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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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1. RESEARCH BACKGROUND AND OBJECTIVES

Urbanisation, a prevalent global phenomenon that influences the development of societies and physical environments, has seen an unparalleled increase in the global urban populace in recent years. The aforementioned rise has resulted in noteworthy territorial, social, and environmental alterations. The urban population in 1950, which was 0.73 billion, had a significant surge to reach 4.38 billion by 2020. Projections indicate that this figure is expected to expand by 68% by the year 2050. Urbanisation refers to the process of shifting from rural to urban ways of life, which involves intricate territorial and socioeconomic changes that have a worldwide influence on natural and semi-natural places.

The global phenomenon of urbanisation has changed societies and physical surroundings like never before. The worldwide urban population boom has caused major territorial, social, and environmental changes. This event shaped our culture and environment. The shift from agricultural to urban living has shaped our housing and environmental interactions. In this context, this paper examines the complicated dynamics of urbanisation, concentrating on the various challenges caused by unregulated and unplanned metropolitan growth. Jordan's capital, Amman, illustrates global urbanisation and its issues.

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).

To understand urban sprawl, one must understand its economic, demographic, and governance drivers. Economic and demographic advances, political restrictions, and land scarcity propel urbanisation into undeveloped areas. Uncontrolled growth, or urban sprawl, affects various landscapes, affecting social, economic, and environmental factors. Urban sprawl affects many elements of life. Social implications include longer travel times, more traffic, and a community divide. Modification of water flow patterns, loss of vegetation, and increased greenhouse gas emissions illustrate the environmental effect, necessitating proactive solutions. Amman, in central

Jordan, illustrates the complex relationship between local dynamics and urbanization. The city's urban area has grown rapidly, like other big cities. Growth in Amman has caused pollution, carbon dioxide emissions, and natural balance upsets. Amman's urbanisation effects mirror worldwide concerns about unchecked urban growth's environmental impact. Amman shows the challenges of rapidly urbanising places and the necessity for concentrated research and organised action to manage the complex relationship between urban growth and ecological sustainability.

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). 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).

Several theoretical frameworks help explain and address urban sprawl in the urbanisation debate. To reduce urban sprawl, the Compact City Theory advocates high-density and mixed-use urban design. However, the Urban Metabolism Theory views cities as organisms and emphasises interdependent material exchanges for resource efficiency. The Triple Bottom Line Approach to Sustainability integrates environmental, economic, and social issues, aligning with the SDGs. This theoretical framework stresses the necessity to understand urbanisation holistically, including economic, social, and environmental factors. The Sustainable Development Goals (SDGs) were adopted internationally in 2015 to address urbanisation's complex and varied concerns. These goals promote development that prioritises economic growth, social fairness, and environmental sustainability. The Sustainable Development Goals (SDGs) emphasise the interconnection of environmental sustainability, economic development, and social welfare as a global goal for progress.

Technology is crucial to understanding and solving urban growth in the face of global issues and different theoretical perspectives. Remote sensing and GIS give invaluable understanding about urbanisation trends and processes. Remote sensing can detect environmental changes and estimate land suitability, making it essential for urban growth monitoring and regulation.

However, Geographic Information Systems (GIS) can analyse land use, ecological, and geological data. These tools are useful for urban sprawl because they reveal land use changes and their causes.

The present study investigates urban sprawl in Amman to contribute to the global urbanisation debate. This research investigates how much Amman's built-up area has grown due to uncontrolled and spontaneous urban growth. This requires a detailed evaluation of land use policies and measures to mitigate urban sprawl's environmental impacts in Amman. The research also seeks to understand how urbanisation and population density affect urban ecological sustainability. This research explores the relationship between urbanisation and agro-vegetation land loss, revealing the complex relationship between the two. This research examines the total impact of urban expansion on environmental sustainability in Amman, including the multiple socio-environmental effects of uncontrolled urban development. This research examines the relationship between land surface temperature (LST) and the normalised difference vegetation index (NDVI) and NDBI. This study seeks to understand the complex interactions between vegetation, built-up areas, and land surface temperature in Amman.

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

1.2 **Research objectives**

The research objectives are as follows:

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

1.3 Research Significance

Increasing urbanisation and associated environmental challenges exist in many parts of the world. 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.

2. METHODOLOGY

2.1 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 Normalised Difference Vegetation Index (NDVI), Normalised 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 as shown in Figure 2. 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.

2.2 Research framework

Amman City's urban land use policies, development, and environmental implications are studied using remote sensing and econometric analysis. Satellite imagery is remotely detected, pre-processed, and improved. This gives accurate land cover, urban growth, and development dispersion data. Econometric studies utilising Ordinary Least Squares (OLS) show relationships between urban land use rules, growth, and environmental consequences. Many fundamentals make up the theoretical framework. First, the research evaluates Amman City's urban land use policies' growth-limiting capabilities. It investigates how policies affect urban development. Second, remote sensing data tracks Amman's urban expansion and geography. Land cover changes and urban development dispersion show urban growth trends. The econometric study concludes with an OLS analysis of urban land use policy's implications for growth and the environment. To evaluate urban sprawl mitigation programmes, this study investigates policy elements, indicators, and environmental impacts. This theoretical framework investigates Amman City's urban land use policies, development, and environmental implications. Remote sensing and econometrics aid in policy evaluation and sustainable urban development.

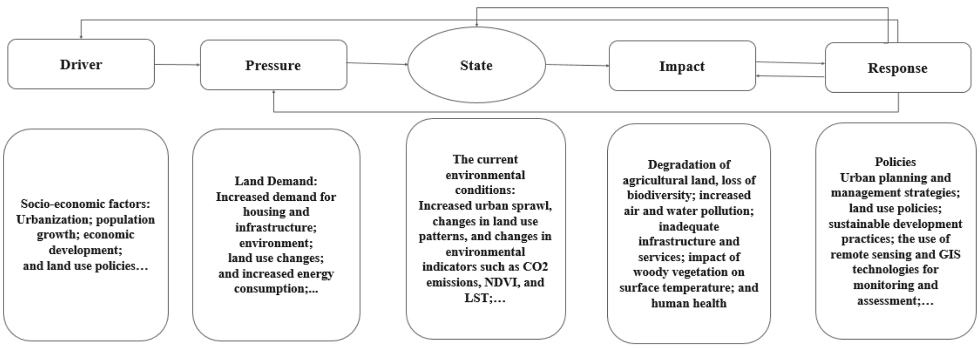


Figure 2. Conceptual Framework of DPSIR Applied to Amman City for Balancing Development and Sustainability: An Environmental Management Study of Urban Sprawl.

2.3 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 3, the population of these cities and their nearby environs 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 3. 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).

2.4 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.

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.

2.5 Data Analysis

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. 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 enabling the simultaneous consideration of multiple independent variables, OLS regression facilitated a more nuanced understanding of the factors influencing environmental pollution and energy consumption in Amman's urban setting. 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 examinations sought to determine the statistical significance, extent, and orientation of connections among these factors, offering insight into the complex interplay between urbanisation patterns and environmental results.

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 using Pearson's or Spearman's rank correlation coefficients, depending on the data distribution. 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.

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. 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. 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.

3. Results & Discussion

3.1 Amman Population-density and urban expansion challenges

Table 1. The 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 1 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 2. 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 2 from Al-Bilbisi in 2019 shows land division statistics for a region in 1987, 1997, 2007, and 2017 in square kilometres (Km^2). 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 km^2 in

1987 to 195.98 km^2 in 1997, 214.94 km^2 in 2007, and 237.86 km^2 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 km^2 in 1987, reduced to 562.58 km^2 in 1997, and further declined to 543.62 km^2 in 2007 and 520.70 km^2 in 2017. This shows urban sprawl or land use policy changes are reducing non-urban land.

Table 3. UEII interpretations of the 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 3, 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.

4.6. 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 4. Overall Accuracy and Kappa Coefficient.

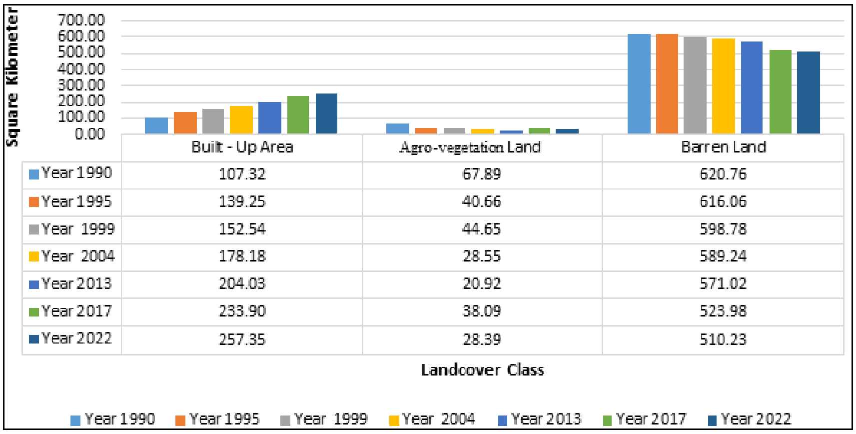
Year	Overall Accuracy	Kappa Accuracy
1990	95.6%	0.85
1995	97.8%	0.89
1999	95.0%	0.79
2004	98.2%	0.93
2013	97.0%	0.93
2017	96.4%	0.91
2022	96.0%	0.91

Source: Abdeljawad, Adedokun, & 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 4 above. Similarly, the Kappa coefficients for the four categorised LULC maps stand at 0.85 (1990), 0.89 (1995), 0.79 (1999), 0.93 (2004), 0.93 (2013), 0.91 (2017), and 0.91 (2022), respectively, demonstrating the substantial utility of the resulting LULC maps as detailed in Table 4 above. Therefore, in accordance with Okwuashi et al. (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.



	Built - Up Area	Agro-vegetation Land	Barren Land
Year 1990	107.32	67.89	620.76
Year 1995	139.25	40.66	616.06
Year 1999	152.54	44.65	598.78
Year 2004	178.18	28.55	589.24
Year 2013	204.03	20.92	571.02
Year 2017	233.90	38.09	523.98
Year 2022	257.35	28.39	510.23

Figure 4. Land cover class statistics of Amman between 1990-2022
Source: Abdeljawad, Adedokun, & Nagy, 2022

Figure 4 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 agro-vegetation land, such that the increase and/or decrease in total land area over the years is inconsistent.

Over the 32-year research period, urban land usage increased due to Amman's population expansion and development. Barren land decreases with time, whereas agro-vegetation 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. 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.

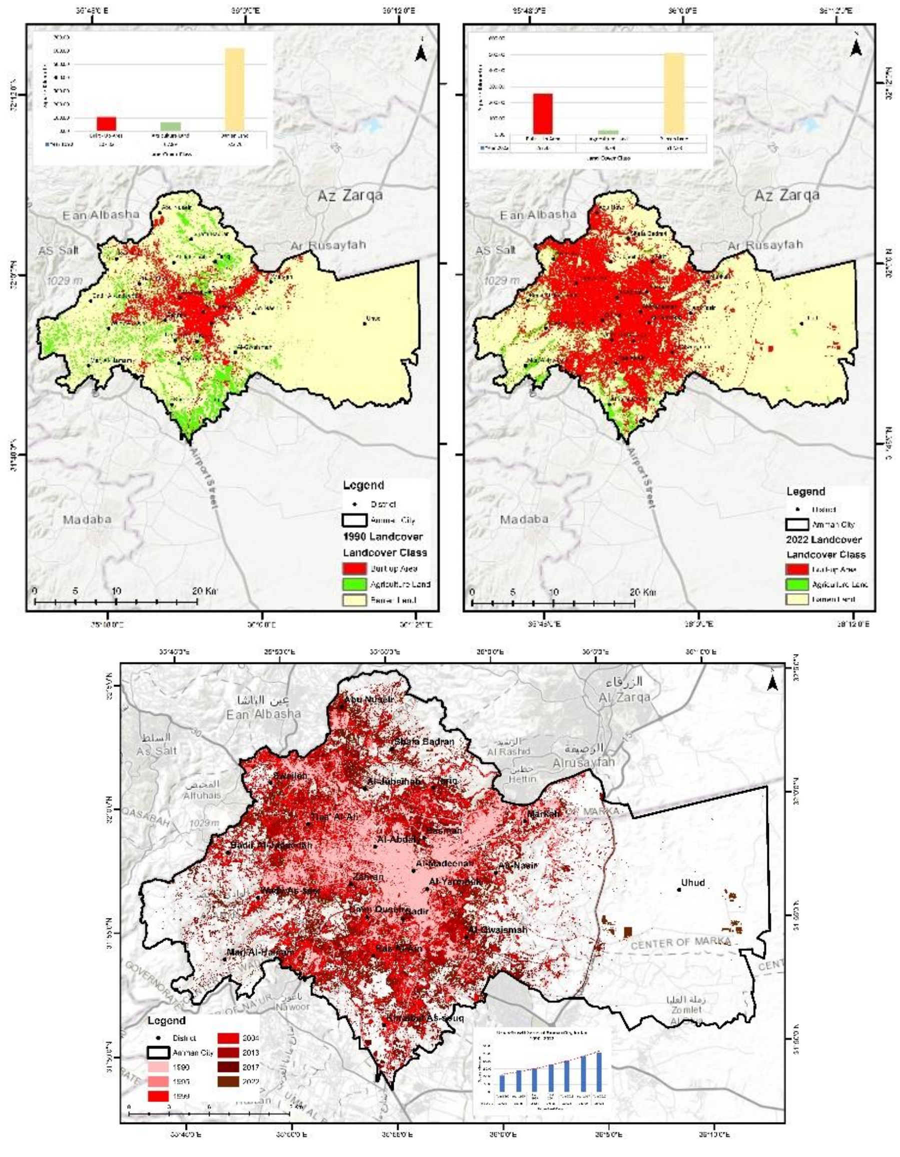


Figure 5. Land cover changes between 1990 and 2022

Source: Abdeljawad, Adedokun, & Nagy, 2023

Figure 5 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 6, 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).

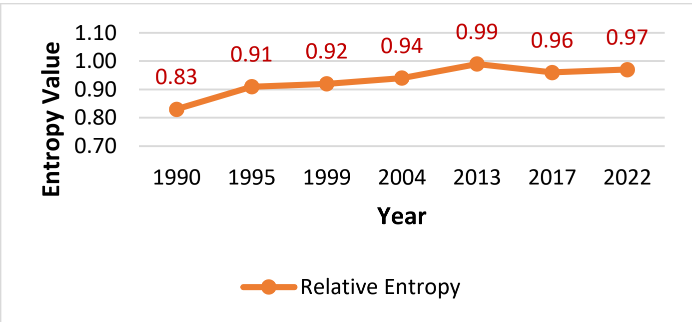


Figure 6. Graphical depiction of the relative entropy of Amman from 1990 to 2022. Source: Abdeljawad, Adedokun, & Nagy, 2022

3.2 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 5. The temperature range of each NDVI threshold was also extracted, as shown in Table 6. Figure 7 shows the spatial distribution of NDVI values within Amman.

Table 5. 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 6. 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 6 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 km2 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.

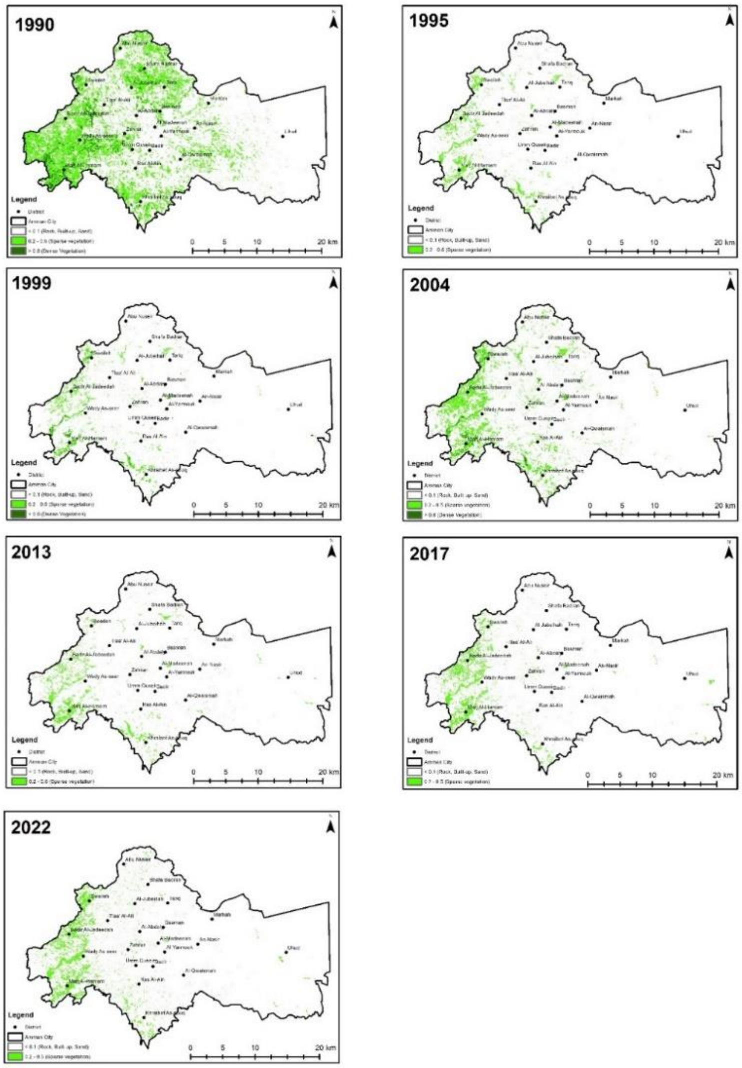


Figure 7. Spatial distribution of NDVI values within Amman.

Source: Author's GIS and RS Analysis, 2024

3.3 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 8, 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.

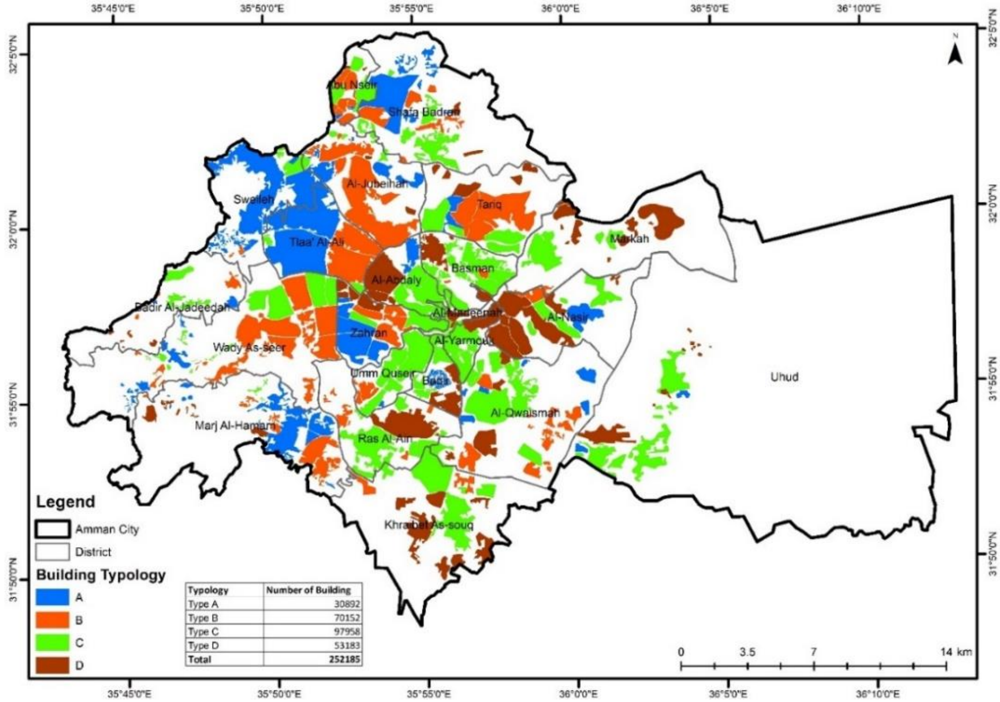


Figure 8. Spatial Distribution of Residential Building Typology in Amman City
Source: Author's GIS and RS Analysis, 2024

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.

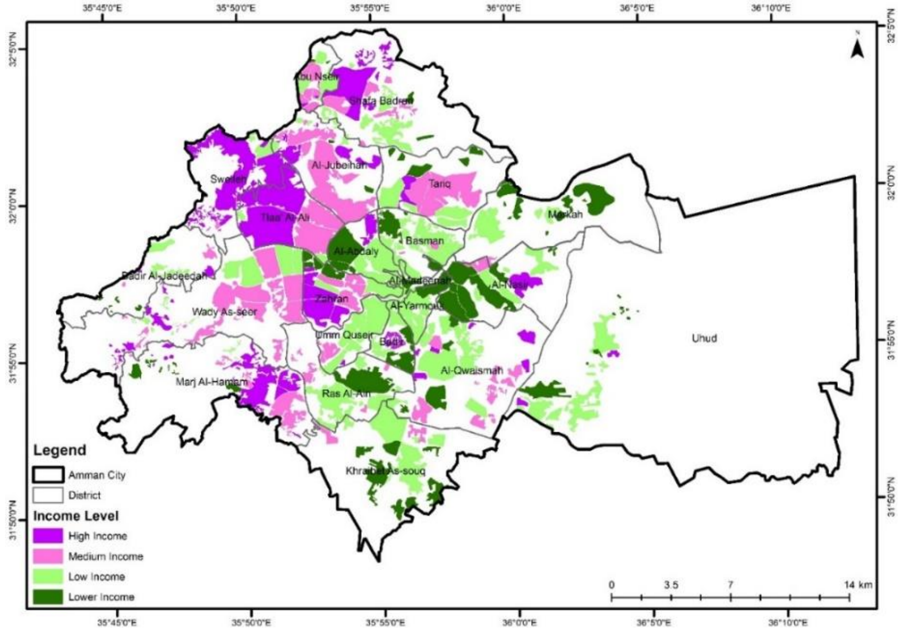


Figure 9. Spatial Distribution of Residential Building Typology in Amman City based on income level. Source: Author's GIS and RS Analysis (2024)

As shown in Figure 9, 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 11. Also, the average LST per building type and income level was calculated as shown in Table 7, respectively.

Table 7. Average LST of Building Type and Income Level

Value	Building Type	Income Level	Average LST (ºC)
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 7, 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. As shown in Figure 10, LST values decrease as household income increases.

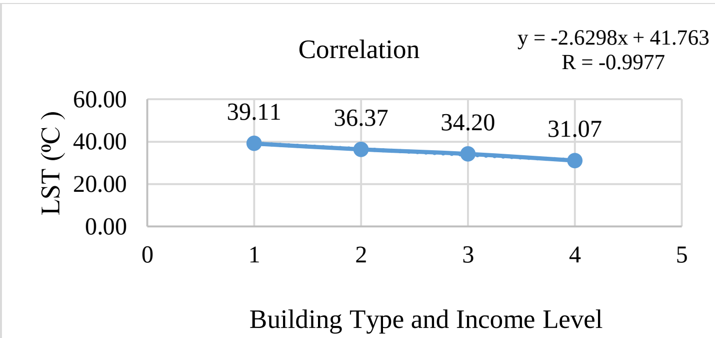


Figure 10. Correlation Between LST, Residential building type, and household income level
Source: Author's GIS and RS Analysis, 2024

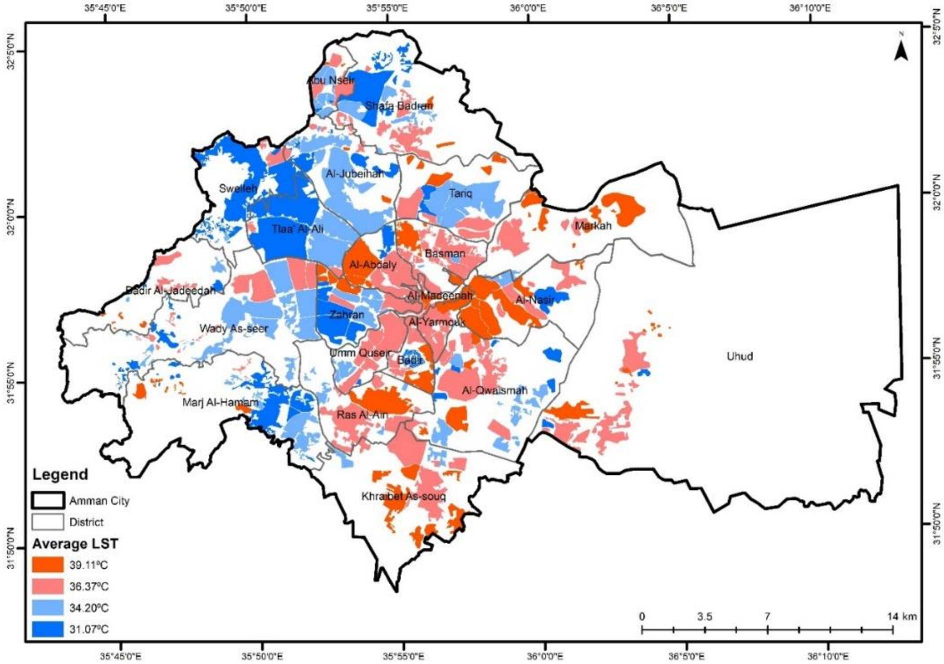


Figure 11. Average LST based on Residential building type, and household income level
Source: Author's GIS and RS Analysis , 2024

As shown in Figure 11, the land surface temperature tends to be lower in the northern and eastern 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.

3.4 Descriptive Statistics

Table 8. 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 (8) 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.

3.5 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 9. Regression Analysis: Impact of urban sprawl on built-up areas

Predictor	Coefficient	Std. Error	t-value	P-value	95% CI LL	95% CI UL
Amman Growth Rate	-0.2127	0.3451	-0.62	0.546	-0.9443	0.5189
Amman population Density	0.0265	0.0029	9.2	0	0.0204	0.0327
GDP per Capita	0.0105	0.0042	2.51	0.023	0.0016	0.0194
Industry including Construction	5.299	2.3604	2.24	0.039	0.2952	10.3029
Constant	51.4291	19.015	2.7	0.016	11.118	91.74

Model	Statistics
R-squared:	0.9756
Adjusted R Squared	0.9694
F-statistic	(4,16): 159.62***
Prob>F:	0
Root Mean Square Error (RMSE)	7.8014

Source: Author’s own Calculation

Table 9 shows the analysis's results. The predictor “Amman growth rate” had a coefficient of -0.2127 (SE = 0.3451), indicating a negative link with the outcome variable, although this relationship was not statistically significant (t = -0.62, p = 0.546). In contrast, "Amman population density km^2 " showed a significant positive correlation (β = 0.0265, SE = 0.0029, t = 9.20, p < 0.001), showing that population density increases the outcome variable. The "GDP per capita for Amman" showed a significant positive correlation with the outcome variable (β = 0.0105, SE = 0.0042, t = 2.51, p = 0.023), suggesting that greater GDP per capita is associated with higher outcomes. The variable "industry including construction" showed statistical significance (β = 5.2990, SE = 2.3604, t = 2.24, p = 0.039), showing better outcomes from increasing industrial and construction activity.

The constant term "_cons" had a coefficient of 51.4291 (SE = 19.0154) and was statistically significant (t = 2.70, p = 0.016), showing it explains the outcome variable. The whole model worked well, with a high R-squared value of 0.9756, suggesting that the predictors explained 97.56% of the outcome variable's variation. Model robustness is shown by the modified R-squared of 0.9694. The model's statistical significance is shown by its F-statistic of 159.62 and probability (Prob > F) of 0.0000. The average outcome variable prediction error was 7.8014. 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 10. Variance Inflation Factors (VIFs) 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 10 show that Variance Inflation Factors (VIF) are within acceptable ranges, indicating low multicollinearity (Mean VIF = 3.68).

3.6 Effects of Urban Sprawl on Environmental Sustainability

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

Model 1

Table 11. 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 11) 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 12. 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 12, the study examined the correlation between carbon dioxide (CO_2) 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 ($\beta = -0.00009$, $p = 0.200$). 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 13. 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 13, 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.

Model 2

Table 14. 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**	0.78	1
*p < 0.05, **p < 0.01									

Table (14) 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 15. 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 15 displays the results of a multiple linear regression study in which the response variable Diff_EnergyUse is compared to the predictors Diff_PopulationDensity and Diff_LnPopulation. 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_PopulationDensity and

Diff_LnPopulation 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_PopulationDensity 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 Diff_LnPopulation is predicted to result in a 1331.707-unit increase in Diff_EnergyUse. Natural logarithmic (Diff_LnPopulation) population 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 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 16. 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 as shown in Table 16. 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.

Model 3

Table 17. 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	-0.35**	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 17 shows that log_CO_2 emission 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 18. 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 18.

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 19. 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 19 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.

Discussion

The rapid urbanisation and expansion of Jordan's capital, Amman, is causing significant problems. Most of these challenges stem from population growth, immigration, and economic growth. The city's tremendous population increase over the last three decades has extended metropolitan districts, encroaching on agricultural territory. This has strained water resources and harmed the ecology. Due to population growth, infrastructure and services have been stressed, resulting in transient settlements and poor housing. This has exacerbated water, energy, transportation, and sanitation issues. This strain threatens the environment and lowers service quality. The ecological imbalances caused by urbanisation may deplete green spaces and agricultural land. These variables increase air pollution and urban heat islands. As rapid urban expansion encroaches on and destroys ancient sites and monuments, Amman's cultural heritage is threatened.

Remote sensing studies revealed Amman's urban development and its environmental impacts. Urbanisation patterns from 1990 to 2022 were assessed using change detection analysis, UEII, and Shannon entropy. The results showed considerable urban growth, with environmental repercussions such as less green space, higher surface temperatures, and indigenous ecosystem fragmentation. Population density is vital to urban development in Amman. Census data shows a sustained urbanization trend driven by economic growth and job opportunities. Clustering of people and businesses caused natural resource depletion, land usage, and infrastructural issues. The Urban Growth Intensity Index (UEII) highlights the continuing nature of urban growth and the need for sustainable urban planning to control development complexity.

The analysis of NDVI values and their impact on land surface temperatures in Amman over various years reveals significant cooling effects associated with different vegetation densities. Higher NDVI values (> 0.6) correspond to cooler temperatures in smaller land areas, while NDVI values between 0.2 and 0.5 indicate cooling effects over larger areas with varying temperature ranges due to dense and sparse vegetation cover. The presence of sparse vegetation, as indicated by lower NDVI values, leads to higher surface temperatures, aligning with previous research on urban climate spatial patterns. The study also reveals that regions in Amman with lower population density and higher household incomes, particularly in the western and northern parts, tend to have lower land surface temperatures (LST), highlighting the significance of green space coverage and housing quality. Conversely, areas characterised by higher population density and limited vegetation cover, such as the city centre and southern and eastern regions, experience higher LST values, underscoring the importance of integrating green infrastructure into urban planning strategies to mitigate heat effects and address temperature disparities.

Between 1990 and 2022, Amman's road infrastructure changed geographically, reflecting the city's changing needs and challenges. Major highways, peripheral roads, and improved connections have been built to accommodate the city's population and economic growth. However, the interaction between the road network and built-up zones has highlighted the need for additional road infrastructure to facilitate land development. Intelligent transportation systems and sustainable practices improve road network performance and reduce environmental impacts.

A detailed examination of Amman's complex dynamics requires a complete understanding of urbanisation, environmental sustainability, and demographic fluctuations. A comprehensive dataset from 1990 to 2021 was investigated to determine how urban growth affects densely populated areas, economic development, and industrial activities. The study found a link between urban growth and population, GDP, and industry. This shows how urbanisation affects numerous socioeconomic factors. The study also noted the environmental impacts of urban expansion, particularly CO_2 emissions. Regression models found significant links between urbanisation, energy use, and CO_2 emissions in Amman. The findings stressed the need for sustainable energy and efficiency in reducing energy use and emissions. Urban dynamics and the unanticipated negative link between population density and energy usage were discussed. This stressed the necessity for comprehensive urban planning. The findings were reliable due to the detailed assessment of time series features and regression model multicollinearity. The residuals' low autocorrelation shows that the models caught the connections without serial correlation concerns. The consequences of urban growth on developed areas and the environment in Amman were interconnected. Uncontrolled sprawl may be linked to the study's negative correlation between urban development and built-up regions. Urban growth correlated well with population density, GDP per capita, and industrial activity. The analysis shows that comprehensive land-use laws and policies that regulate urban growth and protect the environment are needed.

The 32-year research on land cover changes and urban expansion shows Amman's rapid geographical shift. Urban expansion follows global urbanisation trends in the north-west and south directions. However, land use planning, transportation, and environmental protection difficulties were evident. To restrict urban growth, careful planning, infrastructural development, and environmental protection were stressed. Sustainable urban design incorporates parks, green corridors, and eco-friendly landscaping to mitigate urbanisation's environmental impacts.

Overall, Amman's urbanisation and environmental sustainability issues are complex and interconnected. The research stressed the importance of sustainable urban planning to balance economic growth, environmental preservation, and social welfare, addressing population growth, economic progress, and urban sprawl's environmental impacts. A comprehensive approach to addressing urbanisation's multifaceted difficulties must include green infrastructure, intelligent transportation systems, and ecologically friendly activities. Politicians, urban planners, and the people must work together to adopt ecologically responsible and sustainable development policies as Amman expands. This method is essential for creating a city that succeeds economically, is environmentally resilient, and promotes social fairness.

4. CONCLUSION & RECOMMENDATIONS

4.1 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 used satellite data and indicators to define urban, rural, and deserted areas. The study shows how urbanisation has changed land cover distribution.

Table 20. 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 positively associated with high Normalised Difference Built-up Index (NDBI) values, indicating that areas with more built-up surfaces have higher temperatures.	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.

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 20 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.

4.2 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.

5. 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.

6. PUBLICATIONS AND OTHER SCIENTIFIC OUTPUT

6.1 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 amman 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., Viktoria, S., 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

6.2 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. https://doi.org/10.18178/ijesd.2023.14.2.1427
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.

6.3 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).

6.4 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.

6.5 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.

6.6 Research seminar - on, 2021

Urban Environmental Challenges and Management Facing Amman Growing City.