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Balancing Development and Sustainability: An Environmental Management Study of Urban Sprawl in Amman through Remote Sensing and Econometric Analysis.

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ABBREVIATIONS AND ACRONYMS

DN - Digital number

DOS - Department of Statistics

EO - Earth observation

GAM - Greater Amman Municipality

K - Kappa coefficient

LSE - Land Surface Emissivity

LST - Land Surface Temperature

LULC - Land Use Land Cover

$L\lambda$ - Spectral radiance

MDGs - Millennium Development Goals

MIR - Mid-infrared

NASA - National Aeronautics and Space Administration

NDBI - Normalized Difference Built-up Index

NDVI - Normalized Difference Vegetation Index

NIR - Near-infrared

OLI-8 - Operational Land Imager-8

OLS - Multiple Ordinary Least Squares

PSR - Pressure-State-Response

PV - Proportional Vegetation

RS - Remote sensing

SDGs - Sustainable Development Goals

SVM - Support Vector Machine

SWIR - Shortwave Infrared

TIR - Satellite-sensed thermal infrared

TM - Landsat Thematic Mapper

TOA - Top of Atmosphere Reflectance

Tsat - At-satellite brightness temperature

UEII - Urban Expansion Intensity Index

USGS - United States Geological Survey

1. INTRODUCTION

Urbanisation is a global phenomenon that has changed civilizations and landscapes. An extraordinary rise in the worldwide urban population has caused major territorial, social, and environmental changes during the previous several centuries. The chapter provides an introduction to the research topic.

1.1 Background:

Amman's urban area has grown from 80 square kilometres to 128 square kilometres in the previous 12 years, an increase of 16 percent (or 10.7 square kilometres per year). That works out to a 1.3% increase each year. When just urban areas are considered, the overall area of urban areas in 2015 was 64% bigger than in 2003. This equated to an annual growth rate of 5.3% in the first urban area. Amman's population density increased from 2003's 2469 persons per square kilometre to 2015's 4453. This increase happened between 2003 and 2015, specifically. Between 2003 and 2015, the population density increased by 80 percentage points, as shown. The fast increase in population densities (also known as population inflation) in Amman may help to explain the rapid rate of urbanisation in the city, according to a study by Al-Kofahi et al. (2018).

Tewfik (2014) claims that the capital city of Amman is the site of 80% of Jordan's economic and industrial activity. The growing population of the city benefits from this. The city's thriving economy is attracting new residents. Most of Amman's urban development has been done by destroying farmland, whereas rural areas have seen less change. More than half of the cropland that existed in 2003 had disappeared by 2015. This resulted in the loss of 104 square kilometres of agriculture between 2003 and 2015, or around 8.7 square kilometres each year, as reported by Al-Kofahi et al. (2018). Agricultural land made up over 27% of Amman's total land area in 2003, but just 14% in 2015 (a decline of 1.1% annually). It is projected that in another 13 years, the remaining 14% of Amman's land will be completely worthless if there is no further drop in the amount of arable land. The limited agricultural area, water supply, and biodiversity in the city may all suffer as a result, say Al-Kofahi et al. (2018).

Over the last few centuries, the worldwide urban population has grown, changing Earth's physical environment (Sengupta et al., 2023). The 1950 worldwide metropolitan population was 0.73 billion (Kundu & Pandey, 2020). In 2017, their values were 4.23 billion, up 1.93 percent from the previous year (Kundu & Pandey, 2020). The urban population grew 1.89 percent faster than the overall population throughout the period. The urban population is expected to reach 4.31 billion in 2019, up 1.86% from 2018 (Chantakeeree et al., 2022). The worldwide urban population rose 1.8% to 4.38 billion in 2020 (Lee et al., 2021). Global urbanisation is affecting several social sectors (Hiremath, 2021). By 2050, the urban population is expected to rise by 68%, increasing urban land demand (Huang et al., 2019).

Urbanisation—moving from rural to urban lifestyles—is hard (Rosas-Plaza et al., 2022). It describes a region's territorial and socioeconomic development, particularly from undeveloped to developed land use categories (Li et al., 2021). Urbanisation destroys natural and semi-natural areas worldwide (Puplampu & Boafo, 2021). 30–70% of the world's population will relocate to cities this century, increasing urban land usage (Sleeman et al., 2019). 60% of humanity will reside in 100 megacities by 2030 (Lu et al., 2022). Urbanisation will force two-thirds of the world's population into cities by 2050 (Kundu & Pandey, 2020). Urban sprawl is classified as economic, transportation, and geographical spread (Coq-Huelva & Asián-Chaves, 2019). Planners have used "sprawl" since 1937 (Khurram, 2022). "Urban sprawl" is unplanned expansion outside a metropolis (Paramasivam & Arumugavelu, 2020). Urban sprawl hinders physical development management, which provides economically sustainable land use and regulates the borders of rapidly urbanising metropolitan regions (Cobbinah, Asibey, & Gyedu-Pensang, 2020). City policies affect urban sprawl and greenhouse gas emissions. In recent years, metropolitan regions have used 60–80% of the world's energy and produced over 70% of its greenhouse gas emissions (Meng et al., 2019).

Human and economic advancements cause these changes. Urbanisation reduces agricultural project profitability, separates agricultural regions, and reduces agricultural land units, according to Al-Bakri et al. (2013). Food, fibre, clean air, soil, and water from agriculture buffer communities and natural habitats (Doygun, 2009). Abu-Rmeileh & Afifi (2000) claim agricultural land loss destroys biodiversity and indigenous plant species. This land structure change will increase impermeable surfaces, restrict natural drainage, and aggravate waterlogging and runoff (Quan et al. 2010). Developers are likely to construct on undeveloped lands in and around metropolitan centres, swiftly encroaching on neighbouring properties in urban sprawl (Al Tarawneh 2014).

Despite Jordan's severe water and energy shortages, the country has taken a disproportionate share of refugees fleeing wars in Iraq, Syria, and Palestine (Meaton & Alnsour, 2014). The rate of urbanization has surged from 44% in 1961 to 83.6% in 2013, with the latest population census revealing a figure exceeding 11.5 million residents by the end of 2023, as reported by Ammon News (2024). The number of urban centres has increased, while the rural population has decreased due to this rise. The inadequacy of current infrastructure to support growth in both people and housing has contributed to a dramatic acceleration in inflation in major cities. Compared to the biggest cities in Asia, which expanded at a pace of 3% annually between 1970 and 1990 (Ahmad et al., 2013), Jordan's urban centres expanded at a rate of 4.1% (Department of Statistics, 1991).

Many problems have arisen as a result of the ongoing urbanisation and refugee influx. These include overcrowding, informal settlements, degraded agricultural land, poor urban services, congested roads, and an absence of green space (Alnsour, 2014; Meaton & Alnsour, 2012). The ongoing changes and difficulties in Jordan necessitate an analysis of urban growth management in order to implement effective policies and practices that can swiftly and efficiently handle urbanization. A better response to the challenges posed by fast urbanisation can be achieved through the evaluation of urban growth management.

Amman, Jordan's capital, faces urban expansion challenges such as sprawl, congestion, high temperatures, loss of vegetation, and water scarcity as a result of uncontrolled growth with a population of over 4 million. The city's transformation into a regional hub emphasises the critical need for sustainable growth strategies. Despite constraints, Amman's authorities are committed to sustainability by improving services and living conditions while promoting environmentally friendly practices such as hybrid cars and solar panels. Understanding factors such as land surface temperature (LST), land use and land cover (LU/LC), the Normalised Difference Vegetation Index (NDVI), and the Normalised Difference Built-up Index (NDBI) are critical in urban climate change research, emphasising the importance of sustainable urban development approaches. Finally, effective urban planning is critical for efficiently managing rapid urbanisation and addressing sprawl.

1.2 Research Objectives:

The main research objective of this study is:

- To investigate the complex interrelationships among urbanisation, population density, socio-economic factors, land use patterns, and their impacts on vegetation cover, land surface temperature (LST), and environmental sustainability in the context of urban sprawl in Amman, Jordan.

The research objectives are as follows:

1. To explore the impact of land use policies and strategies on the environmental sustainability of urban sprawl in Amman.
2. To find out the relationship between urbanisation, population density, and environmental sustainability in Amman
3. To examine the effect of the increase in built-up areas on agricultural land in Amman
4. To discover the relationship between economic indicators and urban sprawl in Amman.

5. To analyse the correlation between land surface temperature (LST) and socio-economic indicators, specifically household type and income level, in Amman City in order to understand the potential impact of socio-economic dynamics on urban heat patterns.
6. To quantitatively assess the impact of woody vegetation with an NDVI greater than 0.8 on surface temperature reduction in urban areas with arid and semi-arid climates, using Amman as a case study.

1.3 Research Questions:

The main research question of this study is:

- How can the complex interrelationships among urbanisation, population density, socio-economic factors, land use patterns, and their impacts on vegetation cover, land surface temperature (LST), and environmental sustainability in the context of urban sprawl in Amman, Jordan, be investigated and managed to achieve a balance between development and sustainability?

The following are the research questions:

1. How do land use policies and strategies impact the environmental sustainability of urban sprawl in Amman?
2. What is the relationship between urbanisation, population density, and environmental sustainability in Amman?
3. What is the relationship between economic indicators and urban sprawl in Amman?
4. How does the increase in built-up areas affect vegetation and agricultural land in Amman?
5. What is the relationship between land surface temperature (LST) and socio-economic factors, such as household type and income level, in Amman City?
6. To what extent does a higher NDVI value contribute to cooling the city, or to what extent does woody vegetation (NDVI greater than 0.8) cool the surface in cities with arid and semi-arid climates like Amman?

1.4 Significance of the Research:

The rapid urbanisation associated with environmental challenges in many parts of the world has posed a challenge for the people living in them. As cities expand and urban sprawl continues, there is a growing need for effective management strategies to mitigate the negative impacts on the environment, including the loss of green space, increased pollution, and reduced biodiversity. Remote sensing and multivariate statistical approaches offer a promising solution for monitoring and managing the environmental impact of urban sprawl by providing accurate and timely information on land use and land cover changes, as well as identifying the underlying drivers of these changes. The aim is to develop a comprehensive framework for monitoring and managing the environmental impact of urban sprawl, which can be applied in different urban contexts to improve sustainable urban development. The literature review on the topic further highlights the importance of using remote sensing and multivariate statistical approaches for accurate and efficient monitoring and management of urban sprawl.

Figure 1. General view of Amman city Retrieved from Townsend, M. (2023). Jordan At A Crossroads. Retrieved from https://gfmag.com/features/jordan-crossroads/

2. LITERATURE REVIEW

Urbanisation has changed global geography and presented new difficulties and possibilities for communities. It is necessary to explore the quantity of literature to understand and negotiate this complicated change as urban growth continues to reshape our cities. This chapter begins with a detailed analysis of the broad and multifarious literature on urbanisation, its propelling causes, its consequences for different sectors, and its sustainability methods. By synthesising and assessing current evidence, the research aims to illuminate the intricate dynamics of urbanisation and guide sustainable urban development discourse and policies.

2.1 Background:

Urban studies now examine how globalisation is changing cities. Several studies have complicated the topic of the formation of cities, particularly major cities, in a global system based on the deconstruction of contacts and the potential of specific places to attract high-value businesses (Osman, 2019). Cities dominate the creation, distribution, and acceptance of neoliberal urban models in a general rivalry (Zamanifard, Alizadeh, & Bosman, 2018). Urban growth in agricultural regions affects all nations. Most nations, especially growing ones, are facing resource depletion due to the fast population increase, especially in agricultural regions near cities (Abu Hatab et al., 2019).

Housing and human services need land as the population grows. The swift cultural change and population growth in Jordan disrupted the traditional relationship between people and the environment (Abdel Jawad and Nagy 2023b). Urbanisation and inadequate planning caused agricultural regions to disappear. Amman, Jordan, is quickly urbanising as rural inhabitants migrate to metropolitan areas and from neighbouring nations. Amman's urban region grew unexpectedly, causing several challenges. Thus, urban planning in Amman must anticipate future built-up regions (Abdel Jawad and Nagy, 2023a).

This study uses remote sensing and ordinary least squares (OLS) regression, a form of multivariate analysis commonly used in econometric analysis methods, to monitor and manage Amman's sprawl's environmental effects. Remote sensing and multivariate statistics might solve the lack of study on urban sprawl's environmental impact on land cover and usage in the region. This chapter discusses the causes of sprawling worldwide in the current environment, its negative effects on biodiversity, pollution, and green space, monitoring and managing its environmental impacts, its effects on land use and cover changes, the relationship between biophysical variables and land surface temperature, and its effects on agricultural land and the environment. This chapter also describes how econometric and remote sensing analyses will fill literature shortages. On the other hand, a popular method for estimating the coefficients of linear regression equations that describe the connection between a dependent variable and one or more independent quantitative variables is ordinary least squares regression (OLS). This technique can be applied to both simple and multiple linear regressions.

2.2 Urban Sprawling

For various individuals, the definition of urban sprawl can vary. Some perceive it as an unintended consequence of suburban living and driving to work (Yasin et al., 2021), while others view it as a waste of resources such as land, water, air, and energy (Lehmann, 2021). Above all, it is harmful to civic life, if not to the economy and society (Silva & Vergara-Perucich, 2021). This diverse understanding highlights the complexity of urban sprawl and the need for a comprehensive approach to address its negative impacts.

Urban sprawl is described as how metropolitan areas physically grow at the expense of rural and natural regions. This term is not used anymore; however, it is still in use, especially in those areas that are currently in the sub-urbanisation phase. According to literature, urban sprawl has historically been related to adverse consequences, for example, decreasing connection (Rodríguez-Pose & Storper, 2020), a decline in the quality of public services (Narducci et al., 2019), higher energy uses for heating and transportation (Huang et al., 2019), air pollution, and traffic congestion, as well as a source of irreversible harm to regional ecosystems (Zhang et al., 2022). In the United States, urban sprawl has been widely recognised as a significant problem in spatial planning (Glaeser, E.L., and Kahn, 2004), but it has only recently received formal recognition in Europe (Zhongming et al., 2016). Currently, it is also becoming a significant problem in developing countries such as China (Zeng, He, & Chui, 2014), India (Sisodia et al., 2016), Turkey (Ozturk, 2017), and Jordan (Al Tarawneh, 2014). Urban sprawl has no official, widely accepted definition; moreover, no methodology is widely accepted to measure urban sprawl and define the concept quantitatively. Urban sprawl has been described differently in numerous studies in the past. Jaeger et al. (2010) reported at least 11 different definitions of urban sprawl in their review. The following five major characteristics of urban sprawl have been identified in the study of Ewing (1997): (a) scattered and a pattern of discontinuous development; (b) the emergence of low-density areas; (c) the exclusion of land uses; (d) low accessibility and reliance of people on private vehicles; (e) commercial sector development along major transit corridors. Visual perception as an element has been added to describe urban sprawl and highlight the importance of both urban size and urban shape in characterising urban sprawl.

Small and medium-sized cities sprawled most significantly, followed by large cities, while megacities sprawled the least, which was consistent with the existing literature. The sprawling initiated in small to medium-sized cities the most, which later extended to cities, whereas megacities experienced the least sprawling, as concluded in past studies (Feng et al., 2019). According to Tian et al. (2017), it is widely known that to maximise tax advantages and attract investment, local governments have relaxed control and management of urban expansion, resulting in severe urban sprawl. Liu et al. (2018) found that the reasons behind an increase in urban sprawl have not resulted from the additional supply of land for urban construction but from unplanned and illegal developments. Additionally, Lin et al. (2018) concluded that fixed purchase demand for housing and scarcity of land in a region are a few reasons that led to increased land prices, consequently driving housing prices up. However, the challenge of urban sprawl, along with elevated housing costs, has emerged as the main obstacle to future sustainable urban growth.

Nijman & Wei (2020) found that urban sprawl affects social, economic, political, and environmental issues. Wang et al. (2020 a) argue that urban development increases commute times and traffic congestion due to complex transportation networks. Ambinakudige et al. (2017) show that land use segregation creates racially divided communities, urban gaps, and strained social relationships. Spatial dispersion also makes schools and hospitals harder to reach. Urban sprawl's physical isolation reduces job chances, especially in outlying areas, worsening socioeconomic inequality. Lee et al. (2018) note that urban sprawl reduces social well-being, which increases economic inequality through longer commute times and lower household income. Segregation and social concerns concentrate on social effects.

Archer et al. (2019) list the many environmental impacts of urban sprawl. Changing water flow patterns and converting green places to impermeable surfaces degrades the ecosystem and increases flood hazards. Sprawl destroys wetland habitats and destroys biodiversity, according to Siles et al. (2018). Urban sprawl contributes to salinization, soil erosion, and climate change. Urban sprawl may increase soil quality and ecological health by transforming soil for development. Urban sprawl impacts Amman, Jordan. The growing urbanisation in Amman and the predicted 67% worldwide urban population rise by 2050 (Boretti & Rosa, 2019) highlight its social and political importance. Vegetation loss and greenhouse gas emissions show that urbanisation harms the environment (Dobbs et al., 2017; Correia Filho, 2021). From the mid-2000s to the present, Amman's urban footprint has increased carbon dioxide and pollutants, contributing to global warming. Greater Amman's urbanisation of agricultural land threatens ecological equilibrium (Al-Kofahi et al., 2018). This disturbing trend emphasises the need to research urbanisation, ecology, and the environment.

The art of organising human activities to minimise their influence on the natural environment is known as environmental management. It can include land, vegetation, animals, bodies of water, and the atmosphere of the planet. The primary goal of environmental management is to conserve the environment, maintain forms of life, and assure future generations' sustainability. In practice, this could include lowering carbon footprints, safeguarding endangered species, and supporting renewable energy sources (Raymond et al., 2010).

Remote sensing is the collection of techniques, tools, data, and sensors that enable us to study the Earth and its processes using airborne, spaceborne, and in-place sensors without coming into direct contact with the concept under investigation (Dierssen et al., 2021).

2.3 Theoretical Perspectives

2.3.1 Compact City Theory:

The design and control of the infrastructure of a city and transportation is known as urban planning. Sustainable urban planning, also known as sustainable urbanisation, is a method of city design that encourages active mobility and public transport while also increasing biodiversity and the use of energy. The New Urbanism movement explains the importance of sustainable urbanisation, which is centred on constructing walkable and ecologically friendly neighbourhoods (Koszowski et al., 2019).

"Compact city policy" and "multifunctional land use" originated in Europe, where urban planning is older than in the US. It is vital to clarify that multifunctional land use is the blending of several land use activities on one site to promote economic synergy, preserve space, and remain sustainable. Multipurpose land use may be seen in small cities, especially at accessible crossroads like railway stations and metro stops. Compact cities were created to achieve sustainable urban expansion and prevent urban sprawl. "A relatively high-density, mixed-use city based on an efficient public transport system and dimensions that encourage walking and cycling" is a good definition of a compact city (Nadeem et al., 2021).

Like the two urban planning concepts above, compact city strategies aim to minimise private car use and increase infrastructure efficiency. High population densities allow local amenities and services to be maintained, making higher-density communities more socially feasible (KORUR, 2020).

2.3.2 Urban Metabolism Theory:

Urban sprawl can be defined as the eventual growth of cities and their overflowing development, resulting in uncontrollable growth in peri-urban regions. According to UNESCO (2014), between the periphery of major cities and their surrounding rural areas lie peri-urban areas, which serve as a transition zone between rural and urban land usage. Peri-urban areas are located at the urban fringe along the edges of the built-up area and tend to comprise a scattered pattern of lower-density settlements and urban concentrations around transport hubs (Wandl & Magoni, 2017). These areas are economically dependent on the city, providing food and other goods to urban populations, and typically exhibit lower population density compared to urban cores. As cities grow, they encroach on more and more rural and industrial areas, making the lines between these two types of land more porous and fluid.

Understanding the inflows and outflows in the uncontrolled expansion of urban sprawl requires an understanding of the idea of urban metabolism. The fundamental principle of urban metabolism seems to view a city as an organism and respond to the numerous material flows for effective resource use (Parmar et al., 2023). The complementary reliance on material resources is the basis for the simultaneous existence of "peri-urban areas" and "urban cores." For instance, the inflow of food materials from the urban sprawl region to the city core used to differ from the outflow of waste materials from the dense city centre towards outside of the town limits or urban sprawl. Thus, it has become important and uttermost important to deeply understand the network of diverse material flows, which is the urban metabolism in a city. Urban metabolism plays a crucial role as a stimulant of different processes required for the effective operation of the city since these networks of heterogeneous material flows are connected with both the energy and economic flows engaged in them. To understand resource allocation, urban metabolism has become a prerequisite, which is an essential component of sustainable development (Shi et al., 2021).

2.3.3 Triple Bottom Line Approach to Sustainability:

According to the World Commission on Environment and Development (1987), sustainable development means meeting the needs of the present generation while preserving the environment and providing opportunities for future generations (Brundtland, 1987). This idea informs and relates to the triple bottom-line approach. The triple bottom line and sustainability principles are supported in economic growth sectors including business, planning, finance, and real estate. The triple bottom line and sustainable economic development recognise that economic development improves well-being and quality of life by creating wealth and jobs and that economic development involves creating, expanding, retaining, and recruiting jobs and businesses using various strategies.

These tactics include business assistance, workforce development, and the creation of networks, infrastructure, and facilities that facilitate firm growth and affect corporate site decisions. The awareness that social and environmental elements are inextricably related to economic growth and that all three must be considered for economic development adds to this conventional stance. The Millennium Development Goals (MDGs) were upgraded to Sustainable Development Goals (SDGs) in 2015 (Osborn, Cutter, & Ullah, 2015). This transition marked a significant shift in global development priorities, with the aim of addressing a broader spectrum of social, economic, and environmental challenges. The SDGs will guide global social and environmental progress with a more ambitious vision. The SDGs represent a worldwide consensus on progress towards a secure, equitable, and sustainable environment for everyone. They believe every nation should contribute to this ideal. Thus, reducing internal inequities and prejudices will be as important as international collaboration.

The United Nations (UN) General Assembly approved 17 Sustainable Development Goals (SDGs) in 2015. For example, "the goals and targets that will stimulate action over the next 15 years in areas of critical importance for humanity and the planet" (UN 2015, p. 5) are intended to be feasible targets that may be realised as a 2030 agenda for sustainable development. There are now approximately 230 indicators that have been recommended for achieving the 169 targets that compose the SDGs, which are further divided into smaller goals.

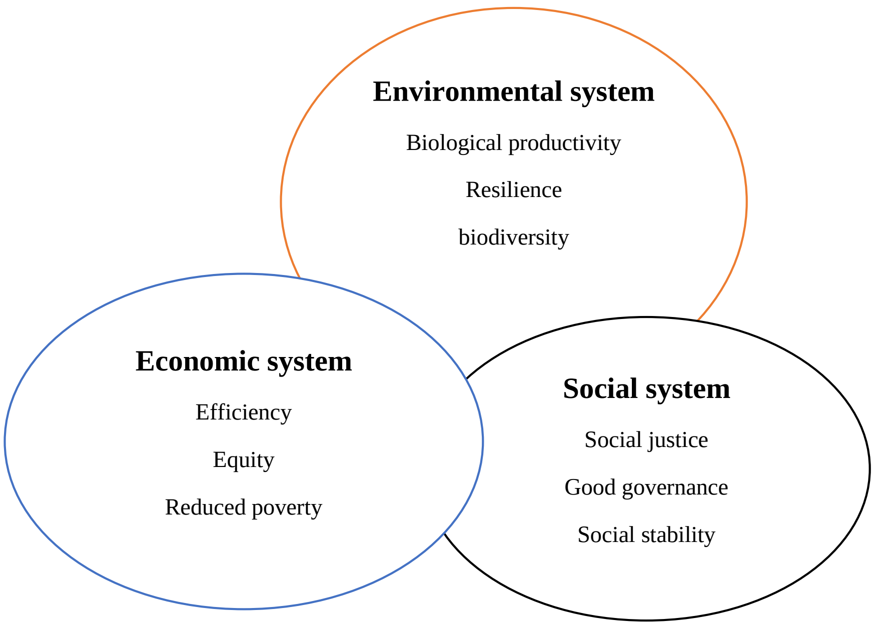

Figure 2. The systems approach to sustainability, Holmberg and Sandbrook, 1992

Source: Barbier et al., 2021

A Venn diagram (mentioned above as Figure 1) illustrates that the systems approach shows sustainable development as the intersection of the objectives assigned to three interconnected systems: the environmental (or ecological), economic, and social systems. The economic system must prioritise effectiveness, equality, and the removal of poverty while also taking into consideration how these factors affect biological production, ecosystems, and environmental adaptability, as well as how they affect fairness, transparency, and stability in society. The intersection of the environmental, economic, and social systems in Figure 1 serves as an example of the overall goal of sustainable economic development, which is to maximise goals across all of these systems through an adaptive process of trade-offs. (Barbier et al., 2021) The systems approach, which contends that sustainability can only be attained by balancing the tradeoffs among the various goals across environmental, economic, and social systems, was one of the first attempts in economics to explain sustainable development (Barbier et al., 2017). By highlighting the interdependence of the environmental, economic, and social systems and the potential consequences of development that is only focused on the objectives of one system, the systems approach has significantly contributed to sustainable development.

2.4 Remote Sensing and Geographic Information Systems in Environmental Analysis:

Visualisation is essential for development evaluation. Remote sensing can detect environmental changes, estimate land suitability, and locate specific land cover or land cover changes. Remote sensing (RS) can monitor large regions and assess desertification indicators, including urban growth (Colwell, 1983). Monitoring and mapping desertification is the best approach to controlling it. Remote sensing has tracked land degradation trends as well as dunes and their temporal dynamics. Satellite data obtained during the previous two decades for global monitoring has increased our understanding of desertification (Rivera-Marin, Dash, & Ogutu, 2022).

Remote sensing data and Geographic Information System (GIS) methods are increasingly used to analyse and extract data on drifting sand regions, urban land use mapping, ecosystem dynamics, and geological monitoring of natural threats like global warming (Richards et al., 1982). Urbanisation causes permanent desertification. Population and economic expansion are forcing agriculture into ecologically fragile areas, which may lead to desertification. The ecology deteriorates due to human population growth, which strains groundwater reserves and residential food and water supplies. Remote sensing categorises land use and urban development to measure urban growth and desertification. SPOT and Landsat data showed major increases in land degradation over 15 years, with urban development being the main cause (Wang et al., 2018).

2.5. Phases of Urbanisation:

Klaassen & Palinck's (1979) research on urbanisation invokes the different stages of urban growth. Pre-industrial, industrial, and post-industrial periods in urbanisation, as classified by Klaassen and Palinck, make clear the difference in urban growth. This method is valuable for assessing suburbanization in Amman. Based on what Klaassen and Palinck stated, before the industrial revolution, trade and commerce were common. The expansion of urban Amman could have begun with this phase, getting ready for the forthcoming changes. Trading and commerce impact urban spaces; hence, that period is pivotal to understanding the city's history. Amman’s urbanisation grows during the industrial period, which is marked by industry and production. understand how this era influenced the first surge in urbanisation and geographical growth to apprehend the city's physical and demographic alterations. We can say that the industrial era moulded Amman's urban landscape and paved the path for urban growth. Amman has now begun moving towards a post-industrial era; the theory of Klaassen and Palinck is thus of growing relevance. The shift to a knowledge-based economy directly influences urban expansion and land consumption. An examination of the factors that ushered Amman into that transformation opens up the underlying forces driving its urban design.

The urbanisation phases are critical to comprehending global urbanization. Urban growth and advancement are exhaustively looked into within the framework. Through studying the pre-industrial beginnings, industrial dynamics that fostered urbanisation, and post-industrial changes, scholars and urban planners can better analyse the intricate interactions leading to urban forms. Add them for intellectual stimulation and practical relevance to Amman urban development talks. Urban growth should be seen from a historical perspective, as this is determined by both the population and physical changes in the city. Urban planning requires this attitude. Planners are concerned with Amman’s urban expansion, and they should analyse the past of trade and commerce, industries’ expansion, and the transformation of the service economy to handle these issues.

2.6 Theoretical Framework:

2.6.1 Environmental Management Frameworks:

The pressure-state-response (PSR) framework can help agencies and stakeholders better understand actions and activities that influence the state of the framework, as well as suitable responses for dealing with them (Quevedo, Uchiyama, & Kohsaka, 2021). The PSR framework was first established by the Organization for Economic Cooperation and Development for environmental policy-making. Initially, Statistics Canada conceptualised the PSR framework (Tu et al., 2022), which was later developed and used worldwide in many nations. This approach to environmental reporting was eventually adopted by the Organisation for Economic Cooperation and Development (OECD) (Buallay, 2019), as shown in Figure 3.

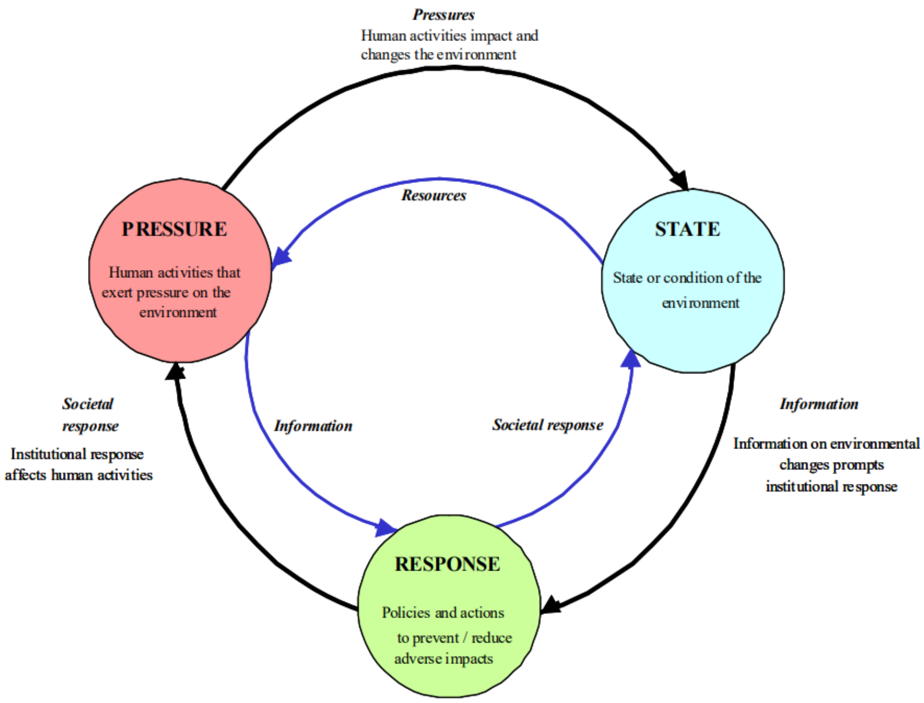

Figure 3. PSR Framework, Adopted from the OECD (Source: Buallay, 2019)

A PSR framework states that human activities exert pressure (such as pollution emissions or land use changes) on the environment, which can induce changes in the state of the quality and quantity of the environment (such as changes in ambient pollutant levels, habitat diversity, and water flows). Society then responds to the changes in pressures or the state with environmental and economic policies and programmes intended to prevent, reduce, or mitigate pressures and/or environmental damage (Wassie, 2020). The PSR framework highlights these causal linkages and helps decision-makers and the public see environmental and other interconnected issues (Büyüközkan & Karabulut, 2018). Based on its wide usage, the PSR framework can be identified as a commonly agreed-upon framework by many organisations and agencies for environmental reporting (Verma & Raghubanshi, 2018).

The PSR framework provides a comprehensive evaluation of regional environmental security from coupled socio-economic and environmental perspectives, which enables the determination of potential obstacles to environmental security (Cheng, Zhu, & Meng, 2022). This makes great sense when we apply our evaluation result to guide land use management to enhance environmental security while maintaining the sustainable development of the economy and society (Lu & Ke, 2018). The pressure-dominated area is characterised by high population density and intense social and economic activity (Cheng, Zhu, & Meng, 2022). Therefore, to improve environmental security, the population and industries should be reasonably controlled, or be orderly, and gradually transferred to the surrounding low-pressure areas so that the high pressure can be relieved while, at the same time, the response level can be improved in the surrounding regions with the development of the economy (Cheng, Zhu, & Meng, 2022). The DPSIR (Driver-Pressure-State-Impact-Response) framework, developed by the European Environment Agency (EEA) in 1999, offers a more comprehensive analysis compared to the PSR (Pressure-State-Response) framework initially proposed by Rapport and Friend in 1979. The DPSIR framework includes an "Impact" component, focusing on the consequences of human activities on the environment, which allows for a deeper understanding of environmental impacts associated with urbanisation and urban sprawl (Bradley & Yee, 2015; Niemeijer & Groot, 2008).

The Driver-Pressure-State-Impact-Response (DPSIR) paradigm is used to examine the complex relationship between urban sprawl and environmental deterioration in Amman City. This research uses a systematic approach to examine how human activities, environmental forces, the environment, and society interact. The DPSIR framework assesses Amman City's urban growth's environmental implications and suggests solutions. Urbanisation’s land use changes, infrastructure building, and population growth harm the environment, the framework admits. Thus, the pressures may increase pollution, habitat loss, and natural resource changes. Given the severity of urban expansion, social responses to these pressures and environmental changes must be recognised and resolved to limit their negative effects. Urban land use regulations and initiatives may mitigate urbanisation's environmental impacts. Understanding urban land use policies, urban sprawl, and environmental degradation is crucial to guiding decision-makers and developing sustainable urban development strategies that balance socioeconomic advancement and environmental conservation.

2.6.2 Econometric Analysis in Urban Studies:

Econometrics is fundamental for economic measurement. However, its importance extends far beyond the discipline of economics (Hill, Griffiths, & Lim, 2018). Econometrics is a set of research tools also employed in the business disciplines of accounting, finance, marketing, and management. It is used by social scientists, specifically researchers in history, political science, and sociology. Econometrics plays an important role in such diverse fields as forestry and agricultural economics (Raihan et al., 2022). This breadth of interest in econometrics arises in part because economics is the foundation of business analysis and is the core social science. Thus, research methods employed by economists, which include the field of econometrics, are useful to a broad spectrum of individuals.

Econometrics helps researchers determine causality, measure links, anticipate results, and evaluate urban policies and projects (Caragliu & Del Bo, 2019). Urban studies, particularly housing markets, use econometric analysis. Policymakers, researchers, and urban planners must understand the variables that affect housing prices, affordability, and market dynamics since housing is so important in cities. Econometric models may study how income, population growth, interest rates, and housing availability affect residential property value (Yap & Ng, 2018). These models show how housing price drivers respond to policy changes like interest rate changes and new housing affordability initiatives. Urban studies' transportation sector benefits greatly from econometric analysis. Econometric models are used to study travel behaviour, mode choice, congestion, and transportation policy in metropolitan regions with complex transportation networks (Guerra et al., 2018). Econometric models can predict transportation demand and evaluate measures like congestion pricing and public transit network development. Travel, socioeconomic, and transportation infrastructure data are analysed to accomplish this. These studies help transportation planners and policymakers enhance urban mobility and reduce congestion. The econometric study helps explain land use trends and urbanization. Economic, demographic, and policy variables affect urban land distribution. Econometric models can capture complex interactions between variables and land use outcomes like office, shop, and factory distribution (Chen et al., 2018). These models may help policymakers and planners understand how land use rules like zoning and urban growth limitations affect urban development. Econometric analysis helps evaluate urban policy. Research on urban rehabilitation, housing subsidies, and transit improvements has examined employment, crime, and property values. These treatments are evaluated using quasi-experimental approaches and difference-in-differences models. These studies provide empirical evidence of policy impacts on urban planning and policymaking. Urban studies may analyse sprawl effects and spatial reliance using econometrics.

2.6.3. Integration of Remote Sensing and Econometrics:

Remote sensing and econometrics can analyse and understand complex socio-environmental processes (Guan et al., 2023). Remote sensing captures and quantifies spatially explicit data, whereas econometric analysis models connections and makes forecasts using powerful statistical methods (Rosenfeld & Curtis, 2022). This combination of methodologies has been especially beneficial in studying urban sprawl and its environmental implications. Remote sensing uses satellites or aircraft to collect Earth surface data. This technique collects data on land cover, vegetation, temperature, and other characteristics needed to understand urban dynamics and their environmental impacts. Remote sensing may reveal land use patterns, built-up areas, and natural habitat fragmentation in urban growth. Alternatively, econometric analysis uses quantitative methods to analyse variables and forecasts. Remote sensing data as explanatory variables in economic models lets academics study urbanisation's effects on the environment (Deng et al., 2015; Gao et al., 2019). Econometric models can assess the influence of urban sprawl on plant cover or land surface temperature by considering socioeconomic variables, including population growth, income levels, and governmental actions. Remote sensing and econometrics help investigate urban growth and its environmental effects. First, remote sensing data measures environmental factors objectively and consistently, unlike subjective or scarce ground observations. Spatial data may be used in econometric models to improve accuracy and coverage. Second, remote sensing and econometrics may study complex urbanisation-environmental interactions. Multiple variables and confounding factors help researchers understand urban sprawl. This comprehensive approach may help understand how urbanisation affects the environment and lead to policy solutions. Remote sensing and econometrics allow for a multiscale examination of urban growth and its environmental impacts. Remote sensing provides a global or regional picture of urbanisation patterns and associated environmental impacts. Then, econometric models may be employed to assess particular case studies or subregions within the wider context, providing more context-specific findings.

2.7 Main Drivers of Urban Sprawl:

There are several factors that contribute to urban sprawl, and it may be difficult to isolate the most important one. Furthermore, urban sprawl's root causes vary by city, region, and even country. Thus, the political, social, and economic conditions of each city affect the causes and potential outcomes of urban sprawl. The primary focus of this chapter has been on the causes of urban sprawl in the Middle East. It is difficult to generalise the causes and effects of urban sprawl because of the vast differences across European countries and cities.

Literature from both nations points to four primary causes: a lack of control over illegal building and agriculture, a rapid growth in urban population, a shift in people from the countryside to the city, and arbitrary law enforcement. All of these aspects are discussed for both nations.

Urban populations can expand as their economies flourish. There may be unintended effects for rural communities as a result of this trend towards concentration (Lehtonen, 2021). There may be a tendency towards more centralization as a result of emigration from smaller towns, which degrades the quality of rural regions. Studies were conducted to determine the effects of a city's industry structure on real estate growth. The premise is that a city's density and centralization are influenced by its underlying industry structure. For instance, the centralization of employment tends to make cities smaller (Barkham, Bokhari, & Saiz, 2022). Sectors of the business world are an excellent example of this, in part because they rely so much on effective communication. But in cities where the economy is concentrated in areas outside the downtown core, urban sprawl is likely to increase.

2.8 Market Failures and Urban Sprawl:

Rodríguez-Pose & Storper (2020) argue that three market failures may explain some of the causes behind urban sprawl. A growing city requires that developers buy up land, whether from agriculture or other types of land. In other words, there is competition over land resources, and general market principles apply. In simplified terms, two perspectives prevail. The developer will consider the area as potential to develop a new property, while the agricultural industry will review it in terms of production potential. The agricultural area is in some cases more valuable than development land, and thus farmers earn more by selling the land to developers. The second market failure is, according to Rodríguez-Pose & Storper (2020), that the market does not take into account the cost of reduced accessibility for commuters. Congestion and reduced speed on roads mean that inhabitants spend more time on the road. This represents costs for each individual. Commuters who drive on the road contribute as well to forming a queue, slowing down other travellers.

The latest market failure, according to Rodríguez-Pose & Storper (2020), is related to cities (municipalities) that do not take into account costs related to both physical and social infrastructure resulting from development. New areas will require investments such as roads, water and sewer, schools, and other social services. These costs are not necessarily tied directly to those who develop or live in these areas. The costs can instead be spread to all inhabitants of the municipality.

2.9 Degradation and Remote Sensing:

Degradation has become a severe environmental issue as a result of human activities over the last century (Akhtar et al., 2021). It has a wide range of environmental consequences, including a detrimental influence on the region's water supply, reservoir storage capacity, agricultural production, and freshwater ecology. In recent years, more individuals have become concerned about human-caused environmental degradation. Urban development's impacts on land temperature and flora are concerning (Niazi et al., 2023). This research uses remote sensing and specialised indicators to study urban expansion dynamics and their effects on plant cover and land surface temperature. This study assessed urban vegetation changes using remote sensing data. The study examines whether urbanisation affects land surface temperature (LST). LST helps reveal urban regions' thermal characteristics. This study examines urban land surface temperature distribution and variations using thermal infrared pictures and other indicators. The research will also employ change detection methods to identify sites with substantial land cover and urban growth changes over time. This strategy will simplify urbanisation processes and their consequences for land cover and temperature. The research will employ GIS and other spatial analytic tools to incorporate and understand remote sensing data. GIS can analyse land surface and plant temperature spatial trends. This will help detect hotspots, vegetation loss areas, and urban growth-related temperature variations. This study aims to improve understanding of urban growth's environmental impacts. This research examines how vegetation changes affect land surface temperature. The results will improve our understanding of urbanisation, vegetation dynamics, and land surface temperature. This study may aid in urban planning and management. These measures reduce urbanisation's impacts on vegetation and improve urban thermal comfort.

2.10 Spatial-Temporal Parameters:

Global urbanisation has accelerated since the turn of the twenty-first century. Schneider and Woodcock (2008) and Xia et al. (2019) both agree that urbanisation is a key driver of globalisation and the primary mechanism through which human activities affect the biophysical world and climate. Terfa et al. (2019) argue that urbanisation is a multifaceted spatial activity with varying manifestations depending on local conditions such as population, economy, policy, and natural hazards. Once land use and cover shifts have occurred, those shifts tend to be irreversible. Because of this, the study of global change has centred heavily on the spatial and temporal growth of urbanization. Many countries in the global south are presently experiencing periods of unprecedented urbanization. The quickening pace of industrialization and economic expansion in these areas has pushed more people towards urban centers. Several problems have arisen in this context that have an adverse effect on the effective functioning of urban systems. These include the wasteful dispersal of valuable farm resources, increased traffic, and environmental deterioration (Zhang et al., 2019). All of these factors contribute to making urban systems less effective. Predicting the growth pattern of urban land use and steering the growth of cities towards sustainability both depend on an understanding of the current difficulties and evolution rules in the urban complex system.

As a direct depiction of urban land use and a key indicator of the urbanisation process, urban expansion has been widely employed in the study of urbanisation's driving causes and processes. This has been done since the growth of cities is a visible result of their intensive land usage. The research has shown that environmental, social, economic, and political variables all have a role in shaping urban development. Further complicating matters is the fact that the forces that drive urban expansion are very dynamic, shifting both spatially and temporally.

Fertile plains may not exist by the middle of the next century if Amman's urbanisation continues at its current rate. The species that make up the intricate food chain that sustains life on Earth have less access to the energy they need to thrive as land becomes less productive, and the repercussions of this are as yet unknowable. As the global population rises, so does the strain on the world's food and fibre supply, a challenge that is exacerbated by the migration of people away from the world's most productive agricultural regions. A number of unexpected difficulties have arisen as a result of Amman's fast population growth. The city is plagued by several issues, including pollution, traffic congestion, and severe water shortages. The government was forced to impose a rationing strategy due to the severe water shortages; as a result, residents' supplies are pumped twice weekly throughout the summer. On the other hand, the ideal situation would be one in which it was in step with the rest of the globe. Thus, we proposed:

H2: Over time, there is a correlation between low NDVI values and high Land Surface Temperature (LST) values in Amman, indicating that reduced vegetation cover contributes to increased surface temperatures, whereas high LST values are positively associated with high Normalised Difference Built-up Index (NDBI) values, indicating that areas with more built-up surfaces have higher temperatures.

H4: High-NDVI woody vegetation has a significant cooling effect on the surface temperature in urban areas with arid and semi-arid climates, such as Amman.

H5: There is a significant impact of uncontrolled and unplanned urban sprawl on the increase in built-up areas in Amman.

H7: The implementation of land use policies and strategies can mitigate the negative impacts of urban sprawl on the environment in Amman.

2.11 Socio-Economic and Demographic Factors:

Urbanization in Jordan is the outcome of a rapid population increase brought on by high natural growth and an influx of migrants. The deterioration of the natural landscape and ecological imprint is the result of this basically unplanned and thus uncontrolled process. Historically, urban immigration in Amman has outpaced infrastructural development in destination towns, resulting in population concentration and density increases. Continuous migrant movements have contributed significantly to an increase in population density and built-up areas, with one of the main consequences being the modification of settlement structures and urban services.

According to the socioeconomic and demographic characteristics of Amman's households, the biggest difference between the features of households is in their different average income levels and household size. The capital has a higher overall degree of prosperity and income. The Household Expenditure and Income Survey found that the average yearly family income in Amman was 6533 JD, compared to 5590 JD nationally (Department of Statistics, Jordan, 2017). In terms of average house size, there are significant discrepancies between the two tiers, with the high-income households having 345 m2 and the low-income households having 82 m2 (Jabarin, Nour, & Atout, 2019). As a result, whereas 76% of low-income households live in homes with

100 m2 or less of living area, 20% of high-income households live in homes with 401 m2 or more. The form and structure of urban facilities in the city mirrored these distinctions. Thus, we proposed:

H3: There is a significant correlation between land surface temperature (LST) and household income level, with higher-income households exhibiting a negative correlation with LST, indicating lower surface temperatures.

H6: Urbanisation and population density have a significant influence on environmental sustainability in Amman city.

A growing urban population, overworked and inadequate infrastructure and services, detrimental effects on the environment, and global warming are all results of rapid urbanization. Supporting decision-making and policy development and measuring the city's progress towards sustainability is crucial. In order to update and monitor progress towards sustainability, this study seeks to construct an assessment and monitoring technique for sustainable development goals at the city level. It focuses on identifying indicators that are suitable for the municipal environment.

The work of Zeadat (2022) on urban green infrastructure in Amman provides insight into possible obstacles and challenges. Incorporating the results from this study may help to increase our understanding of the basic mechanisms that govern this process. It is important not only to evaluate the quantity of green spaces but also to consider the quality of green ecosystems in urban environments, considering their activity and richness. Secondly, it is critical to analyse and respond to the possible ramifications on natural reserves with due consideration. Nature reserves are defined areas that have particular importance in the preservation of biodiversity. Any changes in patterns of land use have the potential to encroach on these valuable ecosystems. A study that compares the implications of changes in urbanised and agro-vegetation areas on nearby protected nature reserves could lead to valuable conclusions regarding the wider environmental effects.

2.12 Evaluation of Urban Sprawl’s Effects on Agro-Vegetation Lands:

Urban growth causes landscape modifications and degradation. Several studies have found that the landscape modification caused by urban expansions has resulted in major environmental challenges that jeopardize long-term development. The effects of urbanisation on the landscape are multidirectional and diverse in time and space. The geography and land use of the impacted area and the demography and economy of a city all influence the dynamic process of urban expansion. The natural environment, which is primarily composed of plants, soil, and rocks, is transformed into a constructed landscape, which is primarily composed of asphalt, concrete, and metals. Landscape transitions into developed land use are one of the primary issues with urban expansion. As a result, landscape changes and urban expansion put more strain on the surrounding land and other resources, resulting in either positive or negative changes in quality of life.

The increasing concentration of population and economic activities in a city necessitates the development of more land for public infrastructure (such as roads, water facilities, and utilities), housing, and industrial and commercial applications. Knowing the underlying driving causes, as well as the chronology and repercussions of urbanisation, is essential for planning and managing urban settings (Dadashpoor & Ahani, 2021). To make the educated judgements required to steer sustainable development in constantly changing urban environments, city planners, economists, and resource managers require advanced methods and a thorough understanding of the cities under their authority. However, because urban landscapes are dynamic and change over time as a city expands, satellite photos may be used to determine the spatial properties of landscape patterns over time.

Blickensdörfer et al. (2022) found that remote sensing gives spatially consistent coverage of broad areas with great spatial detail and temporal frequency, which is valuable for evaluating historical time series. Furthermore, remote sensing data is useful for tracking land-use change, especially when land-use data is inconsistent and insufficient. Remote sensing may now be used to monitor and analyse urban expansion and land-use changes in a timely and cost-effective manner, thanks to greater availability and enhanced multi-spatial and multi-temporal resolution. Thus, we proposed:

H1: There is a significant relationship between the increase in built-up areas and declining agro-vegetation land in Amman.

2.13 The Impact of Urban Sprawl on Pollution and Green Space

The environment is transformed by urbanization. Rapid population expansion, according to research, is causing cities to contract and become more densely populated. It is projected that 60 percent of the world's population will reside in urban areas by the year 2030 (UN, 2014). Rapid urban population growth typically results in increased city size and shifts in land use and land cover. Changes in land use land cover LULC patterns may have an impact on many types of vegetation cover, including grassland and open space, water bodies and wetlands, and vegetation cover (Banti et al., 2019; Ghosh et al., 2019). Many environmental problems are exacerbated by urbanization, and urban planners are exploring whether a shift in LULC may help. Pollution, energy use, plant cover, rubbish management, water supplies, and air quality are only a few of the environmental concerns that urbanisation affects (Ahmad, Shao, & Javed, 2023; Roy et al., 2022). Integrative planning and environmentally responsible land use are essential for inclusive urban growth. One of the major problems of urbanisation is the rise in pollution it causes. Pollution and greenhouse gas emissions rise when cities expand and more people move into them, demanding more transportation, energy, and resources. Commuting with a personal vehicle adds to air pollution because of the fine particles, nitrogen oxides, and volatile organic compounds released into the atmosphere. Problems with breathing, the heart, and general health are all brought on by these toxins. In order to minimise air pollution, policymakers should put an emphasis on environmentally friendly modes of transportation, including walking, cycling, and public transit. Cities may lower their reliance on private automobiles, lower pollution, and enhance air quality by investing in efficient, accessible, and bike-able public transportation networks. Pollution may be mitigated by the implementation of regulations that encourage the use of renewable energy for transportation and electric vehicles.

The use of energy is also influenced by urbanization. Increasing urban populations put a burden on the power grid and cause greenhouse gas emissions. Building retrofits with energy-efficient machinery and promoting renewable energy sources are two examples of energy efficiency programmes that have the backing of decision-makers. Low-energy and carbon-emitting construction methods are made possible by green building practices (Singh, Sharma, & Yadav, 2023). Several examples include solar panels, energy-saving home appliances, and passive building design. Protecting against the negative consequences of urbanisation, plant cover is essential. Parks, gardens, and urban forests are lost as cities expand. Urban animals may thrive in these areas, and they help to clean the air and mitigate the effects of heat islands. It is imperative that urban planners and decision-makers give natural areas the attention they deserve. The air quality, aesthetics, and well-being of city people may all be improved by the use of green roofs, vertical gardens, and urban agriculture.

The environmental impact of urbanisation may be mitigated through effective waste management. As urban areas grow and adopt new consumption patterns, waste generation rises. Waste management systems should place an emphasis on trash minimization, recycling, and correct disposal. Sustainable waste management should be encouraged among urban dwellers through awareness and education campaigns on garbage segregation and recycling. As cities expand, so do their demands on water resources. The infiltration of rainwater is diminished by roads and buildings. The result is more storm water discharge and less groundwater being refilled. Urban flooding and water scarcity are also possible outcomes. By allowing water to percolate through the ground and easing pressure on drainage systems, green infrastructure and permeable surfaces can help mitigate these issues. As a result, fewer issues will arise.

Finally, poor air quality is a result of urbanization. Poor air quality is a common problem in metropolitan areas due to emissions from vehicles, factories, and other sources. That is probably not good for you and might cause health problems (Garai, Garg, & Biswas, 2023). Pollution prevention should be a top priority for decision-makers. Systematic air quality monitoring, tighter emission limitations, and advocacy for environmentally friendly technologies are all examples. Cleaner air and better health for city dwellers can result from a shift away from fossil fuels and towards alternate forms of transportation. Air pollution, energy consumption, plant cover, waste management, water resources, and air quality all suffer as a result of urbanization. Decision-makers can find solutions to these environmental problems with the support of sustainable land use and integrated planning. Focusing on eco-friendly modes of transportation, renewable energy sources, energy efficiency, green spaces, trash reduction, water conservation, and air quality may all help to curb urban sprawl. Lessening air pollution contributes to lessening urban sprawl. By avoiding these problems, cities may develop healthier, happier, and more prosperous communities for their residents now and in the future.

2.14 Gap Analysis:

The present study's literature reviews summary and gaps highlight its originality and contribute to current knowledge. Its integrated technique, which combines land cover research, remote sensing data, and economic modelling in Amman City, makes the study unique. The present study takes a comprehensive approach to these gaps, unlike earlier studies that investigated urban sprawl components separately.

The impacts of LULC modification have been explored over time scales ranging from a few years to decades (Szilassi et al., 2006). Al-Bilbisi (2019), Jaber (2018), and Al-Kofahi et al. (2018) are among the few scholars who have studied Amman's urban expansion and LULC alterations. None of these studies have examined how these changes affect the city's surface temperature and the environment. This work addresses this gap by building on Jaber (2018)'s findings. As in recent research (Abdullah et al., 2022; Vani and Prasad, 2020; Gui et al., 2019; Deng et al., 2018), we extend the body of work by making NDVI and NDBI independent variables. To better understand the link between urban expansion and land surface temperature (LST), we examined how LULC changes affect LST and vegetation in Amman. Our theory is that more plant coverage lowers LST values, and higher NDBI values raise them. We examine the correlations between the biophysical variables NDVI, NDBI, and LST to test this notion. Exploring the correlation between land surface temperature (LST) and socio-economic factors such as household type, population density, and income level can provide valuable insights into how urbanisation influences temperature patterns based on social dynamics. This analysis is crucial for understanding the impact of urban development on temperature regulation in a city facing challenges related to economic disparities and varying household characteristics.

The literature study shows that few studies have used remote sensing indices like NDVI, NDBI, and LST to assess the environmental impacts of urban development in Amman City. Previous research has focused on land cover changes, but this work uses remote sensing to quantify the effects of urban growth on temperature, plant health, and urbanisation patterns. Cutting-edge tools give urban development environmental control a new dimension. There is a need to quantify the specific cooling benefits of greenery in urban environments, especially in regions with arid climates like Amman, where green spaces play a vital role in mitigating heat stress and enhancing urban microclimates.

The analysis also shows the limited use of econometric research to represent Amman's complicated urban sprawl-environmental indicator connections. This research examines the socioeconomic causes of urban development, environmental pressures, and governmental measures to bridge this gap. This analytical technique helps understand urban sprawl and informs sustainable urban development decisions. Investigating the connection between urbanisation, population density, and environmental sustainability is essential for informing policies that promote environmentally conscious development practices tailored to Amman's unique socio-economic landscape.

The lack of data available to urban planners and decision-makers, especially in Amman, highlights the need for measuring, monitoring, and analysing urban growth and spatial inequalities in the research region. Sustainable planning requires understanding the dynamics of urban expansion in the studied region and its potential for future development. The combination of remote sensing (RS), GIS, statistical models, and spatial analysis delivers quick and important insights. A rapidly urbanising metropolis requires effective spatial planning, which this technique provides. In this context, this study aims to: (i) assess the trends and patterns of land use change in Amman city from 1990 to 2022 and their implications for uncontrolled urban expansion onto agro-vegetation land; (ii) examine the relationship between urban expansion, demographic shifts, and land use changes and their effects; and (iii) test conventional change detection methods. The study aims to understand the complex relationships between urbanisation, land use changes, and environmental impacts to help urban planners and policymakers.

3. MATERIALS AND METHODS

3.1 Research design

A planned and structured research design that integrates many methodologies helps investigate the study goals. Complete and systematic data collection begins the process. A complete set of datasets contains remote sensing data from reliable sources, including satellite imagery of dwellings throughout time. Land cover information is extracted from photographs using intensive image processing. Socio-economic, demographic, and environmental data are carefully collected from trustworthy archives and research databases for further study. The study approach relies on remote sensing. This study uses the Normalized Difference Vegetation Index (NDVI), Normalized Difference Built-up Index (NDBI), and Land Surface Temperature to critically analyse land cover changes throughout time. Remote sensing indices diagnose plant vitality, built-up zones, and surface temperature patterns. They capture the environmental pressures caused by urban growth, seamlessly linking with the "pressure" part of the Driver-Pressure-State-Impact-Response (DPSIR) paradigm. Econometric modelling is further integrated into the study design. The study examines the complicated relationships between urbanisation, population density, and environmental factors using advanced statistical methods. This phase of the study analyses the environment after urban expansion and the efficiency of government responses. The DPSIR model analyses the state-response connection, revealing urban sprawl and its effects. The integration of quantitative and qualitative paradigms is key to this research strategy. Econometric modelling provides quantitative insights into relationships and trends. Qualitative synthesis is essential for contextualising these findings within policies, urban planning plans, and environmental management activities.

3.2 Research framework

Remote sensing and econometric analysis are used to study Amman City's urban land use policies, urban development, and environmental impacts. Satellite imagery is remotely sensed, pre-processed, and enhanced. This provides precise statistics on land cover changes, urban growth, and urban development dispersion.

Econometrics refers to the quantitative use of statistical conclusions, economic theory, and mathematical models to establish theories or evaluate existing hypotheses in economics, as well as estimate future trends based on massive amounts of data accumulated over time. Its purpose is to turn real-world data into statistical trials and then compare the results to the hypothesis or theories under consideration for comparable patterns (Baltagi and Baltagi, 2011). It examines theoretical economic models and uses them to formulate economic policy. The primary role of econometrics is to translate qualitative declarations into quantitative ones.

An econometric study using Ordinary Least Squares (OLS) establishes statistical correlations between urban land use regulations, urban growth, and environmental impacts. The theoretical framework has numerous fundamental components. First, the study assesses Amman City's urban land use rules' ability to limit urban growth. This study examines how policies affect urban growth. Second, remote sensing data measure Amman City's urban growth and spatial trends. Land cover changes and urban development dispersion reveal urban growth dynamics and patterns.

The econometric research finishes by assessing urban land use policies' effects on urban growth and environmental impacts using the OLS technique. This research examines policy factors, indicators of urban sprawl, and environmental consequences to assess urban sprawl mitigation programs. This theoretical framework examines urban land use policy, urban development, and environmental impacts in Amman City. Remote sensing and econometric analysis help understand policy efficacy and sustainable urban development.

The DPSIR (Drivers, Pressures, States, Impacts, and Responses) framework is a useful tool for structuring and analysing the interactions between society and the environment. In the case of urban sprawl in Amman, the DPSIR framework (as shown in Figure 4) can be applied as follows:

1. Drivers: These include population growth, economic development, and inadequate urban planning.
2. Pressures: These are the specific activities or processes that result from the drivers, such as land use changes, increased resource consumption, and the expansion of administrative boundaries.
3. State: This refers to the current condition of the environment as a result of pressures such as changes in land cover, loss of agro-vegetation lands, increased energy consumption, and CO_2.
4. Impacts: These are the effects of the state on the environment and society, such as environmental challenges, reduced agricultural productivity, health implications, and an increase in land surface temperature.
5. Responses: These are the measures taken to address the impacts and mitigate the pressures, such as policies to regulate urban growth, initiatives to promote sustainable city planning, and efforts to address the environmental and social consequences of urban sprawl.

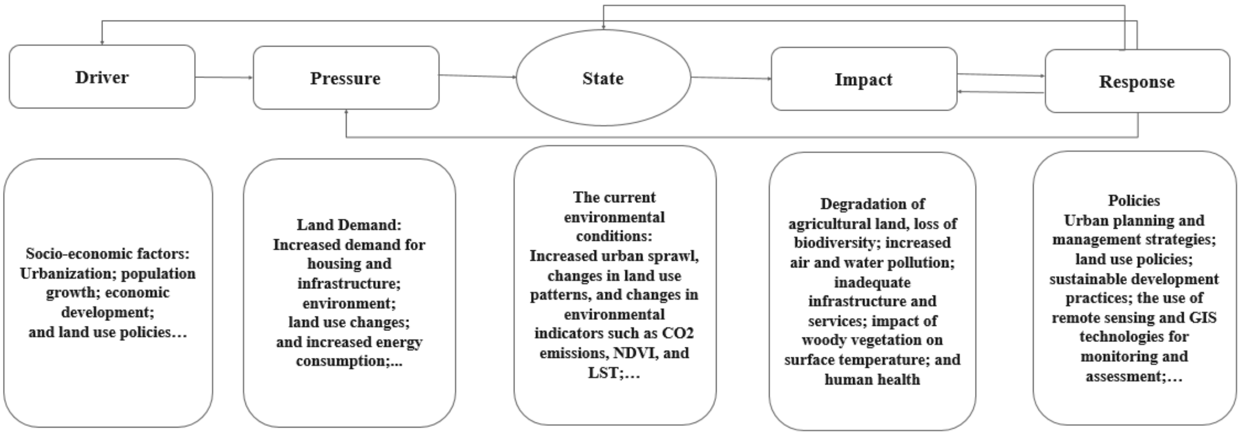

Figure 4. Conceptual Framework of DPSIR Applied to Amman City for Balancing Development and Sustainability: An Environmental Management Study of Urban Sprawl

Applying the DPSIR framework can systematically analyse the complex interactions between urban sprawl, environmental sustainability, and the various factors that drive, influence, and result from this process. This can provide a comprehensive understanding of the challenges and opportunities associated with urban development in Amman and support the development of effective policies and strategies.

3.3 Study Area

Jordan is a small country with a population located mostly near its major towns of Amman, Zarqa, Madaba, Salt, and Irbid, as seen in Figure 5. The population of these cities and their nearby environments accounts for almost 75% of Jordan's population. The city's original location was seven hills, or 'jabals,' around the Wadi 'Ras el Ain,' which runs north-east from the plateau into the River Zarqa basin. The old city centre was located between 725 and 800 metres above sea level. The city's expansion during the last 25 years has resulted in the colonisation of 19 hills in total, with an elevation range of 875 metres and above.

Figure 5. The geographic location of Amman

The research area is characterised by dense human activity, as it is home to 4,744,700 people (DOS, 2022). Amman has a population density of 2,380/km^2 (6,200/sq mi). Due to high population concentrations, the research area's and the country's accessible water resources are under severe strain. Annual groundwater extraction in the studied area climbed from 8.5 million cubic metres (MCM) in the mid-1960s to 120 MCM in the 1990s and around 140 MCM between 2000 and 2010, whereas the safe yield is around 70 MCM (Al-Bawwat et al., 2023).

3.4 Data collection sources

The data used for this study can be divided into two categories: (1) primary data and (2) secondary data. Primary data for the area under investigation was extracted from the satellite imagery. The primary data is from 1990 to 2022. Secondary data from 1990–2020 was obtained from Greater Amman Municipality to examine how urban sprawl contributes to the impact on the environment. The study relied on remote sensing data collection and analysis, as well as secondary data. Sources of secondary data, such as auxiliary population data from the Department of Statistics (DOS), were utilised in the study, along with various data collected from the Greater Amman Municipality (GAM) and World Bank data for environmental socioeconomic indicators.

3.5 Data and Image analysis

Different image processing techniques were utilised for image analysis. The techniques include rectification, processing, enhancement, and supervised classification (LULC change detection analysis). Time series and ordinary least squares regression (OLS) analyses were performed to study the impact of urban sprawl on the environment. A popular method for estimating the coefficients of linear regression equations that describe the connection between a dependent variable and one or more independent quantitative variables is ordinary least squares regression (OLS). This technique can be applied to both simple and multiple linear regressions.

3.5.1 LULC mapping

Different GIS functions and image processing approaches were used to build LULC maps for assessing recent changes. Through an on-screen digitization method, medium-quality satellite pictures from 1990, 1995, 1999, 2004, 2013, 2017, and 2022 were used to create the maps. The backdrop image digitizing approach used in this investigation was different Landsat pictures overlaid by the study region shape file (Memarian et al., 2012).

Data sources

Change detection, a technique for gauging the degree to which a region has changed over time, has been used in a wide range of research to analyse shifts in LULC and patterns of urban growth. Spatio-temporal multispectral pictures are used in change detection and monitoring to assess and extract changes between image collection dates. For this analysis, researchers downloaded a set of Landsat photos from the USGS database (USGS-GLOVIS, 2022) with a spatial resolution of 30x30 m. Due to their suitability and low cost as a source of data for several applications, including urban growth mapping, Landsat 5-TM for 2007 and beyond and Landsat 8-OLI for 2013, 2017, and 2022 were purchased for this study. The images (data sets) were then filtered to only include features relevant to the research field. Bands, wavelength, resolution, and date of capture for satellite images are all included in Table 1.

For each year of the research, high-resolution aerial pictures were obtained using Google Earth Pro and used as a baseline to assess the performance of the image categorization. The administrative map, demographic statistics, and district names for the study region were all given by Greater Amman Municipality. Amman's urban invasion was analysed using the urban expansion intensity index and the Shannon entropy method.

To evaluate the impact of the road network on urban growth and the environment, we digitalized the road network of Amman city using existing aerial pictures for the research period (1990–2022).

Table 1. Specification for satellite image bands, wavelength, resolution, and acquisition date.

Image Specification		
Image Type	**Landsat 5-TM**	**Landsat 8-OLI**
Swath width (Km)	185	185
Spectral range (µm)	Blue Band (0.45-0.52) Green Band (0.52 – 0.60) Red Band (0.63-0.69) NIR Band (0.76-0.90)	Blue Band (0.450-0.515) Green Band (0.525 – 0.600) Red Band (0.630-0.680) NIR Band (0.845-0.885)
Resolution (m)	30	30
Acquisition date	1990-12-15 1995-12-23 1999-12-05 2004-12-02	2013-12-27 2017-12-19 2022-05-26
Revisit time (day)	16	16
Cloud cover (%)	0.00	0.00

Source: Abdeljawad, Adedokun, & Nagy, 2022

Pre-processing

The present study utilises an atmospheric correction process that incorporates a mathematical equation specifically designed to minimise the impact of atmospheric effects on the satellite imagery obtained. The formula employed for atmospheric correction is as follows:

$$L = \frac{(Band\ Specific\ Reflectance\ Mult\ Band\ \times\ DN\ value\ +\ Reflectance\ Add\ band)}{Sin(sun\ elevation)}$$

The estimation of the spectrum radiance (L) at the sensor, which is an essential statistic for further analysis, is impacted by a variety of elements contained within this equation. The original digital data that was produced from the images is denoted by the notation Qcal, which stands for the quantized calibrated pixel value. By applying the appropriate calibration coefficients of offset (b) and gain (a), the value is normalised in order to maintain consistency and accuracy throughout the process. This is accomplished by utilising gain (a) and offset (b).

This variable is incorporated into the calculation so that we can take into account the influence that satellite temperature (Tsat) has on the data that we have acquired. When calculating radiance, it is necessary to take into consideration both the exoatmospheric solar irradiance (Esun) and the Earth-Sun distance (d), which is measured in astronomical units (AU). This allows for the calculation of radiance to be refined. The quantity of solar energy that is able to penetrate the earth's upper atmosphere is referred to as the exoatmospheric solar irradiance. The Earth-Sun distance factor takes into account the way in which the distance that separates the Earth and the Sun varies during the course of a year. Using this reliable method for atmospheric correction is an excellent way to offset the negative impacts that are induced by atmospheric conditions, including scattering and absorption. Researchers are able to get spectral radiance estimates that are more accurate and reliable thanks to this feature, which helps in the subsequent investigation and interpretation of land cover characteristics portrayed in satellite images. In addition, within the context of the image pre-processing workflow, the employment of a band composition approach known as true colour composition was adopted in order to enhance the visual interpretation of land cover features that are visible in the Landsat mages. This was done in order to improve the quality of the data obtained from the images. Bands corresponding to the colours red (R), green (G), and blue (B) were utilised, more precisely band 321 for the Landsat-5TM and band 432 for the Landsat-8OLI, in order to accomplish this goal. Through the integration of these three separate spectral bands, a composite image was generated, which replicated the human eye's visual impression of the natural colours that are present in the world. This approach helps in the recognition and separation of various land cover types, which in turn makes it easier for researchers and professionals working in the related sector to undertake visual interpretation and analysis of the data. In addition, the pan sharpening tool that is included in ArcGIS Pro 2.5 was utilised so that the satellite imagery could be improved in terms of both its precision and its level of detail. When high-resolution panchromatic data is combined with multispectral imaging that has a lower resolution, the result is a pan-sharpened image that has increased spatial resolution and greater visual clarity. This is accomplished by combining two sets of data, one with a lower resolution than the other. An innovative technique is utilised in the process of pan sharpening. This method takes advantage of the complimentary data that is present in both the panchromatic and multispectral bands. The picture is pan-sharpened by merging the high-frequency features gained from the panchromatic band with the colour information received from the multispectral bands. This results in a more accurate representation of the original image. This integration improves the display of land cover aspects in terms of both its accuracy and its aesthetic appeal.

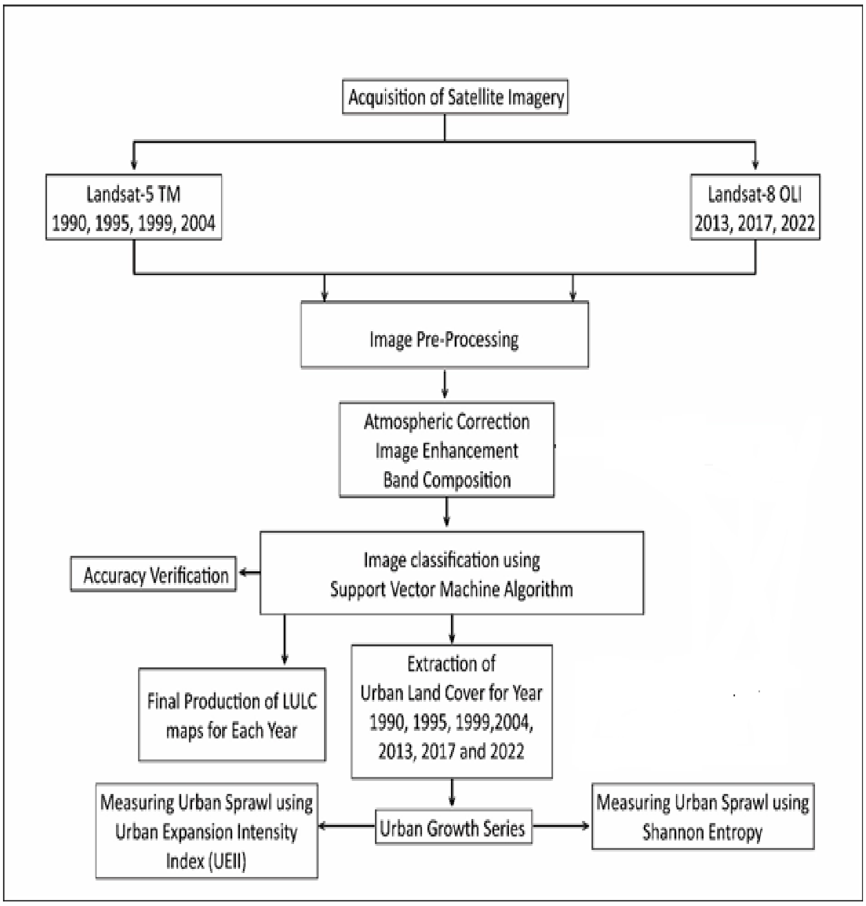

Figure 6. Flow chart of the LULC change detection, urban growth series analysis.

Source: Abdeljawad, Adedokun, & Nagy, 2022

3.5.2 Land-cover classification scheme

Image classification methods are used to assign categories to the individual pixels that make up satellite data in order to differentiate between the many earth characteristics (land cover). For the purpose of classifying the obtained multispectral raster dataset (Landsat images), a pixel-based supervised image classification was used. During the process of classification, the Support Vector Machine (SVM) method was selected for use. In the field of machine learning, the Support Vector Machine, sometimes known as SVM, is one of the most well-known supervised learning algorithms that is used for classification. The operation of the support vector machine method is accomplished by accumulating vector data from training samples in a manner that is determined by the spectral reflectance of the satellite images.

The multispectral raster dataset was categorised using the training samples that were allocated for each of the research years (1990–2022). Each kind of land cover had its own set of samples, which were then manually allocated to the images according to the spectral reflectance of those samples. The plan for this study took into account the participation of three LULC courses. Built-up areas, agricultural land, and barren lands are the three classifications or categories that fall under LULC. The description of these classes is shown in Table 2.

Table 2. LULC Classification Classes and Description.

S/N	Class	Description
1	Built -Up Area	Developed land used for residential and transportation/ communication and industrial purposes (i.e., settlements airports, parking lots, highways, and local roads, Commercial hub, industry, and administrative block).
2	Agriculture land	These includes land cultivated for Agricultural purpose, all vegetation features that are not typical of forest including shrub like vegetation features.
3	Barren lands	Barren or sparsely vegetated areas most often representative of bare earth, rocks, or soil.

Adopted from Khawaldah (2016)

3.5.3 Accuracy assessment of LULC: Overall Accuracy and Kappa Index

Any categorization endeavour should include an evaluation of the level of accuracy involved. Comparing the identified picture to another data source that is thought of as accurate, often known as ground truth data, is part of this process. An evaluation of the accuracy may be carried out using a number of different approaches, including the Kappa coefficient and the overall accuracy.

For the objective of this study, a stratified random sampling approach was used to create 500 points. After that, each point was compared with a reference base map (high-resolution aerial picture) so that the accuracy level of the categorised image could be determined.

Overall, the term "accuracy" is what's used to refer to the appropriate percentage of mapped pixels, and it's the approach for assessing accuracy that is used the most often. When evaluating the overall accuracy, both the confusion matrix and the kappa coefficient were used. It is calculated by taking the total number of cells that have been categorised and dividing it by the total number of cells classified. A measure of agreement between module predictions and reality, the Kappa index or coefficient, is used to assess whether the values included in an error matrix indicate a result considerably better than random. Equational representation of the mathematical concept (1) (Dhanaraj & Angadi, 2021):

$$K = \frac{N\sum_{i=l}^{r} X_{ii} - \sum_{i=l}^{r}(X_{i+} \times X_{+i})}{N^2 - \sum_{i=l}^{r}(X_{i+} \times X_{+i})} \qquad (1)$$

Where Xii is the total crosswise numbers in the error matrix and x is the total number of samples, r = number of rows, xii = number of observations in row i and column i, xi+ = total of observations in row I, x+i = total of observations in column i, and N = total number of observations. Where “1” indicates perfect agreement between reality and the classified image, “0” represents complete randomness or no agreement.

Overall accuracy and the Kappa index show how well categorised maps match ground-referenced information. SVM-based classification offers good accuracy and Kappa coefficients, proving its trustworthiness, as shown in Table 3.

Table 3. Interpretation of the Kappa Statistic

Kappa Value	Interpretation
< 0	No Agreement
0.0 – 0.20	Slight Agreement
0.21 – 0.40	Fair Agreement
0.41 – 0.60	Moderate Agreement
0.61 – 080	Substantial Agreement
0.81 – 1.00	Almost Perfect Agreement

Adopted from Okwuashi et al., (2012)

3.5.4 Urban Expansion Intensity Index(UEII)

Using the UEII, we were able to statistically assess and examine the dissimilarity in urban spatial growth. As an added bonus, UEII may be used to identify a time period in which urbanisation is favoured. The UEII is a comparison of the pace or degree of change in urban land use over time (Al-Sharif et al., 2014; Dhanaraj & Angadi, 2021) as well as a representation of the potential future directions of urban expansions. UEII measures how much of the city is comprised of newly developed land. The UEII is a measure of urban land use change's velocity or intensity through time, and it indicates the potential of urban expansions. The formula for UEII is as follows (equation 2):

$$UEII_{it} = \left(\frac{UL_{i,b} - UL_{i,a}}{t}\right) / TLA_i \; X \; 100 \qquad (2)$$

Where, $UEII_{it}$ is the annual average urban expansion intensity index of (ith) zone in time period (t); $UL_{i,a}$, is the quantity of built-up area at time periods a ; $UL_{i,b}$are the quantity of built-up area at time periods b; TLA_i, is the total area of (ith) spatial zone.

3.5.5 Shannon Entropy and Urban Sprawl

Shannon's entropy has emerged as the predominant and reliable metric for assessing urban expansion patterns, given its widespread adoption and accuracy. The concept of Shannon's entropy (Hn) quantifies the level of spatial compactness and dispersion exhibited by a given surface. This methodology is advantageous for quantifying and differentiating various forms of urban sprawl.

The entropy method is advantageous in the context of Geographic Information Systems (GIS) due to its inherent simplicity and seamless integration capabilities. The mathematical expression denoting Shannon's entropy is represented by equation 5.

The concept of relative entropy, also known as the Shannon equitability index, holds significant significance in the quantification of diversity and similarity within spatially-related matters within the domains of ecology and urban studies. The utilisation of relative entropy allows for the transformation of entropy values into a normalised range between 0 and 1. This transformation can be achieved by employing the following equation: The degree of compactness in the distribution of built-up areas is highest in a particular region when the entropy value approaches zero, while a value close to one indicates an unevenly dispersed spatial distribution of built-up areas, suggesting a presence of spread. The midpoint is commonly regarded as the point of demarcation. The city is classified as sprawling when the entropy value surpasses the designated threshold of 0.5.

$$Hn = \sum_{i}^{n} P_i \ log\ e \ \frac{1}{Pi} / log_e n \quad (3)$$

Where Hn, relative entropy, and Pi refer to the development density. It is the proportion of the variable (built-up area) that is equal to the amount of built-up land divided by the total amount of built-up land in the ith of the n total zones. n is the total number of zones.

Because the distribution of a geographical phenomenon can be measured and determined using entropy, the difference in entropy between time t1 and t2 can be used as an indicator of the magnitude of the change in urban sprawl by calculating the difference in dispersion. This helps to identify whether the land development process adheres to centrifugal (sprawling) or clustered and focused urban development using equation 4:

$$\Delta Hn = HN\,(t2) - HN\,(t1) \qquad (4)$$

Where ΔHn is the change in relative entropy, HN (t1): relative entropy at time 1; HN (t2): relative entropy at time 2.

3.6 Assessing the Environmental Impacts of Urban Sprawl Using Remote Sensing Indices: A Case Study of Amman City

The current study's overall methodology is illustrated in a flowchart (Figure 7 for Landsat 5-TM satellite imagery and Figure 8 for Landsat 8-OLI satellite imagery).

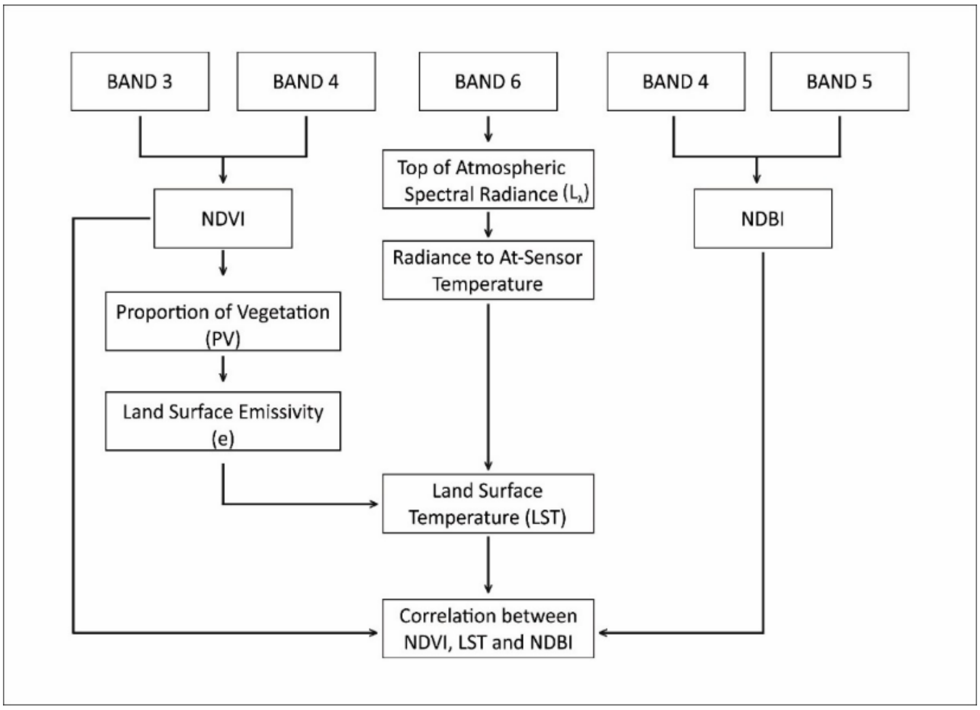

Figure 7. Methodological Flowchart for Landsat 5-TM satellite imagery

Source: Abdeljawad, Adedokun, & Nagy, 2023

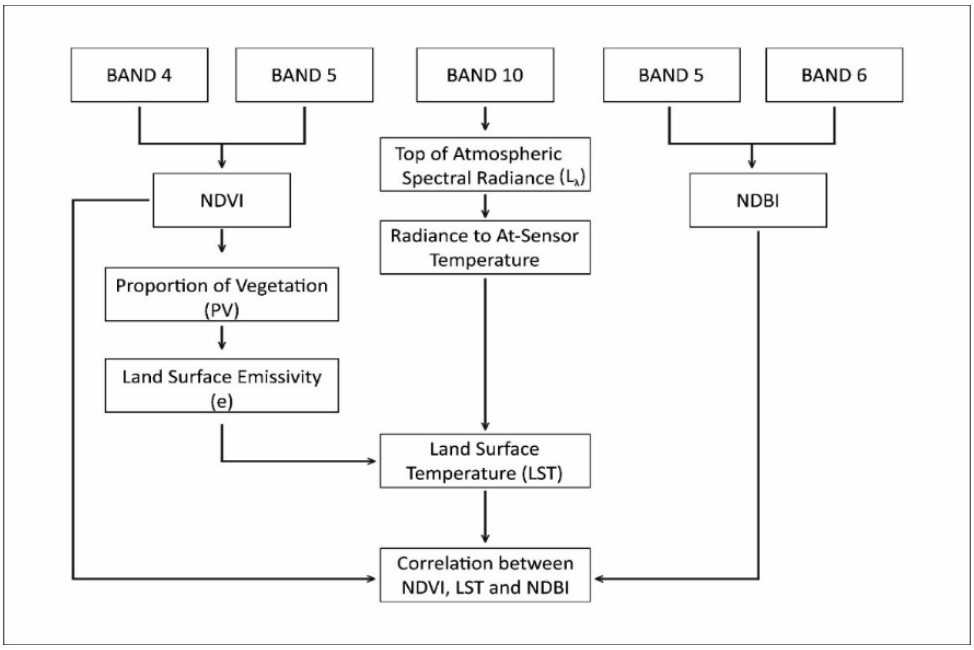

Figure 8. Methodological Flowchart for Landsat 8-OLI satellite imagery

Source: Abdeljawad, Adedokun, & Nagy, 2023

Data from the satellite-sensed thermal infrared (TIR), remote sensing (RS), and near infrared (NIR) bands, in addition to the red band, were used to generate the NDVI, which is an input for the study of land surface temperature. This enabled a more precise NDVI to be built. The red spectrum may also be used to estimate the surface temperature. When it came time to retrieve the built-up index, both mid-infrared (MIR) and NIR were used. Landsat images with a resolution of

30 by 30 metres in each of the three dimensions were requested from the United States Geological Survey (USGS).

We utilised existing aerial pictures of Amman, Jordan, to create a computerised map of the city's road network for the research period (1990–2022). In contrast, the data presented in the supplementary paper was culled from the LULC archives and reveals the sprawling metropolitan area that surrounds Amman. The supplementary file contains these data.

The current study relies on satellite imagery from Landsat 5-TM and Landsat 8-OLI acquired for the years 2007, 2013, and 2022. This was done because these satellites provide a reliable and affordable data source for a wide variety of uses. This data might be used for a variety of purposes, including but not limited to studies of land surface temperature, vegetation index, and built-up index. The scope of the research area captured in the photographs (the data sets) was then reduced to a more manageable amount. Table 4 presents a summary of the satellite images' characteristics, such as the bands, wavelength, and resolution, as well as the date the photos were acquired.

Table 4. Satellite image specification of Landsat 5-TM and Landsat 8-OLI (i.e., image bands, wavelength, resolution, and acquisition date).

Image Specification		
Image Type	**Landsat 5-TM**	**Landsat 8-OLI**
Swath width (Km)	185	185
Spectral range (µm)	Red (3) Band (0.63-0.69) NIR (4) Band (0.76-0.90) MIR (5) Band (1.55-1.75) TIR (6) Band (10.4 0-12.50)	Red (4) Band (0.630-0.680) NIR (5) Band (0.845-0.885) MIR (6) Band (1.57-1.65) TIR (10) Band (10.60-11.19)
Resolution (m)	30	30
Acquisition date	1990-07-21 1995-07-19 1999-07-14 2004-07-11	2013-07-04 2017-07-15 2022-07-13
Revisit time (day)	16	16
Cloud cover (%)	0.00	0.00

Source: Abdeljawad, Adedokun, & Nagy, 2023. Adapted From http://glovis.usgs.gov. 18th July 2022

As can be seen in Table 5 below, time series data on air temperatures were gathered with help from both NASA and the Jordanian meteorological agency. The results of this investigation were contrasted with those from a study of the ground's surface temperature.

Table 5. Air temperature data

Month	YEAR	Mini. Temp (ºC)	Max. Temp. (ºC)
July	2007	20.15	41.92
July	2008	20.57	41.24
July	2009	19.89	39.81
July	2010	21.02	41.13
July	2011	20.46	40.67
July	2012	20.85	41.56
July	2013	19.87	40.02
July	2014	21.01	42.19
July	2015	20.58	41.45
July	2016	20.19	41.98
July	2017	21.23	45.05
July	2018	20.34	42.39
July	2019	20.93	43.19
July	2020	20.11	40.75
July	2021	20.64516	42.72
July	2022	19	39

Source: National Aeronautics and Space Administration (NASA, Jordan meteorological department)

3.7 Derivation of Normalized Difference Vegetation Index (NDVI)

In 1973, the NDVI, which was introduced by Rouse et al. (1974), was frequently utilised to collect as well as investigate the dynamics of urban vegetation and monitor urban growth (Jaber, 2018; El Garouani et al., 2017; Escobedo et al., 2016). The NDVI measures the amount of vegetation by comparing the NIR (which vegetation significantly reflects) and red-light contrasts (which vegetation absorbs) (Kundu et al., 2021). The NDVI for the investigated area was calculated using the map algebra function (raster calculator) of ArcGIS Pro 2.5. It is represented mathematically using the formula (Rouse et al. 1974), as shown below:

$$NDVI = \frac{NIR-RED}{NIR+RED} \text{----------}(5)$$

Where, NIR corresponds to band 4 for Landsat-5 TM and band 5 for Landsat-8 OLI photos, whereas red corresponds to band 3 for Landsat-5 TM and band 4 for Landsat-8 OLI images.

$$NDVI\ (Landsat - 5\ TM) = \frac{B4-B3}{B4+B3} \text{---------------}(6)$$

$$NDVI\ (Landsat - 8\ OLI\ ) = \frac{B5-B4}{B5+B4} \text{------------}(7)$$

The NDVI readings are always between -1 and +1. However, each form of land cover does not have a clear limit. If the NDVI value is near +1, there is a good chance that the plant's densely packed leaves are green (dense vegetation); values between 0.4 and 0.7 depict typical, healthy vegetation; and values between 0.18 and 0.27 correspond to shrubs or grassland. Whereas negative values represent water bodies and highly dense urban areas, Values close to 0 show that there are no green covers; rather, it is likely to be an urbanised area. In general, readings between -0.1 and 0.18 are indicative of desert, a rock outcrop, sand, or snow (Ullah et al., 2020).

3.8 Derivation of Normalized Difference Built-up Index (NDBI)

The Normalised Distinction Built-Up Index (NDBI) is a popular remote sensing technique for calculating urban areas by measuring the contrast between the MIR and NIR spectral ranges. By reducing the impact of fluctuations in ground lighting and atmospheric conditions, the NDBI focuses on improving the image of urban regions. Urban areas are easily distinguished from non-urban areas because of the NDBI's use of the unique reflectance qualities of different land cover types. Because of their unique reflectance properties, the NIR and MIR bands are used in the NDBI computation. From the near infrared to the mid-infrared, urban and desert areas are much more reflective. This shift in reflectance can be largely attributed to the disappearance of natural elements and the appearance of anthropogenic ones. However, it has been determined that the difference between the MIR and NIR frequencies in terms of digital number (DN) values for vegetation is negligible. As a result, the NDBI is able to distinguish the rise across different locations, making it a useful indicator for metropolitan areas.

To determine the NDBI, one must do a differentiation on the NIR and MIR frequencies and then convert them to a binary representation. The NDBI illustrates the disparities associated with urbanised regions by subtracting the DN values of the MIR band from those of the NIR band. Once the numbers are calculated, they may be translated into a binary format that will help identify the urban area from other land cover categories. Differentiation is achieved by comparing the negative values produced for build-up pixels from standardised MIR and NIR differentiation with the positive values of typical land cover categories such as vegetation, aquatic bodies, and bare soil in the NDBI. In real-world scenarios, the NDBI may be calculated using tools like ArcGIS Pro 2.5. Map algebra's raster calculator is commonly used to do the necessary calculations for NDBI computation. Using this function, complicated equations and matrices may be applied to raster datasets with ease.

The NDBI's built-up area may be calculated with the use of a mid-infrared to near-infrared (NIR) difference metric. NIR and MIR frequencies are used by NDBI to highlight metropolitan areas that have been created by humans. It uses ratios to dampen the impact of changes in atmospheric conditions and ground lighting. Reflectance increases considerably from the near infrared to the mid-infrared band in urban and desert locations. However, vegetation has a negligibly different DN value (not significant) in MIR compared to NIR. This is shown by the sharp increase in elevation between these areas. Therefore, the built-up area may be separated from other land cover types and, hence, from the NDBI Pixel values of typical land cover categories after differencing and binary recoding (Xu et al., 2017). By applying conventional MIR and NIR differentiation, we are able to extract positive pixel values.

The NDBI for the studied area was calculated using the map algebra tool (raster calculator) in ArcGIS Pro 2.5. The formula described below represents this concept quantitatively:

$$NDBI = \frac{MIR-NIR}{MIR+NIR} \text{ ------}(8)$$

Whereas NIR is band 4 for Landsat-5 TM and band 5 for photos from Landsat-8 OLI, MIR is band 5 for Landsat-5 TM and band 6 for images from Landsat-8 OLI.

$$NDBI\ (Landsat-5\ TM) = \frac{B5-B4}{B5+B4} \text{ ------------ }(9)$$

$$NDBI\ (Landsat-8\ OLI\ ) = \frac{B6-B5}{B6+B5} \text{ ----------- }(10)$$

3.9 Land Surface Temperature (LST)

The application of LST is employed to analyse any impact of LULC and urbanisation changes on temperature. Estimating the LST comprises various procedures and steps that have been described by NASA (USGS, 2019b). These procedures range from the transformation of DN to at-sensor spectral radiance, the conversion of radiance to at-satellite brightness temperature (Tsat), to the normalised difference vegetation index, proportional vegetation, and land surface emissivity, among others, which are described below:

3.9.1 The conversion of digital number (DN) to At-sensor spectral radiance

The DN of the thermal infrared band is converted into Lλ using the equation taken from the USGS webpage. The calibration parameters can be retrieved from the metadata of the satellite image (USGS, 2019a).

$$L_{\lambda} = M_L\ x\ Q_{cal} + A_L \qquad \text{------------ }(10)$$

Where L denotes TOA Spectral Radiance, ML denotes Radiance Mult-band x, AL denotes Radiance Add-band x, and Qcal is the quantized and calibrated standard product pixel (thermal band).

3.9.2 The conversion of radiance (Lλ) to At-satellite brightness temperature (Tsat)

This involves the conversion of Lλ to Tsat so as to obtain the actual temperature received by the satellite during the time when the image is captured. Equation (11) can be used to convert the thermal band data from at-sensor spectral radiance to effective At-sensor brightness temperature (USGS, 2019b).

$$T_{sat} = \left[\frac{K_2}{lnln\,(\frac{K_1}{L_\lambda}+1)}\right] - 272.15 \quad \text{------------} \; (11)$$

Where Tsat is the At-satellite brightness temperature, Lλ is the TOA spectral radiance, K1 represents the K1 constant of band x, and K2 presents the K2 constant of band x.

Note: The K1 and K2 factors can be recovered from the image meta data.

3.9.3 Derivation of Land Surface Emissivity (LSE)

LSE is a crucial surface characteristic that can be obtained by studying the light that is emitted from measurements taken in space, and it is a feature shared by all naturally existing substances. The TIR data collected by satellites is the most helpful tool for estimating the surface emissivity of a location. High-resolution satellite data, such as satellite-sensed thermal infrared (TIR) bands from Landsat images, might be used to calculate the surface's emissivity (Yang, Wang, & August, 2004). According to a 2020 study by Nse et al., the land surface emissivity is crucial for both calculating the energy budget of the land surface and determining the temperature of the land surface using remote sensing data. To calculate the emissivity of the land, we shall use Equation 12:

$$e = 0.004PV + 0.986 \quad \text{--------------} \; (12)$$

where e is the land surface emissivity, PV presents the proportional vegetation, and PV is computed from NDVI using Eq. 13 below:

$$PV = \left(\frac{NDVI - NDVI_{min}}{NDVI_{max} - NDVI_{min}}\right)^2 \quad \text{-------} \; (13)$$

where PV describes the proportional vegetation, NDVI shows the normal difference vegetation index, NDVImin presents the minimum NDVI value, and NDVImax is the maximum NDVI value.

The final land surface temperature (LST) is estimated using a single mono-window, as stated in Eq. 14 below:

$$LST = \frac{T_{sat}}{1+\left(\lambda+\frac{T_{sat}}{p}\right) X \ln e} \quad \text{------------} \; (14)$$

where LST is the temperature of the Earth's land, Tsat is the temperature of the Earth as seen by satellite, is the wavelength λ of the radiated heat (the thermal band), P is a constant (14380), and e is the emissivity of the Earth's land.

3.9.4 Correlation Investigation Between Land Surface Temperature (LST) and Socio-Economic Factors (Household Type and Income Level) in Amman City.

Socio-economic factors, such as building type and level of household income, play a vital role in the general land surface temperature of a region (Guo et al., 2022). Wealthier neighbourhoods tend to invest more in landscaping and green spaces, which mitigate the LST effect by providing shade and cooling through evapotranspiration. Conversely, lower-income areas may have fewer green spaces and vegetation, contributing to higher LST.

Data Type and Source

The data used for this analysis consists of both attribute and spatial datasets, as specified in Table 6. The attribute data includes residential household type and level of income, which were obtained from the Greater Amman Municipality (GAM), while the spatial data includes residential land uses and building footprints, which were extracted from high-resolution satellite imagery. Table 7 shows the description of each household type.

Table 6. Data Type and Source

S/N	Data Type	Format	Source
1	Residential household type	Excel file	Greater Amman Municipality
2	Household level of income	Excel file	Greater Amman Municipality
3	Residential building footprint	Polygon shapefile	Extracted from high-resolution satellite imagery
4	Residential land use	Polygon shapefile	Extracted from high-resolution satellite imagery

Source: Author's own work, 2024

Residential Classification Scheme

The residential building categories in Amman city were divided into A, B, C, and D based on population income as specified by the Greater Amman Municipality. Category A represents high-income districts, while Category B represents middle-income districts (Al-Adhami, 1996; Potter et al., 2007). Therefore, these categories not only determine building density but also reflect the income levels of the districts in Amman. This classification system is used to understand the income distribution across different districts in Amman. The classification scheme is referenced as per Article No. 11 of the Regulation of Zoning and Building of the City of Amman, No. 76 of the year 1979, and Amendments Thereto (Greater Amman Municipality, 1979; Naimat, 2021; Shteiwi, 1996).

Table 7. Residential Classification Scheme

Residential Zone	Frontal Setback (m)	Side Setback (m)	Rear Setback (m)	Minimum Plot Area (m2)	Allowable Built-area (%)	Height of the building (m)	Minimum Frontage Dimension of the Plot (m)
A	5	5	7	1,000	39%	15	25
B	4	4	6	500	42%	15	18
C	4	3	4	300	51%	15	15
D	3	2.5	2.5	750	55%	15	13

Source: Greater Amman Municipality (1979)

The collected datasets were both analysed spatially and statistically using ArcMap 10.8.2 and Microsoft Excel, respectively. The analysed data was further presented in the form of maps, charts, and tables. The correlation and regression between LST, household type, and income level were also calculated.

3.10 Environmental degradation OLS Analysis

One of the hypotheses examines how uncontrolled and unplanned urban expansion affects Amman's built-up regions. The regression equation is as follows:

$$Builtup = \beta 0 + \beta 1 * POP + \beta 2 * GDP + \beta 3 * ShareInd + \beta 4 * Growthrate \quad ----- (15)$$

This equation's dependent variable, "built-up," represents Amman's built-up area. In this research, "POP" (population), "GDP" (gross domestic product), "ShareInd" (industrial sector share), and "growth rate" (urban growth rate) are independent variables. The independent variables are 1, 2, 3, and 4, whereas the intercept term is 0. "Error term" refers to unexplained factors, whereas "error term" captures random changes in the dependent-independent connection. Built-up areas indicate urban growth and the development of agricultural land. We're interested in this dependent variable. The item symbolises Amman's unchecked growth. This research examines how population growth, economic development, industrial activity, and the urban growth rate increase built-up areas. Analysing the connection between "Built-up" and the independent factors will do this. Assessing the association between "built-up" and dependent variables will accomplish the goal. "POP" is the key independent variable that affects urban sprawl due to population expansion. Population growth increases residential and commercial real estate demand, expanding developed areas. Population growth increases urban sprawl and built-up areas with a positive coefficient (1). If the coefficient was positive, GDP—"gross domestic product"—is the second independent variable. Amman's GDP measures economic growth. Economic growth spurs investment, employment, and urban infrastructure development, which drives urbanisation. If the coefficient is positive, we may conclude that economic development causes built-up area expansion. The independent third variable, "ShareInd," indicates the industrial sector's share. This variable measures urban industrial land area. Manufacturing, industry, and infrastructure need a lot of land. Increased industrial sector allocation may aid urban sprawl and built-up areas. A positive coefficient (3) implies that the industrial sector's percentage contribution to urban sprawl is considerable. "Growthrate," the fourth independent variable, measures the city's growth rate. Urban expansion accelerates urbanisation and expands developed areas. The coefficient would be 4 if the urban development rate significantly affected the rise in built-up areas. The error component, 'a', includes unexplained causes and random oscillations in the dependent-independent relationship. Unmeasured variables, measurement imperfections, and complicated interrelationships are considered in the analysis. Regression analysis can estimate the coefficients (0, 1, 2, 3, and 4) in the model to quantify the relationships between the independent variables (population, GDP, share of industry, and growth rate) and the dependent variable (built-up area). These coefficients will reveal the strength of the linkages and their direction. An analysis of the regression equation could help determine how population growth, economic development, the industrial sector's role in the economy, and urban growth affect Amman's build-up areas. The magnitudes of the coefficients show the relative relevance of each independent variable in explaining variability in built-up areas.

Another hypothesis states,

$$CO2 = \beta 0 + \beta 1 * Builtup + \beta 2 * ShareInd + \beta 3 * Energyuse + \beta 4 * ELEC + \varepsilon \quad -----(16)$$

And,

$$log\_CO_2emission = \beta 0 + \beta 1 * log\_AmmanGrowthRate + \beta 2 * log\_EnergyUse + \beta 3 * log\_GDPpercapita + \beta 4 * log\_RenewableEnergy + \varepsilon \quad -----(17)$$

The regression equation (16) above shows the relationship between CO_2 emissions and urban sprawl land use regulations in Amman. Urban development and fast growth have created concerns about CO_2 emissions. Increased energy use, industrial activity, and transportation demand caused this growth. This research examined CO_2 emissions and land use regulations to determine their environmental impact. Built-up, the first independent variable, measures urbanisation in Amman. The conversion of natural or agricultural land into developed regions owing to urban sprawl may increase CO_2 emissions. These variables measure urban growth and carbon dioxide emissions. ShareInd, the second independent variable, measures Amman's industrial sector's economic contribution. Energy-intensive and fossil fuel-dependent industrial operations often increase CO_2 emissions. The regression model's "ShareInd" variable allows analysis of the industrial sector's economic influence on the city and its CO_2 emissions. This method also evaluates industrial emissions mitigation and land use strategies.

Amman's energy usage is the third independent variable. Urbanisation increases energy demand for residential, commercial, and industrial operations. In recent years, there has been growing concern over increasing energy consumption and carbon dioxide (CO_2) emissions in Jordan’s capital city, Amman, due to the limited availability of renewable and sustainable energy sources. To investigate the relationship between energy consumption and CO_2 emissions, one could include energy use as another independent variable in the regression model presented earlier.

The fourth independent variable is renewable energy. Jordan has made efforts to develop alternative energy resources, particularly solar and wind power. Despite these initiatives, energy consumption and CO_2 emissions remain high in Amman. Amman currently utilises renewable energy sources to power approximately 29% of its electricity grid, with a goal to reach 50% of electricity from renewables by 2030 (Salah, Shalby, & Ismail, 2023). However, with the presence of renewable energy sources in Amman, there is a significant opportunity to reduce reliance on fossil fuels, lower carbon emissions, and enhance energy sustainability in the city.

The fifth independent variable, ELEC, measures electricity use. Electricity production, a major energy consumer, may affect urban CO_2 emissions. By adding the variable ELEC to the equation, it is possible to examine the relationship between electricity consumption and CO_2 emissions and the effect of land use policies on energy conservation and environmentally friendly electricity generation. Random variation and unexplained factors account for the inherent unpredictability and unknown impacts in the dependent-independent relationship. The technique accounts for unobserved factors and measurement errors not in the regression equation. Regression analysis estimates coefficients (0, 1, 2, 3, and 4) to quantify CO_2 emission-independent variable relationships. The coefficient's magnitude and significance indicate link strength and direction. Regression analysis may reveal how land use policies and tactics affect urban sprawl's environmental implications, particularly CO_2 emissions. A positive and statistically significant coefficient for "built-up" suggests that urban growth increases CO_2 emissions. This emphasises the significance of compact and sustainable urban development land use regulations. The positive and statistically significant correlations for ShareInd, energy use, and ELEC imply that industrial activities, total energy consumption, and electricity consumption generate CO_2 emissions. This emphasises the necessity of energy efficiency, renewable energy, and emission-reduction strategies.

The formulation of the regression equation (17) is grounded in established theories and empirical evidence pertaining to the intricate relationship between urbanisation, population density, and environmental sustainability. Drawing on urban economics and environmental management literature, the selected variables are expected to capture key dimensions influencing carbon emissions in the unique context of Amman. Including renewable energy as an independent variable in existing regression models (17) offers valuable insights into understanding its influence on CO_2 emissions, allowing researchers to assess the effectiveness of incorporating renewable energy sources in combating pollution. The logarithmic transformation of variables, such as log_Amman growth rate and log_Energy use kg of oil equivalent, aims to address non-linear relationships and account for potential skewed distributions. Moreover, the inclusion of log_GDP per capita for Amman and log_Renewable Energy reflects the economic and energy-use aspects, respectively, contributing to the environmental impact.

The present study uses Stata 17. Stata v17 has several tools and functions for thorough and comprehensive analysis. Stata v17 allows researchers to quickly manage and clean datasets, generate descriptive statistics, execute sophisticated econometric modelling, and assess model diagnostics. This thesis uses Stata v17 to provide accurate, dependable data that helps answer research problems.

3.10.1 Data Collection

The study utilised secondary data that was obtained from the World Bank, Greater Amman Municipality (GAM), and the Department of Statistics (DOS). The World Bank provides comprehensive and reliable data on various economic, social, and environmental indicators for countries around the world, including Amman. The 1990–2021 data collection period encompasses Amman's complex urban expansion, environmental costs, and sustainability developments.

The GAM and DOS datasets provided urban sprawl variables. These included land use changes, urban development, and population growth. CO_2 emissions, air quality indices, energy consumption per capita, and renewable energy utilisation were also included. Urbanisation and population density factors were also collected to study their effects on environmental sustainability.

3.10.2 Data Analysis

The analytical phase of this study hinged on multiple Ordinary Least Squares (OLS) regression analyses. This statistical technique enabled a comprehensive exploration of the intricate relationships among variables. By accommodating the simultaneous consideration of multiple independent variables, OLS regression facilitated a nuanced understanding of the factors influencing environmental pollution and energy consumption within the urban setting of Amman.

Multiple OLS regression models were constructed, with the dependent variable encompassing environmental costs or sustainability indicators and the independent variables embracing urban sprawl, urbanisation, population density, and other pertinent factors. The analyses sought to ascertain the statistical significance, magnitude, and directionality of relationships among these variables, thereby shedding light on the intricate interplay of urbanization dynamics and environmental outcomes.

3.10.3 Correlation Analysis

This study used a correlation analysis to determine the existence, strength, and nature of associations between the variables of interest. The linearity or uniformity of the relationships was determined by computing either Pearson's or Spearman's rank correlation coefficients, depending on the data distribution. In addition to shedding light on possible causal connections, this research helped pinpoint instances of multicollinearity that might compromise the accuracy of future regression tests.

3.10.4 Unit Root Test

Unit root tests were necessary to determine time series data stationarity before regression analysis. The null hypothesis was non-stationarity, and the alternative hypothesis was stationarity in the Augmented Dickey-Fuller (ADF) test.

3.10.5 Serial Correlation Evaluation

Serial correlation, or autocorrelation, was examined within the residuals of the regression models to ensure the absence of correlation among errors. The Durbin-Watson test, or the Breusch-Godfrey test, was employed to gauge serial correlation. The detection of serial correlation prompted considerations for adjustments or alternative models to accommodate the correlated errors and uphold the reliability of the regression analysis.

Serial correlation means model error factors are systematic and not independent. The main indicator of autocorrelation is the Durbin-Watson statistic, or d-statistic. A statistic near 2 indicates statistical independence, as the residuals are not serially correlated.

3.10.6 Multicollinearity Assessment

To assess multicollinearity among independent variables, tolerance and VIF values were calculated. Multicollinearity may cause high VIF or low tolerance. VIF and tolerance metrics analysed independent variable intercorrelation, assuring regression analysis results' robustness.

4. ANALYSIS & RESULTS

4.1. Amman population-density and urban expansion challenges

Table 8. Population of the Amman Governorate

Amman Governorate	2004 Census	2015 Census	2021 Census
Urban	97.2%	97.2%	97.2%
Rural	2.8 %	2.8%	2.8%
Overall	2.353 Million	4.019 Million	4.642 Million

Source: Department of Statistics (DOS), 2022

Table 8 shows Amman Governorate population patterns from 2004 to 2021. It divides the population into urban and rural divisions and shows census-year population numbers. The governorate's urban population remained steady at 97.2% throughout this period, indicating that 97.2% of inhabitants lived in urban areas. Similarly, 2.8% of the population lived in rural regions for all three years. However, the governorate's population rise is notable. The population rose from 2.353 million in 2004 to 4.019 million in 2015 and 4.642 million in 2021. The population has grown significantly over time. The Department of Statistics (DOS) provides these demographic statistics as of 2022. This data provides demographic insights into the Amman Governorate and affects urban planning, resource allocation, and population trends.

Table 9. Amman distribution of urban and non-urban areas

Year	1987	1997	2007	2017
Urban Area in Km²	147.08	195.98	214.94	237.86
Non-urban area in Km²	611.48	562.58	543.62	520.70

Source: Al-Bilbisi, 2019

Table 9 from Al-Bilbisi in 2019 shows land division statistics for a region in 1987, 1997, 2007, and 2017 in square kilometres (Km²). The studied timeframe shows many land use patterns. The urban area—land created for urbanisation—has grown steadily. The urban area rose from 147.08 Km² in 1987 to 195.98 Km² in 1997, 214.94 Km² in 2007, and 237.86 Km² in 2017. This data shows ongoing urbanisation and building expansion. Non-urban property, which generally includes rural and natural regions, has shown a different pattern. The non-urban area was 611.48 Km² in 1987, reduced to 562.58 Km² in 1997, and further declined to 543.62 Km² in 2007 and 520.70 Km² in 2017. This shows urban sprawl or land use policy changes are reducing non-urban land.

Table 10. UEII interpretations Amman Governorate area

Period	UEII	Interpretation
1987-1997	0.645	Medium Speed expansion
1997-2007	0.250	Slow expansion
2007-2017	0.302	Low Speed expansion
1987-2017	0.399	Low Speed expansion
1990-2022*	0.60	Medium Speed Expansion

Source: Author's Analysis based on data taken from Al-Bilbisi, 2019; Abdeljawad, Adedokun, & Nagy, 2022*

Urban growth and population density in Amman, Jordan, are significant problems. The city must accommodate a burgeoning population and refugees from Iraq and Syria. The 2021 census showed that 97.2% of Amman's 4.642 million people reside in urban areas, reflecting increasing urbanisation over the preceding two decades. The Greater Amman Municipality (GAM) and its bordering regions have a higher population density due to the concentration of people, industries, and jobs. In 2019, Greater Amman had 13,600 people per square kilometre, whereas the entire municipality had 4,987 (Ababsa, Abu Hussein, 2020). Concentration strains natural resources, land usage, and infrastructure, worsening urban sprawl. Amman's economic importance attracts people and companies, increasing population density. Amman, which hosts 80% of Jordan's economic and industrial activity, has grown faster than other regions. Unfortunately, this development has frequently cost agricultural fields, reducing food output and ecological balance.

In Table 10, the urban expansion intensity index (UEII) reveals Amman's urbanisation rate over time. Amman expanded by 0.645 percent between 1987 and 1997, according to the index. From 1997 through 2007, the city grew by 0.250 percent annually. Urban expansion rose modestly between 2007 and 2017, with an annual growth rate of 0.302, indicating low-speed urbanization. From 1987 until 2017, the UEII was 0.399, a low-speed development. The city's footprint has grown despite the slowing growth rate. Amman's fast urbanisation has many causes. First, in 2007, the government added five zones to the Greater Amman Municipality, increasing its territory and urban development area. Second, the forced flight of Iraqis in 2003 and the flood of Syrian refugees have increased the city's population, straining infrastructure and services. Land use and natural resource distribution are affected by this urban growth. Food security and ecological balance are threatened as the metropolis expands into agricultural territory. The Al Hussein and Al Wehdat refugee camps have also caused social problems, respiratory illnesses, and slums. Amman's population density and urban growth demand a deliberate strategy. Policymakers must prioritise sustainable urban design that balances expansion, safeguards agricultural land, and provides enough infrastructure for the expanding population. Diversifying economic activity and creating possibilities beyond Amman can relieve strain on the city and encourage equal growth across the country. The government must also provide refugees and migrants with education, healthcare, and jobs. This will enhance disadvantaged groups' lives and make society more peaceful. Public transit and affordable housing investments can help manage urban development and resource pressure. The government may prevent sprawl and support compact, efficient urban growth by fostering sustainable transportation and affordable housing in well-planned neighbourhoods.

4.2. A Comprehensive Analysis of the Urban Policies of Amman Interpreting the Urban Policies of Amman

Jordan's capital, Amman, has grown and changed throughout time. Due to the many challenges and opportunities of urban growth, numerous laws and initiatives have been created to shape the city's development. This section will examine the main objectives and outcomes of the Amman Master Plan for 2025, the Amman Green City Action Plan 2019 (GCAP), the Amman Resilient Strategy 2017, the Amman Transportation Master Plan 2010, and the planned 2022–2032 Master Plan for Amman. Our goal is to explain Amman's complicated urban evolution and how these policies have affected its present and future status by analysing these policies within a larger context.

4.2.1. The Amman Master Plan for 2025

The 2025 Amman Master Plan is a major urban development milestone. This effort was created to solve several urban issues while supporting sustainable development (Abdeljawad & Nagy, 2023a). The plan encouraged methodical urban expansion to reduce sprawl and maximise land utilization. The main goals were to develop infrastructure, boost economic growth, and promote environmental sustainability while improving social services, housing, and cultural heritage. Transportation, housing, and public engagement are all prioritised in the approach (Beauregard & Marpillero-Colomina, 2011). Researchers see this initiative as a comprehensive effort to meet the different needs of a rising metropolitan center. This effort addressed several urban development issues, including population growth and cultural preservation. The approach acknowledged the interdependence of environmental, economic, and social factors in urban development to create a comprehensive and lasting urban environment. This programme's success depended on its execution, worldwide cooperation, and adaptability. The Amman Master Plan for 2025's success depends on the city's ability to implement these aims and adapt to changing urban dynamics. To fully assess the policy's impacts, it must be examined throughout time in terms of land usage, infrastructure development, economic growth, and Amman inhabitants' overall well-being.

4.2.2. The Amman Green City Action Plan 2020 (GCAP)

The 2020 Amman Green City Action Plan addresses climate change and environmental degradation in a contemporary way. The policy prioritises solid waste, water, wastewater, urban mobility, and building energy efficiency. This conclusion is clear: Amman, as a municipality, understood the global environmental crisis and took proactive steps to reduce its own environmental impact. This strategy prioritises sustainability, energy efficiency, and climate adaptation. Their integration into the city's infrastructure and influence on a greener, more sustainable urban environment must be assessed. GCAP's implications would be examined in terms of waste management, water and energy consumption, and urban transportation options (AECOM, 2021).

4.2.3. The Amman Resilient Strategy 2017 (GAM, 2017)

Amman's 2017 Resilient Strategy, designed as part of the 100 Resilient Cities initiative, envisioned a cohesive, forward-thinking, and ecologically sensitive metropolis. Mobility, sustainability, innovation, equality, and public involvement underpinned the strategy (Shamout & Boarin, 2021). This approach recognises that Amman must address current difficulties and build resilience for future instability. As part of the Resilient Strategy, the city's urban transportation infrastructure improved with the creation of the Amman Bus and BRT systems. Two interpretations are possible in this setting. First, it shows the city's commitment to public transportation and traffic reduction. Second, it stresses the need for creative urban development. The Resilient Strategy emphasises local participation in urban development. Community engagement and grassroots methods affect city resilience, according to this view (Abdeljawad, Szente, Szigeti, and Nagy, 2022). The impact of these mobility activities on urban connections, congestion reduction, and public involvement in Amman's future must be assessed to evaluate this strategy.

4.2.4. The Amman Transportation Master Plan 2010 (GAM, 2010)

The 2010 Amman Transit Master Plan addressed public transport accessibility in newly planned residential neighborhoods. The statement stressed the need for reliable public transit, especially in car-dependent areas. However, implementing the method was difficult and delayed. This method shows how accessible public transportation reduces traffic and promotes sustainable urban expansion. The lengthy construction and launch of the Bus Rapid Transit (BRT) system illustrates the challenges of implementing transportation projects in a growing city like Amman.

Amman's poor pedestrian and cycling infrastructure was highlighted in the show. This emphasises the need to create a pedestrian-friendly urban environment to promote healthy commuting and reduce car usage. Results would include a thorough review of the Bus Rapid Transportation (BRT) system's impact on public transportation accessibility and pedestrian and bicycle infrastructure improvements.

4.2.5. Challenges in Previous Plans

Historical failures to satisfy the city's urban development needs are seen in the hurdles faced during the execution of the 1955 and 1988 urban plans (Abdeljawad & Nagy, 2023b; Abdeljawad & Nagy, 2021). These ideas emphasise the need to learn from past mistakes and change municipal policy to meet evolving local needs. The postponement of important projects like Rapid Bus Transit shows a lack of long-term urban planning vision. The research implies that urban planning must address current needs and predict future growth and challenges. To assess the effects of these historical issues, one must understand how project execution delays affected urban growth and infrastructure development.

4.2.6. Land Management & Planning Boundaries

The examination of land management and planning boundaries in Amman brings attention to the challenges that arise due to outdated planning laws and inadequate intergovernmental engagement. The enduring presence of temporary planning law, as shown by the "Law of Planning of Cities, Villages, and Buildings, No.79," highlights the necessity for substantial modifications in the field of urban planning (UN-Habitat et al., 2022). The analysis highlights the significance of land-use regulation and its potential impact on the expansion and intensification of urban areas. The vacant land situated inside the urbanised area of Amman Governorate presents a favourable opportunity for the implementation of sustainable development projects. However, the inadequate administration of land has been hindered by the absence of a comprehensive national urban policy and the insufficient coordination among governing bodies.

4.2.7. Zoning Policy in Amman

A number of development zones will be established in Jordan as part of the government's effort to stimulate the domestic economy. With the goal of assisting local investors by establishing a competitive business climate and offering them additional investment incentives and tax redemptions, the Development Zones Law No. 2 for 2008 (the "law") establishes six Development Zones, strategically distributed around the kingdom.

Boosting economic capacity in the Kingdom, attracting investments, and developing an advanced investment environment for economic activities are the goals of the development zones, as stated in Article 3 of the law. This is accomplished by carrying out the long-term goals specified by the legislation. The formation of the Development Zones Commission (the "Commission"), world-class regulatory and economic development organisations with strong institutional skills, and public-private and public-public partnerships are among these goals.

4.2.8. Conclusion

In order to accomplish the national objectives in this area, the policy lays out a strategy for all sectors involved in infrastructure, municipal services, GAM, public transportation, urban environment management, and climate change on both a local and regional scale.

The policy's ultimate goal is to facilitate more chances for collaboration and integration across different sectors as part of an action plan to regulate proactive planning, with the ultimate goal of moving all sectors' focus from service provision to development.

In addition to reflecting national action goals, the policy is a tool for achieving the New Urban Agenda and seeks to initiate plans that prioritise agriculture, public transportation, and "pioneering" neighbourhood plans across sectors and governments.

4.3. Managing, assessing and monitoring urban sprawl using remote sensing

H1: There is a significant relationship between the increase in built-up areas and declining agro-vegetation land in Amman.

This section discusses Amman City's 1990–2022 land use and land cover (LULC) data post-processing and analysis. The study uses the support vector machine (SVM) technique to classify Landsat images into built-up regions, agriculture land, and barren terrain. Overall accuracy and the Kappa index measure classification accuracy. The spatial extent of each land cover class across the research period is statistically examined, and the LULC change detection analysis determines the percentage gain and loss of each class.

Table 11. Overall Accuracy and Kappa Coefficient.

Year	Overall Accuracy	Kappa Accuracy
1990	95.6%	0.85
1995	97.8%	0.89
1999	95.0%	0.79
2004	98.2%	0.93
2013	97.0%	0.93
2017	96.4%	0.91
2022	96.0%	0.91

Source: Abdeljawad, Adedokun and Nagy, 2022

All the classified maps were validated using Kappa statistics, producers' accuracy, users' accuracy, and overall accuracy. The overall accuracy for LULC classifications is 95.6%, 97.8%, 95.0%, 98.2%, 97.0%, 96.4%, and 96.0% for 1990, 1995, 1999, 2004, 2013, 2017, and 2022, respectively, as shown in Table 11 above. Similarly, Kappa coefficients for the four classified

LULC maps are 0.85 (in 1990), 0.89 (in 1995), 0.79 (in 1999), 0.93 (in 2004), 0.93 (in 2013), 0.91 (in 2017), and 0.91 (in 2022), respectively, which indicates that the output LULC maps can be significantly used as shown in Table 11 above. Therefore, in accordance with Okwuashi et al.'s (2012) interpretation of the Kappa statistic, it can then be stated that for the year 1999, there is a substantial agreement between the classified map and the ground-referenced information (ground truth). While for the years 1990, 1995, 2004, 2013, 2017, and 2022, there is an almost perfect agreement between the classified map and the ground-referenced information (ground truth).

Analysing the geographical breadth of each land cover class helps explain land cover changes throughout time.

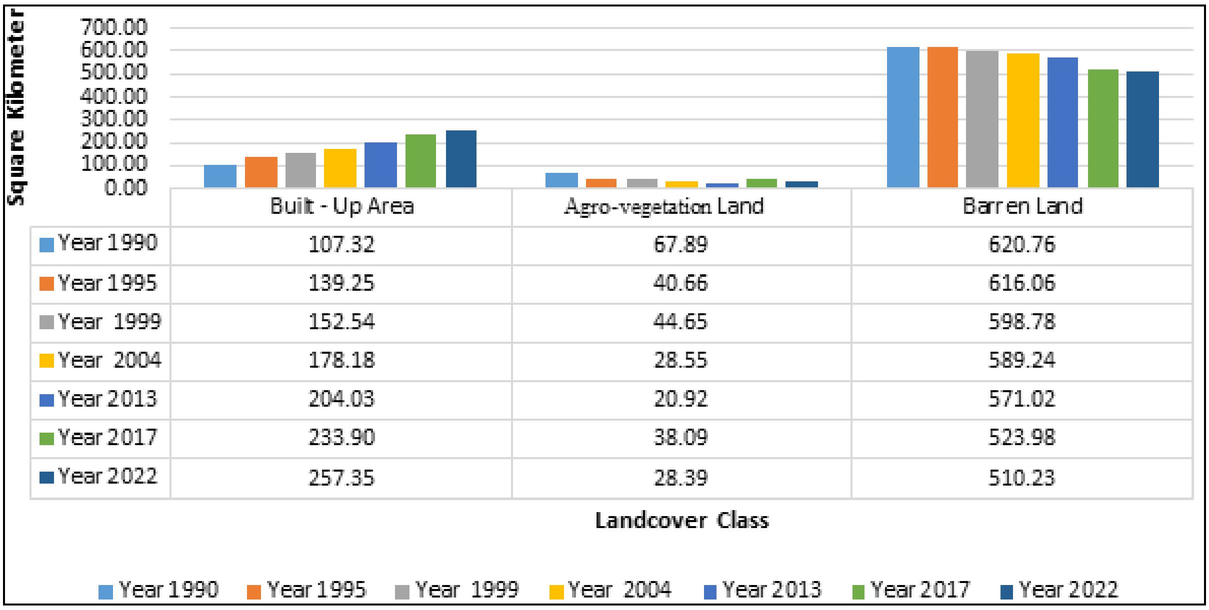

Figure 9. Land cover class statistics of Amman between 1990 and 2022

Source: Abdeljawad, Viktor and Nagy, 2022

Figure 9 shows a consistent increase in urban land use over the 32-year study period. This could be attributed to the steady increase in population growth in Amman between 1990 and 2022. On the other hand, there had been a consistent decrease in barren land from 620.76 km^2 in 1990 to 510.23 km^2 in 2022. Also, there are inconsistencies amongst the variations in agricultural land, such that the increase and/or decrease in total land area over the years is inconsistent.

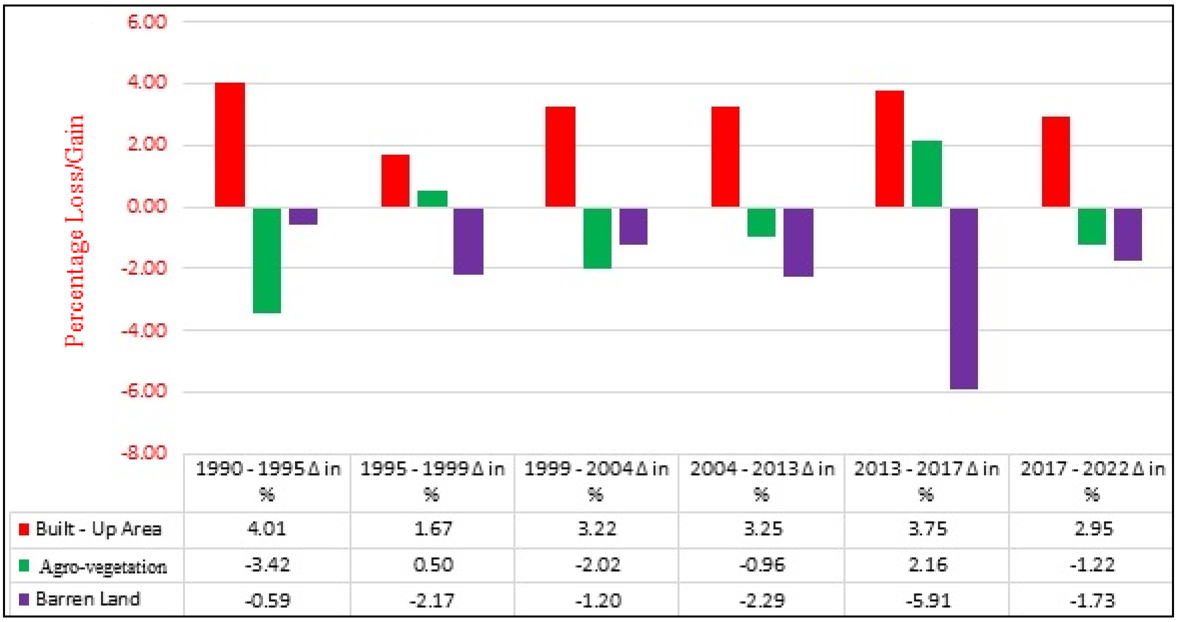

Figure 10. Percentage Loss/Gain in land covers over time

Source: Abdeljawad, Viktor and Nagy, 2022

Over the 32-year research period, urban land usage increased due to Amman's population expansion and development. Barren land decreases with time, whereas agriculture land fluctuates. LULC change detection analysis compares classed maps from two dates to assess the percentage growth and loss of each land cover class over time. Figure 10 shows the percentage change in land cover between 1990 and 2022. Built-up areas increased with time, whereas agriculture and barren terrain decreased. The city's rising population and human activities need the conversion of other land covers to urban regions. From the LULC change detection output, it’s clear that over time there is an increase in built-up area and a reduction in agro-vegetation. We conducted a Pearson correlation between high built-up and agriculture correlations, and the results proved that. The Pearson correlation calculated is -0.7117.

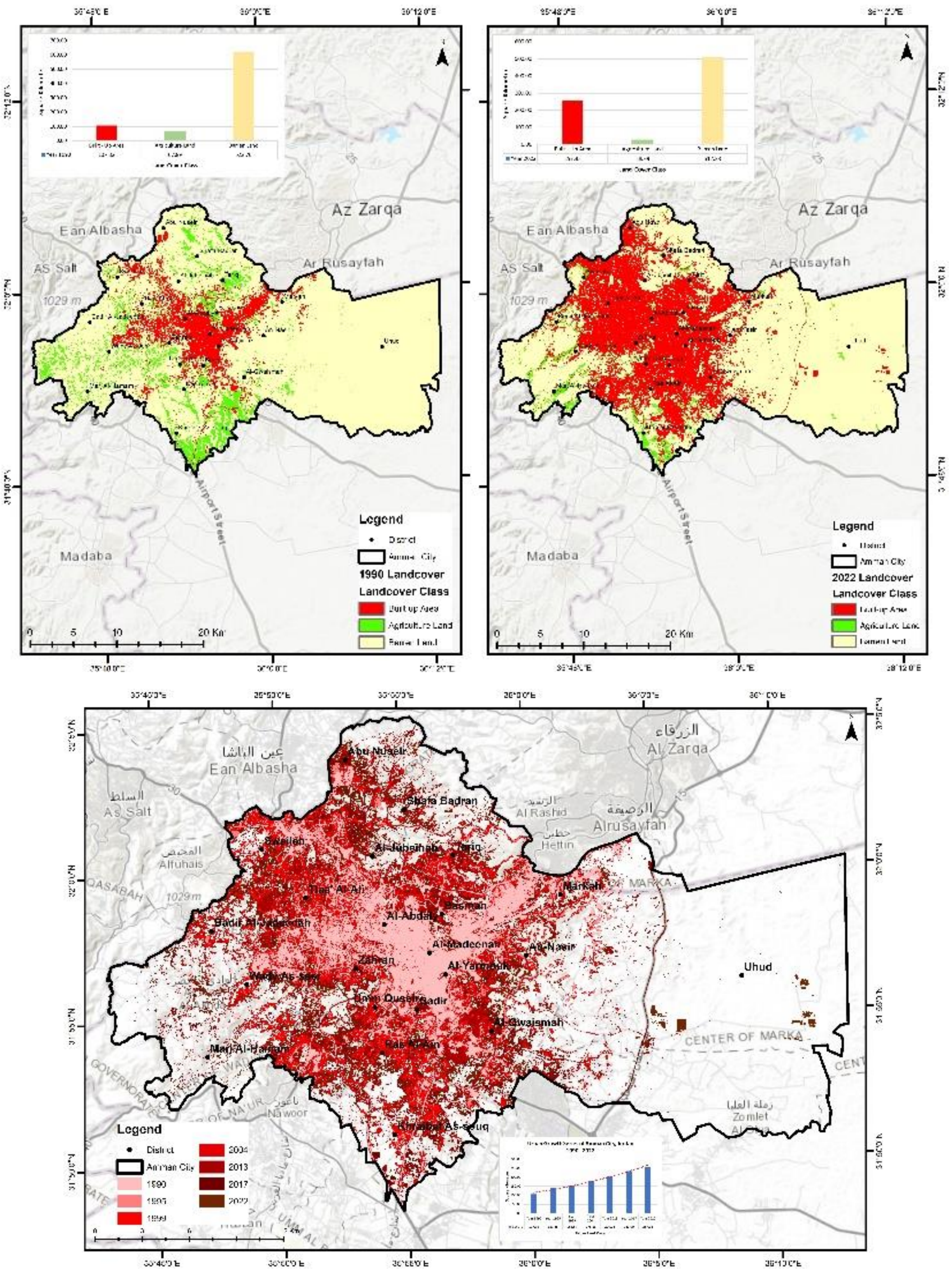

Figure 11. Land cover changes between 1990 and 2022

Source: Abdeljawad, Adedokun, & Nagy, 2022

Figure 11 above shows land cover changes and urban land cover distribution across the research period. Over time, urban land in Amman city has expanded towards the north-western and south. Improved infrastructure attracts people from other places and expands urban land at the expense of other land uses, notably agriculture. The study found that urban sprawl has been a major trend in Amman, notably along transit corridors out of the city centre. Due to its geography, the eastern study region has limited urban expansion. These tendencies suggest sustainable development measures to regulate urban expansion and safeguard agricultural lands (Abdeljawad, Adedokun, & Nagy, 2022).

The relative entropy result, as shown in Figure 12, shows a steady increase in entropy value from 0.83 in 1990 to 0.97 in 2022, with 2013 having the highest entropy value of 0.99. This implies that there is an increase in the growth and development of the study area, with the pattern of growth being dispersed and the direction of growth clearly towards the north-western and south parts of Amman city, as seen in the increase in entropy value (Abdeljawad, Adedokun, & Nagy, 2022).

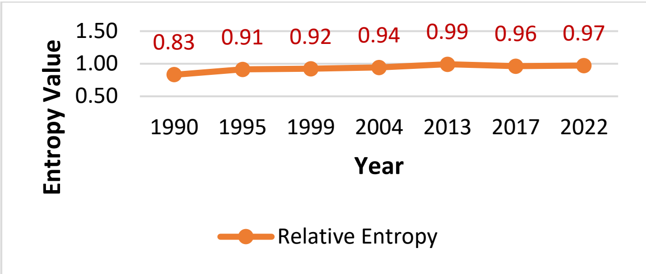

Figure 12. Graphical depiction of the relative entropy of Amman from 1990 to 2022

Source: Abdeljawad, Adedokun, & Nagy, 2022

4.4. Amman spatial distribution of NDVI, NDBI and LST

H2: Over time, there is a correlation between low NDVI values and high Land Surface Temperature (LST) values in Amman, indicating that reduced vegetation cover contributes to increased surface temperatures, whereas high LST values are positively associated with high Normalised Difference Built-up Index (NDBI) values, indicating that areas with more built-up surfaces have higher temperatures.

Urban and environmental studies are interested in Amman's NDBI, LST, and NDVI relationships. These indexes reveal urban characteristics such as built-up areas, temperature, and vegetation cover. LST, NDVI, and NDBI were correlated using Pearson's correlation. The Pearson correlation coefficient measures the linear connection between two data sets, X and Y. Statistics, economics, psychology, and the social sciences utilise it to examine variable associations. R, the Pearson correlation coefficient, is -1 to +1. X and Y rise linearly with a value of +1. Association coefficients vary from -1 to +1, with 1 representing a strong positive association and -1 a strong negative correlation. To determine how land development and agricultural activities affect land surface temperature (LST), the correlation coefficient between LST, NDVI, and NDBI was calculated.

Between 1990 and 2022, NDBI and LST had a significant association. The built-up urban environment in the studied region affects land surface temperature (LST), as shown by the positive association between LST and NDBI (Abdeljawad, Adedokun, & Nagy, 2023). The association between urban sprawl and land surface temperature rises throughout the research years shows the environmental impact of urban growth. The Normalised Difference Vegetation Index (NDVI) for agricultural land and land surface temperature (LST) from 1990 to 2022 show a significant negative link. NDVI and LST have an inverted association, which is intriguing (Shahi et al., 2023).

Agriculture and plant cover lower surface temperatures, and vice versa. The NDVI measures plant density and health. It gives vital vegetation information from satellite photos. Satellites and ground-based equipment monitor Earth's surface temperature as LST. The negative link between NDVI and LST shows that greener, agricultural areas have lower surface temperatures. Several things cause this. Evapotranspiration helps plants regulate temperature. Evapotranspiration is the result of soil evaporation and plant transpiration. This cools the environment, especially the land. Vegetation shades the ground, reducing solar energy. This shadowing effect may greatly affect surface temperature, especially in metropolitan regions where the Normalised Difference Built-up Index (NDBI), Land Surface Temperature (LST), and Normalised Difference Vegetation Index (NDVI) are correlated: a rise in NDBI increases LST and vice versa. This connection reveals how urbanisation affects land surface temperature and vegetation. The NDBI measures urban areas in a region using remote sensing. It is computed using NIR and shortwave infrared (SWIR) reflectance data. Additionally, as the Normalised Difference Vegetation Index (NDVI) grows, the land surface temperature (LST) decreases, and vice versa. This inverse connection between NDVI and LST is crucial in vegetation and temperature analysis applications and research. Because of the presence of agricultural land and bare surface, the northern, southern, and eastern parts of the study area recorded the lowest land temperature in 1990, with a temperature range of 23.80 °C to 29.50 °C, as shown in Figure 13. Whereas in Figure 14, the result of the LST (image C), the built-up area (city centre) recorded the highest land temperature in July 2022 with a temperature range between 38.2°C and 46.0°C, part of the north-east, south-west, and north-western regions of Amman recorded the lowest land temperature in the year 2022 with a temperature range between 26.3°C and 34.1°C as a result of the existence of vegetated and bare land.

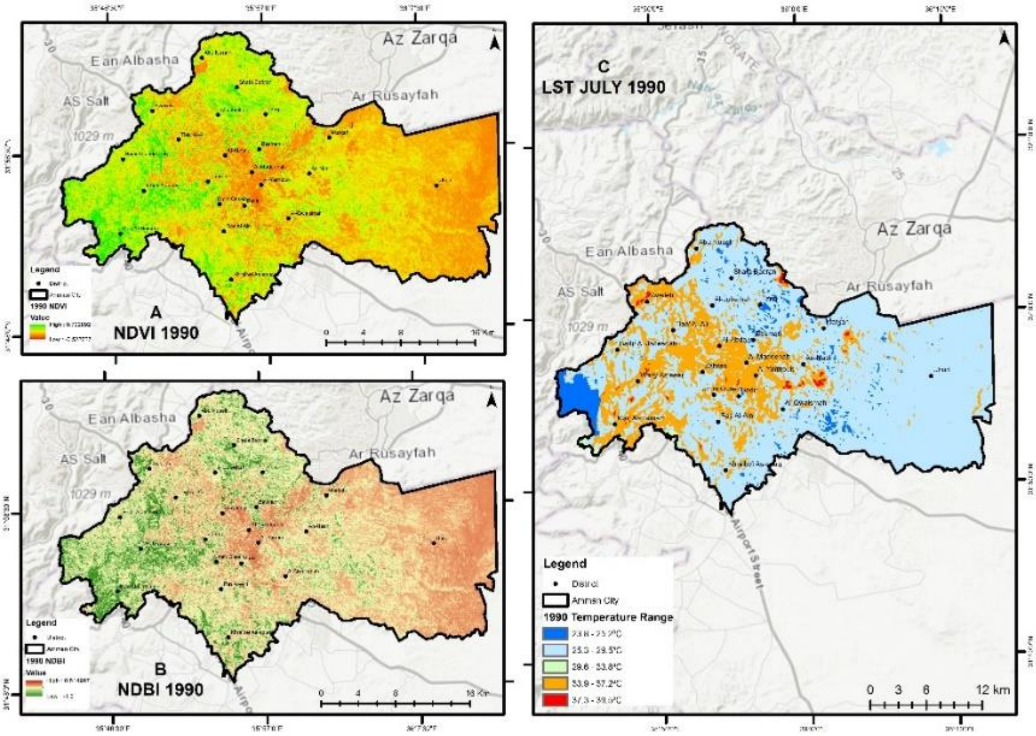

Figure 13. NDVI, NDBI, and LST images 1990

Source: Abdeljawad, Adedokun, & Nagy, 2022

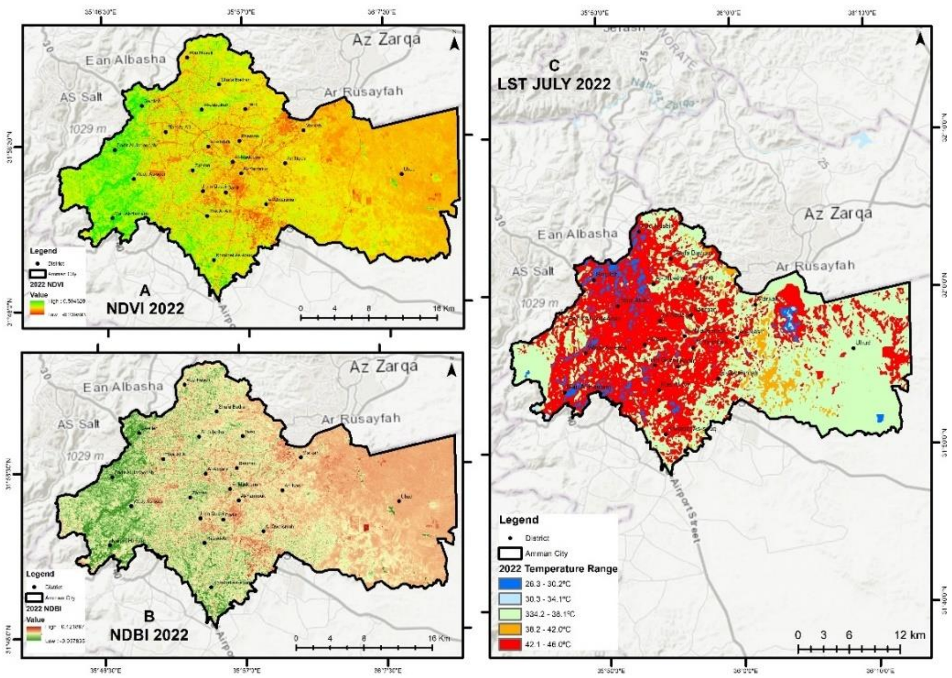

Figure 14. NDVI, NDBI, and LST images 2022

Source: Abdeljawad, Adedokun, & Nagy, 2023

4.5 Impact of NDVI Values on Local Temperature Variations in Amman

The Non-Differential Vegetation Index (NDVI) is a remote sensing approach to measuring and assessing the density of green vegetation and its health. Vegetation covers such as shrubs, grass, and trees are widely recognised for their ability to provide cooling effects on the environment. The Normalized Difference Vegetation Index (NDVI) can be used to identify areas of healthy and stressed vegetation as well as changes in vegetation brought about by natural disturbances like wildfires, human activities like deforestation, or changes in the phonological stage of plants. It is an important remote sensing vegetation index, widely applied in research on global environmental and climatic change (Gao, 1996), with values ranging from +1.0 to -1.0. As specified by the United States Geological Survey (2018), areas of barren rock, sand, or snow usually show very low NDVI values (for example, 0.1 or less). Sparse vegetation such as shrubs and grasslands or senescing crops may result in moderate NDVI values (approximately 0.2 to 0.5). High NDVI values (approximately 0.6 to 0.9) correspond to dense vegetation such as that found in temperate and tropical forests or crops at their peak growth stage.

Since higher NDVI values have a cooling effect on the environment, they are typically linked to healthier and denser vegetation cover. Healthier vegetation engages in higher rates of evapotranspiration, where water is taken up by plant roots and released into the atmosphere through transpiration from leaves. Vegetation cover has a lower albedo (reflectivity) compared to bare soil or impervious surfaces; higher NDVI values usually indicate the presence of more vegetation, which absorbs more solar radiation instead of reflecting it. This absorption helps cool the environment as less solar energy is reflected into the atmosphere. The presence of vegetation cover plays a vital role in the improvement of air quality through capturing and filtering pollutants. Higher NDVI values indicate healthier vegetation, and the presence of such vegetation contributes to a cooler and more comfortable environment through mechanisms like shade, evapotranspiration, albedo reduction, microclimate regulation, and air quality improvement.

To determine the extent to which a higher NDVI value cools the city of Amman, the NDVI raster file for the study year (1990–2022) was reclassified based on the specified threshold, as shown in Table 12. The temperature range of each NDVI threshold was also extracted, as shown in Table 13. Figure 15 shows the spatial distribution of NDVI values within Amman.

Table 12. NDVI Range

NDVI Range	**Interpretation**
< 0.1	Barren rock, built-up area, sand, or snow
0.2 – 0.5	Sparse vegetation
> 0.6	Dense vegetation

Source: USGS, 2018

Table 13. Extent and Temperature range of each NDVI Value

1990			1995		
NDVI Value	**Area (Km^2)**	**Temperature**	**NDVI Value**	**Area (Km^2)**	**Temperature**
< 0.1	606.53	33.9 - 39.5ºC	< 0.1	772.75	29.6 - 40.5
0.2 - 0.5	172.48	25.3 - 33.8ºC	0.2 - 0.5	23.24	22.1 - 29.5ºC
> 0.6	16.98	23.8 - 25.2ºC			
1999			**2004**		
NDVI Value	**Area (Km^2)**	**Temperature**	**NDVI Value**	**Area (Km^2)**	**Temperature**
< 0.1	772.81	29.7 - 40.2ºC	< 0.1	735.11	34 - 45.8ºC
0.2 - 0.5	20.38	24.1 - 29.6ºC	0.2 - 0.5	57.38	30 - 33.9ºC
> 0.6	2.8	22.5 - 24ºC	> 0.6	3.5	26 - 29.9ºC
2013			**2017**		
NDVI Value	**Area (Km^2)**	**Temperature**	**NDVI Value**	**Area (Km^2)**	**Temperature**
< 0.1	773.76	30.5 - 47.3ºC	< 0.1	768.15	33.2 - 51.6ºC
0.2 - 0.5	22.23	26.2 - 30.4ºC	0.2 - 0.5	27.84	28.4 - 33.1ºC
2022					
NDVI Value	**Area (Km^2)**	**Temperature**			
< 0.1	758.77	34.2 - 46.0ºC			
0.2 - 0.5	37.22	26.3 - 34.1ºC			

Source: Author’s GIS and RS Analysis, 2024

As shown in Table 13 in the year 1990, an NDVI value > 0.6 cools about 16.98 km^2 of Amman land area with a temperature ranging between 23.8 and 25.2 °C, while an NDVI value between 0.2 and 0.5 cools about 172.48 km^2 of land area with a temperature ranging between 25.3 and 33.8 °C due to the presence of dense and sparse vegetation, respectively. In 1995, the maximum NDVI value ranged between 0.2 and 0.5, depicting the presence of sparse vegetation, which cools about 23.24 km^2 of Amman land area with a temperature range of 22.1 and 29.5 °C. In the year 1999, an NDVI value > 0.6 cools about 2.8 km^2 of Amman with a temperature ranging between 22.5 and 24 °C, while an NDVI value between 0.2 and 0.5 cools about 20.38 km^2 of land with a temperature ranging between 24.1 and 29 °C due to the presence of dense and sparse vegetation, respectively. In the year 2004, an NDVI value > 0.6 cools about 3.5 km^2 of Amman with a temperature ranging between 26.0 and 29.9 °C, while an NDVI value between 0.2 and 0.5 cools about 57.38 km^2 of land with a temperature ranging between 30.0 and 33.9 °C due to the presence of dense and sparse vegetation, respectively. In 2013, the maximum NDVI value ranged between 0.2 and 0.5, depicting the presence of sparse vegetation, which cools about 22.23 km^2 of Amman land area with a temperature range of 26.2 and 30.4 °C. In 2017, the maximum NDVI value ranged between 0.2 and 0.5, depicting the presence of sparse vegetation, which cools about 27.84 km^2 of Amman land area with a temperature range of 28.4 and 33.1 °C. In 2017, the maximum NDVI value ranged between 0.2 and 0.5, depicting the presence of sparse vegetation, which cools about 37.22 km^2 of Amman land area with a temperature range of 26.3 and 34.1 °C. The result of this analysis further explains that lower NDVI values, i.e., less than 0.1 (Barren rock, built-up area, sand, or snow), recorded higher surface temperatures during the study period, which corresponds to Gherraz et al.'s (2020) research on spatial patterns of green spaces in the urban climate, where the increase in NDVI values caused a corresponding decrease in LST values and vice versa.

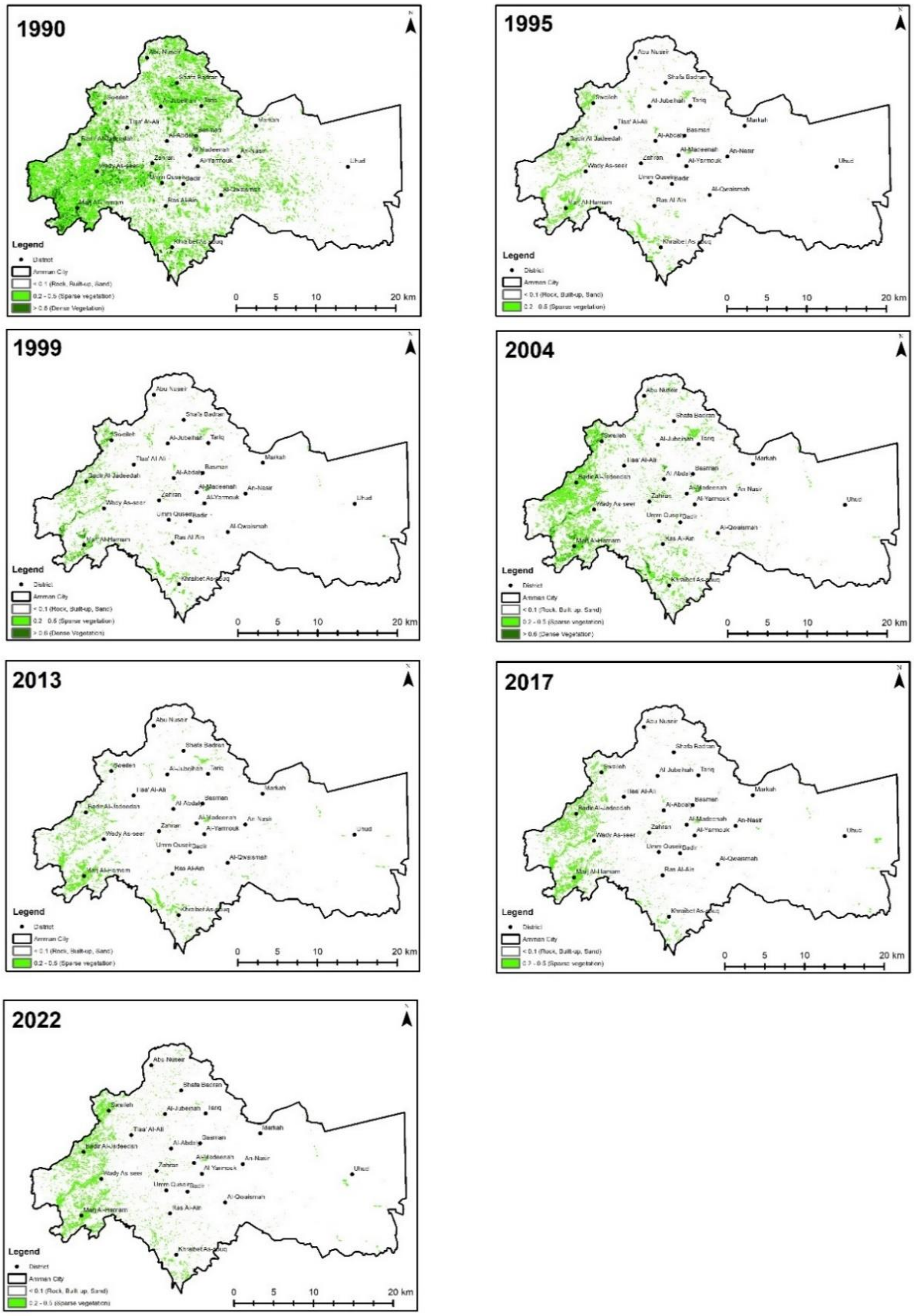

Figure 15. Spatial distribution of NDVI values within Amman
Source: Author’s collection GIS and RS Analysis, 2024

4.6 Exploring the Relationship Between Land Surface Temperature (LST) and Socio-Economic Factors (Household Type and Income Level) in Amman City.

A. Residential Building Typology

The result obtained from the extracted residential building typology shows that residential land within Category A is comprised of 30892 buildings, Category B 70152 buildings, Category C 97958 buildings, and Category D 53183 buildings, respectively. As shown spatially in Figure 16, residential lands with buildings Type A and B are located towards the western and northern parts of Amman city, while residential lands with buildings Type C and D are located towards the city centre and the southern and eastern parts of the study area. Table 14 shows the distribution of housing typology across the 22 districts of Amman.

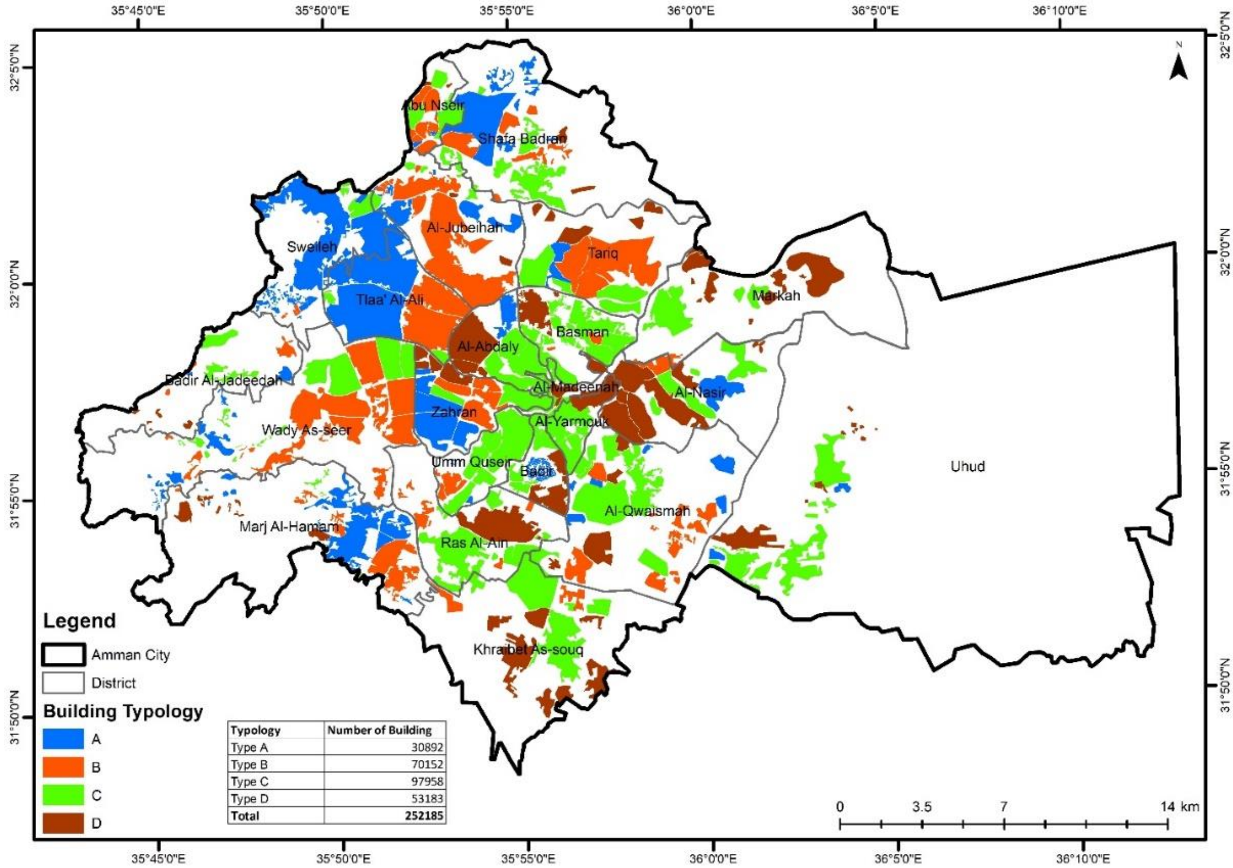

Figure 16. Spatial Distribution of Residential Building Typology in Amman City
Source: Author’s GIS and RS Analysis, 2024

Table 14. Distribution of housing typology across the 22 districts of Amman.

Residential Building Typology				
District Name	**TYPE A**	**TYPE B**	**TYPE C**	**TYPE D**
Abu Nseir	54	4296	1735	137
Al-Abdali	793	2526	3205	24
Al-Jubaiha	2780	8415	2211	73
Al-Madeenah	0	0	480	2203
Al-Nasr	0	0	7475	8568
Al-Qwaismeh	452	5481	10370	5660
Al-Yarmouk	0	0	1165	5703
Badr	1	1009	2417	6089
Badr Al-Jadedah	454	1580	2456	240
Basman	0	2	6278	5853
Khreibet El-souq	945	2621	11187	2714
Marj Al-Hamam	4924	3765	1859	150
Markah	0	0	2154	8248
Ras Al-Ain	0	2	3202	2966
Shafa Badran	1986	10392	4162	482
Sweileh	3428	4214	1963	672
Tareq	23	6974	5747	826
Tila' Al-Ali	7115	3436	1260	181
Uhud	381	823	13893	235
Umm Quseir	1113	4254	5124	548
Wadi El-Sir	2664	8240	8030	1312
Zahran	3779	2122	1585	299
Total	**30892**	**70152**	**97958**	**53183**

Source: Greater Amman Municipality, 2024

B. Household Income Level

Data collected from the Greater Amman Municipality (GAM) shows that the type of residential building depends on the household's level of income. For this study, the level of income was divided into four classes, i.e., high income (Type A), medium income (Type B), low income (Type C), and lower income (Type D). Figure 15 shows the spatial distribution of income within the study area.

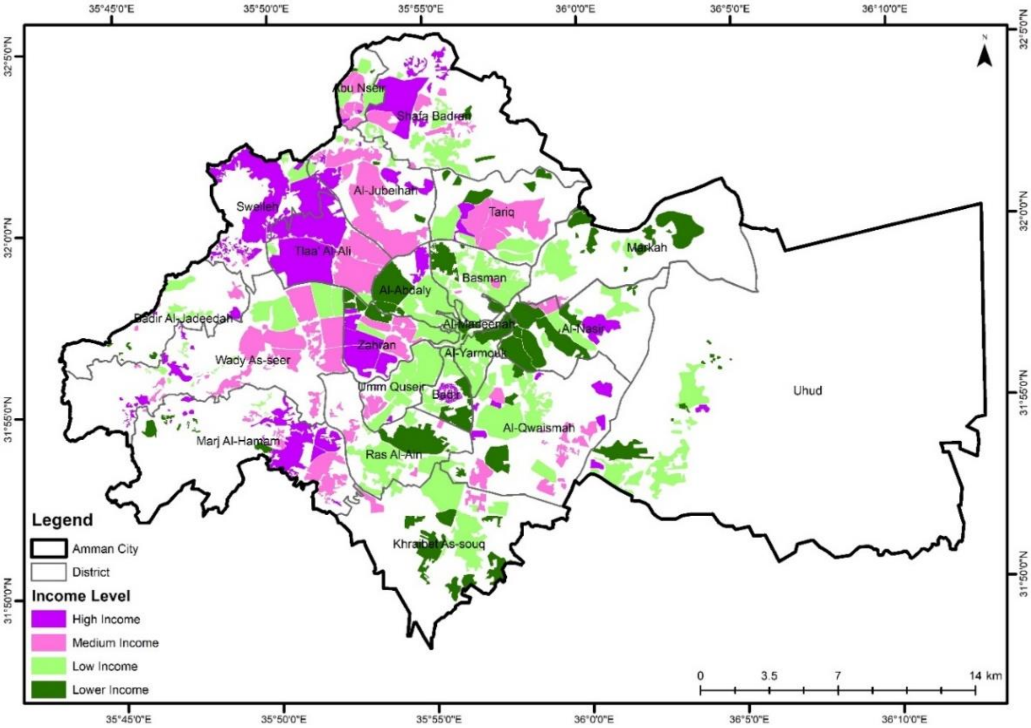

Figure 17. Spatial Distribution of Residential Building Typology in Amman City based on income level
Source: Author's GIS and RS Analysis, 2024

As shown in Figure 17, areas with high and medium levels of income are located in the western and northern parts of the study area, while households with low and lower levels of income are located towards the city centre in the southern and eastern parts of the study area.

C. Correlation Between LST, Residential building type and household income level

In determining the correlation between LST, residential building type, and household income level, 500 points were stratified and randomly created within the building typology and household income to extract the land surface temperature per building typology, as shown in Figure 18. Also, the average LST per building type and income level was calculated as shown in Table 15 and Figure 19, respectively.

Table 15. Average LST of Building Type and Income Level

Value	Building Type	Income Level	Average LST (°C)
1	D	Lower	39.11
2	C	Low	36.37
3	B	Medium	34.20
4	A	High	31.07
Correlation		**-0.9977**	

Source: Author's GIS and RS Analysis, 2024

As shown in Table 15, building type D (lower income) has an average LST of 39.11 °C, building type C (low income) has an average LST of 36.37 °C, while building types B and A have an average LST of 34.20 °C and 31.07 °C, respectively. The result of this analysis further shows that there is a strong negative correlation between LST, building typology, and household income, with a correlation value of -0.9977. The correlation results imply that as income level increases, the choice for better housing also increases, which further contributes to the decrease in LST across the study area. In other words, areas with higher green space coverage exhibited lower surface temperatures compared to densely urbanised regions. As shown in Figure 18, LST values decrease as household income increases.

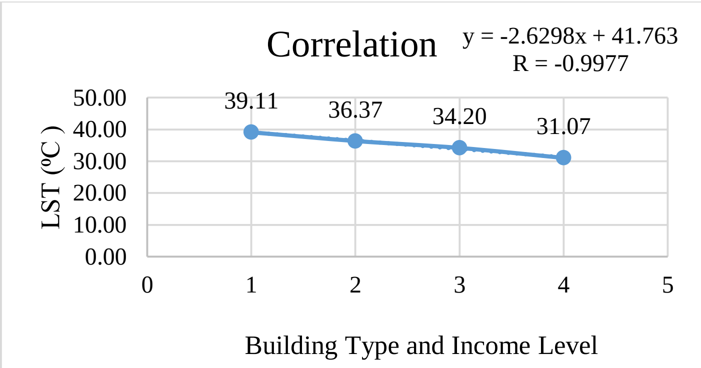

Figure 18. Correlation Between LST, Residential building type, and household income level
Source: Author's GIS and RS Analysis, 2024

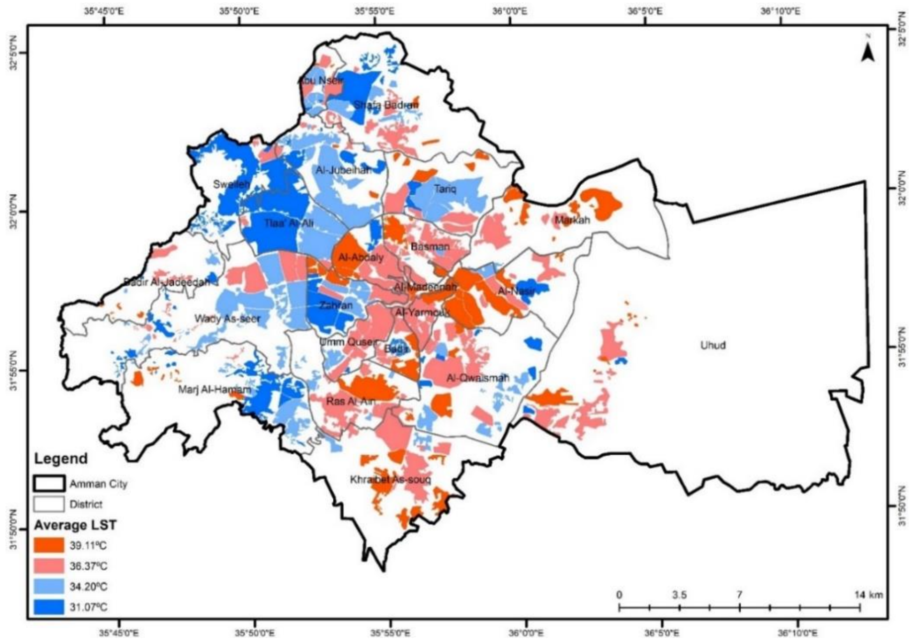

Figure 19. Average LST based on Residential building type, and household income level
Source: Author's GIS and RS Analysis, 2024

As shown in Figure 19, the land surface temperature tends to be lower in the northern and western regions of the study area, which can be attributed to the presence of landscape buildings as a result of high-income dwellers. On the other end, the land surface temperature tends to be warmer in the city centre and southern and eastern regions of Amman as a result of little or no vegetation cover within this region.

4.7 Descriptive

Table 16. Descriptive Statistics

Variable	N	Mean	Std.	Min	Max
Year	32			1990	2020
Amman population	32	2,539,063	1,087,506	1,208,080	4,512,700
Amman Growth rate	31	4.43	4.68	1.13	27.2
Amman population density km^2	32	3,173.83	1,359.38	1,510.10	5,640.87
Amman built up area km^2	22	234.79	52.03	107.32	295.63
NO_2 (Nitrogen dioxide) Microgram/m3/day	14	18.47	9.54	1.72	38.54
total number of private car on Amman	16	493,771.40	197,526.30	206,874	850,000
Number of personal automobiles per capita_VALUE	15	0.2	0.12	0.11	0.6
solid waste ton/capita/year	12	33.10%	6.81%	24.77%	43.39%
Amount of waste (TN/year)	19	1,063,455	332,512.60	447,945	1,584,790
per capita electricity (kwt/hour)	9	1,883.82	329.68	1,200.50	2,293.21
Total annual residential electrical usage of a city in kilowatt hours (kwh/year)	14	4,822,197	1,182,577	2,584,600	6,249,000
Total residential electrical energy use per capita (kwh/year)	14	822.68	204.84	620.51	1,403.26
Total domestic water consumption per capita (liters/day)	13	123.6	36.71	63.5	156.64
Percentage of city population served by wastewater collection	15	80.50%	2.48%	78.63%	89.18%
Amman GDP(current US$)	32	8.16E+09	6.29E+09	1.44E+09	1.85E+10
GDP per capita for Amman (current US$)	32	87,308,700	494,800,000	1,184.89	2.80E+09
GDP per capita, PPP (constant 2017 international $)of Amman	32	9,755.64	1,270.08	7,839.87	12,001.99
CO_2 emissions per capita of Amman	30	1.11	0.15	0.93	1.45
Energy use (kg of oil equivalent per capita) of Amman	25	369.7	60.63	309.33	487.33
Electric power consumption (kWh per capita) of Amman	25	551.67	189.81	324.91	905.59
Energy intensity level of primary energy (MJ/$2017 PPP GDP) of Amman	20	4.02	0.33	3.5	4.62
Industry (including construction), value added (% of GDP)-Amman	32	9.11	1.49	7.08	11.5
AGR (Agrarian practices)	12	372,333.90	43,074.97	297,408.80	435,153.90
Electricity	13	8,068.62	882.44	7,065	9,385
Private Cars	14	492,547.70	177,695.50	229,209.40	850,000
Amount of waste (TN)	19	1,166,517	748,613.20	447,945	4,026,419
Amman city master plan	32	1.41	0.5	1	2

Source: Author's Calculation

This descriptive table (16) shows 32 years of statistical data on Amman's many qualities. Statistics on urban demographics, ecology, and economy are useful. Over 2.54 million people lived in Amman during this time. The growth rate ranged from 1.13% to 27.2%. These variances indicate population pattern fluctuations over time. Amman had an average population density of 3,173.83

people per square kilometer. This suggests the city has a high population density. However, population density ranged from 1,510.10 to 5,640.87 people per square kilometer. This may be due to urbanisation and land use differences. The built-up area of Amman averages 234.79 square kilometres, ranging from 107.32 to 295.63. Variability in this context indicates metropolitan urban growth and land development changes. Environmental factors, including air quality, were studied. The daily average of nitrogen dioxide (NO2) levels was 18.47 micrograms per cubic meter. The measure's range of 1.72 to 38.54 effectively reflected air pollution levels. The average presence of 493,771 cars in Amman shows its dependency on private cars for transportation and energy use. Personal cars per capita averaged 0.2, or one per five people. Solid waste generation and management were considered. Annual per capita waste creation averaged 33.10%, ranging from 24.77% to 43.39%. Waste generation ranged from 447,945 to 1,584,790 tonnes per year. The energy metrics included per-capita electricity use, which averaged 1,883.82 kWh. The city's home power usage ranged from 2,584,600 to 6,249,000 kWh. Additionally, per capita residential electrical energy usage ranged from 620.51 to 1,403.26 kWh. On average, 80.50% of the city's population had wastewater collection services, which were used to evaluate infrastructure and urban development. Small changes in the measure, from 78.63% to 89.18%, may reflect sanitary system improvements. The average GDP of Amman was 8.16 billion US dollars. The GDP varied from 1.44 billion to 18.5 billion US dollars during the years. The mean GDP per capita for Amman was 87,308,700 US dollars, indicating a large economic gap. In terms of environmental impact, Amman's per capita CO_2 emissions averaged 1.11 metric tonnes per year, ranging from 0.93 to 1.45. Per capita energy use ranged from 309.33 to 487.33 kilos of oil equivalent. Annual electric power use ranged from 324.91 to 905.59 kilowatt-hours per person. Primary energy intensity averaged 4.02 megajoules per 2017 PPP GDP dollar, a continuous pattern. Amman's GDP averaged 9.11% from the industry, including construction. This contribution ranged from 7.08% to 11.5%. Agrarian practices and power consumption were also examined, showing changes over time. The qualitative variable Amman city master plan showed multiple urban planning revisions across the analysed timeframe, with an average value of 1.41. Overall, this table shows Amman's demographic, environmental, and economic characteristics. It highlights the city's dynamic character and important 32-year trends and changes.

4.8 Urban Sprawl & Built-up Areas in Amman

H5: There is a significant impact of uncontrolled and unplanned urban sprawl on the increase in built-up areas in Amman.

Table 17. Regression Analysis Impact of urban sprawl on built-up areas in Amman

Predictor	Coefficient	Std. Error	t-value	P-value	95% CI	
					LL	UL
Amman Growth Rate	-1.2140	0. .9003	-1.35	0.196	-3.1227	0. 6946
Amman population Density	0.0247	0.0029	8.33	0.00	0.0184	0.03110
GDP per Capita	0. 0137	0. 00427	3.21	0.005	0.0046	0.0227
Industry including Construction	4.8263	2.0853	2.31	0.034	0.4056	9..2471
Constant	55.570	17.6900	3.14	0.006	18.0692	93.0716

Model	Statistics
R-squared:	0.9775
Adjusted R Squared	0.9719
F-statistic	(4,16): 173.99***
Prob>F:	0
Root Mean Square Error (RMSE)	7.4799

Source: Author's Own Calculation

Table 17 shows the analysis's results. The predictor "Amman growth rate" had a coefficient of -0.2140 (SE = 0.9003), indicating a negative link with the outcome variable, although this relationship was not statistically significant (t = -1.35, p = 0.196). In contrast, "Amman population density km²" showed a significant positive correlation (β = 0.0247, SE = 0.0029, t = 8.33, p < 0.00), showing that population density increases the outcome variable. The "GDP per capita for Amman" showed a significant positive correlation with the outcome variable (β = 0.0137, SE = 0.0042, t = 3.21, p = 0.005), suggesting that greater GDP per capita is associated with higher outcomes. The variable "industry including construction" showed statistical significance (β = 4.8263, SE = 2.0853, t = 2.31, p = 0.034), showing better outcomes from increasing industrial and construction activity.

The constant term had a coefficient of 55.570 (SE = 17.6900) and was statistically significant (t = 3.14, p = 0.006), showing it explains the outcome variable. The whole model worked well, with a high R-squared value of 0.9775, suggesting that the predictors explained 97.75% of the outcome variable's variation. Model robustness is shown by the modified R-squared of 0.9719. The model's statistical significance is shown by its F-statistic of 173.99 and probability (Prob > F) of 0.0000. The average outcome variable prediction error was 7.4799. Population density, GDP per capita, and industrial/construction activity explain the outcome variable, according to this regression study. The constant term matters too. The model's great explanatory power emphasises these components' relevance in explaining the outcome variable.

Table 18. Variance Inflation Factors (VIFs) for the Impact of urban sprawl on built-up areas

Predictor	Vif	1/Vif
Amman Growth Rate	1.45	0.690
Amman population Density	3.94	0.219
GDP per Capita	6.80	0.147
Industry including Construction	1.92	0.522
Mean Vif	3.68	

Table 18 show that Variance Inflation Factors (VIF) are within acceptable ranges, indicating low multicollinearity (Mean VIF = 3.68).

Table 19. Durbin-Watson Test Results for the Impact of urban sprawl on built-up areas

Number of Gaps in Sample	2
Durbin-Watson Statistics	0.797
Degree of Freedom	(5, 21)

Source: Author's own calculation

Our analysis yields a d-statistic of 0.797, as shown in Table 19, much less than 2. Positive serial correlation in residuals is shown by this result. Negative autocorrelation is shown by a d-statistic significantly over 2. However, the Breusch-Godfrey LM test for autocorrelation at lag 1 shows no evidence of serial correlation (chi2(1) = 0.015, p = 0.9036).

The results provide support for the hypothesis that factors such as population density, industrial activity, and GDP per capita have a significant impact on the increase in built-up areas in Amman. However, the non-significant impact of the growth rate variable suggests that unplanned urban sprawl may not be significantly influenced by the growth rate alone, but further investigation is needed to address autocorrelation and enhance the model's robustness.

4.9 Effects of Urban Sprawl on Environmental Sustainability

H6: Urbanization and population density have a significant influence on environmental sustainability in Amman city.

Model 1

Table 20. Correlation Matrix Model 1

	Variable	1	2	3	4	5	6	7	8	9
1	CO_2 emission	1								
2	Population Density	0.48*	1							
3	Energy Use	0.80**	-0.1	1						
4	Agrarian Practices	0.14	0.64**	-0.29	1					
5	Private cars	0.61**	0.93**	0.06	0.75**	1				
6	Built-up Area	0.50**	0.97**	-0.09	0.77**	0.98**	1			
7	Ln Population	0.51**	0.99**	-0.07	0.66**	0.94**	0.98**	1		
8	GDP	0.61**	0.97**	0.05	0.69**	0.99**	0.98**	0.98**	1	
9	Power consumption	0.88*	0.62*	0.52*	0.47	0.82*	0.71*	0.65*	0.79	1
*p < 0.05, **p < 0.01										

The correlation matrix (Table 20) shows how important CO_2 emission factors are in cities like Amman. 0.05 and 0.01 alpha values determined statistical significance. Several key findings from this investigation shed light on regional emissions patterns. The association between Amman's population density and CO_2 emissions per capita is somewhat positive ($r = 0.48$, $p < 0.05$). This shows that densely populated places emit more CO_2. Urban centres with higher population concentrations may have higher emissions due to increased energy and transportation use. Second, energy use is positively correlated with CO_2 emissions in Amman ($r = 0.80$, $p < 0.01$), highlighting its crucial role in driving emissions. This highlights the need for energy-saving and sustainable energy as part of emissions reduction initiatives. AGRA agriculture practices and CO_2 emissions have a positive connection ($r = 0.14$), although statistical significance is not reached. Private car ownership significantly contributes to CO_2 emissions, as shown by a strong positive correlation ($r = 0.61$, $p < 0.01$). This shows how transit policy and alternate forms of travel may reduce private automobile emissions. The significant positive association between Amman's built-up area and CO_2 emissions ($r = 0.5$, $p < 0.01$) highlights urban growth as a key factor in increased emissions. Population size ($r = 0.51$, $p < 0.01$) and GDP ($r = 0.61$, $p < 0.01$) are positively correlated with CO_2 emissions. These data show that Amman's urban emissions are closely connected to population and economic growth. Lastly, the strong positive association between electric power consumption and CO_2 emissions ($r = 0.88$, $p < 0.01$) highlights its significant impact on emissions levels. Transitioning to greener energy and improving energy efficiency are key to reducing emissions.

Table 21. Summary of Regression Analysis for model 1

Variable	Coefficient	Std. Error	t-value	p-value
Diff_PopulationDensity	-9E-05	6.81E-05	-1.32	0.2
Diff_EnergyUse	0.002738	0.000249	10.98	<0.0001
Constant	0.013526	0.011069	1.22	0.235

Notes. N = 24. $F(2, 21) = 66.35$, $p < 0.0001$. R-squared = 0.8791.

Adjusted R-squared = 0.8676. RMSE = 0.03683. No evidence of serial correlation (Breusch-Godfrey LM test, lag 1: $p = 0.3555$).

In the first model, as indicated in Table 21, the study examined the correlation between carbon dioxide (CO2) emissions (Diff_CO_2) and other independent variables, such as population density (Diff_PopulationDensity) and energy consumption (Diff_EnergyUse). The findings of the study demonstrate that there is a statistically significant positive relationship between energy consumption and CO_2 emissions ($\beta = 0.00274$, $p < 0.0001$). This implies that an increase in energy usage is linked to an increase in the release of CO_2 into the atmosphere. Nevertheless, the analysis indicates that there is no statistically significant correlation between population density and CO_2

emissions (β = -0.00009, p = 0.200). This finding suggests that alterations in population density may not exert a substantial direct impact on CO_2 emissions. The constant term (β = 0.01353, p = 0.235) is not statistically significant. The total model has a high level of significance ($F (2, 21) = 66.35$, $p < 0.0001$) and effectively accounts for a considerable amount of the variability seen in CO_2 emissions (R-squared = 0.8791). The adjusted R-squared score of 0.8676 incorporates the influence of the number of predictors and provides an indication of the model's degree of fit.

Table 22. Variance Inflation Factors (VIFs) for Model 1

Variable	VIF	1/VIF
Diff_PopulationDensity	1.44	0.6958
Diff_EnergyUse	1.44	0.6958
Mean VIF	1.44	

The presence of multicollinearity, as evaluated by variance inflation factors (VIFs) as shown in Table 22, does not pose a substantial issue in Model 1. The variables Diff_PopulationDensity and Diff_EnergyUse exhibit VIF values of roughly 1.44, suggesting a lack of strong correlation between them as well as with other predictors included in the model. Furthermore, a serial correlation test was performed utilising the Breusch-Godfrey LM test, which yielded no significant indications of serial correlation within the residuals (p = 0.3555). This observation implies that there is no substantial connection among the residuals, so suggesting that the assumption of no serial correlation in the model is likely to be true.

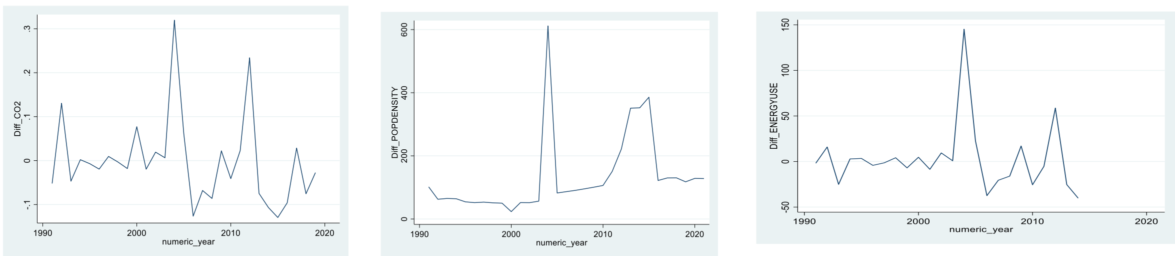

Figure 20. Time series for CO_2, Diff_PopulationDensity and Diff_EnergyUse

Model 2

Table 23. Correlation Table for Model 2

Sr #	Variable	1	2	3	4	5	6	7	8
1	Energy Use	1							
2	Population Density	-0.1	1						
3	Agrarian Practices	-0.29	0.06	1					
4	Private cars	0.06	0.93**	-0.07	1				
5	Built-up Area	-0.09	0.97**	-0.09	0.77**	1			
6	Ln Population	-0.07	0.94**	-0.09	0.98**	0.65**	1		
7	GDP	0.05	0.99**	-0.07	0.98**	0.79**	1.00**	1	
8	Power consumption	0.53*	0.62*	0.47*	0.82*	0.71*	0.65**	0.789	1
*p < 0.05, **p < 0.01									

The table (23) shows the correlation matrix for important energy use factors in Amman's urban setting. 0.05 and 0.01 alpha values were used for statistical significance. Correlations revealed substantial links between these factors. Amman's population density and energy usage have a modest negative association (r = -0.010). This shows that densely populated places consume somewhat less energy. This association is not statistically significant. Second, AGRA agricultural practices negatively correlate with energy usage (r = -0.29, $p < 0.05$), suggesting that places with higher dependence on agrarian practices consume less energy. This implies that sustainable agriculture may boost energy efficiency. However, private automobile ownership has a slight positive connection with energy usage (r = 0.06). The association is not statistically significant, but it suggests that private automobile ownership may increase energy use owing to mobility demands. Energy use is weakly correlated with Amman's built-up area (r = -0.09), suggesting that urban growth may lower energy use. This association is not statistically significant. Ln population (natural logarithm of population) has a modest negative connection with energy usage (r = -0.07), although it is not statistically significant. Amman's GDP has a modest positive association with energy usage (r = 0.05), but it is not statistically significant. A moderately positive association exists between electric power consumption and energy use (r = 0.53, $p < 0.05$), suggesting that locations with higher power consumption also have higher energy usage.

Augmented Fuller Test

The study used Augmented Dickey-Fuller (ADF) tests to detect unit roots in three variables: Ln population (natural logarithm of population), Amman population density, and energy use (kg of oil equivalent). The ADF tests determine if these variables follow a random walk pattern with or without drift, which is important in time series analysis. At 1% significance, the ADF test statistic for the ln population was -2.457, which is below the crucial threshold (-4.334). Thus, we cannot reject the random walk null hypothesis for this variable. The Ln population may have a unit root, suggesting a non-stationary time series. The ADF test for Amman population density yielded a test statistic of -1.947, exceeding the threshold values at 1%, 5%, and 10% significance levels. Thus, we fail to reject the null hypothesis, assuming a unit root in Amman population density, making it non-stationary. At 1% significance, the ADF test for energy use yielded a test statistic of -2.485, below the threshold levels (-4.380). Energy use may be stationary and not have a unit root. Further information comes from these tests' p-values. Population and energy use have p-values over 0.05, while Amman population density has a higher p-value of 0.6302, confirming the absence of statistical significance. The study also tested Diff_PopulationDensity, which represents first-difference Ln-population data, with a Dickey-Fuller test. This transformation is often used to store time-series data. The Dickey-Fuller test statistic was -4.958, much below the threshold values at all significance levels (1%, 5%, and 10%). Thus, the study rejects the null hypothesis of a random walk for Diff_LnPopulation confirming its stationary nature.

Table 24. Regression Analysis for Model 2

Variable	Coefficient	Std. Error	t-value	p-value
Diff_PopulationDensity	-0.2709	0.1069	-2.53	0.019*
Diff_LnPopulation	1331.71	317.247	4.2	0.000**
Constant	-24.081	6.9341	-3.47	0.002**
Note. N = 24. *p < 0.05, **p < 0.01. R-squared = 0. 6217. Adjusted R-squared = 0. 5856				

Table 24 displays the results of a multiple linear regression study in which the response variable differential energy use (Diff_ENERGYUSE) is compared to the predictors differential population density (Diff_POPDENSITY) and differential natural logarithm of the population (Diff_LnPOP). Diff_ENERGYUSE is a time series measure of the variation in energy consumption, and this study aims to determine what causes its fluctuations and what causes it to stabilise. According to the regression model, Diff_POPDENSITY and Diff_LnPOP account for a considerable portion of the variance in Diff_ENERGYUSE (F (2, 21) = 17.25, p 0.0001).

When controlling for all factors, a one-unit increase in Diff_POPDENSITY results in a 0.2709-unit decrease in Diff_ENERGYUSE (p = 0.019 A higher population density was proven to reduce energy use. When all other factors are held constant (p 0.001), a one-unit increase in the differential natural logarithm of the population (Diff_LnPOP) is predicted to result in a 1331.707-unit increase in differential energy use (Diff_ENERGYUSE). Differential natural logarithms of the population (Diff_LnPOP) variations are positively associated with energy consumption. "Constant" is -24.08097 (p = 0.002), and it is a constant term. The value is the predicted size of differential energy use (Diff_ENERGYUSE) when all other factors are held constant. It shows a region's baseline energy consumption if population density and the natural logarithm both remain unchanged.

Table 25. Variance Inflation Factors (VIFs) for Model 2

Variable	VIF	1/VIF
Diff_LnPopulation	8.5	0.1177
Diff_PopulationDensity	8.5	0.1177
Mean	VIF	8.5

The VIF assesses how much multicollinearity among independent variables increases the variance of computed regression coefficients. Here, Diff_LnPopulation and Diff_PopulationDensity have 8.50 VIF values. Due to strong multicollinearity, VIF values above 10 are usually concerning. The model's VIF values are below this level, indicating low multicollinearity. The Breusch-Godfrey LM Test for Autocorrelation evaluates serial correlation (autocorrelation) in regression model residuals. Autocorrelation in residuals violates independence and casts doubt on model results. This test counts lags using the lags (p) variable. A chi-square statistic of 0.515 with 1 degree of freedom yields a p-value of 0.4729. Our p-value is larger than 0.05, thus we cannot reject the null hypothesis (H0: no serial correlation). It appears that the model's residuals do not show autocorrelation.

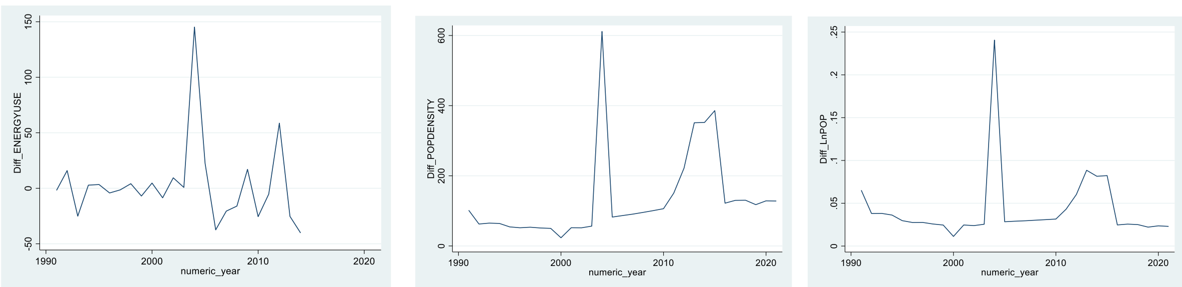

Figure 21. Time series Diff_EnergyUse, Diff_PopulationDensity, and Diff_LnPopulation

Model 3

Table 26. Correlation Table for Model 3

Sr #	Variable	1	2	3	4	5	6
1	log_CO_2emission	1					
2	log_AmmanPopulation	0.292	1				
3	log_RenewableEnergy	-0.351**	0.714*	1			
4	log_EnergyUse	0.948*	0.814*	0.175	1		
5	log_GDPpercapita	0.013	0.039	-0.020	-0.064	1	
6	log_AmmanGrowthrate	0.310	0.116	-0.012	0.319	-0.395*	1
*p < 0.05, **p < 0.01							

Table 26 shows that log_CO_2emission has a strong positive correlation with log_EnergyUse in kg of oil equivalent (0.9483) and a negative correlation of (-0.3510) with log_RenewableEnergy.

Table 27. Regression Analysis for Model 3

Variable	Coefficient	Std. Error	t-value	p-value
log_AmmanPopulation	.1110413	.039188	2.83	0.011
log_RenewableEnergy	-.2963487	0595292	8.28	0.000
log_EnergyUse	.5804806	.0700828	8.28	0.019
log_GDPpercapita	0.0066067	0.0025646	2.58	0.019
log_AmmanGrowthrate	.0791027	.0243297	3.25	0.004
Constant	-4.06624	.2350611	-17.30	0.000
Note. N = 24. *p < 0.05, **p < 0.01. R-squared = 0.96. Adjusted R-squared = 0.95				

This regression model accounts for a considerable portion of the variance in log-transformed CO_2 (F (5, 18) = 89.52, p 0.0001). The overall model fit is statistically significant (Prob > F = 0.0000), indicating that at least one of the independent variables has a significant effect on CO_2 emissions. The R-squared value of 0.9613 suggests that the model explains a substantial proportion of the variance in log-transformed CO_2 emissions, as shown in Table 27.

When controlling for all factors, a 1% increase in population is associated with a 0.111% increase in log-transformed CO_2 emissions. This positive coefficient suggests that higher population density in Amman is linked to increased carbon emissions. An increase in log-transformed renewable energy is associated with a decrease in log-transformed CO_2 emissions. The negative coefficient of -0.2963 indicates that as the share of renewable energy in Amman's energy mix rises, CO_2 emissions tend to decrease.

A 1% increase in energy use (in kilogrammes of oil equivalent per capita) corresponds to a 0.5805% increase in log-transformed CO_2 emissions. This positive relationship suggests that higher energy consumption is associated with increased carbon emissions. A positive relationship is observed between log-transformed GDP per capita and log-transformed CO_2 emissions. The coefficient of 0.0066 indicates that as GDP per capita increases, so do CO_2 emissions. A 1% increase in the urban growth rate is associated with a 0.0791% increase in log-transformed CO_2 emissions. This suggests that a faster rate of urban growth is linked to higher carbon emissions.

Table 28. Variance Inflation Factors (VIFs) for Model 3

Variable	VIF	1/VIF
log_Amman population	4.28	0.233457
log_EnergyUse in kg of oil equivalent	3.63	0.275595
log_AmmanGrowthrate	3.43	0.291819
log_RenewableEnergy	2.99	0.334973
log_GDPpercapita	1.57	0.634925
Mean	VIF	3.18

The variance inflation factor (VIF) values as shown in Table 28 are relatively low (3.18), indicating that multicollinearity is not a significant concern in the model. The IM-test results do not provide evidence of heteroskedasticity, skewness, or kurtosis issues. The Durbin-Watson statistic of 1.5407 is generally within an acceptable range. The Breusch-Godfrey LM test does not suggest the presence of omitted variables or serial correlation.

The overall model fit, diagnostics, and correlation analysis provide robust support for the hypothesis, indicating that urbanisation and population indeed have a significant influence on environmental sustainability in Amman. Policymakers can use these findings to inform strategies for sustainable urban development and environmental conservation.

5. DISCUSSION

Amman, Jordan's capital, is facing urbanisation and urban sprawl. In a city like Amman, where population and economic growth are rapid, urbanisation and expansion issues are becoming more important. Amman's population has grown rapidly due to immigration and a high birthrate (Al-Jedaiah, 2021). Over the past 30 years, Amman's population has urbanised (as shown in Figure 22). Migrants, refugees, and population growth have enlarged the city and changed agricultural land into urban areas. Rapid development has put a huge strain on water and agricultural land, causing considerable environmental damage. Urban sprawl and Amman's long-term sustainability require sustainable urban planning and land usage. Green spaces, agricultural land preservation, and sustainable water management may help Amman expand sustainably.

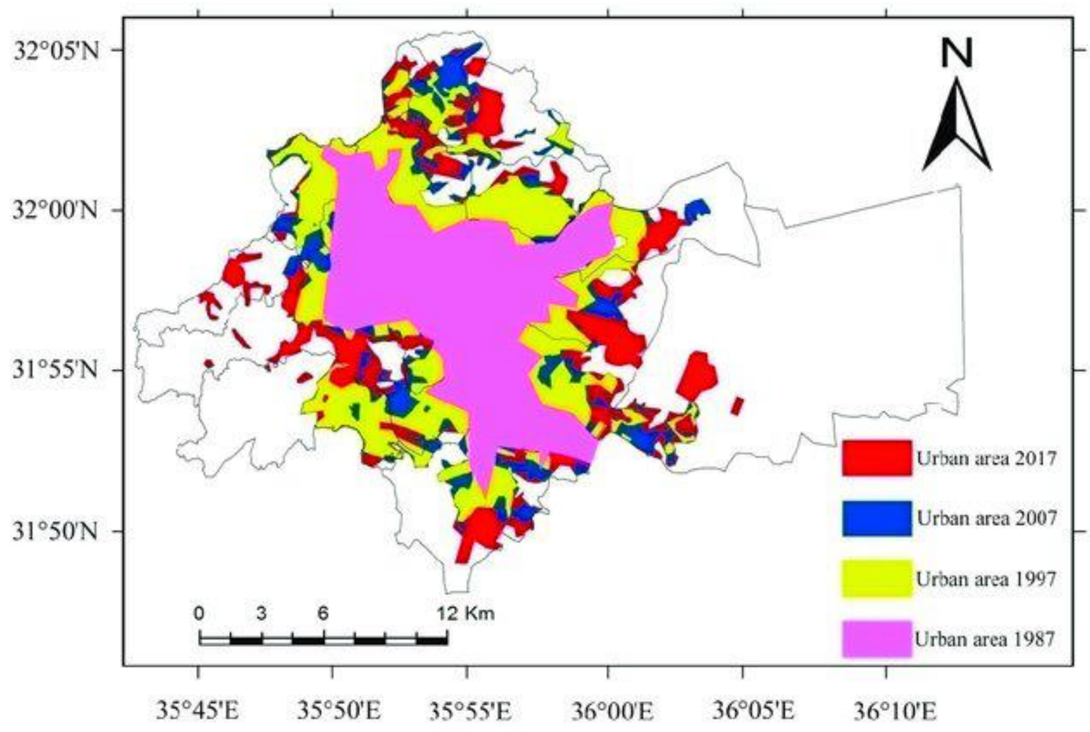

Figure 22. Urban Area over years

Source: Al-Bilbisi, 2019

The city's infrastructure and services are struggling due to population growth. Temporary settlements and substandard dwellings have grown due to a housing shortage. Water, power, transportation, and sanitation demand is straining the city's infrastructure. This might harm the environment and lower service quality. Cities often invade adjacent ecosystems, limit green space, and increase air pollution. Amman's green parks and farms may be paved over soon. This may reduce the city's climate change resilience and increase the urban heat island effect. Increased automobile ownership and traffic aggravate air pollution and carbon emissions. This multiplies climate change and endangers human health. To overcome these environmental issues, sustainable urban planning must prioritise green areas, efficient public transit, and renewable energy. Cities and their suburbs have contributed to socioeconomic stratification. As Amman expands, the poorest villages may be pushed to the city's outskirts, where they will have less access to municipal infrastructure and fewer job opportunities. Geographic divisions can increase poverty, access to education and healthcare, and social inequality. Politicians should promote inclusive urban development to divide resources, affordable housing, and social services fairly. This is essential to reducing material well-being inequities. Amman's rich history is reflected in its many Roman ruins and archaeological sites. However, rapid development threatens this traditional heritage. Urban growth can hide or destroy cultural sites. Urban growth threatens cultural monuments. Urban planners must prioritise historical site preservation and display. Urban planners should prioritise historic preservation in new building developments. Additionally, aggressively educating the public about the need to protect cultural heritage for future generations is crucial. Amman's transport infrastructure is at capacity, causing traffic congestion. People's commuting times, productivity, and quality of life will worsen as urbanisation continues. The city must prioritise public transit development and upgrading to solve this challenge. Improved bus routes, new light rail lines, bike lanes, and pedestrian walkways may help reach this aim. Sustainable urban planning is needed to address urbanisation and urban expansion in Amman. Land use planning is essential for a sustainable future that can accommodate a growing population without compromising economic growth or environmental protection. This requires proper land-use planning. It involves building walkable, mixed-use communities near each other to save travel time, conserve natural areas, and boost social interaction. Using eco-friendly building materials and cutting-edge technologies may improve energy efficiency and resource conservation. Government agencies, urban planners, community members, and environmental professionals must collaborate to implement ecologically responsible and sustainable urban development (Abdeljawad, Szente, Szigeti, and Nagy, 2022).

5.1. Remote Sensing Analysis on Urban Sprawl

The two publications employ remote sensing to assess urban sprawl in Amman City, Jordan, and its environmental impacts (AbdelJawad, Adedokun, & Nagy, 2022; AbdelJawad, Adedokun, & Nagy, 2023). This conversation will assess the findings of the two publications and explore their implications for sustainable urban design and management in Amman. The first research, "Remote Sensing Techniques for Managing, Assessing, and Monitoring Urban Expansion" by Abdeljawad, Adedokun, and Nagy in 2022, discusses these approaches. Change detection analysis, the Urban Expansion Intensity Index (UEII), and Shannon entropy are used to assess urbanisation in Amman

City between 1990 and 2022. The research shows that the metropolitan region has grown, especially along main transit routes and at the city's periphery. Due to its dispersed character, unplanned and unregulated urban growth has substantial environmental impacts (Al-Bilbisi, 2019; Al-Kofahi et al., 2018).

The second study (Abdeljawad, Adedokun, & Nagy, 2023) examines the environmental effects of urban sprawl in Amman City. This study uses remote sensing indices. Amman's areas experiencing high land surface temperatures (LSTs) are mainly found in the central, eastern, and southern parts of the study area. These regions have high construction activities and population densities, particularly in lower elevation zones. Studies in various cities worldwide have shown similar trends, indicating that urban features, construction projects, and population densities significantly influence LST variations (Naserikia et al., 2023; Guo et al., 2020; Azhdari, Soltani, & Alidadi, 2018). Urban growth, marked by decreased green spaces and agricultural land, contributes to the high LSTs. Urban expansion reduces green spaces and agricultural land, raises surface temperatures and the heat island effect, fragments natural habitats, and increases air and water pollution, according to the authors.

These findings highlight the need for ecologically responsible urban development to prevent environmental impacts. By combining the two pieces, we can understand Amman's urban development's environmental impacts. The findings show that rapid metropolitan expansion creates problems that must be addressed early. According to Abdeljawad, Adedokun, and Nagy (2023), converting green spaces and agricultural land into urban areas reduces the city's ability to protect natural resources, reduces biodiversity, and affects local food production. To preserve large parts of the natural environment, land-use planning and zoning laws are needed.

Increased impermeable surfaces like roads and buildings absorb and retain heat, worsening urban heat islands (Vujovic et al., 2021). These occurrences affect energy use, health, and city comfort. Sustainable urban design and green infrastructure can mitigate these effects. Urban parks, green roofs, and other green spaces may minimise the heat island, increase biodiversity, and make a city more livable. Urbanisation fragments natural habitats, making biodiversity conservation in Amman, Jordan, difficult (Al Masri et al., 2019). The separation of huge, unbroken natural regions into multiple smaller, more secluded sites disrupts biological connectivity and reduces flora and fauna habitat quality. To fix this, urban growth needs ecological corridors and green networks. This allows for biological processes and species movement. These actions, which increase biodiversity, may help city ecosystems survive.

Transportation and industrialization increase emissions and waste. These contaminants pollute the air and water, endangering human and environmental health. Eco-friendly transportation must be prioritised to solve this problem. Public transit network improvements and active transportation promotion are examples. Waste management, recycling, and circular economies may also reduce pollution and enhance resource efficiency (Akhtar et al., 2022). The two articles Abdeljawad, Adedokun, and Nagy (2023; 2022) show how urban expansion in Amman, Jordan, has damaged the environment. The city's unchecked urban expansion has destroyed green spaces, agricultural land, and natural ecosystems and raised surface temperatures and air pollution. The expansion raised the surface temperature (Arshad et al., 2023). These effects affect biodiversity, resource preservation, human health, and metropolitan livability.

These issues require sustainable urban planning and management. Land-use planning and zoning may guide urban expansion, protect natural areas, and create dense neighbourhoods with a mix of residential, commercial, and institutional uses (Steiner et al., 2012). Urban parks and green roofs help lessen the heat island effect, increase biodiversity, and improve the urban environment (Mutani & Todeschi, 2020). Sustainable transportation, waste management, and resource efficiency should be combined with air and water pollution reduction and responsible resource usage. Future studies should focus on prediction models and scenario analysis to help Amman City and other rapidly growing cities implement successful urban development plans. To ensure sustainable urban design and mitigate urban expansion's environmental impacts, academics, policymakers, and other stakeholders must work together. The two articles demonstrate the need for sustainable urban development in Amman City to mitigate the environmental impacts of urban expansion. Urbanisation harms the environment. Sustainability makes cities more habitable and resilient while balancing economic growth, environmental protection, and social well-being.

According to historical and current aerial photographs and satellite images, the primary land use classes in the Amman Metropolitan Area up until the 1960s were urban, rainfed cultivation, irrigated farming, small patches of forest, rangeland, and bare land. Rainfed cultivation included cereals, fruits, olive trees, and summer vegetables. Irrigated farming mainly consisted of vegetables and fruit trees. Consistent urban development onto fertile rainfed farmed land occurred in Amman, with residential expansion having a particularly negative effect on neighbouring rural settlements. The city's residential and agricultural regions overlapped. Consequently, the land resources in and around the Amman Metropolitan Area have been significantly degraded. From 1986 to 2017, the percentage of built-up area increased dramatically. Additionally, rangeland and rainfed farmed areas both declined dramatically during that time. Residential growth in the city's north, west, and south has steadily encroached over rainfed land and rangeland. The built-up area has grown at a fairly rapid pace throughout the last 20 years. There were 169 km^2 of built-up area in 1986 and 280 km^2 in 2017 (Farhan & Al-Shawamreh, 2019). Gains (i.e., urban areas and undeveloped land) and losses (i.e., irrigated agriculture, rangeland, and rainfed farmland) have occurred in every category of land use and cover throughout this time. According to Farhan & Al-Shawamreh (2019), there was a decline of 69 km^2 in rainfed farmland and 133 km^2 in rangeland, while the constructed area grew by 280 km^2. Classification output from geographic information systems (GIS) maps for the years 1986, 2003, and 2017 shows how land use and cover changed in any given area of the Amman Metropolitan Area. "The countryside has been extremely eroded," and the city is deemed "environmentally degraded" as a result. On the other hand, the city is best understood as "an exceptional agglomerate of rural and tribal traditions, highly western sophistication, modern urban crisis, and refugee problems." Although there were no parks or communal gardens in the 1950s, the land surrounding the "Seil," which was home to animals, rainfed and irrigated farms, and a few old-fashioned cafes, was still considered open space. The local populations of Amman engage in many customary rituals, recreational activities, and social gatherings that provide them with indirect ways to connect with nature.

5.2. Spatial distribution of road network

Amman expanded throughout the 1990s. During this time, arterial roads from the city's central hub connected varied neighbourhoods and other villages. Mecca, Zahran, and Queen Alia Streets were the primary transportation routes (Aljafari, 2014). However, due to lower population density and traffic congestion, the road network was much smaller. In the 2000s, Amman's population and economy grew, necessitating transportation infrastructure improvements (Ababsa, M., & Hussein, 2020). The municipality responded by building roads. To improve connections and reduce traffic, primary motorways, flyovers, and ring roads were built. The North-South Highway and Eastern Ring Road have improved citywide transportation accessibility (Alsherfawi Aljazaerly et al., 2023). Amman's road network expanded and became complicated throughout the 2010s. Elevated highways, underground tubes, and intersections were built to fit urban topography and improve traffic mobility. In 2006, the Abdoun Bridge connected the western and eastern sides of the city, improving accessibility (Lawson, 2021). Road signs, traffic management systems, and pedestrian amenities also improved road network safety and efficiency.

Recently, Amman has prioritised road infrastructure sustainability and efficiency. The municipality uses intelligent transportation systems with digital traffic signals and real-time traffic information to improve transportation efficiency. Urban planning has also sought to distribute transportation infrastructure more equitably. Bypass roads and peripheral highways are prioritised to reduce city centre traffic and improve suburban links. Amman's traffic network is optimistic. The city wants to use driverless cars and electric mobility to improve transportation (Shatanawi et al., 2022). The road network will expand with the bus rapid transit network. Green infrastructure and eco-friendly road building materials will further reduce the city's environmental impact.

Due to rising urbanisation and the need for better transportation infrastructure, Amman's road network changed significantly from 1990 to 2022, as shown in figure 23. Major motorways, peripheral roads, and increased connections have made the city more accessible. Intelligent transportation systems and sustainable practices improve road network performance. To support Amman's growth, transportation infrastructure must be managed and developed well.

Figure 23. Spatial Distribution of the Road Network in Amman City Between 1990 and 2022
(Source: Abdeljawad, Adedokun, & Nagy, 2023, based on the road data digitised from aerial photographs)

Pearson's correlation method was used by Abdeljawad, Adedokun, and Nagy (2022 to generate the correlation between road network and built-up area. The correlation analysis results show a strong positive correlation (0.98) between the extent of the road network and the built-up area in Amman during the study period (1990–2022). This finding explains how increased road construction has spread land development.

5.3. Amman's Population Density and Urban Expansion Challenges

Based on demographic trends, Table 8 census data shows Amman's constant urbanization. The city's population has grown significantly, maintaining 97.2%. Economic opportunity and job prospects in metropolitan regions drive global urbanisation (United Nations, 2018). Land division figures in Table 9 show a steady increase in Amman's urban area, indicating ongoing urban expansion. Urbanisation and population growth have increased population concentration, particularly in Greater Amman. Urban sprawl's challenges stem from the concentration of people and businesses, which strains natural resources, land use, and infrastructure.

Amman's urbanization pace is revealed by the Urban Expansion Intensity Index (UEII). Despite a slowdown in growth, the index shows a continuing pattern of urban expansion due to government policies, refugee arrivals, and economic activity. The above trends match global urbanisation patterns, emphasising the need for sustainable urban design and management (Jarah et al., 2019; Egidi et al., 2020b). Policymakers must prioritise sustainable urban planning that balances urban growth with agricultural land and natural resource conservation to address these issues. According to Turok & McGranahan (2013), expanding economic activities beyond Amman can alleviate the city's load and promote regional balance. Public transportation and affordable housing can also help Amman residents cope with urban development and resource constraints, creating a more sustainable and habitable city (Aldegheishem, 2023).

5.4. Land Cover Changes and Urban Expansion in Amman

Figure 11 shows Amman's landscape change over 32 years. These data vividly represent the city's urban land expansion, telling a fascinating tale. Academic literature has thoroughly investigated urbanisation trends, which our analysis confirms. These trends show that population growth and development pressures cause urban sprawl (Jarah et al., 2019). Amman's north-western and south-urban expansion resembles other fast-urbanising cities worldwide. Land cover changes affect urban architecture, transit, and environmental sustainability.

The patterns of urban expansion in Amman illustrate the larger subject of urbanisation, which involves geographical changes. Figure 11 shows urban development expanding north-westward and southward. Furthermore, as shown in Figure 12, the entropy values for all dates are greater than 0.5, indicating that no year has a compact structure and that urban growth has taken place as an unevenly dispersed spatial distribution within Amman city, indicating spread-urban sprawl. An increasing population and the need to reduce central city congestion often lead to urban growth (Jarah et al., 2019; Akubia & Bruns, 2019). Urban expansion is generally linked to infrastructure, transit corridors, and residential' areas built to suit the needs of a growing population (Bueno-Suárez & Coq-Huelva, 2020).

Due to population growth and economic improvement, urban expansion creates several challenges that must be addressed. Land-use planning is crucial. Land use planning becomes more complicated in rapidly expanding cities. The north-western and south expansion directions of

Amman necessitate careful zoning, infrastructure, and environmental conservation. Getu & Bhat (2021) say poor planning can lead to disorderly expansion, transportation congestion, and underutilization of land. Urban expansion complicates transportation. Transportation infrastructure needs have grown with urbanization. Carefully built road networks, public transit systems, and effective transportation solutions are needed to reduce traffic and provide neighbourhood accessibility (Bueno-Suárez & Coq-Huelva, 2020).

Environmental conservation is a major concern linked to urban expansion. Urbanisation can cause habitat loss, carbon emissions, and heat island impacts (Wang et al., 2020 b). Amman's southerly growth might invade ecologically essential green areas and natural habitats. These habitats must be preserved to support urban biodiversity and mitigate urbanisation's environmental impacts. Urban growth presents certain challenges, but it also offers opportunities for sustainable urban development. This development might help Amman become a more sustainable and high-quality city. Sustainable urban design ensures that newly created regions are efficient, resilient, and environmentally mindful, helping growth, according to the UN (2018). The outcome of Abulibdeh's (2021) study on "Analysis of urban heat island characteristics and mitigation strategies for eight arid and semi-arid Gulf region cities." It examines the impact of green spaces on land surface temperature (LST) in Abu Dhabi, Dubai, Doha, Jeddah, Kuwait City, Manama, Muscat, and Riyadh. The research reveals a connection between green areas like parks and vegetation and decreased LST values in these urban settings. Aldegheishem (2023) and Bueno-Suárez & Coq-Huelva (2020) also suggest incorporating parks, green corridors, and sustainable landscaping into urban growth strategies to help Amman weather climate change and give residents access to nature. Additionally, investing in public transit infrastructure may reduce vehicle congestion and carbon emissions. Amman may learn from other cities' transit-oriented development methods. These simulations have shown that pedestrian-friendly neighbourhoods and efficient mass transit networks operate (Nafi et al., 2021; Ali et al., 2021; Papagiannakis & Yiannakou, 2022).

5.5. Exploring the Interplay Between Land Surface Temperature (LST), Plant Cover, and Socio-Economic Dynamics in Amman City.

Our analysis then focused on the environmental impacts of urban expansion in Amman, particularly on plant cover and land surface temperature. Urbanisation reduces plant cover, raising the land surface temperature (LST). The discovery fits with urbanisation and ecological studies. Transforming natural green spaces into built spaces worsens heat island effects and depletes vegetation, harming urban ecosystems (Rani, Rajlaxmi, & Kumar, 2023).

This study also investigated the correlation between LST, residential building type, and household income level by integrating socio-economic data collected from the Greater Amman Municipality (GAM) with spatial residential data. It further shows that the level of income earned by residents of Amman determines the choice of housing, which further contributes to either increasing or decreasing the overall land surface temperature. These findings correspond to the broader body of research about this phenomenon, as reported by Meaton & Alnsour (2012). Urban studies have repeatedly explored the relationship between household income and housing choices, such as Duijndam & van Beukering (2021), illustrating the significance of economic factors in the formation of residential domains. In a study conducted by Wu, Li, and Li (2021), the relationship between population density, urban center proximity, and the heat island effect was explored. Their findings demonstrated that increased population density and proximity to urban cores amplify the heat island effect, leading to higher temperatures. Additionally, the study revealed that the distance from green spaces and water bodies had positive effects on spring, summer, and fall land surface temperatures (LST). Kamal et al. (2021) performed research to study the correlation between various types of residential buildings and urban microclimates. Their study revealed the role of built structures in temperature fluctuations. The scope of the geographical area and research carried out in areas similar to Amman, for instance, the Middle East, more especially in locations such as Dubai or Riyadh, offer substantial comparisons to understand the connection between socio-economic attributes, housing alternatives, and land surface temperature (Parvez et al., 2021). Additionally, the use of GIS and spatial analysis in the scope of this study follows the work of Wu, Li, and Wang (2021), which emphasises the significance of these techniques in revealing complicated urban phenomena. Thus, our research not only contributes to a better understanding of Amman’s specific situation but also fits with international research trends exploring complicated relationships between socio-economic issues, housing preferences, and urban microclimates.

Green infrastructure is crucial in mitigating heat island effects, decreasing dependence on air conditioning in buildings, and establishing favorable microclimates for urban residents. Studies in Amman, Jordan indicate that trees can cut building cooling needs by as much as 35% (Abdel-Aziz and Al-kurdi, 2014), and research in Cairo, Egypt demonstrates that green spaces have lower temperatures compared to non-green areas (AboElata, 2017). In line with efforts to combat rising temperatures, an innovative project inspired by Japan's Satoyama model has emerged south of Amman. This initiative integrates diverse ecosystems to mitigate climate change by combining native wilderness with productive systems and implementing regenerative solutions, biologically enhanced agricultural practices, and water-saving farming methods. Notably, the project includes the creation of a Miyawaki forest, which aims to increase urban biodiversity, productivity, and resilience. Investing in local farmer education and community involvement through activities such as field trips and workshops is critical to its long-term viability and effectiveness. The Urban Micro-Lungs project, utilizing the Miyawaki afforestation technique in the Urban Living Lab framework, is actively reforesting areas east of Amman to mitigate climate change impacts, like the urban heat island effect, and enhance living conditions in densely populated urban areas (Borelli, Conigliaro & Cagno, 2023). Led by the German Federal Ministry for Economic Cooperation and Development (BMZ) agency GIZ in partnership with Jordan's Ministry of Environment and the Greater Amman Municipality's TAYYUN Research Studio, this project showcases the possibility of establishing green spaces in densely built urban environments, thus greatly aiding temperature reduction efforts.

5.6. Climate Change

The evaluation of Amman's vulnerability to climate change and extreme weather events is a crucial analysis of the urban plans applied in the city. The positioning of Jordan within the Notre Dame Global Adaptation Index (NDGAIN index), together with the many challenges posed by increasing temperatures, erratic precipitation patterns, restricted water supplies, and other climate-related issues, underscores the urgent need for the adoption of climate adaptation and mitigation strategies. The policy interpretation outlined in this particular context emphasises the importance of urban planning in addressing and reducing the effects of climate change. This highlights the need to adopt effective measures to reduce greenhouse gas emissions and improve resilience in the face of climate-related challenges. The assessment of outcomes encompasses an examination of the municipality's progress in reducing emissions, executing initiatives to adapt to climate change (The Amman climate plan: a vision for 2050), and mitigating the environmental impacts associated with urban development (GAM, 2019; Ababsa & Hussein, 2020).

According to Hamarneh (1996), the downtown region (Wadi) and the citadel in Amman did not have any recorded farming until 1816. As the nineteenth century began, the most noticeable aspect of the social transformation in the Balqa area was the shift from nomadism to settled farming and farming on land.

Except for the nomadic Bedouin tribes, which refused to acknowledge any kind of government and instead sought dominance via bloodshed and the destruction of Amman, the city had no discernible physical settlements until 1840. Numerous scholarly excursions documented Amman and the surrounding Balqa region in the second part of the nineteenth century, yielding a wealth of literature on the subject. At that time, Amman's southern neighbours—Ma'en, Madaba, Hisban, Yajouz, and Wadi Sir—had verdant, expansive corn and wheat fields. Before the government and capitalism meddled, the land was unfairly divided among the tribe's members. Due to the strong central government's authority over the tribal entities, Amman's security improved somewhat in the fourth quarter of the nineteenth century. As a result, land cultivation decreased, and trade and exchange activity increased. The proximity of water made Amman an important halt on the "Hajj" route to Mecca, and as a result, there was a great deal of commerce and exchange between the pilgrims and the Bedouin people of Balqa (Hamarneh, 1996).

5.7. Understanding the Complex Dynamics of Urbanisation, Environmental Sustainability, and Population Trends in Amman

The present study examines Amman's urbanisation-environmental sustainability relationship. The research focused on how urban expansion, land use restrictions, and population density affect these aspects. The research examined urbanisation hypotheses, its environmental impact, and policy responses. The study examined a comprehensive 1990–2021 dataset to do so. The sixth hypothesis was that unregulated and unplanned urban sprawl would severely harm Amman's urban growth. A regression study revealed a statistically significant and favourable relationship between urban sprawl and densely populated areas. Population (POP), economic growth (GDP), the industrial component of GDP, and growth rate are positively correlated, according to coefficient estimates. Industrial activities typically produce heat and pollution, worsening metropolitan heat islands (Irfeey et al., 2023). However, industrial operations can also be economically beneficial, highlighting the complex trade-offs of urban development. Previous studies found similar results on urbanisation's impact on land use (Luo et al., 2020). In Amman, population growth and urban sprawl are positively correlated (Merrier et al., 2020). Urban sprawl is harming Amman's ecology.

The findings emphasise the need for effective land-use policies and strategies to reduce urban sprawl's environmental impacts. The above measures include green infrastructure development, reforestation, sustainable land use, and ecosystem protection zoning (Etim, Attah, & Okon, 2023).

The study confirms previous research in various metropolitan contexts that urban development and sprawl may have large environmental impacts (Egidi et al., 2020b; Almulhim & Cobbinah, 2023). The strong correlation between urbanisation and environmental impacts, notably CO_2 emissions, emphasises the need for sustainable urban design and environmental consideration in policymaking. Urbanisation does not correlate with agriculture; hence, other factors must be considered in Amman's agricultural dynamics.

This study's findings might benefit Amman's policymakers and urban planners. First, sustainable urban growth land use policies must be prioritised for adoption and enforcement. Limiting and managing urban expansion will reduce cities' environmental impact. The study also emphasises how interconnected factors like population density, energy usage, renewable energy, and transportation affect environmental sustainability. Policymakers should emphasise sustainable mobility, energy reduction, and green infrastructure to reduce urbanisation's environmental effects. This study found a positive relationship between urbanisation indicators like population density and built-up areas and environmental indicators like CO_2 emissions and energy use, supporting previous studies on urbanisation and the environment. Several studies have examined the environmental impacts of increasing urbanisation and the need for sustainable urban design. This study found that population density increases CO_2 emissions. Energy, transportation, and garbage production increase with the metropolitan population, increasing the city's carbon footprint. Other worldwide cities showed similar outcomes. City planners and lawmakers should prioritise environmentally friendly urban design and infrastructure that can accommodate expanding populations. This study confirms previous findings that metropolitan areas cause environmental harm (Nathaniel, Nwulu, & Bekun, 2021; Lolli et al., 2020; Islam et al., 2021). Urban growth reduces biodiversity, air quality, and water resources due to the loss of green areas, ecological disturbance, and impermeable surfaces. Urbanisation usually turns agricultural land into cities, but local conditions in Amman may hinder this. Technology, agrarian practices, and regional land use patterns may have caused agricultural land transfers. Since more and more people are settling in urban areas, such places are increasingly vulnerable to environmental and anthropogenic disasters. As a direct outcome of the rural-urban migration phenomenon, there is an urgent need for new building development. However, due to the emergency nature of many construction projects, shoddy construction practices may creep in, placing these buildings at risk of catastrophic collapse. The stress of a large population on some buildings might lead to their being used in ways that are not in accordance with the norms that existed when they were first constructed. Brownfield regeneration in Amman, Jordan, is crucial for urban revitalization, particularly in the city centre and Al Abdali, where abandoned sites hold significant redevelopment potential. Abed and Yakhlef (2019) categorised different brownfield sites by size, use, occupancy, and condition, with many being free of contamination, making them suitable for profitable redevelopment. Transforming eastern Amman's brownfield areas into public parks, like the upcoming green spaces in Al Abdali, represents a strategic shift towards creating lively recreational areas that enhance the city's green infrastructure and quality of life. Innovative financing and community involvement are essential for addressing environmental challenges and cleanup expenses, driving successful brownfield revitalization initiatives, and furthering Amman's urban sustainability and cultural heritage preservation objectives.

5.8. Urban Sprawl and Environmental Sustainability

The results obtained from Models 1, 2, and 3 emphasise the significant correlation between urbanisation, energy consumption, and CO_2 emissions in the city of Amman. The findings from Model 1 indicate that energy use is a significant factor in the generation of CO_2 emissions, which is consistent with previous research that has established a strong connection between energy usage and emissions (AbdelJawad & Nagy, 2023c; Armeanu et al., 2021; Carpio, Ponce-Lopez, & Lozano-García, 2021). The link between sustainable energy practices, energy efficiency programmes, and urban expansion highlights the significance of addressing environmental costs (Armeanu et al., 2021; Rubiera-Morollón & Garrido-Yserte, 2020; Bueno-Suárez & Coq-Huelva, 2020).

In the second model, we investigated the complex relationship between population density, energy consumption, and emissions. The findings indicate an unexpected inverse correlation between population density and energy usage. However, it is important to understand this conclusion within the framework of urban dynamics. According to previous studies conducted by Zhang (2021); Zhao & Liu (2021); and Næss, Saglie & Richardson (2020), it has been shown that densely populated regions tend to display reduced per capita energy consumption. This may be attributed to several causes, including enhanced public transit systems and the implementation of compact urban design strategies. The aforementioned research highlights the necessity of adopting a comprehensive strategy for urban planning that takes into account both population density and energy efficiency methods in order to effectively mitigate emissions (Li et al., 2022).

In the third model, the findings align with existing studies on the connection between urbanisation, population density, and environmental sustainability. We observe that, in line with prior research, higher population density in Amman is associated with a proportional increase in log-transformed CO_2 emissions, emphasising the impact of dense urban areas on carbon emissions. The negative coefficient for renewable energy sources supports the consensus that a greater reliance on renewables corresponds to a reduction in CO_2 emissions, underscoring the importance of sustainable energy practices. Additionally, the positive correlation between energy use per capita and CO_2 emissions underscores the role of energy consumption patterns in environmental impact. The positive relationship between GDP per capita and CO_2 emissions aligns with the established understanding that economic growth is linked to increased industrial activities and energy consumption. Finally, the positive association between the urban growth rate and CO_2 emissions reinforces the environmental implications of rapid urbanization. Our findings contribute to the existing body of knowledge, providing further insights into the intricate relationship between urban dynamics and environmental sustainability in Amman.

The utilisation of Augmented Dickey-Fuller (ADF) tests yielded valuable information about the time series properties of the chosen variables. It is worth mentioning that the non-stationary characteristic of the natural logarithm of population, which suggests a random walk pattern, aligns with similar observations made in other metropolitan settings (Song et al., 2014). Nevertheless, the conversion of the differential natural logarithm of the population (Diff_LnPOP) resulted in a time series that exhibited stationarity, enabling more precise modelling of the influence of urbanisation on energy consumption and emissions. The aforementioned alteration underscores the need to utilise suitable time series methodologies in the examination of urban dynamics (Fotheringham et al., 2000).

The evaluation of multicollinearity through the utilisation of variance inflation factors (VIFs) in both Model 1, Model 2, and Model 3 revealed the presence of negligible multicollinearity among the independent variables. This is consistent with the suggestions made by O'Brien (2007) and Hair et al. (2010) in order to safeguard regression models from the adverse effects of elevated multicollinearity. The lack of significant multicollinearity highlights the dependability of our regression findings. Furthermore, the Breusch-Godfrey Lagrange Multiplier (LM) Test was conducted to assess the presence of autocorrelation in the residuals of both models. The results of the test indicated that there was no significant serial correlation seen in the residuals. The aforementioned observation aligns with previous research conducted by Greene (2008), indicating that our models effectively capture the fundamental associations without being influenced by autocorrelation concerns.

6. POLICY AND MITIGATION MEASURES FOR SUSTAINABLE URBAN DEVELOPMENT

In the context of rapidly growing cities across the world, the question of sustainable urban development is of crucial importance. The negative environmental effects of urban expansion and the necessity for resource-efficient urbanisation make it important that effective policies and mitigation measures be put in place (Ahani, & Dadashpoor, 2021). Amman City in Jordan is the focus of this chapter as it evaluates urban land use policies, sprawl mitigation measures, and waste-to-energy projects. The Amman Master Plan for 2025, also known as the Greater Amman Comprehensive Development Plan, established ambitious targets for municipal growth (Ababsa, & Hussein, 2020). Compactness and its effects on urban development—including infrastructure, economic growth, and environmental sustainability—are the major topics of this chapter. This paper examines Amman's sustainable urban development policies and mitigation solutions. It will evaluate the historical context, secondary planning impacts, and long-term repercussions of these projects.

6.1 Assessing the Compactness Objective

The Amman Master Plan for 2025, sometimes referred to as the Greater Amman Comprehensive Development Plan, was produced using a comprehensive strategy that incorporates diverse aims to effectively steer the sustainable expansion and advancement of the metropolis (Ortiz-Moya, Tan, & Kataoka, 2023). Within this particular area, a thorough examination is conducted of the primary goals of the plan, with a focus on evaluating their importance and potential consequences.

Primarily, the master plan acknowledged the need for effectively managing urban growth. The attainment of this purpose was of utmost importance in the regulation of uncontrolled expansion of urban areas and the facilitation of more effective use of land resources (Koroso, 2023). Nevertheless, while evaluating the results, it became evident that the issue of urban growth in Amman persisted as a formidable obstacle. The observed phenomenon may be ascribed to several variables, including but not limited to population expansion, economic constraints, and cultural inclinations towards certain housing choices. Urban sprawl was influenced by external factors and local dynamics, despite efforts to control its growth (Jarah et al., 2019; Alnsour, 2016).

The purpose of developing infrastructure was another crucial part of the master plan. Improving the urban infrastructure, encompassing transit systems, utilities, and services, was imperative in order to adequately address the demands of the expanding populace. Considerable advancements were achieved in this context, notably via initiatives like the Amman Ring Road and the implementation of the Bus Rapid Transit System (Battarra & Mazzeo, 2022). Nevertheless, the rate at which infrastructure was developed did not consistently correspond with the fast expansion of the urban area, resulting in persistent difficulties pertaining to traffic congestion and the ease of reaching various locations within the city.

The master plan placed significant emphasis on the objective of economic growth. The objective of promoting investment and economic activity in the Greater Amman region was to foster job creation and facilitate economic expansion (Fraihat et al., 2023). Although there was some advancement, the economic development goal encountered obstacles such as the worldwide economic situation and the need for ongoing endeavours to entice investors and promote entrepreneurship. The incorporation of environmental sustainability was a fundamental component of the master plan. The objective was to mitigate the ecological consequences of urban expansion, advance sustainable methodologies, and safeguard green spaces and natural resources. The implementation of the Amman Green City Action Plan (GCAP) and the Amman Resilience Strategy marked notable progress in the endeavour to tackle environmental issues (Al-Addous et al., 2023). Nevertheless, the urban area continued to confront environmental challenges, including the mitigation of carbon emissions and the effective management of garbage.

Enhancing social services, including healthcare, education, and housing, was another essential element of the strategy. The primary objective was to improve the overall well-being and standard of living for the inhabitants. Although there were advancements in the fields of healthcare and education, persistent obstacles persisted, notably in the realm of housing. The demand for affordable housing has consistently exceeded the available supply. The master plan demonstrated the commendable objective of conserving heritage, acknowledging the significance of cultural and historical locations (Al Shawabkeh et al., 2023). The admirable efforts of Amman to safeguard its cultural legacy are being challenged by the mounting demands exerted by urban growth on the preservation of ancient monuments.

The plan included strategies to mitigate traffic congestion and enhance public transit, therefore addressing the issues of transportation and mobility. The implementation of the Amman Rapid Bus Transit (BRT) project marked a notable advancement in this particular trajectory (Ashour & Tarawneh, 2023). Nevertheless, the postponed execution and the need for further enlargement suggested that the issues pertaining to transportation were not completely overcome. The primary goals of housing and land use policies are to effectively respond to the varied housing requirements of a population and to manage land use in order to support urban expansion. Although there were notable advancements in the diversification of housing alternatives, the matter of housing affordability persisted as a significant problem, especially for those with lower and moderate incomes (Saiz, 2023).

The plan included endeavours aimed at population growth management and the facilitation of a well-distributed population throughout Amman. However, the dynamics of the population presented persistent obstacles. The demographic composition of the city was impacted by the arrival of refugees and other contributing factors. The core purpose of fostering public involvement in the planning and development process was pursued, although problems were encountered throughout its actual execution. These issues included the need for good coordination among diverse stakeholders and the successful engagement of the public.

6.2 Urban Land Use Related Policy

Urban land policies are crucial to influencing city growth and limiting environmental damage. Abdeljawad and Nagy (2023a) examined urban land use restrictions that limited urban growth in Amman City, Jordan. This section focuses on the study's results and emphasises the need for effective policy to mitigate urban sprawl's detrimental effects. Urban sprawl, common in fast-growing cities, has occurred in Amman City for years. Urban sprawl—the spread of cities onto undeveloped or agricultural land—leads to increased land consumption, inefficient land use, and fragmented urban patterns. Urban expansion causes habitat loss, energy consumption, air and water pollution, and a lower quality of life for citizens. Urban land use rules guide urban expansion to solve these issues. This ensures sustained and controlled urbanization. Abdeljawad and Nagy (2023a) examined these strategies' effectiveness in slowing Amman's urban population development and limiting its environmental impact. The researchers compared Amman City to two other cities to get insight into policy efficacy in various situations. The research examines several case studies to understand how policy efforts affect urban expansion and the environment. The study shows that comprehensive, well-executed policies support sustainable urban expansion. The study found that compact urban strategies are crucial to city success. Compact urban development promotes infrastructural efficiency, land use diversity, and population density. Thus, less urban development in the countryside preserves agricultural land and natural ecosystems. The research focuses on environmentally friendly transit systems in urban land use strategies. Cities may cut traffic and pollution by prioritising public transportation, bicycle infrastructure, and pedestrian-friendly architecture. Integrated land use and transit planning may help build accessible, well-connected cities. This will reduce commutes and promote greener travel. The research also emphasises land-use planning. Sustainable urban growth requires land-use policies.

The research emphasises the need for well-executed policies for sustainable urban expansion. The research emphasises compact urban designs that improve infrastructural efficiency, land use diversity, and population density. Urban growth within current limits preserves agricultural land and natural habitats. The research emphasises green transportation networks as crucial to urban land use initiatives. Public transit, bicycle infrastructure, and pedestrian-friendly urban planning may minimise traffic and pollution in cities. Land use and transit planning must be integrated to create accessible and well-connected urban landscapes that reduce commuting times and promote environmentally friendly mobility. Sustainable urban growth requires effective land-use policies. These regulations promote building density and discourage urban expansion. Infill development and revitalising underutilised urban areas can maximise infrastructure use. Cities may minimise green space and agricultural land conversion using this technique. However, the evidence shows that these regulations only work if they are fully implemented. This shows the necessity of government, urban planners, developers, and local communities working together.

6.3 Amman Master Plan Long Term Impact

The Amman Master Plan 2025 acknowledged that urban planning is a long-term commitment to the city's future. Since the master plan was implemented over two decades, immediate outcomes may not reflect its long-term influence. One of the plan's goals, a compact city layout, was not achieved in the early years due to the dynamic urban terrain. Urban planning predicts a city's growth, which in Amman means anticipating its changes. Early after the plan's release, the city's demands and demography may have changed, resulting in a less compact city pattern. For instance, population growth may require urban development to accommodate new citizens. Sustainable and efficient land use concepts in the master plan can guide this expansion. Thus, while the immediate consequences may not be compact, they may support a more sustainable and resilient city.

Urban planning has long-term effects beyond infrastructure. The master plan's impact on city economic growth is vital. Economic growth takes time and may not be immediately seen. The plan promoted economic activity and investment in Amman to create jobs and growth. Thus, to assess the plan's long-term impact, the city's economic performance must be monitored, including job creation, business development, and investor appeal. Environmental sustainability is also crucial to urban planning's long-term influence. The master plan may prevent environmental damage even without a compact city pattern in the short term. Cities globally suffer pollution, climate change, and resource loss. The master plan's focus on sustainability, green spaces, and environmental impact reduction supports the city's long-term resilience. Tracking environmental quality, greenhouse gas emissions, and natural resource preservation throughout time is necessary to assess its long-term impact.

Social services are another long-term urban planning effect. Healthcare, education, and housing improvements improve city people's well-being. The master plan improved these services to improve Amman's quality of life. Consider long-term elements like healthcare, education, and affordable housing to assess its influence. The city's population and social fabric may reveal these improvements. Heritage preservation is particular to Amman's urban planning. The long-term effects of heritage preservation measures can be found by keeping an eye on the condition of heritage sites, how involved the public is in cultural preservation, and how well the plan works to protect Amman's unique history. These policies will eventually prove successful in preserving Amman's culture.

6.4 Policy Initiatives and Mitigation Measures

In order to effectively tackle the issue of urban sprawl and encourage sustainable urban growth in Amman, it is imperative to implement a wide range of policy initiatives and mitigating measures. The implementation of these policies is crucial to steering the city towards a future characterised by enhanced sustainability and resilience. Within this particular section, we want to expound upon each of these endeavours in order to foster a more comprehensive comprehension of their inherent importance and subsequent ramifications.

The implementation of the New City project is a significant and transformative endeavour in Amman's pursuit of sustainable urban development. Situated at a strategic location inside the capital city, the primary objective of this newly established urban centre is to effectively mitigate the escalating population density that has imposed a significant strain on Amman. This effort aims to improve the overall quality of life, stimulate economic growth, and effectively manage urban development by implementing a carefully designed infrastructure that can accommodate the present and future population's requirements. The implementation of governmental establishments, residential and commercial zones, recreational facilities, public utilities, and modern transportation systems in New York City is expected to alleviate the increasing strain on the city, thereby promoting a more sustainable form of urban development.

The implementation of compact city development has emerged as a prominent technique for effectively limiting urban sprawl in the city of Amman. Given the ongoing urban expansion, it is essential to promote a denser urban configuration within the already-urban zones. This may include the implementation of incentives aimed at encouraging vertical development, the adoption of regulations that facilitate mixed land use, and the optimisation of existing land resources. One crucial element of this technique is promoting the development of high-rise buildings in defined regions, in accordance with Amman's growth scheme. These strategies play a crucial role in mitigating urban sprawl and promoting the advancement of sustainable urban development.

The enhancement of public transportation plays a significant role in minimising the undesirable consequences associated with urban sprawl. The absence of accessible public transportation services in newly developed residential areas is a significant factor contributing to urban sprawl since it necessitates that inhabitants heavily depend on private automobiles. The commencement of the Amman Rapid Bus Transit (BRT) project in July 2021 is a noteworthy endeavour aimed at tackling the aforementioned concern. The primary objective of this initiative is to alleviate traffic congestion, diminish dependence on private vehicles, and encourage the adoption of sustainable transportation alternatives via the establishment of a contemporary public transit system within the urban area. The achievement and subsequent expansion of the Bus Rapid Transit (BRT) initiative are crucial in order to fully realise these advantages.

Enhanced governance and administration are essential prerequisites for the efficient execution of policies and mitigating measures. The city of Amman has had difficulties in achieving efficient decision-making processes and urban planning due to the overlapping mandates and duties of many governmental entities. In order to effectively tackle these challenges, it is essential to establish a cohesive approach aimed at enhancing governance and administrative processes. One potential measure to consider is the formulation of a comprehensive national urban policy. Such a policy would serve to articulate a consistent and coherent vision for urban development, foster improved collaboration across various urban planning entities, and build an integrated framework for data management and decision-making processes. Through the coordination and integration of these endeavours, the municipality may surmount the challenges presented by disjointed administrative frameworks and progress towards enhanced efficacy and enduring urban advancement.

The issue of climate change adaptation is of great significance for Amman since the city is very susceptible to rising temperatures and the occurrence of severe weather phenomena. In light of the situation, it is imperative to give precedence to the implementation of climate change adaptation strategies. These initiatives comprise a range of efforts, including the reduction of greenhouse gas emissions within the construction industry and the addressing of environmental concerns such as solid waste management and water shortages. Given the municipality's dedication to enhancing sustainability and resilience, it is imperative to prioritise adaptation to climate change problems. The implementation of these measures serves the dual purpose of risk mitigation and the preservation of the city's attractiveness and habitability for its citizens.

The implementation of effective land management and planning strategies is crucial to guiding urban growth towards the goal of sustainability. Efficient land management and planning techniques play a critical role in the regulation of urban growth, the facilitation of efficient land use, and the facilitation of sustainable development. Addressing land shortage concerns is a crucial aspect of effectively controlling urban expansion. In order to achieve this objective, it is essential for the city to investigate potential avenues for enhancing land use, with the aim of optimising current resources and mitigating urban sprawl. The regulations pertaining to building and land use should be designed in a manner that discourages arbitrary growth and promotes the use of sustainable practices in urban development.

6.5 Waste-to-Energy Projects for Urban Sustainability

Amman, like many other cities, struggles with waste management. Abdeljawad, Wikurendra, and Nagy (2022) examine "waste-to-energy" strategies to improve urban sustainability and waste management. Most refuse-to-energy schemes convert waste into power or heat. This section expands on the research's results, emphasising waste-to-energy's pros and cons and the need for a comprehensive waste management plan to achieve a sustainable and circular economy in Amman City. One of the primary benefits that results from the implementation of waste-to-energy programmes is the prevention of garbage from being disposed of in landfills. Landfills are unsightly and hazardous to human and environmental health. Waste diverted to energy conversion facilities reduces landfill waste. Waste disposal will have less environmental impact. This extends landfill life and reduces rubbish disposal land needs.

Additionally, trash-to-energy operations may provide sustainable energy. These initiatives use waste energy to generate power or heat, reducing fossil fuel dependence. This helps reduce greenhouse gas emissions and slow climate change. Amman City's energy security and carbon footprint might improve via waste-to-energy schemes. Waste-to-energy schemes can boost economic growth and jobs. Waste-to-energy plants provide local jobs by requiring qualified workers. Renewable energy from garbage may also diversify the energy industry, lowering dependence on foreign energy sources and promoting energy independence. Refuse-based renewable energy uses waste.

However, waste-to-energy initiatives have hurdles. Technology and finances might be major obstacles. Waste-to-energy systems depend on garbage composition, moisture, and pollutants. Choose systems that can handle Amman's unique waste. Waste-to-energy infrastructure's high starting expenses and ongoing maintenance costs may also be a financial hurdle. To succeed, garbage-to-energy projects must also garner public support. Concerned about pollutants, odours, and health dangers, locals may oppose a project. Thus, comprehensive environmental surveillance and control systems are needed to ensure that waste-to-energy plants use the best waste management practices and meet the strictest emission standards. Public participation and awareness campaigns may address misconceptions and promote waste-to-energy programmes.

Waste-to-energy operations also depend on legislation and regulation. Transparent, supportive laws are needed to attract investment and foster refuse-to-energy projects. Waste management, renewable energy, and environmental laws are examples. Governments must implement waste management policies that reduce garbage, recycle, and recover energy to promote a circular economy. Waste reduction and recycling are the main waste management methods; thus, a complete waste management strategy should prioritise them. Trash-to-energy projects should be considered a complement for waste that cannot be recycled or reused. Source separation, recycling, and trash reduction education can reduce the amount of rubbish processed via waste-to-energy operations in cities.

6.6 Impact of Urban Sprawl on Built-up Areas

As seen in Table 17, the study examined how unrestricted urban sprawl affects Amman's developed regions. The data show a complex relationship between urban sprawl and key parameters. Although not statistically significant, "Amman Built-up Area" correlated negatively with the outcome variable. This conflicting finding suggests that unrestricted urban expansion, as shown by the growth of built-up regions, may not be the sole cause. This work supports the complicated conversation about urban sprawl, which recognises that its consequences depend on local characteristics, land use legislation, and planning methods (Ewing & Hamidi, 2015).

In contrast, "Amman Growth Rate," "Amman Population Density," "GDP per Capita," and "Industry including Construction" correlated with built-up areas. As built-up regions grow, population density, GDP per capita, and industrial and building activities rise. This analysis confirms that population growth, economic activity, and industrialization often affect urban expansion (Roy et al., 2021; Surya et al., 2021). These variables' significant effects demonstrate the complexity of urbanisation processes and the need for comprehensive land-use regulations and strategies to maximise urban growth's benefits and minimise its drawbacks. These measures must balance accommodating a growing population with preserving Amman's agricultural and green spaces.

6.7 Conclusion

This chapter concludes the challenges and successes of the Amman Master Plan for 2025 in managing urban growth in Amman City, Jordan. The plan aimed to manage population growth effectively but faced challenges like traffic congestion and economic constraints. The plan also focused on environmental sustainability, with initiatives like the Amman Green City Action Plan addressing issues like carbon emissions and waste management. However, improvements in social services, housing, and heritage preservation faced obstacles. The chapter also highlighted the importance of urban land use policies in mitigating urban sprawl, emphasising compact city development, green transportation networks, and effective land use planning. While Amman faces challenges related to limited green spaces, biodiversity pressure, and environmental risks, ongoing projects and initiatives are focused on enhancing green infrastructure, improving living conditions in disadvantaged areas, and promoting sustainable urban development. Collaborative efforts between local authorities, organisations, and communities are essential for addressing these challenges and fostering a greener and more sustainable future for the city. To make the best use of resources and stop pointless growth, this chapter stresses the importance of policy initiatives and measures like the New City project, better public transportation, better government, and climate change adaptation strategies.

7. CONCLUSION & RECOMMENDATIONS

7.1 Conclusion

The DPSIR framework and econometric research allowed systematic analysis of urban sprawl policy responses. The study examined how land use rules reduce environmental impacts and promote sustainable urban planning. The association between population density, energy consumption, and CO_2 emissions revealed how urbanisation affects environmental sustainability. Urbanisation has always been and will always be a dynamic process that affects various areas in different ways and over varied lengths of time. For instance, when comparing urbanisation patterns in the West with those in the Middle East, a clear difference becomes apparent. Both the United States and Western Europe began to urbanise in the nineteenth century, and by the turn of the twentieth century, forty percent of their populations lived in urban areas. Even though cities made up just 16% of the overall population, the Middle East was just now feeling the effects of the Industrial Revolution and seeing a growth in its urban population. The east and south of the Mediterranean Sea also felt the effects of the Industrial Revolution. Historical interior towns like Cairo and Damascus gave way to maritime cities due to increased trade.

This research investigated the multiple pressures from urbanisation, population growth, and land use changes in Amman. The research measured urban growth by using remote sensing data to determine its geographical extent and amplitude. The study examined urban sprawl's complicated relationships with socioeconomic indicators, population density, and economic dynamics. The changing land cover patterns in Amman were analysed using remote sensing. The study shows how urbanisation has changed land cover distribution.

Table 29. Summary of Hypotheses and Findings

Hypothesis	Test	Conclusions
H1: There is a significant relationship between the increase in built-up areas and declining agro-vegetation land in Amman.	Urban sprawl influences on agro-vegetation land.	A strong correlation exists between built-up area expansion and agro-vegetation land reduction.
H2: Over time, there is a correlation between low NDVI values and high Land Surface Temperature (LST) values in Amman, indicating that reduced vegetation cover contributes to increased surface temperatures, whereas high LST values are	Correlation between NDVI, NDBI, and LST	NDVI is negatively correlated with LST, while NDBI is positively correlated. This finding suggests that regions characterised by a greater prevalence of developed land surfaces are likely to exhibit elevated temperatures, hence emphasising the phenomenon known as the urban heat island effect.

positively associated with high Normalised Difference Built-up Index (NDBI) values, indicating that areas with more built-up surfaces have higher temperatures.		
H3: There is a significant correlation between land surface temperature (LST) and household income level, with higher-income households exhibiting a negative correlation with LST, indicating lower surface temperatures.	Analysing the correlation between land surface temperature (LST) and socio-economic indicators, specifically household type and income level, in Amman City	Higher-income households experience less increased LST due to their capacity to incorporate green spaces.
H4: High-NDVI woody vegetation has a significant cooling effect on the surface temperature in urban areas with arid and semi-arid climates, such as Amman.	Underscoring the influence of vegetation density on local temperature regulation.	Areas with NDVI values above 0.6 have lower surface temperatures, thereby contributing to a cooler and more comfortable urban environment. Conversely, areas with NDVI values between 0.2 and 0.5, representing sparse vegetation, exhibit higher surface temperatures.
H5: There is a significant impact of uncontrolled and unplanned urban sprawl on the increase in built-up areas in Amman.	Amman population density and urban expansion challenges	The hypothesis is that uncontrolled urban sprawl, as measured by built-up area, is increasing. The study findings reveal a significant increase in the built-up area over time.
H6: Urbanization and population density have a significant influence on environmental sustainability in Amman city.	Correlation of urbanisation factors with environmental changes. Influence on Environmental Sustainability	Our study examined how urbanisation and population density affect environmental sustainability in Amman. Multiple significant relationships between independent variables and dependent variables (CO_2 and energy use) were found. Population density and energy use have significant correlations with the outcome variables.
H7: The implementation of land use policies and strategies can mitigate the negative impacts of urban sprawl on the environment in Amman.	Mitigating urban sprawl's environmental impacts by identifying policy effectiveness in curbing negative effects	Implemented policies have led to a partial mitigation of negative impacts.

This study examines how urban expansion, land use policies, environmental variables, and population density affect Amman's urban development and sustainability. Table 29 summarises the findings, which contradict the initial idea that unrestricted urban sprawl expands developed regions. Hypothesis H1 examined the relationship between urbanisation (built-up area) and agro-vegetation loss. Urbanised regions were negatively correlated with agro-vegetation land. This suggests that urban sprawl converts or degrades agricultural land and vegetation. The findings demonstrate the need for policies that prioritise sustainable urban expansion and maintain vital agricultural resources to conserve agricultural land and green areas. These measures should protect agricultural land. The second hypothesis explores the relationship between low Normalised Difference Vegetation Index (NDVI) values, high Normalised Difference Built Up Index (NDBI) values, and high land surface temperature (LST), supporting the urban heat island phenomenon. The third hypothesis analyses the correlation between land surface temperature (LST) and socio-economic indicators, specifically household type and income level, in Amman City.

The fourth hypothesis underscoring the influence of high vegetation density on lowering surface temperature. The fifth hypothesis measures the impact of uncontrolled and unplanned urban sprawl on the increase in built-up areas in Amman. The sixth hypothesis investigates how urbanisation and population density affect environmental sustainability. This study found significant connections between "Amman Population Density" and sectors like "Industry, including Construction." These findings show that population density may affect industrial activity, which could affect environmental sustainability. The seventh hypothesis explores whether land use policies reduce urban sprawl's environmental impacts.

The incorporation of the DPSIR framework into the analysis of remote sensing indices and econometric techniques offers a reliable approach to comprehensively examining the complex characteristics of urban expansion and its associated environmental impacts. This methodology not only enhances our understanding but also provides policymakers with practical ideas for promoting sustainable urban development in Amman and other areas. The paper proposes a balanced strategy that harmonises scientific investigation with practical policy consequences, aiming to maximise urban expansion while simultaneously protecting the environment.

7.2 Recommendations

Based on the findings of the present study, the following are the recommendations:

1. Amman needs clear land-use planning for urban growth. These designs should protect nature and encourage mixed-use neighbourhoods with residential, commercial, and

institutional purposes. Sustainability ideas like green areas and agricultural land conservation may help Amman grow its metropolis sustainably.

2. Increasing bus, tram, and metro service decreases private car use and emissions. Transit-oriented communities that promote walking and sustainable mobility require land-use planning and transportation integration. These places need various transit choices to decrease the city's environmental impact.
3. Biodiversity, air quality, and enjoyment depend on urban parks. Protect parks, green areas, and farms against sprawl. Additionally, Amman should prioritise the establishment of new urban green areas that integrate into the city. These urban oases eliminate heat islands and increase eco-connection.
4. Green networks help lessen the urban fragmentation of natural areas. These corridors will reconnect dispersed natural habitats, simplifying urban animal transit and conserving biological processes. Environmental groups and stakeholders must work together to build and maintain these corridors.
5. Sustainable urban development demands community engagement. Citizens should learn about sustainability and make decisions. Community gardening, recycling, and energy-saving projects inspire city-wide environmental action. Integrating locals into sustainable practices can make Amman more resilient and sustainable.
6. Incentives and rules should encourage energy-efficient designs, green building materials, and renewable energy technology integration. Green building should be taught and encouraged to construction personnel. Building sustainability is improved via solar panels and rainwater collection.
7. Amman needs better waste management to grow sustainably. Recycling, reducing garbage, and developing circular economies minimise pollution and improve resource efficiency. Sustainable waste disposal methods involve coordination with waste management authorities and stakeholders. Amman can lower its environmental impact and develop towards a circular economy by promoting individual, communal, and industrial waste management.
8. To construct ecologically friendly cities, progress must be monitored and assessed. A comprehensive monitoring and evaluation system allows policy and process analysis, improvement identification, and data-driven decision-making. Policymakers employ land use, air quality, biodiversity, and energy usage data to enhance policies and resource allocation. Continuous evaluation encourages accountability and long-term success.

Finally, these principles lay the groundwork for sustainable urban growth in Amman. Improve land-use planning, invest in public transit, preserve green spaces, create ecological corridors, encourage community involvement, promote sustainable construction, revamp waste management, and implement effective monitoring systems to make Amman resilient and sustainable. These proposals need collaboration between government agencies, urban planners, developers, community organisations, and the public. With constant efforts and sustainable urban development, Amman City may grow, be environmentally friendly, and be inhabited for future generations.

7.3 Limitations

An interdisciplinary approach integrating remote sensing and econometric analysis is used to interpret vegetation and farm data. The methods used to merge vegetation and agriculture provide certain limits. There is limited accessibility to comprehensive datasets covering all dimensions of interest, particularly socio-economic data and fine-resolution remote sensing images. Long-term data is needed to track urban growth and its environmental. Existing land use policies and strategies might not fully reflect actual practices. Although limited, the research acknowledges the necessity to balance development and sustainability in Amman's urban context. The study aims to inform policymakers, urban planners, and stakeholders on urban sprawl's environmental impacts and sustainable development. This study's findings might be utilised to implement effective environmental management strategies to balance urban expansion and ecological preservation in Amman.

8. NEW SCIENCTIFIC RESULTS

This chapter discusses current scientific discoveries from the seamless integration of remote sensing indices, econometric analysis, and the Driver-Pressure-State-Impact-Response (DPSIR) paradigm. This study aims to illuminate the complex dynamics of urban expansion and its effects on sustainable development in Amman.

Urban sprawl and its environmental effects in Amman, Jordan, have been extensively studied. Urbanisation literature comprises policy assessment, review papers, and remote sensing approaches. This study uses econometric analysis and Stata v17 software to evaluate the relationships between factors and their impact on urbanisation and CO_2 emissions in Amman. This quantitative analysis helps us comprehend urban sprawl's causes and environmental impacts. Abdeljawad, Adedokun, and Nagy (2023) and (2022) use remote sensing to assess urban sprawl's environmental impacts. These studies reveal Amman's urban growth's size and scope. Scientists examine urban sprawl's environmental implications using remote sensing indices and change detection techniques. This study combines regression modelling with econometric analysis. Our regression analysis helps us understand how factors affect urbanisation and CO_2 emissions. This study examines how population, GDP, industrial sector share, electricity consumption, private autos, and population density affect urbanisation and CO_2 emissions. Econometric methods can quantify and analyse the statistical importance of these aspects. This study adds a new viewpoint on urban growth in Amman. It enhances scholarly debate on urbanisation by improving understanding of its causes and environmental effects. The new scientific results are based on answering the research questions of the dissertation and are summarised as follows:

1. The integration of the DPSIR model allows for a comprehensive study of urban sprawl and its environmental impacts by combining remote sensing data with rigorous econometric analysis, revealing the complex effects of urban growth on the environment.
2. The research explores the relationship between remote sensing indices and temperature variations, shedding light on the impact of urban expansion on land surface temperature (LST) and plant health in Amman, Jordan. Through the utilisation of remote sensing, GIS, and statistical tools, the study quantifies the impact of urban growth on these environmental aspects. This research holds significance not only for Jordan but also for other countries facing comparable challenges, offering essential insights for urban planners worldwide. By addressing a data gap in Jordan and providing a model for addressing urbanisation issues globally, this study contributes valuable knowledge to the field.

3. The scarcity of data accessible to urban planners and decision-makers underscores the critical necessity for employing remote sensing, GIS, and statistical modelling tools to measure, monitor, and analyse urban growth patterns and spatial inequalities effectively.
4. The research established a strong correlation between household income, housing type, and land surface temperature (LST) in Amman City, revealing that higher-income households exhibit lower LST levels attributed to their ability to integrate green spaces, underscoring the influence of income disparities on urban heat distribution, and highlighting a direct link between socio-economic status and LST levels, emphasizing the necessity for tailored interventions in vulnerable communities.
5. Demonstrated the cooling effect of higher NDVI values on Amman's urban microclimate, linking denser vegetation coverage to lower surface temperatures and providing valuable insights for the integration of green infrastructure and vegetation management in urban planning to mitigate heat island effects and enhance environmental sustainability.
6. The research indicates that urban growth trends, particularly urban sprawl, have significant environmental impacts such as CO_2, energy use, loss of vegetation, and changes in land use patterns, highlighting the pressing need for sustainable urban planning that prioritises ecological sustainability. The assessment of urban sustainability in Amman highlights the importance of sustainable development indicators and methods for assessing city sustainability.
7. Regression analysis confirms strong, positive links between uncontrolled urban sprawl and population density, GDP per capita, industry, including construction, and built-up area growth in Amman, highlighting the role of socio-economic factors in shaping its urban landscape.

9. SUMMARY

Global urbanisation affects the environment, society, and economics. Urban development, especially in emerging nations, is a major issue as cities grow to accommodate increased populations and economic activity. This dissertation analyses urban migration and sustainable development in Amman, Jordan. This multidisciplinary study uses remote sensing indices, economic analysis, and the Drive-Pressure-State-Impact-Response DPSIR paradigm to understand urban expansion and sustainable development. Combining these methods, the research tries to understand urban growth and its effects.

The study begins with remote sensing data to assess Amman's urban growth. Satellite images and remote sensing indices like NDVI and NDBI are used to track land cover changes. The results show that the city's built-up area has grown significantly, indicating urban growth. This conclusion is concerning because unregulated urban growth may degrade the ecosystem, destroy green places, and increase energy use. This study examines whether land-use policies have mitigated the environmental impacts of urban growth. Econometric analysis examines land use policy, urbanisation, and environmental factors. Some interventions have reduced harmful consequences, but the data show that issues remain. To achieve sustainable urban growth, land use restrictions must be tighter and more efficient.

This study also examines how urbanisation and population density affect environmental sustainability, which is vital. Econometric investigation shows a strong link between urbanisation, population density, and environmental conditions. Urbanisation and population density indeed have a significant influence on environmental sustainability in Amman. Policymakers can use these findings to inform strategies for sustainable urban development and environmental conservation. Denser populations consume more energy and emit more CO_2. This underlines the importance of public transit and bike infrastructure to decrease urbanisation's environmental effects. The impact of urban growth on agro-vegetation land is also examined. The analysis shows a strong link between urbanisation and agricultural land loss. This highlights the necessity for land use regulations that balance urban growth with agricultural resource protection. There is a significant correlation between land surface temperature (LST) and household income level, with higher-income households exhibiting a negative correlation with LST, indicating lower surface temperatures. And high-NDVI woody vegetation has a significant cooling effect on the surface temperature in urban areas with arid and semi-arid climates, such as Amman. There is a significant impact of uncontrolled and unplanned urban sprawl on the increase in built-up areas in Amman. Despite facing challenges related to uncontrolled growth and urban sprawl, efforts are being made towards sustainable city planning in Amman. The city is moving towards more sustainable development practices by implementing strategies that focus on efficient land use and ecosystem services. The city's commitment to climate action is evident through the Amman Climate Action Plan and Resilience Strategy, which aim to mitigate emissions and enhance resilience in the face of climate change impacts like decreased rainfall, rising temperatures, and extreme weather events. Amman's efforts align with global commitments to combat climate change and build a more livable and sustainable city for its residents. In summary, Amman's journey towards sustainable urban development involves overcoming challenges posed by rapid growth through strategic planning, environmental initiatives, and a commitment to resilience in the face of climate change impacts.

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11. PUBLICATIONS AND OTHER SCIENTIFIC OUTPUT

11.1 Publications relating to the topic of the dissertation

1. Abdeljawad, N., Adedokun, V., & Nagy, I. (2023). Environmental impacts of urban sprawl using remote sensing indices: a case study of AAmman city – the capital of Jordan. Geojournal of tourism and geosites, 46(1), 304–314. Scopus. Https://doi.org/10.30892/gtg.46134-1028
2. Abdeljawad, N., & Nagy, I. (2023). The Impacts of Urban Sprawl on Environmental Pollution, Agriculture, and Energy Consumption: Evidence From Amman City. Revista de Gestão Social e Ambiental, 17(2), Article 2. Https://doi.org/10.24857/rgsa.v17n2-010
3. Abdeljawad, N., & Nagy, I. (2023). Evaluation Urban Land Use Related Policies to Reduce Urban Sprawl Environmental Consequences in Amman City-Jordan Compared with Other Two Cities. WSEAS Transactions on Environment and Development, 19, 119–137. Https://doi.org/10.37394/232015.2023.19.11
4. Abdeljawad, N., Adedokun, V., & Nagy, I (2022). Managing, assessing and monitoring urban sprawl using remote sensing; change detection, urban expansion intensity index (UEII), and shannon entropy: a case study of amman city, jordan (1990–2022). Journal of southwest jiaotong university, 57(6), article 6. Https://www.jsju.org/index.php/journal/article/view/1417
5. Abdeljawad, N., Wikurendra, E., & Nagy, I. (2022). Waste-to-energy projects for urban sustainability of amman, jordan: challenges and benefits. Journal of Southwest Jiaotong University, 57(6), Article 6. Https://doi.org/10.35741/issn.0258-2724.57.6.102
6. Abdeljawad, N., & Nagy, I. (2023). Thirty years of urban expansion in Amman city: Urban sprawl drivers, environmental impact and its implications on sustainable urban development: A review Article. Resmilitaris, 13(1), Article 1.
7. Abdeljawad, N., Szente, V., Szigeti, O., & Nagy, I. (2022). Urban sprawl mitigation measures towards Sustainable urbanization and Smart Growth in relation to consumer behavior -Amman case study. 21, 2022. Https://doi.org/10.37896/YMER21.12/C8
8. Abdeljawad, N., & Nagy, I. (2021). Urban Environmental Challenges and Management Facing Amman Growing City. Review of International Geographical Education Online, 11, 2991–3010. Https://doi.org/10.48047/rigeo.11.05.192

11.2 Publications not relating to the topic of the dissertation

1. Wikurendra, E., Abdeljawad, N., & Nagy, I. (2023). A Review of Municipal Waste Management with Zero Waste Concept: Strategies, Potential and Challenge in Indonesia. International Journal of Environmental Science and Development, 14, 147–154.

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2. Osiako, P. O., Wikurendra E. A., Abdeljawad, N. S. (2022). Concept of green marketing in environment conservation: A literature review. Environmental and Toxicology Management 2, 8-13. https://doi.org/10.33086/etm.v2i2.3335
3. Abdeljawad, N., Almharat, M., Wikurendra, E., & Nagy, I. (2021). Greater Amman Municipality role in crises management and risk communications with citizens in response to COVID-19. Journal of Positive Psychology and Wellbeing, 5(4), Article 4.
4. Fakhira, A. D., Pawitra, A. S., Diyanah, K. C., Wikurendra, E. A., Nagy, I., & Abdeljawad, N. S. M. (2021). Awareness of doing 3M (wearing mask, physical distancing, washing hands) during pandemic era in rural and urban families. Jurnal Kesehatan Lingkungan, 94–101.

11.3 Publications in books or comparable

1. Abdeljawad, N. (2022). Role of corporate social responsibility for achieving sustainable competitive advantage. Leadership and management theory in practice, 111.
2. Abdeljawad, N. (2022). Applying high-performance organizational model (HPO) in greater amman municipality jordan. In leadership and management theory in practice (p. 53).

11.4 Publication in Conference Proceedings

1. Urban environmental challenges and management facing Amman growing city In: CASEE CONFERENCE 2021 Book of Abstracts : “CASEE universities as laboratories for new paradigms in life sciences and related disciplines” June 7th – 8th, 2021 (online event). (2021) 59 p. pp. 8-8. Paper: 2a.1 , 1 p.
   Abstract (Conference paper) | Scientific

11.5 Publication in Conference book of abstracts

1. Urban City Benefits Landfill Gas Recovery and Power Generation “Waste to energy WTE” in Ghabawi Landfill-Greater Amman Municipality-Jordan (Review article) In: Cseresznyés, D; Király, Cs (eds.) XVI. Kárpát-medencei Környezettudományi Konferencia [16th Carpathian Basin Conference for Environmental Sciences] : absztrakt kötet [abstract book]. Bp, Hungary : ELTE TTK (2021) 239 p. pp. 84-84. , 1 p.
   Conference paper (Chapter in Book) | Scientific

11.6 Research seminar - on, 2020

1. Urban Environmental Challenges and Management Facing Amman Growing City.

PROFESSIONAL CURRICULUM VITAE

Nour Abdeljawad, a Jordanian national born in Kuwait on June 13, 1977, is a dedicated scholar and management professional with a strong academic background. She completed her Bachelor's Degree in Medical Technology at *Amman University* in Jordan in 1999. Driven by her passion for environmental management, she pursued a Master's degree in Environmental Sciences at *Yarmouk University* in Irbid city, Jordan, successfully defending her thesis on the effects of upgrading at Khirbet Assamra wastewater treatment plant on water quality and the environment in May 2002.

Throughout her career, Nour has accumulated valuable professional experience. After her graduation from MSc. She worked as a project assistant at Social development associations for one year. From 2003 till now working at the *Greater Amman Municipality* Department of Business and Health Inspection since 2003, specializing in water and food chemistry, quality control, and internal auditing. In 2009, she assumed the role of Head of the Health Education and Research section, overseeing various projects and initiatives related to healthy city promotion and research.

In 2011 till 2014, Nour had the opportunity to teach as Environmental Health Science Instructor at Princess Nora University for three years, further enriching her academic and teaching experience. Her commitment to professional development led her back to her previous position at the *Greater Amman Municipality* in end of 2014, where she actively contributed to the implementation of the Healthy City initiative.

Since 2020, Nour has been a full-time Ph.D. candidate at the Doctoral School of Economic and Regional sciences, Faculty of Economic Sciences, at the *Hungarian University of Agriculture and Life Sciences*. Her research interests encompass various aspects of urban environmental management and sustainability, including environmental policy, sustainable urban development, solid waste management, public health, urban planning, and the integration of environmental considerations into organizational practices.

Throughout her career, Nour has accumulated valuable professional experience in the field of management. She has worked at the Greater Amman Municipality Department of Business and Health Inspection since 2003, where she has held various positions of increasing responsibility. She has specialized in business and health inspection, with a focus on ensuring compliance with environmental regulations and promoting sustainable practices.

Nour has made significant contributions to the field of management research. She has authored several scientific articles and contributed chapters to academic books, focusing on topics such as environmental management practices, sustainability strategies, and the integration of environmental considerations into organizational decision-making processes.

Her dedication to environmental management and her extensive research experience demonstrate her commitment to promoting sustainable practices and addressing environmental challenges from a management perspective. With her continued contributions to academia and her active involvement in professional networks, Nour aspires to make a lasting impact on urban environmental management and sustainability, both in Jordan and internationally.

DECLARATION

This dissertation is my original work and has not been presented for an academic award in any other institution of learning.

Signature… …… Date…2024/03/ 15

Name: Nour Salah Abdeljawad

This dissertation has been submitted to the Doctoral School of Management and Organizational Sciences for review with my approval as the University supervisor.

Signature……………………

Date……………………………

Name: Prof. Dr. Imre Nagy

Hungarian University of Agriculture and Life Sciences

APPENDIX

Appendix: Producer Accuracy

Table 30. Summary of Producer Accuracy

Producer's Accuracy			
Year	Built-up Area	Agriculture Land	Barren Land
1990	57.7%	87.7%	99.3%
1995	82.9%	85%	99.6%
1999	79.5%	69.2%	98.1%
2004	90.2%	92.9%	99.5%
2013	92.9%	86.8%	99.4%
2017	91.6%	77.8%	98.9%
2022	93.5%	76%	98.5%

Source: Authors Analysis, 2022

Table 31. Summary of User Accuracy

User's Accuracy			
Year	Built-up Area	Agriculture Land	Barren Land
1990	71.4%	95%	96.9%
1995	90.6%	85%	98.9%
1999	85.4%	75%	97%
2004	95.8%	92.9%	98.8%
2013	95.1%	92%	98.1%
2017	94%	93.3%	97.3%
2022	95.6%	82.6%	97.1%

Source: Authors Analysis, 2022