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Urban Green Infrastructure Planning for the Bangkok Metropolitan Region: An Empirical Study for Greenspace Expansion

Malay Pramanik[1], Atul Kumar[2], Soumya Paramanik

1 Asian Institute of Technology
2 Chaudhary Charan Singh University

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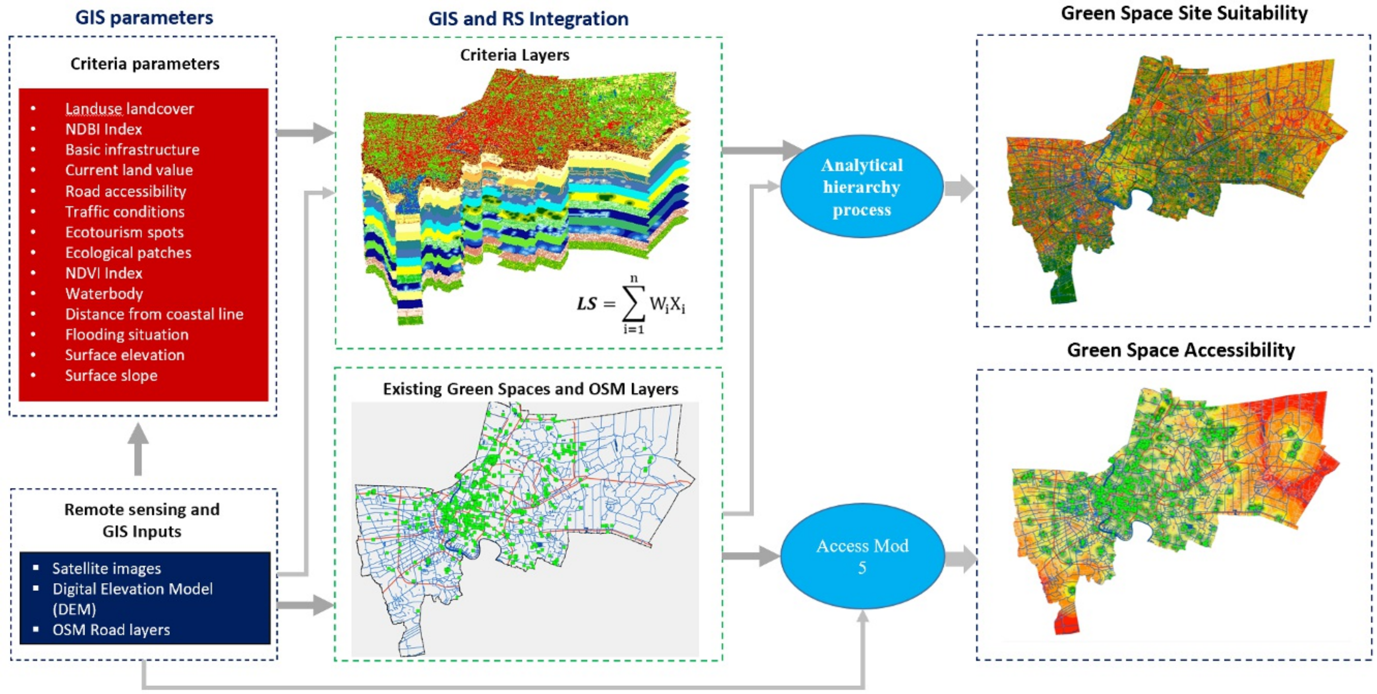
Abstract

Urban greenspaces play a crucial role in enhancing the standard of living in urban areas, offering recreational havens and fostering ecological equilibrium. The Green Bangkok 2030 Project drives collaboration among the public, private, and civil sectors, aiming to expand recreational spaces and contribute to ecological balance, thereby enhancing the overall city life quality. To understand optimal locations, this study employs a comprehensive spatial land suitability and accessibility assessment, integrating Analytic Hierarchy Process (AHP) and Geographic Information System (GIS) modelling based on fourteen criteria identified. Emphasizing the significance of accessibility and traffic conditions, the study assesses physical accessibility, underscoring the importance of convenient green space access for urban dwellers. The study highlights the southern BMA, distant from dense urban areas, as more suitable for green space development and the integrated approaches in land suitability analysis, positing the AHP model as effective in identifying suitable urban greenspace sites, fostering amenity-led metropolitan growth.

Keywords: Bangkok Metropolitan; green accessibility; greenspace equity; infrastructure planning; urban green landscape.

Graphical Abstract



Highlights

- Integration of GIS and AHP for greenspace planning in Bangkok.
- Southern coastal BMR deemed highly suitable for green space planning.
- Western BMR exhibits higher accessibility to green spaces.
- The method signifies fostering amenity-led metropolitan growth.
- Green space suitability and accessibility maps help greenspace expansion planning.

1. Introduction

Urban greenspace refers to the presence of natural and semi-natural areas, including parks, gardens, green corridors, and other vegetated spaces, within urban environments. These spaces provide opportunities for recreation, ecological functions, and aesthetic enhancement within urban areas (Bahrini et al. 2017; Mokhtarzadeh and Ramachandra 2017). They contribute to the general resilience and health of urban ecosystems and are essential to the planning and construction of green structures in cities in the future. By generating oxygen and absorbing pollutants, they enhance air quality, lessen the impact of the urban heat island, and provide habitat for many wildlife species (Derkzen et al. 2017). By decreasing stormwater runoff, offering shade, and enhancing microclimate conditions, green areas also aid in climate change adaptation. There are several advantages to city inhabitants' physical and emotional health when they have access to urban green spaces. They provide opportunities for physical activity, promote relaxation and stress reduction, and improve overall well-being (Mokhtarzadeh and Ramachandra 2017). Urban green space also encourages social interaction and community cohesion, enhancing social connectivity and reducing social isolation.

The environmental consequences encompass biodiversity depletion, air and water pollution, escalating noise levels, heightened greenhouse gas (GHG) emissions, and an augmented risk of runoff and flooding (Atu and Eja 2013). Green spaces also contribute to climate change adaptation by reducing stormwater runoff, providing shade, and improving microclimate conditions (Hansen et al. 2021). They also play a pivotal role as recreational spaces for residents, providing a canvas for a myriad of activities ranging from leisurely walks and invigorating jogs to cycling, picnicking, and spirited sports. Beyond their recreational function, these green oases assume the mantle of cultural and educational hubs, playing host to a vibrant tapestry of events, festivals, and programs (Anteneh et al. 2023, Nigussie et al. 2021). In doing so, they become dynamic platforms fostering community engagement and nurturing environmental awareness among residents (Chen et al. 2022). Well-designed urban green spaces can serve as green infrastructure elements that help manage stormwater runoff. Vegetation and permeable surfaces in green spaces absorb rainwater, reduce the volume of runoff, and enhance groundwater recharge. This helps prevent flooding, reduce pressure on drainage systems, and improve overall water management in cities. Urban green spaces enhance the aesthetic appeal of cities, making them more visually appealing and enjoyable for residents and visitors. Well-designed green spaces contribute to the overall urban design, creating attractive landscapes, improving the livability of neighborhoods, and increasing property values (Kefale et al. 2023).

In future planning and design of green infrastructure, incorporating urban greenspaces is essential for creating sustainable, resilient, and livable cities. They should be integrated into urban planning processes, ensuring equitable access and distribution across neighborhoods. Cities may provide their citizens with settings that are healthier and more sustainable by taking into account the many advantages of urban greenspace (Pietila and Kangas 2015). There are several advantages that urban green infrastructure and green space offer to the city's inhabitants and ecology. Urban green zones provide oxygen into the air while absorbing contaminants, so filtering and purifying it. Parks and green spaces with vegetation can lessen the impacts of air pollution, improving the quality of the air for city dwellers (Anteneh et al. 2023). The heat island effect, in which temperatures are greater in urban regions than in nearby rural areas, urban greenspaces, with their vegetation and shade, help mitigate this effect by reducing surface temperatures and cooling the surrounding environment.

Green infrastructure, including features like green roofs, permeable pavements, and rain gardens, helps manage stormwater runoff. By absorbing and storing rainfall, these components lessen the load on drainage networks and lower the chance of floods. Urban green areas enhance urban biodiversity by serving as homes for a variety of plant and animal species. By encouraging the presence of birds, pollinators, and other species, they help to create more biologically balanced and resilient urban ecosystems. There is evidence that having access to urban green areas improves both physical and mental health results. Spending time in green environments has a positive impact on stress reduction, cognitive function, and overall well-being (Anteneh et al. 2023). Greenspaces also provide opportunities for physical activities such as walking, jogging, and cycling. Parks and other greenspaces act as gathering places for community members, facilitating social interaction and fostering a sense of community cohesion. They provide spaces for social activities, events, and recreational opportunities that bring people together.

Urban greenspaces contribute to the aesthetic value of cities, making them more visually appealing and enjoyable for residents and visitors. Well-designed green infrastructure elements, such as green roofs and vertical gardens, enhance the urban landscape and contribute to a sense of place (Lee et al. 2023). Urban greenspaces can have positive economic impacts. They increase property values, attract tourism, support local businesses (such as cafes near parks), and provide opportunities for job creation related to the management and maintenance of greenspaces. These benefits collectively contribute to creating more livable, sustainable, and resilient cities. They enhance the quality of life for residents, promote environmental stewardship, and improve the overall urban living experience (M'Ikiugu et al. 2012).

The issue of accessibility and equity in urban greenspaces revolves around the uneven distribution and availability of these areas, leading to certain demographic groups experiencing limited or restricted access to these valuable spaces (Sun et al. 2022, Yang et al. 2022). In urban landscapes, greenspaces are frequently distributed disparately, with certain neighborhoods boasting abundant parks and green areas, while others contend with limited or no access to such vital spaces. This spatial imbalance gives rise to disparities in the availability of recreational and environmental amenities, with marginalized communities bearing the brunt of these inequities (Rigolon et al. 2018). The proximity or distance between residential areas and greenspaces emerges as a critical factor impacting accessibility (Long et al. 2022, Wang et al. 2013, Zhang et al. 2021). When greenspaces are situated far from specific neighborhoods, it erects barriers for residents, especially those without personal transportation, posing challenges in accessing and reaping the benefits of these rejuvenating areas. The economic ramifications of urban greenspaces are substantial and positive (Chen et al. 2024; Lee et al. 2023). They not only elevate property values but also serve as magnets for tourism, bolstering local businesses—think charming cafes nestled near verdant parks. Moreover, these green havens offer fertile ground for employment opportunities, notably in sectors such as landscaping, maintenance, and ecotourism (Ahn & Juraev 2023). In concert, these economic advantages play a pivotal role in shaping cities that are not just livable but sustainable and resilient. Residents reap the rewards in the form of an enriched quality of life, while concurrently, the promotion of environmental stewardship elevates the overall urban experience (Banzhaf & De La Barrera 2017, M'Ikiugu et al. 2012, Mathey et al. 2021).

Addressing the issue of greenspace accessibility and equity requires a comprehensive approach. This study seeks to enrich existing literature by exemplifying a land suitability analysis for the advancement of urban green spaces in the BMR, capital of Thailand. The case study of BMR was selected because of its distinctive combination of high-density metropolitan regions with non-urban land uses, including forests, vegetative cover, and farmland. This contrast creates a chance for the development of green spaces by connecting the land used for agricultural purposes in the eastern section with the already-present urban green spaces, which are mostly in the western half. The availability of standardised spatial data on land use, transportation infrastructure, and geophysical features is also advantageous to the BMR. The area of land accessible for the creation of green spaces in urban areas has noticeably decreased, particularly in recent decades, due to the difficulties brought on by the BMR's fast urbanisation and significant population expansion. Consequently, the significance of developing urban green areas in the BMR becomes evident at the local and regional scales.

The BMR is a particularly attractive location for the growth of green space because of its availability for green land usage and its ideal environmental conditions. Therefore, the study objective is to find the suitability and accessibility for the possible expansion of greenspace planning in the Bangkok metropolitan region for sustainable urban planning. Multi-criteria assessment, such as MCDM-AHP, is used to conduct the suitability study, and GIS modelling techniques are employed to offer a thorough understanding of the urban morphological, environmental, and physical parameters. It involves urban planning and design strategies that prioritize equitable distribution, community engagement to ensure diverse voices are heard, policy interventions, and investments in underserved areas. Collaborative efforts involving local government, community organizations, and stakeholders are essential to create inclusive greenspaces that meet the needs of all residents and promote social and environmental equity.

2. Study area

Thailand's capital city, Bangkok, is situated in the nation's centre and possesses a number of unique topographical features. BMR is situated on the Chao Phraya River delta in the Gulf of Thailand, along the country's central coastline. It is positioned on the eastern bank of the river, approximately 40 kilometers (25 miles) from the Gulf. The Chao Phraya River plays a vital role in Bangkok's geography *(figure 1).* It flows through the city, dividing it into the western and eastern banks. The river serves as a major transportation route and has influenced the city's development and urban planning. BMR is characterized by a relatively flat topography. Its elevation ranges from just a few meters above sea level to around 2 meters in some areas. The city's low-lying terrain makes it susceptible to flooding, especially during the monsoon season. BMR has an extensive network of canals, known as khlongs, which were historically used for transportation and irrigation. Many of these canals have been converted into roads or filled in over time, but some still exist and contribute to the city's unique charm. The khlongs are interconnected and connected to the Chao Phraya River, providing additional water transport options. While BMR is not directly on the coast, it is located near the Gulf of Thailand. The city's proximity to the coast has influenced its climate and made it an important economic and transportation hub for the country.

BMR is experiencing subsidence, which is the sinking of the land surface. Factors such as rapid urbanization, groundwater extraction, and the weight of infrastructure contribute to the sinking. As a result, some areas of the city are gradually sinking below sea level, increasing the vulnerability to flooding. Bangkok has witnessed rapid urban expansion, with the city growing in all directions. As a result, high-rise buildings and skyscrapers dominate the city's skyline, especially in the central business district. The urban landscape is a mix of modern high-rises and traditional architecture. Despite being a highly urbanized city, Bangkok has several green spaces and parks that provide recreational areas and serve as lungs for the city. Lumphini Park and Chatuchak Park are among the notable green spaces that offer respite from the bustling city life. These geographical attributes contribute to Bangkok's unique landscape and shape its urban development, transportation systems, and environmental challenges.

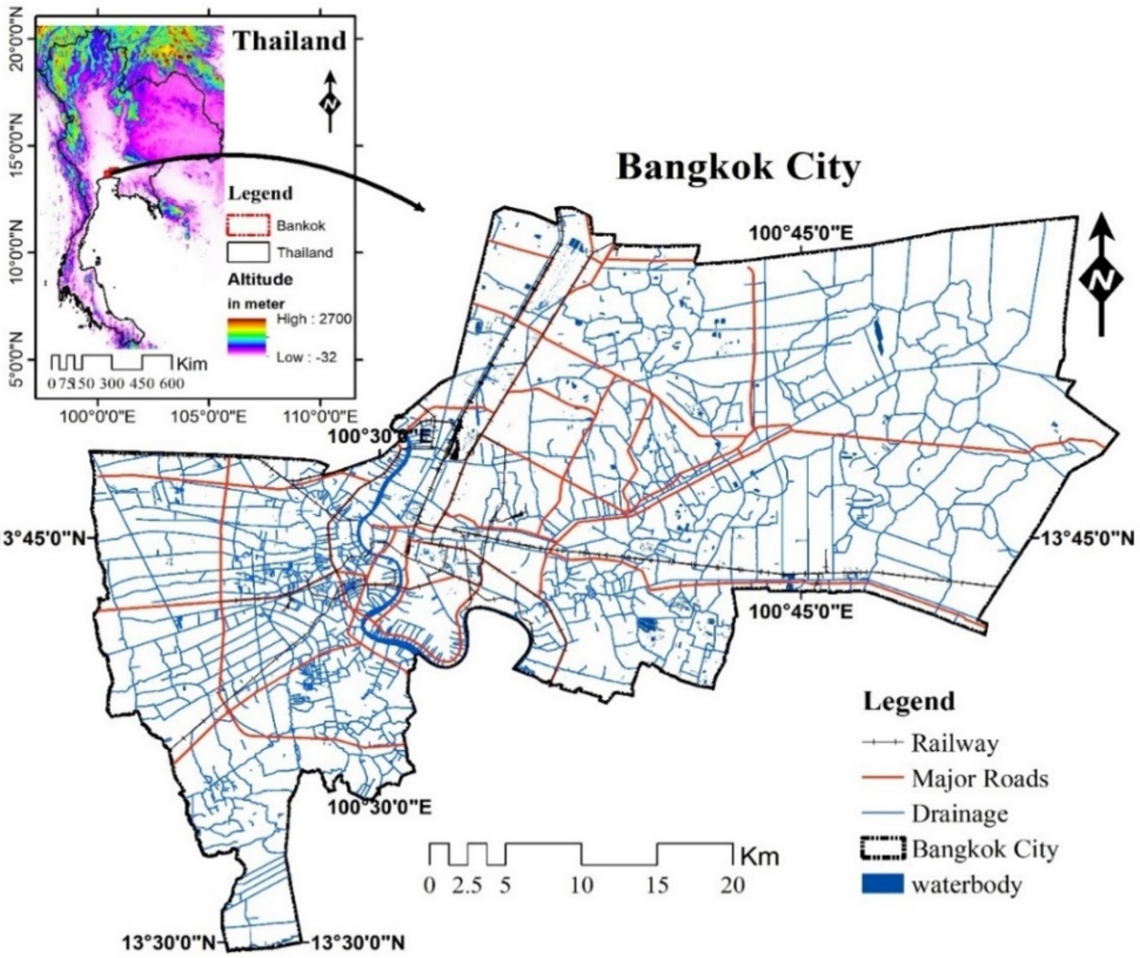
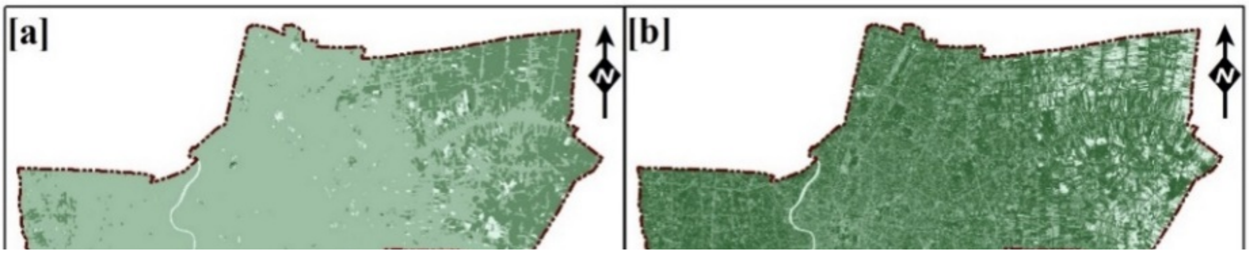


Figure 1. *Showing the geographical location of Bangkok city in Thailand*

3. Database and methods

In conducting this assessment, a myriad of environmental factors, encompassing both physical and cultural dimensions, were considered as conditioning factors. These factors include Land Use Land Cover (LULC), Normalized Difference Built-up Index (NDBI), basic infrastructure components such as roads, buildings, and utilities, current land value, road accessibility (proximity), traffic conditions, ecotourism spots, ecological patches, Normalized Difference Vegetation Index (NDVI), water bodies, distance from the coastal line, flooding situation, surface elevation, and surface slope. These elements collectively formed the basis for establishing a spatial suitability model tailored to green space development in the BMR.



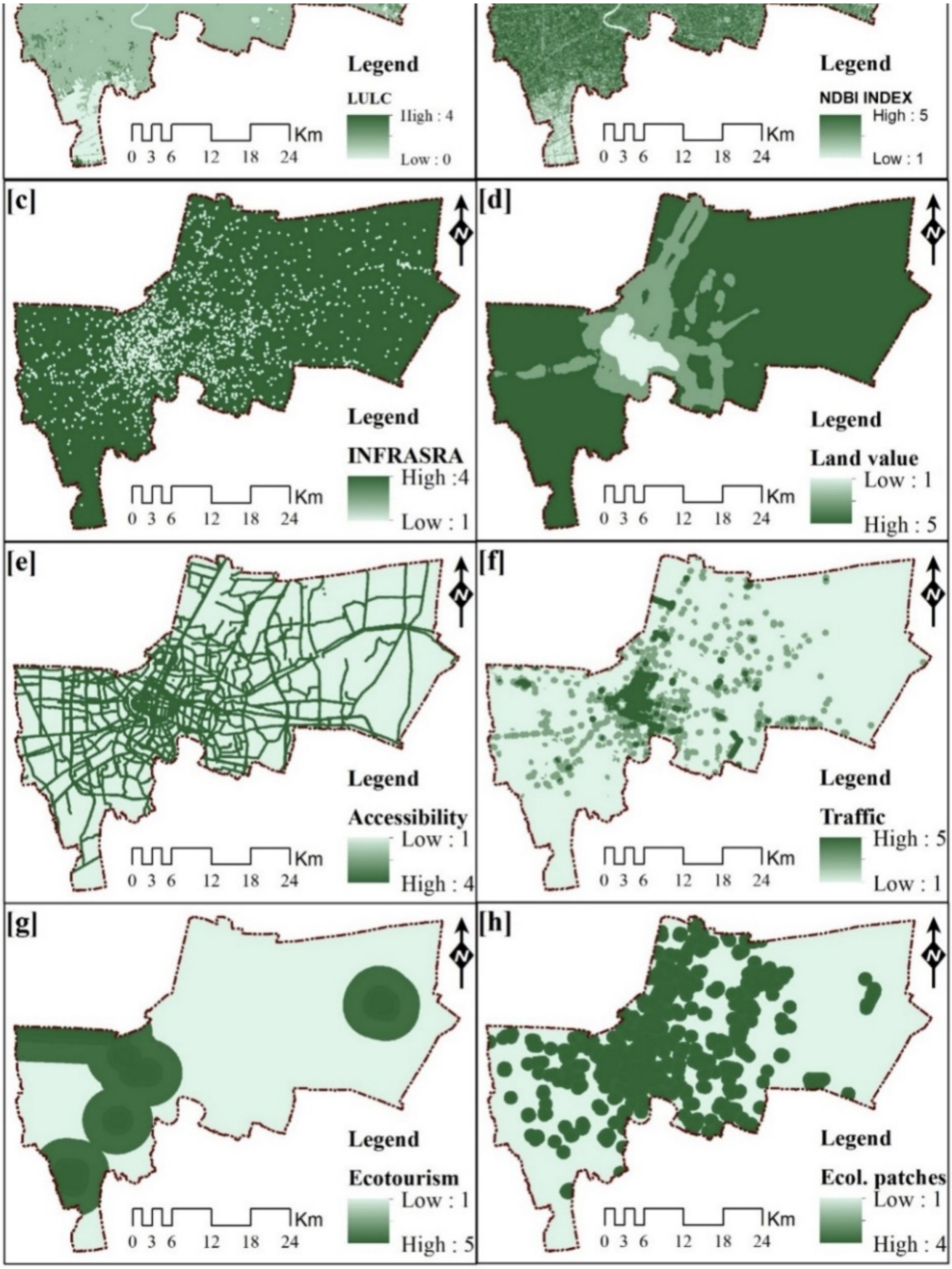


Figure 2. *Showing LULC, NBDI index, basic infrastructures, land value, accessibility, traffic conditions, ecotourism sites, and ecological patches*

In the case of LULC and NDVI, Sentinel multispectral images were employed, offering a comprehensive perspective. For elevation and surface slope analysis, ALOS PALSAR Digital Elevation Models (DEM) were utilized, sourced from the Alaska Satellite Facility. Additionally, crucial spatial attributes such as road and traffic conditions, utilities, water bodies, flooding information, and land value were sourced from Open Street Map (OSM) layers, supplemented by data from the Bangkok Metropolitan Administration. This collaborative approach ensured a holistic and detailed examination of the spatial landscape, combining remote sensing technologies and on-the-ground administrative resources.

3.1. *Generation of Geospatial database for the identification of ideal sites for green space development*

The spatial satellite data, including multispectral images and Digital Elevation Models (DEMs), along with vector layers, underwent comprehensive processing using ArcGIS 10.4 software. GIS techniques played a pivotal role in the creation of a database and the development of various criteria maps. The Analytical Hierarchy Process (AHP) was then used to formulate a site suitability framework specifically designed for the creation of green spaces in cities using the 14 criterion maps that are depicted in figures 2 and 3. The more detail about each criterion and its sub-classification and its corresponding weights was given in *Table 1 and 2.*

Furthermore, the assessment of accessibility to existing green spaces within the city region, vital for evaluating green space equity, was conducted using the AccessMod 5 tool (accessible at https://www.accessmod.org/). This methodology added significant insights to the overall evaluation of urban green space growth by offering a methodical way to measure the availability and reach of green spaces. The study's accuracy and dependability were improved by the incorporation of GIS methodology and specialised tools such as AccessMod 5, which provided a robust and sophisticated analysis.

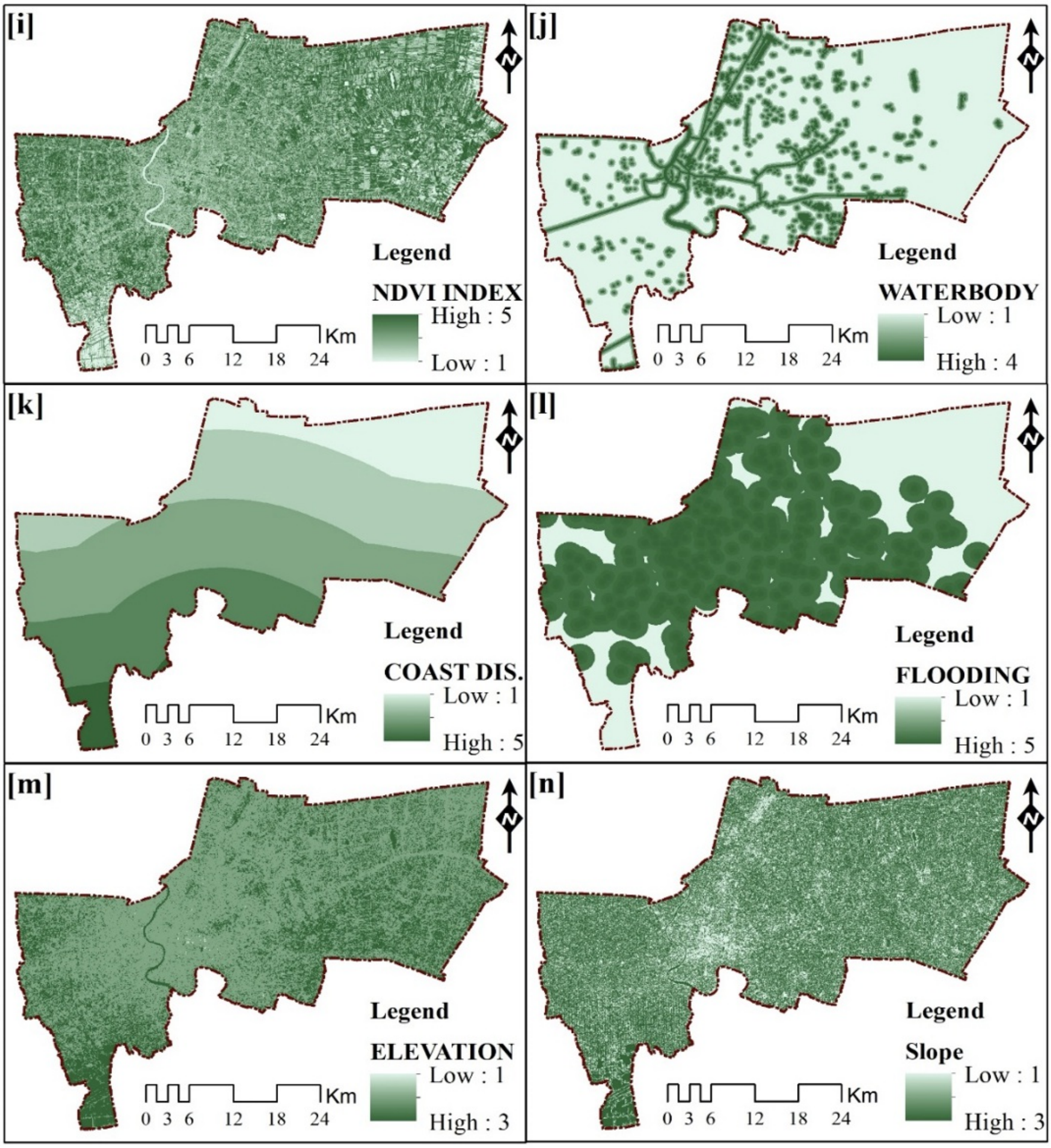


Figure 3. *Showing NDVI Index, waterbodies, distance from coastal line, flooding situation, elevation, and surface slope*

Table 1. *Indicating parameters and criteria used for the assessment of the choosing suitable locations for Bangkok's urban green space advancement*

Sl. No.	Criteria	Very low (1)	Low (2)	Moderate (3)	High (4)	Very high (5)
1	Land use landcover	Evergreen/deciduous vegetation	water bodies/ wetlands	Settlements	Bare areas/shrubs and other	Irrigated/ Unirrigated Cropland
2	NDBI Index	0.32 - 0.70	0.21 - 0.31	0.08 - 0.20	-0.09 - 0.08	-0.5 - -0.09
3	Basic infrastructure (dist. in m.)	-	> 200	80.1-200	40.1-80	< 40
4	Current land value (THB)	15.1K - 43.7K	10.1K - 15K	5.1K - 10K	1.1K - 5K	0 - 1K
5	Road accessibility (dist. in m.)	-	> 200	100.1-200	50.1-100	< 50
6	Traffic conditions (No. of points)	> 50	21 - 50	11- 20	3-10	<2
7	Ecotourism spots (dist. in km)	> 5.0	2.1-5.0	1.1-2.0	0.51-1.0	< 0.5
8	Ecological patches (dist. in m.)		> 1000	501-1000	301-500	< 300
9	NDVI Index	-0.86 - -0.02	-0.02 - 0.14	0.15 - 0.28	0.29 - 0.45	0.46 - 0.76
10	Waterbody (dist. in m.)		>500	301-500	101-300	<100
11	Distance from coastal line (dist. in m.)	> 50	40.1-50	30.1-40	20.1-30	< 20
12	Flooding situation (dist. in m.)	> 2000	1001-2000	501-1000	101-500	< 100
13	Surface elevation (in m.)	-	-	0.01 - 56	-27.9 - 0.0	-62 - -28
14	Surface slope (in °)	-	-	> 6	3.1-6.0	< 3

Table 2. *Showing attributes of all the parameters considered for the assessment*

SN	LULC	Area	Area (%)	Weight
1	Bare Land	106.5	6.73	3
2	Built up area	1198.5	75.70	4
3	Flooded Vegetation	269.4	17.02	5
4	Vegetation	2.4	0.15	2
5	Waterbody	6.4	0.40	1
SN	**NDBI Index**	**Area**	**Area (%)**	**Weight**
1	-0.5 - -0.09	80.6	5.09	5
2	-0.09 - 0.08	155.4	9.81	4
3	0.08 - 0.20	372.0	23.50	3
4	0.21 - 0.31	488.8	30.87	2
5	0.32 - 0.70	486.5	30.73	1
SN	**Distance from infrastructure (m)**	**Area**	**Area (%)**	**Weight**
1	> 40	8.8	0.56	5
2	40.1-80	25.1	1.58	4
3	80.1-200	147.2	9.30	3
4	> 200	1402.2	88.56	2
SN	**Land Value (THB)**	**Area**	**Area (%)**	**Weight**
1	0 - 1K	1261.4	79.67	5
2	1.1K - 5K	261.8	16.54	4
3	5.1K - 10K	29.1	1.84	3

4	10.1K - 15K	13.0	0.82	2
5	15.1K - 43.7K	17.9	1.13	1
SN	**Land Value (THB)**	**Area**	**Area (%)**	**Weight**
1	0 - 1K	1261.4	79.67	5
2	1.1K - 5K	261.8	16.54	4
3	5.1K - 10K	29.1	1.84	3
4	10.1K - 15K	13.0	0.82	2
5	15.1K - 43.7K	17.9	1.13	1
SN	**Distance from roads (m)**	**Area**	**Area (%)**	**Weight**
1	< 50	179.1	11.31	5
2	50.1-100	136.9	8.65	4
3	100.1-200	233.3	14.74	3
4	> 200	1034.0	65.30	2
SN	**No of Traffic points**	**Area**	**Area (%)**	**Weight**
1	< 2	1274.4	80.49	5
2	3-10	228.0	14.40	4
3	11- 20	38.8	2.45	3
4	21 - 50	27.3	1.73	2
5	> 50	14.7	0.93	1
SN	**Distance from Ecotourism sites (m)**	**Area**	**Area (%)**	**Weight**
1	< 0.5	31.0	1.96	5
2	0.51-1.0	30.6	1.93	4
3	1.1-2.0	76.7	4.84	3
4	2.1-5.0	303.8	19.19	2
5	> 5.0	1141.2	72.08	1
SN	**Distance green spaces (m)**	**Area**	**Area (%)**	**Weight**
1	< 300	196.0	12.38	5
2	301-500	146.0	9.22	4
3	501-1000	332.1	20.97	3
4	> 1000	909.2	57.43	2
SN	**NDVI Index**	**Area**	**Area (%)**	**Weight**
1	-0.86 - -0.02	96.7	6.11	1
2	-0.02 - 0.14	367.9	23.24	2
3	0.15 - 0.28	429.6	27.13	3
4	0.29 - 0.45	351.6	22.20	4
5	0.46 - 0.76	337.5	21.31	5
SN	**Distance from waterbody (m)**	**Area**	**Area (%)**	**Weight**
1	< 100	126.2	7.97	5
2	101-300	205.8	13.00	4
3	301-500	199.8	12.62	3

4	> 500	1051.4	66.41	2
SN	**Distance from coastline (m)**	**Area**	**Area (%)**	**Weight**
1	< 20	45.2	2.86	5
2	20.1-30	296.2	18.71	4
3	30.1-40	531.5	33.57	3
4	40.1-50	469.3	29.64	2
5	> 50	241.1	15.23	1
SN	**Distance from flooded areas (m)**	**Area**	**Area (%)**	**Weight**
1	< 100	10.1	0.64	5
2	101-500	194.4	12.28	4
3	501-1000	363.5	22.96	3
4	1001-2000	495.6	31.30	2
5	> 2000	519.7	32.82	1
SN	**Elevation (m)**	**Area**	**Area (%)**	**Weight**
1	-62 - -28	506.2	31.97	5
2	-27.9 - 0.0	1076.2	67.98	4
3	0.01 - 56	0.7	0.05	1
SN	**Slope (°)**	**Area**	**Area (%)**	**Weight**
1	< 3	691.5	43.68	5
2	3.1-6.0	822.3	51.94	4
3	> 6	69.3	4.38	3

3.2. *Conditioning factors in green space suitability assessment*

3.2.1. *Land Use/Land Cover (LULC)*

The supervised LULC classification procedure was adopted to determine five LULC classes in Bangkok city by taking into consideration the Sentinel multispectral image of 2022. Following a review of several literature sources, such as research by Abebe & Megento (2017), Chandio et al. (2011), and Ustaoglu & Aydınoglu (2020), it is advised to establish green spaces on land that is now covered in grasslands and barren areas. The literature, which relies on the knowledge gathered from the aforementioned investigations, indicates that these locations can present advantageous circumstances for the creation of green space. The area covered by bare land is 106.5 sq. km, which accounts for 6.73%; built-up structures cover 1198.5 sq. km, accounting for 75.70%; vegetation cover under flooded areas is 269.4 sq. km, representing 17.02%; vegetation (excluding flooded areas) is 2.4 sq. km, accounting for 0.15%; and water bodies occupy 6.4 sq. km, representing 0.40% of the city's total area.

3.2.2. *Normalized Difference Built-up Index (NDBI)*

The NDBI index plays a role in green space site determination in cities by providing information about the extent and distribution of built-up areas. In order to identify the suitable land for green spaces, NDBI index values were reclassified into five respective classes to indicate the very dense to sparse built-up land. The index values for the NDBI in Bangkok exhibit distinct ranges. Areas with index values from 0.5 to -0.09 cover approximately 5.09% (80.6 sq. km.) of the total area. The range of 0.09 to 0.08 represents 9.81% (155.4 sq. km.), while values from 0.08 to 0.20 occupy a substantial 23.50% (372.0 sq. km.). Additionally, the range of 0.21 to 0.31 encompasses a significant 30.87% (488.8 sq. km.), and values from 0.32 to 0.70 cover an extensive 30.73% (486.5 sq. km.) of the entire area of the Bangkok city. Each category of index value range corresponds to a relative weight value ranging from 1 to 5. While smaller values indicate the lack of built-up regions, higher values reflect the existence of built-up buildings. Therefore, the creation of green spaces in the vicinity is given priority in regions with lower NDBI values.

3.2.3. *Distance from infrastructures*

The major infrastructure components provide a unique opportunity to weave green spaces into the urban fabric, fostering sustainability, resilience, and quality of life in cities. The incorporation of these components in spatial decision-making enables decision-makers to identify the most suitable sites for developing green infrastructure in the cities. This integration not only enhances the environmental and aesthetic aspects of the urban landscape but also addresses the social, economic, and health-related needs of urban residents. This parameter measures the distance of a location from existing infrastructure such as roads, buildings, and utilities. The distances from infrastructure are categorized into four classes based on the distance, e.g., > 40m, 40.1-80m, 80.1-200m, and > 200m, and corresponding areas and weights were displayed in *tables 1 and 2.* The weights assigned to each class range from 2 to 5. It was assumed that the higher the distance, the farther the location is from infrastructure selected for the development of green spaces in the city. The zones categorized by distance from infrastructure include the first zone (less than 40m), covering 8.8 sq. km. (0.56%). The second zone (40.1 to 80 meters) spans 25.1 sq. km. (1.58%). The third zone (80.1-200 meters) occupies 147.2 sq. km. (9.30%). The fourth zone (greater than 200 meters) comprises 1402.2 sq. km (88.56%).

3.2.4. *Land value*

It requires a thoughtful and strategic approach to ensure that green spaces are integrated harmoniously into the urban fabric, even in areas with high land values. The value of land in cities plays a pivotal role in shaping decisions regarding green space development. It involves striking a balance between economic considerations, addressing environmental concerns, enhancing cultural and recreational amenities, and promoting the overall well-being of urban residents. By interpolating the land values at various places in the BMR, a spatial layer was generated and categorized into different classes. The land value rises from its peripheral areas to the core areas of the BMR. *Table 1* categorizes the land values into different ranges (e.g., 0-1K THB, 1.1K-5K THB, 5.1K-10K THB, 10.1K-15K THB, and 15.1K-43.7K THB) based on Thai Baht (THB) and provides the corresponding areas and weights. It was supposed that the areas having the more valuable land should be avoided and the land having less land value should be promoted for green space development. In the first zone, where the land value is below 1,000 THB, the covered area is substantial, accounting for 79.67% (1261.4 sq. km.) of the total. The second zone, with land values between 1,100 and 5,000 THB, occupies 16.54% (261.8 sq. km.). The third zone, within the 5,100 to 10,000 THB range, covers 1.84% (29.1 sq. km.). The fourth zone, representing 10,100 to 15,000 THB, accounts for 0.82% (13.0 sq. km.), and the fifth zone, with values between 15,100 and 43,700 THB, encompasses 1.13% (17.9 sq. km.) of the total land area.

3.2.5. *Distance from roads*

According to Abebe & Megento (2017), Tahmasebi et al. (2014), and Ustaoglu & Aydınoglu (2020), it is recommended to choose a green space site that is situated at an optimal distance from roads to facilitate convenient transportation access. This argument emphasizes the importance of considering proximity to roads when selecting a location for green space development, as it can enhance accessibility and ease of transportation for users. *Table 1* categorizes the distances from the roads into different ranges (e.g., < 50m, 50.1-100m, 100.1-200m, and > 200m) and provides the corresponding areas and weights. The weights assigned to each range are from 2 to 5. The initial zone encompasses an area of 179.1 sq. km., accounting for 11.31% of the overall area. The subsequent zone spans 136.9 sq. km., representing 8.65% of the total area. The third zone occupies an area of 233.3 sq. km., constituting 14.74% of the entire area. Lastly, the fourth zone encompasses 1034.0 sq. km., making up 65.30% of the total area. The creation of green areas beside city roadways has gained importance for a number of reasons, including advantages to the environment, society, and economy. The creation of green areas along roadways is also essential for creating more sustainable, healthier, and livable urban environments. Governments, city planners, and communities recognize the multiple benefits that green spaces bring to cities and are increasingly incorporating them into urban development plans to improve the quality of life for residents and protect the environment.

3.2.6. *Proximity to traffic points*

To obtain real-time or historical traffic data from sources like GPS devices, traffic sensors, or traffic management systems is a tedious task, hence the traffic points in any area provide useful information that indicates the traffic situation in that area. The analysis categorizes traffic points (e.g., < 2, 3-10, 11-20, 21-50, and > 50) based on their counts, associating them with specific areas and weights. The category with a count of less than 2 traffic points covers a substantial area of 1274.4 sq. km., representing 80.49% of the total area considered for assessment. This category is assigned a high importance weight of 5. Similarly, categories with counts between 3-10, 11-20, 21-50, and greater than 50 have areas of 241.1, 100.5, 45.2, and 10.1 km^2, respectively, each accounting for a decreasing percentage of the total area. These categories are assigned weights of 4, 3, 2, and 1, reflecting their respective importance levels. Collectively, these categories and their associated areas offer valuable insights into the distribution and density of traffic points, enabling a comprehensive assessment of the traffic situation in the city. The higher the number of traffic points, the more congested the areas in the city are, as well as vulnerable to pollution. Hence, the open spaces in proximity to the traffic points should be considered for green space development to control pollution in the city.

For a number of reasons, including environmental, social, and economic advantages, the creation of green areas beside roadways in cities has grown in significance. The creation of more sustainable, healthier, and livable urban settings depends heavily on the development of green areas beside roadways. The central part of Bangkok, where most of the highways are, is the area that is ideal for the development of green areas.

3.2.7. *Distance from ecotourism sites*

Ecotourism sites often showcase natural habitats and ecosystems, promoting biodiversity conservation within urban environments. City planners can strategically designate green spaces as ecotourism sites to protect and preserve local flora and fauna. There are seven ecotourism sites located in the BMR, namely Taling Chan Floating Market Area – Clok, Gu Kut Chin Community, Yaowarat Chinese Community, Mon Bang Kradi Community, Bang Mod Phatthana Community, PhaendinThongkoi Ruttan, and Ban Bu Community, covering about 10.7 sq. km. of the city region. Taking into consideration the distance from ecotourism sites, different buffer zones have been created. The table categorizes the distances into different ranges (e.g., < 0.5m, 0.51-1.0m, 1.1-2.0m, 2.1-5.0m, and > 5.0m) and provides the corresponding areas and weights. The buffer zone situated at a distance of less than 0.5 meters from ecotourism sites, covering an area of 50.2 sq. km., corresponds to 3.17% of the total area. Representing locations located between 0.51 and 1.0 meters away from ecotourism sites, with an associated area of 80.5 sq. km., accounting for 5.08% of the total area. Denoting locations positioned between 1.1 and 2.0 meters from ecotourism sites, with an area of 110.3 sq. km., constituting 6.96% of the total area. The category covers locations within a distance of 2.1 to 5.0 meters from ecotourism sites, encompassing 241.1 sq. km., which is equivalent to 15.23% of the total area. Referring to locations situated at a distance greater than 5.0 meters from ecotourism sites, with an associated area of 691.5 sq. km., representing a substantial 43.68% of the total area. The higher the distance from ecotourism sites, the more ecologically unsafe and aesthetically poor it is; therefore, it needs to be promoted for green space development in the city.

3.2.8. *Distance from green spaces*

Any city region's current green areas preserve the ecological balance, enhance the surrounding environment, and make the urban environment more youthful, more sustainable, and more pleasurable. The buffer zone distance from these green spaces is helpful in strategizing to develop more green space in the city region. The table lists four distance ranges: <300m, 301-500m, 501-1000m, and >1000m, and the weight value to each range, with 5 being the highest weight and 1 being the lowest weight. The higher distances from these green spaces are prioritized in terms of developing new green spaces, whereas the areas located in proximity are promoted for other land uses. The category encompasses locations located at a distance of less than 300 meters from green spaces, accounting for an area of 241.1 sq. km., equivalent to 15.23% of the total area. Representing locations positioned between 301 and 500 meters from green spaces, with an associated area of 100.5 sq. km., constituting 6.34% of the total area. Denoting locations located between 501 and 1000 meters from green spaces, covering 80.5 sq. km., which accounts for 5.08% of the total area. Referring to locations situated at a distance greater than 1000 meters from green spaces, with an area of 691.5 sq. km., making up a substantial 43.68% of the total area considered for assessment.

3.2.9. *NDVI index*

The Normalized Difference Vegetation Index (NDVI) serves as a powerful tool for city planners, landscape architects, and environmental managers in monitoring, planning, and managing green spaces within urban environments. Negative NDVI values usually represent non-vegetated surfaces such as water bodies, bare soil, and built-up areas. The lower the value, the less vegetation is present, whereas the higher the value, the more likely it indicates the presence of healthy vegetation. The weight value to each range, with 5 being the highest weight and 1 being the lowest weight. The table categorizes NDVI ranges into five classes based on values. The first range, from -0.86 to -0.02, covers 15.23% (241.1 sq km). The second range, -0.02 to 0.14, encompasses 25.42% (402.8 sq km). The third range, 0.15 to 0.28, spans 22.15% (350.9 sq km). The fourth range, 0.29 to 0.45, includes 22.20% (351.9 sq km). The fifth range, 0.46 to 0.76, extends over 29.64% (469.2 sq km). These categories provide a concise breakdown of NDVI-based zones and their respective proportions in the overall area.

3.2.10. *Distance from waterbody*

The waterbodies and green spaces are often considered complementary elements in city regions. Their synergy creates multifaceted urban environments that promote ecological, social, and cultural sustainability. City planners often strive to integrate these elements thoughtfully to maximize their complementary benefits in city regions. Taking distance from the water bodies into consideration, the four buffer zones were generated, e.g., <100m, 101-300m, 301-500m, and >500m, to parameterize the aspect. The prioritization involves assigning higher scores to locations in close proximity to waterbodies, while relatively lower values are assigned to farther locations for the development of green spaces. Notably, areas within 100 meters from the waterbody, constituting 7.97% of the total area, carry a weight of 5. Distances from 101 to 300 meters cover 13.00% of the total area, with a weight of 4, and distances between 301 to 500 meters represent 12.62% of the total area with a weight of 3. For distances >500 meters, covering 66.41% of the total area, a weight of 2 is assigned. This information provides a basis for the assessment of green space site suitability based on their proximity to waterbodies.

3.2.11. *Distance from coastline*

Bangkok, a coastal city, is confronted with climate change-related issues such as rising sea levels and harsh weather. Green spaces contribute to the city's climate resilience by acting as natural buffers against flooding, storm surges, and several other benefits.

The distance from the coastline is parameterized to prioritize the land for the creation of green spaces in the city region; hence, it is categorized in five consecutive zones, e.g., <20m, 20.1-30m, 30.1-40m, 40.1-50m, and >50m. Like the waterbodies, higher scores were assigned to locations in close proximity to the coastline, while relatively lower values were assigned to farther locations for the development of green spaces in the region. The first buffer zone comprises areas within a 20-meter distance, covering 45.2 sq km (2.85%). The second zone encompasses locations between 20.1 and 30 meters from the coastline, with an area of 80.5 sq km (5.08%). The third zone represents areas situated between 30.1 and 40 meters from the coastline, covering 100.5 sq km (6.34%). The fourth category includes locations between 40.1 and 50 meters from the coastline, with an area of 110.3 sq km (6.96%). Finally, the fifth category represents locations more than 50 meters away from the coastline, covering 691.5 sq km (43.68%). These buffer zones provide a concise overview of the distribution of areas based on their distances from the coastline in the assessed region.

3.2.12. *Distance from flooded areas*

Flooding is a major issue in many coastal cities, and the development of green spaces plays a crucial role in mitigating and managing the impacts of flooding. Therefore, the areas facing this issue should be focused on and prioritized for plantation for green space development. To address this situation, buffer zones were created based on distances from flooded locations. Prioritizing proximity, in the BMR, the nearest zone (<100m) covers 15.23% (241.1 sq. km.), the second zone (101-500m) covers 6.34% (100.5 sq. km.), the third category (501-1000m) covers 5.08% (80.5 sq. km.), and the fourth category (>1000m) covers 43.68% (691.5 sq. km). This categorization provides insights into the distribution of areas concerning their distances from flooded zones, facilitating a comprehensive assessment of flood risk and suitability for various purposes.

The two key variables where there is high adaptability of land uses in closer proximity to urban green places and the shoreline are distance from the coastline and flooded regions. Given that Bangkok's Southwestern and Middle districts include the majority of the city's green space, a significant amount of high-suitability uses of land were calculated for these areas.

3.2.13. *Urban elevational characteristics*

Considering elevation from sea level in the development of green spaces allows for a holistic approach that addresses ecological, aesthetic, recreational, and safety considerations in coastal areas. The BMR extended from -62 to 56m from the mean sea level. To prioritize land elevation for green space development in the region, three elevation zones were classified: -62 to -28m, -27.9 to 0.0m, and 0.01 to 56m. The lowest elevation category (-62 to -28m) covers 15.23% (241.1 sq. km.). The second category (-27.9 to 0.0 meters) comprises about 6.34% (100.5 sq. km.). Lastly, the elevation zone from 0.01 to 56m constitutes about 5.08% (80.5 sq. km.) of the total assessed area.

3.2.14. *Slope features*

Understanding the surface slope of an area and incorporating it into decision-making for green space development in coastal cities has been proven as an efficient approach that contributes to the creation of sustainable and resilient landscapes. Hence, this parameter has been taken into consideration and classified into three respective zones ranging from <3°, 3.1-6.0°, and >6°. The lower slope, situated along coastal areas and in proximity to the Chao Phraya River, is highly susceptible to flooding. Therefore, it is prioritized for careful consideration. In contrast, the higher slope is deemed safer and promoted for the development of other land uses in this assessment. Approximately 691.5 sq. km., constituting 43.68% of the BMR area, has a surface slope of less than 3°. The slope class ranging from 3.1° to 6.0° encompasses 822.3 sq. km, representing 51.94% of the total area. Lastly, slopes greater than 6° cover about 69.3 sq. km, occupying 4.38% of the total BMR area.

3.3. *Standardising a few chosen criteria and developing an overlay model for site suitability modelling based on AHP*

It is imperative that, in the process of standardisation, every layer of the chosen criteria has the same measurement even when they have different units. It is possible to compare ratings obtained from different map characteristics because of this homogeneity. Each criteria map's characteristics were standardised into the same units, which caused the scores to become less dimensional and line with the measurement units of every criterion (Janssen and Herwijnen 1994, Effat and Hassan 2013).

The selected criteria from vector layers, such as roads, utilities, current land value, road traffic conditions, ecotourism spots, ecological patches, rivers, water bodies, coastal lines, etc., were digitized and subsequently converted into raster layers, as depicted in Figures 2 and 3. Conversely, the BMR region is situated in a coastal area where topographic features such as elevation and surface slope significantly influence the decision-making process for identifying land suitable for sustainable green space development. Therefore, during the evaluation of green space sites, all these factors were carefully considered.

These parameters were assessed using digital elevation models (DEMs) and reclassified into different categories to facilitate potential site identification for green spaces. All resulting raster layers were categorized for input data into the weighted overlay analysis, ultimately generating the green space site suitability map. Reclassification and standardization processes were were conducted using the Spatial Analyst tool within ArcGIS. Next, taking into account each of the 14 factors in the study, the overall appropriateness index was determined.   This index was calculated through a weighted linear combination of the various geospatial elements, as outlined in equation (1), and the detailed methodology followed was represented in figure 4.

Table 3. *Pair-wise comparison matrix for determining suitable sites for green space sites affecting criteria involves assessing the relative importance of each criterion in relation to the others*

SN	Main Criteria	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14
1	Land use landcover [C1]	1	2	2	3	4	5	6	6	6	5	8	5	7	9
2	NDBI Index [C2]	1	1	2	3	4	4	5	5	5	6	7	7	8	9
3	Basic infrastructure (dist. in m.) [C3]	1/2	1/2	1	2	3	4	5	6	7	7	8	8	8	9
4	Current land value (THB) [C4]	1/3	1/3	1/2	1	2	3	4	5	5	4	4	8	8	9
5	Road accessibility (dist. in m.) [C5]	1/4	1/4	1/3	1/2	1	2	3	4	4	5	5	7	8	9
6	Traffic conditions (No. of points) [C6]	1/5	1/4	1/4	1/3	1/2	1	2	3	3	4	4	7	8	9
7	Ecotourism spots (dist. in km) [C7]	1/6	1/5	1/5	1/4	1/3	1/2	1	2	2	3	4	5	6	7
8	Ecological patches (dist. in m.) [C8]	1/6	1/5	1/6	1/5	1/4	1/3	1/2	1	1	2	3	4	5	7
9	NDVI Index [C9]	1/6	1/5	1/7	1/5	1/4	1/3	1	1	1	2	3	4	5	7
10	Waterbody (dist. in m.) [C10]	1/5	1/6	1/7	1/4	1/5	1/4	1/2	1/2	1/2	1	2	3	5	7
11	Distance from coastal line (dist. in m.) [C11]	1/8	1/7	1/8	1/4	1/5	1/4	1/3	1/3	1/3	1/2	1	3	5	7
12	Flooding situation (dist. in m.) [C12]	1/5	1/7	1/8	1/8	1/7	1/7	1/4	1/4	1/4	1/3	1/3	1	2	3
13	Surface elevation (in m.) [C13]	1/7	1/8	1/8	1/8	1/8	1/8	1/5	1/5	1/5	1/5	1/5	1/2	1	2
14	Surface slope (in °) [C14]	1/9	1/9	1/9	1/9	1/9	1/9	1/7	1/7	1/7	1/7	1/7	1/8	1/9	1

Table 4. *Synthesized matrix indicating final weight calculation and consistency vector value involve in consistency evaluation*

Criteria	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	Weights	λ Max
C1	0.22	0.36	0.28	0.26	0.25	0.24	0.21	0.17	0.17	0.12	0.16	0.08	0.21	0.96
C2	0.22	0.18	0.28	0.26	0.25	0.19	0.17	0.15	0.14	0.15	0.14	0.11	0.19	1.05
C3	0.11	0.09	0.14	0.18	0.19	0.19	0.17	0.17	0.20	0.17	0.16	0.13	0.16	1.14
C4	0.07	0.06	0.07	0.09	0.12	0.14	0.14	0.15	0.14	0.10	0.08	0.13	0.11	1.22
C5	0.05	0.04	0.05	0.04	0.06	0.10	0.10	0.12	0.11	0.12	0.10	0.11	0.08	1.36
C6	0.04	0.04	0.03	0.03	0.03	0.05	0.07	0.09	0.08	0.10	0.08	0.11	0.06	1.34
C7	0.04	0.04	0.03	0.02	0.02	0.02	0.03	0.06	0.06	0.07	0.08	0.08	0.05	1.33
C8	0.04	0.04	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.05	0.06	0.06	0.03	1.13
C9	0.04	0.04	0.02	0.02	0.02	0.02	0.03	0.03	0.03	0.05	0.06	0.06	0.03	1.20
C10	0.04	0.03	0.02	0.02	0.01	0.01	0.02	0.01	0.01	0.02	0.04	0.05	0.02	1.00
C11	0.03	0.03	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.05	0.02	0.76
C12	0.04	0.03	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.56
C13	0.03	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.01	0.01	0.83
C14	0.02	0.02	0.02	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.82
														14.69

CI = 0.053

CR=CI/RI = 0.034

$$\mathbf{LS} = \sum_{i=1}^{n} W_i X_i$$

Where, in the equation adopted from (Cengiz & Akbulak, 2009), the variables are defined as follows: LS represents the overall score of land suitability, W_i signifies the weight assigned to the specific land suitability criteria, the subcriteria score attributed to the i^{th} land suitability criterion is represented by the symbol Xi, and n indicates the entire number of criteria considered for assessing green space land suitability.

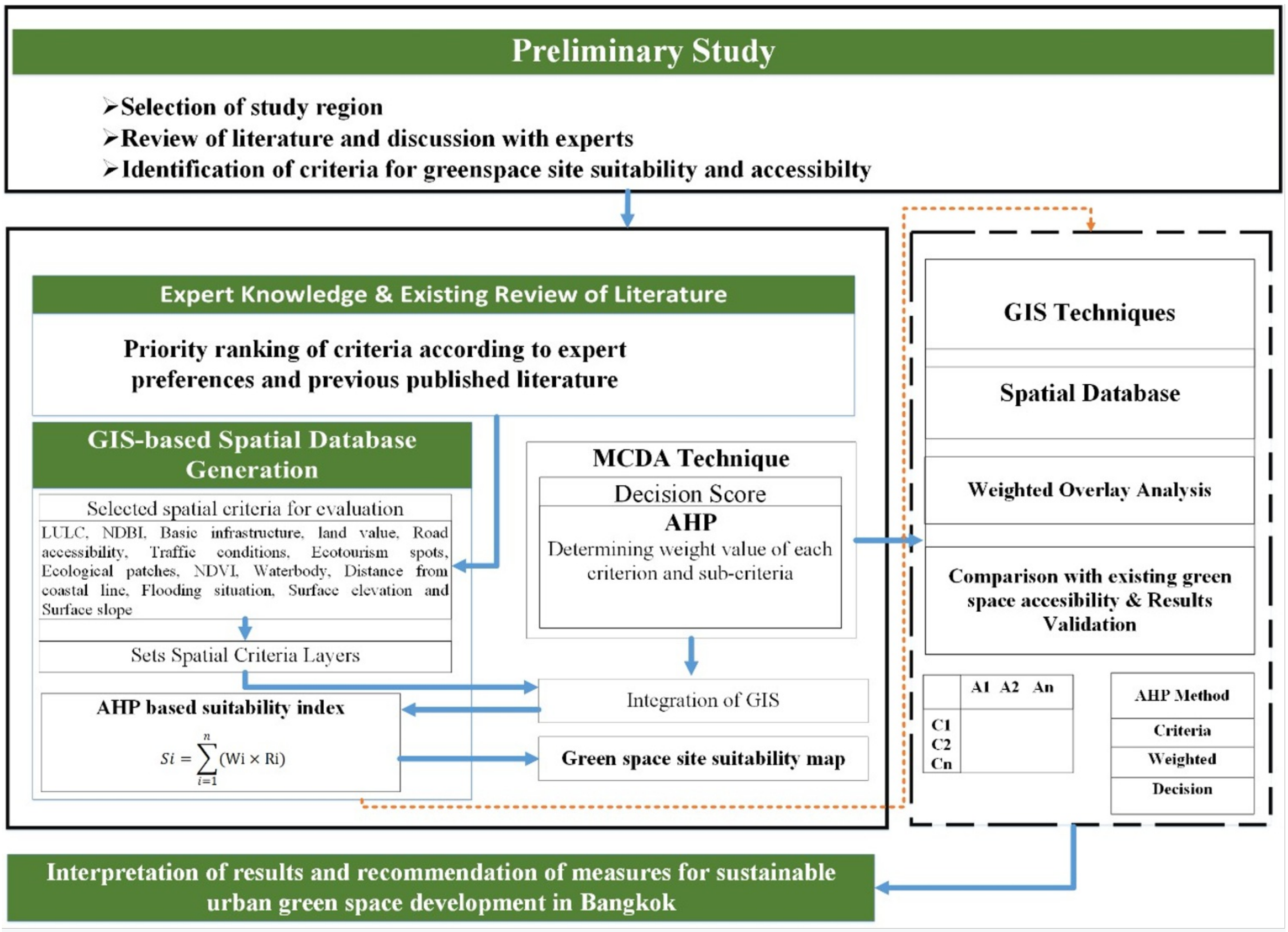


Figure 4. *Showing the detailed methodological steps followed for the study*

3.4. *Validation of findings*

The efficacy of model results hinges fundamentally on their accuracy, and the significance of models lies in their validation (Chaudhary et al., 2022, Pramanik et al., 2018). Various methodologies are employed to validate the outputs of suitability modeling, with common practices including the construction of a Receiver Operating Characteristics (ROC) curve for analyzing the suitability of green space sites. To calculate the commonly used measure Area under Curve (AUC), one is involved.

Across all potential threshold values, the ROC curve is a graphical representation that plots false positive scores on the Y-axis and false negative scores on the X-axis (Pourghasemi et al., 2013; Pramanik et al., 2020). The area under the curve (AUC) in this study indicates how accurate the forecast is, explaining how well the system can predict whether certain "events" will occur or not. The AUC values are in the range of 0 to 1.0, as stated by Pramanik et al. (2020). In contrast, a value of 1.0 denotes complete discrimination, whereas a value of 0 implies that the model's output was nothing more than random.

4. Results

4.1. *Requirements for the appropriateness of green space sites*

The parameters selected in this study govern the mapping of urban green space suitability, as described in Figures 2 and 3. A MCDM approach was developed for assessing green space site suitability, incorporating various thematic layers derived from remote sensing data, topographic features, infrastructure, ecological indicators, economic factors, and field investigations within the study area. Notably, Land Use/Land Cover (LULC) and Normalized Difference Built-Up Index (NDBI) emerged as significant aspects, each achieving high scores of 21% and 19%, respectively, influencing green space management in the BMR city region. Approximately 6.73% of the area falls under the bare land land use category, indicating high potential for green space development, while 17.02% of the BMR area features flooded vegetation, suggesting suitability for green space development. Moreover, NDBI plays a pivotal role in prioritizing areas within the city region for green space development. However, some areas with higher NDBI index values may not be suitable for green space development due to their involvement in other important infrastructure activities within the city region. Furthermore, considerations such as basic infrastructure, road accessibility, traffic conditions, and land value moderately influence site suitability, while relatively lower weights are assigned to factors such as ecotourism spots, ecological patches, NDVI, water bodies, distance from the coastal line, flooding situations, surface elevation, and surface slope (refer to the table).The mapping of green space in urban areas appropriateness is determined by the characteristics used for this study, as shown in Figures 2 and 3. A thorough technique that included many thematic layers generated from topographic characteristics, infrastructure, ecological indicators, economic considerations, and field studies within the research region, as well as remote sensing data, was established for evaluating the feasibility of green space sites.

Notably, Land Use/Land Cover (LULC) and Normalized Difference Built-Up Index (NDBI) emerged as significant aspects, each achieving high scores of 21% and 19%, respectively, influencing green space management in the BMR city region. Approximately 6.73% of the area falls under the bare land land use category, indicating high potential for green space development, while 17.02% of the BMR area features flooded vegetation, suggesting suitability for green space development. Moreover, NDBI plays a pivotal role in prioritizing areas within the city region for green space development. However, some areas with higher NDBI index values may not be suitable for green space development due to their involvement in other important infrastructure activities within the city region. Furthermore, considerations such as basic infrastructure, road accessibility, traffic conditions, and land value moderately influence site suitability, while relatively

lower weights are assigned to factors such as ecotourism spots, ecological patches, Normalized Difference Vegetation Index (NDVI), water bodies, distance from the coastal line, flooding situations, surface elevation, and surface slope (refer to the table). For classification of the parameters, a continuous scale ranging from 1 to 5 was adopted for the maps corresponding to the 14 criteria (see *Table 1*); the lighter hues on the maps, with suitability ratings near 1, signify less favorable land conditions. In contrast, the darker hues represent higher appropriateness, with values representing 5.

4.2. *Land Suitability for Urban Green Space*

The evaluation values were categorized into five grades using Natural Breaks classification: very low suitability, lower suitability, moderate suitability, higher suitability, and very higher suitability outlined in Table 5 and depicted in Figure 4. The findings reveal a consistent pattern in the distribution of green space suitability grades across the BMR region, with higher suitability predominantly observed in the southern part along the riverine and coastal regions and lower suitability in the north-eastern and north-western areas. In the present study, it is estimated that 364.74km^2 (23.06%) of the area has the very least opportunity to develop green spaces in the BMR region because there is a very high involvement of land in other important infrastructure development. Hence, the open spaces that were left for public uses can be utilized for this purpose, and poorly managed parks and recreation spaces can be managed using the best possible techniques to enhance green spaces in these areas (Fig. 4), and 400.54km^2 (25.33%) of the area is mostly aligned with built-up areas, indicating low opportunities to develop green spaces in this metropolitan region. In this zone, the public land patches should be recommended for the plantation of native tree species, discouraging concreting the surface. This will help not only with green space enhancement but also with recharging groundwater in those areas. Green areas should be allotted within the boundaries of urban lots for land uses such as communal, institutional, government, office, and residential. Preserving the remaining natural places in new projects is crucial, especially the green spaces that are already there. In order to improve urban greenery and connectedness, planting possibilities along linear greenway locations, such as promenades and river banks, should be maximized.

Table 5. *Green space suitability output indicating its areal coverage according to its class in the BMR*

SN	Area (km^2)	Area (%)	Green space suitability score and class
1	364.74	23.06	17.3 - 52 (Very low)
2	400.54	25.33	52.1 - 68 (Low)
3	190.4	12.04	68.1 - 75 (Moderate)
4	287.84	18.20	75.1 - 82 (High)
5	337.91	21.37	82.1 - 100 (Very High)

About 190.4km^2 (12.04%) has moderate potential to develop green space sites in the metropolitan region; this zone is mainly characterized by various other residential public spaces, shaded sidewalks, riparian strips, and open ground with gray infrastructure. By participatory involvement of the public and development authorities, the area can be managed for

this use with careful practices in the metropolitan areas of the BMR. About 287.84km^2 (18.20%) and 337.91 km^2 (21.37%) have high to very high potential to ameliorate the green spaces in the metropolitan areas.

These sites are highly prioritized to develop green spaces, and existing green spaces should be strictly protected and conserved to maintain the ecological balance of city life in the region.

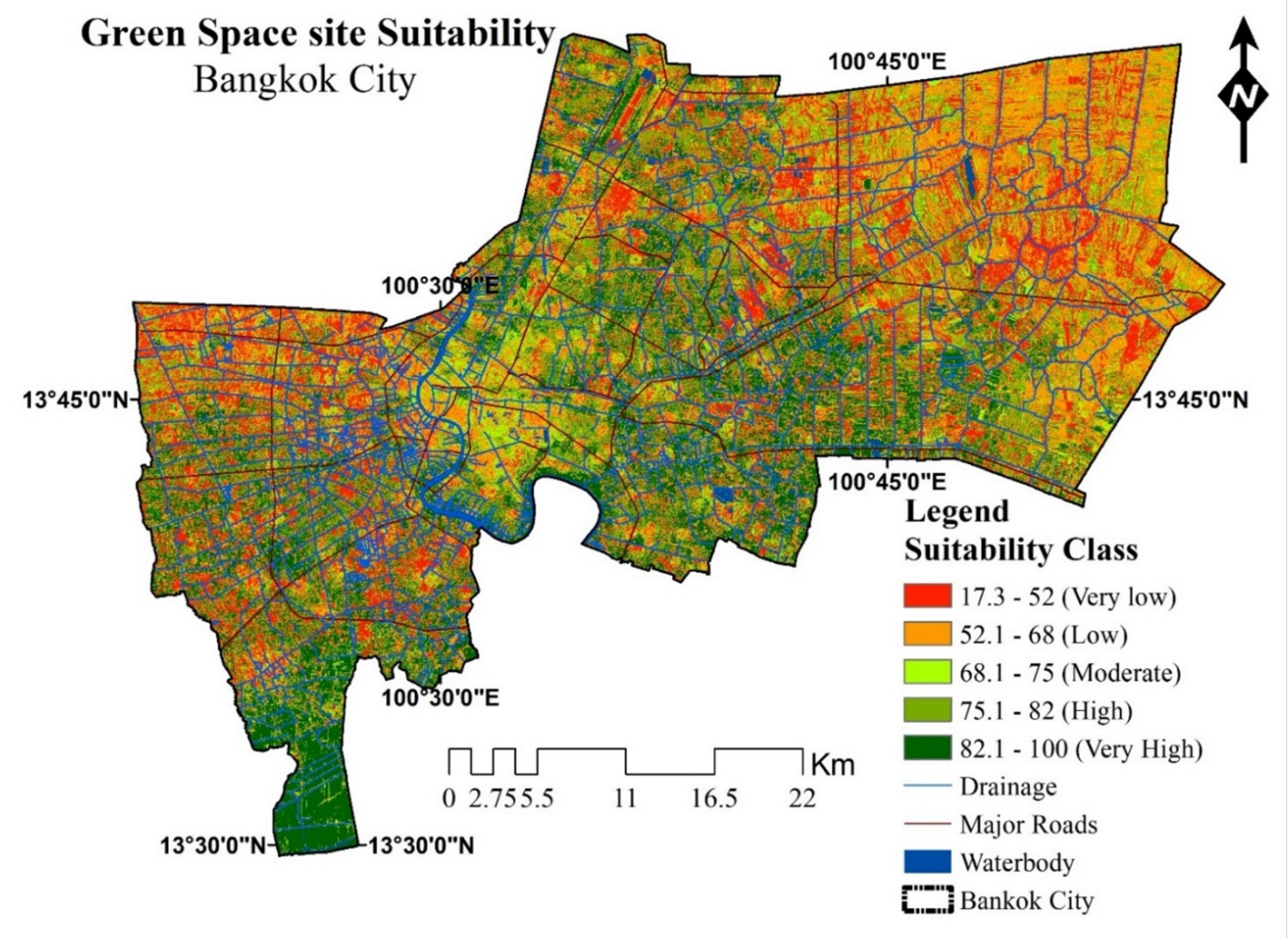


Figure 5. *Showing the greenspaces suitability modeled based on indicators used for the assessment. Deep green indicates higher suitability, and red indicates less favorability for greenspace planning in BMR*

The land parcels located in these zones are economically less valuable, farther from the proximity to gray infrastructure, and mostly fall along the coastal, riverine, and waterbodies (Fig. 5). To foster the development of green spaces within these zones, priority should be given to all available open public land in close proximity to densely populated areas by avoiding farmlands. By prioritizing the establishment of green spaces through strategic plantation efforts, we can enhance urban green coverage and promote a healthier environment for local communities.

4.3. *Physical accessibility and traffic conditions-based suitability:*

The evaluation of green space equity in any city hinges on the prompt accessibility of such spaces to its citizens, ensuring that people can reach these areas quickly and conveniently. In this assessment of green space accessibility in the BMR, the AccessMod5 toolbox, originally developed by the World Health Organization (WHO) for assessing the physical accessibility of healthcare centers, is adeptly utilized. Considering the universal preference for walking as a quintessential warm-up activity embraced by individuals globally, it is chosen as the primary mode of travel to the nearest green space amenities such as parks, stadiums, golf courses, playgrounds, and zoos, meticulously developed for citizen recreation. Employing walking as the mode of conveyance, the accessibility was assessed, and a spatial layer was generated, classified into 10 classes illustrating the accessibility of each green space to its vicinity (see Fig. 6). The visualization in Figure 4 unveils that the western residential part boasts a more concentrated presence of green space amenities compared to the eastern part. Consequently, accessibility to all green space amenities is notably higher in the western region, with any green space accessible in as little as 4 minutes at the least and 119 minutes at the most. This implies that the majority of the population in the BMR can conveniently access any nearby green space within less than 30 minutes, covering 70% of the area, while the remaining areas can be accessed within a range of 30 to 119 minutes (Table 5).

Table 6. *Indicating the existing green space accessibility areal coverage in the BMR*

Time (in min.)	0 – 4	4.01 – 8	8.01 – 10	10.1 – 12	12.1 – 16	16.1 – 20	20.1 – 30	30.1 – 60	60.1 – 70	70.1 – 119
Area (Sq. Km.)	182.5	227.1	110.8	101.2	167.8	126.8	201.4	260.6	66.0	139.2
Area (%)	11.5	14.3	7.0	6.4	10.6	8.0	12.7	16.5	4.2	8.8

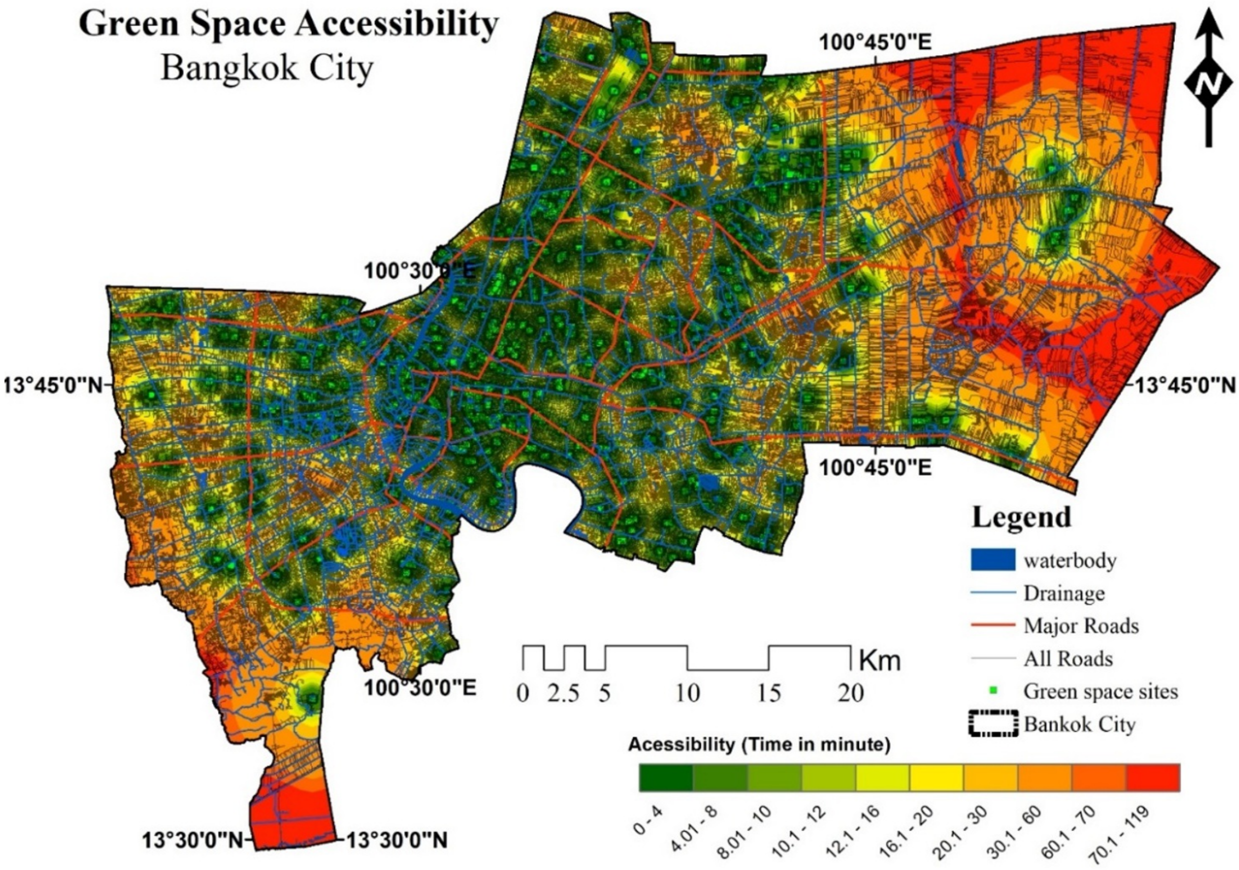


Figure 6. *Showing the spatial distribution of all the existing green space locations and accessibility (in time) towards them from their neighborhood proximity*

4.4. *Land suitability validation*

The final map of predicted green space site suitability underwent validation through multiple means, including the utilization of Google Earth imagery and data collection via regular field surveys in the study area. Furthermore, a comparative analysis was conducted between existing greenspace locations and predicted suitable green space sites in the Bangkok Metropolitan Area (BMR). In our study, the validation of our model results was conducted through the construction of a ROC curve for identifying suitable green space sites and estimating the AUC, among other metrics. To assess green space site suitability using the AHP model (Regmi et al. 2014), existing green spaces were juxtaposed with predicted sites. In ROC curve analysis, the models demonstrated a moderate capacity to distinguish between actual and predicted sites based on the AHP model. The ROC curves, along with the AUC, are visually represented in *Figure 7.*

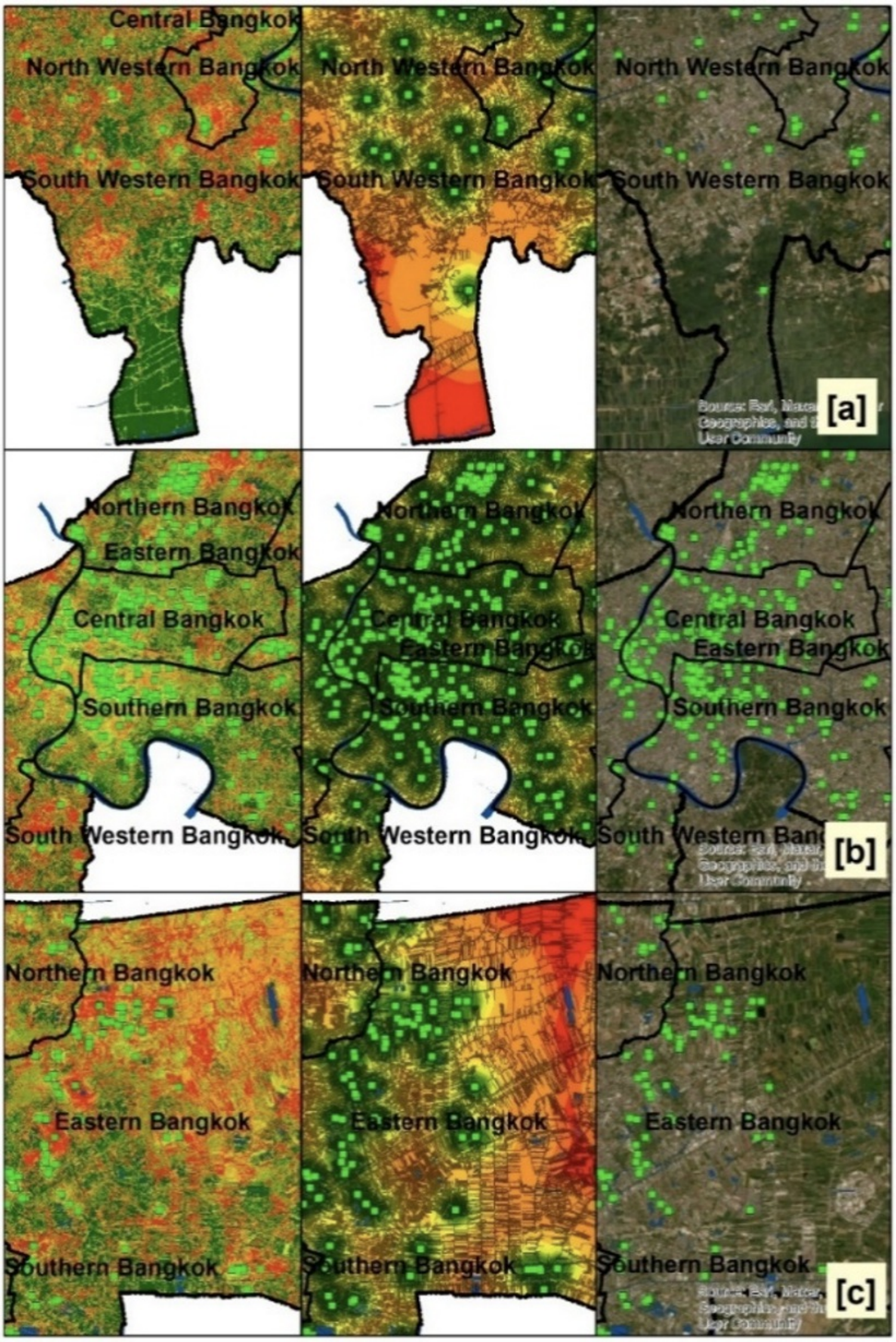


Figure 7. *Random points for results validation of green space suitability and accessibility considering existing green spaces in the BMR*

The AUC value for the AHP method was found to be 77%, indicating that the potentiality maps were predicted quite well, attesting to a moderate level of accuracy. Consequently, the model employed in this study can be reasonably deemed accurate in predicting green space sites in the BMR. Furthermore, the results revealed a congruence between green space site suitability maps generated from both methods and images extracted from Google Earth (Fig. 7). This alignment underscores the reliability of the prediction process, affirming the accuracy of the model in delineating suitable sites for green spaces in the study area.

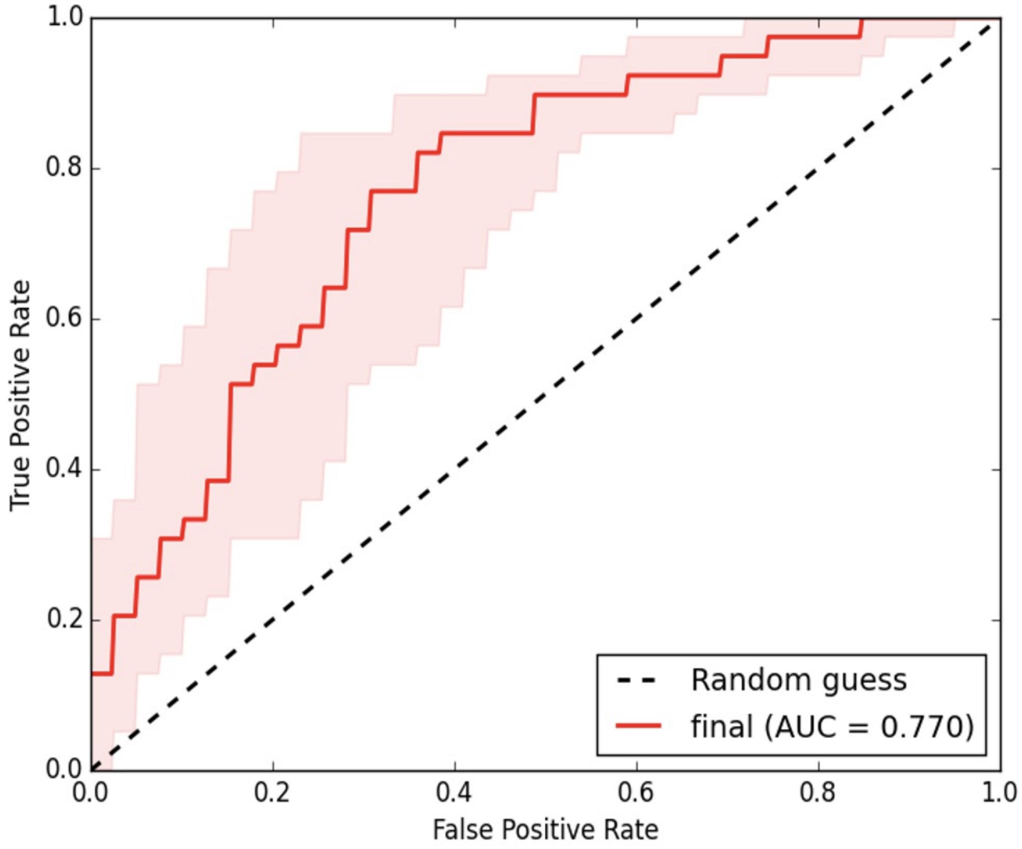


Figure 8. *The ROC curve for the AHP method indicating the AUC values 77% demonstrating a very good level of accuracy of green space site suitability in BMR*

5. Discussion

In this study, we looked at the regional heterogeneity in appropriateness for creating urban green spaces. By applying a spatial land suitability evaluation technique that combines GIS and AHP modelling, we have been able to obtain a deeper comprehension of the methodology that is used for the identification of appropriate areas for future urban amenity enhancements. This was accomplished by evaluating important elements that influence where urban green space is located and potential conflicts that may already exist between various land uses and cover types. In order to ascertain and assess land use appropriateness, integrated and cooperative methods must be used. By assisting in addressing problems caused by the ambiguities, subjectivities, and hierarchical structure of traditional land suitability assessment techniques, these approaches have also enhanced suitability analysis (Zhang et al. 2015). In order to calculate the land suitability index, the AHP-based weights were used to convert the geographical data for each factor. The weights for each element were determined using the AHP technique, while geographical assessment, map processing, AHP modelling, and result presentation were all done using GIS. A collection of techniques called the multi-criteria analysis methodology can help decision-makers work through challenging issues. It minimises costs and offers a framework for analysis in spatial decision-making (Lotfi et al. 2009).

The integration of GIS and multi-criteria analysis has improved previous methods for assessing the suitability of land and spatial decision-making concerns, resulting in a high-performing instrument (Malmir et al. 2016). Thapa and Murayama (2008), Abdel Rahman et al. (2016), Miller et al. (1998), Calıjuri et al. (2004), and many other studies employed traditional selection of sites techniques like spatial overlapping and AHP. This is in line with the recent review of the scientific literature on the appropriateness of land evaluation methods. Compared to earlier research that focused on conventional site selection methods, the current study provides an enhanced method for thorough land suitability analysis. Several studies have employed AHP modelling in their evaluations of the appropriateness of the land (Chang et al., 2008; Keshavarzi, 2010; Donevska et al. 2012; Malmir et al. 2016, Zhang et al. 2015).

When it comes to site selection and land suitability, comparisons between AHP modelling and other conventional techniques like parametric and limiting methods show that the AHP technique for land suitability analysis yields more promising results. For example, Sui (1992) has demonstrated that AHP may be applied in the GIS modelling process to circumvent the shortcomings of standard Boolean logic for the visualisation and manipulation of geographical data. Keshavarzi (2010) showed that AHP modelling may be more accurate and capable in estimating green spaces by displaying continuity in various land use groups. According to a new study by Jamshidi-Zanjani and Rezaei (2017), the AHP approach, incorporation with multi-criteria assessment techniques, created more flexible and superior concepts for dumping site selection than Boolean logic did. Therefore, we recommend employing the fuzzy set approach in conjunction with multi-criteria decision analyses along with GIS in land suitability evaluations, since this integrated strategy is a powerful tool for aiding with green space planning challenges, including the location of urban green facilities.

One of the main issues with land suitability analysis is determining each factor's relative value throughout the multi-criteria evaluation procedure. Various approaches have been used to determine the weights of the components in the site appropriateness evaluation, which vary depending on the kind of land use that is assessed, the geographical data that is accessible for the chosen case study region, and the chosen case study area itself. The weights have been determined through a variety of methods in the literature, including the parametric approach (Albaji et al., 2009), fuzzy membership approach (Chang et al., 2008), AHP/ANP (Malmir et al., 2016), PROMETHEE (Tuzkaya et al., 2009), ELECTRE (Mendas and Delali, 2012), MAUT/MAVT (Liu and Stewart, 2004), and Ordered Weighted Average (OWA)/Weighted Linear Combination (WLC) (Jamshidi-Zanjani and Rezaei, 2017). Falasca et al. (2012) used spatial overlay in GIS, regression analysis (Park et al. 2011), PCA (Gomez-Limon et al. 2009), and analytic neural networks.

Huang et al. (2011) provide a comprehensive assessment of the literature on multiple-criteria decision analysis approaches in environmental sciences. According to the literature currently in publication, which demonstrates that AHP can incorporate heterogeneous data by involving stakeholders in the systematic and logical assignment of weights, the current study uses the AHP approach to weight all of the parameters taken into consideration (Zhang et al. 2015). Because the Consistency Ratio (CR) can be used to evaluate and change the inconsistency of the matrix of pair-wise comparisons of factor values, AHP is a very effective tool for finding factor weights. This makes it preferable to alternative techniques. Numerous studies in the literature have supported this. Numerous investigations in the literature have corroborated this (Dong et al. 2008, Tudes and Yigiter 2010, Kumar and Shaikh, 2012, Bagheri et al. 2013, Romano et al. 2015). The interdependencies of the different elements are disregarded in the model implementations due to the AHP method's subjective assignment of the relative importance of the two factors, which is a downside despite the approach's benefits (Li et al. 2012, Malmir et al. 2016).

The physiological characteristics of the land surface, waterbodies and flooded areas, ecological spaces and vegetation cover, accessibility and traffic conditions, significant infrastructure and economic value of the land, land use, and building up were the six categories of criteria that we looked at in this study to determine the variation in land suitability. The findings show that the chosen criteria that have an impact on judging the value of land use appropriateness cause variations in the geographical distributions of appropriateness of different land uses. High suitability classes encompass narrower strips of the regions, according to accessibility- and blue-based suitability maps; but, when employing geophysical and urban land use-vegetation techniques, a larger portion of the research area yields better suitability. Although it includes all 14 of the criteria for suitability evaluations, the ultimate map of overall appropriateness is more thorough. The southern and central regions of the research area are more suited for the development of green spaces, per the overall suitability map. In order to assess whether land uses for the growth of urban green spaces in the Bangkok region are acceptable, the research has focused on a few important social, ecological, as well as environmental variables. The findings suggest that the appropriateness of land use is also influenced by a wide range of other factors.

With this, the research has presented a useful and efficient method for locating appropriate locations for the creation of green space in metropolitan areas. The aforementioned criteria and fine-scale features should be taken into account by architects and policy makers who prioritise the improvement of amenity-led growth when developing policies. Similar research based on suitability analyses of green land in many nations and areas may be found in the literature. For instance, Do Carmo Giordano and Setti Riedel (2008) assessed the land suitability of greenways in the Brazilian city of Rio Claro. Similar to what we did in our study, they conducted the land compatibility analysis using the AHP approach and GIS. Uy and Nakagoshi (2008) used GIS and the ecological factor threshold approach to conduct a land suitability analysis for green spaces in the city of Hanoi, Vietnam.

The research examined how urban green spaces are organised using landscape-ecology concepts. Chandio et al. (2011) evaluated the feasibility of developing public parks in Larkana, Pakistan, taking into account a number of variables, including land availability, land value and price, accessibility, and socioeconomic considerations. They focused on the following types of suitability maps: (1) availability of land, (2) the value of land, and (3) density of populations. They employed an AHP technique combined with GIS to evaluate the land appropriateness for park construction. Using GIS and AHP methodologies, Abebe and Megento (2017) evaluated possible sites for the Addis Ababa Metropolis' city green space growth in a recent study. The primary factors to be taken into account when assessing whether the urban green space expansion site was appropriate for a particular area were land use/cover, growth in population, road network, rivers, parks, soil type, historical sites, and noise issues.

Future research on land suitability evaluations will be built upon the methods used in this research and the results from our suitability maps. In order to create land suitability maps for various land uses, including agricultural, urban land, water management, and forest development, the integrated adaptability assessment approach may be employed. We recommend comparing our results in further work to the suitability values derived from the use of other methods for suitability evaluation, such as machine learning, logistic regression, artificial neural networks, and GIS integrated with AHP. In addition to suitability analysis, other techniques, including network analysis, accessibility, landscape metrics analysis, and landscape connectivity analysis, are employed in urban green space planning. The study's methodology and results complement those of other green land evaluation methods, making them useful for green amenities planning in identifying and measuring appropriate sites that align with other strategies. Suitability maps for the creation of green spaces may also be integrated into land analysis decision support systems, such as the land use modelling framework. The integration of land cover and suitability maps, considering neighbourhood effects, accessibility, and change amount data, is a key component of the land use modelling technique. Future land use changes have been efficiently simulated and evaluated through the use of land use modelling.

Based on studies conducted by Li et al. (2005) and Uy and Nakagoshi (2008), it has been found that arranging urban green spaces based on linear elements (such as green areas) or non-linear components (like recreation grounds) enhances the connectivity and interconnection of green spaces in urban areas and regions more successfully than considering each attribute separately. Thus, a sustainable method of improving "a connected green network including green wedges, green belts, green ways, green cores, green extensions, etc." is to use green structural design grounded in landscape-ecology principles (Uy and Nakagoshi 2008). In this study, we evaluated the feasibility of land uses by taking into account the distance to the current urban green spaces and by taking into account the ecological advantages of linked green infrastructures. According to our study (Fig. 6 and 7), the majority of the extremely ideal locations for future green space expansion is found in the region of the Bangkok Metropolitan Area's central and southwest current green zones. The findings of our analysis, coupled with an urban forest evaluation model, could be helpful in connecting green features—urban green spaces in the southwest of Bangkok with the surrounding forests and agricultural land in the northeast—and in allocating future demand for urban green space in line with the demands of planners and local authorities (Nowak and Crane 2002, Li et al. 2005).

Bangkok Metropolitan Area has prioritised economic expansion and rapid urbanisation; as a result, choices and planning policies have not been strong enough to govern and manage land use change and urban development, leading to the unsustainable development of urban green areas in the area. An examination of the connections among the current green areas revealed that they have been somewhat divided or separated. The fragmentation of urban green areas may affect the intended effect of green space systems because it is difficult to use one or a small number of diverse green areas to preserve the quality of the ecosystem services and other benefits arising from environmental restoration of urban landscapes (Uy and Nakagoshi 2008). According to research, greenways and green belts are essential for tying together disconnected green areas and existing urban green spaces (Nakagoshi et al. 2006). Therefore, we recommend that designers and policy makers include this ecological viewpoint with our findings from the appropriateness analysis in their development planning. The industrial sites in Pendik's southern region, which are mostly centred on major highways and the public transit system, are another worrying problem. In the current research, we have taken into account the presence of industrial zones as a constraint on the growth of green spaces. (For example, areas close to industrial zones receive a lower score for appropriate land use.) Improving the area's green space is crucial for ecological and environmental concerns as well as for preventing development in cities, which is connected to the fast expansion of the industrial and economic sectors. In fact, industrial zones are a contributing factor to air pollution as well as other issues related to the environment. Characterising urban green spaces is essential for the preservation of urban habitats and the services they provide, as the region's rapid industrialization and urbanisation have resulted in a lack of focus on green amenity planning.

4. Conclusion

The study employed an integrated GIS and AHP modelling approach to evaluate the suitability of land for greenbelt creation in the Bangkok Metropolitan Area (BMA). The spatial distribution of suitability values across the area was illustrated through maps, revealing areas with varying levels of suitability. The accessibility of existing green spaces was also analysed, considering different time intervals, and the results indicated varying degrees of accessibility across the Bangkok Metropolitan Area. The discussion delved into the methodological framework, emphasizing the importance of an integrated approach in assessing land suitability. The study showcased advancements over traditional site selection techniques, highlighting the effectiveness of the AHP method in handling heterogeneous data. Furthermore, a comparative analysis with previous studies conducted in other areas demonstrated the flexibility and relevance of the suggested technique. The study recommended the integration of its results into decision support systems for urban planning and emphasized the need for a sustainable approach to urban green space development. The findings indicated the importance of considering ecological principles and connectivity in planning green infrastructure. The study also drew attention to the challenges posed by rapid urbanization and industrialization in the Bangkok Metropolitan Area, emphasizing the need for careful planning to balance economic growth with environmental preservation. The research findings also add significantly to the conversation on sustainable urban planning and land use management by offering insightful information on whether a piece of land is suitable for the development of urban green spaces.

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