ISSN 1644-0765
DOI: http://dx.doi.org/10.15576/ASP.FC/2017.16.3.217
www.formatiocircumiectus.actapol.net/pl/

ACTA SCIENTIARUM POLONORUM

Acta Sci. Pol. Formatio Circumiectus 16 (2) 2017, 217–230

RAIN GARDENS – CASE STUDY OF POTENTIAL LOCATIONS IDENTIFICATION USING GIS

Veronika Vaculová, Jakub Fuska
Slovak University of Agriculture in Nitra

Abstract. Rain gardens represent a method of storm water treatment at settlement level, where, besides the ecological aspect, they fulfil the aesthetic function in public spaces. Their concept and proposal follows several rules under the natural conditions and site parameters itself. The aim of study was the establishment of methodology for determining the possible locations for the installation of the rain gardens, in application to chosen settlement – village Žirany, Nitra district. Selection of potential sites is based on the attributes of soil properties, slope, land use, ownership and ground water level in the given area, that are processed in GIS software QGIS. The elaboration of the methodology is based on existing analyses in last years. The result of applied methodology is raster map which describes the suitability of sites for rain garden installation in selected village based on the spatial analysis with the use of overlaying of the value raster of the mentioned attributes. Area of fields with best conditions for raingarden placement is approx. 9700 m^2 (0.86% of cadastral area of surveyed village Žirany).

Key words: rain garden, water management, storm water, GIS analysis

INTRODUCTION

Rain gardens, as an important storm water management practice, are common tool in landscape creation of public spaces. Their ecological characteristics include collection, processing, infiltration, transpiration and filtration of storm water, which are increased by strong economic aspects because of its relatively low-cost demand and final money savings. These low terrain depressions planted with perennials, shrubs and small trees are notable aesthetic and landscape element used by landscape architects worldwide.

Corresponding authors – Adres do korespondencji: ing. Veronika Vaculová, Department of Garden and Landscape, Faculty of Horticulture and Landscape Engineering, Slovak University of Agriculture, Tulipánová 7, 949 01 Nitra; ing. Jakub Fuska, PhD, Department of Water Resources and Environmental Engineering, Faculty of Horticulture and Landscape Engineering, Slovak University of Agriculture, Hospodárska 9, 949 01 Nitra; e-mail: xvaculovav@is.uniag.sk.

Soils in urban areas have significantly altered natural structure and impaired functionality that greatly extends the time of infiltration of rain water. Increasing input of water to the sewerage system may result in higher costs of water treatment in the municipalities. Landowners have responsibility of resolving the issue of rainwater.

Rain garden (RG) is a natural infiltration element with an aesthetic impact of used bed planting. It is a terrain depression planted with herbs and small trees. This bio retention ecosystem collects, absorbs, filters and safely infiltrates water from paved impervious surfaces during rainy seasons [Díaz Iglesias 2013]. Water management in landscape requires various approaches in accordance to land use [Halaj et al. 2012, Jurík et al. 2013]. Evaporation rates may be affected in various ways in the real conditions [Zarzycki, Misztal, Bedla 2015, Żarnowiec et al. 2016]. In urban areas, the percentage of impervious ground ranges from 20%, in the areas of housing, up to 85%, in areas of industry [Novotny and Olem 1994]. RG causes higher effectiveness (up to 30–40%) of water absorption in comparison to a lawn. They also act as a sponge, because they are able to take up the pollutants (chemicals, microbial pathogens, fine sediment, P, N and others) and the planting helps to eliminate and treat the storm water [Stiffler 2013] as the water quality may be threatened nowadays [Bedla and Misztal 2014, Policht-Latawiec et al. 2015]. Water content in soil profile and its dynamics can be modelled in various scale levels ranging from profile to whole catchment level [Tárnik and Igaz 2015].

RG construction rules, concept of creation and functionality were basic for elaboration of methodology for presented analysis of potential placement in chosen settlement of village Žirany. This methodology is based on the methodology described by Marney [2012].

MATERIALS AND METHODS

We used various materials for spatial analysis:

- WMS servers
  - Cadastral map (https://kataster.skgeodesy.sk/eskn/services/NR/kn_wms_norm/MapServer/WmsServer)
  - Map of soil units (http://sscri.vupop.sk/arcgis/services/vupop_wms/MapServer/WMSServer?REQUEST=GetCapabilities&SERVICE=WMS&VERSION=1.3.0)
- Web GIS pages
  - Soil maps of Slovakia (http://www.podnemapy.sk/poda400/viewer.htm)
  - Map of of dominant soil units (http://www.podnemapy.sk/Website/pody/web_podysr/legenda_pjd.htm)
  - Map of particular parcels in the village with the orthophotomap layer (http://mapka.gku.sk)
- Parcel ownership identification
  - ownership of the village parcels as database of Cadastral Portal (community/private land), (https://www.kataster portal.sk/kapor/)
- Spatial planning documentation.

Data processing and spatial analysis was performed in software QGIS v. 2.12.0. Analysis of the spatial and ecological parameters of the studied area was based on work of McCormack [2015], Rokus [2005], Marney [2012]. These authors have focused on various input parameters affecting the suitability of the location for RG (Table 1–3).

The authors assigned values on the scale 1–5 or 1–3 to selected parameters, and then multiplied them by a weighting coefficient which varies considerably depending on the particular methodology. Subsequently, each cell of the studied area (according to the selected raster of 5x5 m cells) was recalculated and resulted in a raster map showing the suitability of the site for RG installation based on an analysis of weighted overlap.

Marney [2012] developed the most comprehensive methodology. He assigned to selected parameters a value on a scale 1–3 (Table 3). These categories included soil, slope of area, depth of the ground water, proximity to structures involving civil structures, ownership and the current land use. Values were afterwards multiplied by a weighting coefficient (Table 3). The final value of the RG suitability of the location was calculated for each cell of final raster (1).

$$Y_{RG} = \sum_{i=1}^{n} (W \times C_i), \tag{1}$$

where:

Y_{RG} – the final suitability of the site for RG,
W – the weight of the parameter,
C_i – value of the particular parameter [Rokus 2005].

Table 1. The input parameters for analysis to determine a suitable location for creation RG by McCormack [2015]

Parameter	Coefficient	Parameter value				
		1	2	3	4	5
Hydrological soils group	25%	N/A	D – very high absorption	C – high absorption	B – slow absorption	A – very slow absorption
Minimal soil depth	35%	0–14 inch	–	20 inch	–	20–80 inch
Slope	25%	12–700%	9–12%	6–9%	3–6%	0–3%
Exposure to the cardinal points	10%	0–90°, 270–360°	90–112.5°, 247.5–270°	112.5–135°, 225–247.5°	135–157.5°, 202.5–225°	157.5–225.5° (south)
Use of area	5%	–	–	N/A	–	road, housing, commercial, public

Table 2. The input parameters for analysis to determine a suitable location for creation RG by Rokus [2005]

Parameter	Coefficient	Parameter value		
		1	2	3
% of impervious surface	1/3	designed using complex calculations from the number of parameters		
Soil permeability	1/3	designed using complex calculations from the number of parameters		
Slope	1/3	0–18%	18–25%	> 25%

Table 3. The input parameters for analysis to determine a suitable location for creation RG by Marney [2012]

Parameter	Coefficient	Parameter value		
		1	2	3
Soil	0.25	loam, clay-loam	loamy, loamy-sand	sandy
Slope	0.25	0–1.9%	5–8%	2–4.9%
Depth to ground water	0.10	0–1.9 ft	2–4.9 ft	>5 ft
Proximity of structures	0.15	0–9.9 ft	10–14 ft	>15 ft
Public/private	0.15	private	–	public
Use of area	0.10	housing	industry	commercial

Marney's methodology was the basis for the analysis of the village Žirany, because the parameters used in this method were available in the studied area. In the case of land ownership, private areas and areas in co-ownerships were found to be less suitable for potential placement of RG. Hydrology of land and the minimum soil depth used by McCormack (Table 1) were not applicable in our case, because of the unavailable data. Methodology by Rokus (Table 2) reflects the parameters - impermeable surface, permeability of the soil and slope. However, several sub-parameters were not available in studied area.

According to available documents, we focused on the categories, which are directly involved in the process of proper functionality of RG in the surrounding village. Categories were then assigned the values, which were adjusted with the coefficient by relevance of given parameters in the process of RG creation (Table 4).

Paved areas, buildings and buffer zone of 3 m from buildings represented elements, which had to be considered in the process of analysis as these components were not suitable for installation of RG. These elements were excluded from result map creation process.

Table 4. Input parameters for performing the GIS analysis to determine a location for RG

Parameter	Coefficient	Parameter value		
		1	2	3
Soil	0.25	light soils	medium heavy soils and moderate soils	very heavy soils, heavysoils
Slope	0.25	2–4.9%	5–8%	0–1.9%
Ownership of parcels	0.20	owned by the municipality	co-ownership	private property
Use of area	0.20	public greenery	private greenery	industry
Depth to ground water	0.10	More than 2.00 m	2.00–1.00 m	Less than 1.00m

Workflow analysis to the development and subsequent assessment in the form of map output included following steps:

- vectorization of village boundaries;
- vectorization of parcels with the use of cadastral map and Land Register portal map:
  - assigning properties of location to each parcel,
  - calculation of parcel size,
  - assigning the values: 1 – owned by the municipality, 2 – parcels co-ownership, 3 – exclusively private property;
- vectorization of soil types boundaries:
  - the characteristics of the soils in Žirany using maps and Guide for Valuated Soil – Ecological Units [Linkeš 1996],
  - assigning the values for categories of soils in accordance to the main unit of soil and soil granularity classifier: 3 – very heavy soils and heavy soils, 2 – moderate soils and medium light soils, 1 – light soils;
- vectorization of buildings and paved surfaces using cadastral maps, ortho photo maps, Land Registry portal maps.
- vectorization of land use zones using a land use plan and a field survey
  - assigning the values of the land use: 1 – public greenery, 2 – private greenery (housing, vineyards, grassland, gardens), 3 – industry;
- creation of a digital terrain model (DTM) from the nodes extracted from the contours of the area;
- adding a layer of ground water levels - data from the Department of Biometeorology and Hydrology SUA in Nitra, used ground water levels value represented average value for the period of 2016.

RESULTS

Result maps showing the values of particular parameters within the boundaries of the village Žirany were produced by processing the input data according to the methodological model. There were created 9 maps that were utilized to create the resulting map of suitability of sites for RG placement.

Soil type and its characteristics were considered as one of the most important parameters in RG construction process. Using Valuated Soil – Ecological Units maps and Soil map of Slovakia, different soil types in area were identified (Fig. 1). According to the analysis, the most abundant type of soils of the surveyed area is modal saturated and acidic cambisol. The Map of soil categories (Fig. 2) was created by converting the soil types into three categories based on methodology process model – light soils, medium and heavy soils with their associated values – in studied area are located only moderate soils and lighter moderate soil (value 2) and very heavy and heavy soils (value 3). Soils

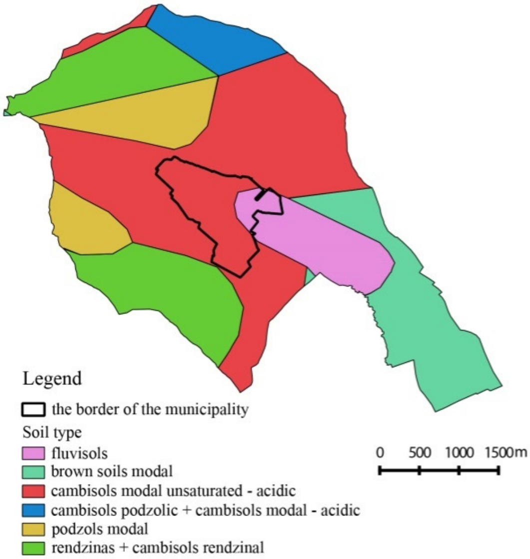

Fig. 1. Soil types in Žirany cadastral area

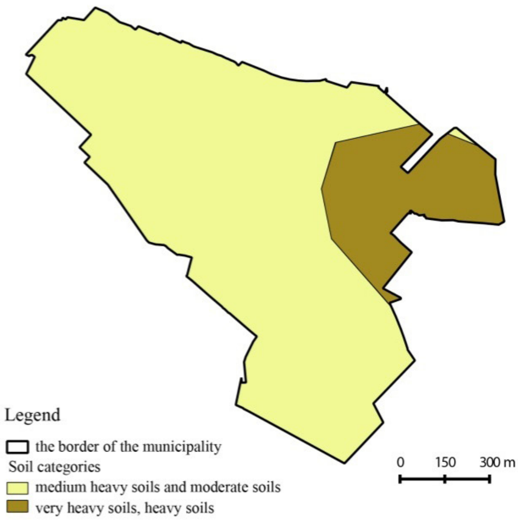

Fig. 2. Map of soil categories

in the studied area are less suitable or not suitable for RG creation; however it is still possible to improve them with local substrate replacing.

Digital elevation model was created after vectorization of contours and extraction of their nodes (Fig. 3) using TIN interpolation. The model shows that the whole urban area is slightly sloping downward to the west (the entrance to the village). Total elevation difference is approximately 90 meters (from 217 to 308 m ASL).

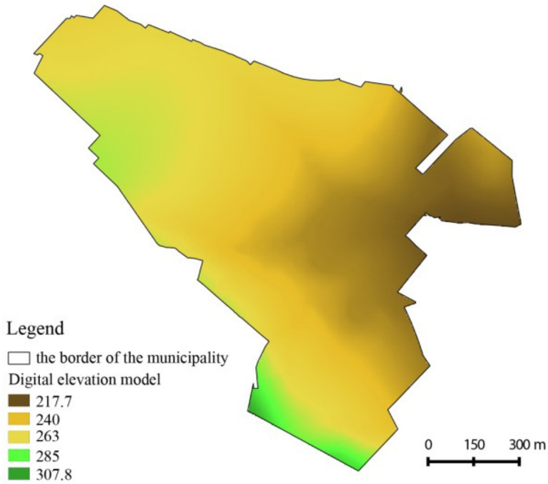

Fig . 3. Digital elevation model

Digital elevation model was used to create the map of slope, which was afterwards categorized and reclassified to values from 1 to 3 (Fig. 4) in accordance to the used methodology (Table 4). Sites, where the slope was exceeding 8%, were considered as unsuitable for RG placement and thus they were excluded from the analysis by adding null values to cells.

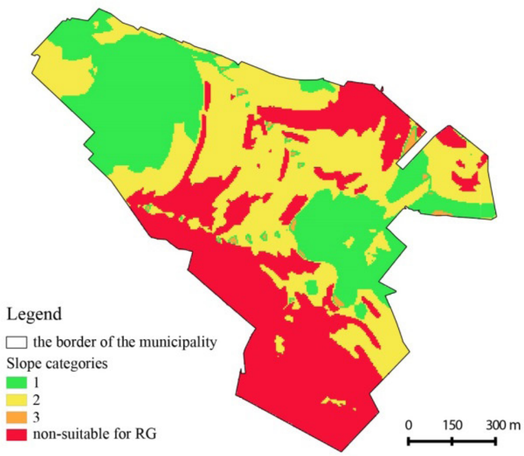

Fig. 4. Map of slope categories

Map of ownership within the boundaries of the village Žirany (Fig. 5) was created with the use of ownership parameter obtained from Cadastral Portal.

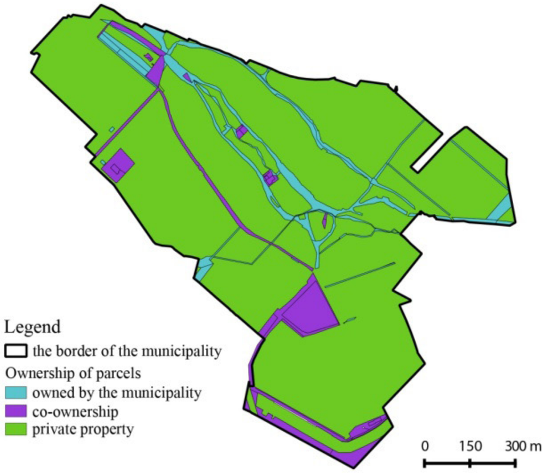

Fig. 5. Map of ownership of parcels

Map of land use (Fig. 6) was created with the use of land use plan and a field survey. The area is divided into 3 categories - public greenery (value of 1), and thus constitutes the most suitable areas for the design and installation of RG. The value of 2 was assigned to private green areas which contain the parcels of housing gardens, vineyards, meadows and permanent grassland. The value of 3 was allocated to industrial sites. Locations with parameter 2 and 3 are not considered as suitable for the RG installation, because it is a private land of industrial production. There are areas with a high proportion of the paved surface compacted by heavy machinery, a high degree of dust, etc.

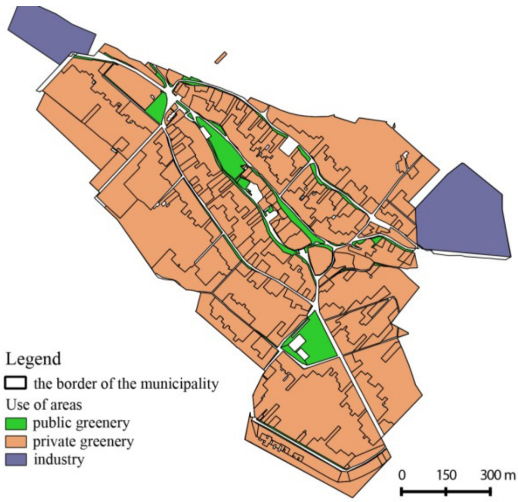

Fig. 6. Map of land use

Map of ground water levels (Fig. 7) is relatively simple, as the value of this parameter is constant in accordance to available resources (survey data from Department of Hydrology and Biometeorology). The level of ground water is the annual average for 2016 and it represents 1.064 meters. In the methodological model, this value means the value of 2 - interval from 2.00 to 1.00 meter depth to the ground water. The development of ground water level has increased about 0.67 meters from 2013 to 2016.

Zones excluded from the suitable locations for RG (Fig. 8) are paved asphalt roads and buildings, these layers were subsequently merged into a single layer - areas excluded from the analysis (Fig. 9). The roof area of the buildings was extended with a buffer

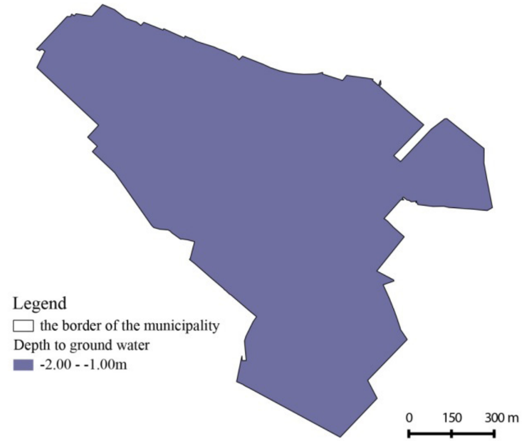

Fig. 7. Depth to ground water level

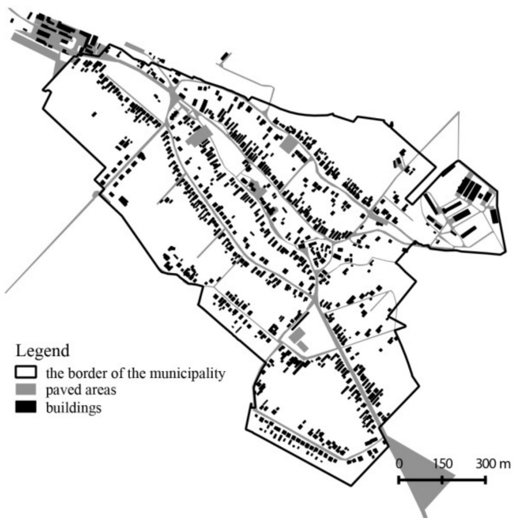

Fig. 8. Map of paved area

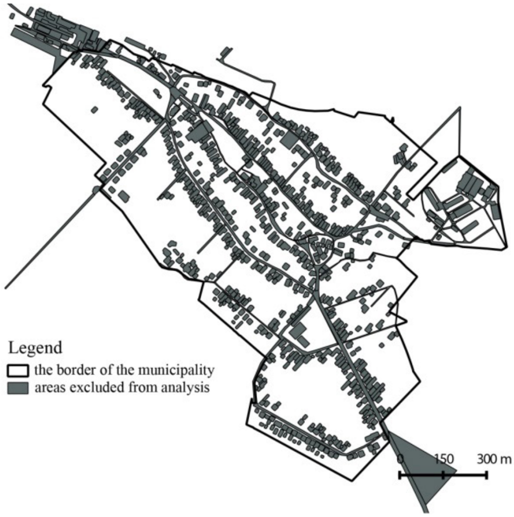

Fig. 9. Areas excluded from the analysis

distance of 3 meters, because studied manuals recommend the placement of RG at least 3 m from the buildings. It is generally considered inappropriate to install RG beyond this limit, as they could lead to waterlogging of subsoil and construction disturbances of structures of buildings.

The result of this study consists of raster map (Fig. 10), which shows division of area to three categories in respect to their suitability to RG placement. Green areas with value 1 represent the most suitable zones, red areas with value 3 the less suitable.

Fig. 10. Map of the categories of suitability for RG design within the boundaries of the village Žirany

Raster map of suitability for RG placement was reclasificated to contain only the integer-datatype values of categories of suitability to RG placement (Table 5).

Table 5. Reclassification rules for suitability to RG placement calculation

Original value	Categories of suitability	Description of category
0–1	1	Best locations in study area
1.001–2	2	Average locations in study area
2.001–3	3	Worst locations in study area

Reclassified map of categories suitability for RG placemenr was vectorizated to create a set of polygons with corresponding category of suitability. The value of polygon area was calculated for each polygon. Value of total area size of each category was calculated in MS Excel (Table 6).

Table 6. Size of areas suitable for RG placement in village Žirany

Suitability category	Category area, m^2	Category relative area	
		% of suitable area	% of cadastre area
1	9672	1.79	0.86
2	299195	55.36	26.63
3	231566	42.85	20.61
Area suitable for RG placement (sum of all categories)		540 433	
Cadastre area		1 123 535	

DISCCUSION

Based on the present methodology and implemented process of analysis, it can be summarized than the application of described procedure in conditions of municipalities can help to identify suitable locations for RG placement.

In the surveyed area of village Žirany, there were identified the values of suitability for the RG placement. Category „1" covers approx. 9 700 m^2 (1.79% of suitable area; 0.86% of cadastre area), category „2" covers approx. 299 200 m^2 (55.36 % of suitable area; 26.63% of cadastre area) and category „3" covers approx. 231 600 m^2 (42.85% of suitable area; 20.61% of cadastre area).

Slope is the most limiting factor for the RG placement in Žirany. Predominantly, there are locations with high slope which excesses 8 % value. This fact eliminates 583 102 m^2 of possible cadastral RG placement zones.

Area of the category „1" is very small in comparison to other categories – this is the result of slopes conditions in the cadastre as the best slope conditions (2–4.9%) cover northwest and southeast parts of village, but ownership and land use in that parts do not fulfil the optimal criterions (municipality ownership and public greenery). Parts of land in this category are fragmented in the cadastre area of the village, which allows the construction of more RG in the cadastre. The position of these fragmented fields can be staked in the field and offered for constructing of RG for the citizens or municipality in exact position.

Total area of category „2" covers the largest part of suitable area and approx. 27% of cadastre area. This is mainly the result of the overlaps of the areas of suitable slopes and private greenery in the area. Parts of land in this category are forming larger connected areas in southeast and northwest parts of the village. These areas can be used for construction of the RG without special tasks such as staking as those areas are quite large and the land owners can easily identify their property (and possible RG placement) directly from the map.

Total area of category „3" covers the large part of suitable area and approx. 21% of cadastre area. This is mainly the result of the terrain morphology with larger slopes. This part covers the middle part of the village. This part is least suitable for the placement of the RG and it is clearly visible and easy for identification for land owners to find their property that lies in this area. Upper part of this area (middle northern part of village) also contains the small areas in the category "1" forming islands of suitable placement of RG. It can help the municipality to communicate this information to the land owners of the category "3" to create the RG within the category "3" area with possible transfer of water to these locations with better properties for RG construction.

Specific value of the parameters and its suitability must be supported with further research in order to create more detailed categorization of suitability. The given fact is related to verification of individual methodologies McCormack [2015] and Marney [2012] in the field. To improve the quality of the research it is appropriate to apply a specific field measurements in selected localities focused mainly on soil conditions.

This study forms preliminary area assessment which can be used in consequent decision-making process of stormwater management. It determines potential locations of suitable placement for RG, which should be afterwards surveyed (hydro-pedological survey) to distinguish the most optimal placement.

However, areas with value 2 and 3 can be conditionally included in creation process of RG. Private owners can easily identify their properties and decide about the usage of RG as stormwater management practice next to other solutions (stormwater sewers, artificial local infiltration).

CONCLUSION

This paper is focused to propose a solution of storm water management in public spaces of smaller settlement of the Nitra region - the village Žirany with use of RG. Solution aims to establish methodology for identification of the suitable locations for RG creation after analysing the conditions of each locality – slope, soils type, ownership, land use and ground water level. The methodology sets the values of necessary parameters for evaluation of suitability of the areas, the weight value, and impact on the overall suitability of the sites.

ACKNOWLEDGEMENT

This study was supported with the following grants and projects:

- APVV-15-0562: Effective irrigation management as a device of changing climate
- APVV-16-0278: Use of hydromelioration structures for mitigation of the negative extreme hydrological phenomena effects and their impacts on the quality of water bodies in agricultural landscapes

REFERENCES

Bedla, D., Misztal, A. (2014). Zmienność chemizmu wód małych zbiorników wodnych o zróżnicowanej strukturze użytkowania terenów przyległych. Rocz. Ochrona Środowiska, 16, 431–439.

Díaz Iglesias, M.I. (2013). Jardines de lluvia, Spain. Universidade de Santiago Compostela, Santiago de Compostela

Halaj, P., Bárek, V., Igaz, D., Horák, J., Čimo, J., Jurík, Ľ., Báreková, A., Halajová, D. (2012). Impact of catchment land use on hydromorphological status of streams in rural areas. J. Earth Science & Climate Change, 3(3), 73.

Jurík, Ľ., Kaletová, T., Halászová, K., Bako, A., Ochmanová, L. (2013). Soil water content evaluation and modelling in small catchment with agricultural use. Acta Sci. Pol., Formatio Circumiectus, 12(3), 53–62.

Linkeš et al. (1996). Guide for Valuated Soil – Ecological Units. Výskumný ústav pôdnej úrodnosti, Bratislava.

Marney, R. (2012). Creation of a GIS Based Model for Determining the Suitability of Implementing Green Infrastructure. University of Nebraska, Lincoln.

McCormack, K. (2015). Identifying Potential Rain Garden Sites, Texas GIS Forum, https://tnris.org/spotlights/2015-11-09/identifying-potential-rain-garden-sites/.

Novotny, V., Olem, H. (1994). Water Quality: Prevention, Identification, and Management of Diffuse Pollution. Van Nostrand Reinhold, New York,

Policht-Latawiec, A., Żarnowiec, W., Majewska, M. (2015). The analysis of variability in water quality in the Biala Tarnowska river. Ecolog. Engineer., 44, 217–226

Rokus, D.D. (2005). GIS Analysis of Potential Storm Water Infiltration and Runoff Modeling for BMP Construction in Hadley Valley Watershed. Rochester, Minnesota.

Stiffler, L. (2013). Are Rain Gardens Mini Toxic Cleanup Sites? Partnership for Water Sustainability, 1–7, http://waterbucket.ca/wscblog/files/2013/02/Lisa-Stiffler_Are-Rain-Gardens-Cleanup-Sites_Jan2013.pdf

Tárník, A., Igaz. D. (2015). Quantification of soil water storage available to plants in the Nitra river basin. Acta Sci. Pol., Formatio Circumiectus, 14(2), 209–216.

Żarnowiec, W., Policht-Latawiec, A., Ostrowski, K. (2016). Assessment of the possibility of estimating water evaporation from the roof surfaces on the basis of selected empirical formulas. Acta Sci. Pol., Formatio Circumiectus, 15(4), 17–28.

Zarzycki, J., Misztal, A., Bedla, D. (2015). Efficiency of utilization of water for evapotranspiration of mountain grasslands. Infrastr. Ekol. Ter. Wiej., 4(3), 1275–1283.

OGRODY DESZCZOWE – STUDIUM PRZYPADKU IDENTYFIKACJA POTENCJLANEJ LOKALIZACJI Z WYKORZYSTANIEM TECHNIK GIS

Streszczenie. Ogrody desczowe są jednym ze sposobów uzdatniania wód deszczowych na terenach osadniczych, gdzie poza aspektem ekologicznym spełniają także funkcję estetyczną w przestrzeni publicznych. Ich koncepcja i propozycja lokalizacji uwzględniają kilka zasada dotyczących warunków naturalnych i parametrów terenu. Celem pracy było opracowanie metodologii określania potencjalnych lokalizacji ogrodów deszczowych, na przykładzie wybranej lokalizacji – osada Žirany, obwód Nitra. Wybór możliwych lokalizacji opierał się na określeniu: właściwości gleby, nachylenia terenu, użytkowania gruntów, ustaleniu własności oraz zaleganiu wód gruntowych na danym obszarze, a dane te przetworzono w programie QGIS. Opracowanie opiera się na istniejących analizach pochodzących z ostatnich lat. Wynikiem zastosowanej metodologii jest mapa rastrowa, w której opisano przydatność miejsc do budowy instalacji deszczowych w wybranej miejscowości, na podstawie analizy przestrzennej z wykorzystaniem nakładania wartości rastrowej wspomnianych wcześniej atrybutów. Obszar pól z najlepszymi warunkami lokalizacji ogrodów deszczowych wynosi ok. 9700 m^2 (co stanowi 0,86% powierzchni katastralnej badanej wsi Žirany).

Słowa kluczowe: ogród deszczowy, gospodarka wodna, woda deszczowa, analiza GIS

Accepted for print – Zaakceptowano do druku:1.09.2017.

For citation: Vaculová, V., Fuska, J. (2017). Rain gardens – case study of potential locations identification using GIS**.** Acta Sci. Pol., Formatio Circumiectus, 16(3), 217–230.