International Journal for Quality Research 20(1) 59–76
ISSN 1800-6450

Ammar A Naji[1]

Article info:
Received 20.11.2024.
Accepted 28.05.2025.

DOI – 10.24874/IJQR20.01-04

LEVERAGING GIS FOR SUSTAINABLE URBAN DEVELOPMENT: A DATABASE-DRIVEN APPROACH TO ENHANCING URBAN QUALITY OF LIFE

***Abstract**: This paper aimed to systematically review the papers on how GIS can be leveraged for sustainable urban development and related to quality of life. Google Scholar was searched to identify papers, and 25 papers were selected using the PRISMA flow process. The main points of each paper along with four parameters of quality were tabulated. Overall, the results of this review showed that many papers have discussed the role and integration of geospatial information which implies the use of GIS in many ways and contexts. Many of these papers included factors related to quality of life, some of them not using the term. Based on all observations, it can be concluded that GIS can be leveraged for a data-driven approach for sustainable urban development and enhancing Urban Quality of Life. Some limitations of this review have been mentioned in the end.*

***Keywords:** GIS, sustainable development, quality of life, urban planning, smart cities, frameworks*

1. Introduction

A detailed description of GIS in urban planning as a smart approach to sustainable city development is given by Safal (2024). Geographic Information Systems (GIS) are causing a paradigm shift in urban planning. For the development of sustainable smart cities, GIS has become an important tool in facilitating the decision-making process. Sustainable urban infrastructure and development are the keys to these processes.

Planners can visualise, analyse, and interpret spatial data using GIS. GIS provides city planners with a comprehensive, real-time overview of various urban elements like land use, population density, transportation networks, and environmental factors. While traditional methods depend on static data, GIS relies on continuous real-time updates from multiple sources. This leads to dynamic decision-making to improve city layouts and infrastructure. The process is described in Figure 1.

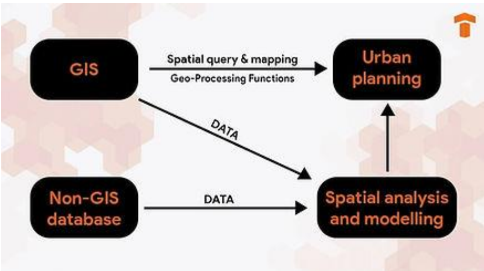

Figure 1. GIS in urban planning process description (Safal, 2024)

As could be observed, the GIS data and non-GIS data are integrated for spatial analysis and modelling of the urban city structure.

[1] Corresponding author: Ammar A Naji
Email: anaji@kau.edu.sa

One vital aspect of GIS use for urban planning is land use zoning. It is aimed at an effective space management. The method of achieving this is explained in Figure 2.

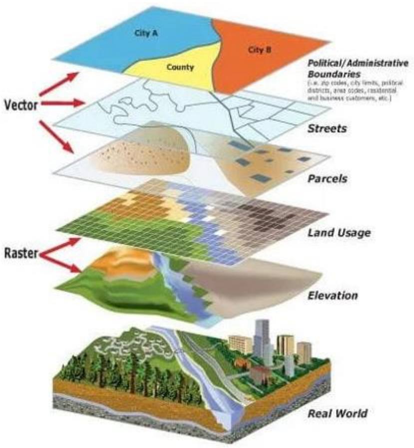

Figure 2. GIS for land zoning (Safal, 2024)

In the case of smart city development, real-time data IoT devices, sensors and surveillance systems are integrated into GIS platforms to enable decision-making by city planners. In this process, infrastructure improvement and resource management are important. The environment and climate-conscious public demand their cities to be sustainable. This aspect also needs to be integrated into the planning.

Public engagement in all important decisions will enhance the transparency of the project and ensure their cooperation in implementing the plans.

The above description amply demonstrates the scope and importance of using GIS for sustainable urban development and improving urban quality of life. These GIS applications are made possible by research in these areas. Hence, this review aims to systematically evaluate the research done on leveraging GIS for sustainable urban development and enhancing urban quality of life using a database-driven approach. The methodology used for this systematic review is outlined in the next section.

2. Methodology

Google Scholar was used for identifying papers related to the topic. The search terms used for this were “leveraging GIS for sustainable urban development” and “GIS to enhance urban quality of life”. The contents of papers were examined for additional terms like “Urban planning”, ‘Sustainable development” and “land zoning”. The papers identified using this process were screened using the inclusion and exclusion criteria listed in Table 1 using the PRISMA flow process (Appendedix) to select a targeted 25 papers.

Table 1. Selected paper

Inclusion criteria	Exclusion criteria	Remarks
Full texts	Abstracts	However, if abstracts contain useful information, they will be included.
Papers in English	Other languages	Even the best translation may not give the exact meaning.
Papers published during 2020-2024.	Earlier years	To reflect the recent trend. However, classic papers cited in the selected papers will be used without adding them to the selected papers.
Only research papers, reviews, and reports.	Dissertations	Dissertations are guided works and may not reflect the author’s views.
	Editorials, Comments and opinions.	These will be certainly excluded.
	Books, book chapters.	However, if full texts are available, they will be considered.
	Papers for which adequate reference details are not available.	Even if they contain useful information, the difficulty of citing properly excludes these papers.

Along with the textual description of the selected papers, an Excel spreadsheet was made containing reference details, aim, method, theory or framework used, findings, limitations and quality ratings as per the following parameters.

2.1 Citations per year

The number of citations is available for most papers in Google Scholar. However, the years of their publications are different. To compare the quality of papers based on the number of citations the total number of citations was divided by the number of years from publication to 2024. Thus, if a paper was published in 2020, the division factor is 5, for 2021 the division factor is 4 etc. The average number of citations per year was estimated as a quality measure in this manner.

2.2 Adequacy of evidence assessment

Whether the evidence presented is adequate to reach the stated conclusion was qualitatively assessed using 1 (lowest) to 5 (highest) levels of adequacy.

2.3 Risk of Bias (RoB)

The National Toxicology Program's Office of Health Assessment and Translation (NTP OHAT) risk of bias (RoB) tool was used. This tool assesses RoB based on the criteria to select study participants, confounding, measurement of exposure and outcomes, follow-up of study participants, adequacy of the reporting of outcomes, and pre-specification of study analysis/study protocol. RoB was rated as 1 (lowest) to 5 (highest).

2.4 GRADE

Certainty of evidence was evaluated by the Grading of Recommendations Assessment, Development and Evaluation (GRADE) framework. This depends on whether there was an adequate sample size and whether adequate validity and reliability tests were done. This was assessed as 1(lowest) to 5 (highest).

2.5 CCAT

Crowe Critical Appraisal Tool (CCAT; version 1.4) was used as a quality index of papers. CCAT consists of preliminaries, introduction, design, sampling, data collection, ethical matters, results, and discussion as the assessment items. The range of scores is 1 (lowest quality) to 5 (highest quality).

2.6 Overall quality

This score was obtained by adding the scores of mean citations per year, adequacy of evidence, GRADE and CCAT, subtracting the risk of bias from it (as it is a negative factor), and then dividing the net sum by 5. That is-

Overall quality = (Citations+ Evidence adequacy + GRADE+ CCAT- RoB) /5.

2.7 Synthesis of literature

The data collected in the Excel spreadsheet were used for some quantitative synthesis across the papers to discover general trends. The detailed discussions were based on these and the topics reviewed. Similar findings across different papers were pooled together and differentiated from contradictory findings to achieve the desired level of synthesis. In the results section, each paper is described in detail cross-referring to earlier concepts or frameworks if relevant.

The selected papers are described in the next (Results) section. This is followed by the Discussion section which mainly deals with the analysis of some trends identified from the Excel entries. Then the main points of the review are summarised in the Conclusion section. Some lines for future research are indicated. Then, the limitations of this review are mentioned in the final section.

3. Results

In this section, the finally selected 25 papers are described along with some comments on their merits and shortcomings. However, this is not compulsorily done for all papers. Where such comments are not required, they are avoided. If limitations are not stated by the authors, an analysis of the content was done to identify any possible limitations. When such limitations are not detected, the paper was deemed to have no limitation. Most of the abstracts, while providing useful information, may not contain limitations or enough detail to identify any. In these cases, also, the paper was deemed to have no limitation.

Search term: Leveraging GIS for sustainable urban development and improving urban quality of life.

The study by Batum et al. (2024) successfully created a tailored Land Administration Domain Model (LADM) profile for Estonia, which is linked to the PLANK (the Estonian spatial plan database), and showcased the potential of incorporating Industry Foundation Classes (IFC) within the prototype solution for verifying compliance with Estonian spatial plans. By achieving Level 2 conformance with the Abstract Test Suite (ATS) of ISO 19152:2012(E), Estonia's LADM profile effectively meets national requirements while complying with international standards. Furthermore, a case study involving Future Insight and various Estonian organizations demonstrated the practical advantages of this integration, such as the capability to directly read and process spatial data for compliance checks, thus minimizing manual involvement and the risk of errors. Nonetheless, some assumptions made during the development of the FME scripts, and the database will need to be reviewed in future efforts to improve scalability and flexibility.

A study by Puspitarini et al. (2024) showed that the introduction of digital innovation through information systems and databases greatly improved the tourist experience at marine tourism destinations. The incorporation of GIS technology enables the visual representation of location maps, provides valuable information to enhance user engagement and aids in informed decision-making. For instance, integrating snorkelling and diving locations with GIS includes coordinating points and relevant data, showcasing enhanced functionality. This integration broadens the application's reach by supplying users with geospatial information about snorkelling and diving spots, thus promoting informed exploration. Furthermore, the use of GIS reflects a dedication to adopting advanced technologies that enrich user experiences and deliver comprehensive information. Test results have confirmed that the application operates efficiently and can be effectively used for managing tourism destinations in Indonesia, highlighting the real-world benefits of digital innovation in the tourism industry. Ultimately, developing and implementing databases and information systems for marine tourism activities provide significant advantages for destination management and the overall tourist experience in Indonesia. However, a noted limitation of this study was the absence of a reliable database.

Hein and Blankenbach (2021) presented big geospatial raster data within a NoSQL database as well as a benchmark with an existing database system as a part of the research project RiverView® for German cities. The project aimed to develop a novel approach for the holistic monitoring of medium and small watercourses. The core component of RiverView® was an unmanned surface vehicle (RiverBoat) equipped with multiple sensors, which allows for autonomous digital water data acquisition with high spatial and temporal resolution. In addition to chemical-physical sensors, an above-water mapping system was installed containing an omnidirectional multi-camera system with which georeferenced images of the water environment could be recorded continuously at high temporal frequency. A GIS-based water body information system was developed to manage all collected data. Therefore, efficient and powerful storage capacities are required due to the heterogeneous and large-volume datasets. Whilst the scalar and vectorial data (e.g. O2 level, water temperature) can be inputted directly in a relational geodatabase, image data storage, in particular, is a major challenge because it has to fulfil many requirements. A spatial index was created using the GIS information stored in the NoSQL database. For each image, an image pyramid (Gaussian pyramid) was created, each level of the pyramid was tiled using the respective variants ATS, RTS and RoITS, a search tree (R-Tree) was created for each pyramid level, the tilesets were stored on a hard disk while the metadata, a link of each tile, and the R-Tree were stored into Neo4j. An evaluation of this system showed that the Random Tiling Strategy (RTS) and Region-of-Interest Tiling Strategy (RoITS) tiling strategies performed the best. The study showed that efficient geospatial rasta data management with Neo4j is possible based on the developed strategies and can even be used for real-time applications. It is also conceivable to extend the approach to remote sensing and satellite data sets for write-once-read-many use- cases.

A systematic review of 107 papers by Li et al. (2023) dealt with the integration of remote sensing with machine learning methods in urban sustainability studies. Most papers concentrated on physical characteristics and ignored social and economic aspects. This was due to the remote sensing was better at capturing physical characteristics. Combining physical characteristics with multi-sourced social sensing was suggested by the authors. Landsat, MODIS, and Sentinel. Aerial images dominated in urban applications since 2015. Lidar was the best for infrastructure identification. The advantages of availability, low cost, high quality, pre-processed images and other derivatives make remote sensing attractive. Social sensing data can be integrated with it to study various urban issues. Among the machine learning methods, supervised learning dominated. The authors gave some suggestions to improve the remote sensing integration with machine learning. Based on the results, the authors proposed a framework for the integration of remote sensing with machine learning (Figure 3) to understand the benefits of spatial analytics better. The framework handles five aspects: application areas, remote sensing and machine learning data and techniques, and machine learning and remote sensing integration. One limitation of the paper is focusing the review on current research limiting its comprehensiveness.

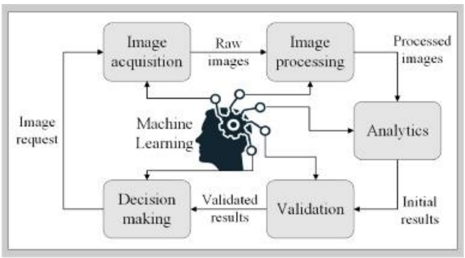

Figure 1. The remote sensing-machine learning integration framework proposed by (Li, et al., 2023)

Stakeholder understanding of environmental factors like air quality is important for the achievement of sustainable urban development. For this, precise spatial and temporal data are required. However, the challenges of handling such complex data need to be addressed. Miles et al. (2024) proposed using web GIS storytelling as a powerful information, communication and dissemination tool to address this challenge. The authors demonstrated the usefulness of the method using a web-based geographic information system (GIS) in a case study in Bergen, Norway. This platform “Web GIS Bergen, air quality and thermal comfort” was created as an open portal. As the explanations of the various aspects of this case study showed, it provided a user-friendly experience to understand the complex environmental data including invisible aspects like air pollution. The model can be extended to other similar activities as practical tools to engage stakeholders for a sustainable and healthier environment. An integrated framework of Web-GIS: Air Quality and Thermal comfort of the authors is shown in Figure 4. It consists of an immersive web narrative on the air quality and local climate zones of Bergen and an embedded web GIS which arranges the urban environment images using complex thematic layers.

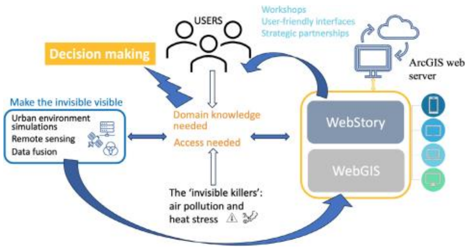

Figure 4. An integrated framework: Web GIS Bergen Air Quality and Thermal Control (Miles et al., 2024)

To address the inadequacy of electrical vehicle charging stations, Desai and Patel (2023) proposed a framework for developing a public charging infrastructure plan using GIS to estimate the demand for public charging based on ten indirect parameters including population density, petrol stations, public spaces, and others. The proposed method was demonstrated using the Indian city of Surat as a case study. A public charging demand map for 2025 was made using the method. To satisfy the projected demand and ensure their optimum utilisation, policy interventions are required. The method can be extended to other cities.

Costa et al. (2024) reviewed 15 papers on the research status in the use of geospatial data-driven methods for sustainable smart city development. Resource management and risk analysis were the main themes in most papers. There was a substantial effort to integrate ML methods with GIS data. IoT and remote sensing were used especially for pollution monitoring, smart urban agriculture, smart grids, and smart health applications. The authors reviewed five successful case studies consisting of the All4land project of Seoul, the PortlMaps of Rotterdam, InfoSTB of Bucharest, PGIL of Lisbon and the Geospatial Master Plan of Singapore. These projects covered multiple issues including infrastructure, traffic, crime, pollution, disasters etc. Increasing public consciousness on environment, pollution, sustainability and climate change serve as driving forces for further research in these areas and more cities. However, there are technological, operational, and ethical challenges in researching these topics. It may also be difficult to achieve a cohesive and unified perspective of the researched cities. Data heterogeneity, complexity and high costs associated with research and practice can be addressed only by using advanced analytical techniques discovered through more research. Stakeholder engagement can address ethical issues. Sustainable smart cities can impact citizens by improving their quality of life and addressing social and spatial inequalities. The limitations of narrowly focused reviews using very few papers are recognised.

Changes in land use and land cover (LULC) driven by urbanisation, which leads to an increase in impervious surfaces, seriously impair urban meteorological conditions and threaten long-term sustainability. In this study, Waleed et al. (2023) utilised machine learning, spatial modelling, and cloud computing to examine and forecast the evolving patterns of urban expansion and their thermal effects in Bahawalpur, Pakistan. By analysing multi-source earth observations from 1990 to 2020, the authors estimated the Urban Thermal Field Variance Index (UTFVI) to quantitatively assess the urban heat island effect. From 1990 to 2020, the urban area expanded by approximately 90%, mainly at the expense of vegetation and barren land, with a projected further increase of 50% by 2050 based on artificial neural network predictions. The land surface temperature has risen by 0.88 °C in summer and about 5 °C in winter. There is notable spatial variability in the UTFVI from 1990 to 2020, and the city is anticipated to see a roughly 140% rise in areas classified as having severe UTFVI due to expected LULC changes by 2050. Some limitations of this study are the possible errors in the choice of model, training samples, the spatial and spectral resolution of satellite images and the use of satellite data instead of directly measuring in situ temperatures. The authors addressed these limitations by adopting different methods.

GIS played a critical role in understanding the spatial clustering and transmission trend of the ongoing COVID-19. John Hopkins University provided the best real-time GIS-based tracking of COVID cases, followed by the WHO. Governments at various levels used this data to report the daily confirmed cases, deaths and trends. GIS data were also used to study the effect of meteorological factors and to identify the hotspots of COVID-19. Various estimation methods were used in all these reports. However, there were very few studies on geospatial analysis to identify Spatiotemporal clusters and prediction modelling for COVID-19 transmission and spatially explicit growth prediction. The authors suggest ArcGIS and other open-source GIS software to provide web-based application development options for more accurate and geocoded surveillance and contact tracing (Ahasan & Hossain, 2020).

To achieve the global sustainability targets on time, evidence-based local decision-making and resource allocation are necessary. Prakash et al. (2020) suggested the use of earth observation (EO) data for this purpose. EO provides timely, spatially disaggregated information for this use. However, there is scarce research on spatially disaggregated information as it is costly, low technical capabilities due to skill shortages and reluctance to change the present systems. To address the first two issues, the authors highlighted the importance of EO in sustainable city development with some successful examples. The EO community, via the Group on Earth Observations (GEO) and its members trying to increase the accessibility of this data by lowering the barriers. Various EO applications are shown in Figure 5.

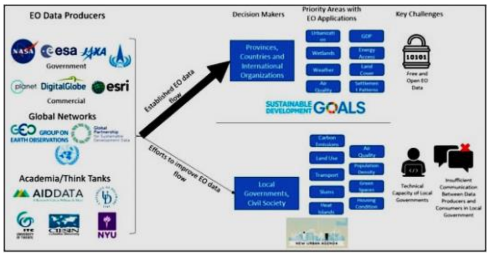

Figure 2. EO applications (Prakash et al., 2020)

A review of 68 papers by Rezvani et al. (2023) revealed the major areas of research in the reviewed papers were climate change, disaster risk assessment and management, GIS, urban and transportation infrastructure, decision-making and disaster management, community and disaster resilience, and green infrastructure and sustainable development. The main research gaps were a lack of a common definition for resilience and multidisciplinary analysis, a need for a unified scalable and adoptable UR model, a margin for an increased application of GIS-based multidimensional tools, stochastic analysis of virtual cities, and scenario simulations to support decision-making processes. These gaps can be addressed using asset and disaster risk management methods along with GIS-based decision-making tools to improve resilience in urban areas. This solution can be applied to urban planning and design, disaster risk management and asset management planning decisions. These methods improve the ability of cities and communities to withstand and recover from disruptions better. The authors presented a diagram of the background knowledge for improved multidisciplinary decisions towards sustainability and urban resilience as shown in Figure 6. In this diagram, GIS is one of the decision support mechanisms or tools. However, it is not clear how MCDM is a tool, MCDM is the aim.

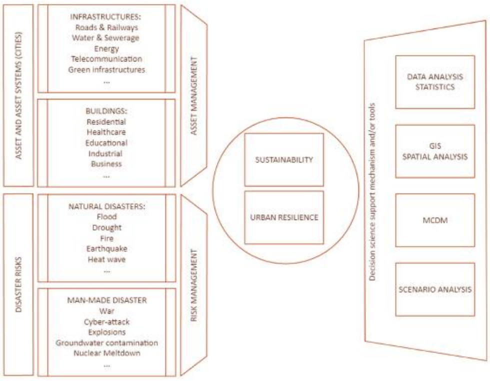

Figure 6. Background knowledge for improved multidisciplinary decisions for sustainability and urban resilience (Rezvani et al., 2023)

To involve stakeholders in the decision-making process on resilience to natural hazards, problem-specific information needs to be provided to them in a language understandable by them. Villani et al. (2023) tested some low-code platforms to digitalise resilience reports rapidly. In these platforms, the authors incorporated all the stakeholder perspectives for analysis and making practical decisions. The best method was a co-creation-based approach to develop GIS-based user-friendly dashboards for the identification of resilience strategies against natural hazards. This approach was developed within the framework of the European project ARCH. The authors applied this approach in a case study on Camerino municipality, Italy. This area is highly vulnerable to earthquakes. In the case of Camerino, GIS was used for urban plans; climate change plans; snow emergency plans, post-disaster reconstruction plans and reconstruction progress status quo. The ARCH DSS of Camerino was made publicly accessible via the internet and additional users from the municipality were invited to evaluate it offline until the end of the project (period from May to July 2022). A survey, prepared for all case studies showed positive feedback. From the details of the survey given in Appendix of the paper, the number of participants seems to be seven. This sample size is too low for a survey.

The study by Ahmed et al. (2024) tested an innovative approach using unsupervised learning algorithms, K-means and Gaussian Mixture Models (GMM) along with GEOBIA techniques to accurately extract land parcels from decades-old cadastral maps of Karachi, Pakistan. First, the maps were georeferenced using ArcGIS software. Then, unsupervised machine-learning algorithms were applied to pre-processed scanned images. Both clustering algorithms were evaluated for precision, recall, and F1 scores. In the experiments, both algorithms performed well. GMM slightly outperformed K-means in all aspects. GMM achieved 0.87 precision and recall and 0.86 F1 score of 0.86, compared to the corresponding values of 0.82, 0.78, and 0.78 for K-means. A geometric criterion based on feature size and shape was used to remove unwanted features. This approach successfully differentiates between neighbouring land parcels and accurately extracts cadastral boundaries and land plots, laying a dependable groundwork for urban research and modelling.

A study by Yun et al. (2022) examined the occurrence of cost overruns (COO) due to socioeconomic conditions using ML techniques and GIS due to a lack of information on how socioeconomic factors influence cost overruns in transportation infrastructure projects. The authors gathered socio-geospatial data from various sources and created a random forest model to identify the relationships between these features and the COO. The models highlighted significant factors impacting the COO, including the initial budget, project duration, management districts, number of lanes, population aged over 16, commuting patterns, industrial landscape, and average temperature. The results underscored the crucial influence of socioeconomic conditions on the actual costs of projects.

This research by Alausa et al. (2023) utilised geospatial technology to assess electricity distribution to aid planning and management in Omole Estate (Phase One) and nearby areas in Lagos, Nigeria. The main objectives were to identify land use in the region, locate transformers, and analyse the energy costs per household. Spatial data was gathered using a handheld GPS, and a Google Earth image was obtained to enhance the dataset. Additionally, a thorough analysis of collected and returned questionnaires was performed to enrich the information. ArcGIS 10.6.1 software was used to build the database and visualize the area, incorporating all necessary details. The findings revealed that 72% of respondents rely on electricity for residential purposes, while 18% use it for commercial activities and 10% for both. A notable number of households (33%) still utilize outdated postpaid meters, and 35% of respondents are unaware of their monthly power consumption or the cost per unit of electricity. Among the respondents, 67% have installed prepaid meters (per kilowatt). In terms of expenses, 10% of participants spend between N1000 and N5000 on monthly electricity bills, 27% spend between N5,000 and N10,000, 38% between N10,000 and N17,000, 24% between N17,000 and N25,000, and 2% exceed N25,000 monthly.

The study by Shaikh and Birajdar (2024) examined the progress, applications, challenges, and emerging trends in the use of remote sensing and Geographic Information System (GIS) technologies for groundwater monitoring. It underlined the importance of monitoring groundwater and positions remote sensing and GIS as vital tools for understanding and managing these resources. First, a thorough review of traditional monitoring techniques was done, highlighting their limitations and the necessity for technological progress. The usefulness of remote sensing methods like satellite imagery, aerial photography, and LiDAR in groundwater monitoring has been discussed pointing out the benefits like extensive coverage and real-time data collection. The GIS applications discussed included spatial analysis, visualisation, and decision support systems, demonstrating varied ways in which GIS can improve groundwater management. It also investigated the integration of remote sensing and GIS using case studies that showcase successful initiatives worldwide, illustrating the complementary benefits of these technologies for sustainable groundwater management. The paper also confronts the challenges faced by remote sensing and GIS like spatial and temporal restrictions, data accuracy issues, and cost limitations, proposing solutions and emphasizing the importance of continuing research and interdisciplinary cooperation. It highlighted processing and modelling methods that facilitate accurate groundwater assessments and aquifer characterization, as well as the contributions of machine learning and artificial intelligence in this field. Various case studies exemplify the effective application of these approaches in practical scenarios. The paper concluded by discussing new technologies and trends, such as enhanced satellite sensors, Synthetic Aperture Radar (SAR) technology, hyperspectral imaging, UAVs, advancements in LiDAR, and the increasing relevance of machine learning and artificial intelligence.

The study by Pitts et al. (2020) aimed to focus on big data science for food, energy, and water systems (FEWSs). A research methodology is described to frame in the FEWS context, including decision tools to aid policymakers and non-governmental organizations (NGOs) in tackling specific UN Sustainable Development Goals (SDGs). Through this exercise, the authors aimed to improve the “supply chain” of FEWS research, from gathering and analysing data to decision tools supporting policymakers in addressing FEWS issues in specific contexts. The authors used a case study of an ongoing project in SE Asia to demonstrate their research methodology and its results. The specific challenges in this respect were inherent data class properties, the need for specific techniques and tools to process the large data, conflict of interests among stakeholders, the requirement of many data types and expertise required to handle all aspects of the study. A general framework of the FEWS studies used in Southeast Asia is shown in Figure 7. The authors studied the FEWS risks in Cambodia due to the construction of two dams upsetting the FEWS balance in the area.

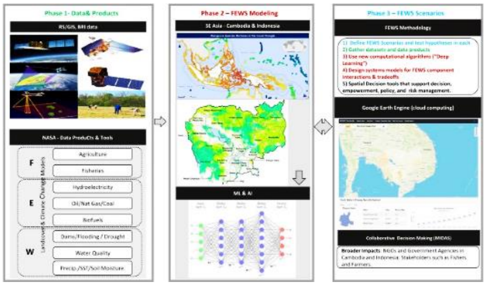

Figure 7. The general framework of FEWS studies in Southeast Asia (Pitts et al., 2020)

The application of the research methodology gave encouraging results in identifying the FEWS status and the need to improve it through many policy interventions by the respective countries. The challenges were also listed, and solutions were proposed.

Geological data is essential for civil engineering projects, linking it closely to urban infrastructure. A new geological data model that integrates building information modelling (BIM) and geographic information systems (GIS) was developed by Khan et al. (2023) for the 3D modelling and management of geological data. This model incorporates geometric, semantic, and spatial information. Additionally, it includes industry foundation classes (IFC), city geographical markup language (CityGML), and application domain extensions (ADE). The mapping of BIM and GIS data is achieved through IFC and CityGML. The model employs a combination of boundary and voxel geometric representations for geological data. Algorithms have been developed to efficiently generate a 3D geological boundary and voxel model based on this framework. It allows for the dynamic adjustment of voxel size, quantity, and attributes, enabling the representation of geological information at various scales. A case study using geotechnical investigation data from Peshawar, Pakistan, validated the proposed BIM-GIS framework. The model proved to be superior to the traditional methods. To assess its practical implications, a questionnaire survey was conducted. This method enhanced the efficiency of geological data management and improved the process of exchanging geological information, enabling better analysis through effective 3D visualization, accommodating diverse geological data, and promoting greater integration. Only the response percentages to the questions by participants to the questions are given. There is no information on the number or characteristics of the participants. The proposed framework of the authors is shown in Figure 8.

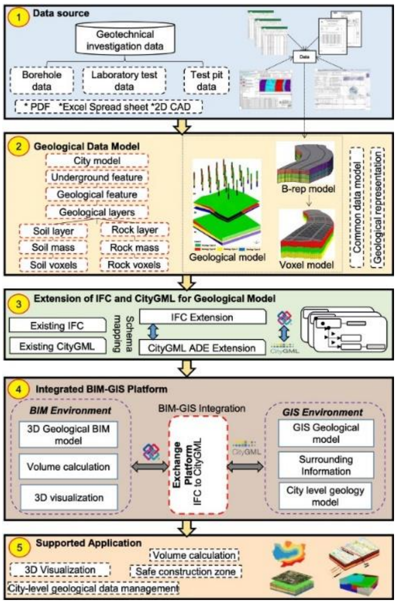

Figure 3. The proposed BIM-GIS model (Khan et al., 2023)

A city is defined as a geographic area that can benefit from analysis and optimisation through geospatial technology. To be classified as a 'Smart City,' several factors must be assessed, including livability, water and electricity supply, sanitation, waste management, public transport, housing affordability, IT connectivity, governance quality, safety, and citizen engagement, all contributing to sustainable development. Smart cities necessitate a harmonious blend of modern infrastructure and technology, employing geo-smart mapping for various applications, such as managing groundwater, locating essential services, and optimizing public transit routes. Scanpoint Geomatics Limited (SGL) utilised their Indigenous integrated platform—IGiS, which combines GIS, image processing, photogrammetry, and CAD—to implement smart city projects in seven Indian cities. They established a centralised geospatial database with standardized maps, generated from high-resolution satellite data and DGPS surveys, organizing city assets in a spatial database. This database enabled geo-tagging of utilities for operations and maintenance, with mobile GIS applications and citizen portals developed for ease of access. Integration with e-governance applications was facilitated by APIs and compliant web services. SGL's Mobile GIS framework, Qpad, was used for verifying spatial data, while IoT devices provided real-time insights for emergencies. The foundation for smart cities was laid with detailed spatial databases, allowing for improvements such as enhanced revenue management, traffic control, accessible information during the COVID-19 pandemic, and effective urban planning. The evaluation of the seven cities revealed that six scored a perfect 20 out of 20 by the Indian Ministry of Home and Urban Affairs, while one city scored 10 out of 20. The certification levels of the cities ranged from beginner to explorer (Shah, 2021). The author proposed the potential use of AI to further optimize certain aspects of smart city development. It would have been better to use an international independent organisation to rate these smart cities. The IGiS enterprise suite is shown in Figure 9.

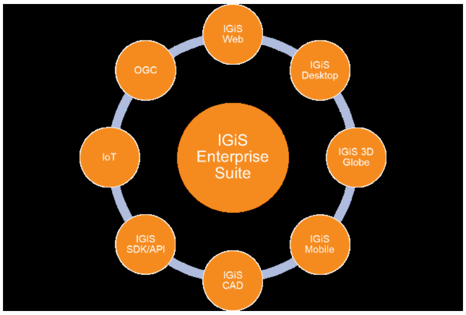

Figure 9. The IGiS Enterprise Suite (Shah, 2021)

The infrastructure architecture for smart cities and the system solutions architecture are shown in Figure 10 and 11.

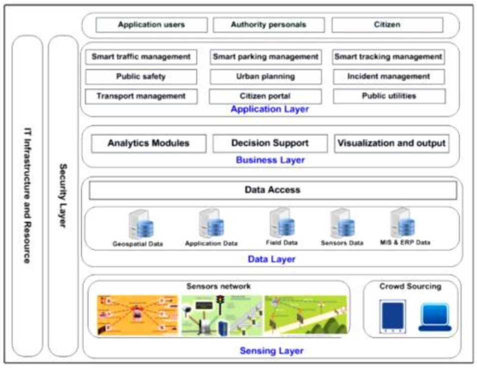

Figure 10. The infrastructure architecture (Shah, 2021)

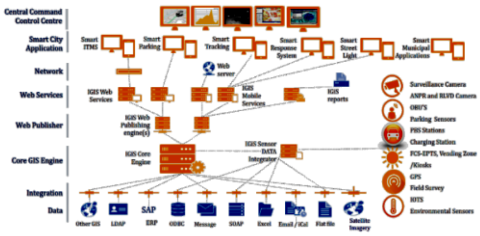

Figure 11. The systems solutions architecture (Shah, 2021)

In a review, Mortaheb and Jankowski (2023) found that smart cities can leverage the synergies between urban planning and three technological and scientific domains- Big Data, Geographic Information Science and Systems, and Data Science—to form a new field known as Geospatial Artificial Intelligence (GeoAI). This approach can help achieve four key policy objectives: improving the efficiency of urban services, enhancing the quality of life for all city residents, tackling significant societal, ecological, and economic challenges faced by urban systems at various levels, and aiding in the generation of spatial data, information, and knowledge about human-urban interactions. Additionally, there's a need for a human-centred conceptual framework that demonstrates how the integration of city planning with these three technological fields can benefit planning practices and support the goals of smart city policies. A diagram of GeoAI is given in Figure 12.

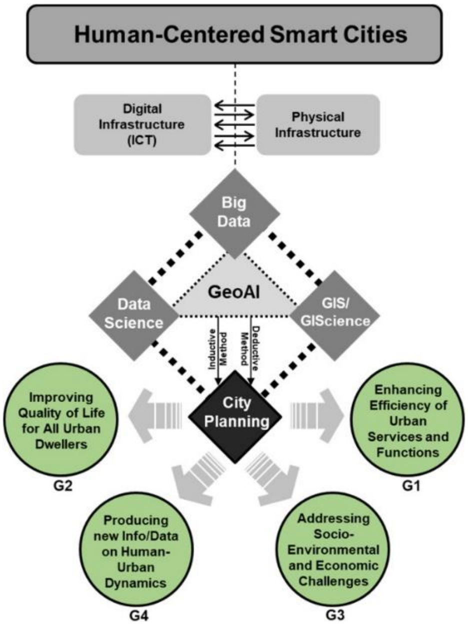

Figure 12. The GeoAI framework (Mortaheb & Jankowski, 2023)

Although the authors categorise this paper as a systematic review, the method followed is that of a simple qualitative review.

The study by Ozegin et al. (2024) identified and characterised groundwater potential zones (GPZs) in parts of southern and north-central Nigeria, using a variety of geoenvironmental factors such as lineament density, geomorphology, slope, drainage density, soil type, land use, elevation, land surface temperature, and rainfall. The researchers transformed these geoenvironmental elements into thematic layers with GIS and remote sensing techniques, integrating them to determine GPZs. They employed the Analytic Hierarchy Process (AHP) to assign scores to different factors based on their influence on groundwater potential. The identified GPZs were categorized into four groups: “high,” “moderate,” “low,” and “very low.” Results indicated that 61% of the area had low to very low groundwater potential, mainly in upland zones, whereas high potential zones accounted for 23% of the region. Key factors affecting groundwater presence included rainfall, lineament density, and geomorphology. The groundwater potential zonation model was validated using borehole data, showing a 90.50% agreement with the AHP and geospatial methodologies. A linear regression analysis confirmed the methodology's effectiveness, yielding an R^2 value of 0.911. Overall, the study presents a reliable and practical approach to mapping GPZs using GIS and AHP techniques.

The use of open-access transport models to tackle issues such as air pollution, physical inactivity and climate change was reviewed by Lovelace et al. (2020). Such models are based on GIS. These models have the potential to support the transition from fossil fuels to renewable energy. Based on an already used example of the “Propensity Cycle Tool”, the authors concluded that open-access transport models can leverage the planning process due to their ability to provide robust, transparent and actionable evidence that is available to a range of stakeholders apart from professional transport planners. The tool was originally based on 16% commute trip data with 20%

of them by distance. It can be extended to use origin-destination data for any trip purpose, especially cycling as the name implies. Overall, 68% of trips in England are less than 5 miles and these have the greatest potential to switch to cycling. It is now used in more than 50 locations in the UK. Open-access transport models can be regarded as a disruptive technology. Further research and development, by planners, researchers and citizen scientists on this aspect has the potential to change transportation systems in urban areas. For this, it needs to be supported by software developers, advocacy groups and financial and policy support from governments. The authors have not provided any diagram of the transport models.

Cities need to play a crucial role in global initiatives aimed at conserving and restoring biological ecosystems and the ecosystem services they provide. Additionally, urban areas should strive to generate these services in greater quantities through architecture and the incorporation of blue and green spaces. Pedersen Zari (2020) reviewed recent data on the synergistic and conflicting interactions between ecosystem services in ecology and then synthesised, translated, and visually represented this information for the fields of architecture and urban design. The diagrams produced in this study are designed to assist designers and policymakers in making informed decisions on how to enhance the availability of various ecosystem services in urban settings without inadvertently harming others. The findings suggest that while the goals for ecosystem services can be quantified both spatially and metrically across different scales, their effectiveness can be improved by considering the interrelationships between them during the design stages of projects. Some illustrative case studies might have been helpful.

The World Avatar utilises knowledge graph-driven technology to integrate various data sources, such as flood data, OpenStreetMap data, land plot information, and 3D CityGML building data, through the use of ontologies. These ontologies enable semantic representations that enhance machine-readability and automation, facilitating cross-domain analyses for emergency response and urban planning. The paper introduces OntoIsochrone, which semantically describes isochrones and their relationships with transport modes, road conditions, time thresholds, and sources.

The authors have developed a suite of connected agents that leverage knowledge graphs to support intelligent flood routing, promote safety for emergency responders, optimise post-disaster routing, conduct accessibility analyses under flooding conditions, and perform critical path analyses for recovery efforts using the betweenness centrality metric. The paper showcases applications in disaster response for King’s Lynn, a coastal town in the UK, and urban planning insights for Pirmasens, a mid-sized town in Germany. In King’s Lynn, the agent-based approach aids in disaster response by calculating optimal routes, dynamically avoiding flooded areas, assessing infrastructure accessibility, identifying inaccessible populations, guiding infrastructure restoration, and conducting critical path analyses.

For Pirmasens, the isochrone generation from knowledge graphs offers data-driven insights into existing amenity coverage and supports scenario planning while complying with land regulations. Overall, the use of agents and knowledge graphs enhances interoperability and urban resilience, improving accessibility by allowing comprehensive analyses across various domains, including geospatial data, demographics, and land use (Phua et al., 2024). As can be seen from Figure 13, GIS ontology is a part of the framework proposed by the authors. The framework in Figure 13 has three domains of user, knowledge and external data sources and utilises one input agent (*i.e.,* OSM Agent) and four output agents (*i.e.,* Routing Agent, Isochrone Agent, Travelling Salesman Agent, Network Analysis Agent). Two of these agents (*i.e.*, OSM Agent and Isochrone Agent) instantiate information and results back into the KG. These agents interact with the KG.

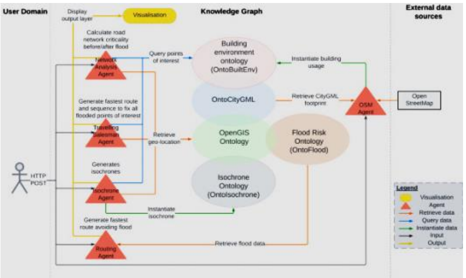

Figure 4. The framework proposed by (Phua et al., 2024)

Ammar and Dadi (2021) reviewed the integration of BIM to provide comprehensive semantic information on construction projects and GIS to provide spatial data and details about the surrounding environment. The BIM-GIS integration can leverage their adoption. The review showed that the applications mainly cover the modelling and design of infrastructure assets, infrastructure construction and scheduling, monitoring and compliance checks, and infrastructure facility and asset management. Although the authors stated that they studied the optimisation requirements, a separate section of this was absent in the paper.

4. Discussion and Conclusion

In this review, a general description of the various GIS applications was provided. The list of applications was verified using a systematic review of 25 selected papers. For effectiveness, GIS data need to be integrated with other real-time data obtained from manual and technological outputs. Since the volume of the data is big, ML methods need to be applied to convert these data into information useful for the targeted purposes.
Many papers have discussed the role and integration of geospatial information which implies the use of GIS. GIS or geospatial information has been used for information on waterbodies in German cities (Hein & Blankenbach, 2021), groundwater monitoring (Shaikh & Birajdar, 2024), and groundwater potential zones (Ozegin et al., 2024), using satellite data as the source of GIS information (Li et al., 2023), stakeholder understanding of environmental factors in urban projects (Villani et al., 2023; Miles et al.,2024), to estimate and predict the demand for charging stations for electric vehicles (Desai & Patel, 2023), sustainable smart city development (Costa et al., 2024), changes in land use patterns and land cover due to urbanization (Waheed et al., 2023), to map spatial clustering, transmission patterns, contact tracing and factors of COVID-19 (Ahasan & Hossain, 2020), as an aid to achieve global sustainability targets (Prakash et al., 2020), various disruptions to urban life (Rezvani et al., 2023), extract historical information from old records of lands (Ahmed et al., 2024), to examine the lack of information on project cost overruns (Yun et al., 2022), electricity distribution and planning management (Alausa et al., 2023), food, energy and water systems in cities (Pitts et al., 2020), civil engineering projects of urban infrastructure (Khan et al., 2023), smart city requirements (Shah, 2021), (Mortaheb & Jankowski, 2023), transport models (Lovelace et al., 2020), ecosystem conservation (Pedersen Zari, 2020), urban planning and disaster response planning (Phua et al., 2024) and BIM-GIS integration (Ammar & Dadi, 2021).
Many of these papers included factors related to quality of life, some of them not using the term.

4.1 Some quantitative trends

The year-wise distribution of papers
The year-wise distribution of the 25 reviewed papers is shown in Figure 14. The number of papers is slowly picking up in the last two years of the review.

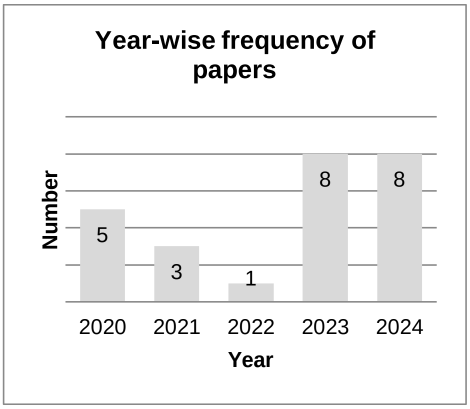

Figure 14. The year-wise distribution of papers

Methods used in the reviewed papers
Figure 15 provides information on the methods used for their studies by the authors of the reviewed papers.

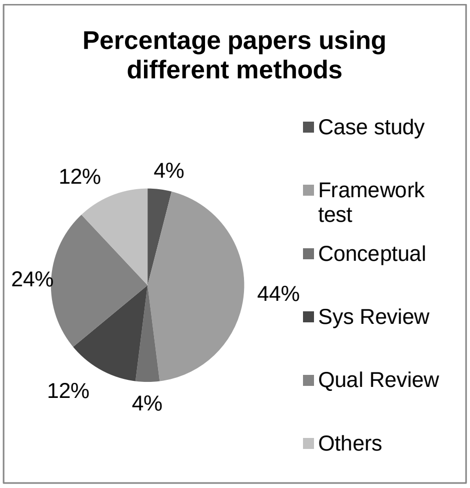

Figure 15. Percentages of papers according to methods

Out of 25 papers, the use of frameworks for studies dominated with 11 (44%) papers. This was followed by qualitative reviews with six (24%) papers. Both systematic reviews and other methods had 12% (3 papers each). A survey was used only by one paper.

Other trends
Out of 25 papers, 13 used theories or frameworks and the rest 12 did not use any. Limitations were mentioned in or derived from the contents of 16 papers. No information on this was possible for nine papers.

Quality assessment
Citations per year were less than 5 for 12 papers. For others, it ranged from one to six. The mean values of evidence adequacy, RoB, GRADE and CCAT were 4.65, 2.97, 4.63 and 4.38. These values are reflected in the mean value of overall quality as 9.12 with 19 papers getting the overall score of lower than 5. It can be deducted from these observations that citations per year are the critical factor affecting the quality of the paper. However, if a paper is published in 2024, citations may be very few. If the score of overall quality can be used as the indicator of the quality of the reviewed papers, the conclusion is that their quality is low. However, all the other variables scored high. From that point of view, the quality of the papers was very good.

4.2 Conclusion

Overall, many papers have discussed the role and integration of geospatial information which implies the use of GIS in many ways and contexts. Many of these papers included factors related to quality of life, some of them not using the term.

Based on all observations, it can be concluded that GIS can be leveraged for a data-driven approach for sustainable urban development and enhancing Urban Quality of Life. Using only one database, targeting the number of papers and selecting only the papers in English would have missed many important papers related to the review topic. However, this was a deliberately chosen strategy considering the limit prescribed for the length of such papers.

References:

Ahasan, R. & Hossain, M. M. (2020). Leveraging GIS and spatial analysis for informed decision- making in COVID-19 pandemic. *Health policy and technology*, 10(1), pp. 7-9.

Ah Ahmed, M. W., Ahmed, M., & Shaikh, A. A. (2024). Digitizing Karachi's Decades-Old Cadastral Maps: Leveraging Unsupervised Machine Learning and GEOBIA for Digitization. *Engineering, Technology & Applied Science Research*, *14*(5), 16404-16410..

Alausa, O. A., Adaradohun, O. S., Adekunle, G. T., & Priyono, K. D. (2023, December). Leveraging Geospatial Technology for Enhanced Utility Management: A Case Study in Electrical Distribution Power Systems. In *Forum Geografi* (Vol. 37, No. 2, pp. 164-177).

Am Ammar, A., & Dadi, G. B. (2021). Towards an Integrated Building Information Modeling (BIM) and Geographic Information System (GIS) Platform for Infrastructure. In *ISARC. Proceedings of the International Symposium on Automation and Robotics in Construction* (Vol. 38, pp. 129-136). IAARC Publications.

Bat Batum, S., Kalogianni, E., Broekhuizen, M., Raitviir, C., Mägi, K., & van Oosterom, P. (2024). Leveraging BIM/IFC for the Registration of Spatial Plans and Compliance Checks and Permitting in Estonia based on LADM Part 5-Spatial Plan Information. In *12th International FIG Workshop on the Land Administration Domain Model & 3D Land Administration* (pp. 161-186). International Federation of Surveyors (FIG).

Costa, D. G., Bittencourt, J. C. N., Oliveira, F., Peixoto, J. P. J., & Jesus, T. C. (2024). Achieving sustainable smart cities through geospatial data-driven approaches. *Sustainability*, *16*(2), 640.

Desai, A., & Patel, C. R. (2023). Leveraging GIS to deploy demand-driven public charging infrastructure in an Indian Metropolitan city. *Spatial Information Research*, *31*(4), 467-474.

H Hein, N., & Blankenbach, J. (2021). Evaluation of a NoSQL Database for Storing Big Geospatial Raster Data. *GI_Forum. Munster*, 76-84.

Khan, M. S., Kim, I. S., & Seo, J. (2023). A boundary and voxel-based 3D geological data management system leveraging BIM and GIS. *International Journal of Applied Earth Observation and Geoinformation*, *118*, 103277.

Li, F., Yigitcanlar, T., Nepal, M., Nguyen, K., & Dur, F. (2023). Machine learning and remote sensing integration for leveraging urban sustainability: A review and framework. *Sustainable Cities and Society*, *96*, 104653.

L Lovelace, R., Parkin, J., & Cohen, T. (2020). Open access transport models: A leverage point in sustainable transport planning. *Transport Policy*, *97*, 47-54.

M Miles, V., Esau, I., & Pettersson, L. (2024). Using web GIS to promote stakeholder understanding of scientific results in sustainable urban development: A case study in Bergen, Norway. *Sustainable Development*, *32*(3), 2517-2529.

Mortaheb, R., & Jankowski, P. (2023). Smart city re-imagined: City planning and GeoAI in the age of big data. *Journal of Urban Management*, *12*(1), 4-15.

Ozegin, K. O., Ilugbo, S. O., & Akande, O. N. (2024). Leveraging geospatial technology and AHP for groundwater potential zonation in parts of South and North-Central Nigeria. *Sustainable Water Resources Management*, *10*(4), 146.

Pedersen Zari, M. (2020). Biomimetic urban and architectural design: Illustrating and leveraging relationships between ecosystem services. *Biomimetics*, *6*(1), 2.

Phua, S. Z., Hofmeister, M., Tsai, Y. K., Peppard, O., Lee, K. F., Courtney, S., ... & Kraft, M. (2024). Fostering urban resilience and accessibility in cities: A dynamic knowledge graph approach. *Sustainable Cities and Society*, *113*, 105708.

Pitts, J., Gopal, S., Ma, Y., Koch, M., Boumans, R. M., & Kaufman, L. (2020). Leveraging big data and analytics to improve food, energy, and water system sustainability. *Frontiers in big Data*, *3*, 13.

Prakash, M., Ramage, S., Kavvada, A., & Goodman, S. (2020). Open Earth observations for sustainable urban development. *Remote sensing*, *12*(10), 1646.

Puspitarini, T., Christanto, H. J., & Singgalen, Y. A. (2024). Analysis and Design of Marine Tourism Information System Using Rapid Application Development. *Journal of Information Systems and Informatics*, *6*(1), 83-102.

Rezvani, S., Falcão, M. J., Komljenovic, D., & de Almeida, N. M. (2023). A systematic literature review on urban resilience enabled with asset and disaster risk management approaches and GIS-based decision support tools. *Applied Sciences*, *13*(4), 2223.

Safal, S. (2024). *How GIS Transforms Urban Planning: A Smart Approach to Sustainable City Development.* Retrievved November 24, 2024. from https://www.agsrt.com/post/how-gis-transforms-urban-planning-a-smart- approach-to-sustainable-city-development#:~:text=GIS%20is%20revolutionizing%20urban%20planning,of%20smarter%2C%20more%20sustainable%20cities.

Shah, P. (2021). IGiS for Managing Cities Smartly–Urban Geoinformatics. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *46*, 509-513.

Shaikh, M., & Birajdar, F. (2024). Advancements in remote sensing and GIS for sustainable groundwater monitoring: applications, challenges, and future directions. *International Journal of Research in Engineering, Science and Management*, *7*(3), 16-24.

Villani, M. L., Giovinazzi, S., & Costanzo, A. (2023). Co-creating gis-based dashboards to democratize knowledge on urban resilience strategies: Experience with camerino municipality. *ISPRS International Journal of Geo-Information*, *12*(2), 65.

Waleed, M., Sajjad, M., Acheampong, A. O., & Alam, M. T. (2023). Towards sustainable and livable cities: leveraging remote sensing, machine learning, and geo-information modelling to explore and predict thermal field variance in response to urban growth. *Sustainability*, *15*(2), 1416.

Yun, J., Ryu, K. R., & Ham, S. (2022). Spatial analysis leveraging machine learning and GIS of socio-geographic factors affecting cost overrun occurrence in roadway projects. *Automation in Construction*, *133*, 104007.

Ammar A. Naji
King Abdulaziz University
Jeddah
Saudi Arabia
anaji@kau.edu.sa
ORCID 0000-0002-2164-0600

Appendix

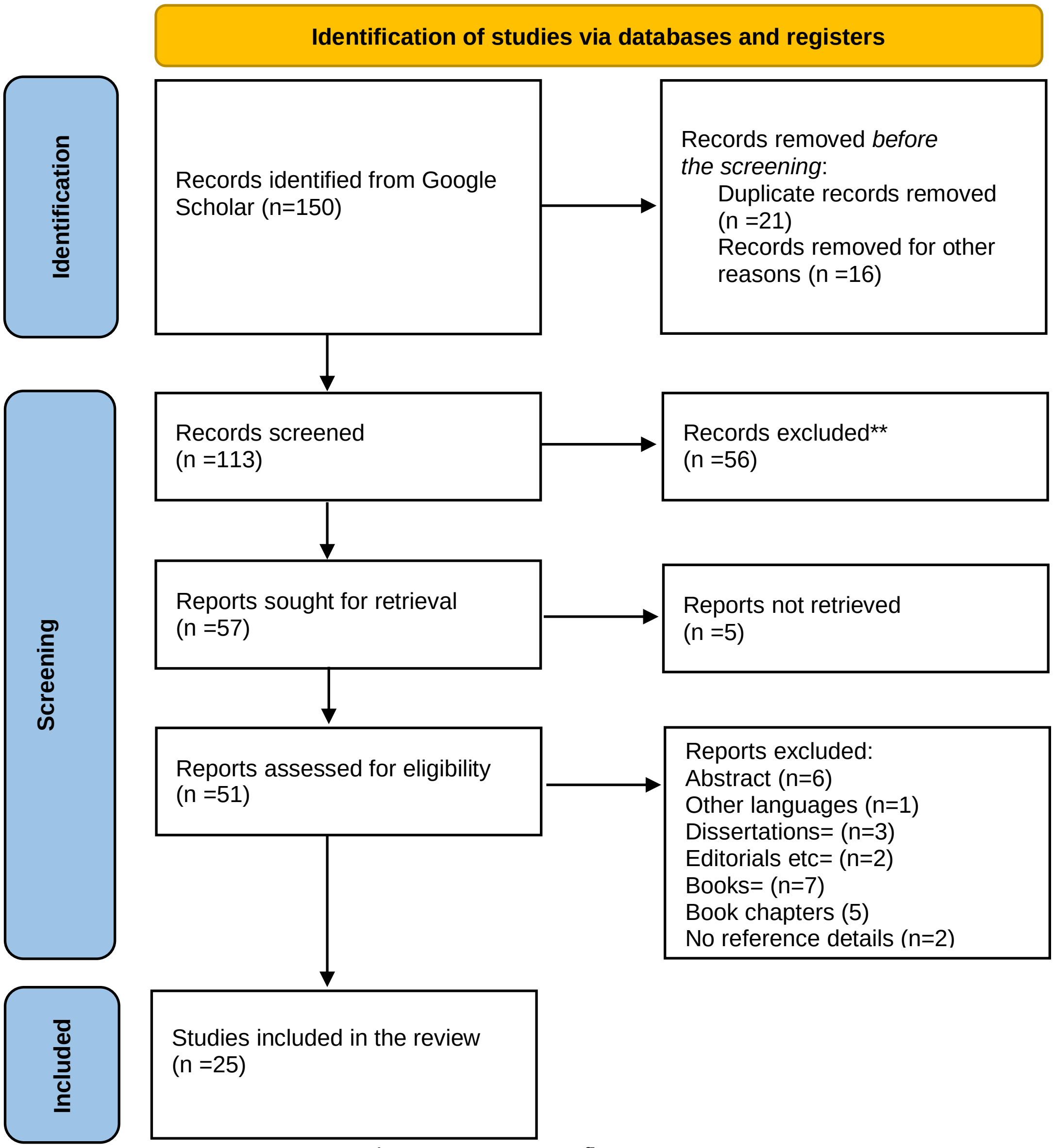

Figure 16. PRISMA flow process