A SUSTAINABLE MUNICIPAL GIS STUDY WITH URBAN DESIGN CRITERIA AND POLICY

KENTSEL TASARIM KRİTERLERİ VE POLİTİKASI İLE SÜRDÜRÜLEBİLİR BİR BELEDİYE CBS ÇALIŞMASI

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To my beloved wife and son, Selva and Ömer Ertuğrul BAŞEĞMEZ,

Infinite love and boundless joy, our journey together is my greatest treasure.

ABSTRACT

A SUSTAINABLE MUNICIPAL GIS STUDY WITH URBAN DESIGN CRITERIA AND POLICY

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The escalating population in urban areas underscores the critical importance of managing and planning cities effectively. Ensuring the sustainability of cities and creating livable spaces for people necessitates the planning or improvement of cities based on objective criteria and needs analyses. Since cities are communal spaces shared by all their inhabitants, planning according to urban design criteria is essential for enhancing the livability of cities. The consideration of numerous criteria in urban planning directly influences the decision-making processes of planners. The integration of Geographic Information System (GIS) and Multi-Criteria Decision Making (MCDM) methods into a Municipal GIS (MGIS) model presents an effective approach for addressing emerging issues and conducting planning based on objective criteria. This study aims to develop an efficient urban planning and management model, MGIS, by utilizing GIS and MCDM methods together, and employing the Game Theory method to minimize the differences among selected MCDM methods. Within this context, urban design criteria identified for this study have been analyzed using the Analytical Hierarchy Process (AHP), Entropy Weight Method (EWM), Game Theory, and Weighted Linear Combination (WLC) methods, and applied in the Konak district of Izmir. Furthermore, to enable local governments to manage their limited resources effectively, identify areas for investment, and rank these areas according to their importance, the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) method has been integrated into the MGIS model. The findings of the study reveal that the proportion of the most livable areas in the application site is 17.92% according to the AHP method, 19.86% according to the EWM method, and 18.67% according to Game Theory. The weighted ranking by AHP and Game Theory identified the primary investment area as I_12, whereas the EWM method indicated this area as I_9. In the equal-weighted ranking, I_9 was determined to be the most prioritized investment area across all methods.

Keywords: GIS, MGIS, MCDM Methods; Game Theory, Urban Design

ÖZET

KENTSEL TASARIM KRİTERLERİ VE POLİTİKASI İLE SÜRDÜRÜLEBİLİR BİR BELEDİYE CBS ÇALIŞMASI

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Haziran 2024, 135 sayfa

Kentlerin artan nüfusuyla birlikte ortaya çıkan sorunlar, kentlerin yönetilebilmesinin ve planlanabilmesinin önemini ortaya koymaktadır. Kentlerin sürdürülebilirliğinin sağlanması ve insanlara yaşanabilir alanların oluşturulabilmesi için kentlerin nesnel kriterlere ve ihtiyaç analizlerine göre planlanması ya da iyileştirilmesi hayati önem taşımaktadır. Şehirler, bu alanlarda yaşayan tüm insanların ortak paylaşım alanları olduğu için planlamada kent tasarım kriterlerine göre bir planlanmasının yapılması kentlerin yaşanabilirlik seviyelerinin arttırılması için gerekli bir unsurdur. Kentlerin planlanmasında birçok kriterin dikkate alınması plan yapıcıların karar süreçlerini doğrudan etkilemektedir. Geographic Information System (GIS) and Multi-Criteria Decision Making (MCDM) yöntemlerinin entegre edildiği Municipal GIS (MGIS) modelinin planlamalarda uygulanması, ortaya çıkan sorunların ortadan kaldırılması ve nesnel kriterlere dayalı planlama yapılması için etkili bir yöntem oluşturmaktadır. Bu çalışma GIS ile MCDM yöntemlerinin bir arada kullanıldığı ve seçilen MCDM yöntemleri arasındaki farkı azaltan Game Theory yöntemiyle etkin bir kent planlama ve yönetim modeli olan MGIS'in oluşturulmasını amaçlanmaktadır. Bu kapsamda belirlenen kent tasarım kriterleri Analytical Hierarchy Process (AHP), Entropy Weight Method (EWM), Game Theory, and Weighted Linear Combination (WLC) yöntemleriyle birlikte analiz edilerek İzmir'in Konak ilçesinde uygulanmıştır. Ayrıca yerel yönetimlerin sınırlı kaynaklarını etkin şekilde yönetebilmek, yatırım yapabilecek alanların tespitlerini sağlamak ve bu alanların önem derecelerine göre sıralamalarının yapılabilmesi için MGIS modeline entegre olan The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) yöntemi uygulanmıştır. Çalışma sonucunda; uygulama alanındaki en yaşanabilir alanlarının oranının AHP yöntemine göre %17,92, EWM yöntemine göre %19,86 ve Game Theory yöntemine göre ise %18,67 olduğu tespit edilmiştir. AHP ve Game Theory'nin ağırlıklı sıralamasında en öncelikli yatırım alanının I_12 yatırım alanı olduğu belirlenmiştir. EWM yönteminde ise bu alanın I_9 olduğu görülmüştür. Eşit ağırlıklı sıralamada ise I_9 yatırım alanının tüm yöntemlere göre en öncelikli yatırım alanı olduğu tespit edilmiştir.

Anahtar Kelimeler: GIS, MGIS, MCDM Yöntemleri; Game Theory, Kent Tasarımı

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Murat BAŞEĞMEZ

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS

Abberviations

AHP	Analytic Hierarchy Process
CI	Consistency Index
CR	Consistency Ratio
ESA	European Space Agency
ESRI	Environmental Systems Research Institute
EUKN	European Urban Knowledge Network
EWM	Entropy Weight Method
GIS	Geographical Information Systems
IDW	Inverse Distance Weighting
LST	Land Surface Temperature
MCDM	Multi-Criteria Decision Making
MGIS	Municipal Geographical Information System
MoEUaCC	Ministry of Environment, Urbanization and Climate Change
MoNE	Ministry of National Education
NASA	National Aeronautics and Space Administration
NIS	Negative Ideal Solution
PIS	Positive Ideal Solution
RI	Random Consistency Index
TOPSIS	Technique for Order Preference by Similarity to Ideal Solution
TUCBS	Türkiye National Geographic Information System
UN	United Nations
UTM	Universal Transverse Mercator
WLC	Weighted Linear Combination
WUC	World Urban Campaign

1. INTRODUCTION

Throughout history, cities have emerged as areas with sparse populations. However, with the onset of the Industrial Revolution, people became more interested in cities, leading to increased migration. The advancement of technology has further accelerated this inclination towards cities. The increasing demands of people for education, health, employment, and a comfortable life are significant factors contributing to the rise in urban populations. A United Nations report predicts that the global population will rise to 8.5 billion by 2030, 9.7 billion by 2050, and 10.4 billion by 2100 [1,2]. This anticipated increase suggests a potential rise in urban populations.

The growth of urban populations significantly increases the land area utilized by cities. It is estimated that developing countries' urban population will double and their cities' land area will triple from 2000 to 2030. This situation implies that existing problems will further escalate in the absence of necessary measures in health, education, economy, infrastructure planning, and urban planning [3].

Thus, the creation of sustainable urban models is of vital importance for solving the problems caused by rapid urbanization due to population growth worldwide. To this end, governments are defining their plans in government programs, strategic plans, and development plans. Moreover, international organizations such as the World Urban Campaign (WUC), European Urban Knowledge Network (EUKN), and the UN, along with universities, are conducting studies within their institutions to contribute to the development of healthy, livable, and sustainable cities [4–9]. An example of this can be seen with the UN. In response to the challenges of urbanization globally, the UN has produced various projects and published "The Sustainable Development Goals" report, which aims to make cities and human settlements inclusive, safe, resilient, and sustainable [10]. This document serves as a guide for addressing urban challenges.

In Türkiye, which is among the developing countries, the increase in population has led to a rise in the urban population. For instance, as of 2023, Türkiye's population is

85,372,377, with 93% living in urban areas and 7% in rural areas [11]. This situation underscores the need for well-planned urban development processes and the improvement of current conditions. For this reason, in Türkiye, the Ministry of Environment, Urbanization and Climate Change (MoEUaCC) and local governments are responsible for sustainable urban planning, enhancements and designs. Additionally, research centers established by universities also contribute to the formulation of public policies and studies on urban design [12–19]. The MoEUaCC aims to establish a system through its urban design guide that enhances people's quality of life, plans for the future of cities, preserves local cultures, and fosters the development of sustainable cities. Furthermore, the Twelfth Development Plan (2024-2028) published by the Presidency of the Republic of Türkiye calls for the creation of city models that preserve historical urban textures and for institutions to work towards livable cities and a sustainable environment. In this context, the goals include establishing a highly accessible transportation system and creating infrastructure resilient to disasters and climate change. Additionally, the other targeted objectives are forming a sustainable production and consumption mechanism, implementing long-term integrated urban planning and design, and effective disaster management [20].

The efforts to create livable cities in Türkiye and around the world encompass a wide range of criteria. Factors such as walkability, adaptability, connectivity, parking, transportation, traffic density, green spaces, and landscape play a significant role in the planning of cities where people can live in peace, happiness, and prosperity [21–27]. In addition to these planning criteria, urban planners and other stakeholders also consider the balanced and harmonious evaluation of livability, economy, social life, cultural environment, land use, and environmental development criteria [28–31].

These significant criteria in urban planning enhance the livability of these areas. However, many cities around the world are still grappling with numerous structural issues. Cities often face challenges such as urban sprawl, environmental degradation, poor living conditions, and serious accessibility problems [3]. The resolution of these issues faced by cities and the creation of sustainable urban environments depend on the management of information related to settlement areas. Spatial information, in particular, plays a fundamental role in urban planning and management practices. Most of the information used by planners is geographical in nature, in terms of utilizing topographic maps or being linked to a geographic location through a coordinate reference, a street address, or an administrative region [32]. However, the inability of large datasets related to settlement areas to interrelate leads to challenges in managing this information. GIS technology has emerged as a powerful toolset for managing and analyzing spatial data [33–37]. With these features, GIS is seen as a solution for the problems faced by local governments. In this regard, by leveraging the efficient structure of GIS, the MGIS approach put forth by UN-Habitat is emphasized as an important and effective factor in enhancing the management and organizational capacities of cities by local governments [37].

The worldwide impact of GIS on the formation and planning of sustainable and livable cities is demonstrated through its effective structure. GIS assists local administrators in identifying and developing city landscapes and green spaces, water management, designing walkable areas, creating energy sectors, and addressing issues such as transportation, climate change, and land use [5,38–44].

In Türkiye, MoEUaCC, which formulates urban and environmental policies, has developed the "Türkiye National Geographic Information System (TUCBS) Atlas" application. This application gathers data from all geographic data producers in Türkiye within this information system. With this system, the MoEUaCC ensures the implementation of policies in both urban and rural areas across the country based on objective criteria and an analysis of the current situation. Moreover, each municipality contributes to the management of areas within its jurisdiction by creating its own GIS portal [45–48].

The creation of livable cities has become a significant objective, both globally and in Türkiye. To accomplish this objective by utilizing cutting-edge technology, policymakers have begun to actively use GIS technologies. In this context, the MGIS approach has emerged as a crucial tool for managing cities, ensuring their sustainability, and facilitating effective planning. Thus, the objective of this study is to contribute to the development of urban design policies and the creation of livable spaces in the Konak district of Izmir by utilizing an MGIS model that combines urban design criteria with GIS and MCDM methodologies. To determine this, the weights of the criteria were first established using the MCDM methods, AHP, and EWM.

Thereupon, the equilibrium points were identified using the Game Theory method, and the weights of these points were determined. Subsequently, livable areas in the application site were revealed by applying the WLC method with GIS. The study thence compared the livable areas resulting from the separate applications of AHP, EWM, and Game Theory methods, and the results were examined. The TOPSIS method was also used to identify priority investment areas to increase livable spaces in the study area, and policy recommendations were presented. Additionally, the impact of urban design criteria on the study was evaluated by assessing the criteria within themselves.

2. URBAN DESIGN

Urban design is the art of creating spaces for people. This concept evaluates the functioning of spaces, community safety, and other issues. Through these evaluations, the planning processes for villages, towns, and cities are carried out by establishing connections between people and spaces, movement and urban form, and nature and the built environment [49].

Urban design is a crucial part of creating sustainable developments and conditions for a growing economic life, prudent use of natural resources, and social progress. A well-designed project can play an inclusive role in creating vibrant spaces with distinct characters. With all these features, urban design brings together many elements of planning to create beautiful places and diverse identities [50]. It also benefits from related fields such as planning and transportation policy, architectural design, development economics, landscape, and engineering. Good urban design is necessary to offer places that create social, environmental, and economic value sustainably. Ensuring the optimal design of these places is a priority for everyone involved in shaping and maintaining the built environment [51,52].

Urban design, which plays a key role in making cities more livable and in creating distinct characters within them, is not solely of interest to a particular profession or interest group. This was highlighted in 1998 when five professional institutes came together with other organizations to form the Urban Design Alliance, which aimed to find a common purpose across their disciplines. These professions (urban planners, landscape architects, surveyors, architects, and civil engineers) all play significant roles in creating strong impacts for better urban design [27,49,53].

In sustainable planning, it is first necessary to analyze the city's social, cultural, economic, environmental, and governance issues [54]. To help planners and local administrators create sustainable cities and livable environments, a quality analysis process paves the way for a planning process that has very few drawbacks in terms of land use, plans developed for the city’s growth, transportation, walkability, planning of green spaces, biodiversity, and conservation of natural areas. In this context, as indicated by the urban working group, the best way to encourage successful and sustainable renewal, conservation, and creation of new places is to consider urban design from the beginning of the planning and development process. Leaving urban design to the final stage can slow down the planning process, become a source of conflict among people, and negatively affect achieving the desired outcome in terms of city quality [49].

For successful urban design, a comprehensive understanding of the factors that directly contribute to the sustainability, livability, and character of cities is essential. This includes the identification of conditions that enable urban development and the implementation of appropriate decisions. The outcome of the design process and the types of spaces created are determined or influenced by several factors, including the following:

- A clear framework provided by development planners and consistently provided complementary guidance for the development of those plans,
- A response based on local desires,
- Facts about what is possible in terms of economic and market conditions,

An innovative and appropriate design approach by those designing the city’s development and managing the planning process [27,49].

Combining these top factors is vital for successful and quality planning. Moreover, applying specific criteria is necessary for successful streets, spaces, villages, towns, and cities. These criteria assist planners and decision-makers in understanding the conditions required to create quality spaces. These criteria are defined in Table 1 [49].

Table 1. Objectives of urban design

Criteria	Explanation
"Character"	"Promoting the character in the cityscape and landscape by responding to and reinforcing local patterns of development, landscape, and culture."
"Continuity and Enclosure"	"Encouraging the continuity of street frontages and the enclosure of spaces through development that clearly defines private and public areas."
"Quality of the Public Realm"	"To promote public spaces and routes that operate in an attractive, safe, orderly, and efficient manner for everyone in society, including individuals with disabilities and the elderly."
"Ease of Movement"	"By creating interconnected and easily navigable spaces, prioritizing people over traffic, and integrating land uses with transportation, to encourage accessibility and local permeability."
"Legibility"	"To promote legibility through development that provides recognizable routes, intersections, and landmarks to assist individuals in navigating their way."
"Adaptability"	"To promote adaptability through development that can respond to changing social, technological, and economic conditions."
"Diversity"	"Through a mixture of harmonious developments and uses working together to create livable places that respond to local needs, and to encourage diversity and choice."

Urban design, which utilizes a multitude of resources to create a livable city with a distinct identity, defines both human and physical geography as planning tools [51]. In this context, spaces within cities must primarily sustain human life. Buildings and open spaces should be designed to be comfortable and safe. Furthermore, in a good planning process, factors such as how secure people feel, the ease of moving around, accessibility of transport, proximity of shops and commercial centers, the presence of state or privately-owned facilities and schools, and the availability of safe places for children to play should be considered [27,55,56]. For such planning purposes, knowing the demands and identities of local communities is necessary. Urban planning tailored to the needs of communities will enhance the quality of living spaces and affect every aspect of life. In this thesis, the criteria in urban planning have been identified by considering these needs.

3. URBAN DESIGN PRACTICE

Urban design practices today are of significant interest, particularly to municipalities and local governments. These practices integrate factors such as habitat, design, environment, and landscape, serving as tools for planners to redesign urban areas. The initial step in this planning process involves determining how urban mapping technologies and digital strategies for cities can be used to assess the identified factors for sustainable design, and how to obtain the necessary urban data [57]. Although the first step of urban design applications has a complex structure, the interoperability of design principles with technological methods can provide significant data for many institutions [58–60]. In addition to this feature, urban design studies aim to offer better services to people, create safe and responsive spaces that can improve people's quality of life, and plan places where people can experience joy and happiness [49,61,62]. For instance, design studies have a direct relationship with social amenity areas, transportation and security, as well as a significant impact on comfort. Thus, the main goal of urban design studies is to analyze the components related to cities and environmental factors together (Table 2) [49]. This stage is crucial for assessing the current situation, identifying planning-related issues, conducting quality design work, and making necessary adjustments to the design.

Table 2. Urban design issues

"Places for People"	"Enrich Existing"	"Make Connections"	"Design for Change"
"Urban design should allow people to live in lovely, safe, vibrant, and attractive places."	"Urban design should be at a level that will allow the enrichment of the quality of life."	"The designer should plan the places in a way that is accessible and easily integrated with their surroundings. Physical accessibility by foot, bicycle, and public transport are also very important."	"Urban redesign works should be sufficiently flexible to meet the needs of future changes. At this point, lifestyle, demography, public spaces, infrastructure services, parking, and traffic management are also important issues."

Sustainable models must be developed to increase the livability levels of cities and to enhance their designs. Hence, the concept of sustainability holds great significance for our urban environments today. Map engineers, urban planners, and environmentalists frequently utilize this concept to create more livable cities [63]. In addition, sustainable urban design is a subject that merges numerous aspects such as economy, visual harmony, aesthetic appearance, and social life. It also has a strong association with aspects of social life, including transportation, traffic management, parking, engineering planning, infrastructure services, and landscaping. In other words, urban design involves creating vision and innovation within a certain area and utilizing the necessary skills and resources to complete this process. However, different fields and disciplines are represented by various data that need to be collected in a precise, reliable, and swift manner. Therefore, the data collection phase is crucial for implementing the envisioned project. Another key feature of urban design is its ability to establish connections between buildings, building facades, streets, sidewalks, open spaces, parks, and urban areas. Thus, it is important for the components related to urban structures, such as habitat, culture, streets, and pedestrian areas, as well as the landscape and environmental harmony of the urban area, to have good integration (Figure 1) [49].

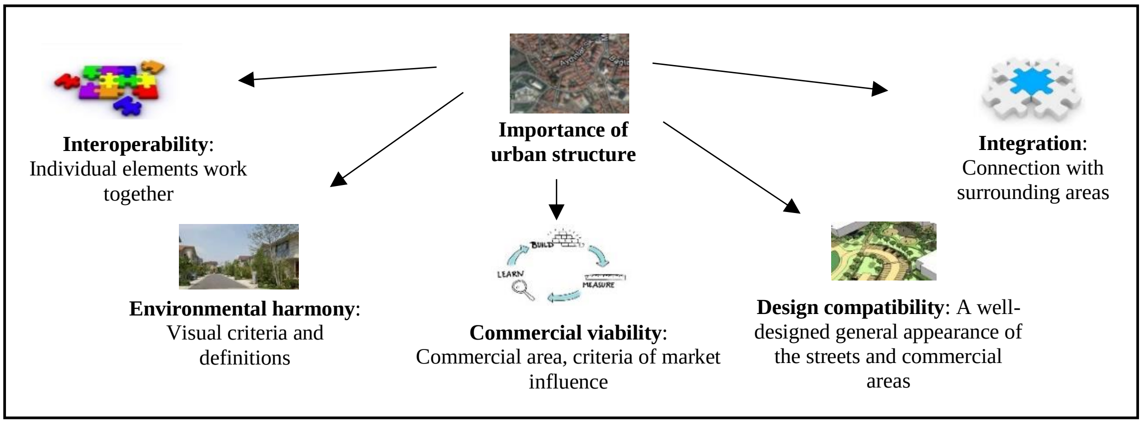

Figure 1. The importance of urban structure generally in meeting some criteria

Figure 1 demonstrates some criteria related to the development of urban structures. Local governments also play roles in the implementation and maintenance of projects, considering the criteria mentioned above. The integration of these criteria with policies laid out by policymakers to further improve people's lives can contribute to enhancing the livability of cities and the formation of sustainable urban models.

4. MATERIAL AND METHOD

This study develops a decision-making approach that evaluates multiple criteria for a location-based urban design, integrating GIS, MCDM methods, and Game Theory into urban design criteria for creating and assessing sustainable and livable urban models. In this context, the workflow of the study is constructed to ensure the repeatability of the proposed approach in different regions. The procedures carried out towards this objective are:

- Conducting a literature review,
- Identifying criteria and sub-criteria for the WLC method,
- Determining the weights of main criteria and sub-criteria using AHP and EWM methods,
- Balancing the weights of AHP and EWM with Game Theory to a point of Nash-equilibrium,
- Acquiring existing data and maps,
- Transferring the criteria into a GIS environment in a common coordinate system,
- Classifying layers according to the values of sub-criteria,
- Weighting the layers according to each MCDM method and Game Theory, and determining the most suitable areas with the WLC method,
- Identifying priority investment areas with the TOPSIS method,
- Determining the study area.

4.1. Study Area

A study area (Figure 2) has been determined for the application of specified urban design criteria to assess the livability of residential areas. The study was conducted in the Konak district of Izmir (38°.428673, 27°.134898). The Konak district is home to 7.45% of the population of Izmir. According to 2023 data, Konak is the 5th most populous district in Izmir with a population of 332,300 [64].

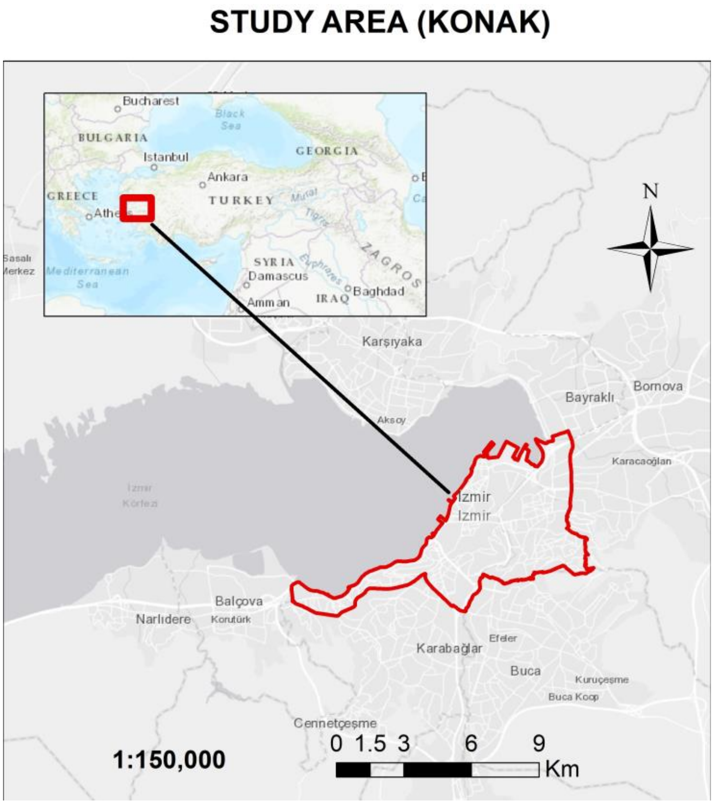

Figure 2. Study area

4.2. Data

In this study, national and international legislation and academic studies have been reviewed to determine the criteria for urban design and assess the livability of residential areas. Following the literature review, five main criteria and twenty-five sub-criteria were identified, which were then used in the analysis phase (Table 3-4). Some of these sub-criteria have been evaluated under more than one main criterion.

Table 3. Urban design criteria used in the application

No	Criteria
1	Walkability
2	Environment
3	Connectivity
4	Transportation
5	Climate Change

Table 4. Layers of data used in the application

Data Layer Name	Data Type	Date	Data Source	References
Green Spaces	Polygon	2023	Open Street Map	[65]
Subway Station	Point	2023	Open Street Map	[65]
Bus Station	Point	2023	Open Street Map	[65]
Railway Station	Point	2023	Open Street Map	[65]
Bike Sharing Station	Point	2023	Open Street Map	[65]
Parking	Point	2023	Open Street Map	[65]
Bank	Point	2023	Open Street Map	[65]
Religious Area	Point	2023	Open Street Map	[65]
Public Sector Area	Point	2023	Open Street Map	[65]
School	Polygon	2023	Ministry of National Education (MoNE)	[66]
Health Facility	Point	2023	Open Street Map	[65]
Culture, Art, and Entertainment Areas	Point	2023	Open Street Map	[65]
Museums and Historic Sites	Point	2023	Open Street Map	[65]

Table 4. Layers of data used in the application (continue)

Data Layer Name	Data Type	Date	Data Source	References
Sports Facility	Polygon	2023	Open Street Map	[65]
Road	Line	2022	Open Street Map	[65]
Subway	Line	2022	Open Street Map	[65]
Railway	Line	2022	Open Street Map	[65]
Cycling Path	Line	2023	Open Street Map	[65]
LST	Raster	2023	National Aeronautics and Space Administration (NASA)	[67]
Temperature	Raster	2023	European Space Agency (ESA)	[68]
Precipitation	Raster	2023	University of East Anglia	[69]
SO2	Raster	2023	ESA	[70]
CO	Raster	2023	ESA	[70]
Land Cover	Raster	2023	Copernicus and ESRI	[71,72]
Slope	Raster	2023	NASA	[73]
Landslide	Raster	2023	MoEUaCC	[74]

4.3. Database Design

ArcGIS 10.3 software was used to analyze and manage the data. Additionally, the Universal Transverse Mercator (UTM) projection Zone 35N coordinate system was chosen for the data. The necessary data were digitized in raster, point, line, and polygon formats (Figure 3). Furthermore, the scores for the sub-criteria are shown in Table 5.

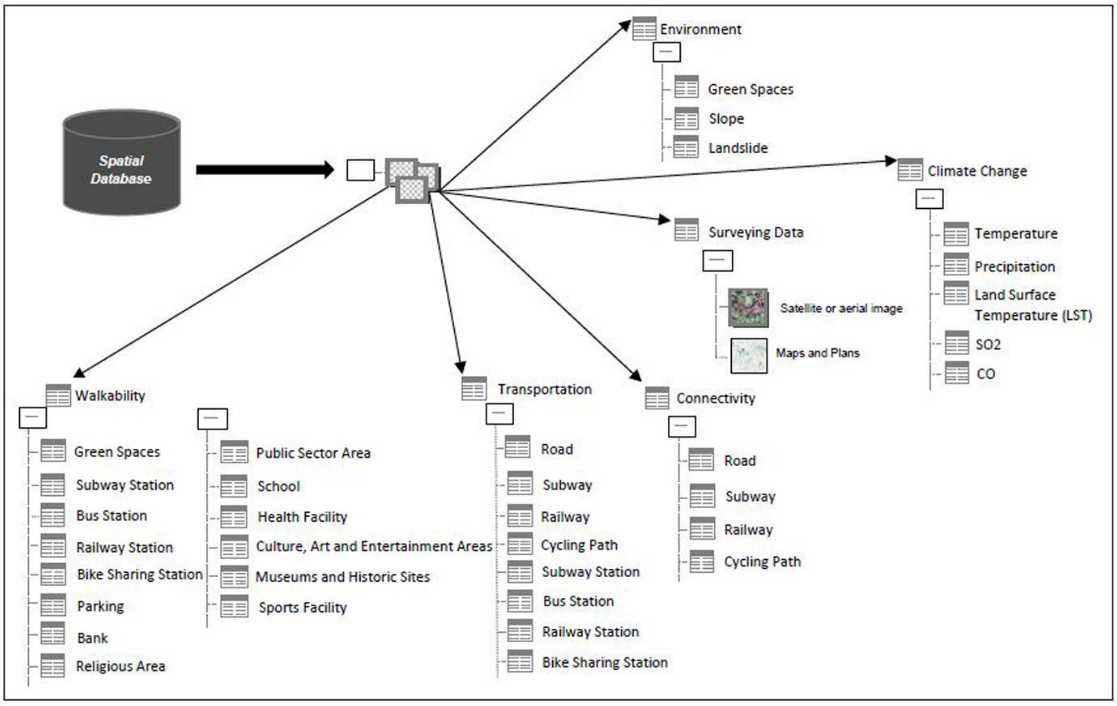

Figure 3. Database design

Table 5. Criteria and sub-criteria

Criteria	Sub-Criteria	Score
Green Spaces	<250 m	5
	250–500	4
	500–750	3
	750–1000	2
	1000<	1

Table 5. Criteria and sub-criteria (continue)

Criteria	Sub-Criteria	Score
Subway Station	<250 m	5
	250–500	4
	500–750	3
	750–1000	2
	1000<	1
Bus Station	<250 m	5
	250–500	4
	500–750	3
	750–1000	2
	1000<	1
Railway Station	<250 m	5
	250–500	4
	500–750	3
	750–1000	2
	1000<	1
Bike Sharing Station	<250 m	5
	250–500	4
	500–750	3
	750–1000	2
	1000<	1
Parking	<100 m	5
	100–200	4
	200–300	3
	300–400	2
	400<	1

Table 5. Criteria and sub-criteria (continue)

Criteria	Sub-Criteria	Score
Bank	<250 m	5
	250–500	4
	500–750	3
	750–1000	2
	1000<	1
Religious Area	<250 m	5
	250–500	4
	500–750	3
	750–1000	2
	1000<	1
Public Sector Area	<500 m	5
	500–1000	4
	1000–1500	3
	1500–2000	2
	2000<	1
School	<500 m	5
	500–1000	4
	1000–1500	3
	1500–2000	2
	2000<	1
Health Facility	<500 m	5
	500–1000	4
	1000–1500	3
	1500–2000	2
	2000<	1

Table 5. Criteria and sub-criteria (continue)

Criteria	Sub-Criteria	Score
Culture, Art, and Entertainment Areas	<500 m	5
	500–1000	4
	1000–1500	3
	1500–2000	2
	2000<	1
Museums and Historic Sites	<500 m	5
	500–1000	4
	1000–1500	3
	1500–2000	2
	2000<	1
Sports Facilities	<250 m	5
	250–500	4
	500–750	3
	750–1000	2
	1000<	1
Road	<50 m	5
	50–100	4
	100–150	3
	150–200	2
	200<	1
Subway	<250 m	5
	250–500	4
	500–750	3
	750–1000	2
	1000<	1

Table 5. Criteria and sub-criteria (continue)

Criteria	Sub-Criteria	Score
Railway	<250 m	5
	250–500	4
	500–750	3
	750–1000	2
	1000<	1
Cycling Path	<250 m	5
	250–500	4
	500–750	3
	750–1000	2
	1000<	1
Land Surface Temperature (LST)	<20 C	2
	20-30	3
	30<	1
Temperature	<17 C	1
	17-18	2
	18<	3
Precipitation	<604.7 mm	1
	604.7-755.748	0
SO2	<1.30 mol/m^2	5
	1.30–1.50	4
	1.50–1.70	3
	1.70–1.90	2
	1.90<	1

Table 5. Criteria and sub-criteria (continue)

Criteria	Sub-Criteria	Score
CO	<0.51 mol/m^2	3
	0.51–0.56	2
	0.56<	1
Slope	<5°	5
	5 – 10	4
	10–15	3
	15–20	2
	20<	1
Landslide	Risk-Free	5
	Low Risk	4
	Risky	3
	Very Risky	2
	Most Risky	1

4.4. Determination of Criteria

4.4.1. Walkability

Walkability holds a significant place in determining the quality of life in cities. It contributes to the formation of a human-centered environment by evaluating the amenities within cities under the scope of needs and values. Therefore, it has become one of the fundamental components of public policies designed for urban areas in recent years [75–80]. The goal of these emerging policies is to enhance the quality of life in cities.

The quality of life in cities largely depends on the accessibility of services, facilities, activities, and places. The ability to walk to central areas where people can socialize and use as venues for activities is an important aspect. Hence, the creation of a walkable environment is very important for a healthy and livable environmental design as it also reduces vehicle usage [53,81–83].

When examining studies on walkability, it is observed that the majority of global studies focus on higher planning criteria like street networks or accessibility to destinations, or on studies that reveal the relationship between walkability and the environment [84–87].

In Türkiye, some higher planning criteria have been established on this subject. For instance, the 12th Development Plan published by the Presidency of the Republic of Türkiye, in Article 2/91, emphasizes the need to promote public transportation and walking by reducing car dependency to lower the carbon footprint. Additionally, it is mentioned that the creation of mixed-use areas for walking or biking and planning decisions will be encouraged [20].

Fourteen sub-criteria have been identified in the study area (Figure 2) after considering the needs of people and the walkability studies conducted in Türkiye and around the world. The details of the identified sub-criteria are listed below (Table 6).

Table 6. The sub-criteria of walkability

Walkability Sub-Criteria	Definition	References
Green Spaces	These are areas created by parks, gardens, and forest areas where people meet their health and physical needs.	[88–92]
Subway Station	A type of station established for the subway.	[93–96]
Bus Station	The place where buses start and end their routes.	[97–100]
Railway Station	The location with one or more buildings and platforms where trains stop for people to board or alight.	[101–104]

Table 6. The sub-criteria of walkability (continue)

Walkability Sub-Criteria	Definition	References
Bike Sharing Station	Places where bicycles are parked.	[105–109]
Parking	Areas where vehicles are left for a certain period.	[53,110,111]
Bank	An institution or place where individuals and businesses can invest, borrow, and exchange foreign currency.	[112,113]
Religious Area	Places of worship related to religion.	[114,115]
Public Sector Area	Places owned or controlled by the government.	[116–118]
School	Places where children go to receive education.	[119–124]
Health Facility	Locations where people receive health services.	[125–128]
Culture, Art, and Entertainment Areas	Venues where people engage in social and cultural activities.	[129–132]
Museums and Historic Sites	Areas where historical artifacts or sites are located.	[133–135]
Sports Facility	Spaces where people perform or watch sports activities.	[136–138]

4.4.2. Transportation

Transportation is a fundamental element in the economic development of a society [139]. Therefore, the transportation networks of cities are a significant indicator of a country's level of development. The demand for vehicles, especially in developed and developing countries, directly demonstrates this. The growth of cities, population increase, improvement of living standards, and the expansion of business and industrial areas have led to an increasing demand for transportation services in urban areas [140]. Consequently, there is a strong relationship between the level of development of countries and their urban transportation networks. As a result of this strong relationship, transportation networks, which are a critical criterion of urban design, need to be well-planned in cities. For this planning to be possible, local governments need to establish transportation policies. Involving experts from various fields such as engineering, architecture, urban planning, landscaping, and transportation planning in these policy processes contributes to the creation of livable cities and healthy living spaces [141–143].

The effective management of policy processes created for transportation planning plays a significant role in developing sustainable urban models and solving the problems of cities. For this reason, various studies are conducted worldwide specifically for these processes. These studies generate applications and policy suggestions aimed at reducing traffic, air pollution, noise pollution, and traffic accidents [144–150].

In Türkiye, reducing the impact of the transportation factor on climate change holds an important place in the 12th Development Plan published by the Presidency of the Republic of Türkiye. Additionally, it aims to reduce traffic and transportation problems, increase pedestrian traffic, and further develop highways with electric vehicles, smart transportation systems, and autonomous systems compatible with new smart roads [20].

The increase in studies on the transportation problems of cities in recent years and the desire to develop sustainable urban models highlight the effectiveness of decision-making processes. Considering the impact of making decision processes based on objective and scientific values in policy development processes, it has enabled both central and local governments to actively use GIS technologies in the fields of transportation and urban planning [123,144,148,149,151–153]. The utilization of these systems in directing investments to the correct locations contributes to improving the quality and livability of cities.

Information on the sub-criteria related to transportation from studies conducted worldwide and in Türkiye is presented in Table 7.

Table 7. The sub-criteria of transportation

Transportation Sub-Criteria	Definition	References
Road	Areas formed by parks, gardens, and forested areas that serve people’s health and physical needs.	[88–92]
Subway	One of the most important and busiest points of a city's transportation network.	[93–96]
Railway	The rail system on which trains travel.	[154–156]
Cycling Path	A designated path for cycling.	[157–159]
Subway Station	A type of station established for the subway.	[160–162]
Bus Station	The place where bus services start and end.	[163–165]
Railway Station	Locations with one or more buildings and platforms where trains stop for people to board or alight.	[166–168]
Bike Sharing Station	Places where bicycles are parked.	[169–172]

4.4.3. Connectivity

Emerging as a fundamental concept in urban design, connectivity refers to the relationship between urban transportation networks, infrastructure, and social spaces within cities [173,174]. Additionally, connectivity is identified as a crucial element that not only links various transportation routes within urban areas but also integrates the social and physical fabric of cities [53]. Therefore, connectivity is not merely a concept describing the relationship between roads or transportation lines; it also stands out as an integral part of a sustainable urban model that meets people's needs and creates livable cities. With these characteristics, connectivity significantly aids policymakers by making cities greener, more accessible, and more resilient during the planning processes [175].

Understanding how and in what ways people move is vitally important for urban policymakers and planners during the planning processes of cities. Planning in newly designed neighborhoods and residential areas particularly focuses on human movement. During this planning process, a city's central point is determined, and planning is developed around it. Additionally, land uses and types of buildings within walking distance are defined to form the content of the planning process. This process concludes with the design of narrow or wide roads, the planning of pedestrian-friendly streets, and the establishment of a high level of connectivity to unify all planning elements [53,174,176–178] .

In all planning studies, especially the general layout of connection roads and street networks is one of the most fundamental elements of urban planning. Academic research on street networks around the world demonstrates that high levels of road connectivity are associated with reduced travel times for pedestrians, indicating good planning. Furthermore, evidence suggests that such planning will shape land use patterns and densities over time [174,179–181].

Studies conducted in Türkiye highlight the significant role of connectivity in various aspects such as children's transportation and walking behaviors, the impact of residential area planning on crime rates and security perception, identifying the quality of transportation networks, improving green infrastructure, and urban planning topics [182–184].

All these planning processes not only contribute to the sustainable structure of cities but also have various effects on people. Studies have shown that well-organized streets and neighborhoods significantly impact people's quality of life and health [80,185–189].

Studies on connectivity in the world and Türkiye have been reviewed, and the determined sub-criteria are presented in Table 8.

Table 8. The sub-criteria of connectivity

Transportation Sub-Criteria	Definition	References
Road	Areas formed by parks, gardens, and forested areas that serve people's health and physical needs.	[190–192]
Subway	One of the most important and busiest points of a city's transportation network.	[193–196]
Railway	The rail system on which trains travel.	[155,197–200]
Cycling Path	A designated path for cycling.	[201–204]

4.4.4. Climate Change

Climate change is increasingly emerging as a global issue causing serious environmental, economic, and social impacts worldwide. The primary cause of climate change, seen as one of the most significant problems in recent years, is the increase in greenhouse gases released into the atmosphere through the burning of fossil fuels and deforestation. These gases prevent the reflection of sunlight, causing it to remain on the earth's surface, which leads to an increase in global temperatures worldwide [205–207]. Furthermore, climate change particularly results in negative effects in various areas such as weather events, rising sea levels, loss of biodiversity, environmental pollution, fires, reduction in land use, and agriculture [208–212]. Due to these effects, climate change creates serious impacts not only on the natural environment but also on cities, urban planning, and the livability of cities [213–217].

Cities are areas where people live densely. According to a study by World Urbanization Prospects in 2019, the population living in urban areas is projected to increase by 68% worldwide by 2050. The projected urban population growth in less developed regions is expected to reach two billion by 2050, with a 90% increase in Asia and Africa [218]. This anticipated population increase is expected to lead to significant changes in current land use and land cover in urban areas. The main reasons for these changes are assessed to be rapid and unplanned urbanization, lack of green spaces, and environmental degradation [219–221].

The increasing impact of climate change on the environment, cities, and people necessitates the adoption of global measures to solve emerging problems. In this context, immediate actions to reduce greenhouse gas emissions and a swift systemic transformation to enable communities to adapt to the effects of climate change have been brought to the forefront [222]. Although there may be some obstacles to cities taking the lead in transforming quickly to combat climate change, city administrations' close connections with the populace and access to local knowledge provide a significant advantage in reaching climate goals [223,224]. Moreover, the ability of local and central governments to enact laws and regulations, effective communication, and purchasing authority to reduce carbon emissions in cities and work towards climate adaptation contributes significantly to the systemic transformation. Thus, it is projected that by 2050, the effects of climate change on nearly 80% of the world's population that lives in cities will be mitigated if the measures adopted in cities are regularly implemented and controlled [225].

It is vital to address the issues posed by climate change in cities through planning, urban policy formulation, management, and development of sustainable urban models. Various studies are conducted worldwide focusing on these processes. These studies aim to reduce land surface temperatures, prevent the spread of urban heat islands in cities, reduce air pollution, take measures against flooding events, and create urban designs that ensure thermal comfort for people [226–230].

In Türkiye, the highest-level program in this fight is the 12th Development Plan. This plan sets goals in many areas such as achieving a green transformation against climate change, increasing the resilience of cities against natural resource-based disasters, reducing emission levels, planning livable environments, sustainable transportation, agricultural production, energy efficiency, and forest conservation [20]. Furthermore, academic studies are conducted in Türkiye on issues such as tourism, agriculture, drought, desertification, and sustainable development due to climate change. These studies lead to policy recommendations that help Türkiye mitigate the effects of climate change [231–234].

Studies on climate change conducted worldwide and in Türkiye have been reviewed, and the determined sub-criteria are shown in Table 9.

Table 9. The sub-criteria of climate change

Transportation Sub-Criteria	Definition	References
Temperature	The measured amount of temperature at a location.	[235–237]
Precipitation	Especially, water falling from clouds to the ground in the form of rain or snow.	[238–240]
Land Surface Temperature (LST)	A measure of the land being hot enough to touch.	[241–243]
SO2	A sharp-smelling, colorless, non-flammable, poisonous gas.	[244,245]
CO	A colorless, odorless, and tasteless poisonous gas.	[246,247]

4.4.5. Environment

As a result of the global population growth, migration to cities has increased to meet people’s health, education, and economic needs. This situation has led to more than 60%

of people living in urban areas [248]. As a result of these developments, cities are facing serious environmental issues such as air pollution, heat islands, and habitat loss, alongside various health problems [249–252]. Therefore, planning according to environmental criteria characteristics is crucial for the formation of livable urban models to solve these problems in cities.

Globally, various studies are conducted to reduce environmental risks in cities and increase livable spaces. One such study focuses on the planning of green spaces. Efforts are made to increase green areas in cities or create green spaces in suitable locations for newly planned areas [253–256]. The main goal of these studies is to enhance the livable and sustainable structures of cities. However, these processes also encounter certain challenges. Thus, in effect, providing public access to green spaces, which is an essential choice and integral part of environmental planning, poses some problems for both planners and local governments. These problems, which include criteria such as topography, walkability, proximity to housing and main roads, emerge as significant factors affecting the design of green spaces [27]. Despite these challenges, green spaces planned according to the above-mentioned criteria are crucial for sustainable urban models as they not only reduce environmental issues but also improve people's health and living spaces.

Another important factor for creating a livable environment and sustainable urban planning is the slope. Slope has an impact on many aspects of urban planning, such as walkability, transportation, and the effects of natural disasters on cities [257–260]. These impacts influence cities in terms of economy, society, and sustainability. Overcoming these adversities is essential to creating sustainable and livable urban areas, which highlights the importance of carefully selecting sites for transportation, commerce, and social areas based on slope criteria.

In Türkiye, similar studies are conducted to improve the existing conditions of cities. These studies involve organizing park areas, planning and distribution of building surroundings, aesthetic planning, and many other areas [261–264].

Studies conducted on the environment worldwide and in Türkiye have been reviewed, and the determined sub-criteria are presented in Table 10.

Table 10. The sub-criteria of environment

Transportation Sub-Criteria	Definition	References
Green Spaces	Areas formed by parks, gardens, and forested areas that serve people's health and physical needs.	[253–255]
Slope	A surface at a certain angle to the horizontal, with some points higher than others.	[257–259]
Landslide	A mass of rock and soil moving suddenly and swiftly down a steep slope.	[265–267]

4.5. MCDM Methods

Multi-criteria decision making is an effective method for analyzing alternatives that involve a variety of environmental, social, and economic impacts. This method allows for the integration of data by comparing the ratios of alternatives to each other, taking into account the selected criteria. This integration also permits the simultaneous analysis of many criteria related to location and characteristics, as well as the management of numerous variables [268].

There are many multi-criteria decision-making methods used in site selection studies. The common ones are listed below.

- Weighted linear combination [269,270]
- Weighted multiplication [271]
- Cost/benefit function-based approaches [272]

- TOPSIS method [271]
- ELECTRE method [273]
- Analytic hierarchy process [274]

4.5.1. AHP

The Analytic Hierarchy Process (AHP), one of the MCDM methods, was developed by Thomas L. Saaty in 1977 [275]. This method uses discrete and continuous pairwise comparisons in a multi-level hierarchical structure [276]. The Analytic Hierarchy Process employs a hierarchical model consisting of objectives, criteria, possible sub-criteria levels, and alternatives for all problems [277]. Starting from the general objective, criteria, and sub-criteria rankings are obtained, followed by the determination of alternatives. Decision-makers decide how important one criterion is relative to another when forming pairwise comparison matrices [278]. The purpose of creating the matrix is to transform the preferences of decision-makers into a calculable scale. This transformation is performed using scales shown in Table 11 [279]. Moreover, this scaling approach ensures the homogeneous determination of the weights of criteria. Pairwise comparison matrices are created using all criteria. Subsequently, the eigenvalue vector method is applied to quantitatively calculate the weights of the criteria [280].

AHP also allows for the mathematical determination of inconsistencies in decision-makers' judgments. The consistency ratio (CR) can be calculated based on the characteristics of the comparison matrices. If (CR) is less than 0.1, the pairwise comparisons are considered acceptable. Otherwise, the matrices must be reconstructed, and then the new (CR) value must also be checked for consistency [279].

Table 11. AHP importance scale

Important Values	Value Definitions
1	Equally important, likely or preferred
3	Moderately more important, likely or preferred

Table 11. AHP importance scale (continue)

Important Values	Value Definitions
5	Strongly more important, likely or preferred
7	Very strongly more important, likely or preferred
9	Extremely more important, likely or preferred
2, 4, 6, 8	Intermediate values to reflect compromise

4.5.2. EWM

The concept of entropy, a parameter that measures the degree of randomness or disorder, originates from thermodynamics. It also represents the heat energy that cannot be used to produce work [281]. In 1948, Claude Shannon expanded the use of entropy beyond its original application by applying it to information theory, thereby demonstrating that entropy methodology could be used to measure the order of a system [282].

The application of EWM in information theories, especially in decision problems, has become widespread. The simplicity of EWM's mathematical algorithm for ease of use in decision-making problems has increased its adoption by decision-makers [283,284]. However, since the mathematical model of EWM is based on data differences, it overlooks the potential correlation among criteria. Due to this feature, criteria with lower weights can easily influence criteria with higher weights in this method [285].

EWM follows the following processes until the solution phase [286–288] :

Construct of decision matrix based on criteria,

$$DM = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix} \quad (1)$$

x_{ij}, is the performance value of alternative i for criterion j (i =1, 2, …, m; j = 1, 2, …, n)

Creation of normalized matrix with decision matrix (N),

$$n_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}} \quad (2)$$

N denotes the normalized value of alternative i for criterion j.

$$N = \begin{bmatrix} n_{11} & n_{12} & \cdots & n_{1n} \\ n_{21} & n_{22} & \cdots & n_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ n_{m1} & n_{m2} & \cdots & n_{mn} \end{bmatrix} \quad (3)$$

Entropy values (E_j) are calculated,

$$E_{ij} = - k \sum_{i=1}^{m} n_{ij} \ln n_{ij}, (k = 1/\ln m) \quad (4)$$

“k” is a constant.

Calculate the degree of diversification (d_j),

$$d_j = 1 – E_j \quad (5)$$

A high d_j value means that the c_j criterion is a more important criterion for the problem presented.

Calculate criteria weights (w_j),

$$w_j = \frac{d_j}{\sum_{j=1}^{n} d_j}, \quad w_1 + w_2 + \ldots + w_n = 1 \qquad (6)$$

4.5.3. Game Theory

Game theory is a theory that influences the decision-making processes of decision-makers in independent and interdependent situations. It is a decision-making method used in processes where the outcome depends on the decisions about the process made by two or more independent players and no single player has complete control over the outcomes [289–292].

Game theory is expressed as an important branch of modern mathematics. Fundamentally, game theory examines the relationship between competitive choices and optimization strategies. The main objective of a game is to find a balanced combination that maximizes the common interests of all players [293,294]. The operational steps of game theory are stated below [295–297].

Step 1

Based on N weighting methods, n weights are obtained, and then the basic weight vector set $W = \{w_1, w_2, \ldots, w_n\}$ is formed. A possible set of weights is combined with n vectors in the form of an arbitrary linear combination:

$$W = \sum_{k=1}^{n} a_k w_k^T \ (a_k > 0) \qquad (7)$$

where w is a possible weight vector in set W, and a_k is the weight coefficient.

Step 2

According to the concept of Game Theory, determining the most balanced weight vector w* among possible weight vector sets is the primary objective. This indicates that a compromise has been reached among the n-weight values. Such a situation shows that optimization of the weight coefficient a_k, which is a linear combination value, has been achieved. The goal of optimization is to minimize the deviation between w and w_k using the following formula:

$$\min || \sum_{j=1}^{n} a_j \times w_j^T - w_i^T ||2 \quad (i = 1, 2, \ldots, n) \tag{8}$$

The condition of the optimal first derivative according to the differentiation property of the matrix in formula (9) is as follows:

$$\sum_{j=1}^{n} a_j \times w_i \times w_j^T = w_i \times w_i^T \quad (i = 1, 2, \ldots, n) \tag{9}$$

The corresponding system of linear equations is

$$\begin{bmatrix} w_1.w_1^T & w_1.w_2^T & \ldots & w_1.w_n^T \\ w_2.w_1^T & w_2.w_2^T & \ldots & w_2.w_n^T \\ \vdots & \vdots & \ldots & \vdots \\ w_n.w_1^T & w_n.w_2^T & \ldots & w_n.w_n^T \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \\ \vdots \\ a_n \end{bmatrix} = \begin{bmatrix} w_1.w_1^T \\ w_2.w_2^T \\ \vdots \\ w_n.w_n^T \end{bmatrix} \tag{10}$$

Step 3

The weight coefficient (a_1, a_2,…, a_n) is calculated according to formula (11). After that, it is normalized with formula (12):

$$a_k^* = \frac{a_k}{\sum_{k=1}^{n} a_k} \tag{11}$$

Finally, w* is obtained from formula (13):

$$w^* = \sum_{k=1}^{n} a_k^* . w_k^T \quad (12)$$

4.5.4. WLC

The WLC method is one of the simplest and most widely used methods in multi-criteria decision making. This method is particularly popular in unidimensional decision-making problems. It is based on the decision maker assigning weights to each criterion. For each option, the assigned weight value is multiplied by the corresponding criterion's scaled value to obtain a total score [298].

For instance, if there are M alternatives and n criteria, each alternative is scored separately for each criterion. Next, weights are given to each criterion to indicate its importance relative to other criteria. Subsequently, the weighted average score for all alternatives is calculated according to the following equation [299–301]:

$$\mathrm{A(i)} = \sum_{j=i}^{n} \mathrm{a(i,j)w(j)} \quad (i = 1,2,3, ...) \quad (13)$$

A(i): Weighted total score of alternatives (i)

A(i,j): Score of alternatives (i) according to (j) criteria

W(j): Weight of j criteria

4.5.5. TOPSIS

The TOPSIS approach was developed by Kwangsun Yoon and Lai Hwang Ching in 1981 [302]. This approach offers an easy solution to MCDM problems encountered in applications. TOPSIS is a powerful MCDM method that operates by determining the optimal solution as the one furthest from the Negative Ideal Solution (NIS) and closest to the Positive Ideal Solution (PIS). In the TOPSIS methodology, PIS is defined as the alternative with the most favorable values for all criteria, while NIS is a hypothetical alternative representing the worst possible values for the criteria. This approach assists decision-makers in effectively comparing alternatives to determine the best solutions for complex problems. It is particularly helpful for engineers and decision-makers in evaluating and prioritizing a set of alternative options to address encountered problems [303–307].

In the TOPSIS methodology, the ranking of alternatives is determined based on their closeness to PIS and distance from NIS. The product of the two distances determines the closeness coefficient, and hence the solution with the highest closeness coefficient is considered the optimal solution [308,309]. The mathematical model of the TOPSIS method is shown below [310–313].

Step 1. Determination of criteria weights and formation of the decision matrix

The first step requires the preparation of a decision matrix based on the performance values of the criteria.

$$R=(r_{ij})_{mxn} = \begin{bmatrix} A_1 \\ A_2 \\ \vdots \\ A_m \end{bmatrix} \begin{bmatrix} u_1 & u_2 & \cdots & u_n \\ r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ r_{m1} & r_{m2} & \cdots & r_{mn} \end{bmatrix} \quad (14)$$

where r_{ij} is the value of the j^{th} attribute in the i^{th} alternative.

Step 2. Calculation of the normalized decision matrix

The normalized decision matrix is obtained using the following equation.

$r_{ij}=x_{ij} / \sqrt{\sum_{i=1}^{m}(x_{ij})^2}$, (i= 1, 2, … m; j= 1, 2, …, n) (15)

Step 3. Calculation of the weighted normalized decision matrix

In this step, the values of the normalized decision matrix (r_{ij}) are multiplied by the normalized weights of the parameters (v_j) to determine the weighted normalized values (v_{ij}).

$v_{ij} = v_j \times r_{ij}$, (i= 1, 2, …, m; j = 1, 2, …, n) (16)

Step 4. Determination of PIS and NIS values

PIS is valuable because it maximizes benefits while minimizing costs simultaneously. NIS produces the opposite outcome. The following equations are used to obtain these values:

$A^+ = [v_1^+, \ldots, v_j^+, \ldots, v_n^+]$, $v_j^+ = max_i\{v_{ij}\}$, i = 1, 2, …, m (17)

if the j^{th} parameter is beneficial,

$A^- = [v_1^-, \ldots, v_j^-, \ldots, v_n^-]$, $v_j^- = min_i\{v_{ij}\}$, i = 1, 2, …, m (18)

where A^+ defines PIS, and A^- defines NIS.

$v_j^+ = min_i\{v_{ij}\}$, i = 1, 2, …, m (19)

if the j^{th} parameter is not beneficial,

$$v_j^- = max_i\{v_{ij}\}, \text{ i = 1, 2, …, m} \quad (20)$$

Step 5. Calculation of the separation value

In TOPSIS two separation measures are utilized, one is for Positive Ideal Distinction (s_i^+) and another one is Negative Ideal Distinction (s_i^-).

$$S_i^+ = \sum_{j=1}^{n} \left|v_{ij} - v_j^+\right| = \sum_{j=1}^{n} D_{ij}^+ \quad (21)$$

$$S_i^- = \sum_{j=1}^{n} \left|v_{ij} - v_j^-\right| = \sum_{j=1}^{n} D_{ij}^- \quad (22)$$

Step 6. Calculating relative closeness (RC_i^+) to the PIS

In this step, the Relative Closeness value of the ith alternative is calculated using the following equation.

$$RC_i^+ = (S_i^-)/(S_i^+ + S_i^-) \quad (23)$$

Larger RC values indicate a better position for the i^{th} alternative, while a smaller RC value indicates a worse situation.

4.6. Definition of Models for The Concept of MGIS

4.6.1. GIS

GIS is a multidisciplinary field with applications across various disciplines such as earth sciences, geography, environmental sciences, and urban and regional planning. GIS technology is a powerful tool used for the collection, storage, processing, analysis, and visualization of spatial data [314]. This technology plays a crucial role in supporting decision-making processes and policy development and offers convenience to practitioners [34,315]. The fundamental components of GIS are location information (coordinates) and attribute data associated with these locations. These systems can perform various functions, including data collection, data management, data analysis, and data visualization. Specifically, GIS provides advanced analytical tools for extracting meaningful information from large and complex datasets [316–319].

Recent advancements in GIS technologies for data analysis have expanded its application areas. This expansion has increased the importance of GIS in various fields, including urban planning, disaster management, agriculture, forestry management, water resources management, and environmental monitoring [320–322]. For example, in urban planning, GIS is used to plan city development, manage infrastructure projects, and optimize traffic flow [323]. In disaster management, GIS serves as a fundamental tool for assessing disaster risks, developing emergency response plans, and conducting post-disaster damage analyses [324].

Another significant application area of GIS technology is environmental monitoring. In this field, GIS is utilized to track environmental changes, assess habitat loss, and support the sustainable management of natural resources [325]. Moreover, in climate change research, GIS has become an indispensable tool for analyzing climate models and assessing the potential impacts of climate change [326].

The development of GIS technology also encompasses integration with technologies such as big data, artificial intelligence (AI), and machine learning. This integration significantly enhances GIS analytical capabilities, thus, enabling the processing and analysis of more complex datasets [327]. With all these features and applications, GIS actively contributes to decision-making processes, aids in policy creation, and provides conveniences to practitioners.

4.6.2. MGIS

MGIS is a system designed to facilitate the management and planning of cities through the use of information technologies. This system includes the necessary tools to optimize and organize decision-making processes, urban planning, and infrastructure management for local governments. The primary aim of MGIS is to create a database essential for understanding and directing various aspects of urban development. MGIS provides a structure that helps city planners, engineers, and policymakers examine the physical and social structure of cities in detail, thereby assisting them in making more informed and effective decisions. MGIS offers both local administrators and policymakers the opportunity to evaluate issues such as urban expansion, transportation networks, the distribution of public services, and environmental impact assessments [328].

The applications of MGIS are broad and include areas such as infrastructure management, land-use planning, transportation and traffic management, environmental protection, distribution of public services, and disaster management are the main areas supported by this system. Furthermore, local governments or governments are responsible for the long-term health, safety, and welfare of citizens. Therefore, broader issues need to be considered, including incorporating public values into the decision-making process, ensuring that services are delivered fairly and equitably, and representing the views of citizens in collaboration with elected officials [328]. Typical GIS applications, therefore, include monitoring public health risks, managing the housing stock, allocating social aid funds, and monitoring crime. Similar to geo-demographic analyses, geographical information systems are also used for operational, tactical, and strategic decision-making in law enforcement, health services planning, and education system management [37]. GIS applications available for local governments are detailed in Table 12 [37,314]. In this context, local governments can use MGIS to collect citizens' needs and expectations through an internet-based system, analyze this data to gain a better understanding of citizen demands, and shape their services accordingly.

Table 12. GIS applications used in local governments

“GIS Application Area”	“Inventory Applications (Locating property information such as ownership and tax assessments by clicking on a map)”	“Policy Analysis Applications (E.g. number of features per area, proximity to a feature or land use, correlation of demographic features with geological features)”	“Management/ Policymaking (E.g. more efficient routing, modelling alternatives, forecasting future needs, work scheduling)”
“Economic Development”	“Location of major businesses and their primary resource demands”	“Analysis of resource demand by potential local supplier”	“Informing businesses of availability of local suppliers”
“Transportation Planning and Service Routing”	“Identification of sanitation truck routes, capacities, and staffing by area; identification of landfills and recycling sites”	“Analysis of potential capacity strain, given development in certain areas; analysis of accident patterns by type of site”	“Identification of ideal high-density development areas, based on criteria such as established transportation capacity”

Table 12. GIS applications used in local governments (continue)

"Housing"	"Inventory of housing stock age, condition, status (public, private, rental, etc.), durability, and demographics"	"Analysis of public support for housing by geographic area, travel time from low-income areas to needed service facilities, etc."	"Analysis of funding for housing rehabilitation, location of related public facilities; planning for capital investment in housing based on population growth projections"
"Infrastructure"	"Inventory of roads, sidewalks, bridges, utilities (locations, names, conditions, foundations, and most recent maintenance)"	"Analysis of infrastructure conditions by demographic variables such as income and population change"	"Analysis to schedule maintenance and expansion"
"Health"	"Locations of persons with particular health problems, locations of health facilities"	"Spatial, time-series analysis of the spread of disease; effects of environmental conditions on disease"	"Analysis to pinpoint possible sources of disease"

Table 12. GIS applications used in local governments (continue)

“Property Taxation”	“Identification of ownership data by land plot”	“Analysis of tax revenues by land use within various distances from the city centre”	“Projecting tax revenue changes due to land-use changes”
“Land Administration”	“Identification of ownership data by land parcels”	“Analysis of land tenure and land development”	“Analysis to map out effective land control mechanisms”
“Human Services”	“Inventory of neighbourhoods with multiple social risks indicators; location of existing facilities and services designated to address these risks”	“Analysis of match between service facilities and human services need and capacities of nearby residents”	“Facility siting, public transportation routing, programme planning, and place-based social intervention”

Table 12. GIS applications used in local governments (continue)

"Law Enforcement"	"Inventory of location of police stations, crimes, arrests, convicted perpetrators, and victims; plotting police beats and patrol car routing; alarm and security system locations"	"Analysis of police visibility and presence; officers in relation to the density of criminal activity; victim profiles in relation to residential populations; police experience and beat" duties	"Reallocation of police resources and facilities to areas where they are likely to be most efficient and effective; creation of random routing maps to decrease predictability of police beat"
"Land Use Planning/District Profiling"	"Parcel inventory of zoning areas, flood plains, industrial parks, land uses, trees, green space, etc."	"Analysis of percentage of land used in each category, density levels by neighbourhoods, threats to residential amenities, proximity to locally unwanted land uses"	"Evaluation of land use plan based on demographic characteristics of nearby population (e.g. will a smokestack industry be sited upwind of a respiratory disease hospital?)"

Table 12. GIS applications used in local governments (continue)

"Parks and Recreation"	"Inventory of park holdings/ play areas, trails by type, etc."	"Analysis of neighbourhood access to parks and recreation opportunities, age-related proximity to relevant play areas"	"Modelling population growth projections and potential future recreational needs/play area uses"
"Environmental Monitoring"	"Inventory of environmental hazards in relation to vital resources such as groundwater; layering of nonpoint pollution sources"	"Analysis of spread rates and cumulative pollution levels; analysis of potential years of life lost in a particular area due to environmental hazards"	"Modelling potential environmental harm to specific local areas; analysis of place-specific multilayered pollution abatement plans"
"Natural Resource Management"	"Inventory of natural resources such as land, water, soils, plants"	"Analysis of how people interact with natural landscapes"	"Evaluation of how human activities affect the natural environment (e.g. is deforestation for agriculture use sustainable?)"

Table 12. GIS applications used in local governments (continue)

"Municipal Services"	"Identification of administrative boundaries and identification of the citizen needs"	"Analysis of basic services to be provided to the citizens"	"Evaluation of how the basic services are available to all citizens within their areas of jurisdiction"
"Emergency Management"	"Location of key emergency exit routes and their traffic flow capacity and critical danger points (e.g. bridges likely to be destroyed by an earthquake)"	"Analysis of potential effects of emergencies of various magnitudes on exit routes, traffic flow, etc."	"Modelling effect of placing emergency facilities and response capacities in particular locations"
"Citizen Information/ Geodemographics"	"Location of persons with specific demographic characteristics such as voting patterns, service usage and preferences, commuting routes, occupations"	"Analysis of voting characteristics of particular areas"	"Modelling effect of placing information kiosks at particular locations"

The significance of MGIS in urban management is its power to solve complex urban problems and achieve sustainable development goals. MGIS enables cities to be managed more efficiently and effectively which also contributes to energy savings and improves traffic flow, air quality, and conservation of green spaces. This system also aids in reducing the environmental impacts of urban growth and enhancing the livability of cities [328]. The benefits of using GIS applications in local governments, along with the implementation costs, are shown in Table 13 [37,329].

Table 13. Benefits and implementation costs of GIS in city management

"Benefits"	"Explanation"	"Implementation Costs"	"Explanation"
"Cost Savings"	"A GIS allows management to consider the role of geography. It plays a role in improving the delivery and utilization of a service."	"Technical Resources"	"Establishing and maintaining a GIS requires resources such as computers, software, and supporting peripherals."
"Improved Accuracy"	"GIS technology combines sources of information providing accurate and up-to-date facts. Accurate information enables better products, decisions, analyses, reports, and development solutions."	"Skilled Staff"	"The operation and maintenance of a GIS require both technical and office personnel."

Table 13. Benefits and implementation costs of GIS in city management (continue)

“Benefits”	“Explanation”	“Implementation Costs”	“Explanation”
“Effective Communication and Collaboration”	“A GIS can compile and share various pieces of information in a way that is understandable and beneficial for staff working in various municipal departments, external stakeholders, business partners, and the public.”	“Training”	“Staff training will be a relatively high proportional cost due to the need for acquiring essential skills initially to manage the system successfully.”
“Improve Transparency and Accountability”	“Maps can be a valuable part of government transparency since they help citizens quickly visualize and understand what the government is doing in areas important to them.”	“Data Purchase or Collection”	“Creating a comprehensive, high-quality database is a challenging task, especially in a developing country. Moreover, not all data are created equal; the type, scale, accuracy, compatibility, and currency of the information are concerns wherever data are analyzed.”

Table 13. Benefits and implementation costs of GIS in city management (continue)

“Benefits”	“Explanation”	“Implementation Costs”	“Explanation”
“Support Decision Making”	“A GIS efficiently and swiftly runs multiple scenarios and offers multiple alternatives for examination.”	“Institutional Issues”	“A GIS department should function as an interdepartmental unit that assists other departments within the municipality. A lack of coordination between the GIS unit and other departments can pose a threat and may result in wasted effort and cost.”
“Build an Information Base”	“Organizing data in a GIS creates reusable and geographically referenced datasets.”		

It is expected that the importance of MGIS will continue to increase in the future. With the integration of technologies such as artificial intelligence and machine learning, MGIS will be capable of conducting more advanced analyses and offering more predictable models. These developments will make urban planning more dynamic and flexible, thus allowing cities to respond more quickly and effectively to rapidly changing needs.

With all these features, MGIS is an indispensable part of urban planning and management. This system makes significant contributions to the sustainable development of urban areas and will continue to play a crucial role in shaping the future of city life. The effective use of this powerful tool by local governments is critical in building more livable, efficient, and sustainable cities.

4.6.3. Design of Model

Planning issues and the creation of sustainable urban models in city areas significantly affect the livability levels of cities. In recent years, policies have been developed and various methods have been applied to overcome these problems [56,58,330–332]. Additionally, there is a desire to give cities an identity to increase their desirability among people and to create sustainable urban models.

In this study, a model design is created that can analyze the current and future needs of cities and facilitate the creation of sustainable urban models (Figure 4). However, the TOPSIS method is not included in the MGIS model design. The reason for not incorporating the TOPSIS method into the model design is that this method is used only for identifying areas for investment and can be applied to different methodologies at the discretion of decision-makers.

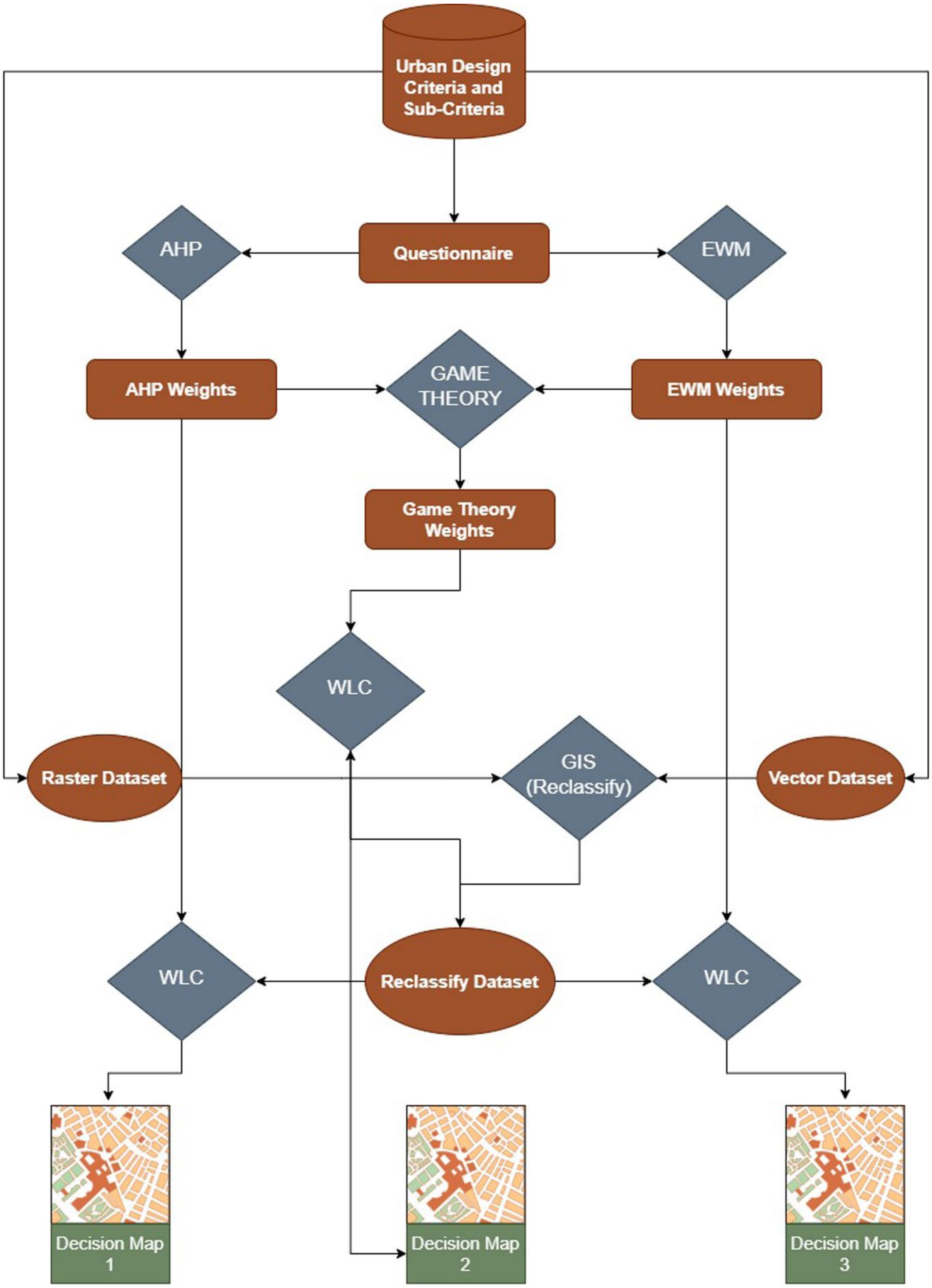

Figure 4. Design of MGIS solution model

5. APPLICATION STAGE

The objective of this study is to develop an MGIS approach that integrates urban planning criteria with GIS, MCDM methods, and Game Theory. This approach will allow for the evaluation of urban planning criteria to determine the current state of cities and identify their livability levels using the applied methods.

In this context, initially, data related to urban planning criteria were first transferred to a GIS environment for a preliminary assessment. Subsequently, the criteria and sub-criteria to be used in the study were identified (Figure 3), and a survey was conducted with twenty individuals. The survey included expert geomatic engineers, urban planners, architects, and professionals from other engineering disciplines.

During the application phase, both AHP and EWM were used to calculate the weights of the criteria. Therefore, survey participants were asked to evaluate the criteria in comparisons using a priority score ranging from 1 to 9. The geometric means of the data obtained from the survey results were calculated to determine the scores to be used in AHP and EWM methods. Thence, the Game Theory methodology was used to determine the final weights of the criteria, taking into account the differences in criteria weights that would arise between methods. Afterwards, the WLC method was used to create decision maps based on the weight results obtained, and the resulting data was compared. The pixel values of the created decision maps were evaluated in the TOPSIS methodology to determine the priority order of areas requiring investment for enhancing the livability and sustainability of cities, and the findings were compared.

5.1. Determination of Criteria Weights with AHP

In the study, pairwise comparison matrices of AHP were created to obtain the weight of each criterion. In doing so, all criteria--walkability, environment, connectivity, transportation, and climate change-- were divided into five main groups according to their domains of influence (Figure 5). These five groups were evaluated independently, and their weights were calculated separately. Subsequently, the sub-criteria were also evaluated according to the characteristics of their groups, and their weights were determined (Tables 14-20). The CR value has been calculated as acceptable for all pairwise comparison matrices.

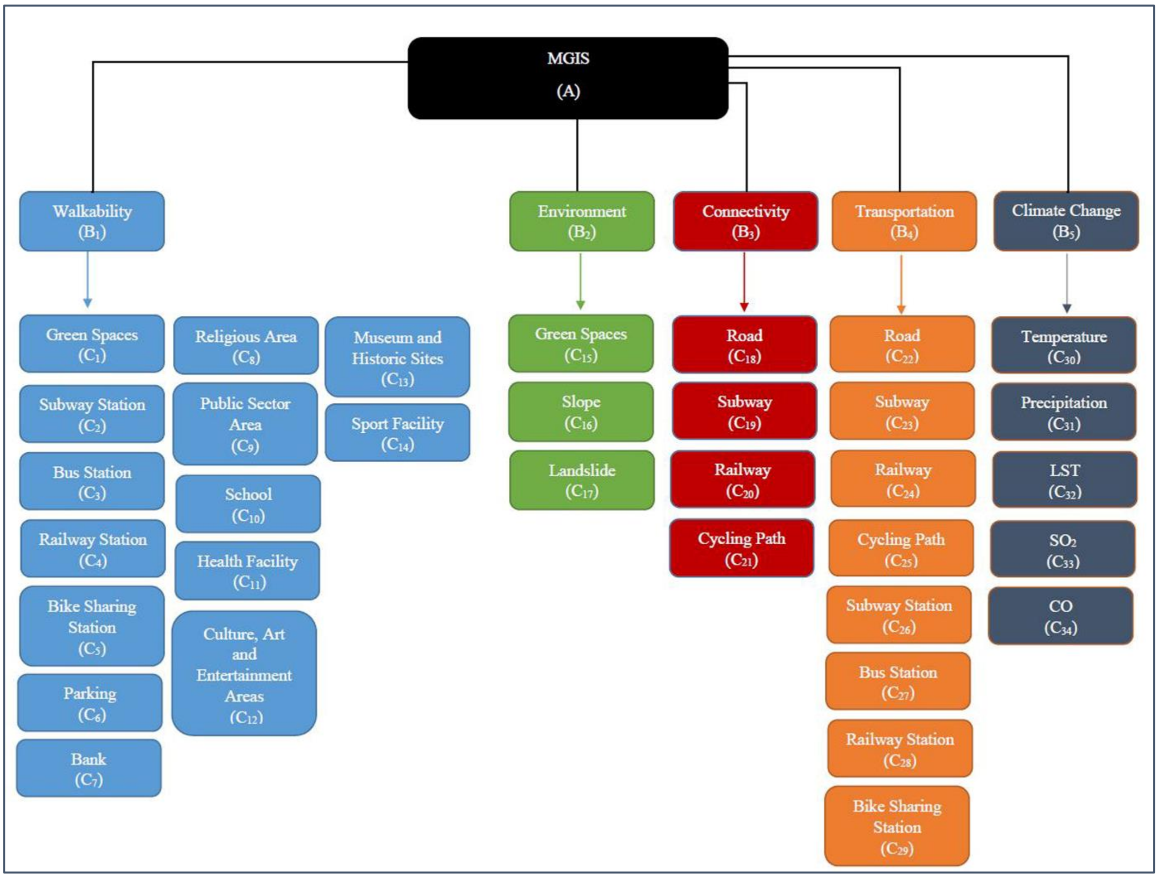

Figure 5. AHP hierarchy

Table 14. The pairwise comparisons matrix of groups

A	B_1	B_2	B_3	B_4	B_5	W
B_1	1	1/2	1/2	1/2	1/2	0.1078
B_2	2	1	1	1	2	0.2490
B_3	2	1	1	1/2	1/2	0.1705
B_4	2	1	2	1	2	0.2798
B_5	2	1/2	2	1/2	1	0.1929

CR= 0.044, B_1: Walkability, B_2: Environment, B_3: Connectivity, B_4: Transportation, B_5:Climate Change

Table 15. The pairwise comparisons matrix of walkability sub-criteria

B_1	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	W
C_1	1	2	2	3	6	3	8	3	5	2	2	3	7	2	0.1614
C_2	1/2	1	2	2	7	3	8	4	4	2	2	5	5	3	0.1477
C_3	1/2	1/2	1	2	6	3	6	4	4	2	2	3	4	2	0.1198
C_4	1/3	1/2	1/2	1	4	1	5	2	2	1/2	1/2	3	4	1/2	0.0627
C_5	1/6	1/7	1/6	1/4	1	1/4	2	1/3	1/4	1/7	1/6	1/6	1/3	1/6	0.0154
C_6	1/3	1/3	1/3	1	4	1	3	2	2	1/2	1/2	3	4	1/2	0.0574
C_7	1/8	1/8	1/6	1/5	1/2	1/3	1	1/2	1/3	1/8	1/8	1/4	1/3	1/5	0.0139
C_8	1/3	1/4	1/4	1/2	3	1/2	2	1	1	1/4	1/4	1	1	1/4	0.0313
C_9	1/5	1/4	1/4	1/2	4	1/2	3	1	1	1/4	1/4	1/2	1/2	1/4	0.0298
C_{10}	1/2	1/2	1/2	2	7	2	7	4	4	1	1	4	6	2	0.1065
C_{11}	1/2	1/2	1/2	2	6	2	7	4	4	1	1	4	5	2	0.1038
C_{12}	1/3	1/5	1/3	1/3	6	1/3	4	1	2	1/4	1/4	1	2	1/3	0.0398
C_{13}	1/7	1/5	1/4	1/4	3	1/4	3	1	2	1/6	1/5	1/2	1	1/3	0.0278
C_{14}	1/2	1/3	1/2	2	6	2	5	4	4	1/2	1/2	3	3	1	0.0826

CR= 0.039, C_1: Green Spaces, C_2: Subway Station, C_3: Bus Station, C_4: Railway Station, C_5: Bike Sharing Station, C_6: Parking, C_7: Bank, C_8: Religious Area C_9: Public Sector Area, C_{10}: School, C_{11}: Health Facility, C_{12}: Culture, Art and Entertainment Areas, C_{13}: Museums and Historic Sites, C_{14}: Sport Facility

Table 16. The pairwise comparisons matrix of environment sub-criteria

B_2	C_{15}	C_{16}	C_{17}	W
C_{15}	1	2	1	0.4000
C_{16}	1/2	1	1/2	0.2000
C_{17}	1	2	1	0.4000

CR= 0.000, C_{15}: Green Spaces, C_{16}: Slope, C_{17}: Landslide

Table 17. The pairwise comparisons matrix of connectivity sub-criteria

B_3	C_{18}	C_{19}	C_{20}	C_{21}	W
C_{18}	1	2	2	3	0.4168
C_{19}	1/2	1	2	2	0.2695
C_{20}	1/2	1/2	1	2	0.1928
C_{21}	1/3	1/2	1/2	1	0.1209

CR= 0.026, C_{18}: Road, C_{19}: Subway, C_{20}: Railway, C_{21}: Cycling Path

Table 18. The pairwise comparisons matrix of transportation sub-criteria

B_4	C_{22}	C_{23}	C_{24}	C_{25}	C_{26}	C_{27}	C_{28}	C_{29}	W
C_{22}	1	1	2	3	1	1	2	2	0.1629
C_{23}	1	1	2	4	1	2	2	3	0.1927
C_{24}	1/2	1/2	1	3	1/2	1/2	1	4	0.1063
C_{25}	1/3	1/4	1/3	1	1/4	1/3	1/3	1	0.0443
C_{26}	1	1	2	4	1	1	2	5	0.1848
C_{27}	1	1/2	2	3	1	1	2	3	0.1560
C_{28}	1/2	1/2	1	3	1/2	1/2	1	4	0.1063
C_{29}	1/2	1/3	1/4	1	1/5	1/3	1/4	1	0.0468

CR= 0.026, C_{22}: Road, C_{23}: Subway, C_{24}: Railway, C_{25}: Cycling Path, C_{26}: Subway Station, C_{27}: Bus Station, C_{28}: Railway Station, C_{29}: Bike Sharing Station

Table 19. The pairwise comparisons matrix of climate change sub-criteria

B_5	C_{30}	C_{31}	C_{32}	C_{33}	C_{34}	W
C_{30}	1	1/2	1/2	1/3	1/3	0.0882
C_{31}	2	1	2	1/2	1/2	0.1830
C_{32}	2	1/2	1	1/2	1/2	0.1397
C_{33}	3	2	2	1	1	0.2945
C_{34}	3	2	2	1	1	0.2945

CR= 0.016, C_{30}: Temperature, C_{31}: Precipitation, C_{32}: LST, C_{33}: SO_2, C_{34}: CO

Table 20. The weight of criteria according to AHP

Goal A	Hierarchy B	Hierarchy C	W
A	B_1	C_1	0.0174
		C_2	0.0159
		C_3	0.0129
		C_4	0.0068
		C_5	0.0017
		C_6	0.0062
		C_7	0.0015
		C_8	0.0034
		C_9	0.0032
		C_{10}	0.0115
		C_{11}	0.0112
		C_{12}	0.0043
		C_{13}	0.0030
		C_{14}	0.0089
	B_2	C_{15}	0.0996
		C_{16}	0.0498
		C_{17}	0.0996
	B_3	C_{18}	0.0711
		C_{19}	0.0459
		C_{20}	0.0329
		C_{21}	0.0206

Table 20. The weight of criteria according to AHP (continue)

Goal A	Hierarchy B	Hierarchy C	W
	B_4	C_{22}	0.0456
		C_{23}	0.0539
		C_{24}	0.0297
		C_{25}	0.0124
		C_{26}	0.0517
		C_{27}	0.0436
		C_{28}	0.0297
		C_{29}	0.0131
	B_5	C_{30}	0.0170
		C_{31}	0.0353
		C_{32}	0.0269
		C_{33}	0.0568
		C_{34}	0.0568

5.2. Determination of Criteria Weights with EWM

In the study, the pairwise comparison matrix of AHP was used to obtain the weight of each criterion, followed by the application of the mathematical model of EWM to calculate the weights of the five groups and their sub-criteria (Tables 21-27).

Table 21. The pairwise comparisons matrix of groups

A	B_1	B_2	B_3	B_4	B_5	W
B_1	1	1/2	1/2	1/2	1/2	0.0686
B_2	2	1	1	1	2	0.1207
B_3	2	1	1	1/2	1/2	0.2685
B_4	2	1	2	1	2	0.1444
B_5	2	1/2	2	1/2	1	0.3978

B_1: Walkability, B_2: Environment, B_3: Connectivity, B_4: Transportation, B_5:Climate Change

Table 22. The pairwise comparisons matrix of walkability sub-criteria

B_1	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	W
C_1	1	2	2	3	6	3	8	3	5	2	2	3	7	2	0.0377
C_2	1/2	1	2	2	7	3	8	4	4	2	2	5	5	3	0.0881
C_3	1/2	1/2	1	2	6	3	6	4	4	2	2	3	4	2	0.0939
C_4	1/3	1/2	1/2	1	4	1	5	2	2	1/2	1/2	3	4	1/2	0.0742
C_5	1/6	1/7	1/6	1/4	1	1/4	2	1/3	1/4	1/7	1/6	1/6	1/3	1/6	0.0325
C_6	1/3	1/3	1/3	1	4	1	3	2	2	1/2	1/2	3	4	1/2	0.0809
C_7	1/8	1/8	1/6	1/5	1/2	1/3	1	1/2	1/3	1/8	1/8	1/4	1/3	1/5	0.0340
C_8	1/3	1/4	1/4	1/2	3	1/2	2	1	1	1/4	1/4	1	1	1/4	0.0572
C_9	1/5	1/4	1/4	1/2	4	1/2	3	1	1	1/4	1/4	1/2	1/2	1/4	0.0547
C_{10}	1/2	1/2	1/2	2	7	2	7	4	4	1	1	4	6	2	0.1006
C_{11}	1/2	1/2	1/2	2	6	2	7	4	4	1	1	4	5	2	0.0979
C_{12}	1/3	1/5	1/3	1/3	6	1/3	4	1	2	1/4	1/4	1	2	1/3	0.0743
C_{13}	1/7	1/5	1/4	1/4	3	1/4	3	1	2	1/6	1/5	1/2	1	1/3	0.0736
C_{14}	1/2	1/3	1/2	2	6	2	5	4	4	1/2	1/2	3	3	1	0.1004

C_1: Green Spaces, C_2: Subway Station, C_3: Bus Station, C_4: Railway Station,
C_5: Bike Sharing Station, C_6: Parking, C_7: Bank, C_8: Religious Area
C_9: Public Sector Area, C_{10}: School, C_{11}: Health Facility,
C_{12}: Culture, Art and Entertainment Areas, C_{13}: Museums and Historic Sites, C_{14}: Sport Facility

Table 23. The pairwise comparisons matrix of environment sub-criteria

B_2	C_{15}	C_{16}	C_{17}	W
C_{15}	1	2	1	0.3333
C_{16}	1/2	1	1/2	0.3333
C_{17}	1	2	1	0.3333

C_{15}: Green Spaces, C_{16}: Slope, C_{17}: Landslide

Table 24. The pairwise comparisons matrix of connectivity sub-criteria

B_3	C_{18}	C_{19}	C_{20}	C_{21}	W
C_{18}	1	2	2	3	0.1904
C_{19}	1/2	1	2	2	0.3883
C_{20}	1/2	1/2	1	2	0.2748
C_{21}	1/3	1/2	1/2	1	0.1465

C_{18}: Road, C_{19}: Subway, C_{20}: Railway, C_{21}: Cycling Path

Table 25. The pairwise comparisons matrix of transportation sub-criteria

B_4	C_{22}	C_{23}	C_{24}	C_{25}	C_{26}	C_{27}	C_{28}	C_{29}	W
C_{22}	1	1	2	3	1	1	2	2	0.0705
C_{23}	1	1	2	4	1	2	2	3	0.1024
C_{24}	1/2	1/2	1	3	1/2	1/2	1	4	0.1664
C_{25}	1/3	1/4	1/3	1	1/4	1/3	1/3	1	0.0864
C_{26}	1	1	2	4	1	1	2	5	0.1262
C_{27}	1	1/2	2	3	1	1	2	3	0.1661
C_{28}	1/2	1/2	1	3	1/2	1/2	1	4	0.1664
C_{29}	1/2	1/3	1/4	1	1/5	1/3	1/4	1	0.1157

C_{22}: Road, C_{23}: Subway, C_{24}: Railway, C_{25}: Cycling Path, C_{26}: Subway Station, C_{27}: Bus Station, C_{28}: Railway Station, C_{29}: Bike Sharing Station

Table 26. The pairwise comparisons matrix of climate change sub-criteria

B_5	C_{30}	C_{31}	C_{32}	C_{33}	C_{34}	W
C_{30}	1	1/2	1/2	1/3	1/3	0.1244
C_{31}	2	1	2	1/2	1/2	0.3251
C_{32}	2	1/2	1	1/2	1/2	0.2035
C_{33}	3	2	2	1	1	0.1735
C_{34}	3	2	2	1	1	0.1735

C_{30}: Temperature, C_{31}: Precipitation, C_{32}: LST, C_{33}: SO_2, C_{34}: CO

Table 27. The weight of criteria according to EWM

Goal A	Hierarchy B	Hierarchy C	W
A	B_1	C_1	0.0026
		C_2	0.0060
		C_3	0.0064
		C_4	0.0051
		C_5	0.0022
		C_6	0.0055
		C_7	0.0023
		C_8	0.0039
		C_9	0.0038
		C_{10}	0.0069

Table 27. The weight of criteria according to EWM (continue)

Goal A	Hierarchy B	Hierarchy C	W
		C_{11}	0.0067
		C_{12}	0.0051
		C_{13}	0.0050
		C_{14}	0.0069
	B_2	C_{15}	0.0402
		C_{16}	0.0402
		C_{17}	0.0402
	B_3	C_{18}	0.0511
		C_{19}	0.1043
		C_{20}	0.0738
		C_{21}	0.0393
	B_4	C_{22}	0.0102
		C_{23}	0.0148
		C_{24}	0.0240
		C_{25}	0.0125
		C_{26}	0.0182
		C_{27}	0.0240
		C_{28}	0.0240
		C_{29}	0.0167
	B_5	C_{30}	0.0495
		C_{31}	0.0129
		C_{32}	0.0810
		C_{33}	0.0690
		C_{34}	0.0690

5.3. Determination of Criteria Weights with Game Theory

In the study, the mathematical model of Game Theory was applied to the weights determined by AHP and EWM methods to finalize the weights of criteria and sub-criteria. In this process, the weights obtained through the AHP method were initially defined as subject weight (SW), and those obtained through the EWM method were defined as object weight (OW). Weight matrices W_1 and W_2 were formed with the weights derived from the AHP and EWM methods, respectively.

The transpose of the created W_1 and W_2 matrices were obtained as W1T and W2T. Utilizing Formula 10, $w_i \times w_j^T$ matrix was first derived, followed by the $w_i \times w_i^T$. Next, by multiplying the inverse of the $w_i \times w_j^T$ matrix with the $w_i \times w_i^T$ matrix, the weight coefficient matrix was obtained in the form of $a_k^* = a_1, a_2$. This matrix was normalized to calculate the normalized weight coefficient matrix (Formula 12).

The weight matrix $w^*$was derived by multiplying each row of the W_k^T matrix, created by taking the transpose of the W_1 and W_2 matrices, with the a_k^* matrix (Formula 13). The weights obtained according to the applied methodology are shown in Tables 28-34.

Table 28. The weight of groups

Methods	B_1	B_2	B_3	B_4	B_5
AHP	0.1078	0.2490	0.1705	0.2798	0.1929
EWM	0.0686	0.1207	0.2685	0.1444	0.3978
Game Theory	0.0780	0.1515	0.2450	0.1768	0.3486

a_1 = 0.2398, a_2 = 0.7602,
B_1: Walkability, B_2: Environment, B_3: Connectivity, B_4: Transportation, B_5:Climate Change

Table 29. The weight of walkability sub-criteria

B_1	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}
AHP	0.1614	0.1477	0.1198	0.0627	0.0154	0.0574	0.0139	0.0313	0.0298	0.1065	0.1038	0.0398	0.0278	0.0826
EWM	0.0377	0.0881	0.0939	0.0742	0.0325	0.0809	0.0340	0.0572	0.0547	0.1006	0.0979	0.0743	0.0736	0.1004
Game Theory	0.1550	0.1446	0.1185	0.0633	0.0163	0.0586	0.0149	0.0326	0.0311	0.1062	0.1035	0.0416	0.0302	0.0835

a_1 = 0.9487, a_2 = 0.0513,
C_1: Green Spaces, C_2: Subway Station, C_3: Bus Station, C_4: Railway Station, C_5: Bike Sharing Station, C_6: Parking, C_7: Bank, C_8: Religious Area, C_9: Public Sector Area, C_{10}: School, C_{11}: Health Facility, C_{12}: Culture, Art and Entertainment Areas, C_{13}: Museums and Historic Sites, C_{14}: Sport Facility

Table 30. The pairwise comparisons matrix of environment sub-criteria

B_2	C_{15}	C_{16}	C_{17}
AHP	0.4000	0.2000	0.4000
EWM	0.3333	0.3333	0.3333
Game Theory	0.4000	0.2000	0.4000

a_1 = 1.0000, a_2 = 0.0000,
C_{15}: Green Spaces, C_{16}: Slope, C_{17}: Landslide

Table 31. The pairwise comparisons matrix of connectivity sub-criteria

B_3	C_{18}	C_{19}	C_{20}	C_{21}
AHP	0.4168	0.2695	0.1928	0.1209
EWM	0.1904	0.3883	0.2748	0.1465
Game Theory	0.3230	0.3187	0.2268	0.1316

a_1 = 0.5855, a_2 = 0.4145,
C_{18}: Road, C_{19}: Subway, C_{20}: Railway, C_{21}: Cycling Path

Table 32. The pairwise comparisons matrix of transportation sub-criteria

B_4	C_{22}	C_{23}	C_{24}	C_{25}	C_{26}	C_{27}	C_{28}	C_{29}
AHP	0.1629	0.1927	0.1063	0.0443	0.1848	0.1560	0.1063	0.0468
EWM	0.0705	0.1024	0.1664	0.0864	0.1262	0.1661	0.1664	0.1157
Game Theory	0.1334	0.1639	0.1255	0.0577	0.1661	0.1592	0.1255	0.0688

a_1 = 0.6810, a_2 = 0.3190,
C_{22}: Road, C_{23}: Subway, C_{24}: Railway, C_{25}: Cycling Path, C_{26}: Subway Station,
C_{27}: Bus Station, C_{28}: Railway Station, C_{29}: Bike Sharing Station

Table 33. The pairwise comparisons matrix of climate change sub-criteria

B_5	C_{30}	C_{31}	C_{32}	C_{33}	C_{34}
AHP	0.0882	0.1830	0.1397	0.2945	0.2945
EWM	0.1244	0.3251	0.2035	0.1735	0.1735
Game Theory	0.1029	0.2409	0.1657	0.2453	0.2453

a_1 = 0.5929, a_2 = 0.4071,
C_{30}: Temperature, C_{31}: Precipitation, C_{32}: LST, C_{33}: SO_2, C_{34}: CO

Table 34. The weight of criteria according to AHP, EWM, and Game Theory

Goal A	Hierarchy B	Hierarchy C	W (AHP)	W (EWM)	W (Game Theory)
A	B_1	C_1	0.0174	0.0026	0.0121
		C_2	0.0159	0.0060	0.0113
		C_3	0.0129	0.0064	0.0092
		C_4	0.0068	0.0051	0.0049
		C_5	0.0017	0.0022	0.0013
		C_6	0.0062	0.0055	0.0046

Table 34. The weight of criteria according to AHP, EWM, and Game Theory (continue)

Goal A	Hierarchy B	Hierarchy C	W (AHP)	W (EWM)	W (Game Theory)
		C_7	0.0015	0.0023	0.0012
		C_8	0.0034	0.0039	0.0025
		C_9	0.0032	0.0038	0.0024
		C_{10}	0.0115	0.0069	0.0083
		C_{11}	0.0112	0.0067	0.0081
		C_{12}	0.0043	0.0051	0.0032
		C_{13}	0.0030	0.0050	0.0024
		C_{14}	0.0089	0.0069	0.0065
	B_2	C_{15}	0.0996	0.0402	0.0606
		C_{16}	0.0498	0.0402	0.0303
		C_{17}	0.0996	0.0402	0.0606
	B_3	C_{18}	0.0711	0.0511	0.0791
		C_{19}	0.0459	0.1043	0.0781
		C_{20}	0.0329	0.0738	0.0556
		C_{21}	0.0206	0.0393	0.0322
	B_4	C_{22}	0.0456	0.0102	0.0236
		C_{23}	0.0539	0.0148	0.0290
		C_{24}	0.0297	0.0240	0.0222
		C_{25}	0.0124	0.0125	0.0102
		C_{26}	0.0517	0.0182	0.0294
		C_{27}	0.0436	0.0240	0.0281
		C_{28}	0.0297	0.0240	0.0222
		C_{29}	0.0131	0.0167	0.0122

Table 34. The weight of criteria according to AHP, EWM, and Game Theory (continue)

Goal A	Hierarchy B	Hierarchy C	W (AHP)	W (EWM)	W (Game Theory)
	B_5	C_{30}	0.0170	0.0495	0.0359
		C_{31}	0.0353	0.0129	0.0840
		C_{32}	0.0269	0.0810	0.0578
		C_{33}	0.0568	0.0690	0.0855
		C_{34}	0.0568	0.0690	0.0855

5.4. Analysis

The main aim of implementing the MGIS Solution Model was to identify livable areas in the study area. For this purpose, criteria such as Green Spaces, Subway Stations, Bus Stations, Railway Stations, Bike Sharing Stations, Roads, Subway, Railway and Cycling Paths were scored in different criterion groups in this study and received varying points according to their relative importance within each group. The purpose of this is to demonstrate that criteria in urban planning can have different levels of importance depending on their use or planning purpose.

To identify livable areas in the study area, rasta data were created by first analyzing the criteria listed in Table 5 in accordance with the sub-criteria. The analysis of climate change raster data (C_{30-34}) was conducted at a cell resolution of 100m x 100m, while the analysis of other raster data was performed at a 30m x 30m cell resolution. Moreover, the inverse distance weighting (IDW) method was used in creating the climate data. Suitability maps (Figure 6-13) were reclassified in the ArcGIS software and scored between one and five. Thus, unsuitable areas were represented with one point, and the most suitable areas were represented with five points.

All the resulting suitability maps were multiplied separately by the weights determined in the AHP, EWM, and Game Theory methods according to the methodology shown in Figure 4 in a GIS environment (ArcGIS 10.3, Raster Calculator Tool) and summed up to produce weighted decision maps with a cell resolution of 30m x 30m (Figure 14).

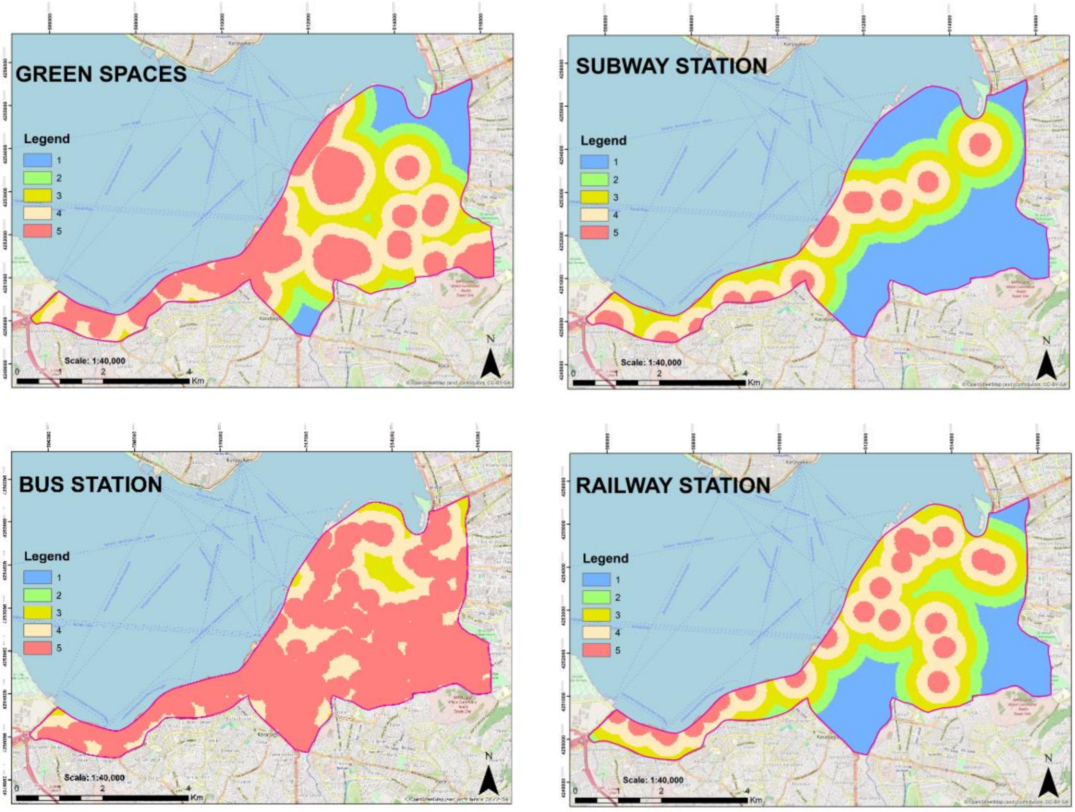

Figure 6. Suitability maps ($C_{1\text{-}4}$)

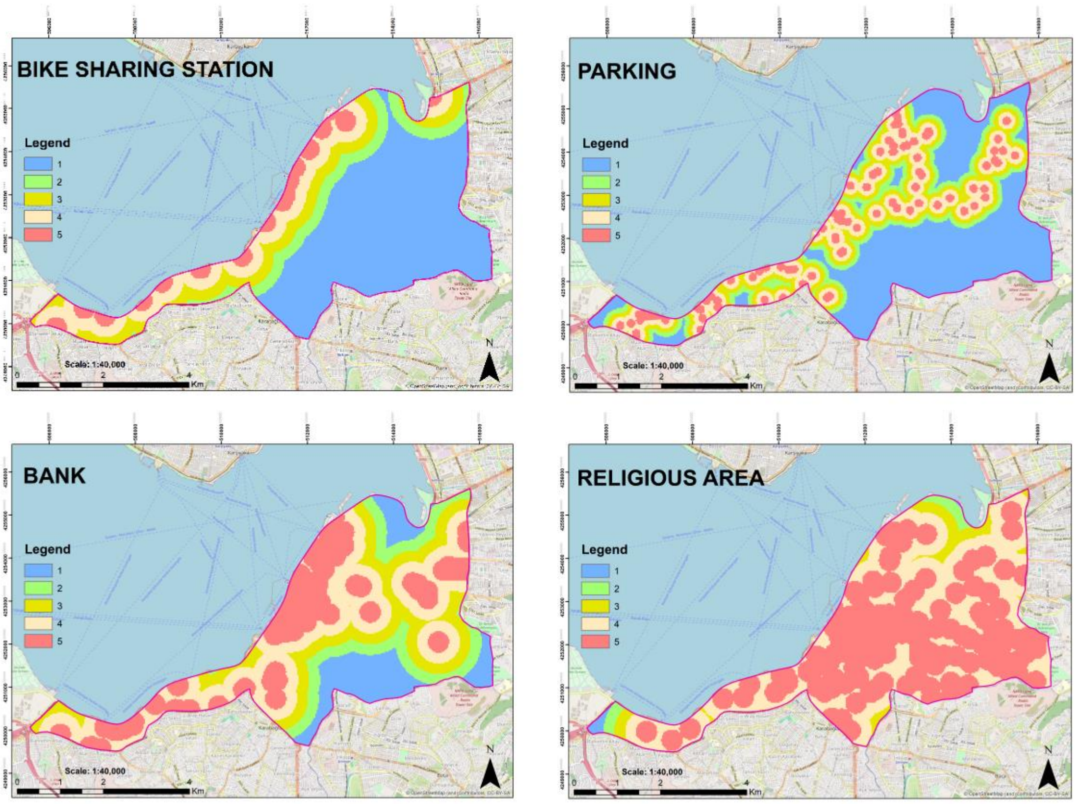

Figure 7. Suitability maps ($C_{5\text{-}8}$)

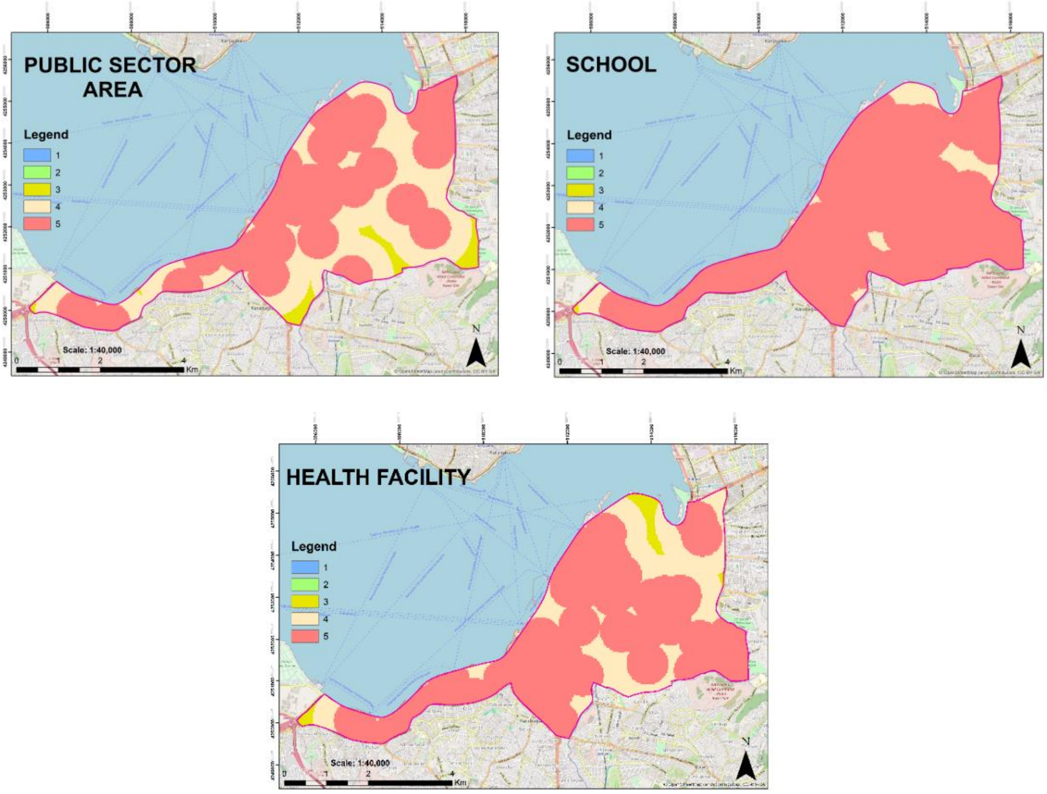

Figure 8. Suitability maps (C_{9-11})

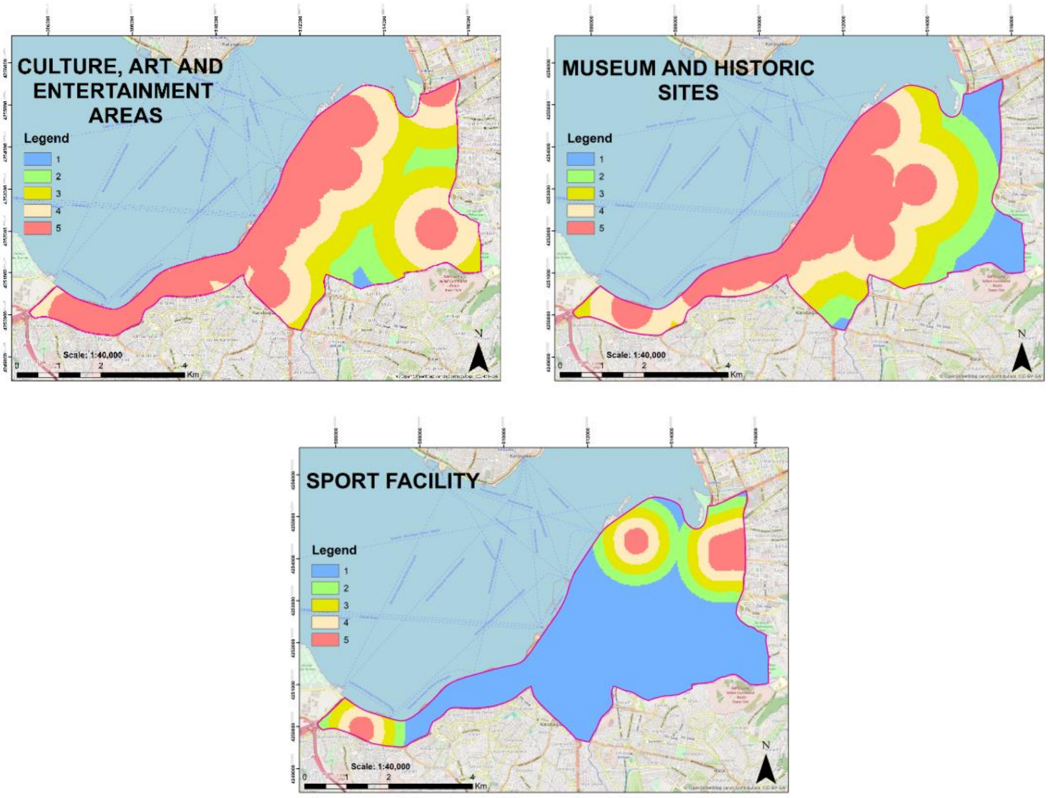

Figure 9. Suitability maps (C_{12-14})

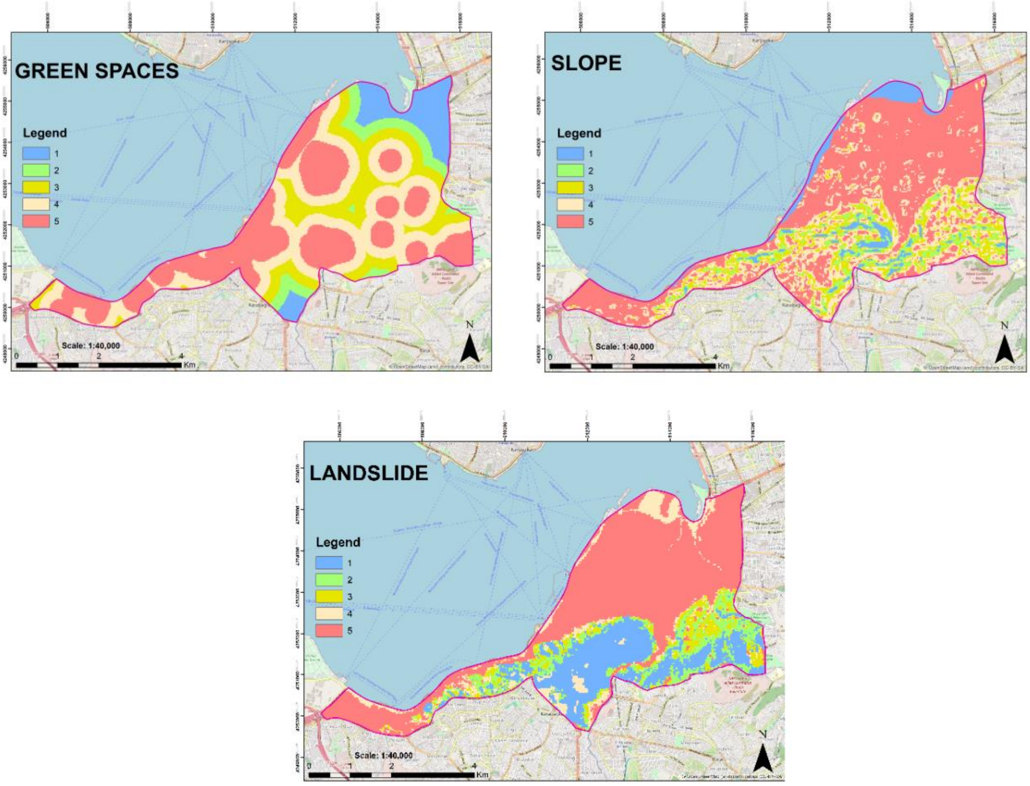

Figure 10. Suitability maps ($C_{15\text{-}17}$)

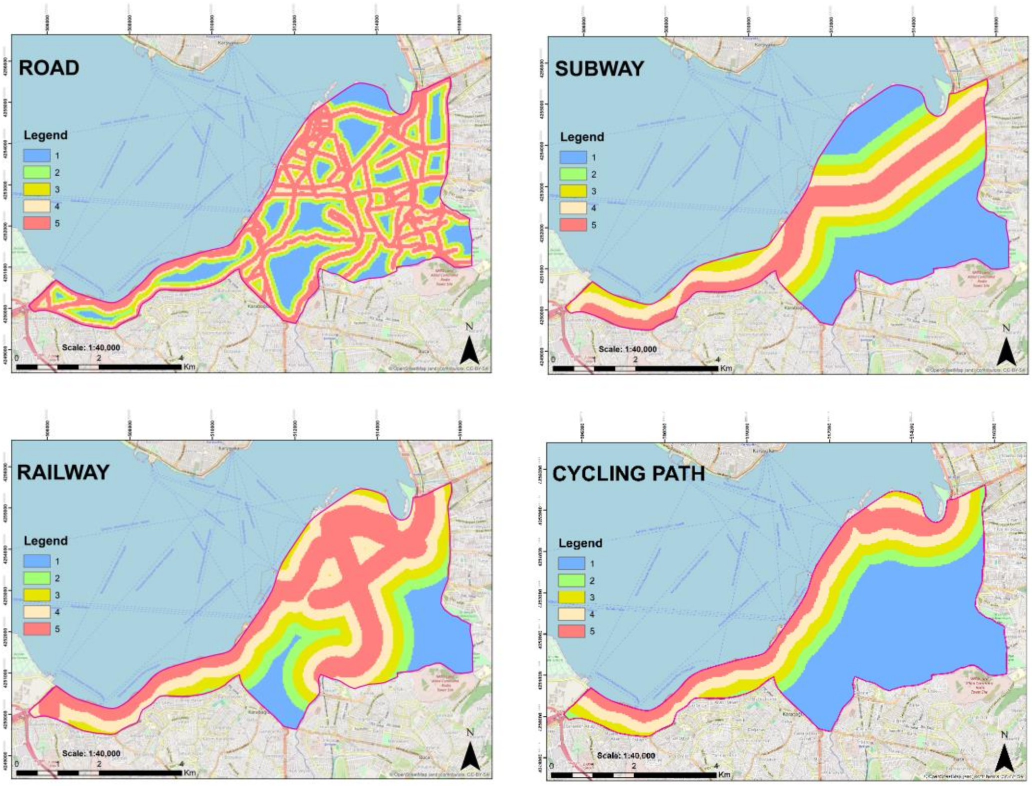

Figure 11. Suitability maps ($C_{18\text{-}21}$; $C_{22\text{-}25}$)

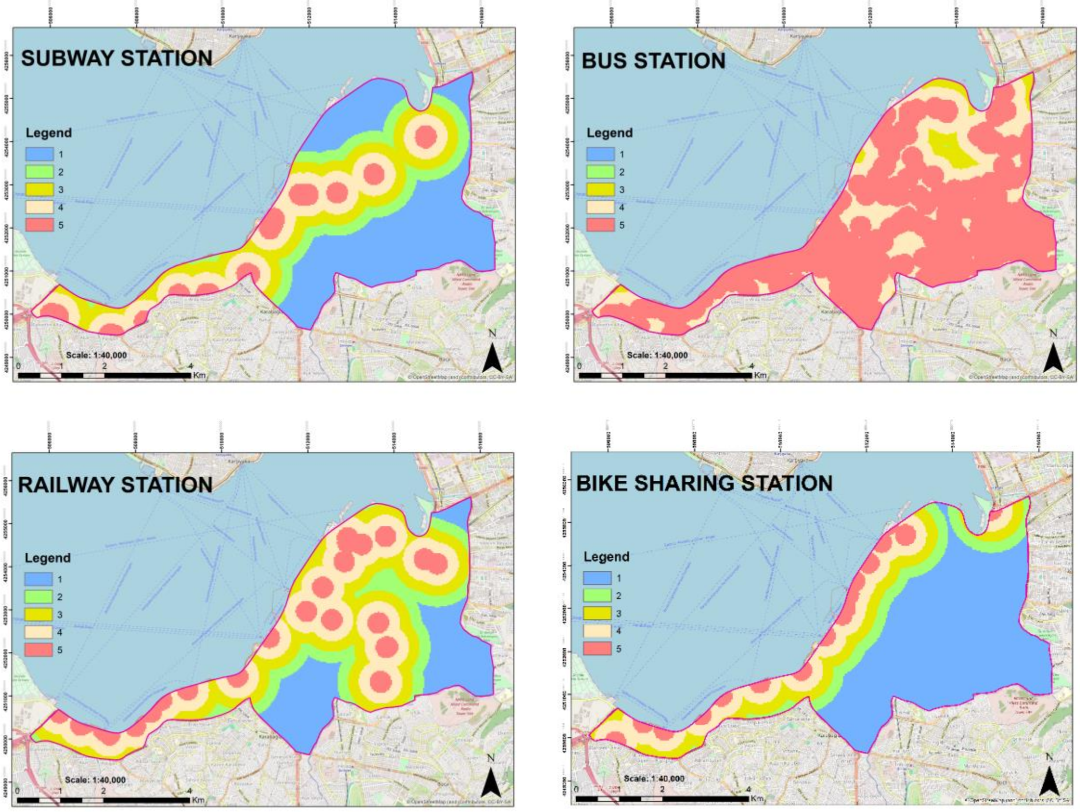

Figure 12. Suitability maps (C_{26-29})

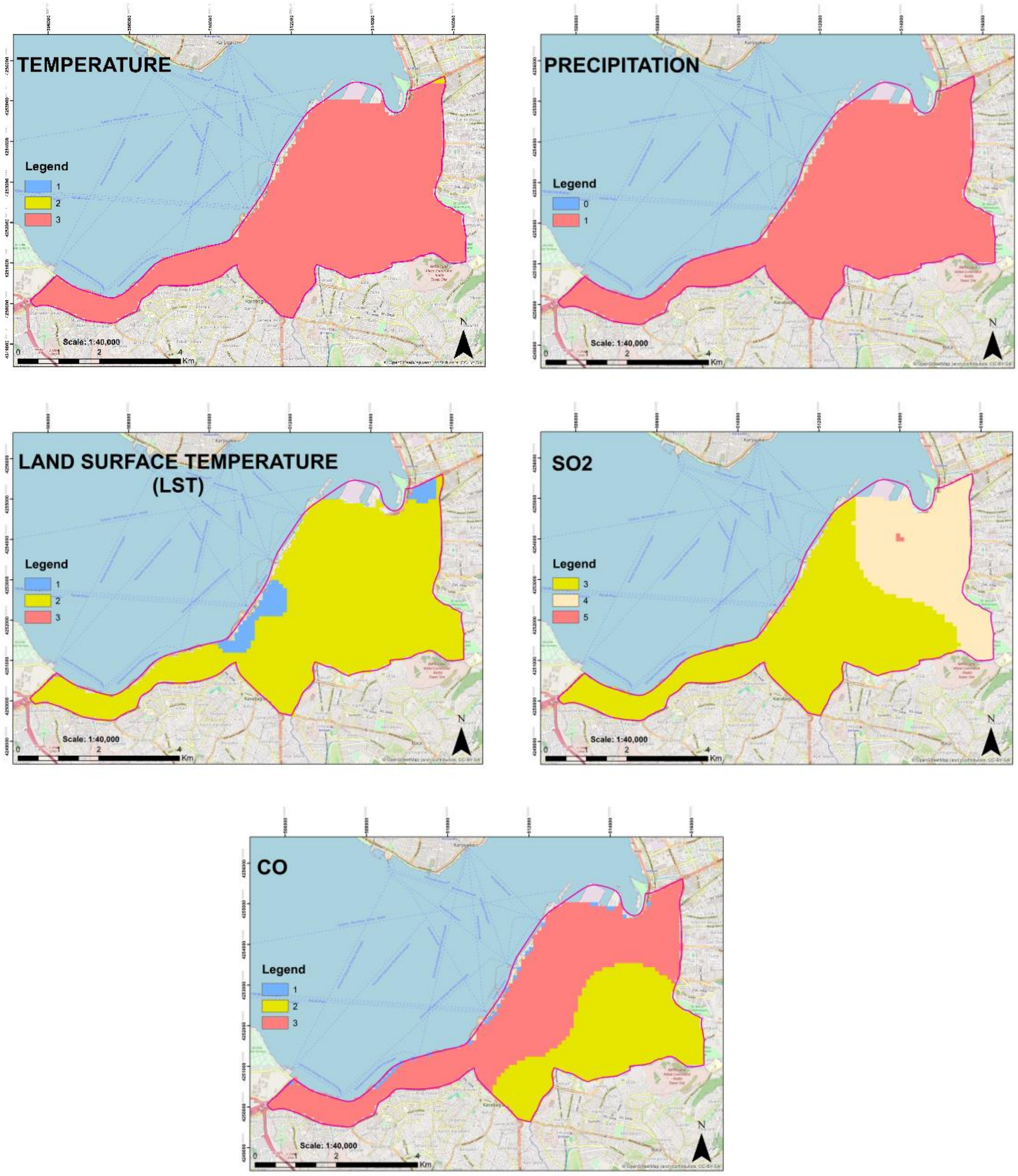

Figure 13. Suitability maps ($C_{30\text{-}34}$)

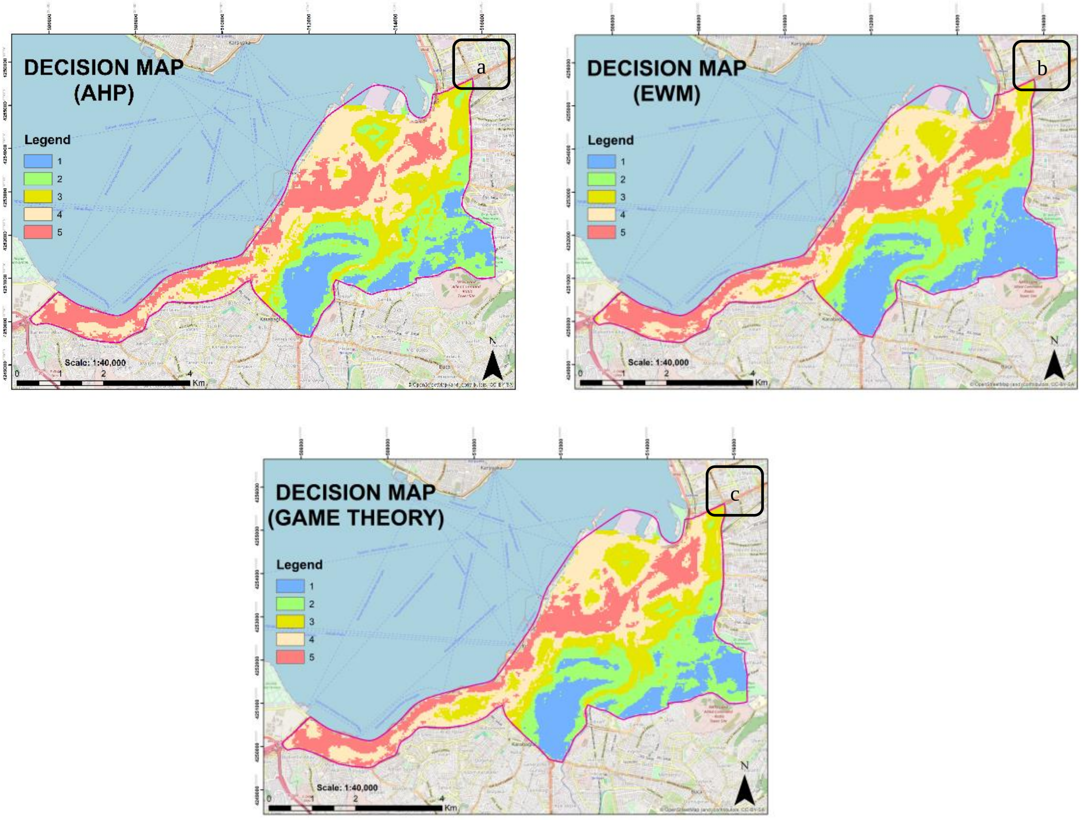

Figure 14. Decision maps

6. RESULTS

The findings section comprises three separate parts where the results obtained from the AHP, EWM, and Game Theory methodologies are compared and evaluated. Thus, by highlighting the differences between the methods, it is demonstrated that the Game Theory method, which minimizes the differences between the methods, should be actively used in the decision-making processes of municipalities. In addition, this section emphasizes the facilitative effect of the developed model on urban planning and site selection studies. Furthermore, using the data from the decision maps in the TOPSIS method, areas in the study area where investments can be made to achieve livability and sustainability have been identified.

The study concludes that, although the suitability values of each criterion differ according to its sub-criteria, the suitable areas vary within a hierarchy where AHP, EWM, Game Theory, and WLC methods are utilized.

6.1. Evaluation of MGIS Solution Model with AHP

The decision map (Figure 14a) resulting from the application of the AHP methodology based on urban planning criteria within the MGIS model was examined. The AHP decision map identifies that the most suitable areas (Score: 5) are concentrated in the north, west, and southwest sections of the Konak district. The parts where the most suitable areas are concentrated are close to the central residential areas, transportation lines, parking spaces, culture, arts and entertainment areas, sports facilities, the sea, and green areas of the Konak district. It has also been determined that these areas have less slope.

Very suitable areas (Score: 4) are densely located in the northern part of the study area and partially in the west and southwest. Suitable areas (Score: 3) are mainly found in the north and northeast, with some in the south and southwest. Conversely, when the less suitable areas (Score: 2) are examined, it is seen that albeit they are more prevalent especially in the south and southeast parts, there are also comparatively less suitable areas in the north and northeast. Finally, upon examining the unsuitable areas (Score: 1), they are found to be in the south and southeast regions.

The findings show that the lack of other forms of transportation infrastructure than buses, the area's slope, the scarcity of green areas, the distance from parking areas, being remote from sports facilities, culture, arts and entertainment areas, the risk of landslides, and the lack of an effective local settlement plan are all significant factors. Additionally, the AHP method revealed that the criteria for Green Spaces, Landslides, and Roads had the highest weights. The results obtained demonstrate that these three criteria have played a significant role.

6.2. Evaluation of MGIS Solution Model with EWM

In the EWM decision map (Figure 14b), it has been determined that the most suitable areas (Score: 5) are located in the north, west, and southwest sections of the study area. Particularly in the north and southwest sections, it has been identified that the most suitable areas cover a large spread. The parts where the most suitable areas are concentrated are close to the central residential areas, transportation lines, the sea, parking spaces, culture, arts and entertainment areas, and green areas of the Konak district. It has also been determined that these areas have less slope.

Very suitable areas (Score: 4) are densely located in the northern part of the study area and partially in the west and southwest. The difference between these areas compared to the most suitable ones is primarily their slightly greater distance from transportation lines. Suitable areas (Score: 3) are mainly found in the north, northeast, and central sections of the study area, with some also in the south and southwest. However, upon examining the less suitable areas (Score: 2), it is observed that these areas are especially located in the central, south, and east sections. The southerly section of these sections has been found to have a higher concentration of less suitable areas. Also, when the unsuitable areas are examined (Score: 1), they are found to be in the south and southeast regions.

The results indicate that the absence of a subway, railway, cycling path, subway station, railway station, bike sharing station areas, being a sloped region, the scarcity of green areas, the distance from culture, arts and entertainment areas, the absence of parking and sports facilities areas, landslide risk, and not having a good local settlement plan are significant factors. Furthermore, the criteria with the highest weights according to the EWM were Subway, Railway, and LST. The outcomes indicate that these three criteria have had a significant impact, and the weighted results of the criteria are different from those obtained by the AHP method.

6.3. Evaluation of MGIS Solution Model with Game Theory

In the Game Theory decision map (Fig 14c), it has been determined that the most suitable areas (Score: 5) are located in the north, west, and southwest sections of the study area. Particularly in the north and west sections, it has been identified that the most suitable areas cover a large spread. The parts where the most suitable areas are concentrated are close to the central residential areas, transportation lines, the sea, parking spaces, culture, arts and entertainment areas, sports facilities, and green areas of the Konak district. It has also been determined that these areas have less slope.

Very suitable areas (Score: 4) are densely located in the northern part of the study area and partially in the west and southwest. The difference between these areas compared to the most suitable ones is primarily the impact of the transportation factor. Suitable areas (Score: 3) are mainly found in the north, northeast, and central sections of the study area, with some also in the south and southwest. Conversely, when the less suitable areas (Score: 2) are examined, it is observed that these areas are especially located in the central, south, and southeast sections. Additionally, it has been identified that less suitable areas also partially occur in the north and northeast. Among these sections, a higher concentration of less suitable areas has been identified in the southeastern part. Finally, when the unsuitable areas are examined (Score: 1), these areas are found in the south and southeast regions.

The results indicate that the absence of transportation diversity and the lack of stations for these modes of transport, the scarcity of green areas, the distance from culture, arts and entertainment areas, the absence of parking and sports facilities areas, the presence of sloped areas with a high landslide risk, and not having a good local settlement plan are significant factors. In addition, according to the Game Theory method, the criteria of Precipitation, SO2, and CO have been assigned the highest weights. These findings also display variations from the results obtained through the AHP and EWM.

6.4. Comparison of AHP and EWM Methods in the MGIS Solution Model

When comparing the decision maps produced using AHP and EWM methodologies (Figure 14a, 14b), it has been determined that the most suitable areas (Score: 5) located in the northern section of the AHP decision map are less extensive than the same region in the EWM decision map. The most suitable areas in the western part of the AHP decision map are more extensive than the same region in the EWM decision map. It has been found that the most suitable areas in the southwestern parts of both decision maps are approximately of the same extent.

It has been identified that the very suitable areas (Score: 4) in the north and central sections of the AHP decision map cover less area compared to the same region in the EWM decision map; especially in this region, there is an increase in the most suitable areas (Score: 5) in the EWM decision map. Additionally, it has been observed that the very suitable areas (Score: 4) in the west and southwest sections of the AHP decision map have decreased as a result of the application of the EWM methodology (Figure 14b), while suitable areas (Score: 3) have increased in these regions. Moreover, it has been determined that the most suitable areas (Score: 5) in the southwestern extremities of Figure 14a have decreased with the application of the EWM method, and there has been an increase in very suitable (Score: 4) areas (Figure 14b).

The suitable areas (Score: 3) located in the north of the AHP decision map cover less area compared to the same region in the EWM decision map. When the suitable areas in the northeast and east regions of the AHP decision map were examined, it was found that these areas also covered less area compared to the EWM decision map; especially in these areas, an increase in very suitable (Score: 4) and less suitable areas (Score: 2) was observed. Additionally, it has been determined that the suitable areas in the southwest region of the AHP decision map cover more area compared to the same region in the EWM decision map. This area has seen an increase in very suitable areas (Score: 4) due to the effect of the EWM methodology.

The less suitable areas (Score: 2) located in the north and northeast of the AHP decision map were not found in the EWM decision map, where an increase in suitable areas (Score: 3) has been identified. While the less suitable areas (Score: 2) in the eastern part of the AHP decision map have shown an increase in the same region with the application of the EWM methodology (Figure 14b), the less suitable areas (Score: 2) in the southeast part of the AHP decision map have significantly decreased in the EWM decision map. Contrarily, it has been determined that there is a substantial increase in unsuitable areas (Score: 1) in these regions. Moreover, when the southern parts of the study area were examined, it was observed that the less suitable areas (Score: 2) in the AHP decision map showed a partial increase in the EWM decision map; especially in these areas, a decrease in suitable areas (Score: 3) was noticed.

The unsuitable areas (Score: 1) in the southeast part of the AHP decision map have shown a significant increase in the EWM decision map. Similarly, a partial increase has been observed in the unsuitable areas in the southern part of the AHP decision map. Thus, it has been determined that the unsuitable areas have replaced the less suitable areas (Score: 2).

The changes in the suitability values obtained as a result of the application of the AHP and EWM methods across the study area are presented in Table 35.

Table 35. Area analysis of AHP and EWM decision maps according to their suitable values

Suitability Index	AHP (ha)	Percentage (%)	EWM (ha)	Percentage (%)	Percentage Difference
1	349.65	15.86	492.35	22.33	- 6.47
2	436.79	19.81	371.44	16.85	+ 2.96
3	453.32	20.56	383.64	17.40	+ 3.16
4	569.91	25.85	519.62	23.57	+ 2.28
5	395.23	17.93	437.86	19.86	- 1.93
Total	2204.91	100	2204.91	100	

The application of the EWM methodology has increased in the most suitable areas (Score: 5), whereas decreases have been observed in the very suitable (Score: 4), suitable (Score: 3), and less suitable (Score: 2) areas when the changes in the suitability values across the study area are examined. The unsuitable areas, on the other hand, have shown an increase of 6.47% when the EWM methodology was applied. These results stem from the mathematical model of the EWM method being simpler compared to the AHP method.

6.5. Comparison of AHP and Game Theory Methods in the MGIS Solution Model

The most suitable areas (Score: 5) in the northeast section of the Game Theory decision map have increased when compared to the same region in the AHP decision map, according to a comparison of the decision maps created using the AHP and Game Theory methodologies (Figure 14a, 14c). However, the distribution and extent of the most suitable areas located in the west and southwest regions are found to be almost the same in the results obtained from both methodologies.

Despite the very suitable areas (Score: 4) in the northeast section of the AHP decision map covering less area compared to the same region in the Game Theory decision map, an increase in this ratio has been observed in the north and northwest sections. Similarly, an increase in very suitable areas has been determined in the central, south, and southwest sections with the application of the Game Theory methodology.

Furthermore, it has been determined that the suitable areas (Score: 3) located in the north and northeast regions of the AHP decision map cover less area compared to the same region in the Game Theory decision map. A decrease in suitable areas has been observed in the eastern and southern sections with the application of the Game Theory methodology. Additionally, an increase in suitable areas has been observed in the southwest section of the Game Theory decision map.

Findings from the analysis of the study area's less suitable areas (Score: 2) indicate that areas located in the north and northeast of the AHP decision map have decreased in the Game Theory decision map. Contrarily, an increase in these areas has been observed in the eastern part. Overall, partial decreases and increases have been seen regionally in the southern sections with the application of the Game Theory methodology. Although there have been some minor regional decreases and increases, the analysis of the unsuitable areas (Score: 1) has not revealed any significant changes in either of the decision maps.

The changes in the suitability values obtained as a result of the application of the AHP and Game Theory methods across the study area are presented in Table 36.

Table 36. Area analysis of AHP and Game Theory decision maps according to their suitable values

Suitability Index	AHP (ha)	Percentage (%)	Game Theory (ha)	Percentage (%)	Percentage Difference
1	349.65	15.86	356.55	16.17	- 0.31
2	436.79	19.81	445.94	20.22	- 0.41
3	453.32	20.56	459.66	20.85	- 0.29
4	569.91	25.85	531.03	24.08	+ 1.77
5	395.23	17.93	411.73	18.67	- 0.74
Total	2204.91	100	2204.91	100	

In summary, after a thorough analysis of these changes, it was found that the application of the Game Theory methodology led to decreases in all areas except for the very suitable areas (Score: 4). However, these decreases have not been significant, indicating that the AHP methodology produces similar results to the Game Theory method.

6.6. Comparison of EWM and Game Theory Methods in the MGIS Solution Model

When the decision maps produced using EWM and Game Theory methodologies (Fig 14b, 14c) were compared, it was observed that the most suitable areas (Score: 5) located in the northeastern and western sections of the Game Theory decision map had decreased compared to the same regions in the EWM decision map. Similarly, by applying the Game Theory methodology, a partial regional decrease was detected in the most suitable areas located in the southwest section.

Furthermore, it has been determined that the very suitable areas (Score: 4) in the northeastern section of the EWM decision map also increased in the same region in the Game Theory decision map. This increase has also been observed in the northwest, southwest, and central sections of the study area. However, according to both methods, no significant change was identified in the western region.

With regards to the suitable areas (Score: 3), it has been determined that the suitable areas in the northern region of the EWM decision map cover a larger area than the same region in the Game Theory decision map. Additionally, regional decreases and increases have been observed in the east and northeast regions. However, no significant changes have been noticed in other regions.

Upon examination of the less suitable areas (Score: 2) in the study area, a significant increase has been found in the areas located in the southeast of the EWM decision map in the Game Theory decision map. Contrarily, no significant changes have been found in other regions.

The examination of unsuitable areas (Score: 1) has determined a significant decrease in areas located in the southeast of the EWM decision map in the Game Theory decision map. Although no significant changes have been found in other regions, partial decreases have been observed.

The changes in the suitability values obtained as a result of applying the EWM and Game Theory methods across the study area are presented in Table 37.

Table 37. Area analysis of EWM and Game Theory decision maps according to their suitable values

Suitability Index	EWM (ha)	Percentage (%)	Game Theory (ha)	Percentage (%)	Percentage Difference
1	492.35	22.33	356.55	16.17	+ 6.16
2	371.44	16.85	445.94	20.22	- 3.37
3	383.64	17.40	459.66	20.85	- 3.45
4	519.62	23.57	531.03	24.08	- 0.51
5	437.86	19.86	411.73	18.67	+ 1.19
Total	2204.91	100	2204.91	100	

The analyses have shown that the application of the Game Theory methodology resulted in decreases in the most suitable (Score: 5) and unsuitable areas (Score: 1), while increases occurred in other areas. In particular, a significant decrease has been observed in unsuitable areas following the application of the Game Theory methodology. In effect, the formation of these results has been influenced by the Game Theory method, which balances the AHP and EWM methods with the “Nash Equilibrium”, and this equilibrium point creates differences with the EWM mathematical model.

6.7. Ranking of Investment Sites with TOPSIS

The study results identify unsuitable areas (Figure 14) that demonstrate where investments can be made to enhance livability and create sustainable cities. However, the challenge arises in deciding which of these areas should be prioritized when making investment plans. Thus, the TOPSIS method was used to solve this problem. Before applying the TOPSIS method, planning and suitability index domains were evaluated, and the unsuitable areas were divided into 15 alternative areas (Figure 15-17). Afterwards, the identified alternative areas were compared with each other based on the pixel values of each criterion (Table 38-52).

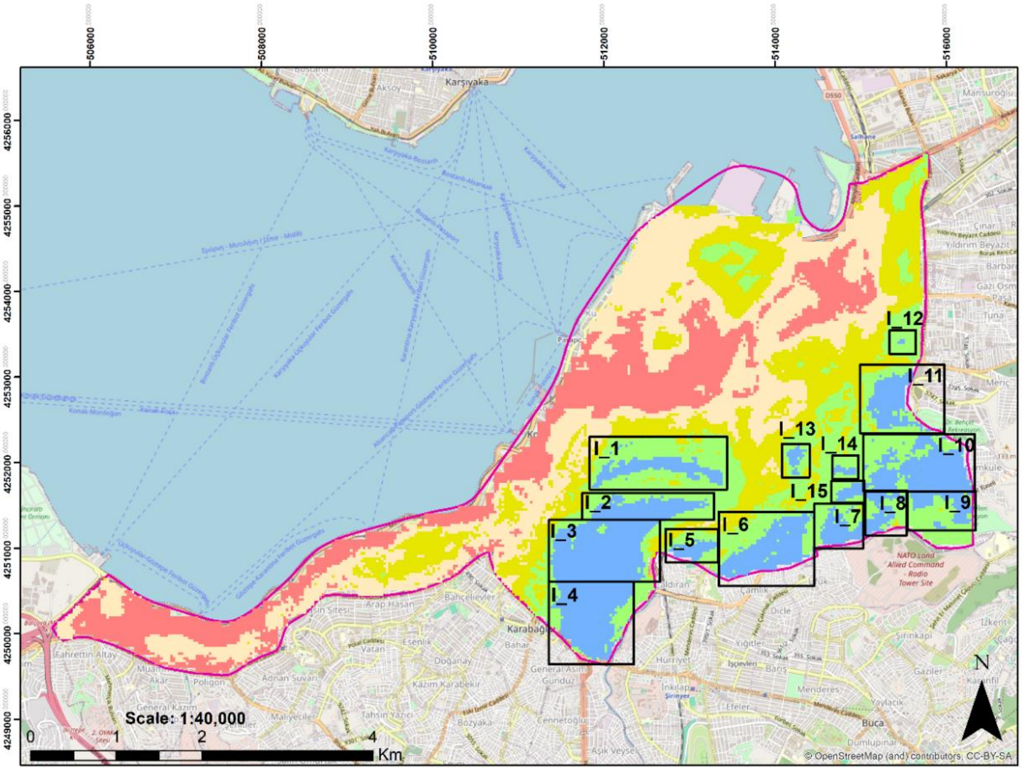

Figure 15. Alternative investment sites map (AHP)

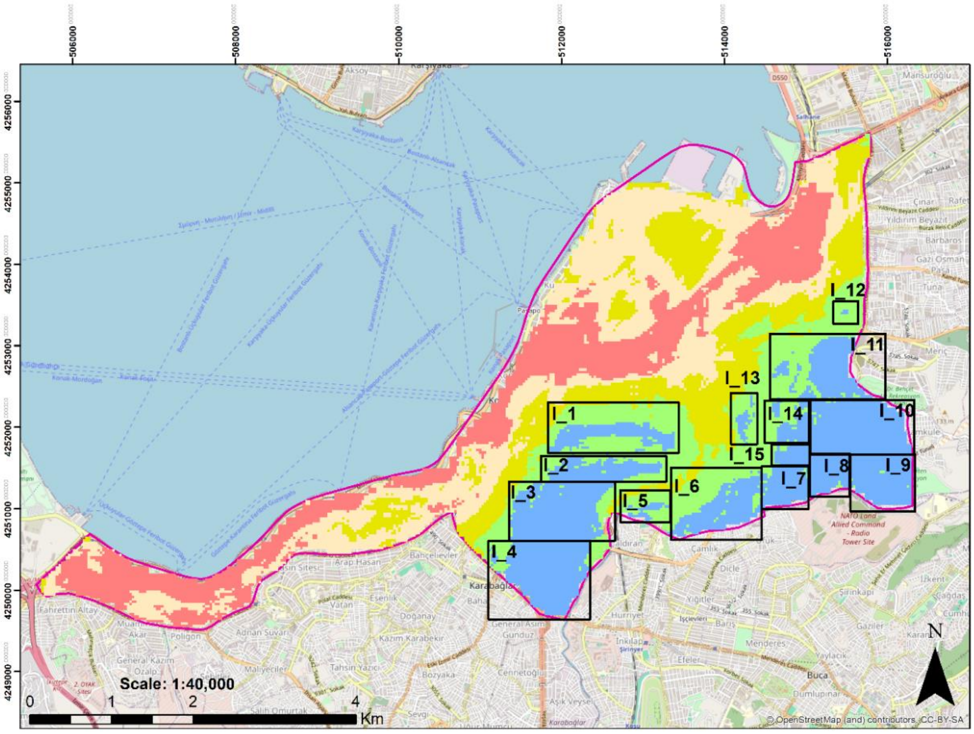

Figure 16. Alternative investment sites map (EWM)

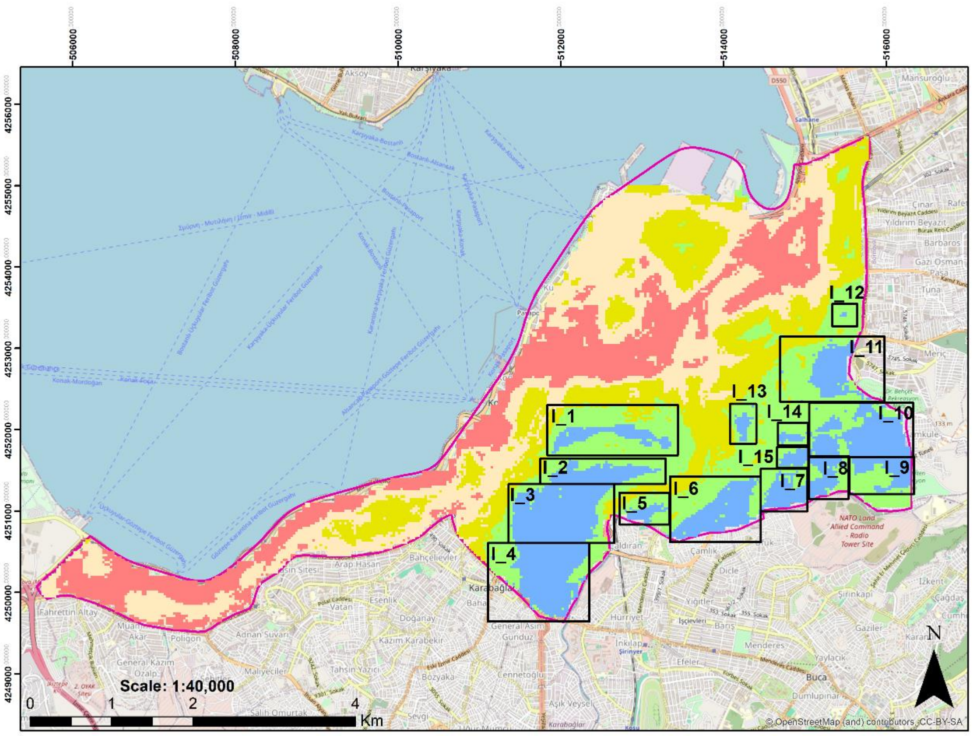

Figure 17. Alternative investment sites map (Game Theory)

Table 38. Alternative investment sites' values according to pixel values with AHP (Walkability)

Site Index	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}
I_1	4	2	5	2	1	1	3	5	5	5	5	4	5	1
I_2	5	1	5	3	1	1	2	5	5	5	5	3	5	1
I_3	4	1	5	1	1	1	3	5	4	5	5	4	4	1
I_4	2	1	5	1	1	1	3	4	4	5	5	4	2	1
I_5	5	1	5	3	1	1	1	5	5	5	4	2	4	1
I_6	3	1	5	4	1	1	1	5	4	5	5	2	3	1
I_7	5	1	5	2	1	1	2	4	4	5	5	4	2	1
I_8	5	1	5	1	1	1	3	5	4	5	5	4	1	1
I_9	5	1	5	1	1	1	1	5	4	5	5	4	1	1
I_10	4	1	5	1	1	1	4	5	4	5	5	5	1	1
I_11	4	1	5	1	1	1	4	5	4	5	4	4	2	1
I_12	2	1	5	2	1	1	4	4	4	4	4	3	2	3
I_13	5	1	4	4	1	1	2	5	4	5	5	4	3	1
I_14	4	1	5	2	1	1	4	5	5	5	5	5	2	1
I_15	4	1	5	1	1	1	4	5	5	5	5	4	2	1

Table 39. Alternative investment sites' values according to pixel values with AHP (Environment)

Site Index	C_{15}	C_{16}	C_{17}
I_1	4	3	1
I_2	5	3	1
I_3	4	4	1
I_4	2	3	2
I_5	5	3	1
I_6	3	4	2
I_7	5	4	2
I_8	5	4	1
I_9	5	3	2
I_10	4	4	2
I_11	4	4	2
I_12	2	5	5
I_13	5	3	2
I_14	4	4	2
I_15	4	3	1

Table 40. Alternative investment sites' values according to pixel values with AHP (Connectivity)

Site Index	C_{18}	C_{19}	C_{20}	C_{21}
I_1	3	2	3	1
I_2	2	1	3	1
I_3	2	2	2	1
I_4	3	1	2	1
I_5	2	1	5	1
I_6	3	1	4	1
I_7	3	1	2	1
I_8	4	1	1	1
I_9	3	1	1	1
I_10	4	1	1	1
I_11	3	1	1	1
I_12	3	1	2	1
I_13	2	1	4	1
I_14	4	1	2	1
I_15	4	1	2	1

Table 41. Alternative investment sites' values according to pixel values with AHP (Transportation)

Site Index	C_{22}	C_{23}	C_{24}	C_{25}	C_{26}	C_{27}	C_{28}	C_{29}
I_1	3	2	3	1	2	5	2	1
I_2	2	1	3	1	1	5	3	1
I_3	2	2	2	1	1	5	1	1
I_4	3	1	2	1	1	5	1	1
I_5	2	1	5	1	1	5	3	1
I_6	3	1	4	1	1	5	4	1
I_7	3	1	2	1	1	5	2	1
I_8	4	1	1	1	1	5	1	1
I_9	3	1	1	1	1	5	1	1
I_10	4	1	1	1	1	5	1	1

Table 41. Alternative investment sites' values according to pixel values with AHP (Transportation) (continue)

Site Index	C_{22}	C_{23}	C_{24}	C_{25}	C_{26}	C_{27}	C_{28}	C_{29}
I_11	3	1	1	1	1	5	1	1
I_12	3	1	2	1	1	5	2	1
I_13	2	1	4	1	1	4	4	1
I_14	4	1	2	1	1	5	2	1
I_15	4	1	2	1	1	5	1	1

Table 42. Alternative investment sites' values according to pixel values with AHP (Climate Change)

Site Index	C_{30}	C_{31}	C_{32}	C_{33}	C_{34}
I_1	3	1	2	3	3
I_2	3	1	2	3	3
I_3	3	1	2	3	2
I_4	3	1	2	3	2
I_5	3	1	2	3	2
I_6	3	1	2	3	2
I_7	3	1	2	3	2
I_8	3	1	2	3	2
I_9	3	1	2	4	2
I_10	3	1	2	4	2
I_11	3	1	2	4	2
I_12	3	1	2	4	3
I_13	3	1	2	3	2
I_14	3	1	2	3	2
I_15	3	1	2	3	2

Table 43. Alternative investment sites' values according to pixel values with EWM (Walkability)

Site Index	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}
I_1	4	2	5	2	1	1	3	5	5	5	5	4	5	1
I_2	5	1	5	2	1	1	2	5	5	5	5	3	5	1
I_3	4	1	5	1	1	1	3	5	4	5	5	4	4	1
I_4	3	1	5	1	1	1	3	4	4	5	5	4	2	1
I_5	5	1	5	3	1	1	1	5	5	5	4	2	4	1
I_6	3	1	5	4	1	1	1	5	4	5	5	3	3	1
I_7	5	1	5	2	1	1	2	5	4	5	5	4	2	1
I_8	5	1	5	1	1	1	3	5	4	5	5	4	1	1
I_9	5	1	5	1	1	1	1	5	3	5	5	4	1	1
I_10	4	1	5	1	1	1	3	5	4	5	5	5	1	1
I_11	4	1	5	1	1	3	4	5	4	5	5	4	3	1
I_12	2	1	5	2	1	1	4	4	4	4	4	3	2	3
I_13	5	1	5	4	1	1	2	5	4	5	5	4	3	1
I_14	4	1	5	2	1	1	4	5	5	5	5	5	3	1
I_15	4	1	5	1	1	1	4	5	5	5	5	4	2	1

Table 44. Alternative investment sites' values according to pixel values with EWM (Environment)

Site Index	C_{15}	C_{16}	C_{17}
I_1	4	3	1
I_2	5	3	1
I_3	4	4	1
I_4	3	3	2
I_5	5	3	2
I_6	3	4	2
I_7	5	4	2
I_8	5	4	1
I_9	5	3	2
I_10	4	4	2

Table 44. Alternative investment sites' values according to pixel values with EWM (Environment) (continue)

Site Index	C_{15}	C_{16}	C_{17}
I_11	4	4	3
I_12	2	5	5
I_13	5	4	2
I_14	4	4	3
I_15	4	4	2

Table 45. Alternative investment sites' values according to pixel values with EWM (Connectivity)

Site Index	C_{18}	C_{19}	C_{20}	C_{21}
I_1	3	2	3	1
I_2	2	1	3	1
I_3	2	2	3	1
I_4	3	1	1	1
I_5	2	1	5	1
I_6	3	1	4	1
I_7	3	1	2	1
I_8	4	1	1	1
I_9	4	1	1	1
I_10	4	1	1	1
I_11	4	1	1	1
I_12	2	1	2	1
I_13	2	1	4	1
I_14	4	1	2	1
I_15	4	1	2	1

Table 46. Alternative investment sites' values according to pixel values with EWM (Transportation)

Site Index	C_{22}	C_{23}	C_{24}	C_{25}	C_{26}	C_{27}	C_{28}	C_{29}
I_1	3	2	3	1	2	5	2	1
I_2	2	1	3	1	1	5	2	1
I_3	2	2	3	1	1	5	1	1
I_4	3	1	1	1	1	5	1	1
I_5	2	1	5	1	1	5	3	1
I_6	3	1	4	1	1	5	4	1
I_7	3	1	2	1	1	5	2	1
I_8	4	1	1	1	1	5	1	1
I_9	4	1	1	1	1	5	1	1
I_10	4	1	1	1	1	5	1	1
I_11	4	1	1	1	1	5	1	1
I_12	2	1	2	1	1	5	2	1
I_13	2	1	4	1	1	5	4	1
I_14	4	1	2	1	1	5	2	1
I_15	4	1	2	1	1	5	1	1

Table 47. Alternative investment sites' values according to pixel values with EWM (Climate Change)

Site Index	C_{30}	C_{31}	C_{32}	C_{33}	C_{34}
I_1	3	1	2	3	3
I_2	3	1	2	3	3
I_3	3	1	2	3	2
I_4	3	1	2	3	2
I_5	3	1	2	3	2
I_6	3	1	2	3	2
I_7	3	1	2	3	2
I_8	3	1	2	3	2
I_9	3	1	2	4	2
I_10	3	1	2	4	2

Table 47. Alternative investment sites' values according to pixel values with EWM (Climate Change) (continue)

Site Index	C_{30}	C_{31}	C_{32}	C_{33}	C_{34}
I_11	3	1	2	4	2
I_12	3	1	2	4	3
I_13	3	1	2	3	2
I_14	3	1	2	3	2
I_15	3	1	2	3	2

Table 48. Alternative investment sites' values according to pixel values with Game Theory (Walkability)

Site Index	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}
I_1	4	2	5	2	1	1	3	5	5	5	5	4	5	1
I_2	5	1	5	2	1	1	2	4	5	5	5	3	5	1
I_3	4	1	5	1	1	1	3	5	4	5	5	4	4	1
I_4	2	1	5	1	1	1	3	4	4	5	5	4	2	1
I_5	5	1	5	3	1	1	1	5	5	5	4	2	4	1
I_6	4	1	5	4	1	1	1	5	4	5	5	2	3	1
I_7	5	1	5	2	1	1	2	4	4	5	5	4	2	1
I_8	5	1	5	1	1	1	3	5	4	5	5	4	1	1
I_9	5	1	5	1	1	1	1	5	4	5	5	4	1	1
I_10	4	1	5	1	1	1	3	5	4	5	5	5	1	1
I_11	4	1	5	1	1	1	4	5	4	5	5	4	3	1
I_12	2	1	5	2	1	1	4	4	4	4	4	3	2	3
I_13	5	1	4	4	1	1	2	5	4	5	5	4	3	1
I_14	3	1	5	1	1	1	4	5	5	5	5	5	2	1
I_15	4	1	5	1	1	1	4	5	5	5	5	4	2	1

Table 49. Alternative investment sites' values according to pixel values with Game Theory (Environment)

Site Index	C_{15}	C_{16}	C_{17}
I_1	4	3	1
I_2	5	3	1
I_3	4	4	1
I_4	2	3	2
I_5	5	3	1
I_6	4	4	2
I_7	5	4	1
I_8	5	4	1
I_9	5	3	2
I_10	4	4	2
I_11	4	4	2
I_12	2	5	5
I_13	5	3	2
I_14	3	4	2
I_15	4	3	1

Table 50. Alternative investment sites' values according to pixel values with Game Theory (Connectivity)

Site Index	C_{18}	C_{19}	C_{20}	C_{21}
I_1	3	2	3	1
I_2	2	1	3	1
I_3	2	2	3	1
I_4	3	1	2	1
I_5	2	1	5	1
I_6	3	1	4	1
I_7	3	1	2	1
I_8	4	1	1	1
I_9	3	1	1	1
I_10	4	1	1	1
I_11	3	1	1	1
I_12	2	1	2	1

Table 50. Alternative investment sites' values according to pixel values with Game Theory (Connectivity) (continue)

Site Index	C_{18}	C_{19}	C_{20}	C_{21}
I_13	2	1	4	1
I_14	5	1	2	1
I_15	4	1	2	1

Table 51. Alternative investment sites' values according to pixel values with Game Theory (Transportation)

Site Index	C_{22}	C_{23}	C_{24}	C_{25}	C_{26}	C_{27}	C_{28}	C_{29}
I_1	3	2	3	1	2	5	2	1
I_2	2	1	3	1	1	5	2	1
I_3	2	2	3	1	1	5	1	1
I_4	3	1	2	1	1	5	1	1
I_5	2	1	5	1	1	5	3	1
I_6	3	1	4	1	1	5	4	1
I_7	3	1	2	1	1	5	2	1
I_8	4	1	1	1	1	5	1	1
I_9	3	1	1	1	1	5	1	1
I_10	4	1	1	1	1	5	1	1
I_11	3	1	1	1	1	5	1	1
I_12	2	1	2	1	1	5	2	1
I_13	2	1	4	1	1	4	4	1
I_14	5	1	2	1	1	5	1	1
I_15	4	1	2	1	1	5	1	1

Table 52. Alternative investment sites' values according to pixel values with Game Theory (Climate Change)

Site Index	C_{30}	C_{31}	C_{32}	C_{33}	C_{34}
I_1	3	1	2	3	3
I_2	3	1	2	3	3
I_3	3	1	2	3	2
I_4	3	1	2	3	2
I_5	3	1	2	3	2
I_6	3	1	2	3	2
I_7	3	1	2	3	2
I_8	3	1	2	3	2
I_9	3	1	2	4	2
I_10	3	1	2	4	2
I_11	3	1	2	4	2
I_12	3	1	2	4	3
I_13	3	1	2	3	2
I_14	3	1	2	3	2
I_15	3	1	2	3	2

Investment areas were ranked according to their priorities using the pixel values of the criteria, the weights obtained through AHP, EWM and Game Theory methods, and the mathematical model of the TOPSIS method (Table 53-58). In conducting these priority rankings, the weighted criteria recommended by the MGIS model for evaluating the criteria were utilized. Additionally, results have been obtained in the study for scenarios where equal-weighted criteria are used instead of the weighted criteria, and these two data sets have been compared (Table 59). The purpose of this comparison is to highlight the significance of identifying priority criteria for livable cities, given that each criterion has a different impact level on the study.

Table 53. Alternative investment sites' values according to equal weights (AHP)

Site Index	Si+	Si-	Ci	Rank
I_9	0.0149	0.0072	0.3277	15
I_4	0.0141	0.0070	0.3331	14
I_3	0.0131	0.0079	0.3764	13
I_8	0.0130	0.0089	0.4065	12
I_12	0.0122	0.0088	0.4194	11
I_5	0.0125	0.0092	0.4234	10
I_7	0.0114	0.0084	0.4261	9
I_11	0.0129	0.0096	0.4271	8
I_15	0.0127	0.0099	0.4383	7
I_10	0.0127	0.0107	0.4582	6
I_6	0.0126	0.0108	0.4618	5
I_2	0.0101	0.0099	0.4947	4
I_14	0.0099	0.0114	0.5344	3
I_13	0.0092	0.0128	0.5827	2
I_1	0.0078	0.0112	0.5887	1

Table 54. Alternative investment sites' values according to AHP weights

Site Index	Si+	Si-	Ci	Rank
I_12	0.0053	0.0012	0.1787	15
I_4	0.0055	0.0013	0.1861	14
I_11	0.0046	0.0024	0.3446	13
I_3	0.0046	0.0025	0.3516	12
I_15	0.0046	0.0025	0.3541	11
I_10	0.0046	0.0026	0.3612	10
I_6	0.0044	0.0028	0.3903	9
I_14	0.0042	0.0027	0.3919	8
I_9	0.0045	0.0034	0.4351	7
I_8	0.0045	0.0035	0.4366	6
I_7	0.0041	0.0035	0.4636	5
I_5	0.0040	0.0037	0.4814	4

Table 54. Alternative investment sites' values according to AHP weights (continue)

Site Index	Si+	Si-	Ci	Rank
I_2	0.0039	0.0038	0.4925	3
I_13	0.0038	0.0041	0.5193	2
I_1	0.0019	0.0046	0.7015	1

Table 55. Alternative investment sites' values according to equal weights (EWM)

Site Index	Si+	Si-	Ci	Rank
I_9	0.0198	0.0070	0.2616	15
I_4	0.0184	0.0074	0.2858	14
I_3	0.0182	0.0080	0.3058	13
I_2	0.0171	0.0084	0.3282	12
I_8	0.0181	0.0090	0.3313	11
I_7	0.0169	0.0085	0.3348	10
I_10	0.0181	0.0091	0.3357	9
I_12	0.0174	0.0091	0.3433	8
I_5	0.0176	0.0097	0.3556	7
I_15	0.0179	0.0104	0.3678	6
I_6	0.0171	0.0114	0.3994	5
I_14	0.0159	0.0118	0.4270	4
I_1	0.0147	0.0116	0.4411	3
I_13	0.0153	0.0132	0.4632	2
I_11	0.0131	0.0158	0.5458	1

Table 56. Alternative investment sites' values according to EWM weights

Site Index	Si+	Si-	Ci	Rank
I_9	0.0034	0.0010	0.2235	15
I_4	0.0033	0.0010	0.2285	14
I_3	0.0033	0.0010	0.2358	13
I_12	0.0031	0.0010	0.2360	12
I_8	0.0033	0.0011	0.2465	11
I_15	0.0033	0.0012	0.2651	10
I_2	0.0031	0.0011	0.2655	9

Table 56. Alternative investment sites' values according to EWM weights (continue)

Site Index	Si+	Si-	Ci	Rank
I_10	0.0033	0.0013	0.2789	8
I_7	0.0030	0.0012	0.2830	7
I_5	0.0030	0.0014	0.3231	6
I_14	0.0030	0.0015	0.3415	5
I_6	0.0029	0.0020	0.4070	4
I_1	0.0026	0.0019	0.4174	3
I_13	0.0028	0.0021	0.4344	2
I_11	0.0024	0.0026	0.5181	1

Table 57. Alternative investment sites' values according to equal weights (Game Theory)

Site Index	Si+	Si-	Ci	Rank
I_9	0.0154	0.0072	0.3197	15
I_4	0.0145	0.0071	0.3289	14
I_3	0.0136	0.0080	0.3702	13
I_2	0.0120	0.0080	0.3992	12
I_8	0.0135	0.0090	0.3994	11
I_10	0.0135	0.0091	0.4045	10
I_12	0.0124	0.0091	0.4221	9
I_7	0.0117	0.0085	0.4223	8
I_11	0.0133	0.0099	0.4269	7
I_5	0.0127	0.0095	0.4279	6
I_15	0.0132	0.0101	0.4327	5
I_14	0.0135	0.0106	0.4399	4
I_6	0.0124	0.0118	0.4893	3
I_1	0.0082	0.0113	0.5798	2
I_13	0.0092	0.0133	0.5902	1

Table 58. Alternative investment sites' values according to Game Theory weights

Site Index	Si+	Si-	Ci	Rank
I_12	0.0038	0.0009	0.1873	15
I_4	0.0039	0.0009	0.1884	14
I_14	0.0036	0.0013	0.2685	13
I_3	0.0033	0.0018	0.3449	12
I_11	0.0033	0.0018	0.3471	11
I_15	0.0033	0.0018	0.3480	10
I_10	0.0033	0.0018	0.3537	9
I_9	0.0033	0.0024	0.4253	8
I_8	0.0032	0.0024	0.4274	7
I_2	0.0030	0.0025	0.4535	6
I_7	0.0029	0.0025	0.4576	5
I_6	0.0029	0.0025	0.4643	4
I_5	0.0029	0.0026	0.4794	3
I_13	0.0027	0.0030	0.5225	2
I_1	0.0014	0.0032	0.6918	1

Table 59. Comparison of rankings of investment sites with AHP, EWM, and Game Theory

Site Index	EW (AHP)	W (AHP)	EW (EWM)	W (EWM)	EW (Game Theory)	W (Game Theory)
I_1	1	1	3	3	2	1
I_2	4	3	12	9	12	6
I_3	13	12	13	13	13	12
I_4	14	14	14	14	14	14
I_5	10	4	7	6	6	3
I_6	5	9	5	4	3	4
I_7	9	5	10	7	8	5
I_8	12	6	11	11	11	7
I_9	15	7	15	15	15	8
I_10	6	10	9	8	10	9

Table 59. Comparison of rankings of investment sites with AHP, EWM, and Game Theory (continue)

Site Index	EW (AHP)	W (AHP)	EW (EWM)	W (EWM)	EW (Game Theory)	W (Game Theory)
I_11	8	13	1	1	7	11
I_12	11	15	8	12	9	15
I_13	2	2	2	2	1	2
I_14	3	8	4	5	4	13
I_15	7	11	6	10	5	10

In the TOPSIS methodology applied with AHP weights, the area determined as the highest priority for investment (Rank: 15) was identified as I_12. In the scenario where all criteria were considered equal-weighted, the highest priority investment area was found to be I_9. Additionally, it was determined that the area with the lowest investment priority (Rank: 1) was similar in both equal-weighted and AHP-weighted results and was identified as I_1. Except for the I_13 region, it was found that the outcomes for investment areas differed in other areas when weighted criteria were applied.

In the TOPSIS methodology applied with EWM weights, the highest priority area for investment was identified as I_9. Similarly, in the equal-weight scenario, the highest priority investment area was determined to be I_9 again. Moreover, the area with the lowest investment priority (Rank: 1) was found to be I_11 in both equal-weighted and EWM-weighted results. It was observed that the outcomes for investment areas remained unchanged in 7 regions, while differences occurred in the remaining 8 regions when weighted criteria were applied. This occurrence was influenced by the simpler mathematical model of the EWM method compared to the AHP method.

On the other hand, in the TOPSIS methodology applied with Game Theory weights, the highest priority area for investment was identified as I_12. In the equal-weight scenario, the highest priority investment area was determined to be I_9 again. Additionally, the area with the lowest investment priority (Rank: 1) was determined as I_13 in the equal-weighted results, while it was identified as I_1 in the Game Theory-weighted results.

Except for the I_4 region, it was found that the outcomes for investment areas differed in other areas when weighted criteria were applied.

In a nutshell, after employing equal-weighted methods to compare all methods, the analysis identified that the I_9 region had the highest priority investment area (Rank: 15) across all methods, while the area with the lowest investment priority (Rank: 1) varied depending on the method used. Furthermore, following the application of method weights in the analysis, the highest priority investment areas were identified to be I_9 (EWM) and I_12 (AHP and Game Theory), whereas the lowest priority investment areas were determined to be I_1 (AHP and Game Theory) and I_11 (EWM) (Rank: 1).

These results indicate that the use of weighted criteria in the study leads to variations in the outcomes (Figure 18). Additionally, it was found that the Game Theory method proposed in the MGIS model creates a balance point among the other methods, thus providing results that are comparable to those obtained with the AHP method.

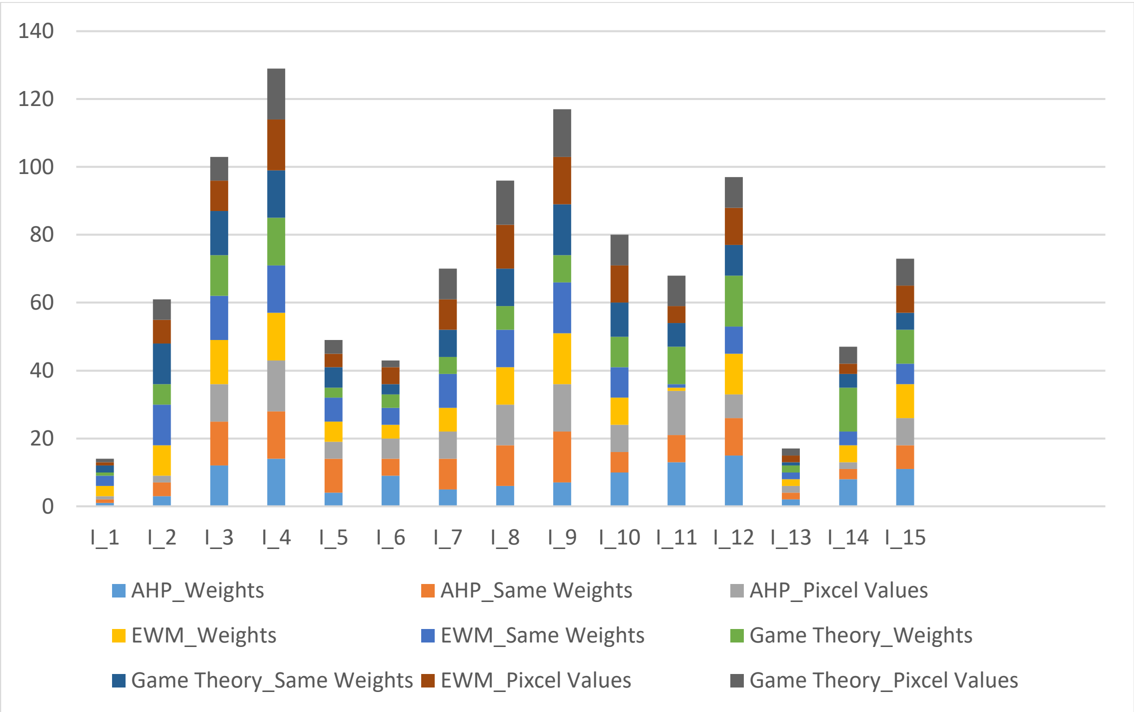

Figure 18. Compare of investment sites' rankings with different methods

7. CONCLUSIONS

Türkiye's increasing urban population, especially in cities, underscores the importance of planning and sustainability. In light of this, cities, which are significant hubs for human activity, need to be accurately planned and developed into livable areas. Thereupon, by using the proposed MGIS model to conduct current analyses of cities, this study proposes a decision support system for improving living spaces and determining investment areas.

The study presents an approach that integrates GIS and MCDM methods. Since the determination of livable areas in cities and the creation of sustainable urban models depend on the evaluation of many factors, MCDM methods have been preferred to determine the priorities of criteria. Three different method weights and equal weights according to these methods have been used to show that criterion weights directly affect the planning of cities. As the identification process of livable areas differs based on the assigned weights, the significance of determining the criteria weights has been underscored in the study. In this regard, interrelationships were created by integrating the criterion weights derived from the AHP, EWM, and Game Theory methods with Hierarchy B and Hierarchy C structures. Additionally, one of the strengths of the study is that it demonstrates the applicability of the MGIS model, created by amalgamating AHP, EWM, Game Theory, WLC, and TOPSIS methods under the analytical tools of GIS, across various domains of urban planning. Another contribution of the study is that it can rank investment areas differently according to equal-weights, AHP, EWM, Game Theory weights, and pixel values based on the TOPSIS method.

It has been found in the application area that 17.92% of livable areas according to the AHP method, 19.86% according to the EWM method, and 18.67% according to the Game Theory method are in the most suitable region with five index values, indicating that criteria-based scientific evaluations are not conducted in city planning. Furthermore, the current state in the study area necessitates actions to improve life quality.

In the study area, regions with unsuitable areas (Score: 1) have been observed to be influenced by deficiencies in certain criteria due to methodological variations.

Particularly, the criteria of the subway, railway, cycling path, subway station, railway station, and bike-sharing station have been identified as playing a significant role in the formation of these areas. Furthermore, the presence of steep topography, scarcity of green spaces, remoteness to cultural, arts, and entertainment areas, lack of parking and sports facilities, landslide risk, and absence of a well-planned local settlement have also been highlighted as negative aspects of these unsuitable areas (Score: 1).

A comparison of the AHP and EWM methods suggested by the MGIS model has revealed significant differences in the results due to the differences in their mathematical models. However, the Game Theory method has reduced these differences to a balance point, thereby positively influencing decision-makers' processes.

Furthermore, the TOPSIS method has been applied to determine areas for investment. As a result, while the I_12 investment area was identified as the highest priority area for investment in both AHP and Game Theory weighted rankings, this area was determined as I_9 in the EWM method. However, based on equal-weighted analyses, I_9 was determined as the highest priority investment area across all methods. The ranking of other alternative areas has shown significant variations in both weighted and equal-weighted rankings.

Creating a livable environment for people living in urban areas is one of the most critical challenges of the present and the future. Therefore, it is vital to either improve the current situation or conduct a process in city planning that is based on objective criteria. GIS is a powerful tool for decision-makers in site selection, urban planning processes, solving urban problems, creating livable spaces, and determining investment areas.

Based on the robust efficacy of GIS, the proposed MGIS model is a significant factor in the processes of planning cities and improving existing living areas by local governments. While the study focuses on evaluating living spaces based on existing urban design criteria, it also analyzes the economic, social, and cultural aspects of local governments to identify the deficiencies of cities. The use of the MGIS model is crucial for accelerating policy makers’ decision processes in creating sustainable and livable cities, especially in efficiently managing limited resources.

Within the scope of the study conducted by local governments, it is of great importance to initiate investments aimed at enhancing and strengthening the transportation infrastructure, increasing the number of green spaces, augmenting parking and sports facilities, and creating spaces where people can spend time for the improvement of identified unsuitable areas (Score: 1). Additionally, the development of settlement plans is imperative for the creation of a sustainable city on a local scale and for the planning of livable spaces.

The innovative approach presented in this study is the applicability of the MGIS model across all urban areas, thereby enhancing the quality and sustainable structures of urban areas and creating better living spaces for people.

8. COMMENT

This document makes several significant contributions to academic literature, particularly in the areas of GIS, MCDM methods, Game Theory methods, and urban design.

Firstly, the introduction of a new MGIS approach in the processes of urban design and the creation of sustainable urban models is fostering the development of livable spaces. This new approach addresses issues that complicate living conditions in cities. For instance, it allows for the consideration of various geographical, topological, and climate change-related factors along with urban design criteria specific to cities. Consequently, it contributes to the creation of more livable and sustainable urban areas for policymakers and local governments. This contribution expands the current understanding of urban planning and provides city managers with practical and evidence-based solution tools.

Secondly, this study presents a model capable of utilizing multiple MCDM techniques concurrently. Furthermore, it facilitates the creation of connections between primary criteria and secondary criteria. By demonstrating that numerous criteria may have varying impact values under various primary criteria, it thereby contributes to academic literature. Additionally, the Game Theory method employed contributes to the determination of optimal weights by harmonizing the differences between MCDM approaches. This, thus, allows policymakers to independently evaluate both methods and optimal values.

Thirdly, the developed model facilitates the integration of GIS and MCDM methods. This integration significantly contributes to policymakers' decision processes by merging location analyses with decision-making techniques to unify criterion priorities. The applicability of the created model across all urban areas and its developmental potential are critically important as they contribute to solving numerous urban problems.

Fourthly, the application of the TOPSIS method on decision maps generated by the model introduces a new approach to the MGIS model for identifying investment areas in cities. It offers an objective-based solution, especially for local administrators to utilize their limited financial resources in the most beneficial way. The implementation of this model will yield both time and cost savings in the creation of livable cities.

Fifth, this document emphasizes the importance of the climate change factor in urban planning processes. The proposed approaches, which include the creation of climate data and maps for entire cities, offer the potential to enhance the quality of life of residents in these areas. Additionally, the development of sustainable urban models and the governance of cities provide significant benefits to policymakers.

Finally, this research demonstrates the effectiveness of a technology-focused approach in the planning and management of cities. This method can contribute to enhancing the livability of cities by enabling rapid and effective analysis of large data sets. Consequently, this approach can play an active role in enhancing data-driven decision-making processes in cities, while also facilitating the development of programs aimed at reducing potential problems.

In conclusion, this document significantly contributes to academic literature by proposing an MGIS method that integrates GIS, MCDM techniques, Game Theory, and urban design criteria. These contributions address critical challenges in the management and future preparedness of cities. Thus, the research sets a new direction for future MGIS studies.

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ATTACHMENTS

APPENDIX 1 – SURVEYS

Within the Framework of a Doctoral Thesis Study at the Department of Geomatics Engineering at Hacettepe University, the Impact of Urban Design Criteria on Urban Design is Being Investigated in the Konak District of İzmir

Your Affiliated Institution/Department:

1) Do you find the criteria listed below acceptable?

Criteria	**Yes**	**No**
Climate Change	☐	☐
Connectivity	☐	☐
Environment	☐	☐
Walkability	☐	☐
Transportation	☐	☐

2) According to importance, what other criteria not mentioned in the first question would you like to add?

a)...

b)...

c)...

d)...

e)...

f)...

RATING URBAN DESIGN FACTORS IN KONAK DISTRICT

Note: During the survey evaluation, if criteria such as connectivity and walkability are deemed equally important, they are rated as 1.
If connectivity is considered more important than walkability, the importance level is marked on the side of connectivity.
Conversely, if walkability is seen as more important than connectivity, the importance level is marked on the side of walkability.

Increasing Importance ←									**Equal Level**	→								**Increasing Importance**
Main Criteria	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**Evaluation Criteria**
Climate Change	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☑	☐	☐	☐	☐	☐	☐	Connectivity
Climate Change	☐	☐	☐	☐	☐	☐	☐	☐	☐	☑	☐	☐	☐	☐	☐	☐	☐	Environment
Climate Change	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☑	☐	☐	☐	☐	☐	Walkability
Climate Change	☐	☐	☐	☐	☐	☐	☐	☐	☐	☑	☐	☐	☐	☐	☐	☐	☐	Transportation
Connectivity	☐	☐	☐	☐	☐	☐	☐	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	Environment
Connectivity	☐	☐	☐	☐	☐	☐	☐	☐	☑	☐	☐	☐	☐	☐	☐	☐	☐	Walkability
Connectivity	☐	☐	☐	☐	☐	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Transportation
Enivironment	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☑	☐	☐	☐	☐	☐	☐	Walkability
Environment	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☑	☐	☐	☐	☐	☐	Transportation
Walkability	☐	☐	☐	☐	☐	☐	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Transportation
	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	

APPENDIX 2 - PUBLICATIONS DERIVED FROM THE DISSERTATION

Başeğmez, M., & Aydın, C. C. (2021). The Covid-19 pandemic teaching modalities in Turkey: An evaluation of school gardens and classes. Health Policy and Technology, 10(3), 100546. https://doi.org/10.1016/j.hlpt.2021.100546