Assessment of the Sources of Pollution and of Surfaces Suitable for Bioretention Systems in Different Sites in Terms of Land Use

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Abstract

The knowledge of the rainwater runoff pollution sources and the flow pattern is essential in evaluation of storm water management options. The aim of the study was to identify the pollution sources, to establish the position of these sources and runoff pathways of the polluted rainwater; identify the areas where can be implemented the bioretention systems; the size analysis of the surfaces suitable for bioretention systems implementation based on location and land use. The study included four types of urban sites: commercial, industrial, low density residential and high density residential. The methodology of identification of diffuse pollution sources in the studied sites used field observation methods, imagery and GIS software. To properly identify the pattern of the stormwater runoff, field observations were made during the days with precipitation, between March 2012 and August 2014. For a clear results, were observed precipitations and runoff for each season separately, including snowfall (was followed water leakage pattern from melting snow). Precipitations with varying degrees of intensity were followed. The sources of diffuse pollution of stormwater runoff were determined on the basis of land use types. The results show that the diffuse sources of contamination of rainwater runoff are characteristic of the studied areas in close relationship with the land use type. The evaluation of suitable surfaces for bioretention implementation in Cluj-Napoca, by studying these four representative areas, shows that in all areas, regardless of the land use types, the surfaces are available for the implementation of these systems. The studied issue related to diffuse pollution sources and areas suitable for bioretention systems does not restrict and recommends their implementation.

Keywords: *diffuse, pattern, pervious, pollution, runoff, urbanization*

INTRODUCTION

The urbanization has an accentuated negative environmental impact through physical and chemical changes on the hydrologic system (Jacobson, 2011, Fletcher *et al.*, 2013). Changing the land use affects both urban and periurban environment (Tavares *et al.*, 2012). A large number of studies show increases of the impervious surfaces in relatively short periods of time (Gerard *et al.*, 2010; Boancă-Pop *et al.*, 2012; Zhou *et al.*, 2012; Miller and Grebby, 2014). The urbanization affects the hydrological regime by increasing of the impervious surfaces (Braud *et al.*, 2013). The

existent studies indicate that the percent imperviousness of a catchment is an important and sensitive parameter in analysing the effects of urbanization of storm-water runoff (Kuichling, 1889; Arnold and Gibbons, 1996; Jacobson, 2011). Gallo *et al.* (2013) show that the effect of urban land cover on hydrologic responses was tightly coupled to the magnitude of rainfall and that runoff quality did not vary in response to impervious cover or land use (Gallo *et al.*, 2013). The loss in pervious surfaces reduces the infiltration into soils, while the introduction of artificial drainage replaces natural pathways. Urban runoff is a major pollution

source of the hydrographical networks (Gromaire-Mertz, 1999; Fang Huang, 2010; Taebi and Droste, 2004). The management of urban stormwater through bioretention systems implementation is a sustainable solution (Scholz and Yazdi, 2009; Kazemi *et al.*, 2009; Kazemi *et al.*, 2011; Trowsdale and Simcock, 2011) but which depends on the type of existing surfaces (pervious and impervious) and of the pollution diffuse sources.

The knowledge of the diffuse pollution sources (D'Arcy *et al.*, 2000) and rainwater runoff pattern is essential in assessing the stormwater management options. Although, in general, the literature provides comprehensive data related to the above issues, we believe that these aspects should be treated according to local conditions of a particular site. Implementation of the bioretention cells as sustainable solution for managing urban runoff depends on particular factors that must be treated fairly in terms of the given context: geographical coordinates, climate, localisation of the pollution sources, runoff patterns, degree of imperviousness and most importantly - areas available and suitable for the bioretention systems construction. The purpose of this paper is to determine if in Cluj-Napoca exist surfaces necessary for the implementation of the sustainable systems based on bioretention and if the land use affects the quality and quantity of these areas. In addition was aimed to identify diffuse pollution sources and to establish the runoff patterns in the studied areas. The coverage degree with impervious surfaces, the sources of diffuse pollution and runoff pattern varies both for the urban areas from Romania and the ones abroad. We consider that in order to obtain functional bioretention facilities, these elements should be considered and should be a preliminary basis in their implementation. The methods based on direct observation and GIS techniques, used in this study, can be applied successfully in order to obtain important data for modelling of the bioretention systems - regardless of the location of urban area.

MATERIALS AND METHODS

The assessment of studied sites followed well-established and significant steps in the research process of the bioretention cells implementation conditions: identification of the pollution sources and creating maps with these sources position and

with the polluted rainwater pathways; identify the areas in which the bioretention systems can be implemented; size analysis of the areas suitable for the bioretention cells implementation, based on location and land use.

Identification of the diffuse pollution sources and runoff pattern. The methodology for the identification of diffuse pollution sources - in the studied site - included: field observation methods, imagery and GIS software (Mitchell, 2005). For the correct identification of runoff pattern, field observations were made during days with precipitation, between March 2012 and August 2014. Photographs were made for each site, were noted flow directions and problematic zones in terms of pollution sources or rainwater stagnation. For clear results, field observations were made observing the precipitation and the runoff for each season separately, inclusive for snowfalls (was observed the pattern runoff of water from snow melt). Also, precipitations with different degrees of intensity were monitored. Pollution sources have been established on the basis of site characteristics (land use types). Maps that contain sources of pollution and stormwater runoff patterns from impervious surfaces were made based on satellite images, and photographs made during the field research. In the figure 1 are presented images taken during field observations.

Identification of the areas in which the bioretention cells can be implemented. The methodology used to identify this type of areas relied on classical methods (direct observation, photographs) and contemporary methods (satellite imagery, geographic information systems - GIS, and CAD software) (Berke *et al.*, 2006; Malczewski, 2004; Miller and Grebby, 2014). Information extracted from the use of this methodology constituted a database used for specific analyses. Thus, using Google Earth Geographic Information System have been visualized sites components that on the field cannot be spotted easily. SketchUp software was used to import and scale the images taken from Google Earth and for making accurate maps of the areas in which the bioretention cells can be implemented. For identification of these areas were considered existing buildings, thoroughfares, existing green spaces and impervious areas that allow rehabilitation in terms of sustainable development.

Fig. 1. Field observations during days with precipitation - Cluj-Napoca: a) Mehedinți street, July 2013; b) Primăverii street, May 2013; c) Primăverii street, February 2014

Fig. 2. Pluvial runoff pattern in studied sites: a) industrial area; b) high density residential area; c) low density residential area; d) commercial area

Size analysis of areas suitable for the bioretention systems implementation based on location included the next steps: calculation of the areas available in each site; calculating the percentage of areas available from the total surface of each site individually; comparison of results (Christianson *et al.*, 2004; Davis *et al.*, 2009; Brown and Hunt III, 2011). Given that land availability may be limited depending on land use type, were calculated the impervious surfaces areas - existing green spaces in the studied areas. To be implemented, the bioretention cells require various surfaces, surfaces that under different

conditions offered by the targeted sites restrict the implementation of these systems (Hitchcock *et al.*, 2014). The aim was to obtain complete information for each site included in the research, being calculated for each site an equal area (165,745.00 m²). After the mapping and reconstruction of the components elements of the sites, were calculated areas occupied by roads, parking lots, buildings and green spaces/permeable surfaces.

RESULTS AND DISCUSSIONS

From the research process to identify the diffuse sources of rainwater runoff, the results

show that they are characteristic to the studied areas and are in close relation to the land use type. The direct observation in field - during May 2012 and August 2013 - which included the observation of the activities in the four urban areas studied, showed that:

In low density residential area the identified the possible diffuse pollution sources are: automobile and activities of the residents: fertilizer, use of the herbicides, insecticides, fungicides, soil washing from the exposed areas in the private yards, detergents from car washing and other household activities, waste from pets, unmaintained septic systems, improper storage of paints, oils and other chemicals; small and medium coverage degree with impervious surfaces - represented by the roofs, walkways, streets, private parking; construction activities. In high density residential area the pollution sources identified are similar with those in low density residential area, with some differences: a high coverage degree of impervious surfaces and commercial activities. In the commercial area pollution sources identified are: parking and their related actions: washing of pavements, fuel and oil leaks etc.; car and pedestrian path; maintenance activities of green areas: fertilization, the use of fungicides, insecticides, herbicides. In the industrial area the pollution sources identified are: traffic, especially heavy car traffic; manoeuvring operation of contaminated water; various industrial activities; high coverage degree with impervious surfaces; improper storage, etc.

The research results on the runoff pattern are shown in Figure 2. The maps show that rainwater runoff follow the natural topography and the slope of built areas. Using the runoff pattern has been determined the locations for bioretention cell implementation. The results show that the stormwater runoff pattern follows the car and pedestrian traffic routes. Problematic points were identified during field observations. Problems are compounded by the large amounts of sediment from soil washing on steep slopes and transported to the sewage network. These problematic points are located at the intersections of secondary roads in slope with road.

In the figure 3 it can be observed the large amount of sediment transported by runoff from high and average intensity rainfall. The results of observations show that due to large impervious

surfaces and water-related infrastructure, natural flow pattern is affected and changed.

Fig. 3 Runoff pattern
- sediment transported after soil washing

In low-density residential area results show that the bioretention cells can be implemented in areas with vegetation related to private property; in the green spaces adjacent to parking and streets; in areas with impervious surfaces (pedestrian path, parking, streets) where the dimensions allow restructuring through intercalation of pre-constructed bioretention systems. In high density residential area the bioretention cells can be implemented, in general, in the green areas around of residential buildings, parking and streets (green spaces which delineates the pedestrian and cars circulation). In the industrial area, the results show that the areas available for bioretention cells are located near circulation routes, near industrial buildings, and in the area adjacent to the existing car parking. As a result of calculations made in order to analyse the size of areas suitable for the bioretention cells implementation based on location follows that:

In the low-density residential area: permeable surfaces/green spaces, where there is opportunity to be implemented the bioretention cells, occupy a percentage of 47%; the buildings occupy 39%, while the roads and parking lots occupy 14% of the studied area (Fig. 4).

In the high density residential area: has been identified an area suitable for bioretention cell implementation in a percentage of 44% of the total studied area; the rest of percentages are represented of 29% - roads and 27% - buildings (Fig. 5).

In the commercial area the resulted percentage is: 47% areas in which could be implemented

Fig. 4. Low density residential area

Fig. 5. High density residential area

■ roads ■ buildings ■ green spaces/pervious surface

Fig. 6. Commercial area

■ roads ■ buildings ■ green spaces/pervious surface

Fig. 7. Industrial area

Fig. 8 Comparative analysis of suitable surfaces for bioretention cell implementation, identified in studied sites

bioretention systems; 37% surface occupied with roads and parking; 16% surface occupied with buildings (Fig. 6).

In the industrial area the results show that: the surfaces suitable for bioretention cells occupy only 17% from the total of the studied surface; the buildings occupy 56% from the total surface, and the roads and parking - 27% (Fig. 7).

Discussions. The size of the bioretention cells is dictated by the size of the impervious surfaces in the targeted catchment area (Christianson *et al.*, 2004; Davis *et al.*, 2009; Brown and Hunt III, 2011). In order that bioretention facilities to capture the first 1.27 cm runoff from impervious surface, the area of bioretention cell must be 5% from the impervious area (Hunt, 2003; UW-Extension, 2003; MPCA, 2005; U.S. EPA, 2009) or, in

the studied case, 202.522 m² bioretention surface for 4046.9 m² (0.406 ha) impervious surface. It is recommended that the minimum length and width of a bioretention cell to be 3 m and 4.5 m. May be used smaller widths - 1.2 m - in the cases in which the stormwater runoff have a dispersed flow along the bioretention cells arranged in vegetable strips adjacent to car or pedestrian circulation routes. The results of the assessment of the surfaces suitable for bioretention cells implementation in Cluj-Napoca, through the study of four representative areas (commercial, industrial, low density residential, high density residential) show that in all areas, regardless of the land use type, are available implementation surface. The available surfaces, even if they are found in different proportions depending on the type of site (Fig. 8),

meet the minimal condition of bioretention cells sizing – exposed above – conditions that ensure efficient operation and successful performance of these facilities functions.

The research presented in this paper started from the hypothesis that any pervious surface (in particular available green spaces) can be used for placement of bioretention cells –thus resulting larger areas of implementation, in a higher percentage than minimum standards. Given that there are certain types of areas undesirable for the bioretention cells construction, it was taken into account the exclusion from the suitable surfaces percentage, resulting from the assessment of sites in Cluj-Napoca. Even in the conditions of the exclusion of these surfaces, results a sufficient percentage of suitable area for bioretention systems. Undesirable areas to implement bioretention cells include: areas where mature trees were identified - to avoid the removal of this; areas where the existing slopes have an inclination degree of 20% or more, and area situated above or close to the unstable soil. It is recommended that in the residential area the bioretention cells to be combined with other stormwater runoff management practices. In the commercial area, the bioretention cells can be implemented successfully, the results showing that the suitable surfaces are adjacent to the parking lots, inside the parking lots and along the car and pedestrian circulation paths.

CONCLUSION

After this study we conclude that the methods used, even if it involves larger periods of time, are inexpensive and can be applied successfully in any urban area to obtain important data for correct implementation of the bioretention systems.

Regarding the sources of diffuse pollution - after the investigations based on direct observation in the four urban areas studied in Cluj-Napoca – it resulted that they are influenced by the type of land use. To ensure extensive information we recommend further investigation on runoff pollutants loads in these areas.

Results on runoff pattern indicates that the natural topography has a great influence on them but that inclination of built areas should not be neglected - it has a rather large influence in urban area due to the high coverage degree with impervious surfaces.

The calculation for determining the surface available for the implementation of bioretention system show significant differences between the four areas studied. However the implementation of bioretention systems is not restricted in any of the studied areas by the available pervious surface.

We recommend performing these types of studies - regardless of the location of urban areas in Romania or abroad - when planning the implementation of the facilities based on bioretention. Thus will be avoided initial errors that could lead to bioretention systems with compromised function.

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