NATURE BASED STORMWATER MANAGEMENT SOLUTIONS FOR HOUSING AREA – CASE STUDY OF ROOF GARDEN IMPLEMENTATION

Danijela Milanović, Borislava Blagojević* and Ljiljana Vasilevska**

*University of Niš, Faculty of Civil Engineering and Architecture, Aleksandra Medvedeva 14, 18000 Niš

Abstract: Roof gardens/green roofs are more and more present in built environment due to its diverse potential in mitigating negative environmental effects. Under the umbrella of the Nature Based Solutions, roof gardens are applied for precipitation detention in urban catchments. This research deals with housing area in the city of Niš, Serbia, where flat gravel roofs are converted to pitched ones. The assessment of water quantity retained in the roof, and released as runoff is conducted for the previous, present and potential rooftop condition i.e. roof garden. The specification from a manufacturer is used to simulate roof garden conditions. To assess the urban water cycle main components at the rooftop level, the daily water balance model is used for one year period. The simulation results for the pitched roof are assembled from the inclined roofs due to limitations of the applied simulation model. A set of roof efficiency indicators is introduced to quantify role of each rooftop cover to relieve the roof runoff load from the stormwater management system. According to three of four considered roof efficiency indicators, the roof gardens performed best in the studied area.

Keywords: Roof garden, green roof, nature based solutions, roof runoff indicators, pitched roof runoff.

INTRODUCTION

Increased attention to negative environmental effects in urban areas worldwide, has lead to the development of many planning, design, and maintenance strategies for their mitigation. Nature Based Solutions (NBS/NbS) represent a collective name for approaches designed by scientists and practitioners in many fields. For instance, the Integrated Stormwater Management (ISWM) in urban areas relies on the principle of atmospheric water safe detention in the urban catchment and gradual release into the recipient. Its relation with both natural and built environmental systems is more complex compared to conventional SWM systems, due to its measures and techniques that utilize terrain surface area for infiltration, retention and storage of stormwater. Consequently, ISWM greatly intertwines with landscaping architecture. Demiroz Kiray&Yildizci (2014) show a number of examples in this respect in their research results produced through the Sustainable Sites Initiative (SITES) Guidelines and Performance Benchmarks, including protection of water resources quantity, as one of the strategies to achieve sustainable outcomes in the landscape architecture. On the other hand, taking water quality as a design strategy, Aytac&Kusuluoglu (2014) conduct a parallel study of two highly populated urban areas in the U.S.A. and Turkey. Both studies generally overlap with the existing set of approaches emerging from ISWM with the aim to develop strategies and options for environmental protection, including Water Sensitive Urban Design (WSUD) and Sustainable Drainage Systems (SUDS). One of the most applied SUDS measures according to Gordon-Walker et al. (2007) is green roofs, besides the replacement of nonporous for porous pavement, the detachment of roof drainage from the conventional system, and replacement of conventional street and road gutters by swales. These measures refer to retrofitting of SUDS, the activity meaning replacement or/and extension of the existing SWM system.

Roof gardens (RG), also known as vegetative, and green roofs, are vegetative layers on the rooftops of two general types: intensive and extensive. The intensive RG are heavier, thicker, and walakble, compared to extensive RG that are thinner, thus lighter, and require minimum maintenance. The recognized benefits from RG are perceived as public, private and design-based benefits. Public benefits include improved air quality (Yang et al., 2008), moderation of heat urban island effects, and improved SWM potential (Stefanescu et al., 2013). Liu et al. (2015) show a simple linear reservoir conceptual model for simulating existing experimental extensive RG, enabling quantification of RG impacts on roof runoff volume and dynamics.

The research aim in this paper is to assess site-specific public benefits related to roof runoff for hypothetic RG implementation in the ‘Krive livade’ neighborhood in the city of Niš, Serbia.

MATERIAL AND METHODS

Study area

The selected neighborhood (Figure 1B) is a part of Blvd. Nemanjića housing area with a population of approximately 60,000. It was developed on the outskirts of the city in the 1970s as a typical socialist mono-functional housing area. The study area has a similar spatial-functional and urbo-morphological characteristics as the whole area, except that it appears in the form of semi-block while the rest of area is organized in the form of urban blocks. It is typical large housing estate, where urban pattern is based on repetition of group of buildings that have the same architectural and structural features, and generously dimensioned public open spaces (Figure 1C). The similarity of features and possibility to replicate the computational experiment for the whole area, are the main reason a compact group of buildings is chosen for the research (Figure 1C- dark grey feature).

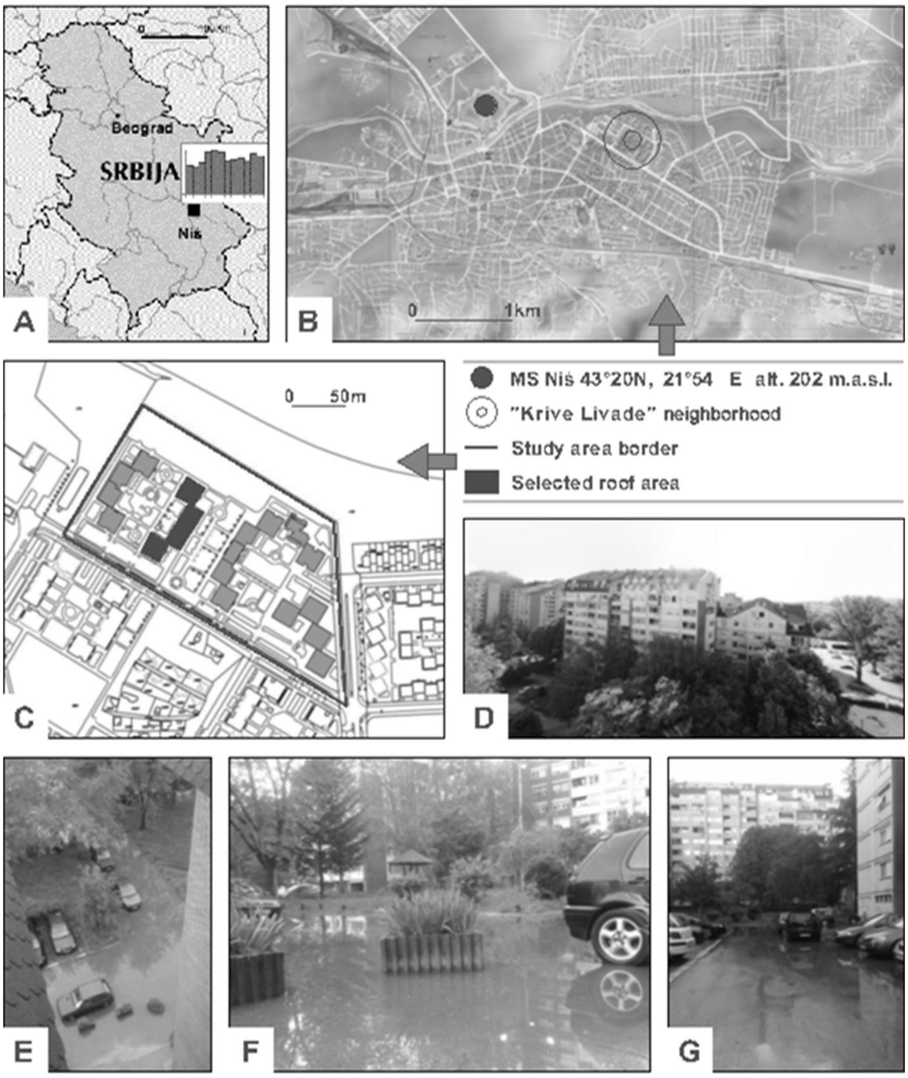

Figure 2. A- City of Niš in Serbia. B- City map. C- Study area plan. D- Typical pitched roof. E, F, G- Flooded carpark.

The neighborhood has undergone significant urban changes in the post-socialist period. From the mid-1990s there have been intensive changes in terms of transformation of the existing buildings through: 1) adaptation of the ground floor spaces into retail stores or other services; and 2) multi-story extensions on the top of the host buildings with flats exclusively intended for the market. The origin of the latter can be found in the initial urge for repairing flat roofs, the most critical issue of continuous decay and deterioration of ageing housing stock. However, due to the absence of urban renewal projects and unwillingness or economic inability of homeowners to invest in their maintenance, the existing buildings became a suitable "infrastructure" for market-driven housing activities, and an initial urge for reparation was soon turned into extensive construction of additional storeys with flats on the building tops (Vranić et al., 2015) with, as a rule, pitched roofs (PR) (Figure 1D). New (re)development increased population density which, in synergy with the absence of adequate parking solution, resulted in quantitative and qualitative decrease of public open spaces, including belonging vegetation (Vasilevska et al., 2014). Consequently, this situation imposed stress to the existing SWM system, exhibiting frequent pluvial flooding (Figure 1 E, F, G).

Methods

Three rooftop conditions are assessed concerning water quantity retained in the roof, and released as runoff: 1) flat roof (FR) - previous condition, 2) PR- present condition, and 3) RG. Assessment focus is a compact group of buildings in the study area (Fig. 1 C). To estimate the main urban water cycle components at the rooftop level a daily water balance model is used. Through the public domain software 'The GreenRoof model' (Raes et al., 2006) the simulation is run. There are three groups of input required for simulation: meteorological data, roof characteristics and program parameters.

Meteorological data

The model simulation period is one year. A 'normal' year 1997 is chosen - the annual precipitation total is 591.1 mm, while in the period 1981-2010 the average is 580.3 mm. This period is considered due to the reference evaporation (*ET0*) data availability for Meteorologic Station (MS) Niš (Fig. 1 B, the dot mark). Monthly *ET0* data are obtained by Penman-Monteith equation for the MS Niš (Gocić&Trajković, 2010, 2014). The model itself performs downscaling of monthly *ET0* to daily values by linear distribution. The daily precipitation data for rainfall input file are taken from the official data records (RHMSS, 2021).

Roof characteristics

The model compares water balance of two roofs at the time. Two sets of simulation are run using the FR as a reference: one to compare it to the RG, and the other to the PR. The FR is a fully exposed gravel roof. A fully covered extensive RG is used with 7 cm substrate layer depth according to the manufacturer's specification (Optigruen, 2021). To adjust to local climate conditions, succulents and grasses are selected for vegetation cover, and according to the location surroundings, a fully exposed position. A standard roof area is the actual building top area of 1650 m^2. For the second set of simulations (the comparison of FR to PR), the model is run four times, once for each of the PR plains, modelled as a separate inclined roofs. The specifications for each run are: bitumen, 30° inclined roof, orientation, and area - East and West (600 m^2 each), North and South (each 225 m^2). For the final result, the total of results for substituting PR segments is considered.

Program parameters

The standard model values for evaporation and evapotranspiration (*Kc, p*) are accepted. In the 'Green Roof' tab, the substrate standard depth for flat RG is 7cm, while the standard parameters for water retention are changed both in substrate and drainage layer, from 2.5 to 3.0 l/m^2/cm and from 2.0 to 9.0 l/m^2 respectively. The water storage layer is not included, to achieve water retention total (30 l/m^2) for 7cm substrate layer depth (Optigruen, 2021). In the 'Rainfall on inclined roofs' and 'ET from inclined roofs' standard correction is applied. Regarding *ET* for open/sheltered roofs, to adjust for local conditions, standard correction for fully exposed roofs is used.

Simulation

Specified simulation period is 01.01.-31.12. and initial water content on the roof is set to moderately wet conditions.

RESULTS AND DISCUSSION

The response from three studied rooftops regarding retention volume during the simulation period is shown in the Fig. 2 b. Expectedly, the PR holds the least water volume; it is followed by FR, because both are limited by specified water retention capacity. The RG water retention capacity is more sensitive to cumulative effect of consecutive daily rain depths, as in April 1997, than to individual heavy rain events, as in August (the annual daily maximum), or May (the second largest annual daily precipitation sum). This is also due to antecedent moisture condition in the substrate layer and *ET0*.

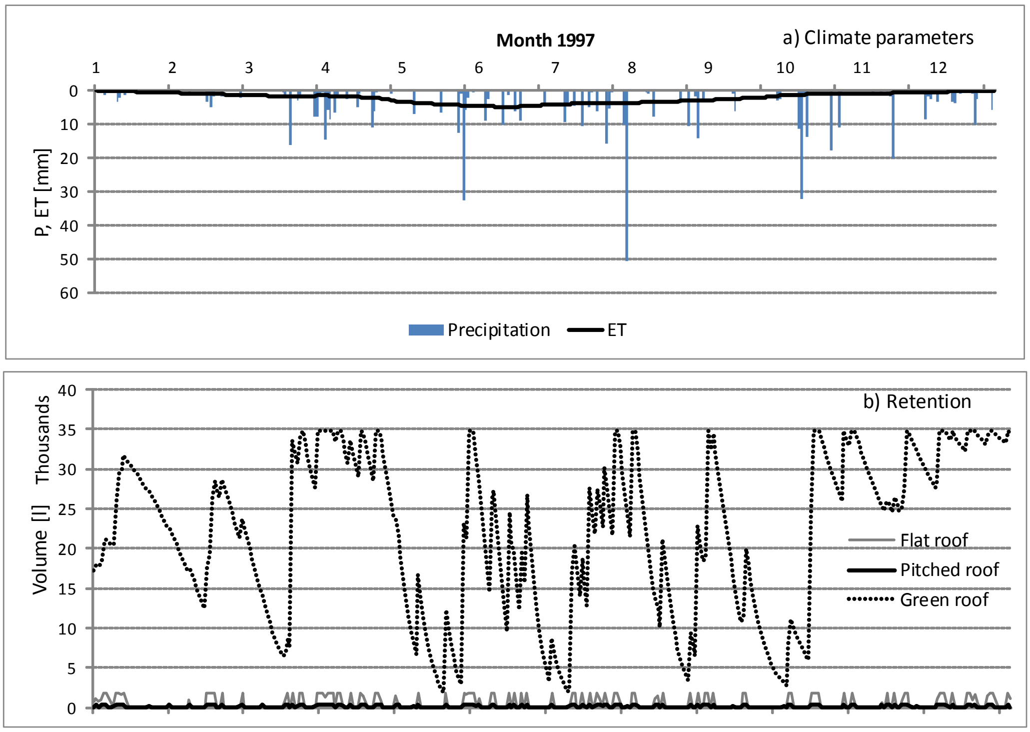

Figure 2. The model input meteorological data (a) and simulation results for the roof retention volume (b).

The individual runoff volumes from each rooftop are shown in the Figure 3 a, b and c for the study period. The runoff dynamics in the Fig. 3 shows both PR and FR are sensitive to the whole range of the observed precipitation depths (Fig. 2 a), the lowest daily precipitation sum to trigger runoff from PR is 0.3mm and 1.2mm for FR (Tab. 1). RG, as shown in the Figure 3 b, attenuates runoff most of the studied period, and exhibits the longest period without roof runoff (Tab.1). According to the runoff coefficient, RG acts as porous surface, while FR and particularly PR, as nonporous (Tab.1). FR shows the largest quantities of runoff from the daily precipitation (e.g. in May, August and October- Fig. 3c), followed by RG and PR (Tab.1).

Table 1. The roof efficiency indicators in the year 1997.

Roof efficiency indicator	PR	RG	FR
Min. precipitation triggering runoff [mm]	0.3	2.2	1.2
Max. number of days without runoff	17	83	32
Max daily runoff volume [l ·10^3]	72.0	80.5	81.7
Runoff coefficient	0.95	0.43	0.82

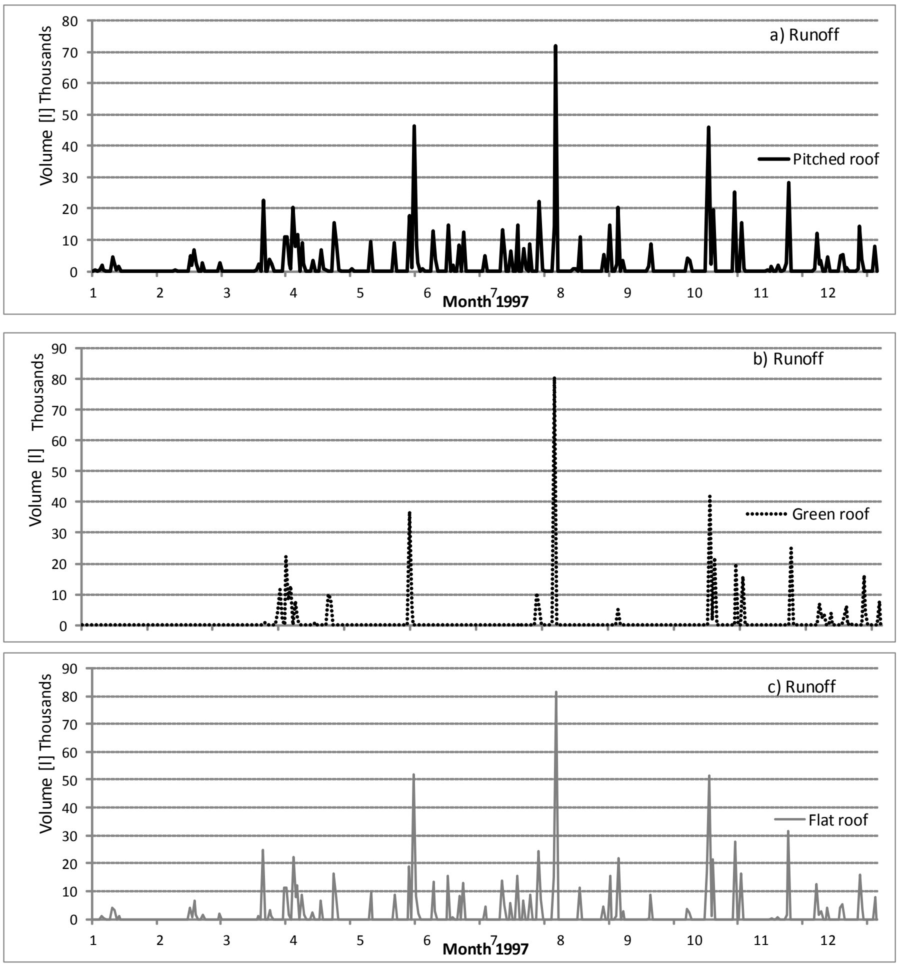

Figure 3. The model simulation results for roof runoff volume: a) PR, b) RG, c) FR.

CONCLUSIONS

In the presented research, three rooftop conditions are assessed in regard to water volume retained in the roof and released as runoff, for a compact group of buildings in the ‘Krive livade’ neighborhood in the city of Niš, Serbia. Besides the obvious water quantities that indicate performance of each rooftop during one year, a set of roof efficiency indicators is considered. Two new approaches for the role of roofs in SWM investigation are introduced: 1) assembling peached roof water volumes from the inclined roof segments of the water balance simulation model, and 2) roof efficiency indicators: minimum precipitation sum that triggers roof runoff, and maximum number of days without roof runoff. The importance of these approaches is in the capability: 1) to assess peached roof potential, and 2) to compare different types of roofs according to the site-specific conditions. For instance, in the study area, roof gardens are the best option, according to all of the indicators, regardless of maximum daily runoff volume, close to the one for flat roofs. Considering public benefit regarding SWM from roof garden implementation in the study area, it may be concluded that in the process of roof reconstructions, the chance to improve environmental status of the neighbourhood is missed. Furthermore, the public benefit could be quantified on annual basis through cost estimate of roof runoff volume sanitation at the wastewater treatment plant (Sainati et al., 2020), due to combined drainage system.

The research results show the importance of including roof gardens as technical elements in any contemporary SWM system preliminary design approach. Not only for housing areas, such an approach should be a part of the urban retrofitting design process. Due to limitations of land as a resource in urban areas, retrofitting interventions similar to the studied case are not only expected in the future, but happening right now. With a careful redistribution of porous and nonporous area in the urban catchments, the collective effect of lowering the catchment average runoff coefficient can be achieved. This is important for reducing stress from the existing SWM system, and application of the remaining set of technical elements in Nature Based Solutions that require less urban space due to decreased design volume.

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