GIS Multicriteria Decision Analysis in Selecting the Optimal Location for Urban Green Space: A Case Study of Zadar City

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Abstract: The urbanization process has proceeded rapidly in recent decades, resulting in the rapid transformation of natural surfaces into impervious ones which has numerous impacts on the environment and human health. Urban green spaces are recognized as a critical spatial component for maintaining ecological balance and improving human mental and physical health. Therefore, the rational and even distribution of green spaces in the city is particularly important, as they represent the most accessible natural environment for city dwellers. The main objective of this study is to propose criteria and create a UGS suitability model (UGSSM) for the urban area of Zadar. The model is generated by applying the GIS multicriteria decision analysis (MCDA) and analytical hierarchical process (AHP). The model resulted in 580 ha of very high suitable (VHS) zones, mostly located in the northwestern part of the city. However, only 0.05% (*N=38*) of VHS zones are consolidated areas larger than 2 ha. Among VHS consolidated areas (>2 ha), the optimal one is depicted based on ownership verification. This framework can be applied to other small cities with some minor modifications. For future research, we suggest including residents with physical disabilities in the selection and landscaping of the location.

1 INTRODUCTION

The process of urbanization has progressed rapidly in recent decades and by United Nations projections will inevitably continue to increase (UN, 2018). Urban areas are already home to approximately half of the world's population and most industrial activities (Semeraro, 2021, The World Bank, 2020). Life in highly urbanized areas affects residents' living rhythm, which has become faster and more stressful. Additionally, urbanization affects the environment in various ways transforming natural surfaces into impervious such as roads, roofs, or parking lots. Some direct effects are the occurrence of urban heat islands (Song et al. 2015, Xu et al. 2022), pluvial floods, and biodiversity loss (McDonald et al. 2013, Song et al. 2015).

To mitigate these negative effects the importance of the natural environment is emphasized due to its various benefits. Urban green spaces (UGS) are considered one of the main components of urban environments (Gupta et al. 2012) in the context of recreation, social contributions (Nath et al., 2018), health (Jennings & Bamkole, 2019), and environmental outcomes (Hunter et al. 2019). It maintains the urban ecological balance by affecting the urban microclimate, purifying the air, and reducing the risk of heat islands, soil erosion, and pluvial or flash flooding (Hunter et al. 2019). UGS positively impacts city residents' mental and physical health by reducing stress, providing social contact, enabling physical activity, and reducing exposure to pollutants, noise, and excessive heat (Jennings & Bamkole, 2019). They are also considered one of the indicators of quality of life and housing in cities (Šiljeg et al. 2018).

There are various definitions of UGS. According to the Urban Green Belt project, UGS is defined as any public or private open space covered with vegetation, directly or indirectly accessible to users (Šiljeg et al. 2018). The World Health Organization defines it as any urban space that is covered with vegetation and is crucial in promoting healthy living conditions for all urban residents (WHO, 2017).

According to the ANGSt (Accessible Natural Green Space standard) developed by Natural England, green spaces are places where human activities are not intense and natural processes prevail

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(English Nature, 2003, Šiljeg et al. 2020). This standard emphasizes that green space is available when it can be used without fees and time constraints. In addition, the importance of size (area) and distance of UGS are emphasized. The upgrade of this methodology (ANGSt Plus) includes the concept of connectivity, defined as the physical possibility of access to green spaces. It also states the importance of an even distribution of green spaces in urban areas with respect to the socioeconomic characteristics of the area.

The mentioned definitions are not encompassing the importance of arrangement and mantainment the UGS. However, to use a particular UGS for rest and recreation some basic elements of accessibility must be achieved. These include basic infrastructure such as paths and benches, that do not significantly alter the natural environment. This infrastructure is especially important for people with physical disabilities who often do not use the benefits of UGS due to its lack of adaptation. The rationality and equity of UGS distribution are particularly important nowadays as the UGS is the most accessible natural environment for city residents (Semeraro, 2021). However, UGS management can be very challenging, especially in densely populated city areas (Haaland et al. 2015), and is often affected by the specific characteristics of each urban area (Linh et al. 2022). Some of the studies of UGS are focused on the ecological suitability of the location (Li et al., 2018; Linh et al. 2022). For the big cities, several general criteria are typically used. However, for smaller urban areas, the selected criteria are more specific to their locations, involving their individual distances and infrastructure (WHO, 2017; Linh et al. 2022).

Therefore, the main goal of this study is to determine the optimal location for UGS landscaping in the city of Zadar. The mentioned study case is depicted because Šiljeg et al. 2018 performed a UGS accessibility analysis and pointed out the lack of landscaped UGS in the city. The multiple-criteria decision analysis (MCDA), and AHP process were used to determine additional potential locations for UGSs arrangement.

2 STUDY AREA

Zadar (25 km²) is the administrative center of Zadar county (Figure 1). In the last decades, Zadar is characterized by intense urban sprawl followed by an increase in urban population due to dynamic and strong development as a regional center (Magaš, 1991, Magaš, 2011). At the latest census (2021), the total population was 75,082 (DZS, 2021). Recent economic and demographic trends are also reflected in urban physiognomy. For example, the old city center (Peninsula) is predominantly the central business district, while peripheral parts (Novi Bokanjac, Dračevac, Smiljevac) are now having a residential role (Graovac, 2004). Rapid urbanization also resulted in an increase in impervious surfaces and a lack of UGS (Šiljeg et al. 2018).

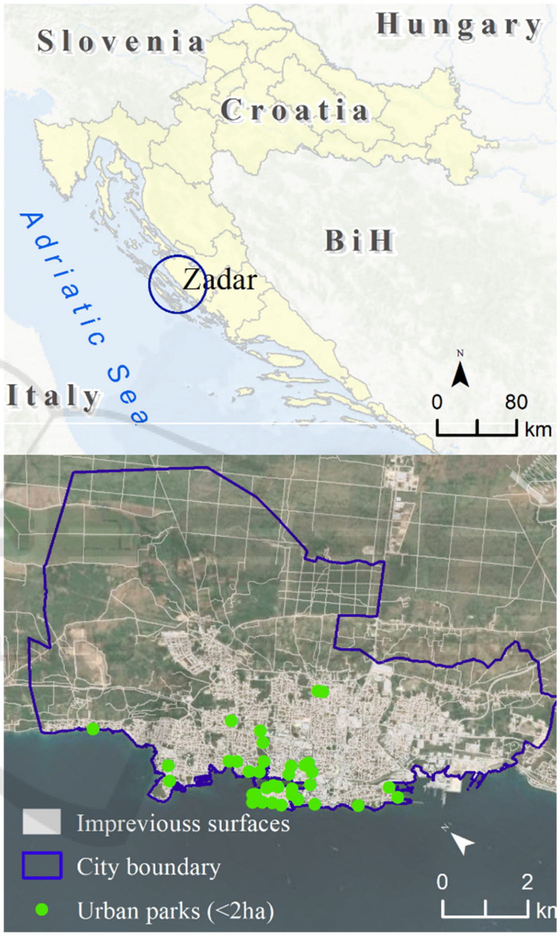

Figure 1: Study area.

3 MATERIALS AND METHODS

The main goal of this study is to suggest criteria and create the UGS suitability model (UGSSM) for the urban area of Zadar. To create the model GIS-MCDA and *Analytical hierarchical process* (AHP) were used. Since the Zadar is a smaller urban area, the selected criteria are specific to the research area involving individual distances and infrastructure.

3.1 GIS - MCDA

The GIS-MCDA is one of the most popular procedures used to estimate the suitability of land for various purposes (Modica et al. 2014). The procedure consists of 1) identification of the problem and defining the goal, 2) criteria selection, 3) criteria standardization, 4) calculation of weight coefficients, 5) criteria aggregation, and 6) model validation (Domazetović et al. 2019) (Figure 2).

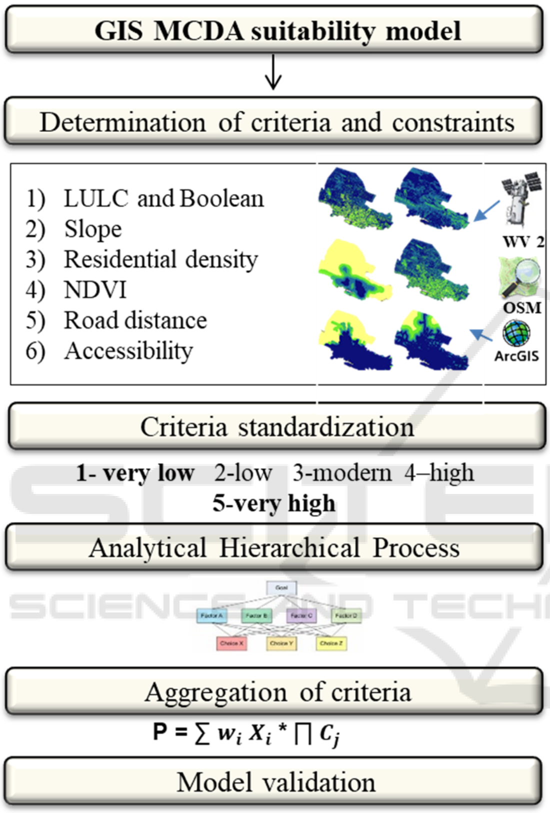

Figure 2: Methodology workflow.

To create UGSSM, criteria were derived in the ArcGIS environment using *Network Analyst* (*Service area*), *Spatial Analyst* (*Slope, Point Density, Raster Calculator*), and *Analysis tool (Proximity - Buffer)*. Input data include WorldView 2 (WV-2) multispectral (MS) imagery and *OpenStreetMap* (OSM) data. The land cover model (LULC) is generated from the WV-2 MS imagery, using the *Geographic Object-Based Image Analysis* (GEOBIA) and *Support Vector Machine* (SVM) algorithm.

To be comparable, all derived criteria (except Boolean) were standardized to scale from 1 to 5 (1 – very low suitability, 5 – very high suitability) using the *Jenks method.* Boolean criteria were standardized to a binary scale (0-false and 1-true). An AHP was used to rank criteria according to their level of suitability and to calculate the weighting coefficient for each (W_i). For the matrix validation consistency ratio was calculated (CR) (Figure 3).

	LULC	*SLOPE*	*RESID.*	*NDVI*	*ACC*	*ROADS*	W_i
LULC	**1**	9	1	3	3	6	0.339
SLOPE	1/9	**1**	1/3	1/3	1/3	1/3	0.046
RESID.	1	3	**1**	3	3	6	0.293
NDVI	1/3	3	1/3	**1**	1/3	3	0.108
ACC	1/3	3	1/3	3	**1**	3	0.153
ROADS	1/6	3	1/6	1/3	1/3	**1**	0.062
						CR	**0.08**

Figure 3: Pairwise matrix (AHP).

The following formula is used to aggregate the criteria (Eastman 1999):

$$P = \sum wi\ Xi * \prod Cj$$

where: P = suitability Cj = restriction wi = weighted coefficient $\sum$ =sum of weighted criteria; $\prod$ = sum of restrictions (1 – suitable, 0 – unsuitable) Xi = criteria value.

3.2 Selection of Optimal Location

The generated GIS-MCDA suggests the most suitable location for UGS based on the selected criteria. However, verifying public availability, i.e., ownership of potential UGS is necessary. Verification of ownership is a complex process due to the large number of cadastral parcels in the Zadar. Therefore, ownership is verified only for the very high UGS suitability classes. The ownership verification is performed by overlaying the GIS-MCDA model with the official cadastral parcel map prepared by the State Geodetic Administration (DGU). In addition, the UGSs with a larger area have priority in the selection of the optimal site.

4 RESULTS AND DISCUSSION

4.1 Criteria Selection

To select the optimal location for UGS seven criteria were used: land cover model (LULC), slope, residential object density, accessibility, road distance, NDVI, and constraints (Boolean).

4.1.1 LULC and Boolean

Land cover has an important role in the selection of locations for UGSs as it determines the feasibility of UGSs (Linh et al. 2022). Therefore, it is ranked as the most important criterion in selecting the location for UGS in the urban area of Zadar.

The land cover model consists of a total of eight classes (Figure 4). The existing UGS such as lawns and forest vegetation were rated as the most suitable classes for arrangement. The Boolean criterium is based on LULC and all build-up areas (impervious and objects), bare land (soil), and water surfaces are classified as constraints.

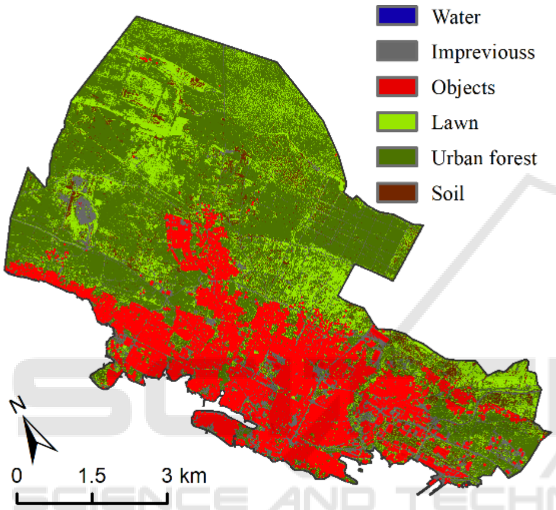

Figure 4: Land cover model (LULC).

4.1.2 Slope

Generally, low-incline areas are considered more appropriate for the UGS as it will determine the soil characteristics and rate of erosion (Sharma et al. 2022). Accordingly, gentle slopes are classified as the most suitable for UGS landscaping. Although the most of urban area of Zadar is characterized by a gentle slope, the most suitable zones are located in the north-western part of the city (Figure 3). Ovo je dio grada

4.1.3 Residential Objects Density

The residential objects' density represents the spatial distribution of the population. To make UGS accessible to as many people as possible, areas with a higher density of residential buildings were assessed as more suitable. The highest density of residential buildings is in the central part of the city (Figure XX), while the density decreases towards the outskirts where most of the arable agricultural areas are located.

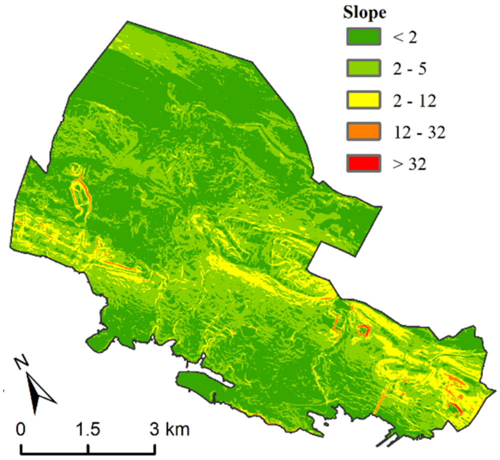

Figure 5: Slope.

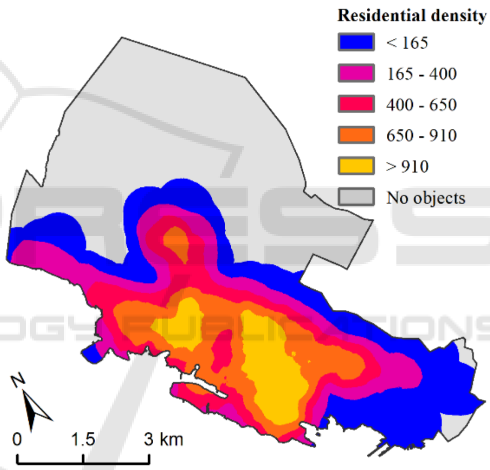

Figure 6: Residential objects density.

4.1.4 NDVI

NDVI represents the vegetation's health and helps distinguish areas with poorer vegetation health from areas with healthier and dense vegetation. The higher values of NDVI indicate more suitable locations for UGS (Linh et al. 2022). In the area with an NDVI value lower than 0.1 UGS is deemed inappropriate. NDVI was extracted from the multispectral WV2 satellite image using the following formula:

$$NDVI = \frac{NIR - RED}{NIR + RED} \qquad (1)$$

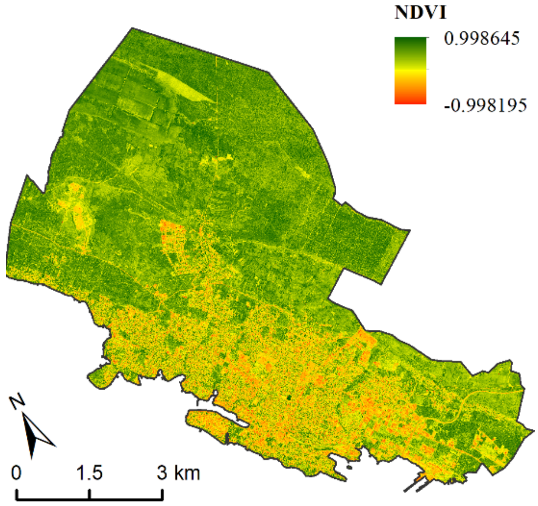

Figure 7: NDVI.

4.1.5 Accessibility

The accessibility refers to the amount of time required to get from the residential buildings to the first UGS. According to European Environment Agency (EEA), an individual should have access to a green space within 15 min (walking distance) of their residence (David et al., 1995). However, this distance differs depending on the region (Lieh, 2022). Using the *Network Analyst Service area* tool five zones of accessibility were created for Zadar urban area: less than 5 minutes, 5 - 10, 10 - 15, 15- 20, and more than 20 minutes (walking) from residential buildings. Due to the dense road network most of the urban area of Zadar is accessible within 5 minutes (Figure 8).

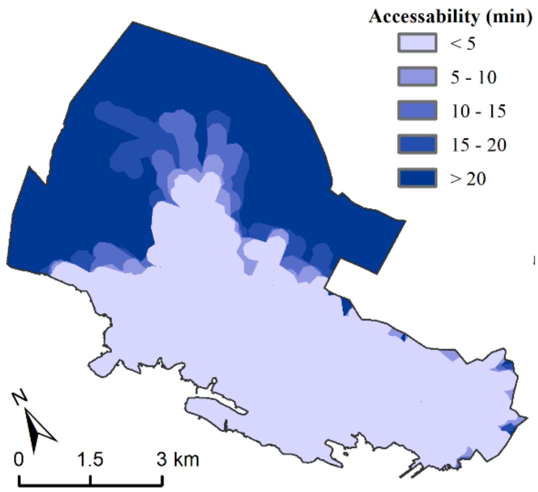

Figure 8: Accessibility from residential units (minutes).

4.1.6 Distance to Main Roads

The distance from roads is important regarding people's ability to easily access UGS areas (Linh et al. 2022). In this study, main roads include all road infrastructure together with pedestrian and bicycle routes. Macadam roads on the outskirts of the city were excluded from the analysis due to inaccessibility and poor maintenance. Using the *Multiple buffer tool* five classes of road distance are derived: 0-100 m, 100-250 m, 250-500 m, 500-1000 m, and more than 1000 m. Most of the city area is within less than 100 meters distance from roads (Figure 9).

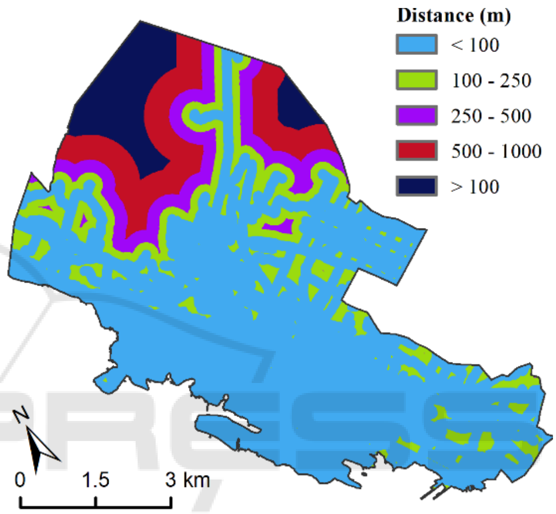

Figure 9: Road distance.

4.1.7 Urban Green Spaces Suitability Model

GIS-MCDA resulted in a total of 64,128 polygons representing the most suitable UGS (5- very high suitability (VHS)) (Figure 7). The total area of VHS is 558 ha.

VHS land classes are mostly located in the western part of the city, while the very low suitable classes are predominately located in the old city centrum. High-suitable classes are located in the eastern part of the city, near the industrial zone "Gaženica". Arranging UGS in this part of the city would maintain the ecological balance. However, UGS in this part of the city is not accessible from many residential objects within 5 or 10 minutes.

4.1.8 Selection of Optimal Location

To select the optimal location two additional criteria were included: size and ownership. From the total number of generated VHS classes, only polygons (*N=38*) with an area higher than 2 hectares were

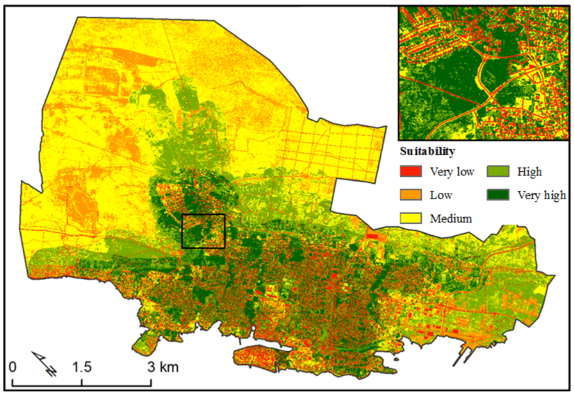

Figure 10: GIS-MCDA suitability model.

extracted (Figure 8). This criterium is included because of ANGst's suggestion: each resident should have at least one UGS of more than 2 ha in size at a maximum distance of 300 m. Based on the ownership verification, it appears that almost all very high suitability land classes are privately owned and cannot be used by the public. Only one UGS is property of Zadar city and can potentially be landscaped (Figure 11).

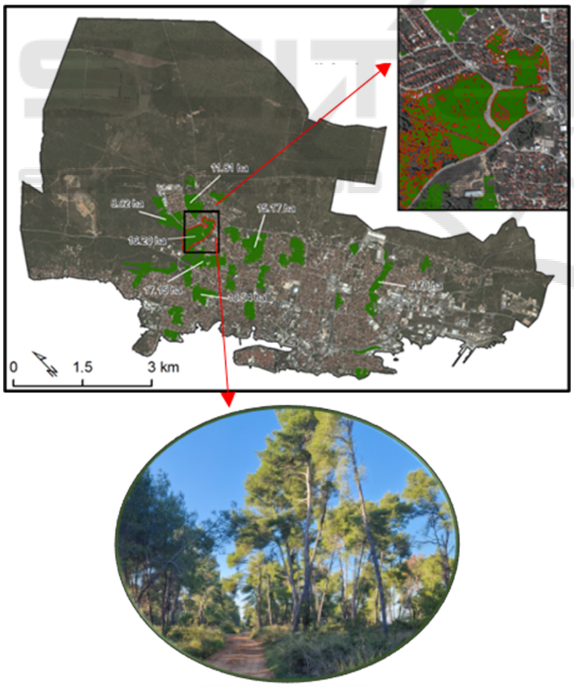

Figure 11: Extracted UGS (> 2 ha and very high suitable) and selected optimal location for potential UGS in Zadar.

5 CONCLUSIONS

This paper represents an attempt to improve UGS accessibility in small urban areas by suggesting criteria and conducting the GIS-MCDA process. The research has shown that GIS-MCDA is an efficient technique that can be used in urban green infrastructure planning and related fields. Created suitability model resulted in several zones of very high suitability. Among these zones, the optimal one is depicted based on ownership verification. For future research, we suggest including residents in the selection of the location. To gather information about their needs and preferences it is recommendable to conduct a public perception survey. In addition, it is particularly important to include people with disabilities in research to recognize the measures that can be taken to improve accessibility. With some minor modifications, this framework can be applied to other small cities. The results of this research could be useful to decision-makers in developing land use plans.

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