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RAINWATER MANAGEMENT AIMING TO IMPROVE THE QUALITY OF URBAN SURFACE RUNOFF

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ABSTRACT. – Rainwater Management Aiming to Improve the Quality of Urban Surface Runoff. Currently many urban areas experience the quality degradation of rooftop runoff and accumulated rainwater. The present study aims to estimate the volume of water draining from rooftops within an area of 0.68 km^2 in the municipality of Cluj-Napoca. The volume of water flowing from rooftops presents a beneficial alternative not only for collecting rainwater for later use, but also for reducing the volume of water and for improving surface runoff quality in urban areas. The procedure was based on the Michel Simplified SCS-CN model, a derived variant of the most popular hydrological model, the Soil Conservation Service Curve Number (SCS-CN). The results of the applied method reveal that the highest rooftop runoff water values correspond to the summer months, these being based on daily rainfall data. Estimating the volume of water draining from rooftops for future harvesting is an important step in the sustainable management of rainwater in urban areas and in improving water quality.

Keywords: *SCS-CN method, rooftop runoff, urban area, impervious area*

1. INTRODUCTION

In urban areas surface runoff can present a real danger to the population if the drainage system can no longer handle the large volume of runoff rainwater or when inlets get clogged with certain materials. The large volume of water that runs off the surface in urban areas is mostly due to extensive impervious surfaces. Impervious areas like roads, pavements, parking lots, and building rooftops are the main source of rainwater pollution especially during the first flush phase. In order to reduce the volume of urban runoff and to improve water quality certain solutions have to be implemented, such as the expansion of pervious surfaces or the introduction of techniques for rainwater capture and storage.

In the present study we intended to estimate the rooftop runoff volume that can assist local authorities in the implementation of sustainable techniques for collecting and storing rainwater. Rainwater harvesting technologies in urban areas can be applied by local public services and it can also improve the quality of runoff and accumulated water in urban areas.

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In urban areas impervious surfaces lead to the most significant flow of runoff rainwater, and among these surfaces rooftops are the most extensive and their extent is on the increase. Rooftop runoff volumes can be estimated on the basis of several methods. One of the most versatile and widely used procedures for estimating runoff volume and managing water resources is the SCS-CN model (The Soil Conservation Service Curve Number). This model takes into account a number of characteristics like land use, soil types and antecedent soil moisture conditions in order to estimate runoff volume (Crăciun *et al*, 2007; Hawkins *et al,* 2010; Mishra *et al*, 2004; Shadeed and Almasri, 2010; Soulis and Valiantzas, 2012), and based on the information related to soil types and land use using the ArcCN-Runoff extension, developed by Zhan and Haung, (2004), a CN map can be created which is essential in generating overland flow using GIS technology. GIS technology has been widely used in many studies for modelling overland flow (Ebrahimian *et al*, 2012; Fan *et al,* 2013; Greene and Cruise, 1995; Shadeed and Almasri, 2010). Over time several modified variants of the basic SCS-CN model have appeared, which were developed by Mishra *et al* (1999), Michel *et al* (2005) quoted by Singh *et al,* (2013) and a model developed and described by Hawkins *et al*, (2010). Singh *et al,* (2013) conducted a comparison between five models in relation to the quantification of potential of rooftop catchments for rainwater harvesting and the results revealed that the Michel Simplified SCS-CN model yields highest rooftop runoff.

In the present study, in order to estimate the volume of water that runs off impervious catchment areas (roof), we resorted to using the Michel Simplified SCS-CN model that can be applied to completely impervious surfaces and that has been developed based on the SCS-CN model.

2. MATERIALS AND METHODS

2.1 SCS-CN methods

The Soil Conservation Service Curve-Number (SCS-CN) method was developed by the US Department of Agriculture in 1956 and is documented in Section 4 of the National Engineering Handbook, Hydrology (USDA - NRCS, 2004). The model is widely used for estimating runoff volume and water resource management, and it constitutes the basis for a number of other new models with wide applicability.

Runoff volume at a single rainfall event based on the SCS-CN model is calculated using the following equation:

$$Q = \frac{\left(P - I_a\right)^2}{\left(P - I_a\right) + S} \quad (1)$$

where: Q – direct runoff

P – total rainfall

S – potential maximum retention

I_a – initial abstraction

The initial abstraction (I_a) represents all the losses before the runoff begins such as infiltration or evaporation, rainfall retention in surface depressions or interception by vegetation, is given by the empirical equation:

$$I_a = 0.2S \tag{2}$$

Substituting eq. (2) in eq.(1), eq.(3) becomes:

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)} \quad P \geq 0.2S \tag{3}$$

Q = 0 P ≤ 0.2S

The potential maximum retention storage S value (mm) can be obtained by using the relationship:

$$S = \left(\frac{25400}{CN} - 254 \right) \tag{4}$$

The parameter CN (Curve Number) is a function of land use, land treatments and soil types. The CN indicates surface runoff potential and its value varies from 0 to 100. Lower numbers indicate low runoff potential in the case of pervious surfaces while larger numbers are for increasing runoff potential characteristic of impervious surfaces.

2.2 Michel Simplified SCS-CN (MSCN) Model

This model has been developed on the basis of the SCS-CN model and is based on soil moisture conditions. The model was developed for three soil moisture store levels as follows (Michel *et al* (2005)) cited by Singh *et al*, 2013):

For AMC I : $$Q = P \frac{P}{S + P} \tag{5}$$

For AMC II : $$Q = P \frac{(0.48S + 0.72P)}{(S + 0.72P)} \tag{6}$$

For AMC III: $$Q = P \frac{(0.79S + 0.46P)}{(S + 0.46P)} \tag{7}$$

where: Q - direct runoff, P - total rainfall, S - potential maximum retention, AMC I-dry condition, AMC II –normal condition, AMC III-wet condition of watershed.

In the present study from the three models developed for the three soil moisture levels (AMC I, AMC II and AMC III) we only used model (7) to estimate the runoff potential of rooftop surfaces which correspond with wet or completely impervious surfaces (Sahu *et al*, 2007; Singh *et al*, 2013).

3. APPLICATION

3.1 Study area

The estimation of rooftop runoff volumes was based on the Michel Simplified SCS-CN model in the study area of 0.68 km² within the total surface area of 98.38 km² of the municipality Cluj-Napoca. The area of study is located in the district of Mănăştur (Fig. 1) and is characterised by mixed land use with buildings covering an area of 0.114 km².

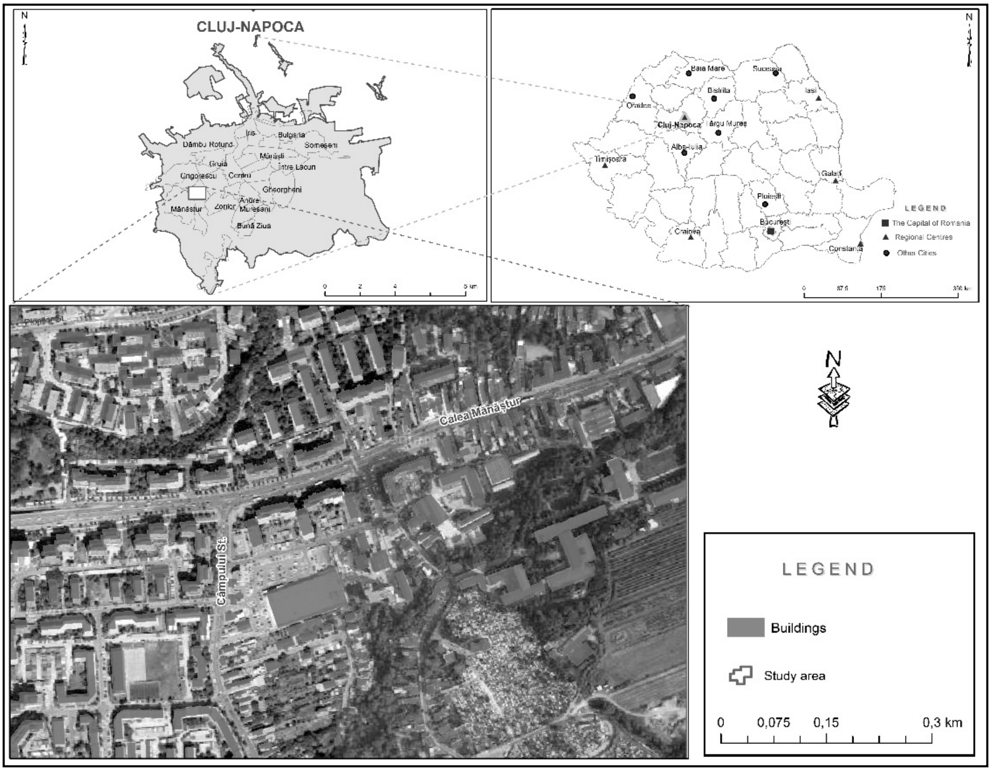

Fig. 1. Location of the study area within the country and the city.

The areas occupied by buildings that served as the basis for estimating rooftop runoff volumes were mapped using topographic plans of 1:500 scale and satellite images. Besides the cartographic database, rainfall data was also considered to estimate runoff volumes in the studied urban area.

3.2 Rainfall data

The estimation of rooftop runoff rainwater volume that can be captured for later use was based on daily rainfall data collected for the meteorological station in Cluj-Napoca from the European Climate Assessment & Dataset (ECA&C). The data was collected and analyzed for the period 1969-2013. In the period under review, the average monthly rainfall values were the highest in June (95.3 mm), July (93 mm), May (75 mm) and August (66.8 mm) (Fig. 2). Since the highest rainfall values in 44 years were recorded during these months, it can be stated that the summer season is the most suitable period for capturing the largest volume of rooftop runoff rainwater and its future harvesting.

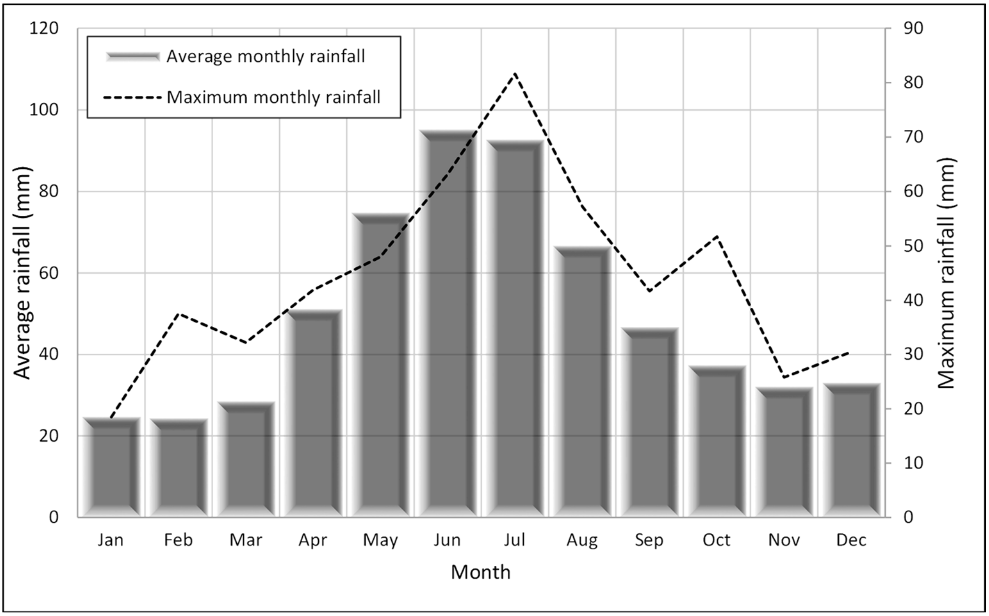

Fig. 2. Average monthly rainfall, Cluj-Napoca (1969-2013).

When estimating the volume of water draining from rooftops, in addition to using the daily rainfall data, a CN parameter with the value of 98 was assigned to completely impervious surfaces (buildings). Using the assigned CN value in equation (4) the potential maximum water retention was computed, which was later used in equation (7) to estimate the runoff potential of rooftop surfaces. Thus it was possible to estimate the runoff potential for every rainfall event throughout the year 2013.

4. RESULTS AND DISCUSSION

The results concerning the estimation of rooftop runoff volumes for each day for 2013 revealed large amounts of runoff during the summer season. The greatest amount of rooftop runoff rainwater corresponds to the rainfall event (P = 25 mm) recorded in July with a runoff depth of 23.3 mm (Figure 3a). In June, the highest value of runoff depth (21.6 mm) corresponds to the rainfall event (P = 23.2 mm), and in May and August the greatest amounts of rooftop runoff were 12.6 mm and 19.4 mm respectively.

When analyzing the monthly rooftop runoff volumes of 2013 that were estimated based on the MSCN model, results show a total runoff depth of 70.6 mm in May, 96.5 mm in June, 26.3 mm in July and 66.5 mm in August, values which were computed as the result of a total of 13 rainfall events recorded in May, 17 events in June, 5 events in July and 10 events in August (Fig. 3 a-d). The greatest amounts of runoff rainwater per month was recorded in June (96.5 mm) and the lowest amount was in December (8.1 mm).

The estimated daily and monthly rooftop runoff potential may help the local authorities to take measures for collecting and storing these amounts of water. Rooftops make up a significant percentage of the impervious surfaces within an urban area and roof-catchment systems are the most suitable for rainwater harvesting in these areas. Collecting rainwater in urban areas can offer a number of benefits. Harvested rainwater in urban areas can be used for washing roads, watering gardens and also for reducing overland flow in the urban area.

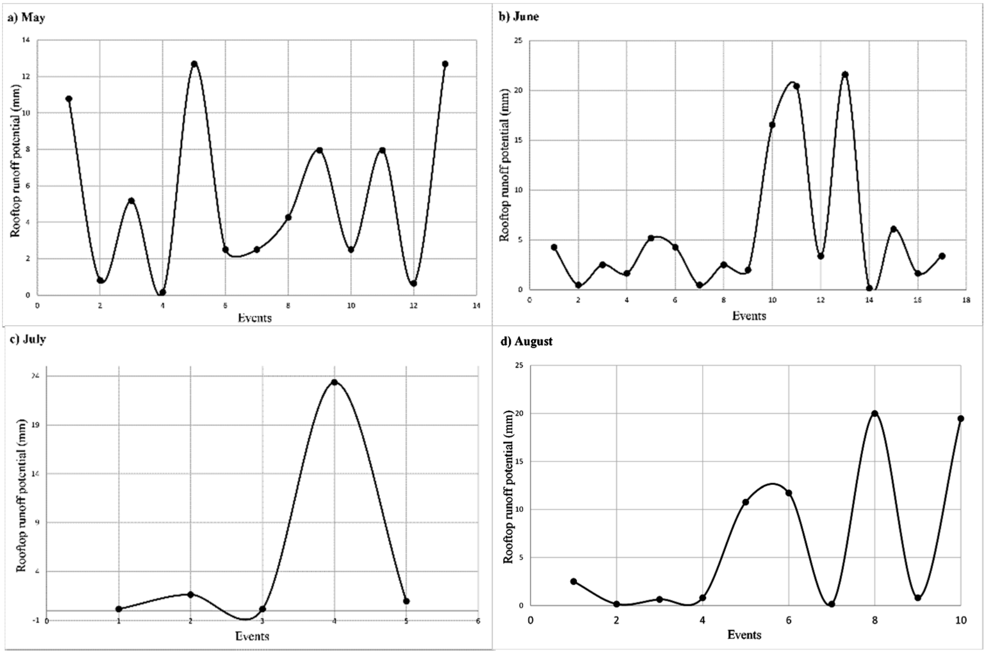

Fig. 3. Daily potential of rooftop runoff for the months of May, June, July, August.

Rooftop runoff capture and storage can address urban runoff problems and can lead to the improvement of surface runoff quality. Dry summer months or dry periods between rainfall events allow for pollutant build-up to occur on road networks or on building rooftops. Following the quality assessment of runoff rainwater accumulated on roads in three different areas of Cluj-Napoca (industrial, residential and commercial) during the cold and warm periods of 2015 we observed that the analyzed rainwater showed values that exceeded the maximum allowable limits for water quality parameters. The limits on the pollutants accumulated on road surfaces were established in accordance with the Norms, NTPA – 002, on discharging conditions of wastewater into sewerage systems of localities and directly into wastewater treatment plants (H.G. 352/2005). 11 parameters were set to assess the quality of urban runoff rainwater discharged into the sewage system: temperature, pH, Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), NH_4^+-N, P, Cu, Zn, Pb, Ni and Total Suspended Solids (TSS).

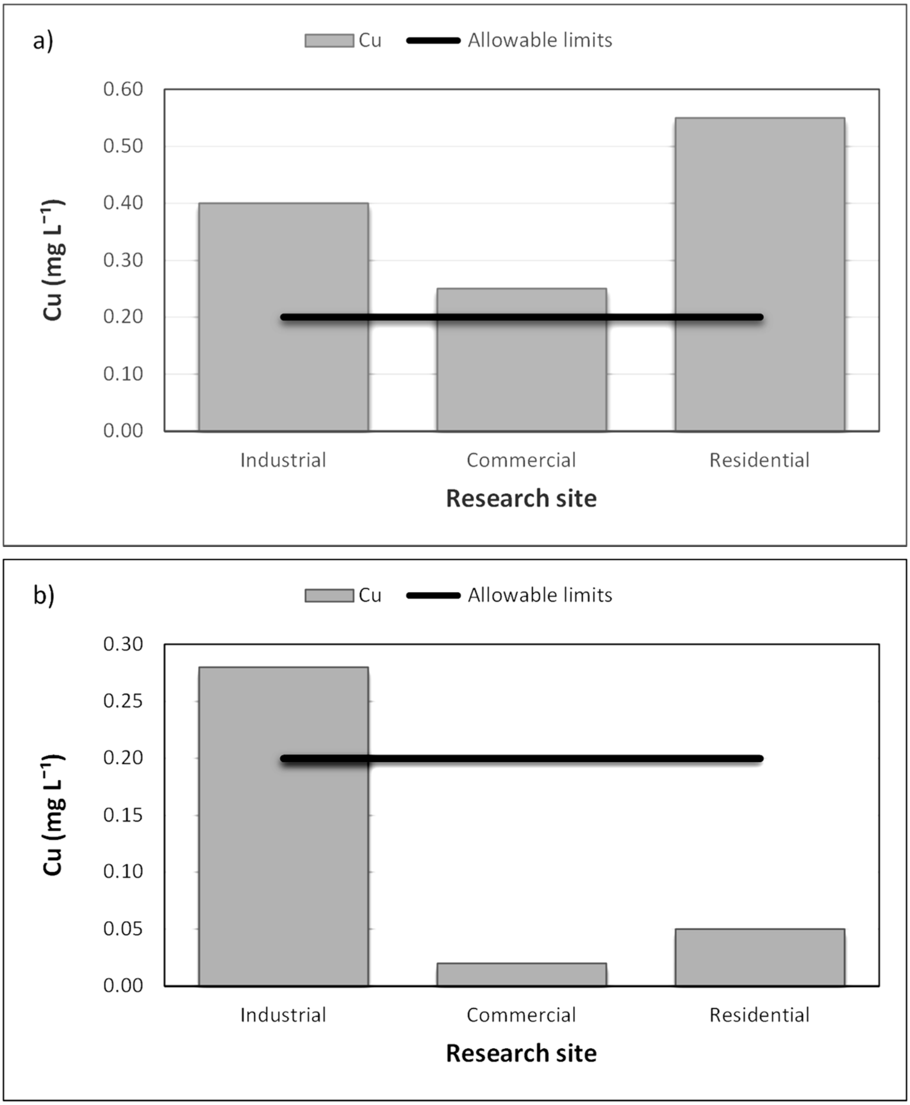

Fig. 4. Variations in copper concentration in the three urban areas and the maximum allowable limits a) in winter b) in summer.

Results showed that the degree of organic water pollution was high in the residential area during the cold season and in the industrial area during the warm season. The low levels of NH_4^+-N and P found in the rainwater that ran off road surfaces in both seasons showed a very low degree of pollution caused by these two parameters. Regarding heavy metal contamination, high levels of copper pollution in all three sampling areas characterized the cold season and in the warm season the degree of pollution was high only in the industrial area (Fig. 4), while the influence of zinc, lead and nickel on the degradation of water quality was minimal.

The level of total suspended solids (TSS) was high in the industrial area in both seasons and low in the commercial area, water temperatures did not exceed quality standards, while the recorded pH values were below 6.5 in the residential area during the summer period.

The primary sources of Zn and Cu in urban runoff are rooftops (Bannerman *et al*, 1993; Brown and Peake, 2006; Chow *et al,* 2013; Gnecco *et al,* 2005), brake wear from vehicles (Budai and Clement, 2011; Chow *et al,* 2013**)** and industrial activities (Bannerman *et al,* 1993; Brown and Peake, 2006; Chow *et al*, 2013). The capture of rooftop runoff water therefore leads to the quality improvement of surface runoff in urban areas.

5. CONCLUSIONS

In urban areas, due to rapid urbanization processes, impervious surfaces are continually spreading and this leads to an increase in runoff water volume and water quality degradation. The highest percentage of the land surface in urban areas is covered by rooftops and their extent is on the increase.

The estimation of rooftop runoff volumes for a series of daily rainfall events revealed a high runoff potential in the summer months. The greatest amount of daily runoff rainwater (23 mm) was recorded in July 2013, and the greatest amount of monthly runoff rainwater was recorded for June (96.5 mm). The lowest amount of monthly runoff was 8.1 mm recorded in December. The estimated daily and monthly rooftop runoff potential may help the local authorities to take measures for collecting and storing these amounts of water. Harvested rainwater in urban areas can be used for washing roads or watering gardens.

The implementation of sustainable measures for runoff capture and storage has an important role in urban rainwater management, flood prevention and improving surface runoff quality in urban areas. In addition to rainwater harvesting techniques implemented to reduce runoff volumes in urban areas, impervious areas should be directly connected to the sewerage system, parking lots and alleys should be covered with cobblestones or permeable pavers to allow the infiltration of water into the soil and green areas should be expanded. The percentage of impervious surfaces within an urban area is important because it directly affects the amount of runoff.

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