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Research paper

MODELING THE EXPANSION OF URBAN GREEN INFRASTRUCTURE: A GIS-BASED APPROACH TO PARK ACCESSIBILITY IN NIŠ

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Abstract

Provision of equitable access to urban green spaces available is one of the key elements for promoting environmental justice as well as well-being among the population in urban areas. This research introduces a spatial model for park-network extension in Niš, based on an analysis of accessibility focused on network-based methodologies and GIS-based spatial decision support. The paper considers three scenarios of service area estimation for: 1) existing parks, 2) parks defined by the General Urban Plan 2010-2025 (GUP), and 3) identified free parcels that could become grounds for developing new parks. Accessibility analysis is conducted for two cases: 1) considering built-up areas, and 2) population distribution. An 800-meter walking distance is accepted as a threshold boundary, the standard threshold measure for park accessibility considering maximization of environmental and socio-cultural ecosystem services. The findings indicate that existing and GUP-planned parks offer considerable potential for the improvement of urban life since almost 60% of the built-up area in the study area contains a park in proximity of 800 m, however, even though physical coverage reveals considerable beneficial change, the accessibility analysis about population points to social inequality in the planned spatial distribution of parks, where a significant share of the population remains without a park >1.5 hectares within 10 minutes' proximity. The outcome is a replicable model of analysis for park accessibility and expansion, which offers a systematic framework to urbanists for strategic augmentation of their green infrastructure systems.

Key words: *Urban Green Infrastructure (UGI), Park Accessibility Optimization, GIS-Based Spatial Analysis, Environmental Justice, Network-Based Accessibility Modeling, Spatial Decision Support Systems*

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1. INTRODUCTION

Despite occupying less than 3 percent of the Earth's land area, urban regions are accountable for approximately 71% of worldwide energy-related carbon emissions [1]. With this in mind, the United Nations identified three primary challenges for sustainable urban development in 2010: 1) enhancing the living conditions within cities; 2) minimizing their environmental impact; and 3) preparing them for climate change [2], which were later reflected in the 11th Millennium Development Goal - Sustainable Cities and Communities [3].

Natural habitats within cities are becoming more susceptible to their own causes; with urbanization and the extension of impervious surfaces, it is imperative to integrate nature into urban planning for the improvement of public health. Different eco-oriented urban concepts have been developed to meet these challenges, e.g., Nature-based Solutions (NbS) [4-6], Ecosystem-based Adaptation (EbA) [7,8], Urban Green Infrastructure (UGI) [9], and Blue-Green Infrastructure (BGI) [10,11]. All these terms describe approaches to city planning that hold together care, management, and restoration of natural ecosystems within urban areas. Other commonalities, which are, however, not exhaustive, tend to revolve around a general reliance on urban green spaces (UGSs) as a basis for sustainability, as well as nature-based decision-making [12].

UGS offers a wide spectrum of environmental and social ecosystem services contributing to environmental protection, improvement of public health, and climate change adaptation. They can offset urban heat island effects (UHI) by decreasing air temperature, improve air quality by filtering pollutants from the air, contribute to urban water management by enabling infiltration of rainwater into the soil, decreasing risk from flooding and relieving drainage systems, and supporting biodiversity in urban centers. [13,14].

On the other hand, the existence of urban parks encourages physical activity, decreases stress, and improves the general well-being of citizens. Also, serving as a meeting point it encourages social interaction and joint activities among citizens, affirming social cohesion [15].

To maximize expected ecosystem services, the size of and proximity to parks play a key objective in UGS planning. The size of the park directly influences the capacity for the environmental ecosystem services like microclimate regulation and reduction of UHI effects [16]. Using Land Surface Temperature (LST) Landsat 8 OLI/TIRS satellite imagery, the study found that parks larger than 1.55 hectares with dense vegetation and water bodies significantly reduced ambient temperatures by up to 8.28 °C. Furthermore, the study reveals that park cooling effect was significantly influenced by park size, plant density, and the presence of water bodies, with larger parks, denser vegetation, and water bodies exhibiting increased cooling capacity. These findings emphasize the significance of including green areas in urban development as critical infrastructure for increasing urban resilience, lowering heat-related health risks, and assuring equal access to public health benefits.

On the other side, the proximity to parks is crucial for harvesting benefits for social and cultural ecosystem services they provide. Parks that are in greater proximity to citizens are more likely to be visited. The study presented in [17] shows that people tend to visit parks closer to them. This also emphasizes the need of resolving socioeconomic discrepancies in park accessibility, since these have significant consequences for equitable urban development. While World Health Organization (WHO) suggests 300 meters as a minimum standard, many cities and planning frameworks extend this up to 800 meters (~10 minutes walking) as a more desirable threshold [18]. Thus, the optimal combination of size and proximity of urban parks can maximize the potential benefits for urban dwellers.

Therefore, in planning the spatial distribution of parks optimizing their size and proximity to residents should be considered as a priority. A Geographic Information System (GIS) proximity analysis is regarded as a significant tool in urban planning for determining the types, geographical distribution, connectivity, and role of UGS in the UGI at various urban sizes. Although this planning method is widely applied in other countries, it is underutilized in Serbian urban planning practice.

This paper builds on the work of Vranić and Vasilevska [19]. Their research evaluates the spatial proximity to 1) extensive urban parks, neighborhood/residential parks and pocket parks) and 2) riverbank green, linear parks or urban corridors which are identified on the territory of the urban settlement Niš, and examine their accessibility from the aspect of the ''15-minute city'' urban planning concept [20-22]. In line with the abovementioned the main objective of this paper is to move forward previous findings introducing a spatial model for the optimization of park-network extension in Niš, considering only parks above 1.5 hectares that can offer meaningful environmental services and simultaneously satisfy social and cultural ecosystem services with an 800-meter threshold proximity. The study integrates data of the General Urban Plan (GUP) for Niš for 2010-2025, compatibility with an analysis of accessibility focused on network-based methodologies and GIS-based spatial decision support.

2. MATHERIALS AND METHODS

This study utilizes network-based analysis in the QGIS environment to assess accessibility, i.e., park service areas, to identify underserved urban areas and potential locations for new parks. Using real network distances provides more precise insight into the spatial distribution of UGS. This section describes the selection of data, description of the study area, and application of the Time Travel plug-in for QGIS for the definition of isochrones and proximity analysis.

2.1. Study area

With an area of 596.73 km2 and 178,976 inhabitants in the urban area and 249,816 inhabitants in the administrative territory, the City of Niš is the third most populous city in Serbia [23]. Since 2004, the city of Niš has been administratively divided into five city municipalities: Medijana, Palilula, Pantelej, Crveni Krst and Niška Banja. Besides the urban settlements of Niš and Niška Banja, there are also 68 rural settlements on the administrative territory. This study focuses on chosen parks which are identified on the territory of the urban settlement Niš (which represents the central part of the administrative territory of the city of Niš), with high population density and a well-developed transportation system, so it can accurately represent the context (Fig. 1).

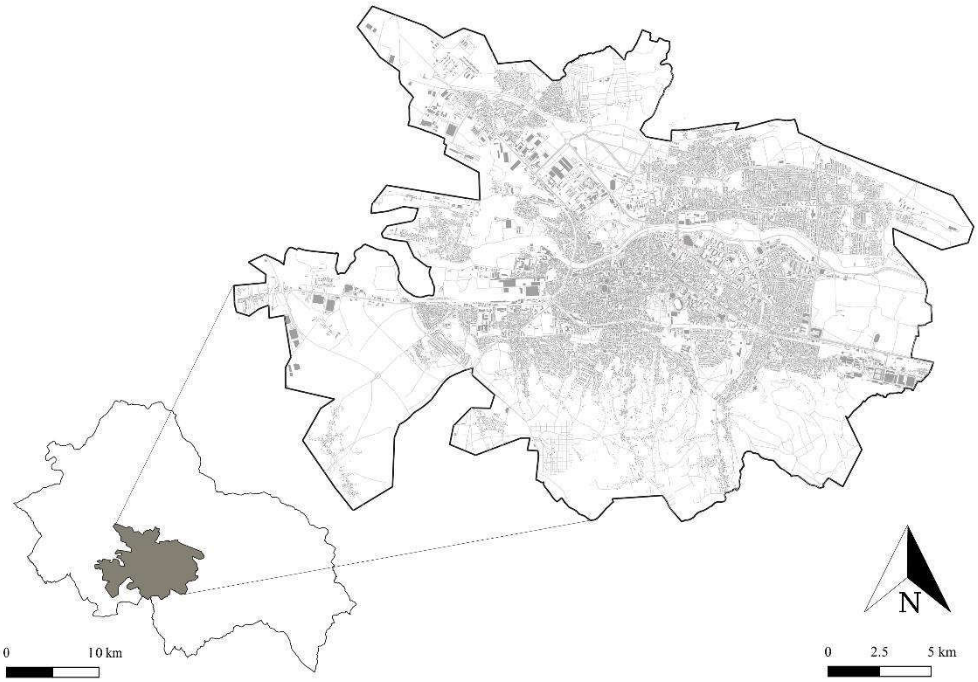

Figure 1. Study area

2.2. Data

Table 1. shows sources of input data for network analysis. Data are generated within the boundaries of urban settlement Niš as presented in Figure 1. All data used in this research are open access.

Table 1. Data

Data	Rationale	Type of data	Source
The road network	Necessary for calculating proximity and accessibility using network-based distances. Highways are omitted from the network since they are not used by pedestrians.	Vector	Data derived from OpenStreetMap (OSM) using Overpass API through QuickOSM - a QGIS plugin.
Buildings inventory	In this research all buildings are included, since the primary focus of the paper is to model expansion of parks in relation to its environmental services not only recreational that are more relevant in residential neighborhood. Thus, this	Vector	Data derived from OpenStreetMap (OSM) using Overpass API through QuickOSM - a QGIS plugin.

	feature is used for calculation of the efficiency of expansion of park service area in relation to building spatial distribution.		
Existing parks	Present destination layer or supply points in network analysis.	Vector	GUP and Google Maps Satellite image in QGIS environment.
Planed parks	Present destination layer or supply points in network analysis.	Vector	GUP and Google Maps Satellite image in QGIS environment.
Potential locations for new parks	Present destination layer or supply points in network analysis.	Vector	GUP and Google Maps Satellite image in QGIS environment. Only locations that falls in category of public areas according to GUP are considered.
Population data	Used for calculation of the efficiency of expansion of park service area in relation to population density	raster	Joint Research Centre (JRC) [24].

OpenStreetMap (OSM) is an open-source, collaboratively contributed geospatial database holding freely accessible geographic data for a variety of spatial objects and can be used as an alternative to commercially procured datasets in the context of spatial information up to date via web-based services. OSM has certain limitations but is an inexpensive, flexible, and scalable method of obtaining spatial data. It is increasingly utilized in scientific research, particularly in disciplines such as GIS, urban planning, environmental studies, and transportation analysis.

2.3. Network-based analysis

For modeling the expansion of the park network in Niš, the Time Travel plugin is used. The Time Travel plugin for QGIS is a powerful network analysis tool, especially in time travel estimation and transport system access. It enables the user to simulate and analyze movement along a network based on various transportation modes using real-time or historical traffic data.

This plugin ordinarily uses OSM data for street networks or General Transit Feed Specification (GTFS) data for public transportation. It implements routing algorithms that calculate travel time considering speed limits, traffic congestion, road conditions, and public transport schedules. The plugin uses network-based distances instead of Euclidean distances, so it offers more realistic travel estimations. In contrast to Euclidean distances, which measure straight line speed, network distances consider real roads, pedestrian routes to support practical accessibility or connectedness analysis. Also, it supports the generation of Isochrones, enabling visualization of the reachable area for the given time. It can support the identification of underserved areas, optimize transport routes, and improve the accessibility of public assets. In this way, it offers insights into equitable infrastructure distribution, enhancing decision-making in transport planning and urban mobility.

To quantify accessibility of the parks, an 800-meter cut-off is isochrone is generated for each park. This threshold is applied since the empirical studies showed that the cooling effect is strongest within the park but can extend up to 650 meters into the surrounding urban fabric, depending on park size and wind conditions [25,26]. Given that the origins of network analysis should be park access sites rather than centroids in order to replicate where people enter and depart parks, the authors conducted on-site surveys of all access points and compared them to satellite imagery. For the new park location author assumed logical entries in relation to the surrounding street network. The algorithm is run from every park entry. Isochrones created for one group of parks are merged into a single isochron to provide a final service area for examination. Features within that distance to any park are regarded as being well accessible, while those outsides are considered underserved sites.

The analysis considers two aspects service area in relation to 1) the built environment, and 2) the population. The first aspect looks at building proximity to all park categories, while the second aspect calculates population coverage within the service area for each park category. For the latter zonal statistics is used to extract the number of citizens that who within each service area.

The results are then integrated into a spatial analysis framework to quantify the efficiency of the current park location and identify potential locations for new parks that have the maximum accessibility considering the territory of the urban settlement Niš.

4. RESULTS

Through inventory 43256 buildings are identified, 9 existing parks >1.5ha, 11 parks planned by GUP >1.5 hectares, and 5 new public areas >1.5 hectares for potential extension of park network. The service area for each category is shown in Figure 2. The figure shows the expansion of the service area for two scenarios b) implementation of planned parks defined by the existing GUP, and c) implementation of additional park areas. In the initial scenario, underserved pockets were identified based on the service area generated. In the final scenario, an empty parcel was selected within each pocket, where it was possible, to achieve a more equitable distribution of urban parks.

The analysis of the expansion of parks concerning the spatial distribution of buildings, as shown in Table 2, suggests how each analyzed category influences accessibility through the number of buildings that fall within the service area of 800 m network distance. Within the service area of the existing parks, 12192 buildings are identified (28.2%). With the full realization of planned parks by GUP, the city can benefit from an additional 12228, or 28.8% of buildings within the same range. And finally, by incorporating newly identified parcels as parks, an additional 4783 (11.1%) can be covered.

Table 2. Proximity analysis in relation to buildings

Parks	Number of buildings that falls within service area of 800m	%
Existing parks >1.5 hectares	12192	28.2
GUP planned parks >1.5 hectares	12228	28.3
New parcels for parks >1.5 hectares	4783	11.1

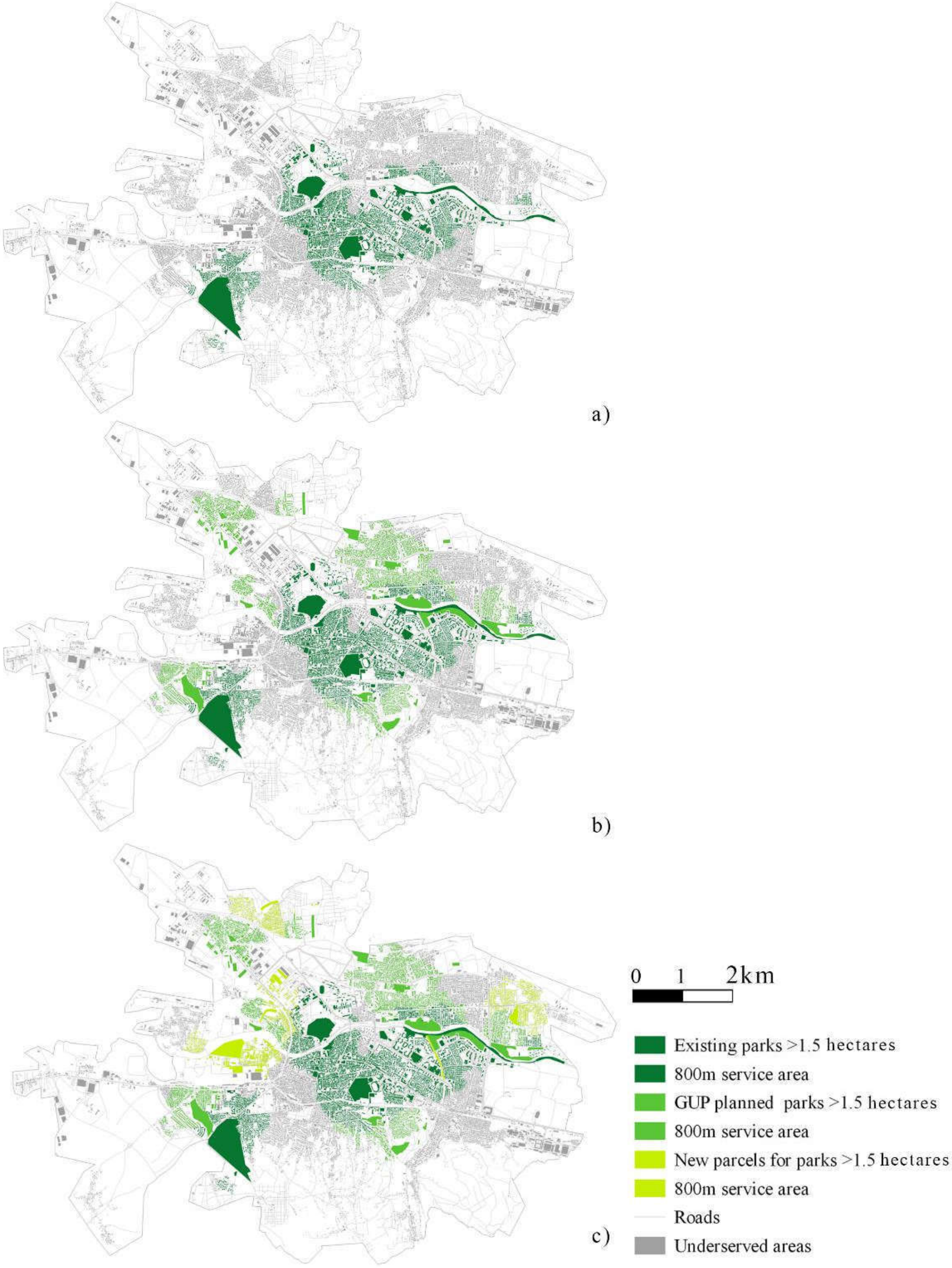

Figure 2. Service area of the urban park network: a) existing parks service area of 800m, b) expansion of service area for GUP-planned park, c) expansion of service area for newly identified parcels for parks

This result reveals that the expansion of parks by realizing GUP-planned green areas will have a significant influence on the general accessibility of parks in a physical sense since their coverage is almost as much as the existing ones. However, planned locations for parks have certain constraints. They are largely allocated in the less densely populated areas of the city. Thus, their effects might remain limited. The same applies to the potential new location for parks. With the realization of the planned parks, the proximity to buildings can expand up to 51.4%, while with the addition of the suggested location, up to 61.4%, meaning that 38.6% of the built-up area will remain underserved, i.e., it will not have a park within a range of a 10-min walk.

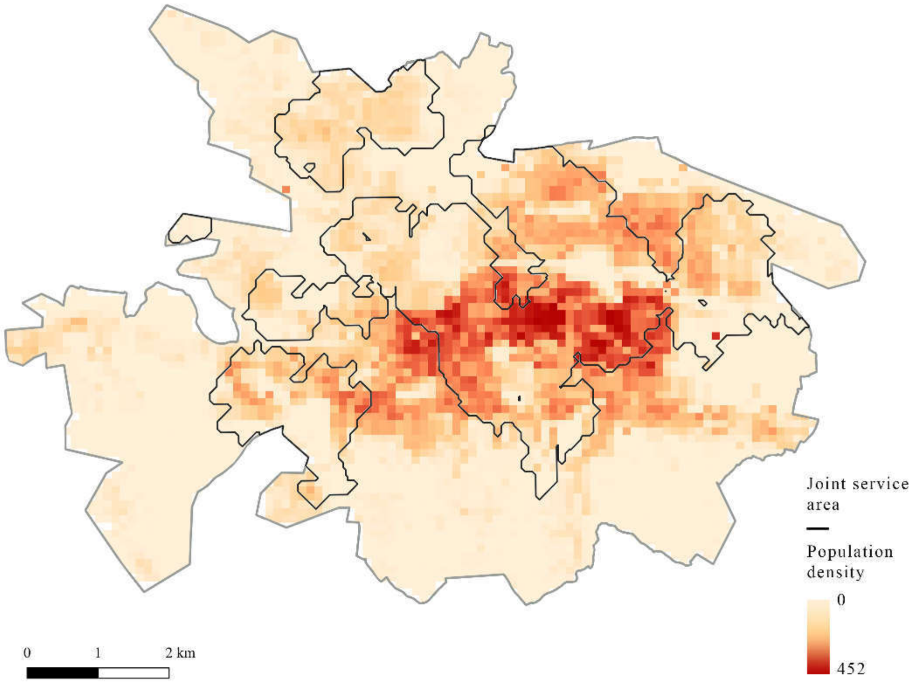

Figure 3. Grided population data resolution 100m with joint service area of existing, planned and suggested parks [25]

Table 3. Proximity analysis in relation to population

Parks	Population that falls within service area of 800m	%
Existing parks >1.5 hectares	77833	30.5
GUP planned parks >1.5 hectares	29156	11.4
New parcels for parks >1.5 hectares	11366	4.4

On the other hand, when service area coverage is analyzed using the population proximity, we found a different ratio (Table 3, Figure 3). 77833 citizens (i.e., 30.5%) are in 800m proximity to existing parks, which is relatively proportional to the building coverage. However, the GUP-planned parks will exert a far smaller effect on the population since only 29156 (11.4%) citizens will benefit from their realization, which is a considerable decrease compared to the number of buildings that are located within their service area. Finally, a newly recognized location may offer better proximity to the additional 11366 citizens (4.4%), which is also significantly lower compared to the percentage of buildings covered within this service area (11.1%).

This finding reveals a potentially inequitable distribution of parks concerning demographic needs. Although planned parks promise to deliver considerable coverage, their demographic reach remains insignificant. With the realization of the planned parks, the proximity to buildings can expand up to 42% of the total population, while with the implementation of the suggested locations, up to 46.7% in total. It means that even with the full realization of potential parks, 53.3% of the population will have to walk more than 10 minutes to the nearest park.

5. CONCLUSION

In park proximity analysis, often the population that has access to it is put forward. However, the number of buildings that are located within the park service area is an equally relevant indicator, especially from the perspective of the environmental ecosystem services. The built environment defines the spatial pattern and influences the functioning of an urban ecosystem. The more buildings in greater proximity to urban parks, the better the chance for urban green spaces to deliver spectrum of ecosystem services and microclimate benefits to urban environments. This aspect is particularly highlighted in highly urbanized, i.e., densely built city areas with limited possibility for the expansion of green infrastructure. In that sense, demonstrated analysis indicated that existing and GUP-planned parks offer considerable potential for the improvement of urban life since almost 60% of the built-up area in the study area contains a park in proximity of 800 m. On the other hand, GUP-planned parks, with the addition of suggested alternative locations, do not contribute to the proportional benefit in densely populated city blocks. Even though physical coverage reveals considerable beneficial change, the accessibility analysis about population points to social inequality in the planned spatial distribution of parks, where a significant share of the population remains without a park >1.5 hectares within 10 minutes' proximity.

Presented findings point out the need for more detailed analysis in planning the expansion of urban parks, including the qualitative aspects of selected parks, maximization for park demographic coverage, and implementation of advanced or hybrid multicriteria GIS analysis for modeling different spatial distribution scenarios for accessibility optimization.

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