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Orginal Article

Assessing the impact of degraded urban green infrastructure on disaster risk resilience: A case study of Amman city centre, Jordan

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Abstract: Amman, the capital of Jordan, has been growing rapidly, particularly in its city centre. This has led to the spread of high-density buildings and a loss of green spaces. As a result, the city's ecosystem services have been significantly reduced, making it more vulnerable to climate-related disasters such as floods and heatwaves. This study examines the current state of green space and green infrastructure (GI) in downtown Amman, using historical and recent maps from 1918 to 2020 to understand how urban development has affected the environment. The findings show that the amount of green space per person is far below the World Health Organization's recommended level, highlighting the decline of natural areas and the lack of green infrastructure in urban planning. The study emphasises the importance of green infrastructure in enhancing cities' resilience to climate risks, while also noting that Amman has not done enough to implement it. This research provides valuable insights into how urban growth impacts green space and resilience in cities of the Global South, urging policymakers to prioritise green infrastructure to better manage disaster risks and promote sustainable urban development.

Keywords: Green Infrastructure (GI), Green Space (GS), urban resilience, climate change, urban sprawl, amman city centre, environmental degradation

1. Introduction

At the dawn of the 21st century, with half of the world's population living in cities, urban areas – with their high concentration of people, industries, and infrastructure – face the most severe impacts of climate change, natural and human-made disasters, overcrowded built environments, diminishing green spaces, waste production, and energy crises, making them more vulnerable to shocks and stresses [1]. This challenge necessitates that cities enhance the resilience of both natural and engineered infrastructures, as well as organisations and communities. However, urban resilience requires new approaches within urban planning policies to address the multidimensional challenges that cities are likely to face or are already facing [2-3].

Urban planners often use terms such as Green Infrastructure (GI), Green Space (GS), and Open Spaces (OS) interchangeably, but these terms represent different concepts within urban development. To ensure clarity, this study defines them as follows. Green Infrastructure (GI): A strategically planned network of natural and semi-natural features that deliver multiple ecosystem services, such as stormwater management, temperature regulation, and biodiversity enhancement. GI includes parks, green roofs, street trees, and water bodies. It is a holistic concept that integrates ecological and functional urban elements, providing a sustainable framework for addressing urban challenges. Green Space (GS): A subset of GI, GS refers specifically to areas with vegetation, such as parks, gardens, lawns, and urban forests. These spaces play an essential role in improving air quality, providing recreational opportunities, and promoting public health and well-being. Open Spaces (OS): Areas not covered by built infrastructure, which may include both natural and human-made sites such as plazas, parking lots, or vacant lots. These spaces do not necessarily provide ecological benefits but serve social, recreational, and aesthetic functions within urban environments [4-5]. For this study, Green Infrastructure (GI) is the central concept, as it encompasses both natural and built elements aimed at improving urban resilience [6]. Green Space (GS) will be treated as a component of GI, highlighting its role in providing environmental and social benefits, particularly in the context of disaster risk resilience (NDRR).

Urbanisation in the Global South, particularly in the Middle East, has been characterised by rapid, often unplanned growth, resulting in challenges related to infrastructure, environmental sustainability, and social equity [7]. Amman, the capital of Jordan, exemplifies these issues, as the city has experienced significant urban sprawl and population growth in a relatively short period. Growth has been driven by factors such as migration, refugee inflows, and regional conflicts, resulting in the concentration of urban populations in cities with limited natural resources [8]. In this context, Amman mirrors urbanisation patterns observed in other cities in the Middle East and the Global South, where urban infrastructure struggles to keep pace with the demands of expanding populations.

Recent studies have shown that cities in these regions often face unique challenges related to green infrastructure and green space. While green infrastructure is becoming an essential part of urban resilience strategies in many cities worldwide, its implementation in Middle Eastern cities such as Amman has been hindered by rapid urban sprawl, the degradation of natural ecosystems, and a lack of integrated planning strategies [9]. Specifically, the degradation of urban green spaces and the increasing urban heat island effect are significant challenges in cities like Amman, which are particularly vulnerable to climate change impacts such as flooding and extreme temperatures [10].

Furthermore, green infrastructure remains underutilised in many cities across the Global South, where the focus tends to be on traditional, engineered infrastructure. This paper therefore seeks to fill a critical gap in the literature by focusing on Amman, a city facing both rapid urbanisation and climate-related resilience challenges. The study investigates how green infrastructure can be integrated into urban planning in cities such as Amman, offering insights that could be applied to other, similar urban contexts in the Middle East and beyond.

This research aims to contribute to the growing body of work that explores the role of green infrastructure in enhancing urban resilience, particularly in Middle Eastern and Global

South cities. By addressing the relationship between green infrastructure, green space degradation, and climate resilience in Amman, the study offers practical recommendations for cities grappling with similar challenges, emphasising the importance of integrating green infrastructure into urban planning to mitigate the impacts of climate-related disasters.

The experience of Amman is highly relevant to the broader discourse on urban resilience and sustainability, especially within the context of cities in the Global South. Amman's rapid urbanisation, unplanned growth, and increasing vulnerability to climate-related challenges such as flooding, heatwaves, and air pollution are reflective of trends observed in many cities worldwide that are grappling with similar pressures. Like many cities in the Middle East and other regions experiencing rapid population growth, Amman faces the challenge of balancing urban development with environmental sustainability and resilience [8,10].

Furthermore, Amman's historical and socio-political context, including the influx of refugees and migrants, presents a unique case study of how urban infrastructure struggles to accommodate increasing populations, especially in regions with limited natural resources. The city's rapid population growth, driven by migration and the refugee crisis, mirrors urbanisation patterns seen in other parts of the Middle East and the Global South, where cities face challenges in providing adequate infrastructure and services [11-12]. Cities around the world, particularly those in conflict-prone areas or those experiencing high levels of internal and external migration, face comparable challenges. Amman's experience is therefore not only significant to Jordan but also to many cities in the Global South, where rapid urban sprawl, inadequate infrastructure, and climate resilience remain key issues [13].

By focusing on Amman, this study aims to provide insights into how green infrastructure can address these common urban challenges and improve resilience, offering lessons that are generalisable to other cities facing similar urbanisation pressures. The findings from this case study can inform global urban planning strategies and contribute to the development of more sustainable and resilient cities worldwide.

While substantial research has been conducted on urban green space and resilience, particularly in cities of the Global South, a critical gap remains in understanding the specific role of green infrastructure (GI) in enhancing disaster risk resilience (DRR) in rapidly urbanising cities such as Amman. Existing studies often focus on green infrastructure as a tool for climate adaptation or social welfare [14], but there is limited work exploring its direct connection to disaster risk management in the context of dense, rapidly growing urban environments.

This study fills this gap by examining how green infrastructure can mitigate climate-related risks such as flooding, heatwaves, and air pollution in Amman. The novelty of this research lies in its spatial analysis of green space degradation and its impact on disaster resilience, using historical and current maps to track urban development and changes in green infrastructure over time [15]. By focusing on Amman's specific urban challenges, the study provides insights that can inform urban planning strategies in similar cities worldwide, contributing to the integration of green infrastructure into disaster risk reduction efforts.

The purpose of this study is to assess the role of green infrastructure (GI) in enhancing natural disaster risk resilience (NDRR) in Amman's urban environment. The research objectives are: to evaluate the current state of green space (GS) and green infrastructure in Amman's city centre, assessing how it has changed over time; to investigate the relationship between green space degradation and increased vulnerability to climate-related risks, such as flooding, heatwaves, and air pollution in Amman; to explore how green infrastructure can be integrated into urban planning to mitigate natural disaster risks and enhance resilience in the context of rapid urbanisation in Amman; and finally, to provide recommendations for integrating green infrastructure into urban planning in Amman and similar cities, highlighting its potential to reduce climate-related risks and improve urban resilience.

Urbanists often focus on traditional infrastructure within the city context. However, this approach can overlook the negative impacts on both the built environment and its residents, as highlighted by Arefi and Nasser [16]. The search for more effective infrastructure that benefits both the natural and social systems of a city is ongoing, with green infrastructure (GI) emerging as a potential solution to replace traditional models. GI offers the ability to moderate climate change impacts while providing essential recreational and health benefits to urban populations [14,2]. However, despite the growing popularity of GI, cities continue to face substantial challenges in implementing large-scale GI planning [9].

One of the main obstacles is the degradation of natural systems due to rapid urban growth, referred to as urban sprawl and urban spurt. Urban sprawl denotes the gradual, unplanned expansion of urban areas, while urban spurt refers to sudden, rapid population growth, often in areas lacking the necessary infrastructure [17]. This degradation reduces the benefits provided by green space, increasing the vulnerability of urban areas to climate-related disturbances such as heatwaves, flooding, and air pollution [15].

The city of Amman, Jordan, exemplifies these issues. Urban growth in Amman has led to the concentration of built-up areas in the city centre, leaving limited space for natural environments. This has reduced the ecosystem services available to inhabitants and resulted in increased disturbances such as flooding, higher temperatures, and pollution in downtown Amman. These challenges form the core focus of this research in terms of natural disaster risk resilience (NDRR).

Amman was recently incorporated into the 100 Resilient Cities (100RC) initiative [1], which spurred interest in developing strategies to enhance the city's resilience. While recent studies have focused on the transformation of the built environment in Amman [13], this study focuses on the natural environment and how its degradation impacts the city's ability to cope with climate-related stresses. The research will analyse the greening patterns in the city centre of Amman and assess their role in disaster risk resilience.

To quantify these impacts, the study compares historical and current data on green spaces and urban development, focusing on changes from 1918 to 2020. Climatology data for Amman, including mean temperatures and precipitation levels over time, will also be integrated to understand the climate-related changes affecting urban resilience.

The statistical analysis will assess the ratio of green space relative to the demographics of the city centre, comparing it with the World Health Organization's (WHO) minimum standards for green space per capita [18]. This analysis will provide a clearer picture of the current status of green space in Amman and the challenges it faces in terms of both natural environment degradation and urban resilience. This study will propose key strategies for improving urban greening and reinstating green infrastructure (GI) to promote resilience against climate-related stressors, not only for Amman but also for other cities facing similar challenges.

2. Materials and methods

2.1. Methodological approach

This study employs a mixed-methods approach, combining both qualitative and quantitative research methods.

- Qualitative Research: The first part of the methodology relies on a case study approach and documentary research, collecting data from secondary sources such as archives, books, articles, and publications. A narrative descriptive approach is used to trace the historical development of Amman over time, employing a longitudinal strategy to observe changes in key urban variables across different periods.

- Quantitative Research: The second part uses statistical data and mapping analysis to assess changes in green space and urban development over time. This includes the analysis of four key variables: the city's boundary, buildings, the natural blue infrastructure (e.g., the Seil Amman water stream), and green space (GS), which has been fragmented by urban sprawl and rapid population growth from 1918 to 2020. Data on green space per capita are collected and compared with the World Health Organization's (WHO) minimum standards for green space.

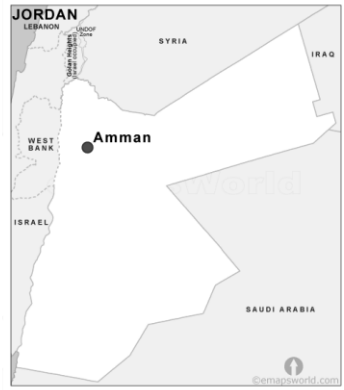
Spatial analysis methods are applied to map the main networks of built environments (buildings/road networks) and natural environments (blue/green networks) throughout the study period, providing an approximation of the factors being assessed in relation to area. The methodology uses a descriptive approach to evaluate the extent of green space degradation in Amman, following a series of historical periods: 1918, 1953, 1981, 2005, and 2020. Although this study takes a descriptive approach, the spatial analysis methods employed are appropriate for evaluating the longitudinal changes in green space and urban development.

The study uses two main techniques. Firstly, Mapping Analysis, where primary maps were created by the researcher using historical aerial photographs and satellite imagery. These maps illustrate the development of the city and its green space. The mapping process was carried out using AutoCAD software, with particular attention to green space, built-up areas, and natural infrastructure. Secondly, Data Analysis, where the maps produced through spatial analysis were used to calculate the ratio of green space relative to land area, demographics, and population density. This data helps to quantify the impact of urban sprawl on green space and the natural environment. These methods are suitable for the descriptive nature of this research, as they allow for a detailed comparison of urban growth patterns, green space loss, and their effect on disaster risk resilience in Amman.

2.2. Study area

The study focuses on downtown Amman and the historical and urban core of the city. Amman's city centre (also called Amman Valley) was originally defined by the valley between the surrounding mountains, which forms the heart of the urban area. The study evaluates the city's evolution across several periods: 1918, 1953, 1981, 2005, and 2020. Figure 1 shows the location of Jordan and its capital, Amman, while Figure 2 displays the boundaries of Amman as of 2020, highlighting the city centre.

The study's methodology involves assessing urban growth patterns with a focus on green spaces, open urban spaces, buildings, and street networks across different historical periods. The mapping analysis relies on primary maps, including historical aerial photographs and satellite imagery retrieved from Google Earth Pro and the Royal Geographic Center of Jordan. The study focuses on key elements: green spaces, the built environment, road networks, and blue infrastructure (e.g., the Seil Amman water stream). Due to data limitations, such as the lack of population data before the 1980s and limited available maps, estimated population counts for the early 1900s and 1950s are used. The analysis is based on maps developed using AutoCAD, integrating historical aerial photographs to create the most accurate possible representations. Figures 3 (a–d) illustrate the development of the study area over time across these periods, providing visual context for the study's analysis of urban sprawl and green space degradation.



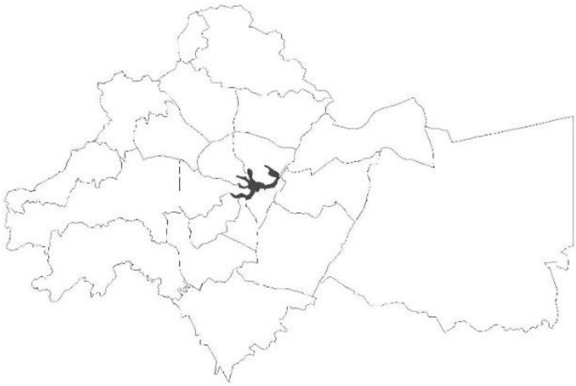


Fig. 1. Map showing the location of Jordan in relation to adjacent countries, indicating the capital city of Amman [19]

Fig. 2. Map showing the boundaries of the city of Amman in 2020, as adopted from GAM, with all districts. The boundary identified in black represents the original nucleus of the city, defined by the valley between the surrounding mountains, which formed the first inhabited area. This marks the study area of this research, known as Amman city centre, Amman Valley, or downtown Amman [20]. (Adapted by the author)

(a): Early 1900s (b): Mid 1900s (c): Late 1900s (d): Early 2000s

Fig. 3. Development of the study area from relatively close perspectives according to the suggested analysis timeline, retrieved from the following sources: (a) Australian War Memorial archives [21]; (b), (c) History of Jordan webpage [22]; (d) Author

Amman’s urban growth began in the late 19th century, with early settlements dating back to the Neolithic period and later to the Roman and Byzantine eras. It was part of the Decapolis and eventually became a key city under Ottoman rule. In the early 1900s, Amman was a small settlement with a population of just 2,000–3,000 people. By 1948, following the Palestinian–Israeli conflict, Amman experienced a population surge as it became a refuge for many displaced Palestinians. By 1967, the population had surpassed 500,000, and urban sprawl had spread beyond the original city centre, extending into the surrounding mountains [23].

Amman’s population continued to rise, particularly during the 1980s, with the arrival of Palestinians and Gulf War migrants, pushing the population beyond 1.5 million by the late 1980s. By the early 2000s, Amman had expanded to accommodate 2.8 million residents. In 2015, the population reached 4 million, partly due to the arrival of Syrian refugees. Figure 4 (a, b) shows the Roman Theatre in Amman in 1878 compared with its current state, illustrating the scale of urban transformation [24].

Fig. 4. (a) on the left shows the site of the Roman Theatre remains in the city centre of Amman in 1878, (b) on the right shows the same site in the present day (Courtesy of Amman Heritage Houses Foundation [25])

This study focuses on Amman's city centre, the most vulnerable part of the city due to overpopulation, unplanned growth, and underdeveloped infrastructure. The following challenges have exacerbated the environmental and social strains on the city:

1. Social Challenges: The city centre is home to a diverse population, including many refugees and migrant communities. Rapid urban growth, combined with the influx of migrants, has strained the city's ability to provide essential services such as education, healthcare, and transportation. This has led to increasing socio-economic disparities, with higher rental rates, job scarcity, and greater demand for water and utilities [1].
2. Environmental Challenges: The city's urban fabric is unplanned and overpopulated, with high traffic congestion contributing to pollution, urban heat island effects, and frequent flooding. Green spaces are minimal, exacerbating the challenges faced by residents and the environment. In addition, the drainage system is inadequate, leading to significant surface flooding during heavy rainfall [10]. Evidence of this is presented in Table 1.

Table 1. Observed Climatology of Precipitation (1901–2020), historical and current mean temperatures and precipitation levels in Amman (statistics retrieved from the Climate Change Knowledge Portal [26])

Year	1901	2020
Mean Temperature (Celsius)	17.64	20.01
Precipitation (mm)	97.33	109.88

3. Infrastructure Challenges: The city's grey infrastructure (e.g., roads and utilities) has struggled to cope with rapid growth. As Amman's population increased (see Fig. 5), urban sprawl stretched the city's infrastructure, leading to the deterioration of essential services such as water management and stormwater drainage. Amman's limited green infrastructure (GI), which could help mitigate flooding, remains insufficient.

Figure 5 illustrates the urban expansion timeline of Amman, showing the city's rapid growth from the early 1900s to the present and highlighting key moments of urban sprawl and population surges.

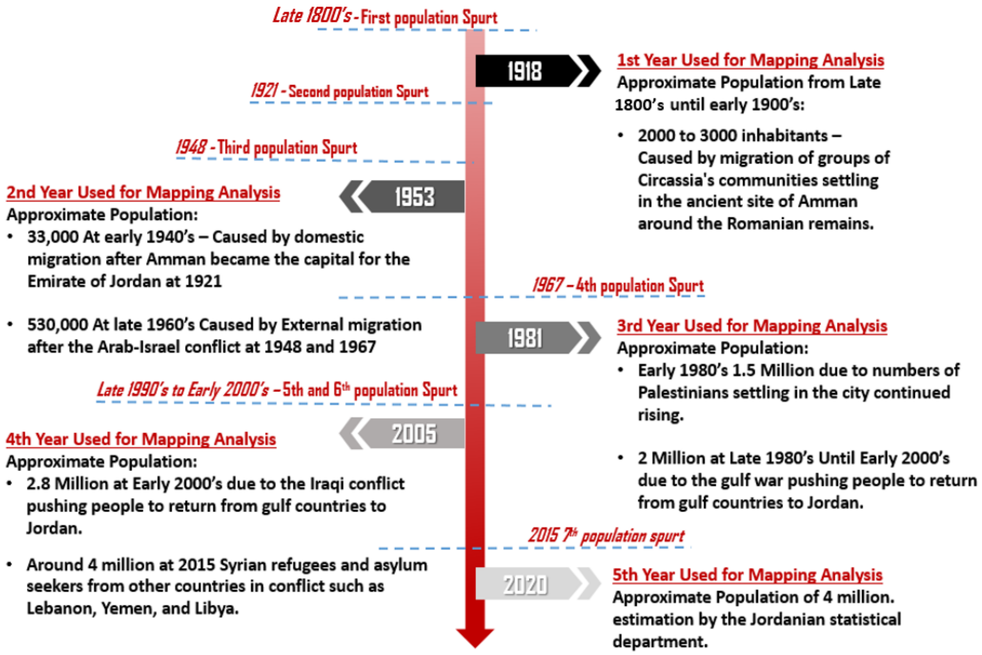


Fig. 5. Timeline summarising the history and recent urban expansion of Amman City. Author

To this end, Amman faces significant resilience challenges due to its rapid urban growth and climate vulnerabilities. These challenges are further exacerbated by the limited resources available to the city and its residents. As Amman continues to expand, it is under increasing pressure to meet the demands of its population while addressing climate impacts and resource scarcity.

The city must tackle both acute events (e.g., flooding, drought, heatwaves) and chronic stressors (e.g., migration, urban sprawl, traffic congestion) to strengthen urban resilience. Planning for green infrastructure (GI) could substantially enhance the city's ability to withstand these challenges by providing solutions for stormwater management, urban cooling, and improved public health [1].

3. Results

The following set of maps illustrates both urban spurt (population increase) and urban sprawl (unplanned expansion of the built environment), presenting an approximate as-built map of the urban fabric that includes buildings and the road network as the main elements of expansion. The remaining areas represent what is left of the natural environment, which is shown to have decreased dramatically between 1981 and 2005. The water stream known as Seil-Amman, which once flowed naturally through the downtown valley, ceased to exist after being channelled underground beneath the streets in the 1980s. The main purpose of these maps is to provide a visual representation of the degradation of the natural environment caused by urban development.

The maps highlight the unplanned nature of urban growth in the downtown area, which spread to the edges of the city boundaries and then extended from the valley into the surrounding mountains in similar patterns, leaving only a few fragmented and disconnected patches of open space (remnants of the natural environment and landscape). Figure 6 shows Amman's approximate as-built map from 1918, retrieved and developed by the researcher from an aerial photograph courtesy of the Royal Jordanian Geographic Information Center. The map depicts the first nucleus of settlement, where the earliest dwellings were constructed around the water stream following the settlers' arrival in the late 1800s, and how this nucleus developed into the early 1900s. The road network follows the natural topography surrounding the valley and extending to the mountains, shaped primarily by the movement of animals and carriages used by the first agricultural communities living in the valley and travelling up and down the hills.

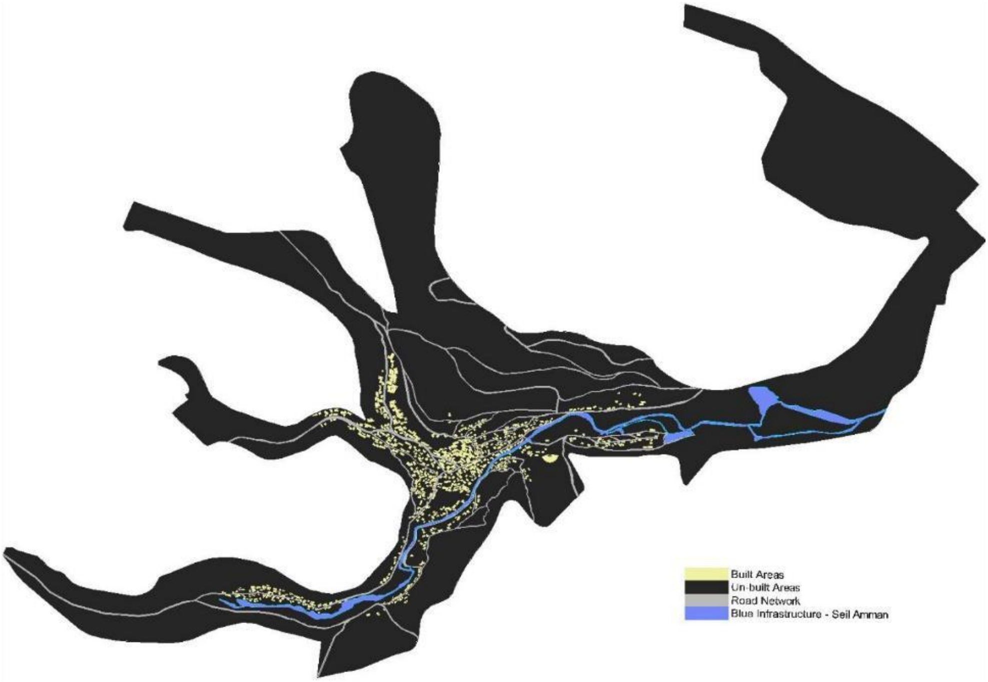


Fig. 6. 1918 map – Downtown Amman. Retrieved from aerial photographs in the archives of the Royal Jordanian Geographic Information System Center and developed by the author [27]

The overall area within the boundaries of downtown, as recently defined by Amman's Greater Municipality, is approximately 2.9 million square metres. Of this, only around 50,000 square metres consisted of built-up areas in 1918. This figure increased rapidly over the following three to four decades, reaching almost 275,000 square metres of built-up areas by 1953, as shown in Fig. 7.

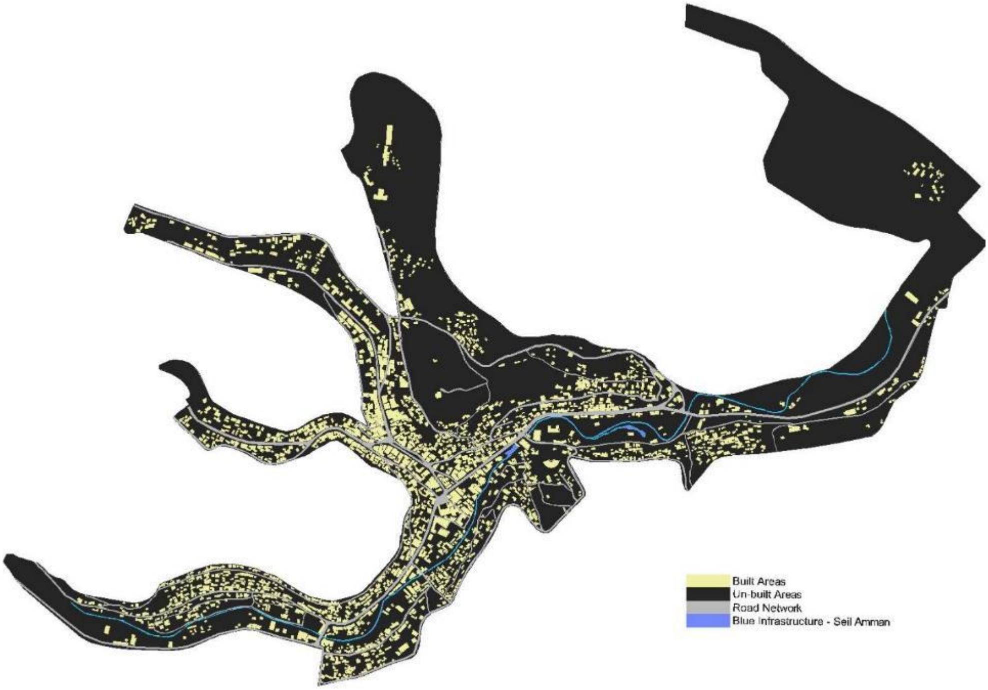


Fig. 7. 1953 map – Downtown Amman. Retrieved from aerial photographs in the archives of the Royal Jordanian Geographic Information System Center and developed by the author [27]

The road network now shows lines cutting through the topography, with urban stairs used for pedestrian movement as urban sprawl extended up the mountains. By this time, vehicles were also in use, which explains the development of what had previously been a very primitive network of roads running through and around the valley. A significant reduction in the water stream area is also evident, decreasing from almost 60,000 square metres to only 12,000.

The water stream ceased to exist in the years that followed due to an urban infrastructure project, during which the buildings of the Greater Amman Municipality were constructed over the remaining parts of the stream, and a street was built above the sealed channel, which continued to flow beneath. By 1981, the area of the natural water stream Seil Amman had decreased dramatically to just 7,390 square metres, as shown in Figs 8, 9, and 10.

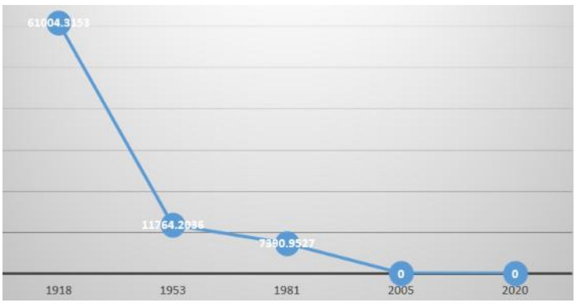


Fig. 8. Chart showing the sudden degradation and subsequent demolition of Seil Amman within the study area, with approximate square metre counts derived from the plans above. Author

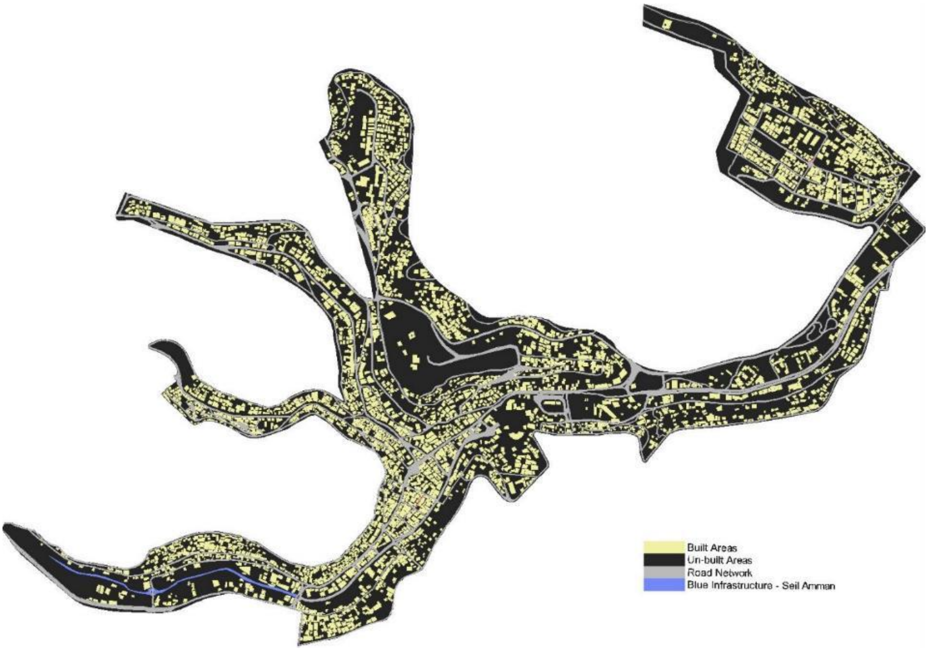


Fig. 9. 1981 map – Downtown Amman. Retrieved from aerial photographs in the archives of the Royal Jordanian Geographic Information System and developed by the author, December 2020 [27]

Fig. 10. (a) on the left shows Amman's first nucleus around the natural water stream known as Seil Amman and the Roman Theatre in 1918 [27], (b) on the right shows the same location in 2020. Note how the stream was incorporated into the urban infrastructure after the city reclaimed it in a development project in the early 1990s, converting it into part of the street network [28]

The expansion of the urban fabric and built-up areas, consisting of buildings and road networks, left very little of the original natural environment remaining, with only a few scattered and disconnected patches of urban open space visible in both 2005 and 2020. By the early 2000s, the area had become extremely overloaded, with no further potential for additional buildings. The unbuilt areas, defined in this study as potential spaces for developing greening strategies, amounted to almost 1.8 million square metres in both the 2005 and 2020 maps, compared with around 2.7 million in 1918.

The maps from 2005 and 2020 show similarities in the total built-up areas, which appear very dense and complex, as illustrated in Figs 11 and 12. It is worth noting that although the built-up areas were almost the same in 2005 and 2020, the population increased significantly. The chart in Fig. 13 provides an overall comparison of the full set of variables selected and shown on the previous maps.

Fig. 11. 2005 map – Downtown Amman. Retrieved from satellite imagery in Google Earth Pro, developed by the author [28]

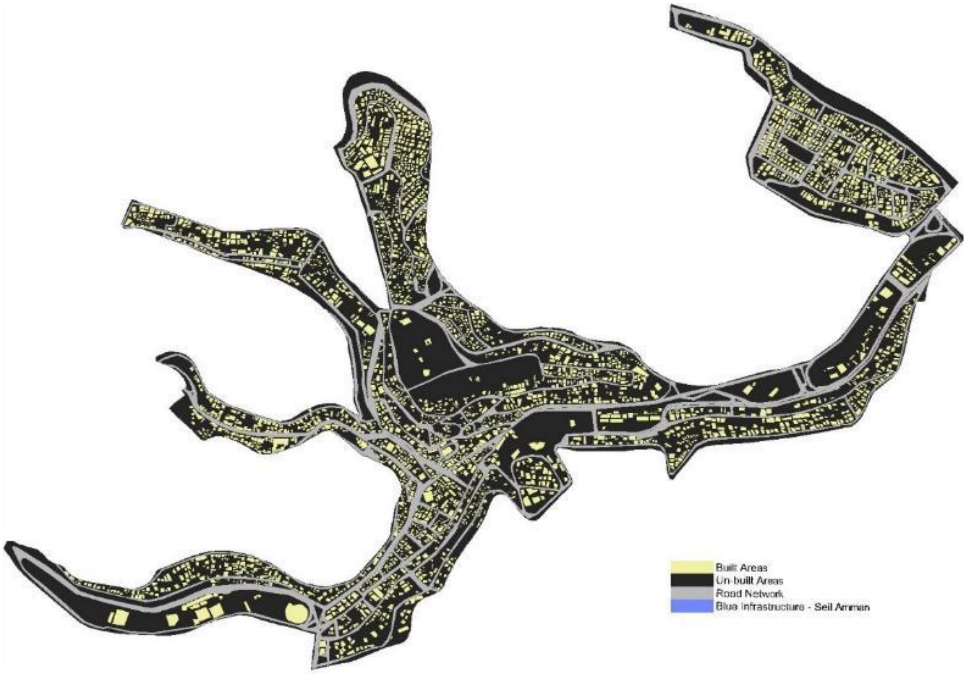


Fig. 12. 2020 map – Downtown Amman. Retrieved from satellite imagery in Google Earth Pro, developed by the author [28]

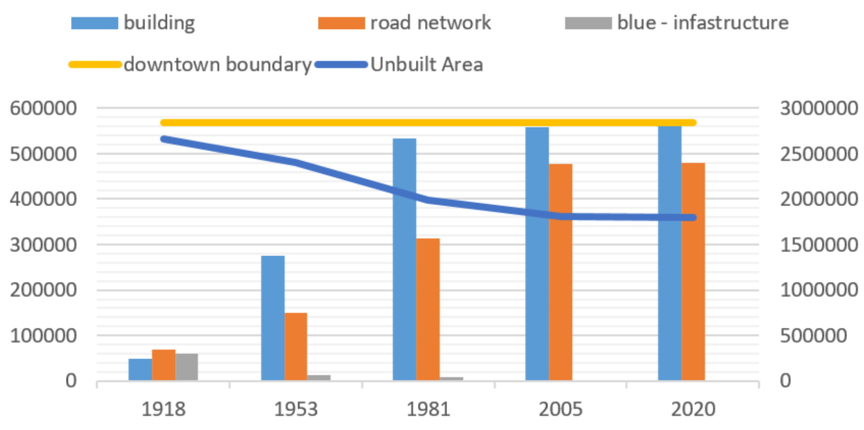


Fig. 13. Chart showing the comparative elements presented in the previous maps in relation to one another (Author)

The chart in Fig. 14 shows the overall increase in demographics over the years, aligned with the timeline set for this study. However, the exact figures for the specific years analysed prior to 2000 were not available for direct extraction. To address this limitation, the study estimated the numbers for the years before 2000 using the total population counts of districts surrounding and intersecting the study area, adjusting proportionally based on the districts known compared with those that were later merged and officially registered by the municipality.

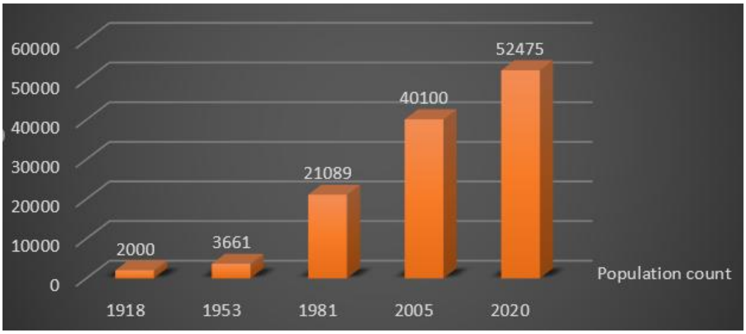


Fig. 14. Demographics of Amman's city centre between the early 1900s and 2020, shown in consecutive periods of years as close as possible to the timeline analysed in the previous maps (Author)

As for the area of green space in relation to demographics, the World Health Organization (WHO) recommends a minimum of 9 m² of green space per capita, with an ideal share of 50 m² per capita [18]. Other publications suggest that a healthy city should provide around 20 m² of green space per person. However, in Amman the figure is around 12 m² per person, according to the most recent publication of Amman's Green 2020 strategy [29]. While this number was calculated for the whole city, the situation in the city centre is worse due to severe overcrowding, with an estimated population of nearly 53,000 people in 2020, according to Amman's General Statistics Department [30]. This represents a dramatic increase from around 2,000–3,000 people inhabiting Amman's first nucleus in the study area a century earlier.

When compared with the area of unbuilt spaces within its boundaries, this equates to 34.34 m² of free space per person. However, according to the green space land use map published by GAM for the study area, only 168,500 m² of green space – shown in Fig. 15 – are actually planned and exist. This reduces the real ratio to just 3.2 m² per person, compared with the mapped 34.34 m², well below the healthy range of 20–50 m². The free spaces referred to in this research do not include buildings or road networks; rather, they comprise planned and defined green spaces, as well as neglected areas and the spaces between buildings, all of which represent potential sites for greening.

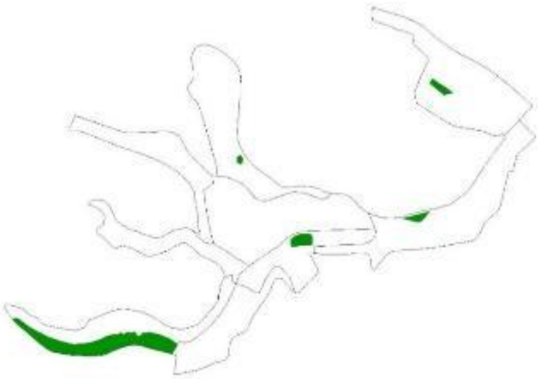


Fig. 15. Map of the study area as adopted from GAM, showing the planned and existing green spaces, with a total area of approximately 168,500 square metres. Developed by the author [20]

The Table 2 presents a summary of the results extracted from the author's primary mapping analysis.

Table 2. Summary of GS ratios from the mapping analysis of Amman city centre in 2020, compared with internationally recognised healthy and ideal minimum GS per capita ratios (Author)

Current GS ratio	Healthy ratio / Ideal Minimum	Available spaces – free of built-up area and road networks	Spaces for further development
3.2 m^2/person	20 to 50 m^2/person	34.34 m^2/person	31.14 m^2/person

4. Discussion

4.1. Interpretation of results

The results show that Amman's urban growth has significantly contributed to the degradation of green space, particularly in the city centre. Over the periods analysed (1918–2020), rapid urban sprawl and population growth transformed previously connected natural environments into fragmented patches of green space. This is consistent with findings from previous studies [5,9], which argue that unplanned urban expansion often results in the loss of critical green infrastructure in growing cities.

The statistical analysis revealed that Amman's green space per capita is well below the WHO's recommended minimum for urban areas. This trend highlights the growing resilience gap in Amman's ability to cope with climate-related stresses such as flooding and heatwaves. This mirrors trends in other cities in the Global South, where rapid urbanisation often outpaces the development of green infrastructure [14].

4.2. Comparison with prior studies

Similar studies [10,4], among others, emphasise the role of green infrastructure (GI) in enhancing urban resilience to climate change. The results of this study support this view, showing that integrating more green space into urban environments can significantly improve cities' capacity to manage environmental stressors, as discussed by Ahren (2011) and Pakzad (2019) [2,14].

The findings also align with Arefi and Nasser (2021) [16], who highlight how urban sprawl leads to a decline in green space availability and limits opportunities for natural cooling and stormwater management. The case of Amman underscores the urgent need for sustainable urban planning that integrates GI into the fabric of rapidly growing cities.

4.3. Implications for policy and planning

The results demonstrate a clear need for integrated urban planning policies that prioritise green infrastructure (GI) alongside traditional urban development. Given Amman's vulnerability to climate-related risks, there is a pressing need to develop policies that promote urban greening and reduce urban heat islands, as recommended by Tauhid [6]. Such policies could include the promotion of green roofs, street trees, and the preservation of blue infrastructure like the Seil Amman water stream.

The study highlights the importance of climate resilience strategies that account for environmental sustainability. Urban policies should integrate disaster risk resilience (DRR) strategies aimed at restoring natural systems, reducing impervious surfaces, and improving stormwater management. This is crucial for Amman and other cities in the Global South, where rapid growth and climate vulnerability intersect.

4.4. Limitations and further research

The study was limited by data availability, particularly for early historical periods before the advent of satellite imagery and detailed maps. Future research could employ remote sensing technologies or detailed field surveys to refine the analysis and extend the timeline of urban growth and green space degradation.

Further studies could also explore the socioeconomic impacts of green space loss, particularly how degraded urban environments affect the health and well-being of residents. Longitudinal studies in other cities experiencing similar growth patterns could further validate the findings and broaden the scope of this research.

5. Conclusions

This study explores the evolution of green space in downtown Amman and its implications for disaster risk resilience (NDRR), with particular focus on the city's urban sprawl and greening patterns from 1918 to 2020. Through a combination of historical mapping analysis, statistical data, and a review of urban growth trends, the research highlights the crucial role of green infrastructure (GI) in improving the resilience of urban areas, particularly in the face of climate-related stresses such as flooding, urban heat island effects, and pollution.

The findings show that Amman's urbanisation has led to significant green space loss due to unplanned growth and population surges, resulting in the fragmentation of green areas and the reduction of ecosystem services they provide. The study also identifies that green space per capita in Amman falls below the WHO's recommended minimum, a critical indicator of the city's vulnerability to climate change and its declining urban resilience. These findings are consistent with prior research on other cities experiencing similar challenges of rapid urbanisation and climate vulnerability [9,14].

By comparing Amman's green space dynamics with international standards, this study underscores the importance of integrating green infrastructure (GI) into urban planning, particularly in rapidly growing cities in the Global South. The analysis reveals that cities like Amman must adapt their planning strategies to incorporate both green and grey infrastructure in order to strengthen climate resilience and mitigate the adverse effects of urban sprawl.

However, several limitations of this study must be acknowledged. The lack of historical population data before the 1980s and the unavailability of comprehensive maps limited the accuracy of some analyses, particularly for earlier periods. Additionally, while this study focused on downtown Amman, further research could investigate how green space distribution and urban resilience manifest in peripheral urban areas or across other cities in Jordan and the Middle East. Future studies could also expand on socioeconomic factors, exploring how the loss of green space impacts social equity and public health in densely populated urban areas.

In terms of policy implications, this research emphasises the need for reforms that prioritise green infrastructure as part of a broader urban planning strategy. This includes initiatives such as urban greening, integrated stormwater management, and the preservation of blue infrastructure, all of which can mitigate the impacts of urban heat islands, reduce flooding, and improve residents' quality of life. Amman's current efforts towards resilience building under the framework of the 100 Resilient Cities initiative highlight growing recognition of these needs, but additional strategic interventions are required to address the climate-related challenges facing the city.

This study contributes to the literature by providing a historical perspective on urban growth and green space degradation in a rapidly urbanising city. By linking urbanisation trends with disaster risk resilience, it offers insights into how cities in the Global South can better prepare for the future. As urbanisation and climate change continue to accelerate, the findings underscore the urgency of prioritising green infrastructure in urban policy to create sustainable and resilient cities capable of adapting to future challenges.

6. Recommendations for further research

Further research should focus on examining the original local typologies of natural green infrastructure, such as trees, soil, and other vegetation types, to identify locally adapted solutions that would provide the most effective environmental benefits [31]. Additionally, a comprehensive assessment of air pollution, noise pollution, and urban temperatures should be prioritised. Integrating these factors into the analysis would provide a more holistic understanding of the study area's environmental challenges and support the development of tailored strategies to enhance urban resilience and promote a climate-resilient, well-functioning city. Water management [32], particularly through the incorporation of sustainable systems such as rainwater harvesting, permeable surfaces, and urban wetlands, should also be considered. These systems not only address water scarcity and flood risks but also contribute to the overall environmental quality and resilience of urban areas. By exploring these aspects, along with issues related to urban agriculture and other greening practices in cities [33], future studies could offer actionable insights for addressing multiple urban stressors in a cohesive and integrated manner.

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