ELEMENTS OF THE GEODESIGN FRAMEWORK AS A TOOL FOR GREEN INFRASTRUCTURE PLANNING ON A LANDSCAPE SCALE

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ABSTRACT

Contemporary urban landscapes are complex spatial systems in which natural and close-to-nature elements are under immovable pressures. An increase in sealed surfaces leads to a reduction of vital ecosystem services that have the potential to provide various benefits to urban landscapes and contribute to economic and cultural quality of life. Green infrastructure is recognized as an approach related to sustainable development and conceived as a multifunctional and strategically planned network whose structure can be identified on various spatial and temporal scales. The intense dynamics of urbanization in conjunction with climate change form a difficult-to-predict picture of the future urban landscape, and in this context, it is necessary to use approaches that enable clearer scenario analyses. A Geodesign framework is a systematic tool that provides a platform made of inter-causal facts that enhance critical thinking and choosing the optimal solutions for improving, in this context, the stability of urban landscapes. Research is focused on the Change and Impact models of the Geodesign applied to Green infrastructure through the assessment of the main ecosystem services in the urban matrix. The basic strategic concept of the Green infrastructure of the city of Belgrade was presented by the Plan of General Regulation of the Green Area System and more recently by the draft version of the Master Plan. The current state of the structure of the urban landscape and the planned improvement through the formation of new Green infrastructure elements on the watershed level present the main representation of the spatial context. A set of geostatistical models provides deep insight into the magnitude of natural processes, which are interpreted through ecosystem services that can be traced on a landscape scale.

KEYWORDS _ *Green infrastructure, Geodesign, Ecosystem services, Urban landscape*

INTRODUCTION

In recent decades, the increase in the number of inhabitants in urban areas have often been referred to as "population ante portas", where the fact that in 2007 it was established that more than half of the world's population lives in cities is often highlighted. The other problem is the simultaneous growth of the complex urban "organism" and its recognizable structures, such as continuous fabric and roads with associated land, as well as industrial, commercial, public, and private units. Urban hardware is built from impervious surfaces and results in soil sealing, which is recognized as the main driving force behind the loss of ecological integrity and disturbance of natural processes that can be identified on a landscape scale (Radić, Gavrilović, 2021).

The quality of the environment in urban landscapes can be expressed through the levels of realization of ecosystem services (de Grot et al., 2002). This concept refers to the various benefits and resources that cities, as a spatial system that operates on a landscape level, derive from natural ecosystems (McPhearson et al., 2014). One of the approaches that has proven to be effective in recent decades is the application of the Green infrastructure concept, which involves incorporating natural elements and processes into urban and landscape planning and design to provide multiple benefits, especially those that are related to ecosystem services (Calderón-Contreras, Quiroz-Rosas, 2017). An important aspect of the Green infrastructure concept is its recognition by the strategies and directives of the European Union and its active promotion and implementation to enhance environmental sustainability, resilience, and the quality of life in cities and regions (Mell, 2015). Green infrastructure has been put into action to conserve biodiversity and provide ecosystem services such as climate regulation, air and water purification, flood protection, and cultural and recreational benefits (De Groot et al., 2010). However, distinct urban landscape types require diverse Green infrastructure and design approaches to realize certain ecosystem functions. The landscapes of urban outskirts are recognized as fragile zones where the interests of different actors and specific environmental conditions overlap (Radić et al., 2023). These zones are isolated enclaves of superior natural soils that act as transmitters of effects that prevent the development of torrential floods (Gkiatas et al., 2021). Furthermore, natural and semi-natural patches of urban outskirts provide diverse, compositional, and configurational-rich landscapes with substantial levels of ecosystem diversity (Asikainen, Jokinen, 2009). Eventually, landscape units that are in the first battle line against fast urban sprawl, usually for a short time, present the last oasis for the outdoor recreation of inhabitants (Pyky et al., 2019). All the aforementioned factors rank urban outskirts high on the value scale as valuable areas that require careful planning and design to preserve their ecological identity and give them a proper place in the unavoidable urban grid.

In the context of upcoming changes in climate parameters, relatively preserved characteristics of naturalness, and partially unpredictable expansion of urban fabric, knowledge of possible development scenarios is an essential activity in the planning process of contemporary cities and their outskirts. In this case, generating scenarios is not just strategic thinking about the future but creative acting in making the optimal links between the structure and function of Green infrastructure, ecosystem services, and sustainable development (Lee, 2016). For more than half a century, according to the Steinitz framework, alternative land use scenarios on the landscape scale, resulting from the implementation of different choices, have been used in planning and urban planning practice (Steinitz, 2014). With the development of spatial and informational technologies, a conditionally different approach called Geodesign was created from this framework. To solve complicated landscape challenges, the Geodesign approach combines the ideas of geography, urban planning, and design. Geodesign incorporates GIS, data, spatial analysis, and visualization tools to make more sustainable, direct, and creative decisions related to the built and natural environment (Goodchild, 2010). Scenarios, in the context of Geodesign, refer to different future possibilities or alternatives that can be created and evaluated using geospatial data and analysis. Overall, Geodesign and its scenarios are crucial for addressing complex spatial challenges in a data-driven and informed manner. It enables landscape planners and designers, as well as decision-makers, to explore multiple options, assess potential impacts, and make more sustainable and resilient choices, especially for fragile landscapes (Slotterback et al., 2016).

MATERIALS AND METHODS

The broader area of research is the territory of Belgrade, the capital of the Republic of Serbia, where, according to the latest census, more than 1.6 million inhabitants live. Belgrade occupies a strategically important place, at the confluence of two great rivers, the Danube and the Sava, at the hub of traffic communications between Europe and Asia. At this relatively small area there are highly diverse landscape types with very diverse achievement of ecosystem services (Vasiljević et al., 2021). In 2019 City of Belgrade made Plan of General Regulation of the Green Area System of Belgrade [PGR] (OGCB, 2019) that made a great contribution to the improvement of the system of green areas through the prism of Green infrastructure, forming a new integrative value with natural and built elements, and improving the identity and character of the Belgrade landscape (Cvejić, Teofilović, 2010). Given that the aim of our research is to illustrate the sub-performance of Geodesign through spatial interventions and their scenarios, considering the effects on the status of ecosystem services, part of the planned land cover provided by the PGR will be partially framed in the intervention phase: the Change model and the Impact model (Steinitz, 2012) (Figure 1).

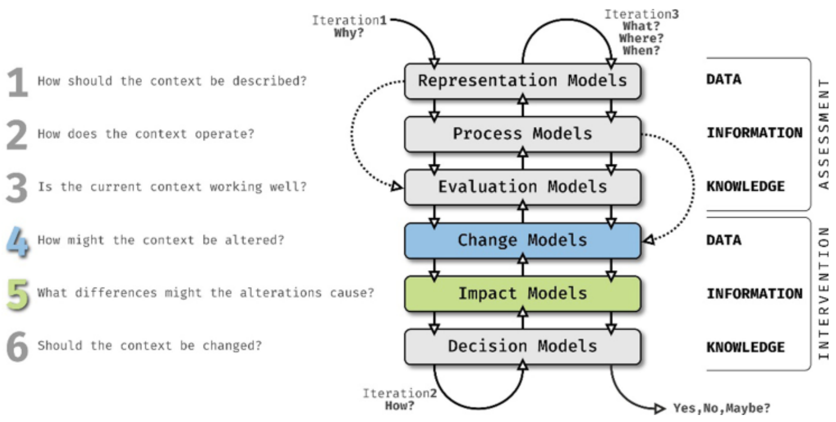


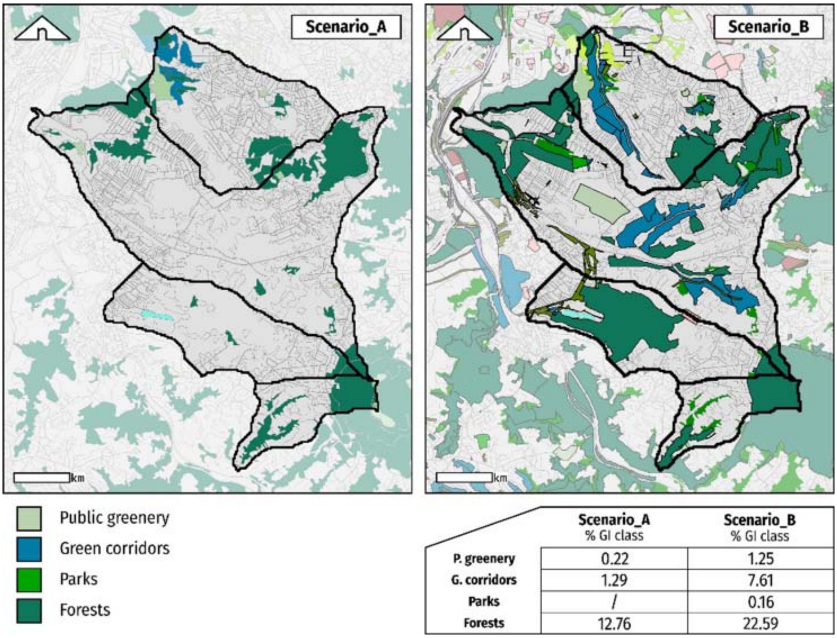
Figure 1. Applied components of the Geodesign framework (modified Steinitz, 2012)

The Change model is a definite landscape design solution, so this option will be treated as "Scenario_B", while "Scenario_A" will be equivalent to the current condition. The Impact model will be presented by the differences in providing selected ecosystem services in scenarios A and B. Eventually, the cognitive platform will contribute to Decision models and allow us to not just identify major stakeholders but also facilitate the process of implementing green infrastructure at lower spatial levels through design solutions. In relation to the selected ecosystem services that have the status of a criteria, indicators, methods, and databases are determined:

- Regulating services > Soil erosion control and surface runoff control (Revised Universal Soil Loss Equation [RUSLE] and Flash Flood Potential Index [FFPI]);
- Supporting services > Connectivity of natural and semi-natural elements (Graph theory method);
- Cultural services > Opportunity for recreation (Distance analysis method).

SPATIAL DOMAIN OF MODEL AND DATASET

The detailed field of the Geodesign framework application is the southern part of the territory on the outskirts of Belgrade, which is identified as a peripheral zone within the Master Plan of Belgrade (OGCB, 2016). The zone is recognized as an area where a significant increase in the number of inhabitants is expected. The basic characteristic of the peripheral zone is the irrational use of land and poor traffic and communal infrastructure, which leads to the degradation of environmental elements (Macura et al., 2019). The precise research area is defined by the complex of urban watersheds. “Scenario_A” represents the current state of the land cover (Figure 2). This scenario is based on data from the Urban Atlas database for 2018, which is a component of the European Union’s Copernicus Earth Observation satellite program. “Scenario_B” assumes the land cover, which is the result of the maximum achievement of Green infrastructure according to the PGR (OGCB, 2019) and replacing the current land cover (Figure 2).



	Scenario_A % GI class	Scenario_B % GI class
P. greenery	0.22	1.25
G. corridors	1.29	7.61
Parks	/	0.16
Forests	12.76	22.59

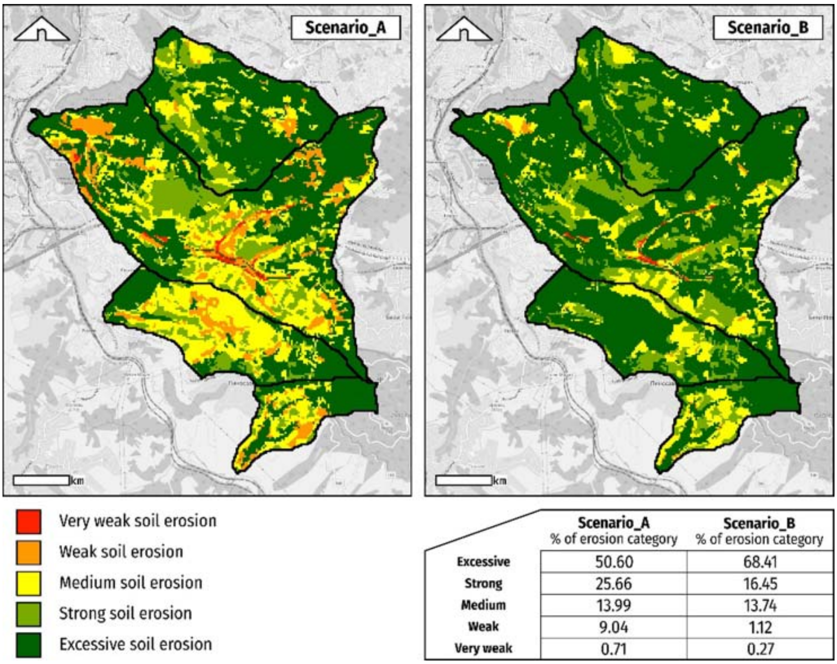
Figure 2: Land cover / Land use related to Green infrastructure elements in both scenarios

METHOD OF INDICATORS

To estimate soil losses as well as erosion risk levels, many models are available today. One of the most frequently applied empirical models for soil erosion assessment is RUSLE (Panagos et al., 2015), which is applied in this work. This model estimates soil loss per unit area, considering the climatic factor (rainfall – erosivity factor), pedological characteristics (soil erodibility), topographic (slope and length), vegetation and land use factors, anthropogenic (conservation measures factor). FFPI is method for determining the predisposition of the territory to the occurrence of flash floods. The FFPI was developed to quantitatively describe the flash flood risk and susceptibility of an area based on its inherent and static characteristics. According to this, the FFPI can be classified as a new generation “tool” for flash flood risk assessment (Duong et al.,2020). Input parameters in the calculation of this method are terrain slope, land cover, land use method, soil infiltration-retention capacity and rainfall. Land use, especially urbanization, has a significant role in water infiltration, reduction of the permeable surface and frequent occurrences of intense surface runoff (after intense rains, snowmelt, and its coincidence). Urban biodiversity is an important aspect of the achievement and level of effectiveness of ecosystem services. Because there are so few naturally occurring carriers of biodiversity in urban environments, assessing the level of biodiversity is a difficult task. The landscape graph-based principle is commonly used in valuing the level of achieved spatial connectivity (Minor, Urban, 2008). This approach allows us to first identify spatial gaps in the ecological continuum but also to prioritize the elements that have higher importance for flows of material, energy, and organisms as essential aspects of biodiversity (Xun et al., 2014). Valuing cultural ecosystem services involves a wide variety of methods and techniques (Cheng et al., 2019). For the purposes of this research, the value of the ecosystem's cultural service will be evaluated through its potential to provide a recreational function to the urban population. Green infrastructure elements provide services on local scale which implies daily recreation. It is necessary for elements of Green infrastructure to be located at a walking distance of no more than 10 to 15 minutes, which corresponds to an aerial (actual) distance of about 300 to 400 meters (Koppen et al., 2014).

RESULTS AND DISCUSSION

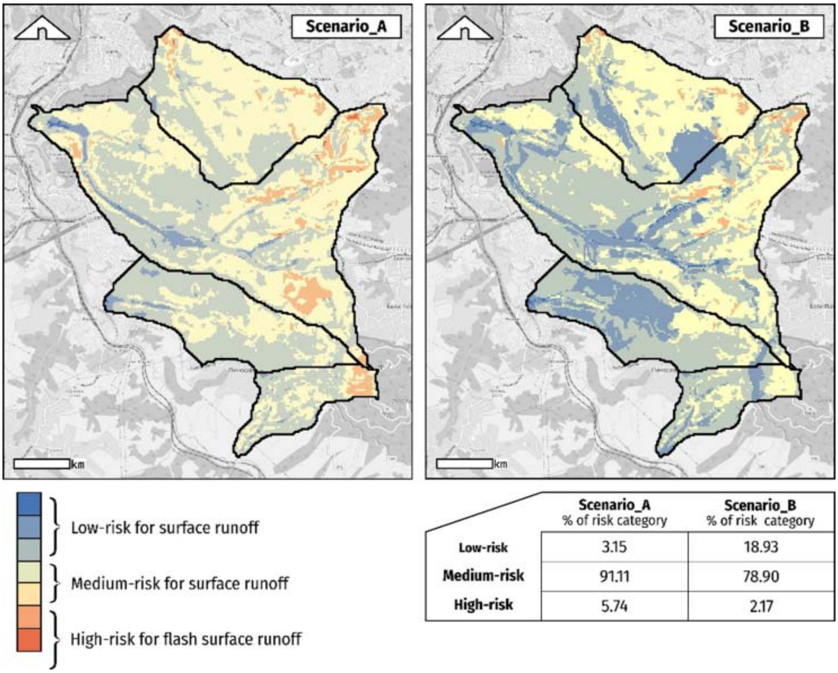
In relation to the spatial distribution of categories of erosion processes, according to the presented scenarios, significant reductions of erosion processes were identified in the categories from excessive to weak erosion (Figure 3).



	Scenario_A % of erosion category	Scenario_B % of erosion category
Excessive	50.60	68.41
Strong	25.66	16.45
Medium	13.99	13.74
Weak	9.04	1.12
Very weak	0.71	0.27

Figure 3: Soil erosion indicators in both scenarios

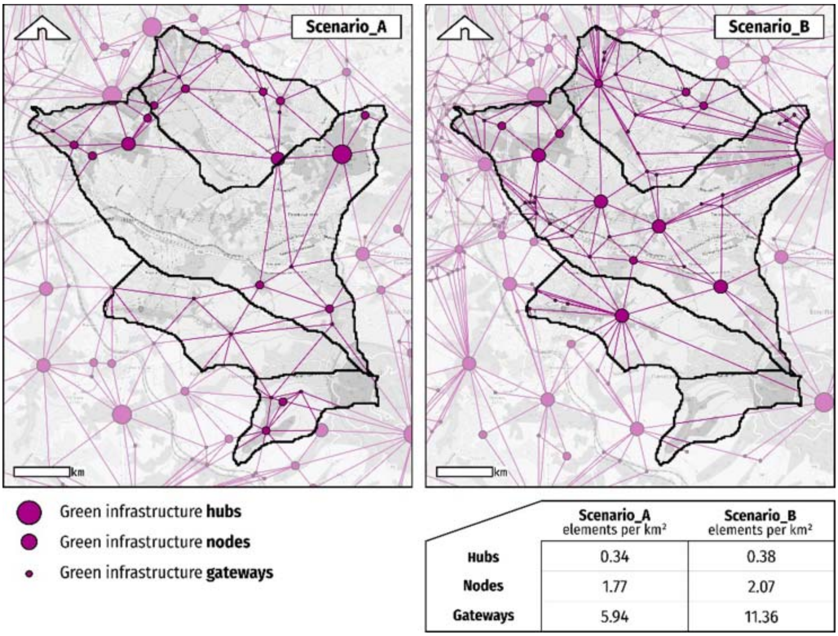
According to the presented scenarios, it can be stated that there has been a significant reduction of the areas identified for the occurrence of flash floods according to "Scenario_B". According to the presented scenario, there was a significant reduction of the areas that were classified under the category of very high risk and medium risk for the occurrence of flash floods (Figure 4).



	Scenario_A % of risk category	Scenario_B % of risk category
Low-risk	3.15	18.93
Medium-risk	91.11	78.90
High-risk	5.74	2.17

Figure 4: Surface flow (potential torrents development) indicators in both scenarios

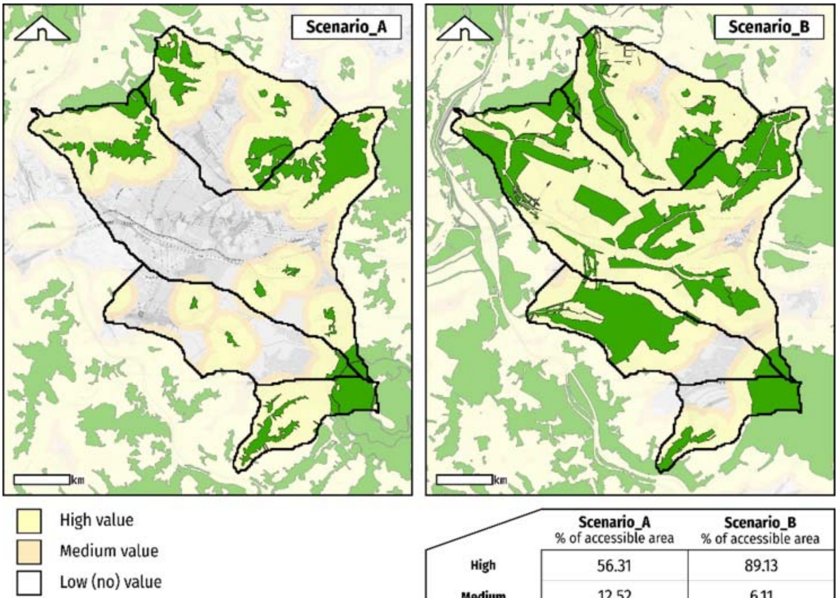
Graph-based modelling of scenarios shows the improvement of landscape connectivity regarding more complex spatial correlations between natural and semi-natural elements, which are represented by Green infrastructure (Figure 5).



	Scenario_A elements per km²	Scenario_B elements per km²
Hubs	0.34	0.38
Nodes	1.77	2.07
Gateways	5.94	11.36

Figure 5: Connectivity indicators in both scenarios

Large-scale interventions involving the afforestation of terrain vulnerable to soil erosion processes, the development of substantial protection belts around populated enclaves, and the creation of a new park area are what caused the notable change in the accessibility level (Figure 6).



	Scenario_A % of accessible area	Scenario_B % of accessible area
High	56.31	89.13
Medium	12.52	6.11
Low (no)	31.17	4.76

Figure 6: Accessibility levels in both scenarios

CONCLUSION

Contemporary cities are a territory where many complex processes take place – the needs for the realization of basic life functions are materialized through the conquest of "unused" areas, generating ecological conflicts that reduce the quality of life and the safety of the urban population. As the capital of Serbia, Belgrade is exposed to these impacts, and there is a long-year aspiration to form a legislative framework that will condition the development of the city in such a way as to enable the rational expansion of the city while preserving nature, landscapes, and ecologically sensitive areas. For the purposes of realizing this vision, the City of Belgrade has adopted the PGR, in which the preservation and improvement of existing areas is a priority while the planning and creation of new areas based on the principles of connectivity, multi-functionality, accessibility, and landscape character improvement are positioned in the focal plane.

Geodesign is a relatively new approach defined by Carl Steinitz that yields a great contribution to the synthesis between the GIS as a comprehensive analytical tool and landscape design as a creative process. Beside this, this approach emphasizes the role of decision-makers and other stakeholders in the final phase of the planning and design process in such a way that it articulately brings them different development scenarios. Given that the PGR was adopted relatively recently (2019), the application of the Geodesign framework has the capacity to enable its further implementation process and the realization of goals at local spatial levels.

Change models are referred to as the core of a Geodesign study. The data used in this phase has the goal of most accurately presenting possible future scenarios. In our research, the Change model is defined by two scenarios. The impact model "breathes life" into change models and assigns measurable process quality parameters that result from different scenarios. These models are functional aspects of Green infrastructure that are valued through the level of realization of ecosystem services. Criteria that are selected are recognized as the domain of realization of certain groups of ecosystem services and estimated to be relevant for the spatial context of the outskirts of Belgrade. Indicators are defined based on the availability of databases that are required for the implementation of modeling methods and techniques. These results clearly indicate that the implementation of Green infrastructure principles through the legal and operational framework will positively change the future urban landscape of Belgrade and give huge efforts to creating an ecologically resilient system that has the potential to meet the challenges of global and climate change.

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