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Integrating GIS and Remote Sensing for Sustainable Urban Infrastructure Development in Amman, Jordan

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Abstract

The rapid urbanization of Amman, Jordan, has intensified the need for sustainable urban infrastructure development to accommodate growing population demands while minimizing environmental impacts. This study explores the integration of Geographic Information Systems (GIS) and Remote Sensing (RS) tools to assess and guide the development of sustainable infrastructure in Amman. By utilizing high-resolution satellite imagery and spatial data, the study analyzes land-use patterns, urban expansion, and infrastructure development to identify key areas for improvement. The research focuses on detecting changes in land use, evaluating environmental impacts, and proposing strategies for enhancing urban infrastructure to align with sustainable development goals. The findings highlight significant gaps in infrastructure services, environmental stress caused by rapid urban growth, and opportunities for smarter, more sustainable urban planning. This research offers a data-driven approach to infrastructure planning, providing urban planners and policymakers with actionable insights to ensure Amman's future growth is sustainable, efficient, and environmentally conscious.

Keywords: GIS, Remote Sensing, Sustainable Development, Urban Infrastructure, Amman, Land-use Change, Environmental Impact, Urban Planning

Introduction

The rapid urbanization of cities worldwide, particularly in developing regions, has necessitated innovative urban planning and infrastructure development approaches. Jordan's capital city, Amman, has experienced significant urban growth over the past few decades, leading to increased demand for sustainable infrastructure. As urban expansion continues, ensuring infrastructure sustainability becomes essential to address the challenges of population growth, environmental degradation, and resource scarcity (Brooks & McArthur, 2019). In this context, GIS and RS tools have emerged as powerful technologies that provide a comprehensive understanding of urban dynamics, enabling the integration of sustainability principles into infrastructure development (Waheed et al., 2023).

GIS and remote sensing technologies offer unique advantages in urban planning by enabling real-time spatial data analysis, monitoring of land-use changes, and evaluation of environmental impacts (Maruna et al., 2018). In Amman, a city characterized by rapid urban sprawl, these tools can help urban planners and policymakers visualize and analyze complex spatial data, thus supporting decision-making processes to foster sustainable infrastructure development. The combination of GIS and remote sensing allows for identifying optimal locations for new infrastructure projects, evaluating existing infrastructure performance, and predicting future urban growth patterns (Abdin et al., 2018).

Amman's urban growth presents unique challenges that underscore the need for sustainable development. With a population nearing 4 million, the city faces pressure to expand infrastructure services, such as transportation networks, water supply, and energy systems. However, rapid growth also contributes to increased environmental stress, such as reduced green spaces, higher air pollution levels, and inefficient resource use (Addas & Maghrabi, 2021). Integrating sustainability principles into infrastructure development is, therefore, critical to mitigate these issues and ensure that Amman's urban growth does not compromise the well-being of future generations (Zeadat, 2022).

This research explores how GIS and remote sensing technologies can effectively guide sustainable urban infrastructure development in Amman, Jordan. By combining satellite imagery, spatial data, and environmental analysis, the study seeks to provide insights into the city's land use and infrastructure patterns. The research will assess the current state of urban infrastructure, identify gaps and opportunities for sustainable growth, and propose strategies for enhancing urban infrastructure that align with environmental, social, and economic sustainability goals.

The study also highlights the importance of integrating advanced spatial technologies into urban planning frameworks, particularly in regions undergoing rapid urbanization like Amman. By leveraging the capabilities of GIS and remote sensing, this research will contribute to a more informed, data-driven approach to urban infrastructure planning (Khalil & Arabia, 2014). Furthermore, the findings from this study will be relevant to urban planners, policymakers, and sustainability advocates aiming to strike a balance between development and environmental stewardship in Amman and other rapidly urbanizing cities across the globe.

Review of Literature

Daniel G. Costa et al. (2024), in the study "Achieving Sustainable Smart Cities through Geospatial Data-Driven Approaches," discussed the growing significance of smart cities in the context of sustainable development goals. The study highlights how smart-city services have tackled common urban challenges and opened new pathways toward sustainability. Geospatial methods have become central to unlocking the full potential of smart urban environments, offering numerous applications that enhance understanding of urban issues and drive innovation. Despite advancements, challenges persist, particularly when the capabilities of available technologies and resources are not fully understood or utilized. The article reviews the field's current state, emphasizing successful cases and ongoing obstacles in employing geospatial data-driven strategies. These strategies often involve geographic information systems, satellites, and distributed sensors for generating and processing geospatial data in urban settings. Additionally, the study offers an organized overview of the field and identifies future trends, aiming to inspire further research that supports the development of smarter, more sustainable cities.

Jeetesh Joshi (2023), in the study "A Systematic Study on Integration of GIS and Remote Sensing for Urban Environmental Analysis," emphasized the growing importance of integrating GIS and RS in urban environmental analysis. The study systematically explores the potential of using GIS and RS to understand better and analyze urban environments. By merging spatial data analysis with remote sensing imagery, the research provides valuable insights into various environmental factors such as land use, vegetation cover, air quality, and urban growth patterns. The study focuses on this integration's benefits, challenges, and opportunities, particularly its application in India.

Arunim Anand and Chirag Deb (2023), in the study "The potential of remote sensing and GIS in urban building energy modeling," emphasized the increasing energy demand in cities driven by rapid urbanization, with buildings accounting for over 75% of urban energy consumption and contributing to more than two-thirds of emissions. The study highlights that assessing energy demand in urban buildings requires an interdisciplinary approach, integrating energy studies, geography, engineering, economics, sociology, and urban planning. Over the past decade, several urban building energy modeling tools (UBEMs) have emerged to estimate and predict energy demand, aiding policymakers in evaluating future energy scenarios. However, obtaining the necessary data for UBEMs has posed a significant challenge. This review thoroughly assesses how remote sensing and GIS techniques can support UBEM data acquisition. It identifies the key input variables for UBEM by analyzing recent publications and explores over 140 research papers on data collection through remote sensing and GIS. The study finds that satellite remote sensing and Unmanned Aerial Vehicles (UAVs) hold considerable potential for enhancing UBEM's data inputs, though their use has been limited. Additionally, the paper discusses the challenges associated with these technologies and proposes potential solutions. It advocates for utilizing existing methods for data extraction and integrating advanced technologies like machine learning and artificial intelligence to improve the effectiveness of UBEM.

Reza Mortaheb and Piotr Jankowski (2023), in the study "Smart city re-imagined: City planning and GeoAI in the age of big data," delve into the evolving discourse around city planning within the context of smart cities. The authors argue for a reconceptualization of the technocentric approach to smart cities, advocating for a greater integration of city planning into the smart city narrative. They suggest that smart cities can benefit from the synergies between city planning and three key techno-scientific domains: Big Data, Geographic Information Science and Systems, and Data Science, which together form the field of Geospatial Artificial Intelligence (GeoAI). The study outlines four policy goals that could be achieved through this integration: 1) increasing the efficiency of urban services and functions; 2) enhancing the quality of life for all urban residents; 3) addressing societal, ecological, and economic challenges at multiple levels; and 4) contributing to the generation of spatial data, information, and knowledge about human-urban dynamics. Additionally, the authors propose a human-centered framework demonstrating how the interplay between city planning and these scientific fields can enhance planning practices and help achieve smart-city objectives. The study's methodology includes a systematic literature review, examining the progress made in combining city planning with GeoAI and identifying challenges in applying GeoAI to urban planning, design, and management.

Objectives of the Study

The study was conducted using the following objectives:

- To analyze urban infrastructure development patterns in Amman using GIS and remote sensing tools.
- To assess the environmental impact of urban expansion in Amman through land-use change detection and spatial analysis.

Research Methodology

The study adopts a descriptive and analytical research design, focusing on using GIS and RS technologies to support sustainable urban infrastructure development in Amman, Jordan. The

research relies on secondary spatial data to develop a comprehensive model for urban planning. The methodology analyzes spatial patterns, urban growth, and infrastructure development by integrating GIS and remote sensing techniques. The study was conducted in Amman, the capital city of Jordan, which is undergoing rapid urbanization. The study area encompasses a range of urban zones, including central business districts, residential areas, and peri-urban regions, focusing on the impact of infrastructure development on sustainability. These images help assess the expansion of urban areas and infrastructure development. GIS data, including urban road networks, utility infrastructure (water, electricity), and demographic layers, are obtained from government agencies such as the Greater Amman Municipality and the Ministry of Public Works and Housing.
Satellite images are pre-processed to correct for atmospheric distortions and ensure consistency in spatial resolution. This includes techniques such as radiometric correction, georeferencing, and image enhancement. A supervised classification method is applied to the satellite images to classify the urban area into land-use categories (e.g., residential, commercial, industrial, and green spaces). The Normalized Difference Vegetation Index (NDVI) is also employed to assess vegetation cover. A temporal analysis is conducted to detect land use and infrastructure development changes over time (e.g., between 2010 and 2024), highlighting urban sprawl and infrastructure expansion in Amman.

NDVI-Based Visualization

NDVI measures vegetation health and density using satellite imagery. It ranges from -1 to 1, where:

- Values close to 1 indicate healthy vegetation.
- Values near 0 suggest sparse or no vegetation.
- Negative values usually indicate water or built-up areas.

NDVI can be calculated using the formula:

$$\text{NDVI} = \frac{(\text{NIR} - \text{RED})}{(\text{NIR} + \text{RED})}$$

, where **NIR** is the Near-Infrared Band, and **RED** is the Red Band.
Satellite images are used to measure the health and density of vegetation using NDVI. The analysis uses NDVI and compares vegetation health in Amman, Jordan, in two different moments (2000 and 2024). It shows the changes in the density and health of vegetation due to urbanization and environmental factors.

Data and Results

Table 1: Urban Infrastructure Development in Jordan

Year	Urban Population (in % of total population)	Built-Up Area (in sq. km)	Green Spaces (in % of urban area)	Infrastructure Investments (in million USD)	Air Pollution Index (PM2.5, Âµg/mÂ³)	Annual Water Supply (in a million mÂ³)
2000	79.5	40	12.5	500	35	45
2005	81.2	52	10.8	720	40	42
2010	83.6	68	9.4	950	48	39

2015	85.3	85	8.1	1200	55	36
2020	87.1	100	7.2	1500	62	34
2024	87.85	112.5	6.625	1625	64.5	31.5

Source: UN-Habitat (Jordan)

The table shows data on urbanization and environmental variables in Amman, Jordan, from 2000 to 2024, focusing on significant developments in urban population growth, built-up area increase, green space loss, infrastructure investment, air pollution, and water supply.
There has been a slow increase in the urban population as a percentage of the total population, 79.5% in 2000 and 87.85% in 2024. This shows a considerable growth of around 10.5% over 24 years, which refers to a fast urbanization process. This continued growth suggests a growing proportion of Amman's population living in urban localized areas due to mobility, economic development, and natural population growth.

The built-up area increased wildly, rising from 40 sq. km in 2000 to 112.5 sq. km in 2024 while almost tripling. This increase is significant and quite visible and also adds immense pressure to the outskirts of our metropolises due to the need to accommodate the growth of our populations and infrastructure. This trend could, however, also reveal aspects of unplanned urbanization leading to resource constraints and environmental degradation.

Urban green spaces (a percentage of urban areas) have significantly declined from 12.5% in 2000 to 6.625 % in 2004. This nearly 50% drop indicates how built-up spaces consume natural landforms like parks. Reducing green spaces affects biodiversity and the city's capacity to alleviate heat island effects, control air quality, and offer recreational areas for its citizens.

On the other hand, investments in infrastructure increased significantly from 500 million USD in 2000 to 1625 million USD in 2024. This is part of the government's attempts to upgrade urban infrastructure to accommodate an increasing population. This trend is good for economic growth, but the failure to align it with its environmental sustainability, as seen in the gradual depletion of green spaces and increased pollution levels, demonstrates the need for more environmentally sensitive planning.

The air pollution index (PM2.5) climbed steadily from 35 µg/m³ in 2000 to 64.5 µg/m³ in 2024, an increase of just under 84%. This pattern correlates with urbanization, increased vehicle exhaust, industrial activity, and diminishing green zones. Increased air pollution is associated with a higher risk of adverse health outcomes, especially respiratory and cardiovascular diseases, and highlights the compelling need for regulatory actions to control pollutants.

Annual water supply decreased continuously from 45 million m³ in 2000 to 31.5 million m³ in 2004, a nearly 30% drop. This trend reflects growing water stress in the region, made worse by population growth, climate change, and water management waste. It underscores a pressing concern for Amman, where water scarcity may seriously impede sustainable development.

Amman's landscape changes due to the rising urban population and built-up areas, significantly affecting infrastructure, resources, and the environment. The green areas in the chart above were lost on the top map of the city, where air pollution is the gravest and urban sprawl is on the rise. Despite increases in infrastructure investments, they are not in line with sustainability principles, as seen through decreasing green spaces and deteriorating air quality. The persistent reduction in water supply highlights the increasing water stress, which is the primary obstacle to urban sustainability. The implications indicate a necessity to leverage green infrastructure with renewable energy and water conservation interventions to tackle such imminent challenges through urban planning.

Figure 1: Urban Infrastructure Development in Jordan

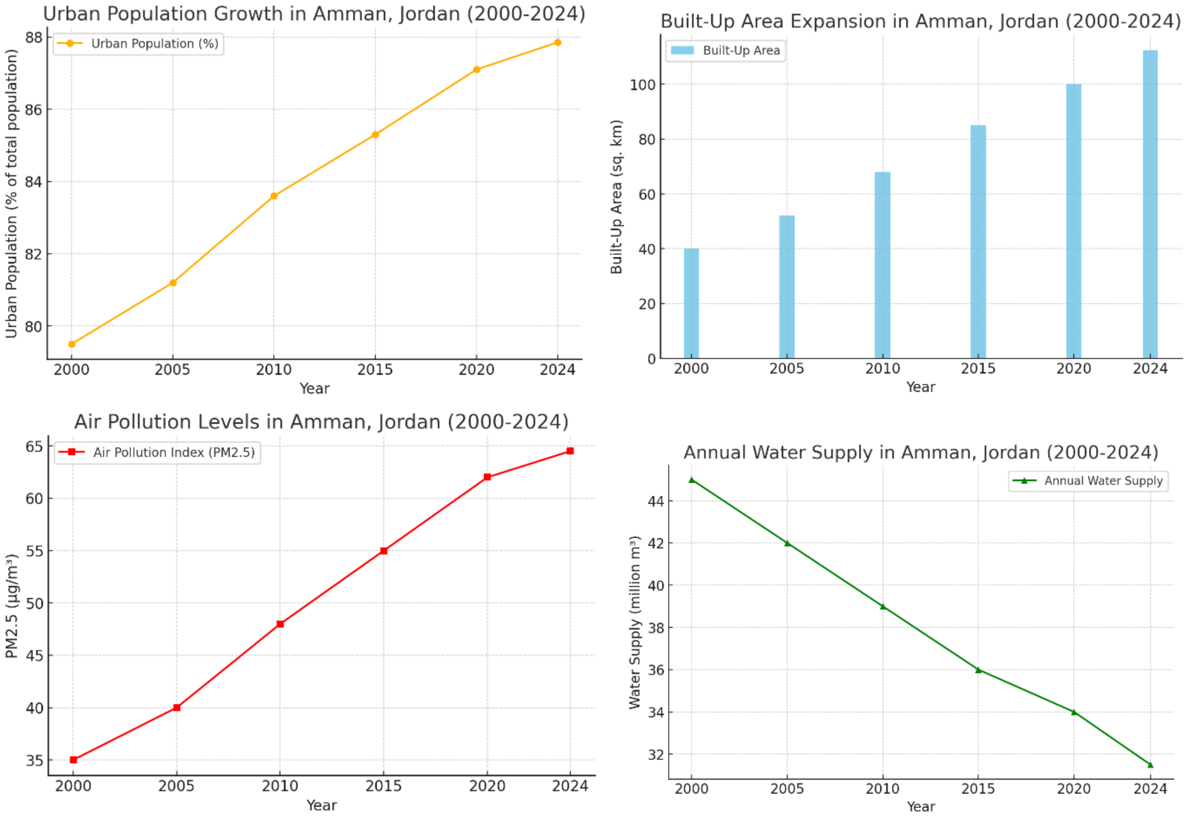
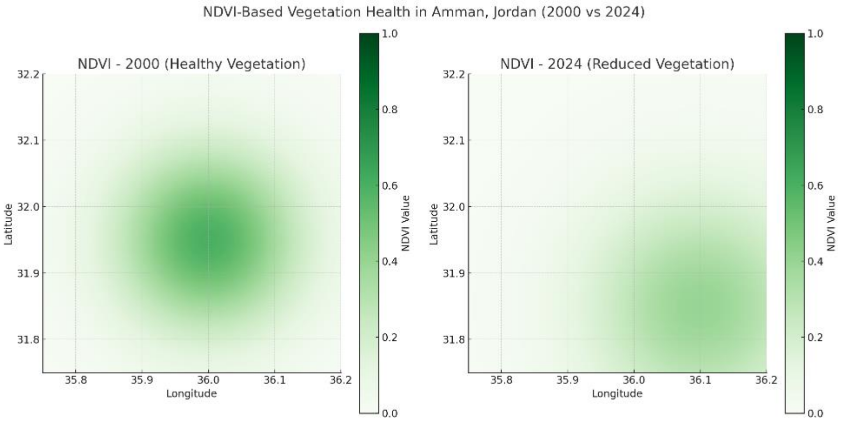


Figure 2: NDVI-Based Vegetation in Amman, Jordan



Source: NDVI (2000-2024)

The two separate panels of the visualization represent different patterns of vegetation health with valuable implications.

The first panel shows NDVI in 2000. It reveals thick and abundant vegetation, especially in the central parts of the map. These high NDVI numbers indicate healthy vegetation, which could be due to agricultural lands, natural landscapes, or public green spaces still untouched by urban growth. If only the year with healthy vegetation (2000) is observed, there would be much less urban density and much more untouched nature, favoring ecological balance.

In contrast, the 2024 NDVI map indicates a significant decrease in vegetation density, evidenced by the lighter green colours and NDVI values. Notice that the high NDVI (the NDVI green) area has decreased a lot, which we could conclude about the damage to the vegetation. This decrease is in line with urban sprawl, which has led to developed land (and consequently urban areas) taking over natural land. The NDVI retreat indicates the compromise in the big city's environmental quality and ecological sustainability. Less vegetation can worsen urban heat island effects, worsen air quality, and reduce the city's capacity to absorb stormwater runoff and perform other ecological functions.

The 2000-2024 comparison shows the devastating influence of urbanization on green spaces. Urban infrastructure is crucial for facilitating population and economic growth, but the visualization highlights that planning must center on sustainable approaches that balance growth. Implementing counter strategies like adding urban green savings areas and increasing reforest areas will dignify policy specifications that will not affect the existing vegetation.
This visualization has important implications for sustainable urban planning. It offers a reference point for tracking vegetation in the long term, allowing policymakers to gauge urbanization's environmental effects. These insights can also shape strategies for reforestation, urban greening, and preserving existing green spaces. They also emphasize how imperative it is to accommodate ecosystems within cities to prevent heat islands, improve air quality, and build urban resilience to climate change.

Discussion and Conclusion

2000-2024 witnessed urban growth accumulation, mainly in Amman, Jordan. The analysis presents trends of urbanization processing with degradation of the built environment and constraints related to urban resource management. Amman has shown signs of growth through the rapid development of urban areas and more significant infrastructure investments that help its growing population and economic development. These advancements were not without significant environmental sacrifices, as can be witnessed by decreasing green spaces, increasing air pollution, and decreasing water resources.

While this gradual increase in the urban population and the built-up areas has altered the overall cityscape, it has also challenged sustainability. This reduction of available green space from 12.5% (2000) to 6.625% (2024) represents the widespread encroachment of natural spaces, leading to the loss of biodiversity and ecosystem services. Moreover, there is a steep increase in air pollution (PM2.5). On the one hand, the degradation of the air quality and water scarcity we suffer highlight the increasing environmental and public health hazards stemming from unregulated urban densification. These findings highlight the importance of sustainable urban planning in Amman to balance urban growth and preserving the environment (Taifour *et al.*, 2022).

The findings highlight the need to incorporate sustainability as part of urban planning. The loss of green spaces and the increasing air pollution indicate the necessity for establishing and preserving urban green spaces. Green infrastructure projects, parks, urban forests, and vertical gardens should be prioritized to reduce the urban heat island effect, increase air quality, and enhance residents' quality of life. The decrease in the annual water availability indicates the current water scarcity problem (Zraqou et al., 2024). Water challenge, which includes effective water management policies like rainwater harvesting, recycling of wastewater, and promotion of water-efficient technologies. Long-term climate adaptation strategies that protect water resources must also be established. Increasing pollution emphasizes the importance of switching to cleaner energy sources and transportation. Emissions can be reduced significantly by implementing policies designed to promote the adoption of electric vehicles, accelerate the uptake of energy-efficient technologies, and invest in renewable energy infrastructure that supports these efforts, supporting global sustainability objectives (Zeadat, 2022). Government agencies, private stakeholders, and locals must work together to achieve sustainability. Grassroots-level movements such as awareness campaigns and community-driven initiatives can be crucial in encouraging environmental sustainability and responsible practices in small communities. Ongoing monitoring and analysis of urban metrics, such as NDVI-based vegetation assessments, air quality indices, and water resource trends, can inform evidence-based policymaking (Qtiashat et al., 2018). Geospatial and satellite-based technologies can be integrated to expedite applicability, build a framework to track urban changes over time, and design adaptive policies.

Integrating green infrastructure within city plans will help combat the urban heat island effect, improve air quality, and provide Amman with recreational and mental wellness opportunities. In addition, zoning should be used to ensure that urban development is balanced with preserving natural ecosystems and open spaces.
Investments in renewable energy and cleaner technology are critical to reducing the city's growing levels of air pollution. Investing in green tech– like solar panels, wind turbines, etc – can reduce already high levels of greenhouse gas emissions and dependence on fossil fuels. Also, encouraging electric vehicles, improving public transport systems, and rewarding energy-efficient home appliances can help. Such measures respond to local environmental

concerns and deeply resonate with Jordan's expansive sustainability agenda and international obligations.

Amman has to improve its water resource management system to address the current water supply challenges. Emphasis should be given to sophisticated water rescues, such as collecting rainwater, recycling wastewater, and desalination. It can also help drive household participation by deploying public awareness campaigns on water-saving practices or aligning market signals around water-efficient technologies. In addition, the city must invest in the city distribution systems to reduce water losses due to leaking water or inefficiency.

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