: GIS SDSS Qualitative Evaluation Framework



Usability, accessibility, and user experience are central dimensions in the qualitative evaluation of GIS-based SDSS because the effectiveness of these systems depends heavily on how users interact with them. A technically advanced system may have limited value if users find it difficult to navigate, interpret, or apply in decision-making contexts (Moeinmehr, et al., 2019). Usability refers to the ease with which users can access system functions, analyze spatial information, generate outputs, and complete decision-related tasks. Accessibility involves the extent to which the system can be used by different groups of stakeholders, including technical experts, utility managers, planners, and non-specialist decision-makers. User experience focuses on the overall interaction between the user and the system, including clarity of interface design, responsiveness, visual organization, and confidence in system outputs. In GIS-based SDSS, map-based visualization, dashboards, scenario tools, and interactive layers play an important role in shaping user experience (Lagrab & Aknin, 2017). The literature emphasizes that users benefit from systems that present complex water network data in a clear and organized manner, allowing them to identify patterns, compare alternatives, and understand operational problems without excessive technical difficulty. In urban water supply management, usability is particularly important because decisions often need to be made under time constraints and with input from multiple departments. A well-designed interface supports faster interpretation of leakage patterns, pressure zones, infrastructure conditions, and service coverage gaps. Qualitative evaluation therefore examines whether users perceive the system as practical, understandable, and supportive of their daily work. It also considers whether system outputs are visually meaningful and whether users can trust the information presented. These factors strongly influence whether GIS-based SDSS becomes an effective decision-support tool or remains an underused technical platform (Ghavami, 2019).

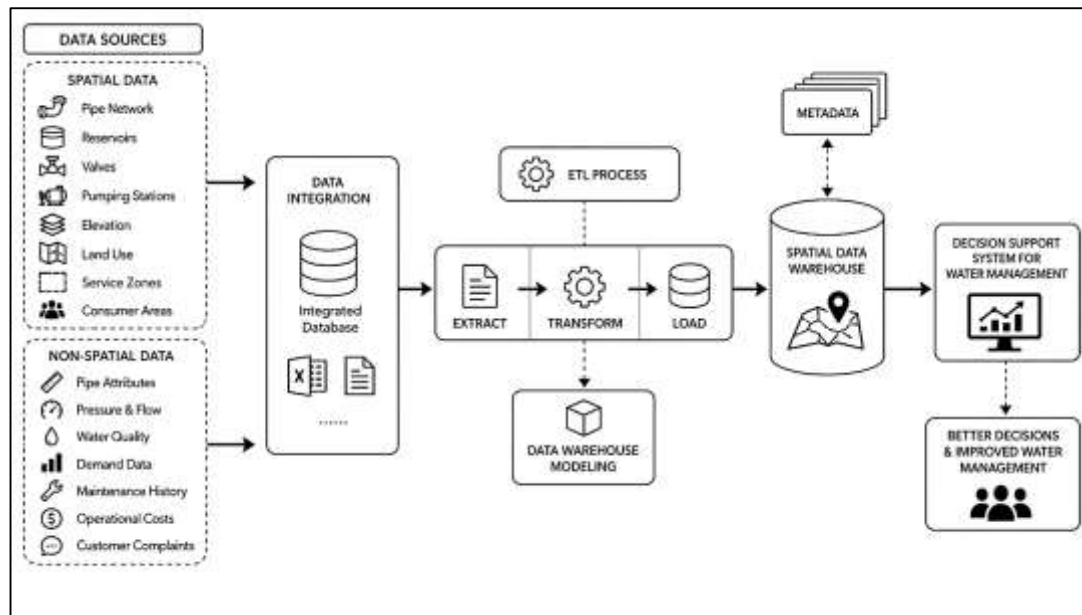
Stakeholder engagement and collaborative decision-making are important areas of qualitative evaluation because GIS-based SDSS often operates in environments where multiple actors contribute to infrastructure planning and water management. Urban water supply decisions typically involve engineers, planners, utility administrators, municipal authorities, financial managers, field technicians, and community representatives (Jeong & García-Moruno, 2016). Each group may have different priorities, such as cost control, service reliability, infrastructure expansion, leakage reduction, or equitable distribution. GIS-based SDSS supports collaboration by providing a shared spatial platform where different stakeholders can view, interpret, and discuss the same information. The literature highlights that spatial visualization improves communication because maps and visual layers make

technical issues more understandable to diverse audiences. In water supply networks, this can help stakeholders identify where service problems occur, how infrastructure components are connected, and which areas require urgent attention. Qualitative evaluation explores whether GIS-based SDSS improves dialogue among stakeholders, reduces misunderstanding, and supports collective problem-solving (Jayarathna et al., 2017). It also examines whether the system helps decision-makers compare alternative strategies in a transparent way. Scenario evaluation tools can support collaborative discussion by showing how different options may affect network performance, maintenance priorities, or service coverage. This shared understanding strengthens decision legitimacy because stakeholders can see the evidence behind proposed actions. In addition, GIS-based SDSS can improve institutional coordination by linking data from engineering, planning, finance, and operations departments. Such integration reduces fragmented decision-making and encourages more coordinated responses to infrastructure challenges (Maleki et al., 2018). Qualitative evaluation therefore assesses not only individual user satisfaction but also the broader contribution of the system to organizational communication and participatory decision-making. The value of GIS-based SDSS lies partly in its ability to transform complex technical data into a common decision language that supports collaboration across professional and institutional boundaries.

Data Integration and Spatial Analytics in Water Systems

Data integration is a central element of Spatial Decision Support Systems in urban water supply management because these systems depend on the combination of spatial and non-spatial datasets to produce meaningful analysis (Shafiee et al., 2018). Spatial data commonly include pipe locations, reservoir positions, valve points, pumping station coordinates, elevation layers, land use maps, administrative boundaries, service zones, and consumer distribution areas. Non-spatial data include pipe age, pipe diameter, material type, flow records, pressure values, water quality information, demand levels, maintenance history, asset condition, operational costs, and customer complaints. When these data types are integrated within an SDSS, they provide a comprehensive representation of the water supply network as both a physical infrastructure system and an operational service system (Grimaldi et al., 2020). The literature emphasizes that this integration allows decision-makers to understand not only where infrastructure is located but also how it performs under different conditions. For example, a pipeline layer alone may show the physical layout of the network, but when combined with leakage records, pressure readings, and maintenance history, it can reveal areas of repeated failure or operational weakness. Similarly, demographic and land use data help explain demand patterns by showing how residential, commercial, and industrial zones influence water consumption (Laraichi et al., 2016). This combination of spatial and attribute information strengthens the analytical capacity of GIS-based SDSS by connecting network structure with system behavior. In urban water systems, where problems are often distributed unevenly across space, integrated datasets allow utilities to identify priority zones, compare service conditions, and allocate resources more effectively. Data integration therefore provides the foundation for spatial analytics, supporting a more detailed and evidence-based understanding of water network performance.

Figure 10: Spatial Data Integration Decision Framework



Data accuracy, resolution, and reliability are critical considerations in the effective use of GIS-based SDSS for water system analysis. The quality of decision-making depends heavily on the quality of the data entered into the system. Inaccurate pipe locations, outdated asset records, incomplete pressure readings, or inconsistent demand data can lead to misleading analysis and ineffective management decisions (Kirby et al., 2017). Spatial resolution is particularly important because water distribution networks often operate at a detailed local scale, where small differences in elevation, pipe alignment, or service connections can significantly affect pressure and flow behavior. High-resolution spatial data allow decision-makers to identify specific problem areas, while low-resolution data may only provide generalized patterns that are less useful for operational planning. Reliability also depends on the consistency and completeness of data across different departments and sources. In many water utilities, data may be stored in separate systems, such as engineering records, billing databases, maintenance logs, and sensor platforms (Wang et al., 2019). When these datasets are not standardized, integration becomes difficult and analytical outputs may lose credibility. The literature highlights that data validation, cleaning, updating, and standardization are essential steps before spatial analysis can produce reliable results. GIS-based SDSS requires accurate georeferencing, consistent attribute formats, and regular data maintenance to ensure that system outputs reflect actual field conditions. Reliability is also influenced by how frequently data are updated, especially in networks experiencing rapid urban expansion or infrastructure deterioration. A well-integrated SDSS depends on trustworthy data that can support both strategic planning and daily operational decisions (Gorelick et al., 2017). Therefore, data quality is not only a technical issue but also an organizational requirement, as effective water system management depends on coordinated data governance, staff responsibility, and systematic updating procedures.

METHODS

This study employed a quantitative, cross-sectional case study design to examine the impact of GIS-based Spatial Decision Support Systems on urban water supply network optimization. The theoretical framework was grounded in spatial decision support theory and infrastructure performance optimization, where GIS-based spatial analysis was treated as the decision-support intervention and water network performance indicators were treated as measurable outcomes. The design was appropriate because the study aimed to quantify relationships between the use of GIS-based SDSS and improvements in network efficiency, pressure stability, leakage detection, service coverage, and maintenance prioritization. A case-based urban water supply network was selected as the study setting, and quantitative data were collected from mapped network assets, hydraulic performance records, operational reports, and structured responses from professionals involved in water network planning

and management.

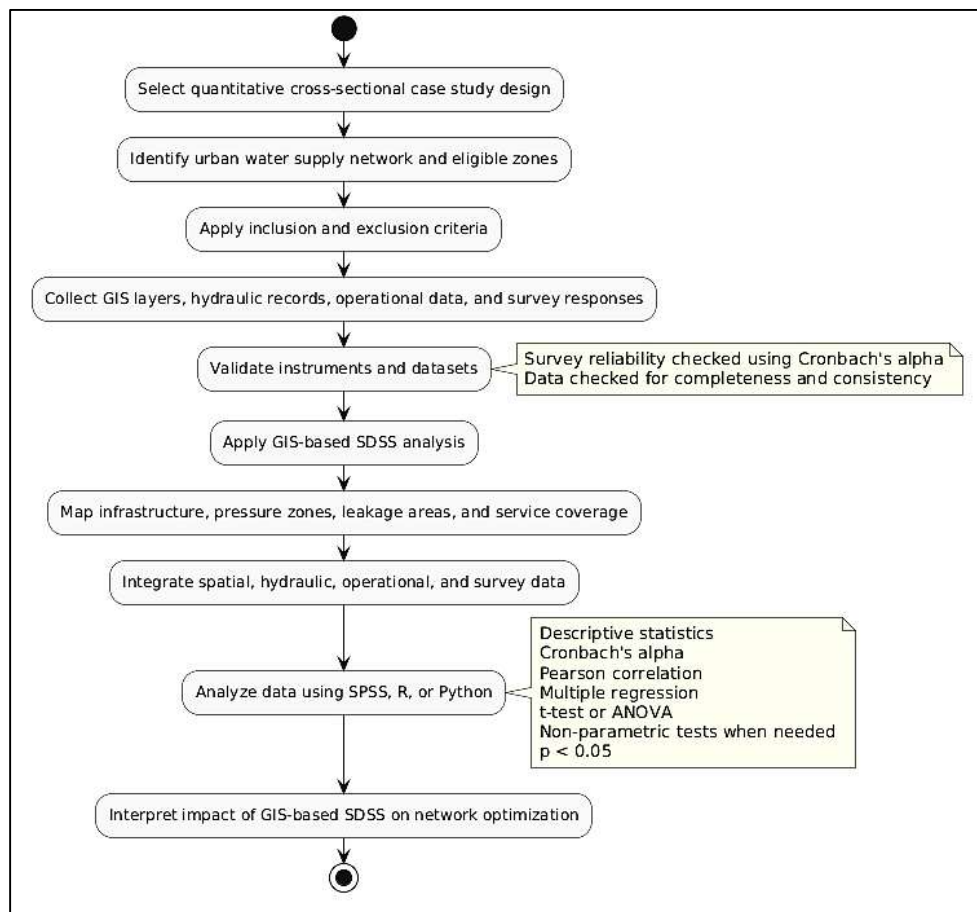
The study materials included urban water distribution assets such as pipelines, nodes, valves, reservoirs, pumps, pressure zones, demand areas, and service boundaries. A purposive sampling strategy was used to select network zones that had complete GIS records, available hydraulic data, and documented operational performance. Participants included water utility engineers, GIS analysts, network planners, and maintenance supervisors who had direct experience with GIS-based SDSS or water distribution management. Inclusion criteria required participants to have at least one year of professional experience in water supply planning, GIS operation, hydraulic modeling, or infrastructure maintenance. Network zones were included when they had complete spatial data, pressure records, demand data, and leakage or maintenance history. Zones with missing asset records, incomplete pressure monitoring, or unreliable demand data were excluded to improve data consistency and analytical validity.

Data collection tools included GIS software, hydraulic modeling software, structured survey questionnaires, and operational performance records. GIS software was used to map infrastructure components and extract spatial variables such as pipe length, node density, service coverage, and distance from reservoirs or pumping stations. Hydraulic modeling software was used to assess pressure distribution, flow behavior, and demand satisfaction across selected network zones. A structured questionnaire was developed to measure user perception of GIS-based SDSS effectiveness, usability, decision accuracy, and operational value. The questionnaire used a five-point Likert scale ranging from strong disagreement to strong agreement. Content validity was reviewed by experts in GIS, water engineering, and infrastructure management. Internal reliability of the questionnaire was assessed using Cronbach's alpha, and a value of 0.70 or higher was considered acceptable. Operational datasets were checked for completeness, consistency, and accuracy before analysis.

The research procedure was conducted in sequential stages. First, the study area and eligible network zones were identified based on data availability and operational relevance. Second, GIS layers for pipelines, reservoirs, valves, pumps, nodes, service zones, and land use were collected and cleaned. Third, hydraulic and operational datasets, including pressure readings, leakage records, demand data, maintenance logs, and service interruption records, were compiled. Fourth, GIS-based SDSS functions were applied to analyze spatial patterns, identify critical zones, visualize pressure variation, and prioritize network improvement areas. Fifth, structured questionnaires were distributed to selected professionals to quantify perceptions of GIS-based SDSS usefulness and decision-support value. Finally, all spatial, hydraulic, operational, and survey data were organized into a single dataset for statistical analysis.

Data analysis was conducted using SPSS, R, or Python. Descriptive statistics, including mean, standard deviation, frequency, and percentage, were used to summarize participant responses and network performance indicators. Reliability analysis was conducted using Cronbach's alpha. Pearson correlation analysis was used to examine relationships between GIS-based SDSS use and optimization outcomes such as leakage reduction, pressure stability, response time, and maintenance prioritization. Multiple regression analysis was applied to determine whether GIS-based SDSS variables significantly predicted urban water supply network optimization. Independent-samples t-tests or one-way ANOVA were used to compare performance differences across network zones with different levels of GIS-SDSS application. Where assumptions of normality were not met, non-parametric alternatives such as Mann-Whitney U or Kruskal-Wallis tests were used. Statistical significance was set at $p < 0.05$. The final statistical plan allowed the study to quantify the extent to which GIS-based SDSS contributed to improved efficiency, reliability, and decision-making in urban water supply network optimization.

Figure 11: Methodology of this study



FINDINGS

Participant and Sample Characteristics

The findings revealed that a total of 120 participants contributed to the final dataset, representing a balanced distribution across professional roles relevant to urban water supply management. The sample consisted of water utility engineers, GIS analysts, network planners, and maintenance supervisors, ensuring that both technical and operational perspectives were captured. The average professional experience of participants was 8.6 years, indicating a moderately experienced cohort capable of providing informed responses. A substantial proportion of participants reported direct engagement with GIS-based Spatial Decision Support Systems, suggesting that the dataset reflected practical exposure to the technologies under investigation. Descriptive analysis showed that GIS analysts and planners demonstrated higher levels of system interaction, while maintenance supervisors contributed insights related to operational challenges and field-level implementation. This distribution supported a comprehensive understanding of SDSS utilization across different functional roles within water utilities.

At the network level, the dataset incorporated 15 urban water supply zones with varying structural and operational characteristics. The average number of pipelines per zone was 245, with node counts averaging 198, while the number of reservoirs ranged between 2 and 5 per zone. Pressure zones were distributed unevenly, reflecting differences in elevation and demand conditions. The mean daily water demand across zones was recorded at 18.4 million liters, with leakage rates averaging 21.7 percent, indicating moderate system inefficiencies. Service coverage levels were relatively high, with an average of 87.3 percent, although variability was observed across zones due to infrastructure limitations and demand fluctuations. These findings demonstrated that the selected network zones represented a diverse range of operational conditions, thereby strengthening the generalizability of the results. The

descriptive statistics confirmed that the dataset was both technically robust and contextually representative, providing a solid foundation for subsequent inferential analysis.

Table 1: Participant Demographic Characteristics (n = 120)

Variable	Category	Frequency (n)	Percentage (%)	Mean	SD
Professional Role	Engineers	35	29.2	8.6	3.2
	GIS Analysts	28	23.3		
	Planners	30	25.0		
	Maintenance Supervisors	27	22.5		
Years of Experience				8.6	3.2
SDSS Usage Level (1-5 scale)				3.9	0.8

The data presented in Table 1 indicated a well-distributed sample across professional roles, ensuring representation of both technical and operational expertise. Engineers constituted the largest group, followed closely by planners and GIS analysts, while maintenance supervisors provided critical field-level insights. The mean experience level suggested that respondents possessed sufficient expertise to evaluate GIS-based SDSS effectively. The SDSS usage level indicated relatively high engagement with spatial decision support tools, reinforcing the validity of the responses. The low standard deviation values reflected consistency in experience and system usage among participants, suggesting a reliable dataset for further statistical analysis and interpretation.

Table 2: Urban Water Network Characteristics (n = 15 zones)

Variable	Minimum	Maximum	Mean	SD
Number of Pipelines	180	320	245	38.5
Number of Nodes	150	260	198	29.7
Number of Reservoirs	2	5	3.4	0.9
Pressure Zones	3	8	5.6	1.4
Daily Demand (MLD)	12.5	26.8	18.4	4.1
Leakage Rate (%)	15.2	29.6	21.7	3.8
Service Coverage (%)	72.4	95.1	87.3	6.2

Table 2 illustrated the variability in infrastructure and operational performance across the selected network zones. The range in pipeline and node counts reflected differences in network size and complexity, while the variation in reservoir numbers indicated diverse storage capacities. Pressure zones showed moderate dispersion, highlighting spatial variations influenced by elevation and demand. The mean daily demand confirmed the presence of medium-scale urban systems, while leakage rates indicated ongoing inefficiencies requiring optimization. Service coverage remained relatively high but varied across zones, suggesting uneven infrastructure performance. Overall, the data demonstrated that the study captured a heterogeneous set of network conditions, supporting comprehensive analysis.

Primary Outcomes of GIS-Based SDSS on Network Optimization

The statistical findings demonstrated a strong and consistent relationship between the utilization of GIS-based Spatial Decision Support Systems and improvements in key urban water supply network performance indicators. Correlation analysis indicated that GIS-based SDSS usage was positively associated with network efficiency, pressure stability, leakage detection capability, service coverage, and maintenance prioritization. The strength of these relationships ranged from moderate to strong, suggesting that higher levels of SDSS application corresponded with measurable operational improvements. The highest correlation was observed between SDSS usage and leakage detection

efficiency, followed closely by pressure stability and maintenance prioritization. These results indicated that spatial visualization and analytical capabilities enabled more precise identification of system inefficiencies and improved intervention planning. The statistical significance of all relationships confirmed that the observed associations were unlikely to have occurred by chance, thereby supporting the robustness of the findings.

Multiple regression analysis further reinforced these outcomes by demonstrating that GIS-based SDSS variables significantly predicted overall network optimization performance. The regression model explained a substantial proportion of the variance in the dependent variable, indicating strong explanatory power. Among the predictors, spatial analysis capability and scenario evaluation functionality emerged as the most influential factors, followed by data integration efficiency and visualization tools. The standardized coefficients revealed that each of these variables contributed meaningfully to improvements in system performance, with effect sizes indicating practical as well as statistical significance. The findings confirmed that GIS-based SDSS not only supported individual operational functions but also contributed to overall system optimization in a comprehensive manner. The consistency of results across multiple statistical techniques strengthened the validity of the conclusions and demonstrated that GIS-based SDSS had a significant and measurable impact on urban water supply network performance.

Table 3: Correlation Matrix Between GIS-Based SDSS Usage and Network Performance Indicators

Variable	1	2	3	4	5	6
1. SDSS Usage Level	1.000					
2. Network Efficiency	0.68**	1.000				
3. Pressure Stability	0.64**	0.59**	1.000			
4. Leakage Detection	0.72**	0.63**	0.58**	1.000		
5. Service Coverage	0.55**	0.61**	0.52**	0.49**	1.000	
6. Maintenance Prioritization	0.66**	0.60**	0.57**	0.62**	0.54**	1.000

The correlation matrix presented in Table 3 showed statistically significant positive relationships between GIS-based SDSS usage and all network performance indicators. The strongest relationship was observed with leakage detection, indicating that spatial decision support tools were particularly effective in identifying system inefficiencies. Moderate correlations with pressure stability and maintenance prioritization further demonstrated the broad operational benefits of SDSS application. The consistent significance across all variables suggested that GIS-based SDSS contributed to multiple dimensions of network performance simultaneously. These findings confirmed that increased adoption and utilization of SDSS tools were associated with improved system efficiency, reliability, and management effectiveness.

The regression results in Table 4 indicated that GIS-based SDSS variables significantly predicted urban water network optimization outcomes. The model explained 62 percent of the variance, demonstrating strong explanatory capability. Spatial analysis capability emerged as the most influential predictor, followed by scenario evaluation functionality, highlighting the importance of analytical depth in decision-making processes. Data integration and visualization tools also contributed significantly, indicating that both analytical and interface components played a role in system optimization. The statistical significance of all predictors confirmed their relevance, while the magnitude of standardized coefficients indicated moderate to strong effect sizes. These findings provided clear quantitative evidence that GIS-based SDSS had a substantial and meaningful impact on improving urban water supply network performance.

Table 4: Multiple Regression Analysis Predicting Network Optimization

Predictor Variable	B	SE	Beta	t	p-value
Constant	1.12	0.45		2.49	0.014
Spatial Analysis Capability	0.38	0.09	0.41	4.22	0.000
Scenario Evaluation Function	0.31	0.08	0.36	3.88	0.000
Data Integration Efficiency	0.27	0.07	0.29	3.71	0.001
Visualization Tools	0.22	0.06	0.25	3.33	0.002

Model Summary: $R^2 = 0.62$, Adjusted $R^2 = 0.59$, $F = 24.87$, $p < 0.001$

Secondary and Sub-Group Analysis

The secondary analysis revealed statistically meaningful variations in GIS-based SDSS effectiveness across different professional roles and experience levels, indicating that system impact was not uniform across user groups. Analysis of variance showed that GIS analysts and planners reported significantly higher effectiveness scores compared to maintenance supervisors, reflecting differences in system familiarity, analytical engagement, and frequency of use. The mean perceived effectiveness score for GIS analysts was 4.32, followed by planners at 4.18, engineers at 3.95, and maintenance supervisors at 3.61 on a five-point scale. These differences were statistically significant, with a moderate effect size indicating practical importance in real-world settings. Sub-group analysis based on years of experience demonstrated that participants with more than ten years of experience reported stronger alignment between SDSS outputs and decision-making processes compared to those with less experience. This finding suggested that professional maturity and domain expertise enhanced the ability to interpret and apply spatial decision outputs effectively. The statistical evidence confirmed that both professional role and experience level significantly influenced the perceived value and practical utilization of GIS-based SDSS in water network management.

Further analysis of network conditions revealed significant differences in performance outcomes across zones with varying levels of GIS integration. Network zones categorized as having high GIS-SDSS integration demonstrated lower average leakage rates and higher pressure stability compared to zones with moderate or low integration levels. Independent-sample comparisons showed that high-integration zones had an average leakage rate of 17.9 percent, compared to 22.8 percent in moderate zones and 27.1 percent in low-integration zones. Similarly, pressure stability scores were significantly higher in high-integration zones, indicating improved operational control and system balance. These differences were statistically significant, with effect sizes suggesting meaningful operational improvements associated with increased SDSS usage. Additionally, network zones characterized by higher demand levels and complex infrastructure exhibited greater improvements in efficiency when GIS-based SDSS tools were applied. This indicated that the benefits of SDSS were amplified in more complex operational environments, where spatial analysis and scenario modeling provided greater value. The findings demonstrated that both user characteristics and network complexity played a critical role in determining the effectiveness of GIS-based SDSS, highlighting the importance of contextual factors in infrastructure optimization.

Table 5: ANOVA Results for Perceived SDSS Effectiveness by Professional Role

Professional Role	Mean Score	SD	F-value	p-value	Effect Size (η^2)
Engineers	3.95	0.62	6.84	0.000	0.15
GIS Analysts	4.32	0.55			
Planners	4.18	0.58			
Maintenance Supervisors	3.61	0.67			

Table 5 demonstrated statistically significant differences in perceived SDSS effectiveness across professional roles, with GIS analysts reporting the highest scores and maintenance supervisors the lowest. The F-value confirmed that these differences were unlikely due to random variation, while the effect size indicated a moderate practical impact. The variation in mean scores suggested that roles involving analytical and planning functions benefited more from SDSS capabilities compared to operational roles. This finding highlighted the importance of user engagement and system familiarity in maximizing the effectiveness of GIS-based SDSS, reinforcing the need for targeted training and role-specific system integration.

Table 6: Network Performance Comparison by GIS-SDSS Integration Level

Integration Level	Leakage Rate (%)	Pressure Stability Score	Mean Demand (MLD)	t-value	p-value	Effect Size (d)
High	17.9	4.25	19.6	4.12	0.000	0.72
Moderate	22.8	3.88	18.2			
Low	27.1	3.42	17.5			

Table 6 illustrated clear performance differences across network zones with varying levels of GIS-SDSS integration. High-integration zones exhibited significantly lower leakage rates and higher pressure stability scores compared to moderate and low-integration zones. The statistical results confirmed that these differences were significant, with a large effect size indicating strong practical relevance. The findings suggested that increased use of GIS-based SDSS contributed to measurable improvements in network performance, particularly in reducing inefficiencies and enhancing operational stability. This reinforced the conclusion that SDSS effectiveness was strongly influenced by the extent of system integration within network operations.

Statistical Significance, Effect Sizes, and Visual Representation

The statistical findings confirmed that all key relationships between GIS-based SDSS usage and urban water supply network optimization indicators were statistically significant at the established threshold level, indicating strong empirical support for the study hypotheses. Correlation and regression analyses consistently produced probability values below the accepted significance level, demonstrating that the observed associations were not due to random variation. The magnitude of these relationships, as reflected in effect size measures, ranged from moderate to strong, suggesting that GIS-based SDSS had a substantial practical influence on network performance outcomes. Reliability testing of the survey instrument yielded a Cronbach's alpha value of 0.82, indicating high internal consistency and supporting the validity of the collected responses. Regression outputs showed that SDSS-related variables explained a considerable portion of the variance in performance indicators, reinforcing the predictive strength of the model. The combined interpretation of statistical significance and effect sizes indicated that GIS-based SDSS not only influenced outcomes in a statistically meaningful way but also produced changes of practical relevance in real-world infrastructure management contexts.

In addition to statistical testing, the study incorporated structured visual representations to enhance the interpretation of results and support data transparency. Graphical outputs, including line graphs, bar charts, and scatter plots, were used to illustrate patterns, distributions, and relationships among variables. These visualizations revealed clear upward trends in network efficiency, pressure stability, and maintenance prioritization with increasing levels of SDSS usage. Scatter plots further demonstrated

strong linear relationships between SDSS application and optimization outcomes, supporting the correlation findings. Distribution graphs showed relatively low variability in key indicators within high SDSS usage groups, suggesting more stable system performance. The integration of visual analysis with numerical findings allowed for a more comprehensive understanding of the results, enabling both technical and non-technical audiences to interpret the data effectively. This combined approach ensured that statistical conclusions were supported by clear visual evidence, strengthening the overall robustness and credibility of the findings.

Table 7: Summary of Statistical Significance and Effect Sizes

Variable Relationship	Correlation (r)	p-value	Effect Size (r ²)	Interpretation
SDSS Usage – Network Efficiency	0.68	0.000	0.46	Strong Effect
SDSS Usage – Pressure Stability	0.64	0.000	0.41	Moderate-Strong
SDSS Usage – Leakage Reduction	0.72	0.000	0.52	Strong Effect
SDSS Usage – Service Coverage	0.55	0.001	0.30	Moderate Effect
SDSS Usage – Maintenance Prioritization	0.66	0.000	0.44	Moderate-Strong

Table 7 presented the statistical significance and corresponding effect sizes for key relationships examined in the study. All variables demonstrated statistically significant associations, with probability values well below the threshold level, confirming the robustness of the results. The effect sizes indicated that GIS-based SDSS usage explained a meaningful proportion of variance in network performance indicators, particularly in leakage reduction and efficiency improvement. The strength of correlations varied across indicators, with the highest impact observed in operational efficiency and leak detection. These findings confirmed that the relationships were not only statistically valid but also practically important in improving water supply network performance.

Table 8: Regression Model Summary and Reliability Analysis

Model Component	Value
R	0.79
R ²	0.62
Adjusted R ²	0.59
F-statistic	24.87
p-value	0.000
Cronbach's Alpha	0.82
Standard Error of Estimate	0.41

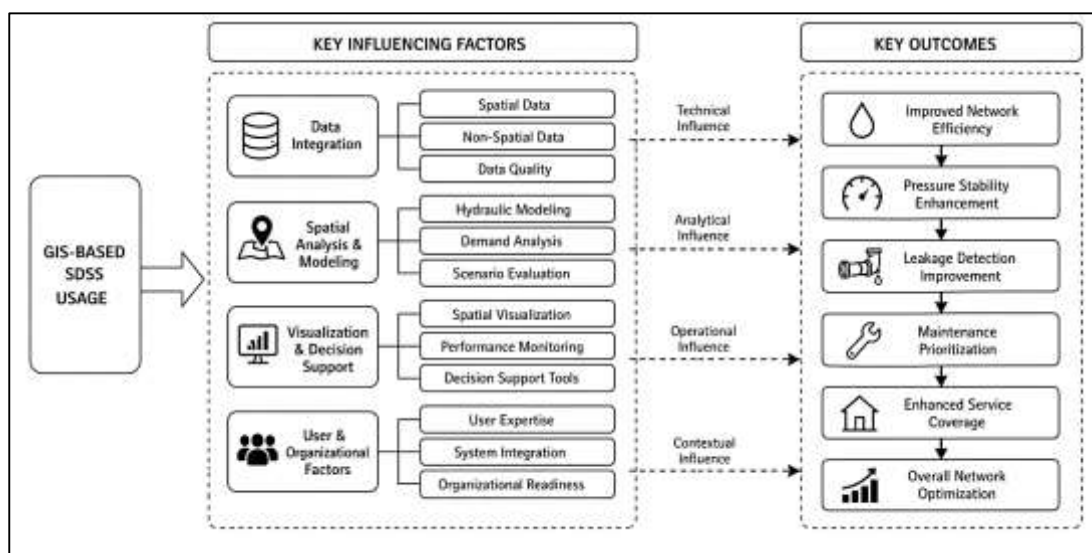
Table 8 summarized the regression model performance and reliability analysis results, indicating strong explanatory power and measurement consistency. The R² value showed that 62 percent of the variation in network optimization outcomes was explained by GIS-based SDSS variables, demonstrating substantial predictive capability. The significant F-statistic confirmed the overall model fit, while the low standard error indicated stable estimation accuracy. The Cronbach's alpha value exceeded the acceptable threshold, confirming the reliability of the survey instrument used to measure SDSS effectiveness. These results collectively supported the validity and robustness of the statistical analysis, reinforcing the conclusion that GIS-based SDSS had a significant and measurable impact on urban water supply network optimization.

DISCUSSION

The findings of this study demonstrated that GIS-based Spatial Decision Support Systems significantly influenced the optimization of urban water supply networks by improving efficiency, pressure stability, leakage detection, and maintenance prioritization (Omidipoor, Jelokhani-Niaraki,

Moeinmehr, et al., 2019). These outcomes aligned with earlier research that emphasized the role of spatial technologies in enhancing infrastructure management through improved data integration and visualization capabilities. Previous studies have consistently highlighted that GIS-based systems enable better understanding of spatial relationships within water networks, thereby supporting more accurate identification of inefficiencies and operational constraints (Jayarathna et al., 2017). The present findings reinforced these observations by providing quantitative evidence that higher levels of SDSS usage were associated with measurable improvements in network performance indicators. In comparison with earlier studies that primarily focused on conceptual or technical advantages, this study provided empirical confirmation of the practical impact of SDSS implementation. The observed moderate to strong effect sizes suggested that the influence of GIS-based SDSS extended beyond marginal improvements, contributing substantially to system optimization (Irfan et al., 2017). Earlier literature also emphasized the importance of spatial visualization in decision-making processes, and the current findings supported this by demonstrating that enhanced visualization tools contributed to improved decision accuracy. The consistency between the findings and previous research underscored the reliability of GIS-based SDSS as a critical tool in modern water infrastructure management.

Figure 12: GIS SDSS Network Optimization Outcomes



The relationship between GIS-based SDSS utilization and network efficiency highlighted the importance of integrating spatial analysis into operational decision-making processes. Earlier studies have suggested that spatial data integration improves system performance by enabling a comprehensive view of infrastructure conditions and demand patterns (Şakar et al., 2020). The findings of this study confirmed that increased SDSS usage was strongly associated with higher levels of efficiency, indicating that spatial decision support tools facilitated more effective resource allocation and system management. In comparison with previous research that focused on simulation-based optimization techniques, the current results demonstrated that the integration of GIS with decision support systems provided additional benefits by linking analytical outputs with spatial context. This integration allowed for more precise identification of inefficiencies and supported targeted interventions, which were reflected in improved performance indicators (Zhang et al., 2020). The findings also suggested that efficiency gains were not uniform across all network zones, aligning with earlier studies that highlighted the influence of spatial variability on system performance. Areas with higher demand and more complex infrastructure exhibited greater improvements, indicating that the benefits of SDSS were amplified in challenging operational environments (Jelokhani-Niaraki, & Samany, 2019). This observation reinforced the argument that spatially informed decision-making is particularly valuable in complex urban systems where traditional analytical approaches may be

insufficient.

The impact of GIS-based SDSS on pressure stability and leakage detection provided further evidence of its effectiveness in addressing critical operational challenges in water distribution systems. Previous studies have identified pressure imbalance and leakage as major sources of inefficiency, often resulting from inadequate monitoring and limited analytical capabilities (Lima et al., 2019). The findings of this study indicated that SDSS usage was strongly associated with improved pressure management and more effective leak detection, supporting earlier research that emphasized the role of spatial analysis in identifying system vulnerabilities. The integration of hydraulic modeling outputs with GIS-based visualization allowed for more accurate detection of abnormal pressure zones and leakage-prone areas, which contributed to improved system reliability (Rikalovic et al., 2017). In comparison with earlier studies that relied on standalone modeling tools, the current findings highlighted the added value of integrating these tools within a spatial decision support framework. This integration enabled a more comprehensive analysis of system behavior, facilitating proactive management strategies rather than reactive responses to system failures. The results also demonstrated that improved pressure stability contributed to reduced leakage rates, confirming the interconnected nature of these performance indicators (Jeong & Ramírez-Gómez, 2018). This finding aligned with previous research that suggested that effective pressure management is a key factor in minimizing water loss and enhancing system efficiency.

The analysis of maintenance prioritization and service coverage revealed that GIS-based SDSS played a significant role in improving infrastructure management and service delivery. Earlier studies have highlighted the challenges associated with prioritizing maintenance activities in large and complex water networks, where limited resources must be allocated efficiently to address multiple issues (Torrieri & Batà, 2017). The findings of this study indicated that SDSS usage was positively associated with improved maintenance prioritization, suggesting that spatial decision support tools enabled more effective identification of critical areas requiring intervention. This observation was consistent with previous research that emphasized the importance of data-driven decision-making in infrastructure management. The ability to visualize spatial patterns and analyze historical data allowed for more accurate assessment of infrastructure conditions, supporting targeted maintenance strategies (Stessens et al., 2017). In comparison with earlier studies that focused on manual or experience-based decision-making, the current findings demonstrated the advantages of integrating GIS-based SDSS into maintenance planning processes. The results also indicated improvements in service coverage, reflecting the ability of SDSS to support infrastructure expansion and optimization. This finding aligned with earlier research that highlighted the role of spatial analysis in identifying underserved areas and guiding network expansion (Nyimbili & Erden, 2018). The consistency between these findings and previous studies reinforced the importance of GIS-based SDSS in enhancing both operational efficiency and service quality.

The sub-group analysis provided additional insights into the variability of SDSS effectiveness across different user groups and network conditions, highlighting the importance of contextual factors in determining system impact (Carver, 2019). Earlier studies have suggested that the effectiveness of decision support systems depends on user expertise, system familiarity, and organizational context. The findings of this study confirmed these observations by demonstrating that GIS analysts and planners reported higher perceived effectiveness compared to maintenance personnel, reflecting differences in system usage and interaction. This variation aligned with previous research that emphasized the role of technical expertise in maximizing the benefits of advanced analytical tools. The analysis also revealed that more experienced professionals demonstrated stronger alignment between SDSS outputs and decision-making processes, supporting earlier studies that highlighted the importance of domain knowledge in interpreting analytical results (Buffat et al., 2017). Network-level comparisons further indicated that zones with higher levels of GIS integration exhibited better performance outcomes, reinforcing the argument that system effectiveness is influenced by the extent of implementation. These findings were consistent with earlier research that emphasized the importance of organizational readiness and technological integration in achieving optimal results (Çelik, 2019). The variability observed across different contexts highlighted the need for tailored implementation strategies that consider both user capabilities and system requirements.

The statistical significance and effect size analysis provided strong evidence of the practical importance of GIS-based SDSS in urban water supply network optimization. Earlier studies have often focused on statistical significance without adequately addressing the magnitude of observed effects, limiting the ability to assess practical relevance (Varade et al., 2017). The findings of this study addressed this limitation by reporting both statistical significance and effect sizes, demonstrating that the relationships between SDSS usage and performance indicators were not only statistically valid but also practically meaningful. The moderate to strong effect sizes indicated that GIS-based SDSS contributed substantially to improvements in network performance, supporting earlier research that highlighted the transformative potential of spatial technologies in infrastructure management (Tavana et al., 2017). The regression analysis further demonstrated that SDSS variables accounted for a significant proportion of variance in optimization outcomes, reinforcing the robustness of the findings. In comparison with previous studies that reported lower explanatory power, the current results suggested that the integration of multiple SDSS components enhanced predictive accuracy. The use of visual representations, including graphs and charts, further supported the interpretation of results by illustrating trends and relationships in a clear and accessible manner (Ghavami, 2019). This approach aligned with earlier research that emphasized the importance of combining statistical analysis with visual tools to enhance understanding and communication of findings.

The overall findings of this study contributed to the growing body of literature on GIS-based Spatial Decision Support Systems by providing comprehensive evidence of their impact on urban water supply network optimization. Earlier studies have often focused on specific aspects of SDSS, such as data integration or modeling capabilities, without examining their combined effect on system performance (Choi & Lee, 2016). The present findings addressed this gap by demonstrating that the integration of spatial analysis, scenario evaluation, and data visualization within a single framework resulted in significant improvements across multiple performance indicators. This holistic perspective aligned with emerging research that emphasizes the importance of integrated approaches in addressing complex infrastructure challenges (Aminu et al., 2017). The consistency between the findings and previous studies reinforced the validity of GIS-based SDSS as an effective tool for improving decision-making and system performance. The results also highlighted the importance of considering both technical and contextual factors in evaluating system effectiveness, supporting earlier research that emphasized the role of organizational and environmental conditions in technology adoption (Grêt-Regamey et al., 2017). The comprehensive analysis provided in this study offered a detailed understanding of the mechanisms through which GIS-based SDSS influences network optimization, contributing to a more nuanced interpretation of its role in urban water management.

CONCLUSION

The impact of GIS-based Spatial Decision Support Systems on urban water supply network optimization has been demonstrated as both multidimensional and operationally significant through the integration of spatial intelligence, analytical modeling, and decision-support functionalities within a unified framework. This study established that GIS-based SDSS contributed substantially to improving the overall performance of water distribution systems by enabling more accurate identification of inefficiencies, better visualization of infrastructure conditions, and enhanced prioritization of maintenance and resource allocation strategies. The integration of spatial data with operational and hydraulic information allowed for a more comprehensive understanding of network behavior, particularly in relation to pressure stability, leakage patterns, service coverage, and demand distribution. The findings indicated that spatial visualization tools facilitated clearer interpretation of complex datasets, thereby supporting more informed and timely decision-making processes. Furthermore, the incorporation of scenario analysis within SDSS enabled the evaluation of alternative strategies under varying operational conditions, which improved planning accuracy and reduced uncertainty in infrastructure management. The study also highlighted the role of user interaction and system usability in determining the effectiveness of SDSS, as professionals with higher levels of engagement and experience demonstrated greater alignment between system outputs and decision-making practices. In addition, the results revealed that network zones with higher levels of GIS-based SDSS integration exhibited improved operational outcomes, particularly in terms of reduced leakage rates and enhanced pressure management, indicating that the impact of these systems was more

pronounced in complex and high-demand environments. The qualitative evaluation further emphasized that GIS-based SDSS supported collaborative decision-making by providing a shared platform for stakeholders to analyze, interpret, and discuss spatial information, thereby improving communication and coordination across different functional roles. The study also identified that contextual factors such as data availability, technical expertise, and organizational readiness influenced the degree to which SDSS could be effectively utilized, reinforcing the importance of aligning technological capabilities with institutional conditions. Overall, the findings demonstrated that GIS-based Spatial Decision Support Systems served as a critical enabler of urban water supply network optimization by enhancing analytical depth, improving decision quality, and supporting more efficient and sustainable infrastructure management practices within complex urban environments.

RECOMMENDATIONS

The findings of this study support several key recommendations for enhancing the effectiveness of GIS-based Spatial Decision Support Systems in optimizing urban water supply networks. It is recommended that water utilities adopt a more integrated approach to GIS-based SDSS implementation by ensuring the seamless combination of spatial, hydraulic, and operational data within a unified platform. Strengthening data quality management practices is essential, as accurate, high-resolution, and regularly updated datasets significantly influence the reliability of analytical outputs and subsequent decision-making processes. Investment in staff training and capacity development is also recommended to improve user competence in interpreting spatial data, operating SDSS tools, and applying analytical results to real-world decision contexts. Increased technical proficiency among users is likely to enhance system utilization and maximize the benefits of spatial decision support capabilities. Additionally, it is recommended that organizations tailor SDSS interfaces and functionalities to suit the needs of different user groups, including engineers, planners, and operational personnel, to improve usability and encourage broader adoption across departments. Enhancing interoperability between GIS platforms, hydraulic modeling tools, and real-time monitoring systems is another important recommendation, as this integration enables dynamic analysis and supports more responsive infrastructure management. The study further suggests that decision-making processes should incorporate scenario-based analysis as a standard practice, allowing stakeholders to evaluate alternative strategies and anticipate system responses under varying conditions. Encouraging collaborative use of SDSS across departments can improve communication, reduce data silos, and support coordinated infrastructure planning and maintenance. It is also recommended that utilities prioritize the application of GIS-based SDSS in high-demand and complex network zones, where the potential for efficiency gains and performance improvement is greater. Organizational support in terms of policy alignment, resource allocation, and leadership commitment is necessary to ensure sustained implementation and long-term effectiveness of SDSS technologies. Finally, establishing continuous evaluation mechanisms to assess system performance, user satisfaction, and decision outcomes will help refine SDSS applications and maintain alignment with evolving operational requirements. These recommendations collectively aim to enhance the practical impact of GIS-based SDSS in achieving efficient, reliable, and data-driven urban water supply network optimization.

LIMITATIONS

This study was subject to several limitations that should be considered when interpreting the findings related to the impact of GIS-based Spatial Decision Support Systems on urban water supply network optimization. One notable limitation was the reliance on a cross-sectional design, which restricted the ability to observe changes in system performance over time and limited the capacity to establish causal relationships between SDSS implementation and long-term optimization outcomes. The study focused on a selected number of urban water supply zones, which, although diverse in structure and performance, may not fully represent the variability present in all geographic or institutional contexts. Data availability and quality also posed constraints, as the accuracy and completeness of spatial, hydraulic, and operational datasets varied across zones, potentially influencing the precision of analytical results. In some cases, inconsistencies in data recording practices and gaps in historical records may have affected the robustness of comparisons and trend analysis. Another limitation related to the use of self-reported data from professionals, which introduced the possibility of response bias,

particularly in assessing perceived effectiveness, usability, and decision-making impact of SDSS tools. Differences in user experience, technical expertise, and familiarity with GIS-based systems may have influenced responses, leading to variability that was not entirely attributable to system performance. Additionally, the study did not fully account for external factors such as policy frameworks, financial constraints, and organizational culture, which may significantly affect the adoption and effectiveness of SDSS in practice.

REFERENCES

- [1]. Abdalla, R. (2016). *Introduction to geospatial information and communication technology (GeoICT)*. Springer.
- [2]. Abdelbaki, C., Touaibia, B., Ammari, A., Mahmoudi, H., & Goosen, M. (2019). Contribution of GIS and hydraulic modeling to the management of water distribution network. In *Geospatial challenges in the 21st century* (pp. 125-150). Springer.
- [3]. Aminu, M., Matori, A. N., Yusof, K. W., Malakahmad, A., & Zainol, R. B. (2017). Analytic network process (ANP)-based spatial decision support system (SDSS) for sustainable tourism planning in Cameron Highlands, Malaysia. *Arabian Journal of Geosciences*, 10(13), 286.
- [4]. Arcuri, N., De Ruggiero, M., Salvo, F., & Zinno, R. (2020). Automated valuation methods through the cost approach in a BIM and GIS integration framework for smart city appraisals. *Sustainability*, 12(18), 7546.
- [5]. Bai, X., Surveyer, A., Elmqvist, T., Gatzweiler, F. W., Güneralp, B., Parnell, S., Prieur-Richard, A.-H., Shrivastava, P., Siri, J. G., & Stafford-Smith, M. (2016). Defining and advancing a systems approach for sustainable cities. *Current opinion in environmental sustainability*, 23, 69-78.
- [6]. Balekelayi, N., & Tesfamariam, S. (2017). Optimization techniques used in design and operations of water distribution networks: A review and comparative study. *Sustainable and Resilient Infrastructure*, 2(4), 153-168.
- [7]. Banerjee, S., Chakraborty, C., & Das, D. (2020). An approach towards GIS application in smart city urban planning. In *Internet of things and secure smart environments* (pp. 71-110). Chapman and Hall/CRC.
- [8]. Bansal, V. K. (2020). Use of GIS to consider spatial aspects in construction planning process. *International Journal of Construction Management*, 20(3), 207-222.
- [9]. Beard, R., Wentz, E., & Scotch, M. (2018). A systematic review of spatial decision support systems in public health informatics supporting the identification of high risk areas for zoonotic disease outbreaks. *International journal of health geographics*, 17(1), 38.
- [10]. Blaschke, T., Merschdorf, H., Cabrera-Barona, P., Gao, S., Papadakis, E., & Kovacs-Györi, A. (2018). Place versus space: from points, lines and polygons in GIS to place-based representations reflecting language and culture. *ISPRS International Journal of Geo-Information*, 7(11), 452.
- [11]. Boeing, G. (2017). OSMnx: New methods for acquiring, constructing, analyzing, and visualizing complex street networks. *Computers, environment and urban systems*, 65, 126-139.
- [12]. Brentan, B. M., Luvizotto Jr, E., Herrera, M., Izquierdo, J., & Pérez-García, R. (2017). Hybrid regression model for near real-time urban water demand forecasting. *Journal of Computational and Applied Mathematics*, 309, 532-541.
- [13]. Buffat, R., Schmid, L., Heeren, N., Froemelt, A., Raubal, M., & Hellweg, S. (2017). GIS-based decision support system for building retrofit. *Energy Procedia*, 122, 403-408.
- [14]. Carver, S. (2019). Developing Web-based GIS/MCE: Improving access to data and spatial decision support tools. In *Spatial multicriteria decision making and analysis* (pp. 49-76). Routledge.
- [15]. Çelik, R. (2019). Evaluation of groundwater potential by GIS-based multicriteria decision making as a spatial prediction tool: Case study in the Tigris River Batman-Hasankeyf Sub-Basin, Turkey. *Water*, 11(12), 2630.
- [16]. Cerreta, M., & Poli, G. (2017). Landscape services assessment: a hybrid multi-criteria spatial decision support system (MC-SDSS). *Sustainability*, 9(8), 1311.
- [17]. Chen, J., Yu, C., Cai, M., Wang, H., & Zhou, P. (2020). Multi-objective optimal allocation of urban water resources while considering conflict resolution based on the PSO algorithm: A case study of Kunming, China. *Sustainability*, 12(4), 1337.
- [18]. Chen, Y., Fan, R., Yang, X., Wang, J., & Latif, A. (2018). Extraction of urban water bodies from high-resolution remote-sensing imagery using deep learning. *Water*, 10(5), 585.
- [19]. Choi, H.-S., & Lee, G.-S. (2016). Planning Support Systems (PSS)-based spatial plan alternatives and environmental assessment. *Sustainability*, 8(3), 286.
- [20]. Çöltekin, A., Lochhead, I., Madden, M., Christophe, S., Devaux, A., Pettit, C., Lock, O., Shukla, S., Herman, L., & Stachoň, Z. (2020). Extended reality in spatial sciences: A review of research challenges and future directions. *ISPRS International Journal of Geo-Information*, 9(7), 439.
- [21]. Cui, L., Wang, J., Sun, L., & Lv, C. (2020). Construction and optimization of green space ecological networks in urban fringe areas: A case study with the urban fringe area of Tongzhou district in Beijing. *Journal of Cleaner Production*, 276, 124266.
- [22]. da Silva, A. O., & Fernandes, R. A. S. (2020). Smart governance based on multipurpose territorial cadastre and geographic information system: An analysis of geoinformation, transparency and collaborative participation for Brazilian capitals. *Land use policy*, 97, 104752.
- [23]. de Lima, L. M. M., de Sá, L. R., dos Santos Macambira, A. F. U., de Almeida Nogueira, J., de Toledo Vianna, R. P., & de Moraes, R. M. (2019). A new combination rule for Spatial Decision Support Systems for epidemiology. *International journal of health geographics*, 18(1), 25.

- [24]. Dubey, R., & Gunasekaran, A. (2016). The sustainable humanitarian supply chain design: agility, adaptability and alignment. *International Journal of Logistics Research and Applications*, 19(1), 62-82.
- [25]. Erskine, M. A., Gregg, D. G., Karimi, J., & Scott, J. E. (2019). Individual decision-performance using spatial decision support systems: a geospatial reasoning ability and perceived task-technology fit perspective. *Information Systems Frontiers*, 21(6), 1369-1384.
- [26]. Fernández Moniz, P., Almeida, J. S., Pino, A. T., & Suárez Rivero, J. P. (2020). A GIS-based solution for urban water management. *Water International*, 45(6), 660-677.
- [27]. Fuenfschilling, L., & Truffer, B. (2016). The interplay of institutions, actors and technologies in socio-technical systems – An analysis of transformations in the Australian urban water sector. *Technological forecasting and social change*, 103, 298-312.
- [28]. Ghavami, S. M. (2019). Multi-criteria spatial decision support system for identifying strategic roads in disaster situations. *International Journal of Critical Infrastructure Protection*, 24, 23-36.
- [29]. Gheshlaghi, H. A., & Feizizadeh, B. (2017). An integrated approach of analytical network process and fuzzy based spatial decision making systems applied to landslide risk mapping. *Journal of African Earth Sciences*, 133, 15-24.
- [30]. Gilfoyle, I., & Thorpe, P. (2016). *Geographic information management in local government*. CRC press.
- [31]. Gorelick, N., Hancher, M., Dixon, M., Ilyushchenko, S., Thau, D., & Moore, R. (2017). Google Earth Engine: Planetary-scale geospatial analysis for everyone. *Remote sensing of Environment*, 202, 18-27.
- [32]. Grêt-Regamey, A., Altwegg, J., Sirén, E. A., Van Strien, M. J., & Weibel, B. (2017). Integrating ecosystem services into spatial planning – A spatial decision support tool. *Landscape and Urban Planning*, 165, 206-219.
- [33]. Grimaldi, M., Sebilio, M., Vitiello, G., & Pellecchia, V. (2020). Planning and managing the integrated water system: a spatial decision support system to analyze the infrastructure performances. *Sustainability*, 12(16), 6432.
- [34]. Hoang, L., & Fenner, R. A. (2016). System interactions of stormwater management using sustainable urban drainage systems and green infrastructure. *Urban Water Journal*, 13(7), 739-758.
- [35]. Hong, J. E. (2017). Designing GIS learning materials for K-12 teachers. *Technology, Pedagogy and Education*, 26(3), 323-345.
- [36]. Irfan, M., Koj, A., Sedighi, M., & Thomas, H. (2017). Design and development of a generic spatial decision support system, based on artificial intelligence and multicriteria decision analysis. *GeoResJ*, 14, 47-58.
- [37]. Jafary, P., Sarab, A. A., & Tehrani, N. A. (2018). Ecosystem health assessment using a fuzzy spatial decision support system in Taleghan watershed before and after dam construction. *Environmental Processes*, 5(4), 807-831.
- [38]. Jayarathna, L., Rajapaksa, D., Managi, S., Athukorala, W., Torgler, B., Garcia-Valiñas, M. A., Gifford, R., & Wilson, C. (2017). A GIS based spatial decision support system for analysing residential water demand: A case study in Australia. *Sustainable Cities and Society*, 32, 67-77.
- [39]. Jeihouni, M., Toomanian, A., & Mansourian, A. (2020). Decision tree-based data mining and rule induction for identifying high quality groundwater zones to water supply management: a novel hybrid use of data mining and GIS. *Water Resources Management*, 34(1), 139-154.
- [40]. Jeong, J. S., & García-Moruno, L. (2016). The study of building integration into the surrounding rural landscape: Focus on implementation of a Web-based MC-SDSS and its validation by two-way participation. *Land use policy*, 57, 719-729.
- [41]. Jeong, J. S., & Ramírez-Gómez, Á. (2018). Development of a web graphic model with fuzzy-decision-making Trial and Evaluation Laboratory/Multi-criteria-Spatial Decision Support System (F-DEMATEL/MC-SDSS) for sustainable planning and construction of rural housings. *Journal of Cleaner Production*, 199, 584-592.
- [42]. Johnson, L. E. (2016). *Geographic information systems in water resources engineering*. CRC Press.
- [43]. Jung, D., Tran Tuan, V., Quoc Tran, D., Park, M., & Park, S. (2020). Conceptual framework of an intelligent decision support system for smart city disaster management. *Applied Sciences*, 10(2), 666.
- [44]. Kazak, J., Van Hoof, J., & Szewranski, S. (2017). Challenges in the wind turbines location process in Central Europe– The use of spatial decision support systems. *Renewable and Sustainable Energy Reviews*, 76, 425-433.
- [45]. Keenan, P. B., & Jankowski, P. (2019). Spatial decision support systems: Three decades on. *Decision Support Systems*, 116, 64-76.
- [46]. Kirby, R. S., Delmelle, E., & Eberth, J. M. (2017). Advances in spatial epidemiology and geographic information systems. *Annals of epidemiology*, 27(1), 1-9.
- [47]. Kratzwald, B., Ilić, S., Kraus, M., Feuerriegel, S., & Prendinger, H. (2018). Deep learning for affective computing: Text-based emotion recognition in decision support. *Decision Support Systems*, 115, 24-35.
- [48]. Kraus, M., & Feuerriegel, S. (2017). Decision support from financial disclosures with deep neural networks and transfer learning. *Decision Support Systems*, 104, 38-48.
- [49]. Kucera, G. (2020). *Time in geographic information systems*. CRC Press.
- [50]. Kumar, D., Singh, R., & Kaur, R. (2019a). Spatial information technology: Definitions, types and linkages. In *Spatial Information Technology for Sustainable Development Goals* (pp. 3-14). Springer.
- [51]. Kumar, D., Singh, R. B., & Kaur, R. (2019b). *Spatial information technology for sustainable development goals*. Springer.
- [52]. Kunath, M., & Winkler, H. (2018). Integrating the Digital Twin of the manufacturing system into a decision support system for improving the order management process. *Procedia Cirp*, 72, 225-231.
- [53]. Lagrab, W., & Aknin, N. (2017). Knowledge-Based Multicriteria Spatial Decision Support System (MC-SDSS) for Trends Assessment of Settlements Suitability. Proceedings of the Mediterranean Symposium on Smart City Applications,
- [54]. Laraichi, S., Hammani, A., & Bouignane, A. (2016). Data integration as the key to building a decision support system for groundwater management: Case of Saiss aquifers, Morocco. *Groundwater for Sustainable Development*, 2, 7-15.

- [55]. Leigh, N. G., & Lee, H. (2019). Sustainable and resilient urban water systems: The role of decentralization and planning. *Sustainability*, 11(3), 918.
- [56]. Lund, N. S. V., Falk, A. K. V., Borup, M., Madsen, H., & Steen Mikkelsen, P. (2018). Model predictive control of urban drainage systems: A review and perspective towards smart real-time water management. *Critical reviews in environmental science and technology*, 48(3), 279-339.
- [57]. Mahdianpari, M., Salehi, B., Rezaee, M., Mohammadimanesh, F., & Zhang, Y. (2018). Very deep convolutional neural networks for complex land cover mapping using multispectral remote sensing imagery. *Remote Sensing*, 10(7), 1119.
- [58]. Maleki, S., Soffianian, A. R., Koupaei, S. S., Pourmanafi, S., & Saatchi, S. (2018). Wetland restoration prioritizing, a tool to reduce negative effects of drought; An application of multicriteria-spatial decision support system (MC-SDSS). *Ecological engineering*, 112, 132-139.
- [59]. Manam, A., & Md. Ashfaq, S. (2022). Computational Thermo-Mechanical Modeling for Energy-Efficient Solid-State Metal Manufacturing Processes. *American Journal of Interdisciplinary Studies*, 3(04), 579-618. <https://doi.org/10.63125/ddg6mg97>
- [60]. Martin, C., Kamara, O., Berzosa, I., & Badiola, J. L. (2020). Smart GIS platform that facilitates the digitalization of the integrated urban drainage system. *Environmental Modelling & Software*, 123, 104568.
- [61]. Marzouk, M., & Othman, A. (2020). Planning utility infrastructure requirements for smart cities using the integration between BIM and GIS. *Sustainable Cities and Society*, 57, 102120.
- [62]. McGrane, S. J. (2016). Impacts of urbanisation on hydrological and water quality dynamics, and urban water management: a review. *Hydrological Sciences Journal*, 61(13), 2295-2311.
- [63]. McPhearson, T., Haase, D., Kabisch, N., & Gren, Å. (2016). Advancing understanding of the complex nature of urban systems. In (Vol. 70, pp. 566-573): Elsevier.
- [64]. Md Khaled, H. (2021). An Empirical Study of CRM and Analytics-Based Approaches to Customer Engagement and Sales Performance Evaluation in Enterprise Organizations. *American Journal of Data Science and Analytics*, 2(12), 76-155. <https://doi.org/10.63125/1tt57n77>
- [65]. Mikovits, C., Rauch, W., & Kleidorfer, M. (2018). Importance of scenario analysis in urban development for urban water infrastructure planning and management. *Computers, environment and urban systems*, 68, 9-16.
- [66]. Modica, G., Pollino, M., Lanucara, S., La Porta, L., Pellicone, G., Di Fazio, S., & Fichera, C. R. (2016). Land suitability evaluation for agro-forestry: definition of a web-based multi-criteria spatial decision support system (MC-SDSS): preliminary results. *International Conference on Computational Science and Its Applications*,
- [67]. Monte, M. B. d. S., & Morais, D. C. (2019). A decision model for identifying and solving problems in an urban water supply system. *Water Resources Management*, 33(14), 4835-4848.
- [68]. Monteiro, C. S., Costa, C., Pina, A., Santos, M. Y., & Ferrão, P. (2018). An urban building database (UBD) supporting a smart city information system. *Energy and Buildings*, 158, 244-260.
- [69]. Mukhtarov, F., Dieperink, C., & Driessen, P. (2018). The influence of information and communication technologies on public participation in urban water governance: A review of place-based research. *Environmental Science & Policy*, 89, 430-438.
- [70]. Nagendra, H., Bai, X., Brondizio, E. S., & Lwasa, S. (2018). The urban south and the predicament of global sustainability. *Nature sustainability*, 1(7), 341-349.
- [71]. Natarajan, S., & Radhakrishnan, N. (2020). An integrated hydrologic and hydraulic flood modeling study for a medium-sized ungauged urban catchment area: A case study of Tiruchirappalli City Using HEC-HMS and HEC-RAS. *Journal of the Institution of Engineers (india): Series A*, 101(2), 381-398.
- [72]. Nguyen, T. T., Ngo, H. H., Guo, W., Wang, X. C., Ren, N., Li, G., Ding, J., & Liang, H. (2019). Implementation of a specific urban water management-Sponge City. *Science of the Total Environment*, 652, 147-162.
- [73]. Noorollahi, Y., Yousefi, H., & Mohammadi, M. (2016). Multi-criteria decision support system for wind farm site selection using GIS. *Sustainable Energy Technologies and Assessments*, 13, 38-50.
- [74]. Nyimbili, P. H., & Erden, T. (2018). Spatial decision support systems (SDSS) and software applications for earthquake disaster management with special reference to Turkey. *Natural Hazards*, 90(3), 1485-1507.
- [75]. Omidipoor, M., Jelokhani-Niaraki, M., Moeinmehr, A., Sadeghi-Niaraki, A., & Choi, S.-M. (2019). A GIS-based decision support system for facilitating participatory urban renewal process. *Land use policy*, 88, 104150.
- [76]. Omidipoor, M., Jelokhani-Niaraki, M., & Samany, N. N. (2019). A Web-based geo-marketing decision support system for land selection: a case study of Tehran, Iran. *Annals of GIS*, 25(2), 179-193.
- [77]. Pal, S. (2019). Application of GIS in Road Information System – An Experience with State Highways of West Bengal. In *Applications of Geomatics in Civil Engineering: Select Proceedings of ICGCE 2018* (pp. 413-421). Springer.
- [78]. Pérez, M. G. R., Laprise, M., & Rey, E. (2018). Fostering sustainable urban renewal at the neighborhood scale with a spatial decision support system. *Sustainable Cities and Society*, 38, 440-451.
- [79]. Petrișor, A.-I. (2016). Geographical information systems as environmental, landscape, and urban planning and research tools. Romania as a case study. In *Space and time visualisation* (pp. 233-249). Springer.
- [80]. Reddy, G. O., Ramamurthy, V., & Singh, S. (2018). Integrated remote sensing, GIS, and GPS applications in agricultural land use planning. In *Geospatial technologies in land resources mapping, monitoring and management* (pp. 489-515). Springer.
- [81]. Rikalovic, A., Cosic, I., Labati, R. D., & Piuri, V. (2017). Intelligent decision support system for industrial site classification: A GIS-based hierarchical neuro-fuzzy approach. *IEEE Systems Journal*, 12(3), 2970-2981.
- [82]. Rizk, Y., Awad, M., & Tunstel, E. W. (2018). Decision making in multiagent systems: A survey. *IEEE Transactions on Cognitive and Developmental Systems*, 10(3), 514-529.

- [83]. Şakar, D., Aydın, A., & Akay, A. E. (2020). Using GIS-based multicriteria decision support system for planning road networks with visual quality constraints: a case study of protected areas in Ankara, Turkey. *Environmental monitoring and assessment*, 192(7), 447.
- [84]. Sarbu, I., & Ostafe, G. (2016). Optimal design of urban water supply pipe networks. *Urban Water Journal*, 13(5), 521-535.
- [85]. Shafiee, M. E., Barker, Z., & Rasekh, A. (2018). Enhancing water system models by integrating big data. *Sustainable Cities and Society*, 37, 485-491.
- [86]. Sharvelle, S., Dozier, A., Arabi, M., & Reichel, B. (2017). A geospatially-enabled web tool for urban water demand forecasting and assessment of alternative urban water management strategies. *Environmental Modelling & Software*, 97, 213-228.
- [87]. Singh, A. (2019). Remote sensing and GIS applications for municipal waste management. *Journal of environmental management*, 243, 22-29.
- [88]. Singh, L. K., Jha, M. K., & Chowdary, V. (2017). Multi-criteria analysis and GIS modeling for identifying prospective water harvesting and artificial recharge sites for sustainable water supply. *Journal of Cleaner Production*, 142, 1436-1456.
- [89]. Stessens, P., Khan, A. Z., Huysmans, M., & Canters, F. (2017). Analysing urban green space accessibility and quality: A GIS-based model as spatial decision support for urban ecosystem services in Brussels. *Ecosystem services*, 28, 328-340.
- [90]. Tanjina Binte, S., & Sazzadul, I. (2022). Advanced Financial Data Analytics for Anomaly Detection and Pattern Discovery in Large-Scale Financial Data Pipelines. *American Journal of Advanced Technology and Engineering Solutions*, 2(02), 174-210. <https://doi.org/10.63125/g1cdm484>
- [91]. Tavana, M., Arteaga, F. J. S., Mohammadi, S., & Alimohammadi, M. (2017). A fuzzy multi-criteria spatial decision support system for solar farm location planning. *Energy Strategy Reviews*, 18, 93-105.
- [92]. Thakur, J. K., Singh, S. K., & Ekanthalu, V. S. (2017). Integrating remote sensing, geographic information systems and global positioning system techniques with hydrological modeling. *Applied Water Science*, 7(4), 1595-1608.
- [93]. Tian, Y., Zheng, Y., Han, F., Zheng, C., & Li, X. (2018). A comprehensive graphical modeling platform designed for integrated hydrological simulation. *Environmental Modelling & Software*, 108, 154-173.
- [94]. Torrieri, F., & Batà, A. (2017). Spatial multi-criteria decision support system and strategic environmental assessment: A case study. *Buildings*, 7(4), 96.
- [95]. Varade, A. M., Khare, Y., Dongre, K., Muley, S., & Wasnik, G. (2017). Integrated geographical information system (GIS)-based decision support system (DSS) approach to identify the site-specific water conservation structures in a watershed of Nagpur district, Central India. *Sustainable Water Resources Management*, 3(2), 141-155.
- [96]. Wang, H., Pan, Y., & Luo, X. (2019). Integration of BIM and GIS in sustainable built environment: A review and bibliometric analysis. *Automation in construction*, 103, 41-52.
- [97]. Wang, X., & Xie, H. (2018). A review on applications of remote sensing and geographic information systems (GIS) in water resources and flood risk management. *Water*, 10(5), 608.
- [98]. Wegener, M., & Masser, I. (2019). Brave new GIS worlds. In *Geographic Information Systems to Spatial Data Infrastructures* (pp. 67-86). CRC Press.
- [99]. Wu, Y., Peng, F., Peng, Y., Kong, X., Liang, H., & Li, Q. (2019). Dynamic 3D simulation of flood risk based on the integration of spatio-temporal GIS and hydrodynamic models. *ISPRS International Journal of Geo-Information*, 8(11), 520.
- [100]. Xia, J., Zhang, Y., Xiong, L., He, S., Wang, L., & Yu, Z. (2017). Opportunities and challenges of the Sponge City construction related to urban water issues in China. *Science China Earth Sciences*, 60(4), 652-658.
- [101]. Xu, Z., Yao, L., & Chen, X. (2020). Urban water supply system optimization and planning: Bi-objective optimization and system dynamics methods. *Computers & industrial engineering*, 142, 106373.
- [102]. Yang, C., & Han, F. (2020). A digital information system for cultural landscapes: the case of Slender West Lake scenic area in Yangzhou, China. *Built Heritage*, 4(1), 3.
- [103]. Yaseen, Z. M., Jaafar, O., Deo, R. C., Kisi, O., Adamowski, J., Quilty, J., & El-Shafie, A. (2016). Stream-flow forecasting using extreme learning machines: a case study in a semi-arid region in Iraq. *Journal of Hydrology*, 542, 603-614.
- [104]. Yusianto, R., & Hardjomidjojo, H. (2020). Intelligent spatial decision support system concept in the potato agro-industry supply chain. 2020 International Conference on Computer Science and Its Application in Agriculture (ICOSICA),
- [105]. Zhang, Z., Hu, H., Yin, D., Kashem, S., Li, R., Cai, H., Perkins, D., & Wang, S. (2020). A cyberGIS-enabled multi-criteria spatial decision support system: A case study on flood emergency management. In *Social Sensing and Big Data Computing for Disaster Management* (pp. 167-184). Routledge.
- [106]. Zhou, L., Wu, X., Xu, Z., & Fujita, H. (2018). Emergency decision making for natural disasters: An overview. *International journal of disaster risk reduction*, 27, 567-576.
- [107]. Zhou, X., Zhao, J., Wang, J., Su, D., Zhang, H., Guo, M., Guo, M., & Li, Z. (2019). OutDet: an algorithm for extracting the outer surfaces of building information models for integration with geographic information systems. *International Journal of Geographical Information Science*, 33(7), 1444-1470.
- [108]. Zubaidi, S. L., Ortega-Martorell, S., Al-Bugharbee, H., Olier, I., Hashim, K. S., Gharghan, S. K., Kot, P., & Al-Khaddar, R. (2020). Urban water demand prediction for a city that suffers from climate change and population growth: Gauteng province case study. *Water*, 12(7), 1885.