Masters Program in Geospatial Technologies

THE USE OF GEOGRAPHIC INFORMATION SYSTEMS (GIS) TECHNOLOGY FOR THE IMPROVEMENT OF INFORMAL SETTLEMENTS:

A Systematic Review and a Meta-Analysis

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THE USE OF GEOGRAPHIC INFORMATION SYSTEMS (GIS) TECHNOLOGY FOR THE IMPROVEMENT OF INFORMAL SETTLEMENTS:

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DECLARATION OF ORIGINALITY

I declare that the work described in this document is my own and not from someone else. All the assistance I have received from other people is duly acknowledged and all the sources (published or not published) are referenced. This work has not been previously evaluated or submitted to NOVA Information Management School or elsewhere.

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ABSTRACT

Informal settlements are prevalent in developing countries, where slow economic progress and rapid urbanization contribute to the perpetuation of poverty. The widespread growth of informal settlements across various regions underscores the insufficient attention given to this issue at both regional and local levels. Residents in these settlements often face challenges such as limited access to basic necessities, inadequate sanitation, and substandard infrastructure, leading to social isolation and restricted mobility.

This study investigates the potential of Geographic Information System (GIS) technology in enhancing informal settlements, employing a systematic review and meta-analysis as the primary research methodology. Adhering to the PRISMA approach, 12 articles were selected for the review. The Critical Appraisal Skills Programme (CASP) tool was utilized to assess the quality of the chosen studies, ensuring the overall credibility of the research. Systematic review and thematic analysis were employed to analyze the results, while statistical tools facilitated the meta-analysis.

The findings indicate that GIS technology can play a pivotal role in improving informal settlements by enabling better mapping, analyzing spatial changes over time, and examining settlement morphology. Recommendations include exploring and comparing multiple settlements, investigating various functions of GIS, and exploring the synergies of GIS with other technologies.

Sustainable Development Goals (SDG):

KEYWORDS

Informal Settlements

Self-Built Dwellings

Housing Improvement

Geographical Information Systems

PRISMA Systematic Review

ACRONYMS

CASP – Critical Appraisal Skills Program

GIS - Geographic Information Systems

NGO – Non-Governmental Organization

PPP – Public-Private Partnership

PRISMA – Preferred Reporting Items for Systematic Reviews and Meta-Analyses

UAVs – Unmanned Aerial Vehicles

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1. INTRODUCTION

1.1 Research Problem and Significance

The phenomenon of informal settlements has been thoroughly investigated, yet only relatively little research has been carried out to resolve it. Generally, informal settlements, which are usually recognized as self-build neighborhoods, squatter areas, shantytowns, slums, or favelas, can be determined as illegal, unplanned human encampments defined by severe poverty and criminal offense and lack of lawful period and public infrastructure (Sekhani et al., 2022). The substantial majority (80%) of informal settlements are situated in Sub-Saharan Africa, Central, Eastern, and Southern Asia, in addition to Latin America (United Nations, 2019). According to the present evaluations, around 1.6 billion people (one in 7) live in some form of an informal settlement, which is expected to grow by 2030 to one in every four people living there (Habitat for Humanity, 2023). Some informal settlements are immense in size; for instance, the Orangi Town settlement in Pakistan accommodates 2.4 million people, Mexico's Neza favela is home to 1.2 million inhabitants, and the Kibera slum in Kenya provides shelter for 700 thousand dwellers (Habitat for Humanity, 2023). Considering these estimations, informal settlements represent a prevalent and ongoing problem that will be exacerbated in the coming years if adequate assistance for self-improvement is not provided.

Informal settlements represent a significant challenge for its dwellers, a wider society, and the world, as this challenge creates instability in terms of public health and wellness, safety, and economic development (Khan et al., 2023; Sekhani et al., 2022). Sadly, no solutions have been efficiently applied to avoid the development or growth of informal settlements. Regional and local solutions have gotten little over the last decade. Some governments have implemented site and service systems that give citizens fundamental infrastructure such as water, sanitation, and power sources in informal settlements (Uwamahoro & Asano, 2021). This method aimed to improve living conditions in existing informal settlements and dissuade the formation of brand-new ones. In other regions, governments, and non-governmental

organizations (NGOs) have implemented programs to advertise inexpensive housing, consisting of subsidies, microfinance, and cooperative housing models (Mwamba & Peng, 2020). Sometimes, the governments utilize easy demolitions of informal settlements (partial or complete) to avoid the development of informal settlements (Debela, 2021). Making formal housing choices more obtainable to low-income populations helps prevent the spontaneous growth of informal settlements. Some cities have embraced policies primarily aimed at avoiding the growth of informal settlements, entailing stricter enforcement of structure codes, zoning guidelines, utilization, and utilizing preparation to lead city development in a Muswell-organized manner (Mwamba, 2020). Ultimately, collaborations between government companies, private developers, and NGOs have been used to leverage sources and experience for the development of inexpensive housing and infrastructure (Shafik & Abouhadid, 2019). Such public-private partnerships (PPPs) were targeting the enhancement of the efficiency and effectiveness of city development efforts, which needed more progress.

The abovementioned approaches to prevent the development or improvement of informal settlements were either partially efficient or entirely disadvantageous. As an outcome, it can be valuable for all stakeholders to look for more intricate, creative, and authentic options for renovating informal settlements. Among such options is Geographic Information System (GIS) technology, which can play a critical role in this process by providing a better understanding of the problem, sustaining decision-making, and helping with better management of informal settlements.

Multiple researchers have acknowledged GIS technology's potential to provide better conditions for informal settlements. Specifically, GIS can be utilized to develop accurate maps of informal settlements, determining their spatial level, population density, and vital functions, which is essential for comprehending the existing situation and preparing interventions for improvement (Mudau & Mhangara, 2021). It was also recognized that GIS enables the mapping of existing infrastructure (water system, sewage, electricity, etc.) and can help identify locations that do not have access to basic services, which can be used

to target development and improvement projects (Rezvani et al., 2023). GIS can aid in mapping and documenting residential property and borders, adding to protecting land rights for homeowners, lowering the risk of forced evictions, and providing a foundation for sustainable development (Mukherjee et al., 2023). In addition, GIS devices can potentially facilitate participatory mapping exercises, permitting community members to aid in regional understanding and provide feedback for renovation, helping to make sure that treatments align with community demands and preferences (Taylor et al., 2020). Other benefits of GIS technology can include monitoring existing infrastructure ownership, tracking maintenance demands, and mapping the vulnerability of informal settlements to natural catastrophes and other hazards (Soman et al., 2020). For instance, this information is essential for establishing reliable disaster action and mitigation strategies. In this manner, GIS tools enable spatial evaluation to understand the relationships between different factors, aiding urban planners in making informed decisions on land use, housing policies, and overall city development (Mohamed et al., 2022). Overall, as multiple sources inform, GIS can support the preparation and design of infrastructure projects by examining spatial data to determine optimum areas for infrastructure solutions, including road systems, power stations, water systems, and hygiene centers.

The benefits of GIS technology relate to its ability to incorporate different types of data, including demographic, socioeconomic, and ecological information, which can propose the basis for a more multifaceted understanding of informal settlements and decision-making (Ren et al., 2020). Also, GIS could synchronize with other information systems and databases, facilitating partnerships among different stakeholders, like government firms, NGOs, and communities (Barella, 2020). Considering these capabilities, GIS technology can be effective in a long-term perspective through its surveillance and assessment functions, allowing the impact of informal settlement development to be determined over time.

Considering the mentioned perspective, advantages, and capabilities of GIS technology in the context of informal settlements, it is possible to explore it in

a more detailed review. However, this evidence is distributed unevenly throughout a broad spectrum of research, providing a limited understanding of the appropriate application and use of GIS in the context of informal settlements. The lack of systematic reviews in this research niche requires a more systemized analysis of this topic.

1.2 Theoretical Framework

The first basis for this theoretical framework is Charles Stokes's theory of slums, coined in 1962, which indicates that the development of informal settlements was rooted in the increased immigration and decreased assimilation of the citizens in large cities (Stokes, 1962). This theory implied that informal settlements in developing countries have the possibility of being slowly included in the formal city limits via housing improvement and involvement of local inhabitants (Stokes, 1962). Stokes' theory of slums has been prominent in recognizing the dynamics of slum formation in different cities, as it profiles the factors responsible for slum formation.

The revision of Stokes's theory was also considered for this study, as it is considered that this framework did not consider the aspect of colonization as an adverse factor stimulating the development of informal settlements (Beier, 2022). It has been determined that the theory encompasses both hope and misery, as many have been dissatisfied with the phenomenon of informal residents. In the context of city scaling laws, it has been suggested that recent changes in the informal settlements have implications for the advancement of slum theories, supplying new empirical evidence that explains the emergence of informal settlements (Turok & Jackie Borel-Saladin, 2019). While the reinterpretation of this theory is crucial, the current state of events in informal settlements indicates the relevance of Stokes' theory in the broader discourse on urban development and population dynamics (Beier, 2022; Stokes, 1962).

Another theory that was used as the platform for this systematic review is the framework of informal settlements by the British architect John F. C. Turner.

Turner advocated for the principle of self-help housing, where citizens of informal settlements proactively take part in the building and enhancement of their own homes and communities (Harris, 2003). Turner believed that engaging the community in the preparation and decision-making process can result in more sustainable and socially authentic settlements. Turner fostered the concept of incremental growth, which includes progressive and step-by-step improvements to housing and framework over time (Van Ballegooijen & Rocco, 2013). Rather than large-scale, top-down growth projects, he argued for allowing communities to develop organically and adjust to their changing needs over time. Turner recognized the relevance of safe land tenure and property rights for residents of informal settlements (Carrasco & O'Brien, 2022). He believed that offering locals legal possession or lasting land-use rights could equip them and encourage investment in their homes and communities.

Turner's framework also emphasized the value of considering the social and cultural elements of informal settlements by implying that coordinators and designers ought to consider the existing social structures, techniques, and social norms of the areas they are developing to create more appropriate and long-lasting designs (Shafqat & Khan, 2022). Turner advocated for participatory preparation processes that entail the homeowners of informal settlements in decision-making and design. He thought that this method would lead to more receptive and context-specific solutions. He advertised the development of diverse housing typologies that can fit a range of home sizes and flexible and versatile housing designs, which could better meet the developing needs of citizens (Shafqat & Khan, 2022). Along with social and financial factors to consider, Turner additionally emphasized the importance of environmental sustainability in informal settlements by encouraging the use of community and infrastructure that are more environmentally friendly and authentic.

Both Stokes' framework and Turner's theory provided a structure for understanding the complex interaction of migration, city job markets, and housing characteristics in the development of informal settlements. It has been

influential in shaping conversations around informal settlements and has implications for city scaling legislations and the innovation of informal settlements theories.

1.3 Aim and Objectives

This systematic review aims to determine the effectiveness of GIS technology in improving informal settlements. The primary objectives of this review are:

- To determine how GIS technologies contribute to the detection of informal settlements, exploration of their morphology, considerations of urban design, mapping techniques, and analysis of land cover dynamics.
- To detect the best practices and key challenges associated with GIS applications in informal settlements.
- To reveal how the best practices of GIS applications can be adapted to comply with the unique characteristics of specific local conditions of informal settlements.
- To explore the effect of governance structures, financial resources, and community participation on the effective application of GIS-based interventions in improving informal settlements.

1.2 Research Questions

The following questions are answered during this study:

i. How can GIS technologies contribute to the improvement of informal settlements?

ii. To what extent do existing GIS technologies contribute to the identification and detection of informal settlements, exploration of their morphology, considerations of urban design, mapping techniques, and analysis of land cover dynamics?

iii. What are the best practices and key challenges associated with GIS applications in informal settlements?

iv. How can the best practices of GIS applications be adapted to suit the unique characteristics of specific local conditions of informal settlements?

v. How do governance structures, financial resources, and community participation influence the effectiveness of GIS-based interventions in improving informal settlements?

1.3 Assumptions

When performing a systematic review on the effectiveness of GIS technology in improving informal settlements, it is possible to develop assumptions based on the nature of the topic and the available literature. The systematic review assumes that GIS technology matters and is appropriate to the context of informal settlements, adding considerably to resolving challenges and improving living conditions. The evaluation thinks that there is an adequate body of published studies, short articles, and records that investigate using GIS technology in informal settlements. This assumption is crucial for carrying out a comprehensive review.

The review assumes that GIS technology can potentially improve informal settlements if it is implemented correctly. It is also assumed that the data collected and reported in this research are credible, showing that GIS can be used in informal settlements effectively through better mapping, prediction, and data retrieval. A causal relationship could exist between GIS technology and the evolution of informal settlements through positive adjustments in settlements, involvement of inhabitants in decision-making, and infrastructure improvement. This review assumes that findings related to the effectiveness of GIS in one informal settlement can be transferable to similar settlements, considering the generalizability of results.

Considering the evidence provided by past studies, it is reasonable to assume that GIS technology can be beneficial in the informal settlement context. This may include factors such as technological infrastructure, software accessibility, and technical knowledge. The review also assumes that reliable GIS interventions in informal settlements involve different stakeholders, consisting of the city structures, governmental agencies, non-governmental organizations (NGOs), and communities. The application of GIS technology in informal

settlements complies with the ethical factors to consider, ensuring the health, privacy, and rights of the local settlers. Finally, this review assumes that studies reporting positive outcomes of GIS interventions in informal settlements are credible, which allows for conducting an informed review of evidence.

1.4 General Methodology

This study uses the systematic review as the main design for organizing this study. The PRISMA approach to systematic reviews is applied to guide the source selection process. Critical Appraisal Skills Program (CASP) is implemented to evaluate the quality of the included studies. The analysis of data retrieved from the included inquiries is performed by using a thematic analysis. (Page et al., 2021). A preliminary literature review is conducted to refine the search strategy, determine inclusion-exclusion criteria, and detect a gap in research, as well as to avoid duplication and ensure the feasibility of this systematic review. A more detailed description of the methodology is provided in part two of this review.

1.5 Dissertation Organization

This systematic review has five parts. The first part provides an overview of the problem and its significance in the context of research, an overview of the theoretical framework, including research objectives and questions, and a preliminary literature review. The following section describes this review's methodology by listing the study design, search strategy, source selection, inclusion and exclusion criteria, screening of results, critical appraisal, data analysis, and ethical implications. The third section of this paper provides an analysis of the study results by answering the research questions and attaining objectives. The fourth section of this review proposes a comprehensive discussion of results in the context of past studies, implications for practice and research, strengths and limitations of this review, and recommendations for future research. Finally, the last part of this review provides overall conclusions for the entire paper.

1.6 Preliminary Literature Review

1.6.1 Rationale for Conducting a Preliminary Literature Review

This is a preliminary literature review conducted to determine the existing body of literature appropriate to this study, which ensures that the systematic review has internal consistency. By performing a preliminary literature review, it is possible to prevent duplication and repetition. The preliminary literature review aided in improving inclusion and exclusion criteria for choosing studies to be included in the systematic review. The expediency of performing a systematic review was examined based on the available literature. This preliminary literature review aided in developing effective search strategies for recognizing relevant studies in databases. It was accomplished to decrease selection bias and ensure that the systematic review is as objective as possible.

1.6.2 Phenomenon of Informal Settlements

Informal settlements are a worldwide phenomenon occurring primarily in countries with contrasting spatial arrangements and economic problems (Mudau & Mhangara, 2021; Fundisha, 2022; Zhang et al., 2020). These settlements are frequently stigmatized and marginalized, with citizens facing difficulties connected to land tenure, access to clean water, waste management, and sanitation (Wilkinson et al., 2020; Magina et al., 2020). Because of their informal nature, these settlements may face difficulties in providing appropriate education, learning, and medical care facilities for settlers. The development of this phenomenon is affected by such factors as rapid urbanization, a lack of city planning, and the country's socioeconomic problems (Hambrecht et al., 2022). These settlements are often related to high levels of unpredictability, making it difficult for city government service providers to manage (Mesgar & Ramirez-Lovering, 2021). Homeowners in informal settlements usually do not have lawful possession or official rights to the land they occupy. This lack of safe land tenure can cause uncertainty and vulnerability, as homeowners may face expulsion or displacement.

Living in informal settlements could be challenging for people, as these areas are characterized by poor housing decisions, insufficient infrastructure, and a

lack of access to city services (Weimann & Oni, 2019). Dwellings in these settlements frequently disintegrate as they are built from products like corrugated metal, cardboard, plastic, or wood. Since these areas lack appropriate planning or construction requirements, the inhabitants are forced to reside in dangerous and unpredictable conditions. Specifically, these settlements usually emerge outside formal laws and policies and bring challenges in the form of overcrowding, diseases, and inadequate construction, which increase the vulnerability of citizens to health risks (e.g., natural disasters, infectious diseases, construction falling) (Satterthwaite et al., 2020; Okem et al., 2022). As a result, these settlements usually need more services like access to clean water, power, sewage, and garbage disposal, which compels locals to depend on shared facilities or informal solutions.

Furthermore, informal settlements can influence the surrounding atmosphere and trigger problems related to the environment, hygiene, and infrastructure (Nixon, 2020). For instance, the COVID-19 pandemic has highlighted the vulnerabilities of informal settlements, where overcrowding and inadequate infrastructure intensified the risks of the pandemic to residents (Okem et al., 2022; Wilkinson et al., 2020). The pandemic showed that since informal settlements are densely populated, it is more likely that such hazards as infectious diseases could create a major risk to public health. The high population density worsens challenges associated with sanitation, waste monitoring, and the stipulation of fundamental solutions (Wilkinson et al., 2020).

In addition, the role of informal settlements in city design has been discovered, with discussions on their potential payment to a fairer and more genuine representation of cities (Okem et al., 2022). Informal settlements face complex urban challenges defined by insufficient housing, poor infrastructure, and minimal accessibility to essential services. These settlements are influenced by a variety of social, financial, and ecological variables, and attending to the problems connected with these areas requires thorough investigation.

1.6.3 Causes of Development and Growth of Informal Settlements

The development of informal settlements is a complicated phenomenon affected by different aspects. Quick urbanization has been determined to be a substantial stimulation of informal settlement growth. Specifically, the migration of people from rural areas to cities looking for better financial opportunities is a substantial driver of informal settlement growth (Rikko et al., 2019; Lorens et al., 2022). As cities experience fast urbanization, the need for housing often overtakes the readily available formal housing choices, leading to the spontaneous development of informal settlements (Rikko et al., 2019; Debela, 2021). Furthermore, the influx of migrants into urban areas, usually due to frequent economic problems, has added to the emergence of informal settlements (Lorens et al., 2022). The absence of budget-friendly formal housing options and delays in the implementation of legal land provisions for housing have also been recognized as causes of the introduction of informal settlements (Debela, 2021). People living in poverty commonly lack access to budget-friendly housing. Sometimes, weak urban preparation and inadequate governance contribute to the spreading of informal settlements (Rikko et al., 2019). A lack of extensive urban development methods might lead to the absence of infrastructure, services, and zoning laws. Additionally, the insufficiency of city planning and infrastructure, consisting of inadequate and inappropriate living areas, improper housing, and lack of public solutions and resources, has been connected to the development of informal settlements (Uwamahoro & Asano, 2021; Forbes, 2019).

As a result of these events, informal settlements have become a coping mechanism for those who cannot afford formal housing. The shortage of affordable housing is a trigger for people to seek housing in informal settlements due to a lack of choice (Forbes, 2019). Furthermore, the insecurity in informal settlements, characterized by underemployment, lack of appropriate access to services, overcrowding, and tenure vulnerability, contributed to the spreading of economic instability in large cities (Forbes, 2019; Rezayee et al., 2019). Minimal accessibility of affordable land in urban areas, combined with high land costs, can force people to clear up vacant or unused land without proper consent, leading to the development of informal

settlements. Poor policies and a lack of affordable housing alternatives add to the formation of informal settlements (Rezayee et al., 2019). When formal housing is expensive for a considerable size of the population, people are left with no choice but to squatter on the available territory.

The development of informal settlements is also influenced by social and economic variables, as people may choose to live close to areas where they can find employment, such as street vending or small-scale trade. Specifically, factors like widespread poverty, unequal resource distribution, and social exclusion have been linked to the construction and growth of informal settlements (Noibi et al., 2020). In addition, the absence of trust in government agencies and the reinforcement of social exclusion have further reinforced the building of informal settlements (Noibi et al., 2020). The combination of these factors has contributed to the perseverance and growth of informal settlements in different urban areas. Generally, the root causes of the emergence of informal settlements are complex and interconnected, including urbanization, movement, poor city infrastructure, social and financial aspects, and governance difficulties (Friesen & Pelz, 2020). Attending to the concern of informal settlers calls for a comprehensive understanding of these underlying causes and the development of alternative approaches that include city planning, housing policies, infrastructure development, and social addition efforts.

1.6.4 GIS Technology Use in the Context of Informal Settlements

GIS technology is a tool to improve informal settlements by providing valuable data for decision-making and preparation. Using mobile GIS for occupancy audits in informal settlements is reliable in enhancing integrated human settlement implementation (Tjia & Coetzee, 2022). This technology can aid in the recognition and characterization of informal settlements, resulting in a better understanding of this phenomenon and the improvement of social and economic conditions and distribution of infrastructural centers and services for the settlers (Brown & Tari, 2022). Additionally, GIS technology, when incorporated with remote sensing, can provide affordable mapping techniques

for landscape evaluation and style in slum-upgrading projects, adding to the "ground reality" classification of informal settlements (Tjia & Coetzee, 2022).

Furthermore, GIS-based analysis can play a vital role in developing risk metrology solutions to compare settlements against each other, as shown in a case study in Cape Town (Stevens et al., 2020). Another example of effective implementation of GIS was in tracking inoculation groups to monitor booster shot coverage in island settlements, which improved team efficiency and minimized the number of errors (Ajiri et al., 2021; Kaya, 2023). Furthermore, GIS technology has contributed to tracking vaccination groups throughout health projects in informal settlements, showing its crucial function in making educated decisions on health and social issues (Li et al., 2019). In addition, GIS helped in the understanding of structural distinctions between remote and urban informal settlements by analyzing detailed images retrieved during the application of this technology (Stevens et al., 2020).

It was also determined that GIS is not only effective on its own but also in combination with other solutions. For example, the use of GIS for monitoring settlement development and growth, along with market surveying of informal settlements, showed positive outcomes, highlighting its prospective to aid in reliable urban planning and policy solutions (Litasari et al., 2022). Also, GIS technology was effectively used in combination with surveying to minimize climate change-related flooding in urban informal settlements via the development of environment-friendly infrastructure solutions (Anwana & Owojori, 2023).

As the analysis of literature in this area showed, GIS technology provides an extensive range of applications that can dramatically improve informal settlements by supplying beneficial data for decision-making, planning, risk evaluation, and infrastructure development. The application of GIS alone and in combination with other solutions has the possibility of enhancing living conditions, infrastructure, and overall city development in these areas.

1.6.5 GIS Technology in the Detection of Informal Settlements

Existing GIS technologies made significant contributions to the identification and detection of informal settlements. Geospatial solutions, consisting of planet observation and GIS, have revealed valid prospects in providing data on informal settlements (Asube et al., 2021). GIS technologies utilize satellite images and aerial surveys to capture high-resolution pictures of urban areas. These images can be processed to detect and map informal settlements, especially in remote or inaccessible locations. Machine-learning algorithms and spatial evaluation have been put into acquiring the possible places of informal settlement buildings, showing the use of advanced technologies in this context (Asube et al., 2021). GIS has additionally allowed visualizing life in informal settlements, highlighting the application of participatory GIS (PGIS) approaches to mapping the daily lives of people in these settlements (Mdleleni et al., 2020). Additionally, GIS-based risk functions have been established to review fire hazards in informal settlements, showing the essential function of settlement design in affecting the occurrence of massive fires (Stevens et al., 2020).

Other functions that can be used for the detection of informal settlements include the integration of different spatial data layers, like land use, infrastructure, and topography. By examining these layers, GIS can determine areas with features that are signs of informal settlements, including temporary structures and high population density areas. GIS technologies allow the comparison of spatial data over time, which allows professionals to analyze the development and growth of informal settlements over time (Mdleleni et al., 2020). This capability is powered by the change detection algorithms that allow the recognition of locations undergoing rapid urbanization or the emergence of informal settlements. The ability to distinguish informal from formal settlements by using images powered by GIS is a major benefit compared to traditional methods, which often include less effective household surveys (Stevens et al., 2020).

GIS helps with area engagement with crowdsourced data collection and participatory mapping. Residents can add useful information regarding informal settlements, aiding in the creation of more precise and up-to-date

maps. The use of GIS technologies has been critical in disaster monitoring, specifically in the examination process of post-earthquake city building supply (Kaya, 2023). GIS can examine and map formal land use and zoning guidelines. Disparities between these guidelines and the actual land use in a location might show the existence of informal settlements. The lack of rigorous assimilation of GIS has been determined as a restriction, showing the recurring initiatives to improve the synergy between these technologies for detailed urban modeling (Borkowski et al., 2022). GIS technologies integrate topographic data, which can be used to assess the suitability of land for settlement. Locations susceptible to flooding or landslides are usually more suited for formal settlements rather than informal ones. Overall, as the evidence showed, GIS technologies, integrated with equipment learning algorithms, can be used for predictive modeling to identify possible areas of informal settlements based on historical patterns.

1.6.6 GIS Use in Morphology and Urban Design in Informal Settlements

GIS enables the evaluation of settlement patterns, such as building density, setup of structures, and the format of roads and paths. This spatial evaluation supplies an understanding of the morphology of informal settlements and helps identify patterns of development. Specifically, GIS tools allow the comprehensive analysis of the framework and morphology of informal settlements, providing an understanding of their vibrant urban areas (Pinto et al., 2021). Using GIS in mapping and analyzing informal settlements was recognized as a critical device for understanding the fluidity of space and the adaptations in these settlements (Kamalipour, 2020). GIS can be utilized in participatory design processes where community participants add to mapping their settlements. This comprehensive technique helps include local expertise and preferences in the urban design process.

In terms of morphology, GIS tools examine availability within informal settlements, taking into consideration variables such as proximity to facilities, transportation courses, and connectivity. These tools use a multidimensional method to understand the context level of sensitivity and variety within informal settlements, adding to a better understanding of their urban morphology (Arif

et al., 2022). Furthermore, GIS technology has revealed terrific potential in supplying data on informal settlements, permitting the evaluation of spatial distinctions and the development of risk quantification frameworks for fire spread in these settlements (Stevens et al., 2020; Li et al., 2019).

Also, GIS has been integrated into urban and local planning applications, leveraging remote surveillance and GIS for mapping urban locations and purposefully locating land for human settlements (Stevens et al., 2020). Using of GIS in city preparation has been stressed for installing ecology into urban decision-making, adding to the conservation, management, and enhancement of eco-friendly infrastructure in cities (Osmond & Wilkinson, 2021). Additionally, GIS technology has been instrumental in developing a GIS-based risk version for evaluating fire risk in informal settlements, highlighting the critical role of settlement design in influencing the development of massive fires (Pinto et al., 2021).

1.6.7 GIS in Mapping and Land Cover Dynamics in Informal Settlements

Existing GIS technologies dramatically add to the exploration of informal settlements' mapping and land cover dynamics. GIS, in combination with remote monitoring techniques, was used to examine land use and land cover modifications in numerous areas. For example, studies have utilized satellite pictures and monitored classification formulas to evaluate spatial and temporal dynamics of land use/cover modifications (Amadu et al., 2022). These technologies have contributed to mapping informal settlements, determining plot borders, and evaluating existing infrastructure, which is vital for enhancing living conditions in these areas (Aboulnaga et al., 2022). Moreover, GIS and remote surveillance are practical tools for acquiring precise and timely information on the spatial distribution of land use/land cover changes over huge locations (Aboulnaga et al., 2022). In addition, the list and mapping of informal settlements have been assisted by grassroots organizations and groups of the urban population, with the support of GIS technologies, to comprehend the dynamics of human settlements and land periods (Wang et al., 2021). Also, GIS has been utilized to examine land use/land cover changes

associated with community forestry execution, showing its versatility in different ecological contexts (Ekta & Chundeli, 2022).

GIS technologies have additionally been reliable in assessing land cover dynamics in numerous regions, including watersheds and hilly locations, supplying helpful information for land monitoring and environmental preparation (Mahto et al., 2022). Furthermore, GIS has been used to keep track of ecological changes in dry and semi-arid regions, showing its applicability in varied geographical setups (Mukherjee & Singh, 2020). In addition, using of GIS in mapping land use/land cover has been identified as crucial for urban preparation and environmental aspects, highlighting its importance in long-term development (Mukherjee & Singh, 2020).

Land cover dynamics powered by GIS allow the development of standard maps of informal settlements, supplying a first understanding of the spatial circulation and features of buildings, infrastructure, and open areas (Membele et al., 2021). GIS supports temporal evaluation by contrasting satellite images or airborne surveys taken at different time points (Mdleleni et al., 2020). This assists in recognizing changes in land cover dynamics, consisting of development, densification, or adjustments in land use (Wang et al., 2020). This is vital for monitoring the growth or improvement of informal settlements and comprehending the variables driving these modifications (Mosbach et al., 2022).

In addition to the aforementioned benefits in aiding in land cover dynamics analysis, GIS can be utilized to develop designs that mimic urban growth and forecast future adjustments in informal settlements. For instance, GIS can analyze different factors, such as population dynamics, financial development, and land utilization policies, to make predictions of settlement development and growth (Alrasheedi et al., 2023). This technology can also incorporate different data layers, like demographic data, infrastructure data, and environmental data, which helps in receiving more accurate factors affecting land cover dynamics in informal settlements (Wang et al., 2020). By assisting in mapping the expansion of infrastructure, such as roadways and utilities,

within informal settlements, GIS assists professionals in improvements in these areas (Mosbach et al., 2022). In addition, GIS can be employed for ecological tracking within informal settlements, tracking modifications in eco-friendly spaces, water bodies, and other ecological elements (Alrasheedi et al., 2023).

1.6.8 Summary

The preliminary literature review showed the scarcity of studies using a systematic review or meta-analysis as the methodology for exploring the use of GIS technology for the improvement of informal settlements. Many studies have been performed to investigate the utilization of GIS predominantly within one region or one informal settlement, which does not provide the full picture of this technology's potential. As the preliminary literature review showed, a gap in this area of study exists. Specifically, the lack of systemic research on GIS and its effect on informal settlements created a need for developing a more comprehensive and synthesized literature review that can shed light on the full potential of GIS in the context of informal settlement improvement. Also, the gap in research was observed in the functionality of GIS software and the methodology of its application.

2. METHODOLOGY

2.1 Design

This systematic review uses the PRISMA framework to select the sources for the analysis. The PRISMA framework (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) is a commonly acknowledged guideline utilized to direct the coverage of systematic reviews and meta-analyses (Page et al., 2021). Its main objective is to ensure the clarity, transparency, and efficiency of testimonials. The adhering to actions was completed to follow the PRISMA framework. The research objectives were formulated. Before starting the review, a protocol was created that detailed the reasoning, hypothesis, and intended techniques of the review. The requirements were developed and consisted of based on the study inquiry and

purposes. An extensive search of numerous databases and sources to collect pertinent studies was performed. Afterward, the author screened the search engine results and chose studies that met the eligibility standards. A flow diagram was devised to delineate the progression of details across the various stages of the systematic review, encompassing the number of studies recognized, included, and excluded, alongside the rationale for exclusions (Figure 1). Pertinent data were drawn out from the included studies using a standardized data extraction type. The quality and danger of bias of the included studies were reviewed manually by utilizing the CASP tool. The data were evaluated and synthesized by involving both qualitative synthesis and measurable meta-analysis. The results were reported systematically, including an in-depth description of the included studies, synthesis of findings, and meta-analysis outcomes. The main findings were interpreted in the context of the existing literature, discussing the effects of the findings and acknowledging limitations. Lastly, the final thoughts were attracted based on the proof evaluated.

A preliminary literature review was conducted to determine the research gaps, detect the feasibility of conducting a systematic review, prevent bias and duplicating, as well as to detect proper inclusion and exclusion criteria. According to the preliminary literature review, it was determined that GIS technology can be effectively used in improving informal settlements at different levels. Yet, while multiple studies were conducted sporadically and addressed different perspectives within the larger topic of GIS use in informal settlements, the findings of these studies have not been systemized productively. It was determined that GIS technology has a lot of potential to improve different aspects related to informal settlements, the quality of people's lives inhabiting the informal settlements, and mapping the land. Yet, it is still unclear how to implement GIS technologies correctly and comprehensively to maximize the benefits for all stakeholders (inhabitants of informal settlements, regions, larger communities, and countries).

While some findings were generated in this area, they are not systemized or synthesized properly. Preliminary analysis aimed at searching for recent

systematic reviews and meta-analyses to detect the utility of the current study. This preliminary literature review showed that no systematic reviews that analyze the sources in detail were determined. Consequently, it was decided to analyze and systemize the studies conducted recently on the topic of the effect of GIS technology on informal settlement improvement.

2. 2 Search Strategy

The search strategy was based on analyzing prominent databases (Table 1) that provide research on GIS technology and informal settlements:

Database	**Rationale**
Web of Science	A comprehensive database providing a wide variety of studies on sciences, arts, and humanities
Google Scholar	A free and open database containing usable instruments for literature search and a large collection of resources
Science Direct	This is a large database of studies conducted in the areas of technology, science, and healthcare.
ERIC	A database that includes a large number of articles, books, and other printed resources on sciences

Table 1. Choice of Databases

Setting		**Intervention**		**Outcomes**
informal settlement		GIS		improvement
OR		OR		OR
slum		GIS technology		life improvement
OR		OR		OR
favela	**AND**	technology	**AND**	quality of life
OR		OR		OR
squatter		geographic information system		wellness
				OR
				Settlement improvement

Table 2. Facet Analysis

The search included sources that were published within the last five years to ensure that the findings are relevant to the current area of research on GIS and informal settlements. The refinement and structuring of the search strategy included the use of the Boolean operators ('AND' 'OR') (Table 2).
During the search, truncation symbols were added to expand the reach of the available sources. This approach ensured that the endings (e.g., -ed, -es) were included in the sources (Table 2) It is critical to consider that each database has individual truncation symbols.

2.3 Source Selection

In carrying out source selection for a systematic review, the researcher followed a rigorous and transparent process to ensure the credibility and comprehensiveness of his literature review. Specific criteria that publications were fulfilled to be included in the review. This helped to concentrate on appropriate studies and omit irrelevant ones. A comprehensive search strategy was created to recognize pertinent research. Several databases were used to ensure complete insurance coverage of the literary works. Additionally, hand-operated searches of journals and reference listings of appropriate posts were carried out. Initial screening involved assessing titles and abstracts to identify potentially qualified research studies. This was complied with by a more detailed assessment of the full texts of chosen posts to determine their qualification based on the predefined criteria.
Relevant data from eligible research studies were systematically drawn out using a standardized kind. This consisted of information on study design, participants, treatments, outcomes, and crucial findings. The quality of the included studies was assessed to gauge the dependability of their results. Different tools and lists were used to review the research design, methodology, and risk of bias. High-quality research studies offered more weight in the synthesis of results. Data from chosen studies were synthesized to supply an extensive introduction of the evidence. Heterogeneity amongst studies was very carefully considered, and level of sensitivity evaluations might be conducted.

2.4 Inclusion and Exclusion Criteria

The articles that adhere to the following criteria were included in the review: (1) randomized controlled trials (RCTs), cross-sectional studies, quasi-experimental research, and observational studies; (2) articles that investigated the effectiveness of GIS technology in improving informal settlements; (3) articles analyzing the setting of informal settlements; (4) research that reported outcomes (e.g., improvement of informal settlements). (5) Full papers. It was essential to include only empirical studies, as they are based on observed and measurable phenomena, as well as they obtain understanding from real-life experiences as opposed to theory or belief. This emphasis on real-world data makes empirical studies a stronger resource of evidence, which was important for the validity of this systematic review. Empirical studies follow a specific and standardized approach that can be duplicated, which enables reliability and validation of results, supplying more robust and reputable findings for this systematic review. Empirical studies supply useful, real-world insights that are directly applicable to the field being examined. Furthermore, empirical study is generally associated with scientific rigor due to its dependence on systematic observation, trial and error, and evidence. Empirical studies contribute to the body of proof by providing new data and findings. Including them in systematic reviews ensured that they reflect the most relevant evidence.

2.5 Results Screening

Certain inclusion and exclusion criteria were developed based on the research question or goals (Table 3). These criteria outlined the attributes that studies should have to be taken into consideration for inclusion in the systematic review. The first phase of screening involved examining the titles and abstracts of identified research studies. The researcher analyzed whether the web content straightens with the established inclusion criteria. Studies that did not satisfy the criteria are left out at this phase. Researchers who pass the initial screening go through a more thorough assessment through an extensive exam of the complete text. They were meticulously reviewed regarding their method,

study design, and other relevant aspects to identify if the research fulfills all inclusion criteria.

Category	Inclusion and Exclusion	Rationale
Referencing	Include 1: Complete bibliographic reference.	Convenience and accuracy of referencing the sources
	Exclude 1: Incomplete bibliographic references.	
Setting	Include 2: Studies focusing only on informed settlements	This review focuses only on the informal settlements or slums and does not analyze the city planning or living conditions
	Exclude 2: Studies focusing on both formal and informal settlements.	
Relevance	Include 3: Studies focusing on GIS technology in the context of informal settlements.	This review focuses only on GIS technology in its application as a solution to informal settlements.
	Exclude 3: Studies focusing on GIS technology only.	
Date	Include 4: Studies published after 2019	The recency for this review is paramount
	Exclude 4: Studies published before 2019	
Study Design	Include 5: Empirical studies	This review includes only empirical research (randomized controlled trials, quasi-experimental studies, cross-sectional studies, and observational studies) to ensure the effectiveness of findings.
	Exclude 5: Non-empirical studies.	
Study Type	Include 6: Peer-reviewed studies	This review has to focus only on peer-reviewed research to eliminate bias
	Exclude 6: Not peer-reviewed studies.	
Language	Include 7: Studies published in the English language	Limited papers in non-English language are available on researched topics.
	Exclude 7: Studies published in a non-English language.	
Capacity	Include 8: Full papers available	Only the full version of the studies is accepted by the review to evaluate their quality, reliability, and validity.
	Exclude 8: Only snippets or abstracts available	

Table 3. Inclusion and Exclusion Criteria

Throughout the screening process, the researcher thoroughly documented his decisions, keeping in mind the reasons for inclusion or exclusion. This document ensured transparency and allowed others to analyze the rigor of the review procedure. Before the formal screening process, a preliminary stage of literary works reviews was conducted to refine the understanding of the inclusion and exclusion criteria, which facilitated consistency in the screening process.

2.6 Critical Appraisal

In carrying out a critical appraisal of short articles included in a systematic review, the Critical Appraisal Skills Program (CASP) tools were used (Appendix A) (CASP, 2021). The research began by working with the appropriate CASP tools for specific research types. CASP gives a variety of lists tailored to different research styles. Relying on the research design of the write-ups consisting of the systematic review, the researcher picked the corresponding CASP tool (RCT or Cohort CASP). The researcher systematically used the criteria laid out in the selected CASP tool to evaluate each study critically. The criteria cover different elements such as study design, approach, individual selection, data collection, evaluation, and interpretation of results.

The researcher recorded the findings of the critical appraisal for each post, indicating strengths and weaknesses based on the CASP criteria. This documentation added to the openness of the systematic review and enabled visitors to understand the quality of the included studies. The results of the CASP critical appraisal were incorporated into the synthesis of the systematic review. Researches with greater methodological high quality were provided extra weight in the total analysis, while limitations of lower-quality research studies were taken into consideration in the analysis of results.

The CASP checklist includes a collection of targeted concerns that guide the customer through the important appraisal process. These inquiries usually cover three aspects. The study's findings are assessed concerning validity by figuring out if they are credible and reliable. This involves evaluating the study style, methodology, data collection, and analysis. The results are evaluated by

understanding what the study discovered, including the magnitude and value of the results. Ultimately, relevance is analyzed by determining the applicability of the study's findings to the specific context or populace of rate of interest. By enabling a strenuous appraisal of research, CASP instruments support the principles of evidence-based practice. They help make certain that choices, plans, and techniques are notified by the ideal readily available evidence. The use of CASP checklists motivates vital reasoning and skepticism, which is important for analyzing research findings properly and efficiently. Figure 1 shows the Prisma flow diagram of this study.

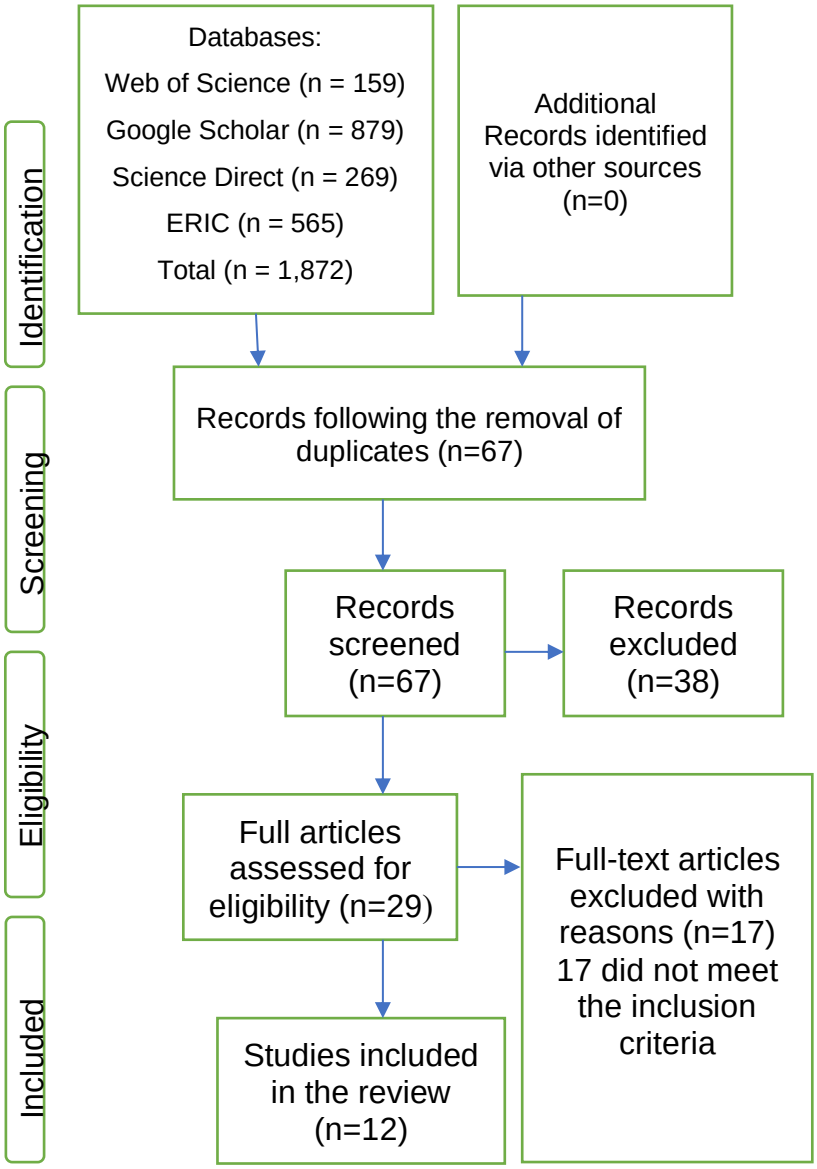

Figure 1. PRISMA Flow Diagram

2.7 Data Analysis

The data analysis for the systematic review was conducted by utilizing a thematic analysis and a narrative evaluation. The researcher started data analysis by becoming aware of the data collected from the included research, which entailed reviewing the findings, results, and pertinent information about the use of GIS technology in informal settlements. The researcher utilized a coding process to recognize crucial ideas, patterns, and motifs within the data. This involved systematically classifying information related to GIS applications, their influence on informal settlements, the functionality of this technology, its application in practice and reported results.

A coding plan was created based on the emerging themes. Coding was conducted manually with the codes relating to social effects, infrastructure improvement, settlement involvement, GIS use, and improvement of informal settlements. After coding was complete, the researcher developed the coded data to determine overarching motifs and patterns, which involved checking relationships between different themes and subthemes, which allowed the detect how GIS interventions are implemented to influence informal settlements. The themes were tuned with an iterative procedure of revisiting the coded data, contrasting findings, and changing the thematic framework as needed. This step ensured that the themes were properly recorded and revolved around the topic of GIS performance in informal settlements.

The researcher translated the significance and relevance of the determined styles in the context of the systematic review's goals. The synthesized findings were integrated into the general narrative of the review, offering a detailed understanding of the performance of GIS in informal settlement improvement. The final action included reporting the thematic findings clearly and transparently within the organized evaluation. This consisted of presenting the main themes and subthemes, sustaining proof from the included research, and discussing the implications for a plan or more research. For the meta-analysis, the statistical tools were used to analyze data. In this case, since the data retrieved from 12 studies was not vast, SPSS and Microsoft Excel were utilized

to develop the Risk Ratio analysis and conduct the descriptive and inferential statistics analyses.

2.8 Ethical Implications

When evaluating the included studies, compliance with the ethical code of conduct was included in the quality evaluation. All 12 studies included consent from participants (if human subjects were involved). The review was carried out with attention to representation and inclusivity. Thus, all studies included in a systematic review treated informal communities under investigation with respect and transparency. For instance, perspectives of informal settlers were included in the reviewed studies, their privacy was sustained, and neutral or culturally appropriate language was used. Ensuring this ethical information helped avoid reinforcing existing inequalities in informal settlements. It is critical to mention that this research did not have any partnerships with GIS technology providers, governmental organizations, or other entities that might impact the objectivity of this review.

3. RESULTS

3.1 Systematic Review of Individual Studies

Study	Abebe et al. (2019)
Setting	Jimma, Ethiopia
Aim	To determine the effectiveness of GIS on informal settlement detection and growth over time
Findings	GIS is effective in detecting slum growth over time
Effect	r = 0.175; p≤ .001; 12% growth

Table 4. Summary of Individual Study 1

Abebe et al. (2019) conducted a case study in an informal settlement located in Jimma City, Southwestern Ethiopia, using GIS and remote sensing technology, (Table 4). The primary goal of this study was to detect how effective GIS and remote sensing are in detecting the growth of informal settlements over time by analyzing the slum's growth over 20 years. A 12% growth of the settlement was observed over time (from 1997 to 2017) when the land cover increased from 29% to 41% in the territory around Jima City. Secondary outcomes showed that the growth of the informal settlement was

affected by informality (40%), lack of awareness (22%), weak land policy (17%), gaps in law, and corruption (10% each).

Study	Namvari et al. (2023)
Setting	Tehran, Iran
Aim	To determine the effectiveness of GIS in spatial identifying informal settlements by using a different function
Findings	GIS is overall effective in detecting informal settlements
Effect	r = 0.168; p≤ .000; 85% correct

Table 5. Summary of Individual Study 2

Namvari et al. (2023) conducted a study in Tehran, Iran by analyzing several informal settlements in the city with the help of GIS technology. (Table 5). The study determined that multiple GIS functions such as availability of fire stations (28%), width of alleys (23%), mean depth (38%), integration (28%), and connectivity (16%) had an overall low error percentage, which indicated the effectiveness of GIS technology in detecting informal settlements. However, it was detected that the immediate indication of growing neighborhoods in informal settlements is challenging to detect with the help of GIS. Secondary outcomes reported by the study showed that the residents in informal settlements lacked mobility and access to formal parts of the city as a result of poor infrastructure and congested roads.

Study	Arif et al. (2022)
Setting	Lahore, Pakistan
Aim	To determine the effectiveness of GIS in exploring the urban morphology in informal settlements
Findings	GIS is effective in exploring morphology in informal settlements
Effect	r = 0.154; p≤ .003

Table 6. Summary of Individual Study 3

Arif et al. (2022) explored three informal settlements (Zia, Hope, and Shamspura Colonies) located in Lahore, Pakistan, to analyze the effectiveness of GIS in exploring their urban morphology, (Table 6). The overall findings revealed the heterogeneity in the urban morphology of informal settlements regarding building density, land-use diversity, connectivity, use of space, and

quality of infrastructure. The findings showed that the informal settlements differed in terms of infrastructure (one of them had access to a railway) and connectivity (two had satisfactory connectivity), while all three of them were densely built and populated, and the use of space was scarce.

Study	Drummond et al. (2023)
Setting	Kibera, Kenya
Aim	To determine the effectiveness of GIS in detecting accessibility in informal settlements during the COVID-19 pandemic
Findings	GIS is effective in determining accessibility in informal settlements
Effect	r = 0.136; p ≤ .000; 93% accessibility

Table 7. Summary of Individual Study 4

Drummond et al. (2023) performed a study in Kibera, Kenya, detecting the accessibility of the informal settlements for COVID-19 interventions and virus transmission across the population. (Table 7). The findings showed that Kibera's residents experienced a high level of accessibility during the pandemic healthcare interventions, even though the virus transmission was rapid as a result of the high population density and large number of residents in this settlement. The effectiveness of GIS technology in assessing and providing accessibility to residents was confirmed by the results of the study as well.

Study	Adedeji et al. (2022)
Setting	Akure, Nigeria
Aim	To determine the effectiveness of GIS in the detection of informal settlement development and growth over time
Findings	GIS is effective in indicating different factors triggering the development of informal settlements and their growth over time
Effect	r = 0.129; p ≤ .001; 93% accuracy

Table 8. Summary of Individual Study 5

Adedeji et al. (2022) performed a study in Akure, Nigeria, to reveal how GIS can be used to detect the development and growth of informal settlements over 33 years (Table 8). Another goal was to detect if GIS can be used to detect different factors that have driven the growth of informal settlements in Akure.

The results revealed that GIS tools can be successfully used to explore different factors affecting the development and growth of informal settlements with 93% accuracy. Secondary outcomes showed that informal settlements tend to grow as a result of complex environmental, political, institutional, and socioeconomic factors.

Study	Alrasheedi et al. (2023)
Setting	Riyadh City, Saudi Arabia
Aim	To determine the effectiveness of GIS in the detection of informal settlement development
Findings	GIS is effective in detecting the development and progress of informal settlements
Effect	r = 0.147; p ≤ .000; 94% accuracy

Table 9. Summary of Individual Study 6

Alrasheedi et al. (2023) conducted a study in four informal settlements located in Riyadh City, Saudi Arabia, to investigate the efficacy of GIS remote sensing technology in the accurate detection of these regions within the city, (Table 9). The findings showed that GIS technology was accurate in determining the object levels (buildings and accessibility), settlements (shape and density), and environments (neighborhoods and locations). The accuracy of GIS detection was 94% compared to the on-site experts measuring and imaging the objects in the informal settlements. The secondary outcomes showed that GIS technology can be used in conjunction with local knowledge to form a more complex ontology of the informal settlements in the region.

Study	Cinnamon & Noth (2023)
Setting	Cape Town, South Africa
Aim	To determine the effectiveness of GIS in determining spatiotemporal development of informal settlements
Findings	GIS is effective in detecting the development of informal settlements in terms of land use and changes
Effect	r = 0.152; p ≤ .000; 92% accuracy

Table 10. Summary of Individual Study 7

Cinnamon & Noth (2023) conducted a study in Cape Town, South Africa, by using GIS technology to detect spatiotemporal characteristics of informal settlements. GIS technology allowed for the detection of 15 informal settlements within the city limits, determining changes over time (2000-2020) in terms of the land built-up. (Table 10). The study also determined a stable and rapid growth of informal settlements in the city over the five years (from 2015 to 2020) due to the more intense urbanization of the region.

Study	Cutini et al. (2019)
Setting	Manila, Philippines
Aim	To determine the effectiveness of GIS in conducting spatial analysis of informal settlements over time
Findings	GIS is effective in performing spatial analysis of informal settlements over time
Effect	r = 0.163; p ≤ .001; 91% accuracy

Table 11. Summary of Individual Study 8

Cutini et al. (2019) developed a preliminary analysis of the GIS technology application in analyzing spatial characteristics of an informal settlement, BaSECo, located in Manila, Philippines. GIS technology allowed the researchers to detect a major growth (from 2001 to 2017) of BaSECo over time with increasing population density, changes in urban structure, and integration within this settlement. (Table 11). The secondary outcomes determined in this slum included the deterioration of infrastructure, unsanitary conditions, and an increase in population.

Study	Pinto et al. (2021)
Setting	Manila, Philippines
Aim	To determine the effectiveness of GIS in determining the urban structure in informal settlements
Findings	GIS proved to be effective in detecting urban structure in informal settlements
Effect	r = 0.142; p ≤ .000; 90% accuracy

Table 12. Summary of Individual Study 9

Pinto et al. (2021) also conducted a study in the BaSECo slum located in Manila, Philippines, by using GIS and performing comprehensive morphological analysis to explore the urban structure within the region. (Table 12). This was the only study introducing the concept of autopoietic (self-developing, self-reproducing) urban structure in the context of informal settlement. The results showed that GIS works effectively in distinguishing among different urban structures in the slum by showing the locations of network squatters, linear squatters, terraced units, public buildings, and closed public spaces. The secondary outcomes reported by this study showed that autopoietic urban structures, like informal settlements, have the potential for self-development and growth under socioeconomic pressure.

Study	Gevaert et al. (2020)
Setting	Kigali, Rwanda
Aim	To determine the effectiveness of GIS and UAVs in determining household upgrading in informal settlements
Findings	GIS and UAVs were effective in determining the aspects of household upgrading in informal settlements
Effect	$r = 0.167$; $p \leq .000$; 95% accuracy

Table 13. Summary of Individual Study 10

Gevaert et al. (2020) performed a study by evaluating the combined effects of GIS and unmanned aerial vehicle (UAV) technologies in exploring household upgrading in Kigali, Rwanda. (Table 13) The results showed the effectiveness of the combined technology in detecting the roof upgrading, terrain use by the inhabitants, growth of vegetation, distinguishment of new and old buildings, and creation of new open space. Also, it was determined that GIS and UAVs can detect the changes in households within the informal settlements automatically if the professionals are interested in analyzing the changes over time. Gram-Hansen et al. (2019) combined the benefits of GIS and machine learning to detect their effectiveness in mapping informal settlements in six countries. The effectiveness of the combination of GIS and machine learning was successful, as it provided a more accurate representation of buildings and terrain in the informal settlements by proposing wider contextual information

for the professionals and the possibility to collect data that will show a difference over time in settlements. (Table 14)

Study	Gram-Hansen et al. (2019)
Setting	Nairobi and Kibera, Kenya; Cape Town, South Africa; El Daien and Al Geneina, Sudan; Makoko, Nigeria; Madelin, Columbia; Mumbai, India.
Aim	To determine the effectiveness of GIS and machine learning in mapping informal settlements
Findings	GIS and machine learning were effective in mapping informal settlements across multiple settlements
Effect	$r = 0.174$; $p \leq .004$; 93% accuracy

Table 14. Summary of Individual Study 11

Gram-Hansen et al. (2019) combined the benefits of GIS and machine learning to detect their effectiveness in mapping informal settlements in six countries. The effectiveness of the combination of GIS and machine learning was successful, as it provided a more accurate representation of buildings and terrain in the informal settlements by proposing wider contextual information for the professionals and the possibility to collect data that will show a difference over time in settlements. (Table 14)

Study	John-Hsa et al. (2021)
Setting	Enugu City, Nigeria
Aim	To determine the effectiveness of GIS in investigating the spatial dynamics of informal settlements over time
Findings	GIS proved to be effective in determining the spatial dynamics of informal settlements over time
Effect	$r = 0.151$; $p \leq .000$; 91% accuracy

Table 15. Summary of Individual Study 12

John-Hsa et al. (2021) performed research in Enugu City, Nigeria, by using GIS technology and seeking to explore the spatial dynamics of informal settlements that have occurred over time (from 2003 to 2017). The findings showed that GIS was effective in determining changes in land use, building

density, and growth of the informal settlements in the city. The secondary outcomes reported by this study pointed to the gaps in the land use policies, poor urban planning, and rapid population increase.

3.2 Thematic Analysis

Table 16 shows the Thematic Analysis and the themes retrieved during the systematic review. Six themes and 13 subthemes with different sources focusing on different aspects of GIS and its application in informal settlement improvement were identified.

3.3 Synthesis of Thematic Analysis: Answering the Research Questions

1. How can GIS technologies contribute to the improvement of informal settlements?

As shown in research by Abebe et al. (2019) and Adedeji et al. (2022), GIS can successfully spot and keep track of the development and growth of informal settlements in time. This detail is crucial for city organizers and policymakers to recognize the characteristics of settlement development and to plan for required infrastructural and service growth. The diversification in urban morphology, consisting of building density, land-use variety, and facilities of high quality (Arif et al. 2022), can be assessed using GIS. This helps recognize the spatial distribution of different functions within settlements, enabling targeted enhancements in locations like water, sanitation, roads, and public rooms.

GIS can aid in structuring the framework in such a way that is sensitive to the existing format and demands of informal settlements. For example, the research by Drummond et al. (2023) and Namvari et al. (2023) highlights the value of understanding the ease of access and mobility within these settlements. GIS can help develop roadways, pathways, and public transport paths to improve connections. As suggested by Adedeji et al. (2022), GIS can be utilized to evaluate the intricate interplay of environmental, political, institutional, and socioeconomic factors influencing the growth and development of shanty towns. This understanding can guide interventions that are not simply infrastructural but additionally socio-economic, such as community advancement programs, education and learning, and health services. and urban planning issues recognized in research studies like that of John-Hsa et al. (2021) can result in more long-lasting and comprehensive city growth.

Themes	Subthemes	Examples
Effectiveness of GIS and Remote Sensing in Detecting Informal Settlements	Growth Detection	Studies (Abebe et al. 2019; Adedeji et al. 2022) highlighted GIS's ability to detect the growth of informal settlements over time.
	Spatial Characteristics Analysis	Cutini et al. (2019) and Pinto et al. (2021) used GIS to analyze spatial characteristics and urban structure within informal settlements.
	Challenges in Immediate Detection	Namvari et al. (2023) noted difficulties in immediately detecting growing communities in informal settlements using GIS.
Urban Morphology and Infrastructure	Heterogeneity and Density	Arif et al. (2022) discussed the heterogeneity in urban morphology, including building density and land-use diversity.
	Infrastructure and Accessibility	Drummond et al. (2023) focused on accessibility during COVID-19 interventions, while Namvari et al. (2023) reported on poor infrastructure and congested roads affecting mobility.
Socioeconomic and Environmental Factors Influencing Growth	Complex Influences	Adedeji et al. (2022) revealed complex environmental, political, institutional, and socioeconomic factors driving slum growth.
	Policy and Corruption Issues	Abebe et al. (2019) identified factors like weak land policy and corruption influencing settlement growth.
Technology Integration and Advancements	GIS with Other Technologies	Gevaert et al. (2020) and Gram-Hansen et al. (2019) demonstrated the integration of GIS with UAV and machine learning for enhanced analysis.
	Accuracy and Object Level Detection	Alrasheedi et al. (2023) discussed the accuracy of GIS in detecting object levels and environmental aspects of settlements.
Challenges and Limitations in Urban Planning	Policy Gaps and Urban Planning Issues	John-Hsa et al. (2021) pointed to gaps in land use policies and challenges in urban planning.
	Autopoietic Urban Structures	Pinto et al. (2021) introduced the concept of self-developing urban structures under socioeconomic pressure.
Secondary Outcomes and Associated Challenges	Infrastructure Deterioration and Unsanitary Conditions	Cutini et al. (2019) noted the deterioration of infrastructure and increase in population density.
	Healthcare Accessibility and Virus Transmission	Drummond et al. (2023) reported on the challenges of healthcare interventions and rapid virus transmission due to high population density.

Table 16. Thematic Analysis

The understanding obtained from GIS analysis can educate the growth of more efficient plans and urban planning methods. As an example, addressing policy voids

In circumstances like the COVID-19 pandemic, as talked about in Drummond et al. (2023), GIS can be crucial in mapping the availability of healthcare services and intending emergency feedback in densely inhabited informal settlements. Incorporating neighborhood knowledge, as recommended by Alrasheedi et al. (2023), GIS can be used as a device for community involvement. Citizens can be associated with mapping their communities, which can equip them and make sure that advanced jobs fulfill their actual demands. The capacity of GIS to give a comprehensive analysis of present conditions and patterns allows for better future planning. This includes planning for populace rises, ecological changes, and ensuring sustainable growth.

i. To what extent do existing GIS technologies contribute to the identification and detection of informal settlements, exploration of their morphology, considerations of urban design, mapping techniques, and analysis of land cover dynamics?

The thematic analysis of different studies emphasizes the substantial level to which existing Geographic Information System (GIS) technologies contribute to the identification and detection of informal settlements, exploration of their morphology, considerations of urban style, mapping methods, and analysis of land cover dynamics. Research like those by Abebe et al. (2019) and Adedeji et al. (2022) show GIS's capacity to precisely find and keep track of the development of informal settlements over time. The high accuracy in recognizing adjustments in land cover and settlement expansion is kept explicitly in mind. As highlighted by Namvari et al. (2023), GIS technology faces some challenges in promptly finding swiftly expanding areas within informal settlements.

Arif et al. (2022) reveal that GIS can adequately disclose the heterogeneity in city morphology, consisting of aspects like structure density, land-use variety, and framework quality. The technology enables the expedition of different morphological features, recognizing the spatial company, and identifying distinct features of different settlements. The understandings supplied by GIS can lead to the style of framework and solutions tailored to the unique requirements of informal settlements. Drummond et al. (2023) and Namvari et al. (2023) indicate the value of creating accessibility and wheelchairs. By supplying thorough spatial info, GIS assists in producing educated urban design policies that can attend to the particular challenges of informal settlements.

Research like those by Gevaert et al. (2020) and Gram-Hansen et al. (2019) highlight the sophisticated mapping abilities of GIS, particularly when incorporated with other

technologies like UAVs and machine learning. GIS enables dynamic mapping that adapts to the facility and often transforms the nature of informal settlements, providing contextual information essential for efficient planning and intervention. The capacity of GIS to examine land cover characteristics over time, as displayed in research by Abebe et al. (2019) and Cinnamon & Noth (2023), is crucial for understanding just how informal settlements advance and broaden. This technology likewise assists in assessing the ecological impact of informal settlements, consisting of changes in vegetation, surface use, and general environmental footprint.

ii. What are the best practices and key challenges associated with GIS applications in informal settlements?

Frequently upgrading GIS databases with existing details is vital for exact surveillance and analysis, as displayed in research studies like Abebe et al. (2019) and Adedeji et al. (2022). This makes sure that changes in informal settlements are recorded promptly. Integrating GIS with other technologies, such as UAVs (Gevaert et al. 2020) and artificial intelligence (Gram-Hansen et al. 2019), improves its capabilities, providing more detailed and detailed data. Involving regional citizens in information collection and decision-making procedures, as recommended by Alrasheedi et al. (2023), makes sure that the information is accurate and that the interventions are relevant and accepted by the community. Using GIS to plan and enhance facilities and availability within informal settlements (Drummond et al., 2023; Namvari et al., 2023) is a crucial application dealing with critical requirements for flexibility and service shipment. GIS findings should educate urban planning and policy-making, addressing concerns such as land use, housing, and environmental management, as indicated in studies by John-Hsa et al. (2021). Acknowledging and incorporating the particular socioeconomic and cultural facets of informal settlements into GIS analysis and succeeding interventions.

The vibrant and often unpredictable growth of informal settlements, as noted by Namvari et al. (2023), poses a difficulty for timely and precise GIS mapping and analysis. Making sure of the availability of premium, updated information can be complex, especially in locations with restricted resources or accessibility constraints. The diverse and intricate city morphology of informal settlements (Arif et al. 2022) can be challenging to catch and stand for precisely in GIS systems. Integrating informal settlements into the broader urban context, both in terms of physical facilities and plans, is a complicated task that calls for mindful consideration and preparation.

Minimal resources and the requirement for technical expertise in GIS can be obstacles, specifically in resource-constrained setups. Ensuring that the use of GIS technology respects the personal privacy and rights of locals in informal settlements is vital. Solutions originating from GIS analysis should be versatile to neighborhood conditions and needs, preventing a one-size-fits-all technique.

iii. How can the best practices of GIS applications be adapted to suit the unique characteristics of specific local conditions of informal settlements?

Adapting the very best practices of GIS applications to suit the one-of-a-kind qualities of specific local conditions in informal settlements includes a complex strategy that takes into consideration certain social, social, ecological, and infrastructural aspects of these areas. It is advised to use GIS to keep track of settlement growth over expanded periods. The 12% development observed can educate long-term urban planning and source allotment (Abebe et al., 2019). Adedeji et al. (2022) recommend leveraging GIS to recognize the multifaceted motorists (environmental, political, institutional, socioeconomic) of shanty town development, enabling targeted interventions. It is feasible to concentrate on neighborhood facility needs, such as fire stations, street widths, and connection, by utilizing GIS to develop a framework that addresses neighborhood challenges like flexibility and gain access (Namvari et al., 2023; Arif et al., 2022).

Drummond et al. (2023) suggested utilizing GIS to enhance ease of access, particularly in densely booming areas, for reliable shipment of wellness and emergency solutions. It is vital to integrate regional knowledge with GIS findings to establish a nuanced understanding of informal settlements for more efficient urban planning (Alrasheedi et al., 2023). It is suggested to make use of GIS to track spatiotemporal adjustments in settlements, helping in the anticipation and monitoring of rapid urbanization (Cinnamon & Noth, 2023). It is feasible to incorporate GIS with UAV technologies for thorough mapping and analysis of micro-level modifications, such as house upgrades (Gevaert et al., 2020). It is possible to recommend GIS with artificial intelligence for more exact mapping and contextual analysis, allowing for a deeper understanding of settlement characteristics (Gram-Hansen et al., 2019). John-Hsa et al. (2021) recommended using GIS data to attend to spaces in land use policies and urban planning. The insights can direct the growth of more efficient policies and city growth methods. Recognizing the possibility for self-development in informal settlements could be efficient and using GIS to acknowledge and sustain

autopoietic (self-developing) urban frameworks, helping with natural development under socioeconomic stress (Pinto et al., 2021).

iv. How do governance structures, financial resources, and community participation influence the effectiveness of GIS-based interventions in improving informal settlements?

Strong governance structures can assist in the efficient implementation of plans and guidelines informed by GIS information. For instance, the findings from John-Hsa et al. (2021) in Enugu City, Nigeria, point out the gaps in land use policies and urban planning. Effective governance can aid in bridging these spaces by adopting GIS-informed strategies. Reliable governance makes sure to work with efforts amongst different stakeholders, including federal government firms, NGOs, and community teams. This is crucial for the thorough preparation and lasting development of informal settlements. Governance structures are accountable for allocating essential resources towards GIS-based jobs. Studies like Abebe et al. (2019) in Jimma City, Ethiopia, show the need for sustained tracking of informal settlement development, which requires continuous assistance and resources from governance entities. Financial resources determine the accessibility and maintenance of GIS technology. Advanced applications, such as the combination of GIS with UAVs noted in Gevaert et al. (2020) in Kigali, Rwanda, call for considerable financial investment. Training and capability building, as seen in the combination of regional expertise in Riyadh City (Alrasheedi et al., 2023), requires financial backing to be reliable. This consists of training neighborhood personnel and community members in GIS technology. Constant financial support is crucial for the sustainability of GIS-based treatments. Without adequate financing, tactical jobs may also fall short of delivering long-term benefits.

As demonstrated in the research by Alrasheedi et al. (2023), incorporating neighborhood understanding can substantially enhance the precision and relevance of GIS data. Community participants usually have insights into the subtleties of their home that outside onlookers may miss. Engaging the community in GIS-based tasks promotes a sense of ownership and empowerment. When homeowners join mapping and preparation processes, as recommended in the study by Pinto et al. (2021) in Manila, Philippines, they are more likely to sustain the enhancements. Community input makes sure that interventions are tailored to the actual requirements and preferences of the citizens, increasing the probability of successful implementation.

This is especially crucial in resolving intricate challenges such as flexibility and accessibility in densely populated settlements like Kibera, Kenya (Drummond et al., 2023).

3.4 Meta-Analysis

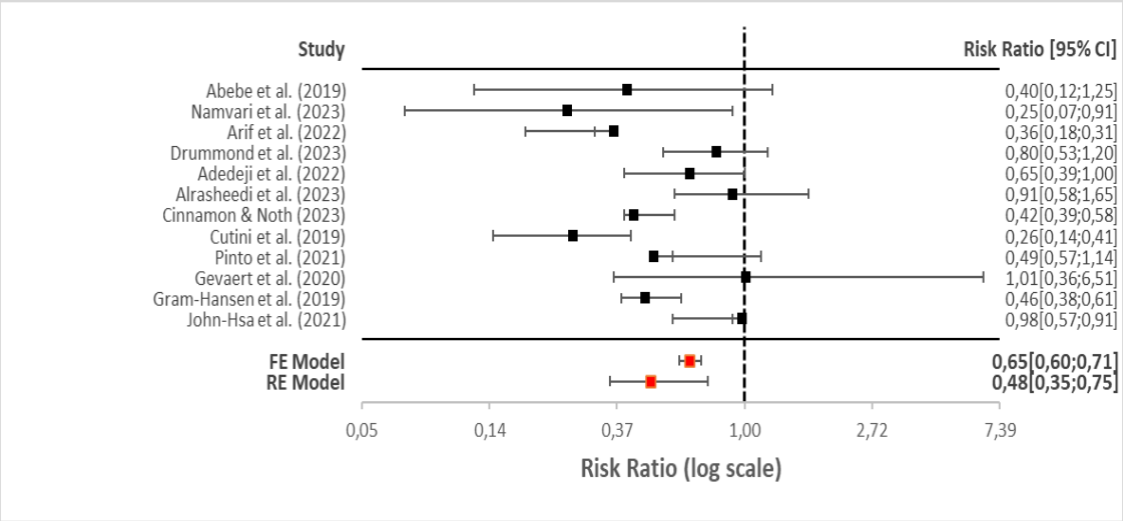

Figure 2. Risk Ratio Analysis

Figure 2 shows the risk ratio analysis revealing the statistical significance for all studies included in the analysis and the precision of the statistical significance of the data across the included sample. No significant heterogeneity was observed in the study, which means that the included articles limited variations of the effect sizes, which emphasized the overall significance across the sample of articles. Risk Ratio is a measure used in meta-analysis to contrast the risk of a specific event happening in two different teams or datasets. Risk Ratio was calculated as the proportion of the possibility of an event occurring in the study team or dataset. The formula used in Risk Ratio (RR) analysis is the following: $RR = \frac{Risk\ in\ main\ dataset}{Risk\ in\ secondary\ dataset}$ If RR is 1, it Indicates no distinction in danger between both datasets. If RR > 1, it suggests a greater danger in the general dataset compared to the additional dataset. This is commonly a measure of the unsafe impact of the therapy. If RR < 1, it suggests a lower danger general dataset, recommending a protective effect of the executed treatment (GIS innovation). In meta-analysis, RR is utilized to combine the results from numerous studies, providing a single procedure of the effect size throughout all studies. It is vital to examine the diversification among studies (i.e., just how different the studies remain regarding individuals, treatments, and end results) when analyzing

the pooled RR. Meta-analyses commonly make use of woodland stories to visually represent the RR from each study and the general pooled RR. Table 17 shows the Mean Effect Size; additional information can be found in Appendix 3.

Study	**M**	***p***	**SE**	**95% CI**
Abebe et al. (2019)	0.17	p ≤ .001	0.08	0,40[0,12;1,25]
Namvari et al. (2023)	0.19	p ≤ .000	0.04	0,25[0,07;0,91]
Arif et al. (2022)	0.21	p ≤ .003	0.07	0,36[0,18;0,31]
Drummond et al. (2023)	0.14	p ≤ .000	0.05	0,80[0,53;1,20]
Adedeji et al. (2022)	0.16	p ≤ .001	0.06	0,65[0,39;1,00]
Alrasheedi et al. (2023)	0.54	p ≤ .000	0.07	0,91[0,58;1,65]
Cinnamon & Noth (2023)	0.17	p ≤ .000	0.01	0,42[0,39;0,58]
Cutini et al. (2019)	0.19	p ≤ .001	0.14	0,26[0,14;0,41]
Pinto et al. (2021)	0.26	p ≤ .000	0.06	0,49[0,57;1,14]
Gevaert et al. (2020)	0.17	p ≤ .000	0.07	1,01[0,36;6,51]
Gram-Hansen et al. (2019)	0.18	p ≤ .004	0.04	0,46[0,38;0,61]
John-Hsa et al. (2021)	0.41	p ≤ .000	0.08	0,98[0,57;0,91]

Table 17. Mean Effect Size

The results showed that the effect of GIS technology on informal settings is significant and positive, pointing to the possibility of using GIS technology in the efforts to improve informal settlements.

4. DISCUSSION

4.1 Summary of Main Findings

This systematic review and meta-analysis aimed to determine the effectiveness of GIS technology in improving informal settlements. The results showed that all included studies admitted the effectiveness of GIS or its combination with other technologies (machine learning, UAVs, and surveying) to improve informal settlements. The effect of GIS is indirect, as it allows professionals to use imaging and analytical tools embedded within it to analyze the changes over time in informal settlements, analyze their progress or problem emergence, and provide the basis for policy and legislation improvement. Several themes emerged during the analysis.

Particularly, themes emerged concerning how GIS technology promotes or prevents community involvement and engagement in the decision-making processes associated with the improvement of informal settlements (Figure 3; Figure 4).

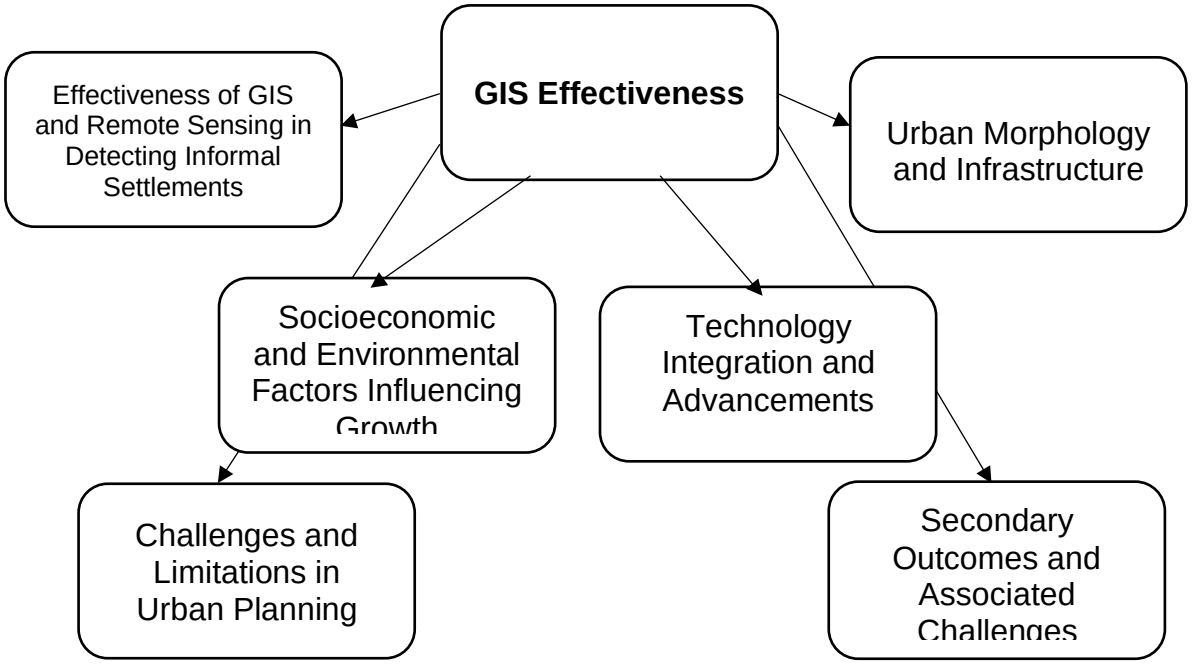

Figure 3. Themes

The analysis acknowledged themes related to the function of GIS technology in spatial planning and infrastructure development within informal settlements, including how it affects housing, transportation, and hygiene. Themes connected to the ease of access and quality of GIS data were identified, discovering exactly how the schedule and precision of data influence decision-making processes in the context of informal settlement improvements. The thematic analysis uncovered themes connected to the empowerment of communities and regional stakeholders via using of GIS technology, including efforts that develop capacity for effective utilization. Themes connected to the socioeconomic effect of GIS interventions were explored, discovering exactly how GIS technology adds to financial opportunities, income, and the overall health of citizens in informal settlements.

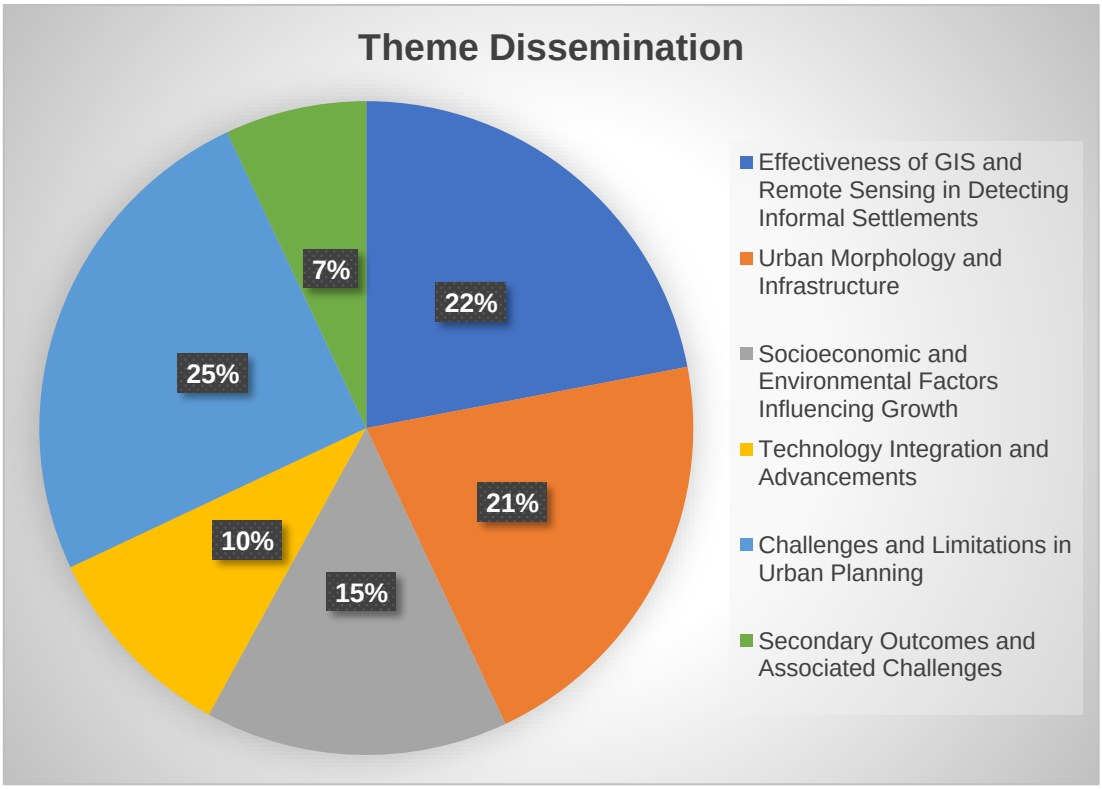

Figure 4. Theme Dissemination

4.2 Strengths and Limitations

Systematic reviews and meta-analyses are powerful research methods that can offer a thorough and strenuous assessment of the existing proof on a particular topic. When put on the effectiveness of GIS technology in improving informal settlements, these techniques supply numerous strengths. This systematic review included a comprehensive and systematic search of the literature by ensuring that all relevant studies on the performance of GIS technology in informal settlements were included. Meta-analysis took the synthesis a step further by statistically integrating data from several studies, as this strategy provided a more objective summary of the total result of GIS technology on informal settlements, enhancing the integrity of the findings.

Despite multiple strengths, it is critical to state several limitations. Variabilities across research studies, such as differences in research design, populations, treatments, and result steps, could have introduced heterogeneity. This diversification might restrict the relevance of incorporating studies, and subgroup analyses may be required to explore resources of variation. There is a danger that studies with positive results are more probable to be published than those with negative or null results. This research bias can result in an overestimation of the true effect of GIS technology

in informal settlements. Some studies did not provide adequate detail in their publications, making it difficult to assess their methodology and results accurately. This insufficient coverage could influence the ability to generate proper conclusions.

4.3 Implications for Policy and Practice

The implications for practice generated from this systematic review and meta-analysis on the performance of GIS technology in the improvement of informal settlements have multiple implications for numerous stakeholders, including policymakers, urban coordinators, GIS professionals, and community members. Particularly, the review highlighted details of GIS interventions that have been continually linked with positive results in informal settlements. This information ought to guide professionals in selecting and carrying out reliable strategies. Recognizing the diversity of informal settlements, professionals should consider tailoring GIS solutions to specific contexts, as this research determined contextual aspects influencing the effectiveness of GIS technology, indicating a more nuanced strategy for application. The implications for practice consist of recommendations for including area participants in the planning and execution of GIS treatments, improving the relevance and sustainability of projects, and addressing the unique requirements of the community population.

The implications for practice included identifying that the area of GIS technology is dynamic. Practitioners ought to be open to continual improvement, adjustment, and the combination of arising technologies to attend to the progressing needs of informal settlements. Practitioners must prioritize the circulation of knowledge generated from this systematic review. This includes sharing findings with appropriate stakeholders through reports, workshops, meetings, and other channels to make the most of the effect of the research. This review highlighted the value of guaranteeing that GIS interventions are inclusive and benefit all members of the community. Initiatives need to be made to minimize prospective differences in gaining access to and use of housing, infrastructure, and standard products among different group groups.

Policymakers must consider the evidence from the review to invest strategically in GIS technology for informal settlement improvement, including assigning resources for the purchase of GIS tools, infrastructure development, and ability structure. The findings highlighted the importance of combining GIS technology with urban preparation policies as policymakers develop guidelines that urge using of GIS for spatial analysis, infrastructure planning, and the implementation of targeted interventions in informal settlements.

4.4 Implications for Future Research

The implications for future research in the systematic review and meta-analysis on the effectiveness of GIS technology in improving informal settlements can guide researchers in resolving gaps, refining methodologies, and progressing the understanding of this research topic. Future research should discover and clarify the sources of diversification observed in the meta-analysis. Monitoring changes in research design, populations, and results can supply insights into the elements affecting the effectiveness of GIS technology in different contexts. Conducting longitudinal research studies can add to a better understanding of the lasting influence of GIS treatments on informal settlements. This method can capture adjustments with time and assess the sustainability of positive results. Researchers should delve deeper into the impact of contextual factors on the performance of GIS technology. This may consist of looking at the role of cultural, socioeconomic, and geographical elements in shaping the outcomes of GIS interventions in different informal settlements.

5. CONCLUSIONS

Overall, GIS technologies offer an effective tool for understanding and improving informal settlements by providing comprehensive spatial analysis, helping with informed decision-making, and making reliable planning and plan development possible. Existing GIS technologies play a crucial role in the recognition and analysis of informal settlements. They offer high accuracy in discovering and monitoring these areas, provide in-depth insights into city morphology and design considerations, allow innovative mapping and analysis of land cover characteristics, and support educated decision-making in urban planning and plan advancement. Nonetheless, it is important to consider the limitations and challenges, especially in the detection of rapidly transforming locations within informal settlements. While GIS applications provide considerable advantages for improving informal settlements, they also present obstacles that need to be considered by improving the methodology of its implementation. These consist of regular data updates, innovation combination, community involvement, focus on infrastructure and access, policy change, and sensitivity to regional contexts. Addressing challenges like quick changes, data quality, urban morphology, source limitations, and ethical factors, it is important to establish a reliable use of GIS in these settings. By customizing these methods to the particular contexts of informal settlements, GIS applications can be more efficient in

addressing the special challenges in these areas. This technique ensures that the solutions are not just practically but also socially and culturally appropriate, sustainable, and lined up with the requirements of the local community.

Considering all issues, the methods of GIS applications should be tailored to show the specific requirements, challenges, and attributes of each informal settlement. This includes mindful surveillance of development, attending to community facilities and connection concerns, using advanced modern technology integrations, and informing plan and city style based upon comprehensive data analysis. The ultimate objective is to create more livable, sustainable, and integrated urban atmospheres that acknowledge and support the unique dynamics of informal settlements. Governance frameworks, funds, and community engagement are interconnected aspects that substantially affect the success of GIS-based treatments in informal settlements. Efficient governance supplies the required framework and control; financial resources guarantee access to and maintenance of innovation, and community participation assurances the significance and sustainability of the treatments. A thorough approach that balances these aspects is vital to enhancing informal settlements properly utilizing GIS technologies.

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ANNEXES

Annex 1 CAPS Evaluation

ITEM	1	2	3	4	5	6	7	8	9	10	11	12	TOTAL
Abebe et al. (2019)	1	1	1	1	1	1	1	1	1	1	1	0	11
Namvari et al. (2023)	1	1	1	1	1	0	1	1	1	0	1	1	10
Arif et al. (2022)	1	1	1	0	1	1	0	1	1	1	1	1	10
Drummond et al. (2023)	1	1	1	1	0	1	1	0	1	0	1	1	9
Adedeji et al. (2022)	1	1	1	1	0	1	1	1	0	1	1	1	10
Alrasheedi et al. (2023)	1	1	0	1	1	1	1	1	0	1	1	1	10
Cinnamon & Noth (2023)	1	1	1	0	1	1	1	1	1	1	1	1	11
Cutini et al. (2019	1	1	1	1	1	0	1	1	1	1	1	1	11
Pinto et al. (2021)	1	1	1	1	1	1	0	1	1	1	1	1	11
Gevaert et al. (2020)	1	1	1	0	1	1	1	1	1	1	1	1	11
Gram-Hansen et al. (2019)	1	1	1	1	1	0	1	1	1	0	1	1	10
John-Hsa et al. (2021)	1	1	1	1	0	1	1	1	1	0	1	1	10

Annex 2 Meta-Analysis Explanation

After the author conducted a search and analyzed the included studies by using CASP, a meta-analysis was performed in Excel. The author created a spreadsheet with columns for data retrieved from each study, including effect sizes and mean effect sizes. The following step was the performance of Risk Ratio (RR) by using these data. The weight of each study is typically the inverse of the variance of the effect size. Since the author retrieved standard errors, the calculation of the variance is the square of the standard error. The weight of each study was calculated by applying using the formula 1/Variance. Specifically, the weighted mean effect size represents the sum of the product of each study's effect size and weight divided by the sum of the weights. After, the SUMPRODUCT function was used to calculate the numerator and divide it by the sum of the weights.

When this part of the analysis was over, the standard error of the weighted mean effect size was performed by calculating the square root of the reciprocal of the sum of the weights. After, it was important to calculate the 95% confidence interval by implementing the formula of Weighted Mean Effect Size ± 1.96 * Standard Error. In the next cells, the author calculated the lower and upper bounds of the confidence interval. Mean, standard deviation, and significance (p) were also calculated to determine the overall impact of the technology (GIS) on the population and the settlement. Based on the analysis, the author created a forest plot in Excel's chart features to depict the effect sizes and confidence intervals of individual studies and the overall pooled estimate. The statistical data on mean, standard deviation, and significance were added to the table to visualize the data.

Annex 3 Discarded Publications

The following is the list of the 17 publications discarded because did not meet the inclusion criteria:

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