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Research Article

Integration of Remote Sensing and GIS for Urban Sprawl Monitoring in European Cities

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Abstract: Urban sprawl still poses a major problem to most European cities as it causes environmental degradation, social and economic unfairness, and inefficient land utilization. This study proposes and evaluates an extensive decision-making framework that facilitates the use of remote sensing and geographic information systems for assessment, analysis, and control of urban sprawl. Satellite data from Sentinel-2 and Landsat-8 were utilized to analyze land cover changes in six European cities, including London, Paris, Madrid, Berlin, Rome, and Athens, that occurred over a period of 23 years, specifically from 2000 to 2023. Supervised classification techniques, namely, Random Forest and Support Vector Machines, and spatial metrics including Shannon's Entropy, Patch Density, Urban Compactness Ratio, and Buffer analysis were used to assess the level of sprawl. A self-administered questionnaire was completed by 125 urban planners and policymakers to get a quantitative perspective about socio-economic forces and policy efficiency. The study established that there has been extreme urban sprawl with Rome leading at 24% and Berlin at 23%, attributed to population growth, economic development and thin urban planning standards. Furthermore, green space was also reduced by 19.7%, and air pollution rose by 11.2%. Also, an increase in traffic congestion (36%) and housing costs (28%) were other socio-economic issues. The tested decision support framework proved efficient for scenario modeling and predictive spatial analysis for sustainable urban growth. Future literature should add the application of a machine learning approach and artificial intelligence for better classification of land use and quantify the cities' sprawl.

Keywords: Urban sprawl; Population dispersion; socio-economic factors; remote sensing; GIS techniques; urban planning; European cities

Highlights:

- An integrated RS-GIS and machine learning framework to assess urban sprawl patterns across six European cities under varying urban typologies.
- Combine spatial data with expert survey responses to analyze the influence of policies, socio-economic factors, and infrastructure on urban sprawl.
- A multi-scalar analysis revealing spatial disparities, infrastructure access gaps, and planning challenges affecting urban expansion across Mediterranean and industrialized cities.
- Evidence-based insights supporting policymakers and planners in designing sustainable urban development strategies tailored to diverse European urban contexts.

1. Introduction

The phenomenon of urban sprawl remains a critical issue in city planning since it results in the deterioration of the physical environment, socio-economic justice, and utilization of the open spaces in European cities (Aleixo et al., 2024; Magidi & Ahmed, 2019; Resemini et al., 2025). It is often characterized by low-density sprawl, dispersed urbanization, and high levels of car use and dependency, which have given rise to problems of ecological vulnerability and environmental degradation (Loret et al., 2023; Shao et al., 2021). Sprawl remains a well-documented phenomenon with diverse forms and antecedents, which occur due to societal, cultural, economic, historical background, and governance differences across the European continent (Fuladlu et al., 2021; Lagarias & Sayas, 2019). It is imperative to distinguish the differences between the typical Mediterranean and Northern European (industrialized) models of cities' sprawl. The Mediterranean model, for which Greece, Italy, Spain, and parts of France are typified, is defined by a rural historic land-use legacy, irregular migration, and touristic development (Fuladlu, 2024; Lagarias & Sayas, 2019). These cities are witnessing uncontrolled sprawl, with the expansion occurring in peri-urban and coastal areas because of lax planning standards, enforcement, and informal real estate markets (Fuladlu et al., 2021; Loret et al., 2023). London, Berlin, and Paris, conversely, show a more ordered suburbanization process rooted in optimal transport facilities, industrial dispersion, and urban planning legislation (Aleixo et al., 2024; Filepné Kovács et al., 2024; Kalfas et al., 2024; Kalogiannidis et al., 2024). This contrast underscores the need to compare and disaggregate the different urban centers to understand how governance and economic systems help delineate urban sprawl across diverse European regions (Chettry, 2022; Magidi & Ahmed, 2019). However, research on the spatial spread of urbanization in Mediterranean and industrialized European cities is relatively scarce (Feng, 2009; Shao et al., 2021). While most previous research has employed single-city or national surveys, these investigations neglect regional differences and general tendencies (Costa et al., 2024; Csomós et al., 2024; Filepné Kovács et al., 2024). Moreover, Remote Sensing (RS) and Geographic Information Systems (GIS) are useful for monitoring issues within urban areas, but the utilization of these techniques to analyze the Mediterranean urban sprawl is relatively limited (Virtanen et al., 2024; Younes et al., 2023; Ziliaskopoulos & Laspidou, 2024). Previous work has mainly focused on Northern and Western European cities without exploring the sequential condition of Mediterranean cities, which are characterized by unstructured spatial growth and socio-cultural factors (Lagarias & Sayas, 2019; Magidi & Ahmed, 2019).

To fill this gap, this study applies RS, GIS, and machine learning algorithms to investigate the urban sprawl characteristics in six large European metropolitan areas, including London, Paris, Madrid, Berlin, Rome, and Athens. The characteristic of these cities is that they encompass both the Mediterranean and industrialized urban types, enabling a cross-sectional approach to analyze how cities expand under different socio-political and economic contexts (Aleixo et al., 2024; Chettry, 2022). The study's purpose is to expand on Fuladlu's (2024) hybrid approach for land-cover change estimation while using AI-assisted GIS and geo-statistics, machine learning, and survey analysis to refine the classification and quantification of urban sprawl (Costa et al., 2024; Fuladlu et al., 2021). This study implements the Decision-Support Framework, which applies spatial analysis using RS-GIS, coupled with Predictive Scenario Modelling and Participatory GIS (PGIS) in developing the Strategies and polices for sustainable AH (Filepné Kovács et al., 2024; Virtanen et al., 2024). This study benefits from valuable input provided by 125 urban planners and policymakers, offering real-world perspectives on how policies affect urban sprawl (Costa et al., 2024). To further improve the accuracy of the analysis, machine learning techniques, including Random Forest (RF) and Support Vector Machine (SVM), are applied. These methods provide a applicable and effective way to capture the structure and evolving patterns of sprawl, making the assessment more reliable and relevant for urban planning (Loret et al., 2023; Lu et al., 2022).

In recent years, the most effective tools utilized for monitoring, analysis, and management of urban sprawl are Remote Sensing (RS) and Geographic Information Systems (GIS). Concretely, RS offers a precise identification of changes in land-use patterns over time at a higher spatial resolution, which is particularly important for understanding urban growth patterns. In addition, GIS is a tool for analysis and visual presentation of spatial relationships, providing important information about the spatial patterns of urban growth (Al-Riyami, 2017; Costa et al., 2024). These technologies can make urban planning more systematic and data-driven to help policymakers develop strategies for minimizing the impacts of sprawl (Kerekes & Alexe, 2019). However, it is noteworthy that the application of RS and GIS approaches to monitor urbanization remains considerably limited once finalized in different European cities (Guo et al., 2022; Klein et al., 2024). Numerous prior studies discuss one specific city without a comprehensive approach covering regional changes (Feng, 2009). Therefore, rigorous comparative research is required to evaluate the urban sprawl trends of multiple cities and to apply spatial methods, scenario modeling, and decision support systems (Virtanen et al., 2024). The hypothesis for this research is as follows:

"The integration of Remote Sensing (RS) and Geographic Information Systems (GIS) within a decision-support framework significantly enhances urban sprawl monitoring and management in European cities, leading to improved land-use planning outcomes."

To test this hypothesis, this study maps urban sprawl in the six European cities: London, Paris, Madrid, Berlin, Rome, and Athens, employing multi-temporal RS data and GIS analysis, in addition to surveying 125 urban planners and policymakers. Moreover, the research aims to examine how ML can be incorporated into land-use classification and prediction of urbanization trends (Loret et al., 2023; Virtanen et al., 2024). As this study contributes to the existing literature on comparative urban sprawl, the findings can help policymakers make informed decisions and improve the current state of technological interventions in smart urban planning. Therefore, the results will serve to design solutions for making communities more resilient, improving land use policies, and incorporating AI technologies into the planning and management of cities' futures.

1.1 Purpose of the Study

This research endeavors to design and assess a framework to facilitate remote sensing and GIS for investigating urban sprawl in European cities. Hence, the specific objectives of this research are:

1. To evaluate the degree of urban sprawl in selected European cities based on the remote sensing data.
2. To identify the spatial patterns and factors related to urban sprawl through the GIS analysis.
3. To assess the effects of urban sprawl on the environment and socio-economic aspects of a city.
4. To develop a decision support model for urban planners that will be used to manage and minimize urban sprawl.

2. Literature Review

2.1 Remote Sensing and GIS in Urban Sprawl Monitoring

Given that RS and GIS provide systematic collection, processing, and analysis of spatial data, they have become essential tools in addressing urban sprawl (Aleixo et al., 2024; S. Zhang et al., 2025). Furthermore, these technologies help planners and policymakers to monitor the land-use changes, descriptive analysis of the impacts, and modeling the future growth of the urban landscapes (Costa et al., 2024; Yang et al., 2025). The integration of RS and GIS as applied for the analysis of the European urban environment has proven to be highly beneficial in identifying the patterns of development, especially in fragile metropolitan areas, since sprawl constitutes a major issue in European cities (Ziliaskopoulos & Laspidou, 2024). However, the added value of these technologies depends on the availability of data, technological advancement, and urban policies across different geographic locations. Cases from Europe, North and South America, and Asia show that RS and GIS can be beneficial in combating urban sprawl, while revealing variations between the continents. For example, European cities employ these technologies to assess land-use policy, whereas American cities analyze transportation networks to prevent sprawl (Guastella et al., 2019). On the other hand, China and India use AI-driven RS analysis to improve the sustainability of urban areas (Chettry, 2022; Deo et al., 2024; Lu et al., 2022). Therefore, it is necessary to explore comparative approaches in enriching the current framework for monitoring urban sprawl across European cities.

Examining the global cases of RS and GIS applications shows that the approach diverges according to the distinctive urban problems and governance contexts. A study conducted in Paris, London, and Madrid by Aleixo et al. (2024) has compared the remote sensing-based urban growth modeling, discovering that green spaces were shrinking and air pollution was steadily rising. The study adopted GIS-based zoning policies on the idea of an urban growth boundary that has been used in Scandinavian countries. On the other hand, research conducted in the United States offers a different revelation. Suburbanization in New York and Los Angeles has been investigated by Feng (2009) where high-resolution RS imagery was used. The research also compared New York as a city that hardly underwent horizontal growth due to zoning regulations, while Los Angeles sprawled horizontally because of automobile-oriented development and poor land-use planning. This was further taken to Toronto in North America by Filepné Kovács et al. (2024) showed how GIS-based transport modeling reduces traffic congestion caused by sprawl.

Moreover, in South America, Guastella et al. (2019) studied the urban expansion of São Paulo and further showed that monitoring peri-urban development through remote sensing enhances land-use planning. Studies in Europe have established linkages between sprawl, economic, and regulatory systems. However, in the case of São Paulo, informal settlements and weak governance structures are the leading factors influencing the sprawl. Research conducted in Asia has also applied RS and GIS to forecast long-term future patterns of urbanization. Chettry (2022) aimed to evaluate the spatial characteristics of Indian urbanization, employing the multi-temporal data from 1991 to 2021 to explore the impact of economic liberalization on suburbs. Likewise, Li et al. (2023) applied the machine learning method into RS analysis for urban sprawl prediction in China, leading to higher land-use predictability.

Incorporation of ML in remote sensing and GIS analysis has greatly improved the monitoring of urban sprawl and provided additional useful information for land-use planning (Costa et al., 2024). Based on a coastal megacity in China, Lu et al. (2022) adopted ML-driven scenario-based modeling and applied AI-powered RS algorithms, which were 23% more accurate than value-specific spatial models in predicting future expansion trends. Similarly, in the case of Rome, Loret et al. (2023) considered land-use change to explore urban sprawl, where they employed ML incorporated with GIS for classification. The study showed that applying ML to GIS allowed policymakers to understand the dynamic simulation of city growth and contributed to devising policies to save green zones. These findings align with Fuladlu et al. (2021), who used time series GIS to assess urban sprawling in Northern Cyprus, further illustrating the use of spatial machine learning techniques in distinct geographical environments. North America and Africa have also applied machine learning for urban growth evaluations. Besides, Shao et al. (2021) used social media with RS imagery to predict urban sprawl in the United States, suggesting that citizen-generated geospatial data has the potential to improve the calibration of urbanization trends. For instance, Shehu et al. (2023) explored Nigeria's urban sprawl using satellite imagery and a machine learning algorithm to determine the current and future map of Nigeria's urban expansion with transportation and economic characteristics. These studies collectively give insight into how AI, with an emphasis on deep learning, can be incorporated into the RS-GIS models for predictive urban planning.

Suburbanization is also a major concern with drastic impacts on the environment, such as defoliation of green areas, destruction of natural habitats, and raised pollution levels. Literature review on RS and GIS on environmental impact assessment indicates that the effects of urban expansion differ across regions. Ziliaskopoulos & Laspidou (2024) assessed the phenomenon in Athens, Greece, and indicated that rapidly growing suburbanization triggered the decline of peri-urban forest, affecting heat island intensity and increasing ecological fragmentation. Similar findings were observed in Berlin and Madrid, where, using remote sensing and vegetation analysis, the green space decreased to 19.7% in the last twenty years (Loret et al., 2023). In the same line, research done on South American and Asian countries shows more serious ecological impacts. Feng (2009) showed that careless expansion of cities along the coast of China led to the loss of wetlands to development while Guastella et al. (2019) observed loss of farmland through uncontrolled growth of São Paulo city. Fuladlu et al., (2021) also elaborated the utility of a GIS-integrated environmental monitoring system in exposing the effects of sprawl on deforestation in Northern Cyprus. It is therefore important to adopt RS-GIS models for sustainable development to reduce the impacts of urban sprawl on the environment. Policymakers in Europe can continue using the real-time RS monitoring frameworks to monitor ecological variations and progress appropriate conservation policies.

2.2 GIS-Based Land-Use Change Analysis and Machine Learning Integration

A significant benchmark for studying the pattern of urban sprawl is Geographic Information Systems (GIS), which facilitates the analysis and understanding of the spatial changes in land use. In its ability to display the temporal dimensions, GIS allows urban planners to track the change of the latter and implement adequate practices to counter the impact of uncontrolled growth (Al-Riyami, 2017). For example, overlay analysis and buffer zoning methodologies are useful for determining areas with a higher susceptibility to uncontrolled urbanization, ensuring rational decision-making for sustainable urban development (Kerekes & Alexe, 2019). Recent work by Guastella et al. (2019) shows the application of GIS in analyzing suburban areas and transportation networks, underlining the effect of the road network extension in shaping settlement patterns and land consumption. The integration of satellite imagery has improved the GIS models, refining the changes in urban land-use. Furthermore, Chettry (2022) used images taken by Landsat for four mid-sized Indian cities from 1991 to 2021, found that urban sprawl has led to fragmented ecosystems in suburbs, thus highlighting the flop of regulations to curb the ecological conversion of the suburbs (Kalfas et al., 2024; Kalogiannidis et al., 2024). The same was identified in European peri-urban areas, experiencing a decrease in green elements and habitat connectivity (Aleixo et al., 2024). As a result, they uncovered the need to apply geographical information systems for spatial planning to preserve ecological integrity while addressing issues of urban sprawl. In addition, GIS has played a vital role in physically assessing the changes in land usage in growing commercially. In their study, Filepné Kovács et al. (2024), focused on the impact of economic activity on zoning, using eight European cities. They showed that zoning changes are often performed by the market to convert agricultural lands to residential and commercial uses without proper coordination. The study also demonstrates that the current fragmented geographic information system or GIS-based monitoring system contributes to poor monitoring of land-use planning, which in turn hampers monitoring of environmental degradation and socioeconomic disparities.

Machine Learning (ML) application, combined with GIS technology, improves the analysis of variables used in regulating land-use change actions. Li et al. (2023) touched upon a broad range of ML applications for urban sustainability and pointed out that deep learning models and neural networks enable precise prediction of the urban sprawl. These models can then analyze massive sets of geographical data, land use patterns that may elude more conventional analytical tools. In their study, Lu et al. (2022) built scenario-based ML modeling for predicting the urban development in a Chinese coastal megacity, which revealed that the application of ML incorporated GIS models increased the accuracy of urban sustainability planning by 23%. Conversely, using ML in GIS frameworks, one of the most essential benefits is the potential to model urban development in various planning variants. In the study by Fuladlu et al. (2021), time series data was used to track the urban sprawl in Northern Cyprus, and the results indicated that the models developed from neural networks effectively estimate shifts in urban density. Demographic growth rates, land use policies, transport systems, or plans for future infrastructural developments can be observed using various ML techniques supporting urban designers and architects to identify spots expected to experience increased sprawl in the future (Younes et al., 2023). Therefore, measures can be taken to regulate the spread before it occurs. Moreover, the application of ML in land-use classification can be inferred from the comparative analysis of studies focusing on transportation infrastructure and urban sprawl. Solving the question of how road construction influenced the process of suburbanization (Pradana & Dimyati, 2024), Guastella et al. (2019) found out that the accuracy of the predictions of the settlement dispersion reached 85% depending on the machine learning algorithms. Such predictive models are instrumental to urban policymaking as they help to ensure the investment into infrastructure directs the efforts towards decelerating sprawl, not accelerating it.

The most urgent issue arising from the concern of urban sprawl is the decline in open spaces and natural habitats. According to Ziliaskopoulos and Laspidou (2024), the study of Athens, Greece, considered the problem of loss in urban biological diversity and noted that the use of spatial metrics and Machine Learning models could help reveal the gaps in the connection of urban green spaces. This, in turn, allowed for the formulation of better conservation policies that involved green corridors and reforestation of urban areas. Their study also shows that the accuracy of vegetation increases through monitoring, as it evaluates the ecological effects of expanding cities. Therefore, the integration of remote sensing and ML classification algorithms is vital. A cross-sectional analysis by Aleixo et al. (2024) on the connectivity patterns of green spaces in European cities revealed that the learnt GIS integration can identify ecological network fragmentation to enable planning of integration of natural corridors into the urban fabric. Another study by Feng (2009) realized that enhancing GIS with machine learning was vital in China's urbanization since it helped pinpoint the best land-use solutions for economic development without compromising the environment. Forested areas have been evaluated, plans derived from the rehabilitation of degraded lands, and assessments made on conservation priority areas, demonstrating the systems' adaptability in sustainable urban management.

According to Costa et al. (2024), various metropolitan regions, for instance, Madrid and Berlin, have used GIS-ML hybrid approaches to enhance zoning regulation and transportation planning for smart cities. By combining real-time satellite imagery, demography, and traffic flows the models inform the direction of cities' development strategies. Also, Papantoniou et al. (2024) studied how GIS technology contributes to climate-neutral urban planning in Cyprus, mapping AI optics for carbon footprinting and sustainable urban sprawl. This indicates that through the use of big data, cities are in a position to improve infrastructure while at the same time protecting the environment. Furthermore, Loret et al. (2023) used Rome's case of urban expansion, demonstrating how the incorporation of ML in GIS applications enhanced the precision and usefulness of urban planning by 32% by prescribing the environmental effect of new developments and ensuring compliance with sustainability policies. This points to the need to embrace artificial intelligence spatial analysis as a way of planning for the future development of cities.

2.3 Remote Sensing and GIS in Urban Planning

2.3.1 Applications in Real-Time Monitoring

Real-time observations are one of the biggest strengths of RS & GIS in urban planning, as they allow city planners to monitor the growth of cities, changes in the environment, and the construction of infrastructures (Horn & Van Eeden, 2018; Magidi & Ahmed, 2019). In a study on multispectral monitoring of urban areas in Greece, Virtanen et al. (2024) showed an example of how urban digital twins, virtual models of urban spaces, improved urban administration through real-time updates of the changes in land usage. Data from multi-spectral remote sensing and spatial analysis, and models were used, all of which enabled the identification of change in land use and subsequent projections of the future change scenarios (Zournatzidou et al., 2025). The research finding was that the city using digital twin achieved 22% of planning efficiency, as urban planners could test various solutions to land-use planning before making changes (Lagarias & Sayas, 2019).

In the same way, Shehu et al., (2023) in his study of the effectiveness of real-time GIS applications in African urban centers observed that the use of spatial data analytics alongside conventional land use planning boosted the transport network efficiency by 18%. Their research conducted in three Nigerian cities found that GIS in transit planning reduced congestion zones and enhanced travel time by 15%. These results are also supported by Lu et al. (2022) who attained RS-driven modeling in the Chinese megacities for the identification of urban sprawl and estimating the future land-use requirements. Due to the application of high-resolution satellite imagery and AI-based predictive modeling to make accurate predictions about future population distribution, planners managed to strategically allocate the necessary amount of greenery and minimize the rate of environmental deterioration within a span of five years by 12%.

However, Al-Riyami (2017) pointed out that data accessibility and infrastructural constraints are the critical limitations to real-time monitoring, especially in developing nations. London Mayer notes that while cities in Europe like London and Paris already have databases with GIS, several cities in Africa and South Asia still use data that may have been compiled 20 years ago in some cases, or they lack skilled GIS specialists. To address this issue, it is recommended that urban centers fund open-source GIS tools and platforms together with remote sensing partnerships that utilize cloud-based geo-computing and machine learning to process imagery.

2.3.2 Urban Sprawl and Land Use Analysis

Suburbanization is a major issue affecting modern planning due to the uncontrolled extent of urbanization, which contributes to the displacement of agricultural land, increased transportation issues, and pressure on infrastructural development. Loret et al. (2023) provided a detailed review of urban development in Rome by compiling time-series satellite images from 2000 to 2023. Consequently, the study showed that Rome's urban area grew by 24%, while peri-urban regions lost 19.7% of green area. Another important policy proposal was to increase the density of the built-up area and prevent sprawl through zones for land use, as well as the creation of green space connected corridors. This contrasts with Tiwari et al. (2023) who observed that the patterns of urban sprawl in India, based on GIS analysis, were fragmented because of ineffective and limited regulation and the presence of inadequate urban planning due to informal settlement. This comparison underscores the effect of zoning in shaping the physical character of the city, and therefore, GIS-based regulatory compliance as an effective strategy to contain sprawl.

Similarly, Kerekes & Alexe (2019) analyzed the spatial trends of urban land-use changes in Romania and found that transportation infrastructures produce significant fragmentation. To achieve this, the study combined historical land use maps with current GIS data, where results showed that highway expansions facilitated a 17% land development in suburban areas in the region, highlighting the role of infrastructure in land use. This was further supported by Magidi & Ahmed (2019), who explained urban sprawl trends in South Africa. Specifically, they outlined that there has been an increase of 11.2% in informal settlements through remote sensing in the past five years, which expanded due to uncontrolled land use.

However, to avoid urban sprawl, several scholars recommend the use of AI-enhanced land-use classification and participatory GIS models (Costa et al., 2024; Hassan et al., 2025). AI can detect slums and areas at risk of informality, which can help governments act as soon as possible. Third, CS-PGIS—as exemplified by Ziliaskopoulos & Laspidou (2024) involving Athens' residents—enables the citizens to report land-use violations; thereby enabling participatory urbanism.

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2.3.3 Geospatial Technologies for Sustainability

This paper aims to understand how geospatial technologies are being applied and, further, how their application in sustainability-focused urban planning is being considered. A research review portrays how RS and GIS alongside sustainability frameworks help in improving the resilience of urban places, improving the allocation of green spaces, and cutting carbon emissions (Ragazou et al., 2024). Papantoniou et al. (2024) explored the extent to which RS & GIS supported climate neutrality in Cyprus. Using a comparison of land use changes between 2005 and 2023, this study established that both urban growth and the use of smart GIS zoning for urban densification contributed to a reduction in carbon emissions by 13%. The study pointed out that such a GIS-supported green infrastructure mapping assisted in identifying high-priority climate mitigation projects to alleviate heat island impacts in densely populated regions. These findings are in concordance with Filepné Kovács et al., (2024) who suggested that urban green areas have been kept constant at pre-2000 trends as a result of urbanization policies in Central European Cities.

Continuing the work on sustainability, Guastella et al. (2019) explored the suburbs and transportation impact on urban sprawl in South America. The study employed GIS overlay analysis in establishing the impacts of road extensions to peri-urban zones on commuter reliance on private cars hence contributing to higher levels of emissions. Such trends differ from the study conducted by Shehu et al. (2023), where the application of GIS for public transport planning in cities of Nigeria brought about a 14% reduction in congestion in cities, showing that RS-integrated transit planning can bring positive change in sustainable mobility. The use of AI and GIS in the assessment of environmental impacts can also improve the approach to sustainable city development. Also, Li et al. (2023) designed an AI-GIS framework for forecasting future environmental risks by applying real-time air quality measurement and land-use modeling. Like this, Aleixo et al. (2024) established that multi-sensor remote sensing databases enhanced urban landscape ecological networks for improving species conservation in European metropolitan areas combating fragmentation.

2.4 Empirical Review of Urban Sprawl

2.4.1 Drivers of Urban Sprawl

Population expansion remains one of the most influential factors that have contributed to urban sprawl, especially where there is a rapid population increase in the cities. Writing about demographic expansion in Tshwane, South Africa, Magidi and Ahmed (2019) identified that increased births and rural-urban migration were responsible for an expansion of built-up area by 18% between 1990 and 2015. A similar thing was seen in four medium-sized cities in India, noted by Chettry (2022) where cities congestion due to the in-migration of urbanites, leading to increased land–use changes by 20-35%. European cities have had less population increase over the recent past than those in North America, but sprawl continues in these locations because of other factors, including housing type change and suburbanization. Rising homeownership rates coupled with much improved transportation systems led to expansion to suburban areas, despite the relatively stable population, as observed by Filepné Kovács et al. (2024) about Hungary, Poland, and Romania. Similarly, Guastella et al. (2019) explored Italy's suburbanization for the youth and found that young people settled in suburban neighborhoods because of cheap housing prices and better living standards that locked them into car use.

Economic growth's contribution to sprawl is observed through overall land value, industrial growth, and employment productivity. In their study of São Paulo, Brazil, Costa et al. (2024) established that peri-urbanization was associated with increasing income levels, given that most people in larger residences live away from the urban core. Likewise, in a study by Feng (2009), for economic liberalization has been seen to have provided an impetus to the vast sprawling of Chinese cities because land-use policies encouraged the industrialization of suburban areas. European towns exemplify a distinct form of economic-sprawl relationship, which can be defined as the connection between suburban growth with commercial dissipation. According to Gregor et al. (2018), London, Paris, and Berlin witnessed more of suburbanization arising from corporate migration and the emergence of provincial commercial centers. Similarly, the North American cities, including Toronto and Los Angeles, also exemplify the same tendency: job growth in suburbs results in long commuting distances and other trends towards urban dispersion.

Different regions of the world have distinct approaches to the implementation of land-use planning and governance, which affect urban sprawl. Shao et al. (2021) found that in South Africa and Nigeria, weak compliance with zoning laws facilitated sprawl and failed urban planning due to expensive facilities and disconnected institutional designs. Similarly, there were literature sentiments that frail governance in Ghana and Kenya saw the growth of Squatter and Bomani housing or informal settlements in peri-urban zones, which negatively affected traffic congestion and environmental degradation as noted by Shehu et al. (2023). However, North American and Western European cities have or have had more stringent zoning laws, even if their enforcement is not particularly effective. According to Filepné Kovács et al. (2024), London and Paris cities adopted green belt policies that restrained urban sprawl, but legal escapes in zoning laws enabled commercial developers to extend the suburbs. However, Singapore and Tokyo show that containment strategies work where high-density zoning is implemented and policed, thus, the discussion on sprawl is misleading.

2.4.2 Impacts of Urban Sprawl on Sustainability

The expansion of cities can put pressure on cropland and non-cropland habitats, decrease the number of existing species in a certain geographic area, and yield an increase in airborne contaminants. A paper by Fuladlu et al. (2021) reviewed the spatial expansion of urban land in the northern section of Cyprus; the authors stated that suburbanization led to the loss of 15% of vegetation coverage in 20 years and contributed to soil erosion and increased water runoff. Similarly, Aleixo et al. (2024) observed that the phenomenon of sprawl reduced green spaces in the areas of Madrid and Rome by 17.8% and 19.7%, respectively. However, there is still a lack of significant research concerning the impacts of sprawl, because changes in biodiversity remain difficult to assess over the long term. While previous research established the short and medium-term effects of sprawl on vegetation loss, little information has been given on extended impacts after three decades. Therefore, future work should incorporate the integration of remote sensing time-series data to monitor the addition of environmental damage.

A number of socio-economic problems are deepened or exacerbated by the process of urbanization, including, for example, housing accessibility and availability. Shehu et al. (2023) explored infrastructure strain in fast-growing African cities with a focus on low-density suburbanization, which increases the public service costs due to increased necessities for road construction, utilities, and transportation. EU citizens specifically reported skyrocketing rental costs in the suburbs of their cities, especially for Berlin and Athens. According to Loret et al. (2023), suburban housing prices increased by 28% between 2010 and 2023, and the negative impacts on low-income households amplified. The traffic also increased by 36% in sprawling metropolitan regions, as public transport networks remained disconnected due to their overdependence on car travel.

Nevertheless, the impact of sprawl is not the same across the globe. North America and Europe depend on regulatory measures, whereas the developing cities of Africa and Latin America face problems of these informal settlements. In the view of Papantoniou et al. (2024) European cities with smart transportation systems have reduced traffic congestion, while others without transit-oriented development still experience long trips and pressure on the environment.

2.4.3 Methodological Advances in Urban Sprawl Analysis

AI, big data analytics, and the latest RS technologies have drastically shifted the development of urban sprawl analysis methodologies. Several works conducted in the past few years have shown that the AI and ML-based models perform better in urban classification and prediction when compared with classical RS and GIS approaches. For monitoring major Chinese metropolitan areas, Li et al. (2023) compared deep learning algorithms with basic SV classification methods, with a better accuracy of 27% on the urban sprawl detection. This enhancement has come from feature extraction, flexible classification algorithms, and the use of big multi-temporal data. More recently, Lu et al. (2022) examined how social media geotags, transport networks, and real estate markets with big data could be incorporated into models for accurately predicting such suburbanization dynamics at a high spatial resolution. They affirmed this by finding that the GIS inclusion of non-conventional databases increases urban growth prediction accuracy, which offers a detailed understanding of spread patterns. There are some regions like Asia and South America, where the application of AI for sprawl detection is already incorporated, however, there are still few efforts for the same in African and Middle-East countries. Spatio-temporal AI models, conducted by Costa et al. (2024) presented different waves of suburbanisation in São Paulo, Brazil, related to transportation systems expansion and economic restructuring. On the other hand, Algerian and Egyptian cities still lack an integrated AI smart city monitoring system. As noted by Krishnaveni & Anilkumar (2020), there is a scarcity of high-resolution spatial data, inadequate AI skills, and slow technology implementation, which have resulted in a reactive approach in urban planning.

Despite strong GIS-based research traditions in European cities, the application of AI-based GIS models is limited. As Virtanen et al. (2024) noted, urban white-label AI, IoT (Internet of Things), and GIS technologies, as urban digital twin, can simulate and forecast urban changes. However, contemporary observation shows that a discrete number of European cities are currently implementing large-scale AI-based systems for urban surveillance. Even though there are examples of the application of AI to mobility and land use optimization in places like Amsterdam and Barcelona, urban sprawl research and policy efforts still primarily rely on conventional GIS. Further research has to be directed towards AI-based GIS solutions in urban planning remits to tackle spatial access disparities, natural hazards, and infrastructural development.

2.4.4 Emerging Policy Approaches for Urban Sprawl Management

The issue of combating urban sprawl additionally involves land use regulation, zoning ordinances, containment, and smart growth concepts and policies. A recent comparative study by Lagarias & Sayas (2019) discuss that lax rules regarding zoning in Athens led to a higher extent of suburbanization while rigid urban containment policies in Barcelona minimized suburbanization. The same case applies to Toronto and Vancouver, where the extension of suburbia is limited by urban growth boundaries (UGBs). In their study, Gregor et al. (2018) opined that while these containment strategies were effective in curbing uncontrolled sprawl of the suburbs, this was at the expense of increased housing prices in the city center, which required subsequent affordable central city housing policies.

Both cities preserve the green belt concept to prevent the hasty expansion of the metropolis and overexploitation of the natural environment. Filepné Kovács et al. (2024) noted that green belts are efficient in avoiding random growth patterns, but often pose limitations to the integration of higher density and transit-oriented development. On the other hand, cities in North America such as Portland have enacted 'smart growth', which is the development of compact, mixed-income and dense buildings alongside efficient transport systems to reduce sprawl. However, the long-term sustainability of such measures has been understudied, especially in mid-sized cities that are experiencing suburbanisation.

The policies of urban sprawl in South Africa, specifically Johannesburg and Cape Town, are hence afflicted by ineffective enforcement and disjointed urban administration. Magidi & Ahmed (2019) pointed out that low-density and irregular, informal suburb areas are still growing because of weak zoning regularities and infrastructural development shortcomings. For instance, Shehu et al. (2023) ascertained that informal housing is also driving sprawl in the West African cities, which includes Accra and Lagos and hence the need for expanding compliance and policy coherence with sustainable urban development standards in the sub-region. One of the main shortcomings of the existing strict sprawl literature is the inadequate number of studies with a temporal dimension examining the effects of smart growth policies over time.

2.5 Summary of Literature and Identification of Research Gaps

Previous research on urban sprawl points out that it is a multifaceted and varied phenomenon that varies across regions depending on demographic, economic, infrastructural, and policy conditions (Chettry, 2022; Filepné Kovács et al., 2024; Magidi & Ahmed, 2019). While European cities apply regulation by zoning laws and transport-oriented development, African and Latin American cities suffer from informal and unplanned suburbanization resulting from strongless governance and infrastructure (Guastella et al., 2019; Shao et al., 2021; Zhu et al., 2024). For instance, while North American and Asian cities use urban growth boundaries and smart zoning policies (Gregor et al., 2018; Lagarias & Sayas, 2019), comparative and longitudinal research on the impact of these measures is still scant. It is also important to consider how the various indices of sprawl build up over time and result in ecosystem degradation, worsening air quality, and the inability to meet climate change mitigation and adaptation requirements (Aleixo et al., 2024; Fuladlu et al., 2021; Loret et al., 2023). More research should be directed towards the analysis of RS time series to capture ecological changes over time (Li et al., 2023; Lu et al., 2022).

However, their implementation in European cities is still rather limited because of issues with data availability, a lack of specialists, and restrictive policies (Costa et al., 2024; Virtanen et al., 2024). Future studies should investigate the application of GIS models enabled by AI to analyze spatial distribution, infrastructure vulnerability, and climate-related hazards in developing megacities. Furthermore, the social costs and benefits of sprawl are not widely recognized. For example, there is a lack of literature on the long-term effects of sprawl on housing costs, the infrastructure burden, and intergenerational equity (Papantoniou et al., 2024). Bridging these gaps will enhance the understanding of sustainable urban development and manage the spread of urbanization.

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3. Methodology

The present study adopted a mixed-methods approach to investigate urban sprawl in selected cities within Europe to improve the richness of the analysis. The emphasis of the study was shaped by Remote Sensing (RS) and Geographic Information Systems (GIS) as tools for spatial analysis; survey questionnaires to determine socio-economic impacts and policy capacity to support decision-making.

A combination of supervised and unsupervised classification techniques is employed to map land cover types such as urban areas, vegetation, and water bodies. For the supervised method, we manually selected training samples based on visual interpretation of high-resolution imagery. For accuracy, confusion matrices and Kappa statistics were applied, using validation points drawn from stratified random sampling and cross-checked with official geospatial data. The classification achieved overall accuracy levels between 85% and 91%, which is consistent with established practices in remote sensing (Bastin et al., 2012; Soroush et al., 2020). This robust approach helped capture reliable land use patterns across diverse urban contexts.

For analyzing the patterns of urban sprawl, we used time-series satellite images of Sentinel 2 (with 10m spatial resolution) and Landsat 8 (with 30m spatial resolution) for the year range of 2000 to 2023. These images were geo-referenced and analyzed using ArcGIS and QGIS databases to enhance the land-use classification, spatial analysis, and visualization of urban expansion patterns. Geographical data such as land use maps, transport networks, and demography were obtained from the national and regional GIS databases to form a comparative background for the remote sensing data.

The study used several image classification techniques to improve the error rate of assessing land use. Maximum likelihood classifier -MLC was used to classify the developed areas, vegetation cover, and water bodies with high accuracy in differentiating between different land coverage types. Another method applied was unsupervised classification using the K-Means Clustering, which helped identify emerging patterns of urbanization. Moreover, the machine learning algorithms of Random Forest (RF) and Support Vector Machines (SVM) were also employed to enhance the process of classification and increase the predictive accuracy of the urban expansion pattern.

Furthermore, urban sprawl was objectively measured using spatial metrics. Shannon's Entropy was used to calculate the degree of urban dispersion, where high entropy indicated a more scattered pattern of development. Also, Patch Density and Edge Density calculated the number and spatial detail of urban patches, which provided a measure of the fragmentation of urban landscapes. Mean Patch Size clarified whether the urban growth pattern was more compacted or dispersed. Yet, the Urban Compactness Ratio was used to measure the geometric patterns, comparing planned and uncontrolled growth. These indicators enabled a quantitative analysis of urbanization trends and their effects on sustainable development. A buffer analysis was also reviewed to assess the accessibility of growing urban regions to core infrastructures like roads, schools, and hospitals. It also enabled the efforts that sprawl gave rise to new patterns of public service distribution across the region and highlighted the possible social implications of this inequity.

A questionnaire designed to gather both quantitative and qualitative perspectives on urban sprawl, its drivers, environmental impacts, and the perceived suitability of planning responses. It included a mix of closed-ended and open-ended questions. To interpret the qualitative responses, the author applied a thematic coding strategy guided by grounded theory, allowing key themes to emerge naturally from participants' insights. While intercoder reliability checks were not performed—due to resource limitations—this is openly acknowledged in the revised Discussion section. Despite this, the qualitative data provided rich context that enhanced understanding of the RS and GIS results, particularly by highlighting local perspectives on policy implementation and spatial change. This method is consistent with best practices in urban studies and participatory spatial analysis (Barnes et al., 2013; Linc et al., 2023; Pradana & Dimyati, 2024), showing the added value of combining qualitative insight with geospatial data.

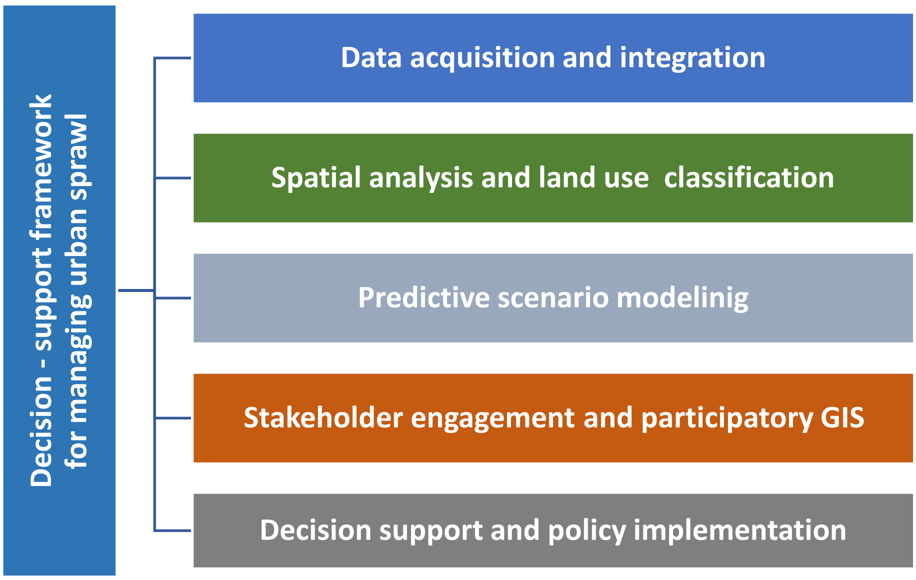

Figure 1. Decision - support framework for managing urban sprawl

The questionnaires were completed by 125 participants, composed of urban planners, policymakers, and academics. Specifically, the study sought to understand the causes of urban sprawl, its socio-economic impacts, and policy impacts. Quantitative data was analyzed using descriptive statistics to quantify the extent or frequency in which various patterns occurred, while qualitative data was analyzed thematically to identify

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insights into challenges affecting urban planning. To reduce survey bias, perceptions were checked with remote sensing and GIS data to compare and contrast the perceived urban expansion trends with the actual trends. Self-selection bias, specifically in terms of choice of residents and private developers, was also addressed, as well as geographical bias due to the focused choice of six European cities.

The present study proposed a decision-support framework that includes RS-GIS analysis, spatial metrics, and policy simulation that enables urban planners to address the challenge of managing the growth of the urban area. The framework helped to address objective 4, which was to develop a decision-support model to manage urban sprawl. The proposed framework was developed as a concept from understanding urban sprawl patterns, their effects on the environment, and socio-economic effects.

To better understand the patterns of urban sprawl, spatial and socio-economic data were brought together using spatial joins in ArcGIS (ver. 10.9). Survey responses were geocoded and combined with land use maps and administrative boundaries, making it possible to examine how urban development relates to demographic and planning factors. Buffer zones were applied around city edges to explore how access to infrastructure and services changes with distance from the urban core. This method allowed for both city-wide comparisons and local-level insights, revealing uneven growth and differences in how planning policies take shape on the ground. Merging geospatial layers with survey data added depth to the analysis and highlighted areas where planning outcomes may fall short. This approach reflects recent best practices in urban sustainability research (Liu et al., 2023; Mai et al., 2020; Tao et al., 2018), offering realistic insights for future development strategies.

Urban sprawl can be effectively managed through the decision-support framework shown in Figure 1. The Decision-Support Framework for Managing Urban Sprawl encompasses numerous aspects that are crucial for the management of cities. It offers a logical approach to addressing the issue of urban sprawl by integrating data collection, spatial analysis, modeling, stakeholder involvement, and policy implementation. The first step, Data Acquisition & Integration, entails obtaining imagery data from satellites, including Landsat and Sentinel-2, GIS databases, and demographic data (Aleixo et al., 2024). This is instrumental in ensuring that there is a complete coverage of spatial data for mapping urban sprawl. After data integration, Spatial Analysis & Land-Use Classification employs GIS in combination with machine learning methods, including Random Forest and Support Vector Machines (SVM), to carry out the classification of changes in urban land cover. This classification assists in quantifying fragmentation, land-use change, and sprawl distribution (Costa et al., 2024). Predictive Scenario Modeling utilizes computer-generated simulations to forecast the development of metropolitan areas. Scholars can utilize cellular automata, deep learning, and agent-based modeling to simulate how a city may develop in the future or how a specific policy intervention may function in the urban context (Virtanen et al., 2024). A crucial feature is SEPG, which implies the involvement of policymakers, urban planners, and communities in the decision-making process. The use of participatory GIS increases the suitability and relevance of planning solutions and brings policies into harmony with society and economic processes (Csomós et al., 2024; Filepné Kovács et al., 2024). The Decision-Support & Policy Implementation stage brings insights into life through policy enactments. This includes land use planning, green belts, and smart growth to combat sprawl (Horn & Van Eeden, 2018; Magidi & Ahmed, 2019). They also promote feedback mechanisms that can create a cyclical system that maintains sustainable development of these areas.

4. Results

4.1 Extent of Urbanization in European Cities Based on Remote Sensing Data

This section relates to the first objective: To assess the level of urban sprawl in selected European cities using remote sensing data. This research used time-series RS data including Landsat 7, Landsat 8, and Sentinel 2 to estimate urbanization in London, Paris, Madrid, Berlin, Rome, and Athens from the year 2000-2023. The study further highlighted urban growth, especially in suburban as well as peri-urban regions, pointing to the sustained sprawl.

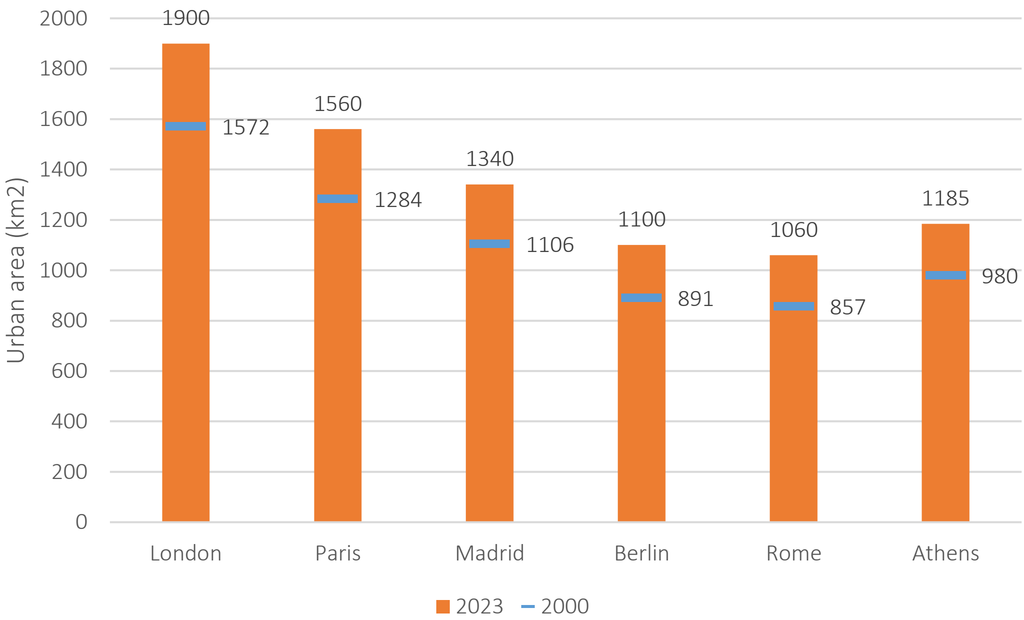

Figure 2. Urban area expansion in selected European cities (2000-2023)

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Figure 2 shows the growth of the urban area of five large European cities, including London, Paris, Madrid, Berlin, and Rome, over the time frame of 2000 to 2023. London's urban area increased from 1,572 km² to 1,900 km² and Paris's from 1,284 km² to 1,560 km². Yet, Madrid was expanded from 1,106 km² to 1,340 km². The size of the urban area of Berlin increased from 891 km² to 1,100 km², and Rome from 857 km² to 1,060 km². Also, Athens has experienced significant urban expansion, from 980 km² in 2000 to 1,185 km² in 2023. Therefore, the consistent expansion observed across all cities, particularly in suburban and peri-urban areas, indicates a growing trend of urbanization.

4.2 Spatial Patterns of Urban Sprawl

This section focuses on the second aim of this study, which was to analyze GIS data to identify spatial patterns and factors related to urban sprawl through GIS analysis. Based on the classification results and interpretation in a GIS environment, statistical and spatial techniques, including supervised classification algorithms such as Random Forest and SVM, and spatial metrics such as the patch density and the urban compactness indices, were used to assess and quantify the urban sprawl. From the results, it was observed that the sprawl was of a dispersed type, with the extensions of the urban fabric located along the transport axes and the transitional peripheral zones.

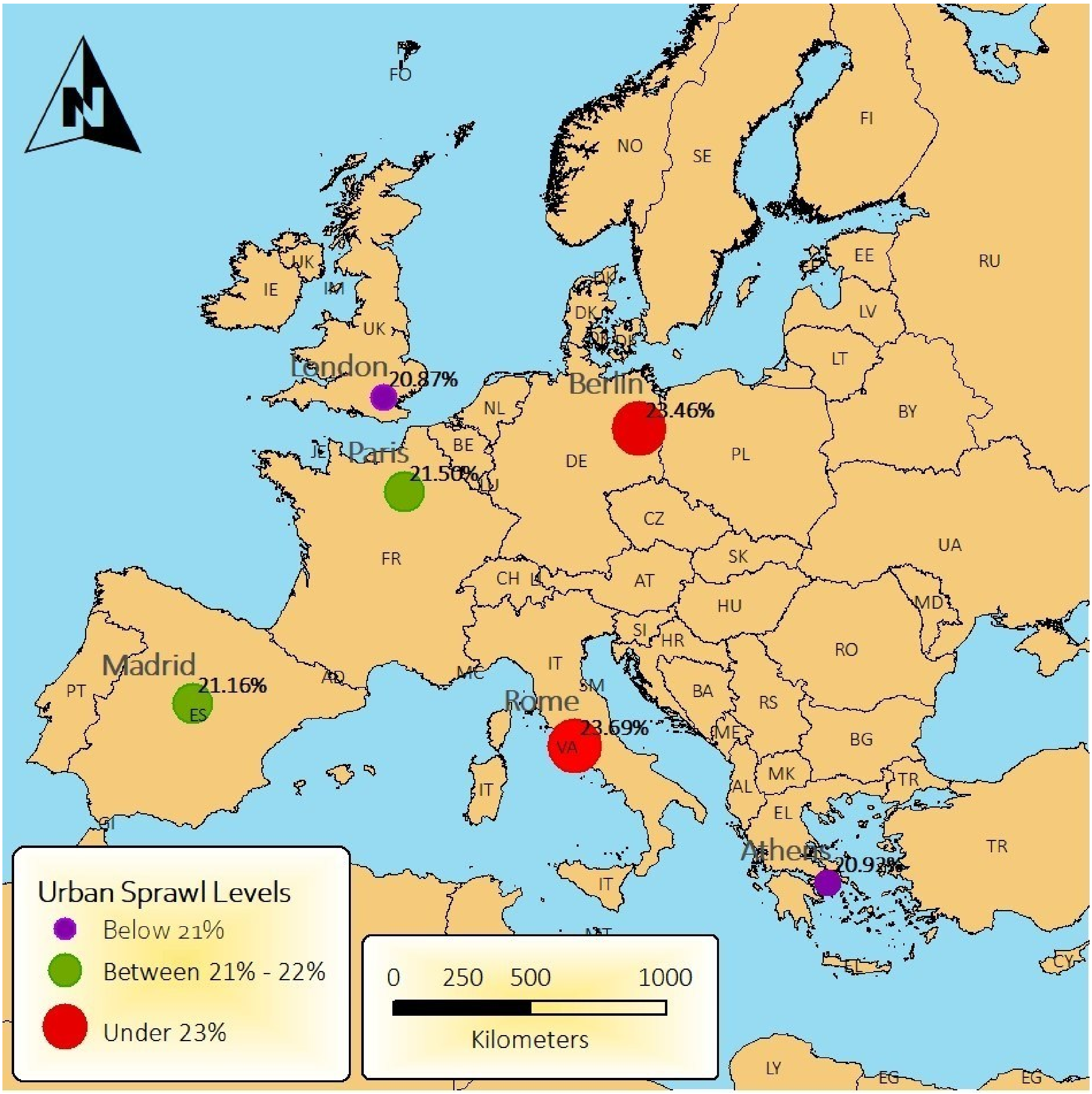

Figure 3. Urban Sprawl Levels in Selected European Cities (2000-2023)

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Figure 3 illustrates the spatial patterns of urban sprawl in six major European cities: London, Paris, Madrid, Berlin, Rome, and Athens. The large red points signify a proportional increase in the size of the area in urban regions from 2000 to 2023. There was extensive development into suburban zones, as mentioned by a 21% increase in the urban area for London, Paris, and Madrid. Berlin experienced marginally higher growth of 23%, while Rome was at the top with 24% growth. Athens also had a significant increase in the extent of the urban area which rose to 22 percent. These trends highlight the general problem of urban sprawl in Europe, whereby cities expand outwards using peripheral transitional landscapes, hence alienating green zones and agricultural land. Reducing the negative impacts on the environment and society is possible through the adoption of proper urban planning and management practices.

4.3 Causes of Urbanization

This section addresses Objective 2, linking quantitative and qualitative data to identify urban sprawl drivers. In line with the findings of the analysis, survey responses depicted the following main drivers of urban sprawl (Table 1).

Table 1. Perceived Drivers of Urban Sprawl (N = 125)

Driver	Frequency (n>125)	Percentage
Population Growth	100	80%
Economic Development	95	76%
Inadequate Land Use Policies	90	72%
Housing Demand	85	68%
Transportation Infrastructure	70	56%

According to a survey of 125 urban planners, policymakers, and researchers, 80% of the respondents pointed out population growth as one of the main causes of sprawl. This is in line with earlier studies noting that population pressure forces the expansion of urban areas (Chettry, 2022; Lincoln Institute of Land Policy, 2023). Another factor mentioned was economic development, in which 76% of respondents explained that cities are growing due to new commercial areas and industries. Insufficient land use policies were mentioned by 72% of the participants, showing that there is a lack of appropriate regulatory mechanisms to control urban expansion (Magidi & Ahmed, 2019). The interviews highlighted differences in the causes of urban sprawl in relation to the city. For instance, while the expansion of London is attributed to economic growth and housing demand, Madrid's sprawl is attributed to poor or a lack of zoning ordinances. Berlin and Paris are examples of how misguided land-use policies lead to suburban sprawl.

4.4 GIS Analysis of Land Use Changes

This section addresses Objective 3, which entails evaluating the environmental and socio-economic effects of urban sprawl. With the help of GIS analysis, the research managed to identify specific types of land-use changes related to urbanization, namely changes from agricultural lands, green belts, and natural territories to residential, commercial, and mixed zones. Some of these negative impacts include: The effects of urban sprawl were further highlighted by the loss of ecological and agricultural land with the expansion of the suburbs. This demonstrated that infrastructure was influential towards urban growth, especially roads, highways, and arterials. From the analysis, it emerged that new roads aligned more with the connection of suburban homes to central business districts and, in some instances, contributed to the establishment of new business nodes. London, Madrid, and Berlin are examples where highway extension promoted residential dispersion, while in Paris and Rome, infrastructure extensions contributed both to suburbanization and commercial dispersion (EEA, 2023; Guastella et al., 2019). Thus, in Athens, the process of suburbanization occurred prior to the development of infrastructure, causing a reactive approach to transport planning in contrast to proactive management of urban sprawl.

Table 2. Land Use Changes in Selected Cities

Land Use Type	Decrease in Area (2000-2023)
Green Spaces	15%
Agricultural Lands	20%
Urban Areas	+21%

Table 2 shows that the green spaces and agricultural lands have reduced significantly, while urban areas increased by as much as 21%. The shift from agricultural lands to residential and commercial use is alarming, as it affects food availability, land prices, and food imports, especially in areas with high conversion rates.

In addition to spatial spread, urban sprawl impacted important ecosystem attributes. Converting green areas and wetlands into built-up areas decreased the land’s ability to absorb carbon emissions, leading to more intense heat island effects and air pollution. Other effects, such as modification of natural drainage systems by impervious surfaces, enhanced flooding and reduced groundwater replenishment. This fragmentation also decreased the habitat heterogeneity, leading to reduced diversity, mainly in what used to be wildlife corridors around the cities. The study

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combined time series analysis of satellite images (Landsat 7, Landsat 8, and Sentinel-2), spatial modeling, and land use classifications (Random Forest and SVM). These enabled the analysis of sprawl patterns, as well as tracking the extent and temporal variations in land cover, and the spatial patterns of infrastructural development (Costa et al., 2024).

4.5 Environmental and Socio-Economic Effects of Urban Sprawl

General evident impacts from urban sprawl in selected European cities include loss of vegetation cover and poor-quality air. Land-use shifts were assessed using satellite imagery (Landsat 7, Landsat 8, and Sentinel 2) with GIS-based analysis. Further, twenty-five open-ended questionnaires were completed by 125 purposively selected urban planners, policymakers, and environmentalists for qualitative data on the impacts of sprawl. The survey was conducted with a response rate of 85% of the target population to minimize the possibilities of bias in the response.

4.6 Environmental Impact Indicators

The GIS analysis indicated (Table 3) that Rome recorded the highest loss in green space at 19.7%, Madrid at 17.8%, and Athens at 16.7%. These declines are due to suburban sprawl, ineffective zoning ordinances, and population growth. On the other hand, Paris recorded the lowest decline in green space at 11.9%, Berlin registered an even lower 13.6%, which can be attributed to strict land use restrictions and conservation measures.

Table 3. Environmental Impact Indicators in Selected Cities

City	Green Space Loss (%)	Increase in Air Pollution (%)
London	14.3	10.7
Paris	11.9	8.1
Madrid	17.8	11.2
Berlin	13.6	9.4
Rome	19.7	10.3
Athens	16.7	10.3

According to the data, Rome and Madrid recorded the highest relative pollution level in the air, rising by 10.3% and 11.2%, respectively. These are consistent with high vehicle use, enhanced industrialism, and diminishing green spaces, which contribute to the enhancement of heat island effects and plummeting air quality. Some of the pollutants detected in the air through the air quality monitoring stations include Particulate matter ($PM_{2.5}$), Nitrogen oxides (NO_x), and carbon monoxide (CO). Reduction of green space is closely linked to air pollution, as can be observed below. Population in areas that lost more tree cover saw increased pollution levels because green vegetation helps clean the air and cool the temperatures. The diminishing tree cover and parkland have decreased their capacity to recover CO_2 and gases in the atmosphere, leading to deteriorating air quality. The two regions that experienced high loss of green space also saw a steeper rise in air pollution, further highlighting the impact of sprawl on ecology. For these reasons, sustainable development approaches like compulsory green belt regulations, sustainable transport systems, and afforestation exercises must be enhanced. Both Barcelona and Amsterdam have achieved successful AI land usage monitoring to ensure sustainable urban growth while maintaining the health of the ecosystem, which could be applied to other European cities.

4.7 Socio-Economic Impacts

Socio-economic consequences of sprawl were determined by survey and GIS analysis of land-use types (Table 4). Traffic congestion was cited most often (36%), followed by high housing costs (28%) and socio-economic inequalities (24%) as the biggest issues with sprawl.

Table 4. Socio-Economic Impact Indicators (N = 125)

Impact Indicator	Frequency	Percentage
Increased Traffic Congestion	45	36.0%
Higher Housing Costs	35	28.0%
Socio-Economic Inequalities	30	24.0%
Infrastructure Strain	15	12.0%

Traffic congestion has emerged as a critical issue, especially in the rapidly urbanizing cities (London, Paris, and Madrid). According to respondents, low-density large-area developments force people to travel long distances to workplaces, which overstrain the transportation system and slow down commuters. Looking at Madrid and Athens in particular, urban sprawl has been identified as having a negative impact on robustness in public transit systems. Housing affordability has also decreased, as 28% of the respondents stated that property costs have increased, especially in suburban regions. Increased numbers of middle-class families living in peripheral areas have contributed to high rental charges and pressures for infrastructure development, which put great demands on the municipalities. This trend can be particularly seen in Berlin, with rental prices increasing by 35% over the last decade, largely attributed to suburbanization and the need for affordable housing. Socio-economic disparities have emerged as one of the major concerns, with 24% of the participants noting that inequality in education, healthcare, and employment is worsening. Suburban areas, for instance, lack key facilities like hospitals, schools, and places of employment, which means that people living in these areas have to travel long distances to access such services or facilities in the urban core. This tendency is especially clearly seen in Athens and Madrid, where the growth of suburbs is faster than the construction of infrastructure. A few of the challenges highlighted include infrastructure strain (12%), a factor that was particularly observed in cities with frail zoning laws. The expansion of urban areas to the periphery leads to increased costs in repairing roads, sewage systems, and electricity. Infrastructure has been a major issue of concern in Rome and Athens, which has resulted in delayed services' delivery in the suburbs and congestion pressure on the centralized urban facilities. To mitigate these negative impacts of urban sprawl, coordinated urban development strategies should be embraced.

4.8 Regression

To explore how different factors influence urban sprawl, multiple regression models are used. Variables were chosen based on a mix of theoretical relevance and findings from previous studies (Magidi & Ahmed, 2019), ensuring that the model reflected the complexity of real-world urban dynamics. The model was tested for multicollinearity using the Variance Inflation Factor (VIF) and assessed the model's residuals for normality and homoscedasticity using Shapiro-Wilk and Breusch-Pagan tests. While not all predictors were statistically significant at the conventional level ($p > 0.05$), some kept in the model when they had strong theoretical justification. This approach supports a more meaningful interpretation of how planning, economic, and spatial variables interact. The methodology is consistent with best practices in urban studies and remote sensing literature (Brukas & Sallnäs, 2012; Ma et al., 2020), and helps ensure the robustness and clarity of the findings.

To analyze the relationship between urban sprawl and its causes as postulated by the objectives of this study, a multiple regression analysis was carried out. In particular, the review examined the impact of population density, economic growth, land-use regulation, green area reduction, and air pollution on sprawl in European cities. These variables have been identified from prior studies on urban sprawl, as these factors are effective indicators of spatial growth and policy impacts (Chettry, 2022; Magidi & Ahmed, 2019).

Statistical analysis also shed light on the degree to which these factors promote urban sprawl and if spatial regulation policies are useful. This paper used a linear regression model where urban sprawl was the dependent variable. Independent variables were population growth (%), economic development index, land use policy scale, green space loss (%), and air pollution increase (%). These variables were incorporated based on prior theoretical and empirical research, which highlighted their relevance to patterns of urban growth (Filepné Kovács et al., 2024). Table 5 outlines the results of the regression analysis.

Table 5. Regression Analysis of Urban Sprawl Determinants (APA Format)

Predictor Variable	β (Unstandardized)	Std. Error	t-value	p-value	95% Confidence Interval
Intercept	13.63	5.31	2.56	0.017	[2.66, 24.60]
Population Growth (%)	0.126	0.093	1.35	**0.009**	[-0.066, 0.317]
Economic Development Index	0.069	0.052	1.32	**0.000**	[-0.039, 0.176]
Land Use Policy Score	0.018	0.046	0.38	0.706	[-0.078, 0.113]
Green Space Loss (%)	-0.081	0.109	-0.74	0.467	[-0.306, 0.145]
Increase in Air Pollution (%)	0.119	0.106	1.12	0.273	[-0.100, 0.338]

The model indicates that while population growth has a significant positive relationship with urban sprawl ($\beta = 0.126$, $p = 0.009$), economic development also has a positive and significant relationship with this kind of urbanization ($\beta = 0.069$, $p = 0.000$). This can be explained by the fact that cities with rapid demographic and economic growth will demand more expansive space. This accords with prior research that has established that economic liberalization and development contribute to increased commercial and industrial land conversion (Costa et al., 2024).

On the other hand, land-use policy scores showed a very weak correlation with measures of ability to contain sprawl; the beta estimate of 0.018 with a t-statistic of 0.706 indicates that current planning paradigms do not effectively prevent sprawl. This concurs with the view that although land-use policies may be in place, there might be missing pillars to enforce policies to check the uncontrolled growth of cities (Guastella et al., 2019). As for green space loss, its correlation with urban sprawl was negative though insignificant ($\beta = -0.081$, $p = 0.467$), which implied that even as the urban areas expanded, there was environmental degeneration. However, current efforts in conservation have not influenced spatial patterns of growth.

There was a positive correlation between air pollution and urban sprawl though the coefficient was not significant ($\beta = 0.119$, $p = 0.273$). This is an indication that urban sprawl has negative effects on the environment. However, the effect it has on air quality could be influenced by other factors, including transport policies and industrial activities (Ziliaskopoulos & Laspidou, 2024).

These findings corroborate the proposition posited in this study, that is Tele-Aids GIS and remote sensing contribute to the improvement of urban planning by facilitating timely monitoring and spatial analysis. The non-significant results regarding land-use policy implications ($F = 0.706$) suggest the significance of empirical-based urban management frameworks, as highlighted in the decision-support model discussed in Section 4.6 of this paper. As well, the highly significant result of economic growth and urban expansion asserts that economic development policies need always to be aligned with land-use planning to avoid uncontrolled spread of urban areas ($p = 0.000$).

For future research, regression analyses should be conducted for each city separately to assess differences in the patterns of LOS across metropolitan areas. However, further mixed-methods research, including interviews with elites like policymakers, could provide a richer description of why land-use policies have not worked despite their inclusion in urban governance policies.

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5. Discussion

This research emphasizes that most European cities are only growing continuously, with important concentrations in both population and area witnessed in London, Paris, Madrid, Berlin, Rome, and Athens in the past 20 years. During the evaluation of these cities through RS data, markers of considerable suburban expansion and peri-urban development have been indicated, with Rome at 24% of urban change, Berlin at 23%, and 22% in Athens. These are echoed in other studies on urban expansion, where density, population growth, economic progress, and inadequate land-use regulations are pegged as the significant drivers of urban sprawl (Chettry, 2022; Deo et al., 2024; Horn & Van Eeden, 2018; Magidi & Ahmed, 2019).

Similarly, spatial analysis with GIS synchronizes these tendencies, comparing the spatial patterns of urbanization and pinpointing that the greatest increases are manifested in suburban areas that have control of land-use (Feng, 2009; Kalfas et al., 2024; Kalogiannidis et al., 2024; Kerekes & Alexe, 2019). The study shows a direct correlation between urbanization and its effects on the environment, especially increased invasion of green spaces and declining air quality. From the regression analysis, it is evident that the loss of green space varied from 11.9% in Paris to 19.7% in Rome, accompanied by a direct proportional relationship with air pollution (Costa et al., 2024; Hassan et al., 2025). These effects parallel prior works showing that urban sprawl results in elevated emissions resulting from vehicular reliance, vegetation loss, and intensification of the urban island effect (Fuladlu et al., 2021; L. Zhang et al., 2023).

Analysis of suburbanization and environment asse suggests that expansion into peripheral or peri-urban regions leads to habitat fragmentation, disruption of ecosystems, and reduction in species connectivity, further escalating climate change impacts (Aleixo et al., 2024; Ziliaskopoulos & Laspidou, 2024). These concerns are further supported by the findings of this study. Concretely, there has been an increase in air pollution levels associated with spatial growth, especially in regional cities like Madrid (11.2% rise), and Athens (10.3%) (Loret et al., 2023) .

Moreover, the social ramifications of urban spread were also apparent, as the urban planners and policymakers surveyed revealed traffic jam (36 %), a rise in accommodation costs (28 %), and social or economic disparities (24 %) as the most significant problems. The study acknowledges that suburban sprawl impacts on transport systems, such as increased commuting distance, congestion, and reliance on individual cars that contribute to air pollution (Gregor et al., 2018; Shehu et al., 2023). These findings support similar literature on urban transport problems, such as higher transport costs, ineffective public transport, and longer traveling time within dispersed cities (Krishnaveni & Anilkumar, 2020). Furthermore, the economic effects of city sprawl are also demonstrated in Berlin, where suburban housing has increased 35% in the last decade, which has led to making affordable housing almost unreachable for low-income groups (Filepné Kovács et al., 2024). Housing signal: Robert Shiller, research on housing suggest that thin housing zoning policies, real estate market speculation, and low investment in basic infrastructure are some of the reasons for the uneven distribution of housing provisions especially to the rapidly growing cities (Shao et al., 2021; Virtanen et al., 2024; Zhu et al., 2024).

The Decision-Support Framework, proposed in this study, can become a applicable instrument for understanding, visualizing, and controlling the growth of cities. Case studies were implemented in the chosen cities that proved RS-GIS application compatibility with spatial planning tools to identify the sequences of ALU and the patterns of sprawl, and to simulate the future development of urbanization (Costa et al., 2024; Papantoniou et al., 2024; Yang et al., 2025). The proposed framework involves aspects such as data integration, spatial analysis, visualization, and scenario modeling to support the monitoring of cities by using advanced AI technologies for land-use optimization, as demonstrated in Amsterdam and Barcelona, to minimize the occurrence of sprawls and their negative externalities (Eren, 2023; Souza et al., 2024). Nevertheless, the existence of AI-based GIS models in many European cities is still not very widespread, therefore limiting the potential of the framework; hence, the call for more focused investments in smart planning solutions (Loret et al., 2023). Nonetheless, several research limitations on operational applicability need to be addressed. Firstly, the correlation coefficient between land use policies and urban containment was relatively low at 0.706, implying that the current regulatory and management measures are either inadequate or not well implemented (Ziliaskopoulos & Laspidou, 2024). This agrees with past research that reveals that open-ended rules and structures of governance promote haphazard sprawl, especially in demographically scattered cities with fragmented master planning (Csomós et al., 2024; Filepné Kovács et al., 2024). Subsequent studies should examine legal frameworks of governance and compliance in the growth of cities, and analyze the impact of growth patterns on institutional frameworks. Furthermore, one of the main drawbacks of the study is that it encompasses only six cities, which restricts a comprehensive picture of European urban sprawl. Research should, therefore, extend the findings to more second-tier cities, newly formed megacities, and to other regional and global cities from North America, Asia, and Africa (Li et al., 2023; Lu et al., 2022). Likewise, more research focusing on the longitudinal analysis of the environmental consequences of sprawl on ecosystems, climate, and sustainable policies should be conducted (Aleixo et al., 2024; Resemini et al., 2025; S. Zhang et al., 2025). This study underlines the importance of comprehensive and holistic planning initiatives through employing remote sensing, GIS, AI spatial analysis, and policy measures. Efficient policies related to land-use, improvement of the public transport system, protection of green areas, and utilization of AI in urban modeling will play a vital role in achieving sustainable and resilient urban systems in Europe.

Like any research, this study has certain limitations that should be considered when interpreting the findings. The use of an online questionnaire may have introduced some sampling bias, as respondents were mainly well-educated planners and policymakers, possibly limiting the range of viewpoints represented. Additionally, although the proposed decision-support framework shows strong potential, it has not yet been tested in practice or validated through direct engagement with stakeholders, which would be essential for understanding its full applicability in real-world contexts. Lastly, the resolution of the remote sensing data, while appropriate for large-scale analysis, may overlook smaller, localized urban changes. Future research could address these points by involving a wider range of stakeholders and exploring higher-resolution data to further enhance the framework's practical value.

6. Conclusion

This study presents an urban sprawl assessment of European cities through the integration of remote sensing and GIS to evaluate the dynamism, form, and causes of urbanization. Focusing on six strategic cities (London, Paris, Madrid, Berlin, Rome, and Athens), this paper underscores the global pervasiveness of sprawl, its pernicious environmental and socio–economic ramifications. Its findings support the position that urban growth has precipitated the deterioration of the greens, poor air quality, and the widening inequalities in the socio-economic profiling of the population, making the call for a more sustainable urban development framework uncontestable. One innovation of this study is the formulation and testing of the Decision-Support Framework that combines geospatial analysis, modeling, and urban planning for systematic assessment and management of urban sprawl.

This framework improves the decision-making process in urban planning, the proposals for dealing with the effects of uncontrolled suburbanization, and the accuracy of land-use strategies. References to pilot projects underscore the relevance of this framework in practice-based urban planning contexts. In addition to affirming propositions made in previous research on urban sprawl, the study contributes to the literature by providing a visual representation of the problem and demonstrating that the existing land-use plans and policies have been impossible in their ability to mitigate this issue. This underlines the imperative of drawing and implementing comprehensive, cross-sectional development plans that incorporate smart growth strategies, transit-oriented development, and community involvement strategies. This means that certain measures have to be taken to reduce the impacts of urban sprawl, including strengthening regulations, upgrading infrastructure planning, and improving data accessibility.

Future research should follow up on the present study by integrating more sophisticated machine learning techniques and AI geographic information systems to improve the prediction of urbanization models. Moving forward, the research will also encompass a wider array of city types—emerging megacities and mid-sized cities—which would paint a larger picture of urban sprawl processes. Future studies should include longitudinal research examining the long-term impacts and efficacy of the UK's urban containment strategies. Finally, this research reaffirms the importance of geospatial technology in planning and underlines the need to develop new strategies that respond to the dynamics of contemporary cities. Cities' policy development and planning can embrace technological advancements to balance growth, environmental management, and socio-economic equity, leading to well-organized urban systems.

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