LAND USE CHANGE AND ITS IMPACT ON SURFACE RUNOFF FROM SMALL BASINS: A CASE OF RADIŠA BASIN

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Abstract
Land use changes in a basin frequently result in an increased surface runoff, which may induce the occurrence of floods or soil erosion. The paper thus aims to estimate and assess the change in surface runoff characteristics based on the analysis of land use change (between the years 1949 and 2017). The research area is represented by the small basin of Radiša watercourse (Western Slovakia). In order to estimate surface runoff, the SCS-CN method, modeling in geographic information systems (GIS) and recorded rainfall data were used. The land use was identified based on aerial imagery (orthophotos) from 1949 and 2017 showing quite significant changes. Arable land decreased the most by more than half (by 15.62%) while the share of forests increased by 4.55%, glades by 3.45% and built-up areas by 3.05%. As for the results of the SCS-CN method, the highest interval of surface runoff depth (27.1-64.4 mm) increased only slightly from 7.27% (in 1949) to 7.57% (in 2017). On the other hand, the lowest values of runoff depth (2.3-3 mm interval) covered most of the basin area in both years (60.65% in 1949 and 64.94% in 2017). The share of high runoff volume values (intervals 20.1-50 m^3 and 50.1< m^3) on the basin area decreased during the years 1949 and 2017 by 1.95% and by 1.05%, respectively. Based on the results, it can be concluded that the risk of surface runoff in the research area decreased over the studied period.

Key words
Land use, surface runoff, SCS-CN method, GIS, small basin, Slovakia

INTRODUCTION

Land use can be defined as the way in which the land has been used by humans usually with an emphasis on the functional role of land for economic activities. The land use pattern of a particular region is thus an outcome of natural and socio-economic factors and their utilization by man in time and space (Lambin et al. 2001; Vojtek, 2018).

In recent decades, there have been intensifying anthropogenic impacts on landscape causing the changes in land use due to various agricultural, forestry, water management, industrial, tourism activities and the like. (Ivanová et al. 2013, Boltižiar et al. 2016, Izakovičová et al. 2017, Munteanu et al. 2017, Lieskovský et al.

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2018). As a consequence, these human activities are subsequently responsible for the increased risk of soil erosion, disrupted hydrologic regime of the landscape or changes in biodiversity.

In a basin, land use changes influence the surface runoff (Chen et al. 2009), occurrence of flood situations (Solín et al. 2011, Jakubcová et al. 2016) or groundwater recharge (Ashraf et al. 2007), transfer of pollutants (Torma et al. 2019) and the like. In this respect, the analysis and assessment of land use and its change is inevitable for planning and management of water resources in a basin (Petrovič et al. 2017).

The technological advances in the field of remote sensing have enabled that land use changes can be studied in more detail referring to better accuracy and resolution of aerial/satellite images (Singh, 1989, Lu et al. 2004). On the other hand, geographic information systems (GIS) are considered a suitable geospatial technology for data storage, analysis and visualization.

Land use, in particular, affects the hydrological transformation of rainfalls in a basin (Bronstert et al. 2005). Two basic groups can be defined when dealing with the influence of land use on hydrological transformation. The first group is characterized by direct impact of land use on rainfall-runoff conditions where interception and evapotranspiration are the main processes. The other group is characterized by land use as the protective factor of soils. In this respect, a substantial part of the transformation of stormwater to runoff occurs in its horizons. Moreover, changes in the vegetation structure or deforestation may induce varied basin response. On one hand, it is a short-term response of a basin (e.g. dynamics and parameters of rainfall-runoff episodes) and on the other hand, it is a long-term response, such as changes in runoff patterns (Fohrer et al. 2001; Vojtek and Vojteková, 2016).

Surface runoff is thus a significant factor which may initiate the occurrence of floods, especially pluvial floods or sheetfloods, soil erosion or other hydrological hazards (Brath et al. 2006, Langhammer and Vilímek, 2008).

The aim of the paper is to estimate and assess the change in surface runoff characteristics based on the analysis of land use change between the years 1949 and 2017. Generally, land use change is considered to have a major role in influencing the creation, progress and concentration of surface runoff. The research area is represented by a small basin of Radiša watercourse (Western Slovakia). As for the estimation of surface runoff characteristics, the SCS-CN method, recorded rainfall data and modeling in GIS were applied.

THEORETICAL FRAMEWORK

The general principle of the SCS-CN method is to link the key parameters of land use and hydrological characteristics of soils into the CN (curve numbers) that reflect the runoff loss in a basin. Curve numbers are determined in the range from 0 to 100. The CN = 100 indicates that all rainwater which falls on the basin will drain away as a surface runoff while CN = 0 means that all rainwater will infiltrate into the subsurface layers.

The SCS-CN method was first elaborated by Chow (1964) whose results were further developed and published in several methodologies and guides for runoff assessment (e.g. McCuen, 1982, Cronshey et al. 1986, Mishra and Singh, 2003).

In recent decades, a number of studies have focused on finding or reviewing the theoretical basis of this method in order to achieve its improvement (Hjelmfelt, 1991, Ponce and Hawkins, 1996, Yu, 1998, Mishra and Singh, 2003, Jun et al. 2015). In Slovakia or Czechia, this method was elaborated, for example, by Pasák et al. (1983), Antal (1996) or Janeček et al. (2002).

Furthermore, the SCS-CN method evolved beyond its original scope and it has been incorporated into many hydrological (rainfall-runoff) models as their integral part (Ali et al. 2011; Moghadasi et al. 2017; Petroselli and Grimaldi, 2018; Młyński et al. 2018). The role of GIS, which is widely used in connection with hydrological models, lies mainly in data pre-processing, parameters extraction or visualization of the model outputs (Mishra and Singh, 2004, Soulis and Dercas, 2007).

Due to the fact that hydrologic response of a basin is driven by the interaction of rainfall (i.e. triggering factor) with physical (terrain) pre-conditions i.e. elevation, land use and soil properties, it is more convenient for the surface runoff estimation process to be carried out using solely GIS tools. The CN-based runoff estimation technique can thus benefit from the main advantages of GIS to store, analyze, interpret and visualize data (Patil et al. 2008, Costache et al. 2014).

In scientific literature, the SCS-CN method has been widely applied across diverse regions with different land use, soil and terrain pre-conditions (e.g. Holman et al. 2003, Camorani et al. 2005, Kadam et al. 2012, Agarwal et al. 2013, Nagarajan, Basil, 2014). The findings of these studies suggest that the application of the SCS-CN method is appropriate, especially, for small basins and thus local spatial scale studies.

For instance, Gallay (2010) recommends using the SCS-CN method in small basins, as an alternative to rainfall-runoff models, for the assessment of vulnerability, capacity, integrated basin management or to create a basic idea about the rainfall-runoff conditions in a basin. Jeníček (2007) used the SCS-CN method for modeling the land cover impact on rainfall-runoff processes in the basin of Blatnica. Results of this study confirmed the assumption that the impact of land cover on runoff conditions in a basin decreases with increasing extremity of input rainfall. Soulis et al. (2009) used this method in two experimental heterogeneous basins of Little River (USA) and Lykorrema (Greece) using the two-CN system approach. Their results suggest that the determination of CN values using the two-CN system approach provides acceptable results and expands the capabilities of the classic SCS-CN method in heterogeneous basins.

In addition, the SCS-CN method is often compared to the Green-Ampt method (King et al. 1999, Unucka et al. 2010). The effect of combining these two methods, referred to as Curve Number for Green-Ampt (CN4GA), was described by Grimaldi et al. (2013).

Based on the aforementioned studies, the application of the SCS-CN method in small basins is relevant and plays an important role in computation and modeling of surface runoff characteristics.

RESEARCH AREA

The research area is represented by a small basin of the Radiša stream (Fig. 1). The Radiša stream has a length of 24.2 km and it creates a left tributary of the Bebrava River. The basin has an area of 110.33 km^2.

The reason for choosing this research area is that it has been subjected to several floods (e.g. flash floods from June 2013 and July 2014) as well as the research area is characterized in the updated preliminary flood risk assessment as having an existing and potential flood risk (Ministry of Environment of the Slovak Republic, 2018).

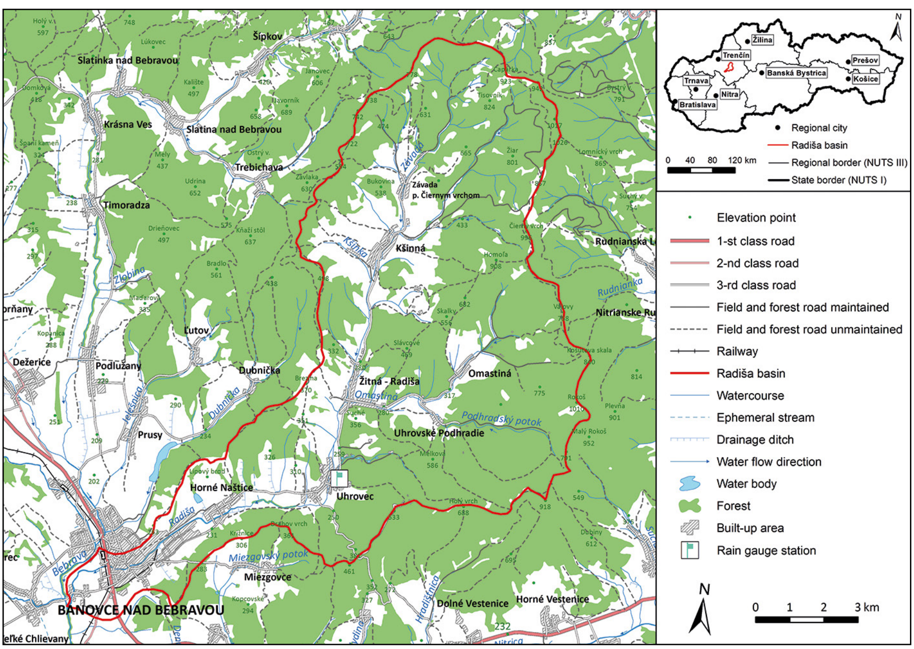

Figure 1

Location of the research area in Slovakia

Source: SVM50 - Geodetic and Cartographic Institute Bratislava

The research area is defined by the following geographical coordinates: 48°51'N and 48°42'N latitude, 18°14'E and 18°26'E longitude.

According to the geomorphological division of Slovakia (Mazúr and Lukniš, 1986), the research area is classified into two geomorphological units: Strážovské vrchy (mountain), which covers most of the basin area, and Podunajská pahorkatina (hills). Suchý vrch (peak) is the highest point in the basin with an altitude of 1027 m a.s.l. It is located in the northeastern part of the basin. The confluence of Radiša stream and Bebrava River represents the lowest point in the basin having an altitude of 190 m a.s.l.

Podunajská pahorkatina (hills) and its geomorphological sub-units Nitrianska pahorkatina (hills) and Nitrianska niva (plain) are dominated by slightly wavy relief and are formed mostly by Quaternary loess, fluvial and deluvial sediments (Pristaš et al. 2000). The geological bedrock of the Strážovské vrchy (mountain) is formed by Paleozoic migmatites, gneiss, paragneiss and granites and Mesozoic rocks such as quartzite, limestone and dolomite (Maheľ et al. 1981).

The research area lies in temperate climate zone and average annual rainfall are approximately 700-800 mm/year.

The Radiša basin is included in the following administrative units: Western Slovakia (NUTS II), Trenčín Region (NUTS III) and Bánovce nad Bebravou District (NUTS IV). Altogether, six municipalities are located in the research area: Kšinná, Žitná-Radiša, Omastiná, Uhrovské Podhradie, Uhrovec, Horné Naštice and part of the town of Bánovce nad Bebravou.

Most of the population is concentrated in the Bánovce nad Bebravou town. As of December 31, 2018, the Bánovce nad Bebravou town had 18,082 inhabitants. The population of the rest of the municipalities represents 14% of the total population in the research area. The largest rural municipality is Uhrovec with 1511 inhabitants while the smallest municipality is Omastiná with 36 inhabitants (Statistical Office of the Slovak Republic, 2018).

DATA AND METHODS

In order to achieve the aim of the paper, several methods, different input data and specialized software were applied.

Digital elevation model (DEM)

As a basis for the creation of DEM, the Basic Map of the Slovak Republic at a scale of 1:10,000 with the contour interval of 2 m was used. Subsequently, Topo to Raster interpolation method in ArcGIS software was applied to create the DEM. This method is designed, especially, for creating hydrologically correct DEMs (Hutchinson, 1988). Different types of vector data can be used for the Topo to Raster interpolation method – in this case the input data was contours, elevation points, watercourses and water bodies. The spatial resolution of the DEM was set to 10x10 m. This pixel size was chosen in order that the value is between the mean and lowest value of contours distance, as suggested by Hengl (2006).

The created DEM was used to perform the calculation of flow accumulation raster using the Hydrology Tools in ArcGIS software. The flow accumulation raster then enters the computation of another surface runoff characteristics, such as depth and volume.

Soil texture and determination of hydrological soil groups

The source data for digitizing soil texture types and their representation in the research area was obtained from the map portals and WMS services of National Agricultural and Food Centre/Soil Science and Conservation Research Institute (VÚPOP) in Bratislava and National Forest Centre (NLC) in Zvolen.

According to the infiltration and drainage characteristics of soils (Chow, 1964), the soil texture types can be generally classified into four hydrological soil groups. However, only three hydrological soil groups were identified in the research area based on the map of soil texture types.

Group B – soils having moderate infiltration rates when thoroughly wetted and a moderate rate of water transmission was assigned to loamy-sand, sandy-loam and loam soil texture types. Group C – soils having low infiltration rates when thoroughly wetted and a low rate of water transmission was assigned to clay-loam soil texture type. Soils in the built-up areas were classified into the group D which is characterized by soils having very low infiltration rates when thoroughly wetter and a very low rate of water transmission.

Land use analysis and interpretation

As for the identification and interpretation of land use categories in the research area, the following aerial images (orthophotos) were used:

- Black-and-white aerial images from 1949 provided by the Topographic institute Banská Bystrica; original scale: 1:25,000; pixel size: 50 cm.
- True color orthophotos from 2017 provided by the Geodetic and Cartographic Institute (GKÚ) Bratislava and National Forest Centre (NLC) in Zvolen; original scale: 1:5,000; pixel size: 25 cm.

The digitization of land use categories was performed manually by the so-called "on screen" method in ArcGIS software at a scale of 1:2,000. The minimum mapping unit (MMU) for the identification and digitization of land use categories was set to 100 m^2. Moreover, the size and share of land use categories on the basin area was quantified.

Maximum daily rainfall estimation using statistical methods

The estimation of maximum daily rainfall with different return periods was based on the set of annual maxima of daily rainfall for 35 years (1981-2015) which were recorded at the Uhrovec rain gauge station, which is localized in Fig. 1 – geographical coordinates: 48°44′44″N latitude, 18°20′29″E longitude; elevation: 193 m a.s.l.

The empirical curve was constructed based on the recorded rainfall data. In order to calculate the estimations of maximum daily rainfall with T-year return periods, three theoretical curves were constructed: Pearson type III distribution, log-normal distribution and Gumbel distribution. As for the estimation of their parameters, two methods were applied: method of moments and method of quantiles.

Application of the SCS-CN method and computation of surface runoff characteristics

The determination of curve numbers is based on the following tasks:

- Definition of hydrological soil groups in the basin,
- Selection of soil moisture conditions expressed by the Antecedent Moisture Condition (AMC),
- Definition of hydrological characteristics of land use categories and their respective curve numbers.

According to Chow (1964), the Antecedent Moisture Condition (AMC) index is expressed as the antecedent moisture content in the soil five days prior to the beginning of the studied rainfall-runoff event. In this study, the AMC III and average conditions were selected. The reason is that only the highest 1-day rainfall in the period 1981-2015 represents 65.3 mm which is more than the defined value of 53< mm (i.e. total rain in previous five days) for the AMC III, as suggested by Chow (1964).

The curve numbers were defined by the combination of the official CN tables (Chow, 1964), map of hydrological soil groups and maps of land use categories (Table 1). Based on these inputs, the CN grid was computed with the use of the HEC-GeoHMS extension for ArcGIS software.

It is well-known that the surface runoff occurs after a certain loss which is characterized as the summation of interception, surface retention and infiltration. This loss is defined as the initial abstraction. Based on the experimental measurements, its size was estimated to 20% of the potential retention ($I_a = 0.2S$) and this value is recommended to be used when applying the SCS-CN method (Cronshey et al. 1986). Using the raster calculator tool in ArcGIS software, the potential retention capacity of the basin was calculated. The following equation was used for defining the potential retention capacity (*S*):

$$S = 25.4\left(\frac{1000}{CN} - 10\right)$$

where *CN* is the curve numbers in the research area.

Table 1 Curve numbers for different land use categories in the research area

Land use category (LUC)	Hydrological soil group		
	B	C	D
Forest	55	70	77
Glade	66	77	83
Grassland	58	71	78
Gardening area	65	76	82
Arable land	75	83	87
Watercourse and water body	100	100	100
Built-up area	74	82	86
Quarry	85	89	91
Road (maintained)	84	90	92
Railway	84	90	92

According to Cronshey et al. (1986), the surface runoff depth (*Q*) can be calculated with the use of the following equation:

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

where *S* is the potential retention of the basin and *P* is the maximum daily rainfall with the selected T-year return period. In this study, the maximum daily rainfall with 100-year return period, which was calculated applying the log-normal distribution (method of moments), was chosen and the value of 64.38 mm was used in this equation.

Contributing areas (*Ca*) in the basin is another surface runoff characteristics which was calculated. In this parameter, each cell is inserted the number of connected cells in the direction of flow above this cell and their size is calculated. To calculate contributing areas (*Ca*), the following equation was applied:

$$C_a = AR \; x \; CS \; (m^2) \; / \; 1000000$$

where *AR* is the accumulation raster, which was calculated based on the DEM, and *CS* is the selected cell size (pixel) with the value of 100 m^2 (10x10 m).

Based on the previous calculations, the surface runoff volume (*V*) was determined using this equation:

$$V = Q \, x \, C_a \, x \, 1000$$

where *Q* is the surface runoff depth and *Ca* is the contributing areas.

RESULTS

By performing the methods, the below described results were achieved.

DEM (hypsometry), soils and land use

As for the hypsometry of the research area (Fig. 2), the highest share was recorded by elevations in the interval from 300 to 400 m a.s.l. (23.85% out of the basin area) which is followed by the interval from 400 to 500 m a.s.l. (19.75% out of the basin area) and interval from 200 to 300 m a.s.l. (19.00% out of the basin area). On the other hand, the equally lowest share (1.24% out of the basin area) was recorded by the hypsometric intervals <200 m a.s.l. and 900< m a.s.l.

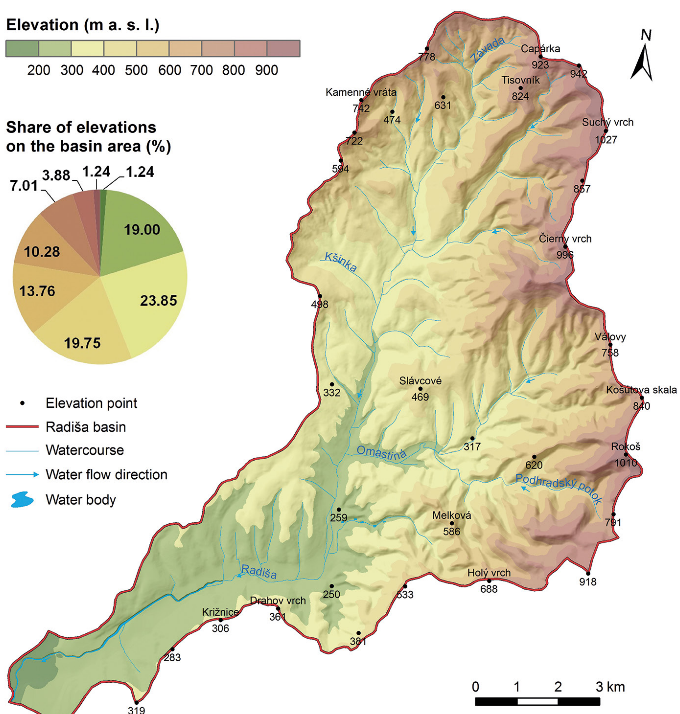

Figure 2
Hypsometry in the research area
Source: Basic Map of the Slovak Republic 1:10,000 - Geodetic and Cartographic Institute Bratislava

The resulting soil map contains four soil texture types: loamy-sand (0.11% out of the basin area), sandy-loam (43.35% out of the basin area), loam (46.14% out of the basin area) and clay-loam (5.73% out of the basin area) (Fig. 3). As for the hydrological soil groups, the highest share was recorded by the hydrological soil group B (89.24% out of the basin area). The share of the hydrological soil group C is 5.73% and the share of hydrological soil group D is 5.03% (Fig. 3).

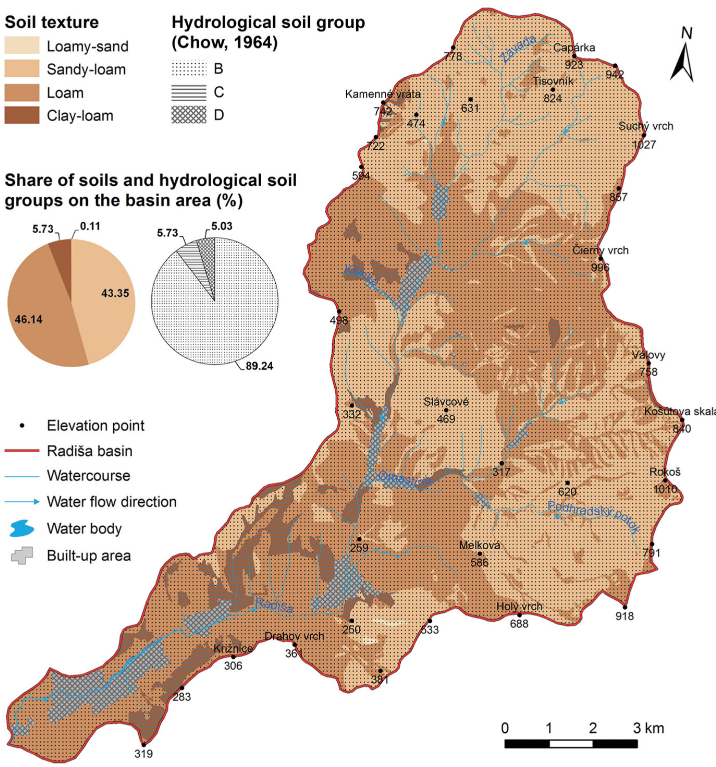

Figure 3

Soils texture types and hydrological soil groups in the research area

Source: National Agricultural and Food Centre/Soil Science and Conservation Research Institute (VÚPOP) in Bratislava; National Forest Centre (NLC) in Zvolen

The resulting land use maps contain nine (year 1949) and ten (year 2017) land use categories (Fig. 4). As can be seen in Fig. 4, arable land decreased the most by more than half (by 15.62%) during the period 1949-2017. As a result of decreased interest in soil cultivation, part of the arable land was naturally subsided by meadows and grasslands which share increased by 2.88%. The highest share in each studied year was recorded by forests, particularly, 62.98% (year 1949) and 67.53% (year 2017). Moreover, the share of forests increased by 4.55% during the studied period. The share of glades, which usually accelerate the surface runoff, increased by 3.45%. Due to urbanization, industrialization processes and population increase, the built-up areas increased by 3.05%, which is more than half compared to the year 1949. The expansion of the settlement structure initiated the construction and expansion of local and forest roads which share also increased by more than half (by 1.14%).

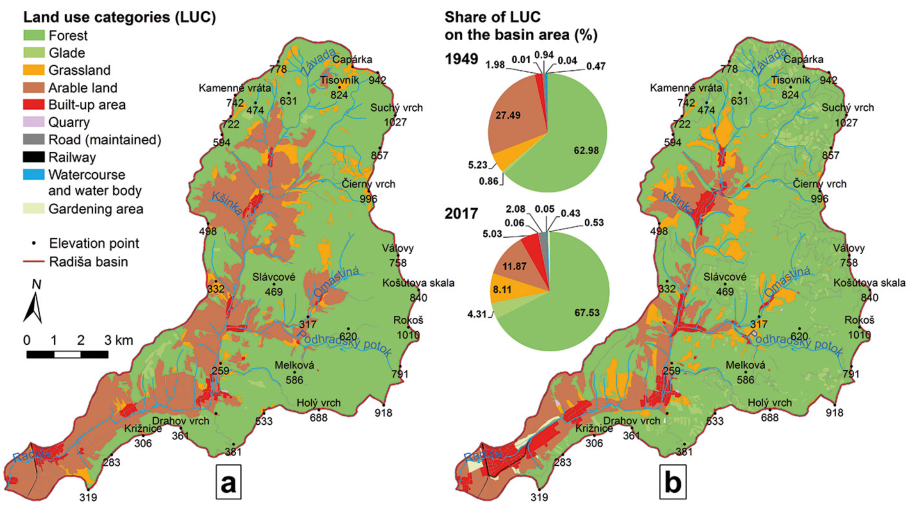

Figure 4
Land use in the research area: a - year 1949, b - year 2017
Source: Topographic institute Banská Bystrica; © GKÚ, NLC; r.2017

Maximum daily rainfall

The resulting probability values of three theoretical curves (Fig. 5) were compared with the empirical curve of probability and the optimal agreement between them was determined i.e. the most suitable theoretical distribution for the determination of T-year maximum daily rainfall from a given set of values was chosen. In this case, it is the log-normal distribution where the parameters were estimated by the method of moments. The value of maximum daily rainfall with 100-year return period for this distribution is 64.38 mm.

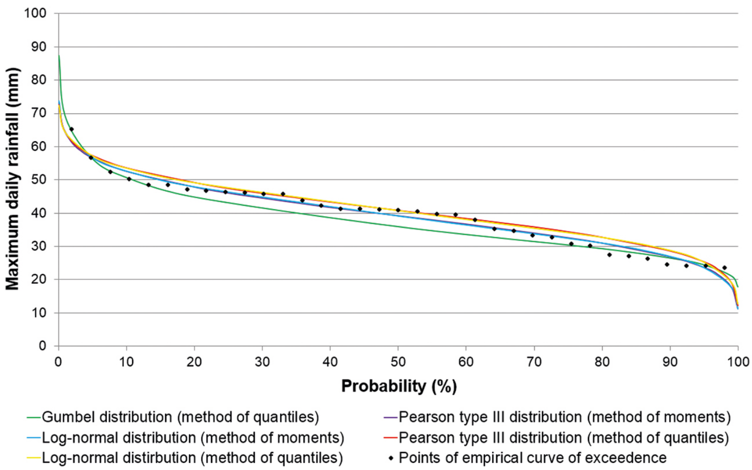

Figure 5

Empirical and theoretical curves of probability

Source: Slovak Hydrometeorological Institute in Bratislava

Curve numbers

The computed curve numbers were classified into 3 intervals based on their runoff potential (Fig. 6).

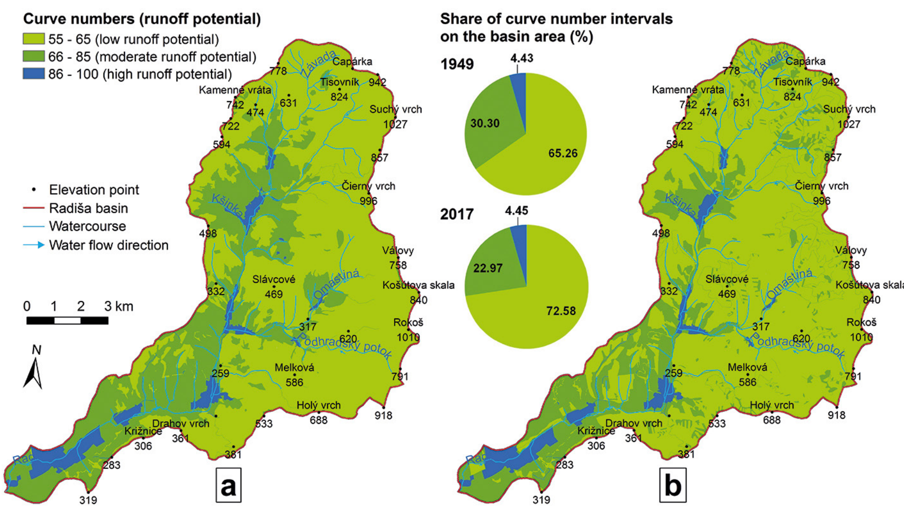

Figure 6

Curve numbers (runoff potential) in the research area: a - year 1949, b - year 2017

Source: own processing

The high runoff potential is characterized by 86-100 curve number interval which share on the basin area was almost the same in the studied years (4.43% in 1949 and 4.45% in 2017). The low runoff potential, represented by the 55-65 curve number interval, had the biggest share in both years (65.26% in 1949 and 72.58% in 2017) and this category increased by 7.32%. This can be interpreted by the increase in forest and grassland areas during the studied period and thus having better effect on water retention and infiltration. On the other hand, the 66-85 curve number interval (moderate runoff potential) recorded a decrease by 7.33% when comparing the years 1949 and 2017.

Surface runoff depth

The resulting surface runoff depth ranges from 2.3 to 64.4 mm depending on the retention capacity of different surfaces (Fig. 7).

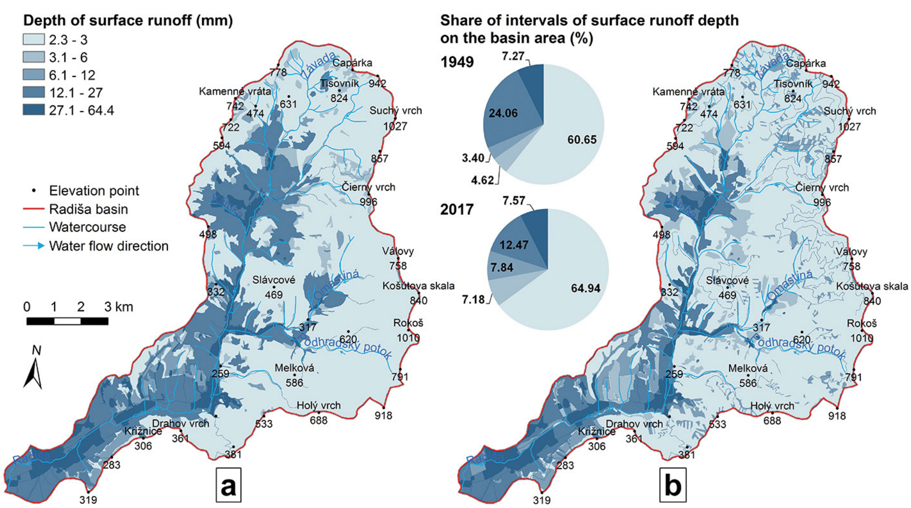

Figure 7
Surface runoff depth in the research area: a - year 1949, b - year 2017
Source: own processing

The lowest values in the 2.3-3 mm interval recorded an increase by 4.29% covering most of the basin area in both studied years (60.65% in 1949 and 64.94% in 2017). The areas with the lowest values of runoff depth more or less correspond to the forested area with high potential of water interception and having predominantly sandy-loam or loam soil texture with better infiltration rates. The most exposed to surface runoff (as well as to potential flooding) are built-up areas which is also documented by high values of runoff depth (27.1-64.4 mm interval) which share on the basin area was approximately the same in both studied years (7.27% in 1949 and 7.57% in 2017). Furthermore, the runoff depth interval of 12.1-27 mm mostly corresponds to arable land which may also have lower potential of water interception especially when being improperly cultivated. The other two intervals of runoff depth recorded and increase by 2.56% (3.1-6 mm interval) and by 4.44% (6.1-12 mm interval).

Surface runoff volume

This surface runoff characteristics provides information on runoff volume (m^3) which would be formed on the surface of each cell. The runoff volume in the resulting raster (Fig. 8) was divided into seven intervals. The highest share can be seen in the first interval of runoff volume (<1 m^3) in both years (23.69% in 1949 and 25.48% in 2017). These areas mostly correspond to the mountain ridges. Moreover, high share of runoff volume was recorded also in 2.1-5 m^3 interval in both years (23.09% in 1949 and 24.86% in 2017). On the other hand, the last two intervals of runoff volume correspond mostly to river valleys or areas with moderate or high runoff potential. Their share on the basin area decreased during the studied years by 1.95% (20.1-50 m^3 interval) and by 1.05% (50.1< m^3 interval).

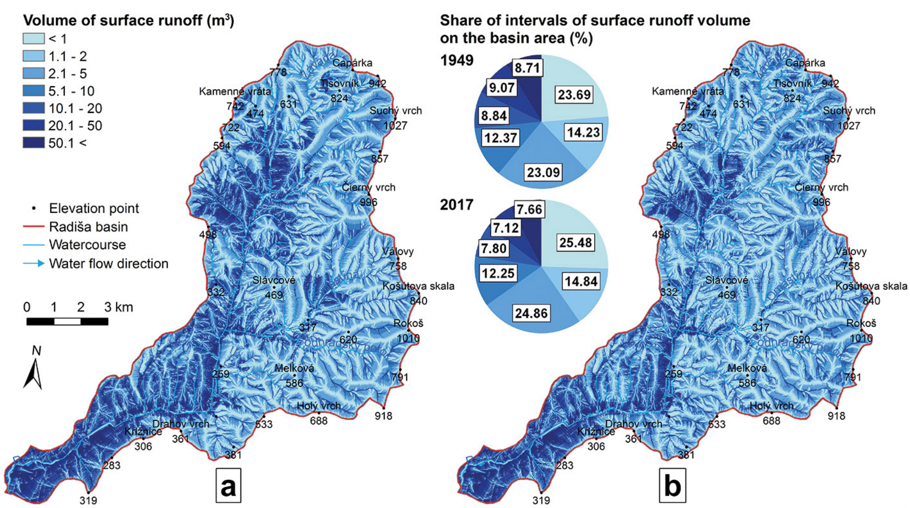

Figure 8
Surface runoff volume in the research area: a - year 1949, b - year 2017
Source: own processing

DISCUSSION

In this section, possible limitations and sources of uncertainty to the achieved results and presented methods are addressed.

The first point regards the accuracy of input data for the performed methods, which plays an essential role in achieving accurate results. In particular, it is the quality of DEM which is crucial for the process of surface runoff modeling. In case of large-scale maps (such as topographic map at a scale of 1:10,000 which was used in this study) for DEM creation, the possible source of uncertainty arises from its generalization. However, when comparing the contour-based DEM from this study and satellite-based DEMs, such as ASTER GDEM (30 m resolution) or SRTM (90 m resolution), the satellite-based DEMs have usually lower spatial resolution. For that reason, they are not so appropriate for the local spatial scale studies focused on detailed runoff modelling where higher spatial resolutions are necessary, as suggested by Šúri et al. (2003). In order to improve the accuracy of results, the best choice would be to use photogrammetrical or Light Detection and Ranging (LiDAR) data which are more accurate and provide the possibility to create high-resolution DEMs, but their acquisition is costly (Sanders 2007).

Regarding the estimation of maximum daily rainfall with T-year return periods using recorded rainfall data and statistical methods, there are several uncertainties which may affect the achieved results. One of the uncertainties may arise from the quality of observed rainfall data. The set of direct observations should be uninterrupted, homogeneous and longer than 20 years according to Makeľ et al. (2003), which was fulfilled in this study. However, Solín and Martinčáková (2007) suggest that a reliable estimation of maximum daily rainfall with 100-year return period for a rain gauge station would require 500-year long observation data. Obviously, none of the rain gauge stations in Slovakia meets this condition. For that reason, the use of statistical methods is inevitable. However, this brings the statistical uncertainty which is connected, for example, with the choice of theoretical curve of probability, method for parameters estimation or deviations resulting from the length of observation data. For that reason, as suggested by Mitková et al. (2004), several types of theoretical distributions and methods for parameters estimation should be used in order to choose the theoretical curve which best balances the empirical values.

With regard to the SCS-CN method for estimating surface runoff, the obtained curve numbers vary with different land use categories. Therefore, land use plays an essential role in affecting and determining the runoff depth/volume in a particular basin. In this respect, the limitation can be seen in the use of manual (sort of simple and subjective) interpretation of land use categories in GIS based on aerial images from the studied years. However, due to aerial images having different original scale, pixel resolution and color, it was not possible to use more sophisticated and less time consuming land use mapping and classification techniques, such as object-based or pixel-based methods (Lechner et al. 2012). Moreover, it was more difficult to manually interpret the land use categories from the 1949 aerial image than from the newer 2017 orthophoto. The reason is that the older aerial image has lower resolution and worse scale (1:25,000) because it was taken from higher altitude and in black-and-white color.

The results achieved in this study support the findings of Dang and Kumar (2017) who also concluded that higher the curve numbers, the higher the runoff i.e. the increase in impervious areas leads to growing runoff depth and volume which may potentially induce flood situations. In addition, the results suggest that attention should be focused, especially, on the protection of built-up areas where high values of runoff depth and volume occur. This was also confirmed by Petroselli et al. (2019) who studied the impact of different hydrologic and hydraulic approaches on flood mapping for the Uhrovec cross section.

The last comment questions the use of more advanced hydrological (rainfall-runoff) models (such as MIKE-SHE) instead of using solely GIS tools for surface runoff modeling. In this regard, it has to be stated that each hydrological model has certain uncertainties and limitations, either in data input or calibration techniques, which was also stressed, for example, by Moretti and Montanari (2008). Moreover, hydrological models are usually more demanding for data input or computational time as well as some of them are less affordable. On the other hand, we tried to justify rather straightforward and less demanding methods for surface runoff estimation, which are based on GIS and remote sensing data.

CONCLUSIONS

The research area was represented by a small basin where the runoff is affected, especially, by the way the land is used. The change in land use during the studied period of 68 years is evident in the share of land use categories. The share of arable land recorded the most significant decrease (by 15.62%). On the other hand, the share of forests increased by 4.55%, glades by 3.45% and built-up areas by 3.05%. This mostly positive land use change in terms of surface runoff, such as increase in forest areas and decrease in arable land, from 1949 to 2017 influenced the results of modeling which point to the fact that the risk of surface runoff decreased in the research area, as evidenced also by the comparison of runoff depth and volume between the studied years.

The SCS-CN method, which was applied in GIS environment, proved its efficiency since the computation and spatial modeling of runoff characteristics revealed vulnerable areas where the exposure to floods or soil erosion is enhanced by high surface runoff depth and volume. These areas also correspond to the areas with an existing and potential flood risk defined in the updated preliminary flood risk assessment (Ministry of Environment of the Slovak Republic, 2018). The results of this study can be useful especially for integrated river basin (flood risk) management and planning. Moreover, the presented runoff maps are considered suitable input variables for assessing flood potential (susceptibility) in the basin and our future research will be directed also towards this issue. Overall, an attempt was made in this study to contribute to the issue of surface runoff estimation and assessment using rather straightforward GIS-based methods which could be simply used and verified in other similar small basins.

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