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The Determination of the Maximum Runoff in the Representative and Experimental Hydrographical Basin of Sebes River (Banat, Romania)

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1. Introduction

The Romanian natural and climatic factors, together with the irrational human activities (massive deforestation, lack of hygiene in the forest exploitation areas etc.) lead to the creation of potential torrential conditions, disturbances in the hydrological regime of most watercourses, leading in most of the times to considerable damage.

The runoff represents the movement of water across the earth's surface owing to the force of gravity and which are influenced many geographic factors (Maftei et al. 2015).

Many methods to estimate runoff exist (Haan et al. 1982, Chow et al. 1988). Runoff volume or rate estimation involves estimating the amount of rainfall exceeding infiltration and initial abstractions, which must be satisfied before the occurrence of runoff. Infiltration excess runoff can be estimated using different techniques.

The Rational Formula estimates the peak runoff rate using remotely-sensed land use data and soils information to determine a runoff coefficient. The coefficient gives the percent of rainfall converted into runoff (Beven 2012).

In the hydrologic analysis for a drainage structure, many important, variable factors affect floods. The primary factors to be considered on a site-by-site basis include: precipitation type, amount, duration, intensity, frequency and distribution; basin size and physiographic characteristics; soil type; vegetative cover; previous moisture condition; surface storage potential; and basin development potential (Virginia Department of Transportation 2002).

Studies focus on measures which increase water yield or enhance temporal water storage in small catchments are scarce. For this reason, it's important to consider the studies on larger scales of one similar hydrographical basin.

These measures have to be adapted to the conditions in small catchments and evaluated with regard to the aim of controlling maximum runoff. The measures, which must be taken, are varied and can take into account the following technical aspects: the effective volume, the time scale, the controllability and conflict potential.

Thus it's necessary to create an evaluation matrix which can be used to help draw up water resources management plans. Since actual concepts that integrate high discharges protection are inadequate, modelling tools and decision support systems that offer measures to control the maximum runoff need to be developed and refined.

The experimental and representative hydrological basin of Sebeş River, a tributary of Timiş River, is located in the south-west part of Romania, is part of European Network of Experimental and Representative Basins (ERB) and has a small surface (124 km^2) (Fig. 1).

The role of the experimental hydrographical basins is to know the process of runoff formation in a small hydrological basin (surface < 150 km^2) (Teodorescu 2003).

The flood formation in this hydrological basin is mainly linked to the climatic conditions to which other factors are added, such as: the geology, the soil through its temperature and humidity, the vegetation, the topography through the slope beds and the slopes, the shape and the surface of the hydrological basins, which influence formation time and water volume.

In order to determine the maximum flow in small hydrographical basins, such as the hydrographical basin of Sebeș River is, an important parameter is the runoff coefficient determined using the ARCGIS software, based on the Frevert tables, knowing the altitude, the slope, the land use cover, the soil texture and the rainfall intensity.

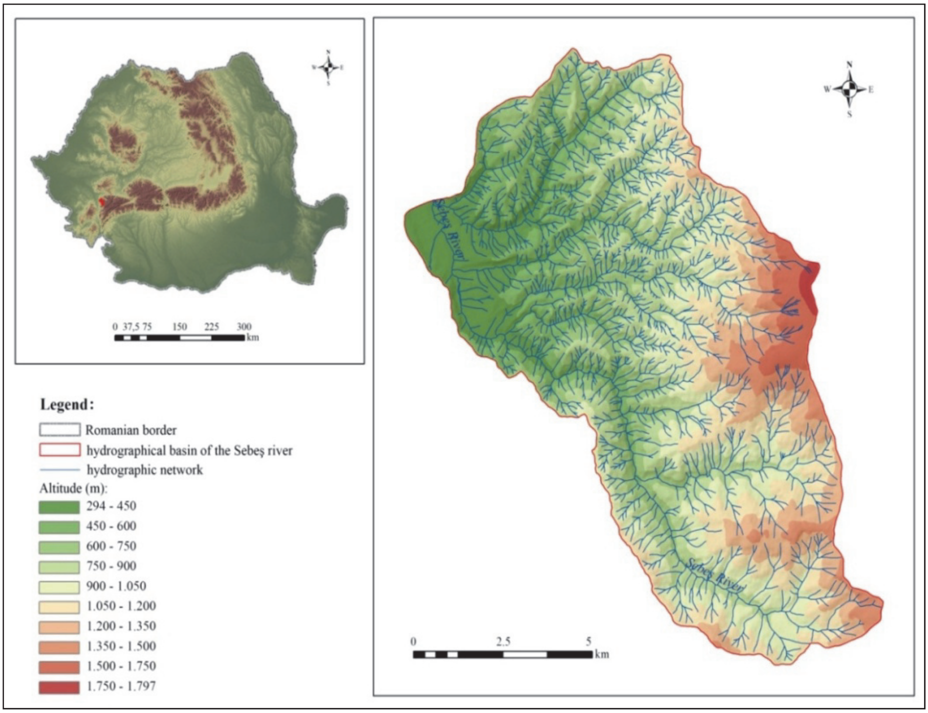

Fig. 1. The representative hydrographical basin of Sebeş River – localization within Romania
Rys. 1. Prezentacja hydrograficzna dorzecza rzeki Sebes – położenie w Rumunii

The runoff regime represents the variation of water flow over time, during several months, seasons, years or decades. This varies according to the determining and conditioning factors of the runoff, such as the atmospheric precipitations, the air temperature and humidity, the flash floods, the morphological and geological structure of the hydrographical basin, the soil structure, the land use cover etc. (Arba 2016).

2. Materials and methods

For the recorded flood in the Sebeş hydrological basin, which occurred during 9-13 January 2015, we used relevant climate data from two meteorological stations (Ţarcu and Cuntu) and two rainfall stations (Borlova and Turnu Ruieni) within the basin.

This analysis required the building of a database with inputs required by the model which we built, both with information on the hydrological basin, found on the cartographic materials, such as: topographic and pedological maps, following the digital elevation model and the satellite images, regarding the land use cover and with climate data strings on heavy rains during 9-13 January 2015 (Table 1).

Table 1. Data sources and types used for the study
Tabela 1. Źródła i rodzaje danych użytych w badaniach

No.	Data source	Type	Attributes	Variable code
1	Land use cover	shp	Yes	*Crops*
2	Soils	shp	yes	*Heavy_texture* *Medium_texture* *Light_texture*
3	Soils	grid	yes	–
4	DEM (digital elevation model)	grid	yes	–
5	Rain intensity	grid	Yes	–
6	Hydrographical basin limit	shp	–	–

Because the runoff is routed through the basin along flow paths itself determined by the topography, this study uses the digital elevation model (DEM) both for viewing the altitude variation in the Sebeş hydrological basin, and for the hydrological analysis of the studied area.

The raster structure of this elevation model is usually used to derive topographic data for distributed hydrological models. So on the basis of the DEM, we determined the water flow direction and accumulation in order to delimit the hydrological basin analysed (Musa et al. 2015).

In order to calculate the maximum flow in small hydrological basins such as Sebeş hydrological basin we used one rational method, which is based on the runoff coefficient.

This method is an empirical relationship between the intensity of the rain and the maximum flow, proper for the estimation of the maximum flow in small hydrological basins with a surface of approximately 200 acres, where there are no important accumulations of water, and is calculated using the following relationship:

The rational method is often used, which is based on the runoff coefficient, to determine the maximum flow in small hydrological basins.

$$Q = k \cdot C \cdot F \cdot I \quad (1)$$

where:
Q – peak surface runoff in m^3/s,
k – conversion coefficient in the metric system 16,67,
C – runoff coefficient,
F – total surface of the hydrographical basin in km^2,
I – intensity of the rainfall in mm/min.

The leakage coefficient (C) from the first relation is determined as weighted average based on the specific leakage coefficients corresponding to the elementary surfaces from the representative and experimental hydrographical basin of Sebeș River with different types of land use:

$$C = \sum(c_i \cdot f_i)/F \quad (2)$$

where:
C – leakage coefficient,
c_i – specific coefficient,
f_i – elementary surface [km^2],
F – total surface of the hydrographical basin [km^2].

The runoff coefficient may have a value between 0 and 1; the zero value indicates that no rain fallen on the surface of the hydrological basin does not generate the maximum water flow, and the value of 1 indicates that all of the rain falling in the basin generates a maximum flow.

The rational method uses the rain intensity to render the average intensity of a rainfall with a specific frequency for a selected duration (Viessman et al. 1977).

Rainfall intensity is selected from an IDF curve (intensity – duration – frequency) generated from rainfall data collected in the local area (Fig. 2).

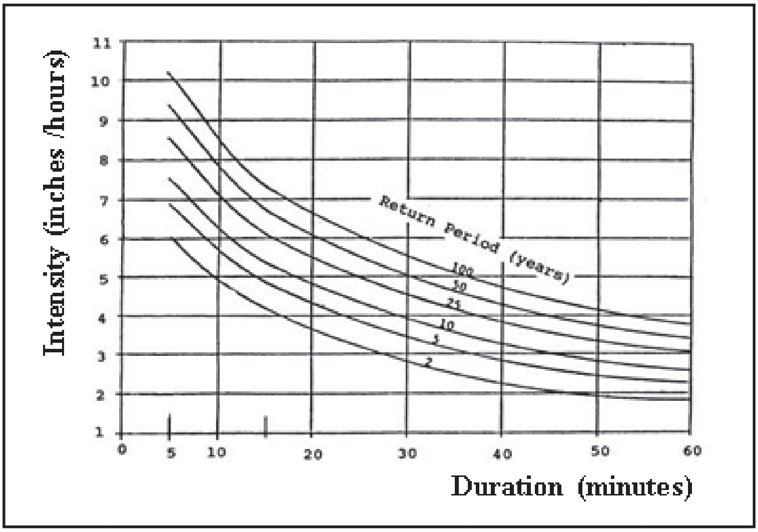

Fig. 2. Intensity – Duration - Frequency curve (Viessman et al. 1977)
Rys. 2. Krzywa Intensywność – Czas trwania – Częstoliwość
(Viessman et al. 1977)

To determine the maximum flow in Sebeş representative hydrographical basin, we used the multi-criteria overlay spatial analyses offered by ArcGIS, one implementation model in the rational formula according to Bilaşco, 2008.

According to this rational method, an important hydrological parameter in assessing the maximum flow of water in the basin is the runoff coefficient as rainfall-runoff integrator.

In order to compute the average runoff coefficient we used his function, which integrates the altitude, the slope, the land use, cover, the soil type (texture) and the rainfall intensity (Maftei et al. 2016) (Fig. 3).

The major factors affecting the rational method runoff coefficient value for a watershed are the land use, the soil type and the slope of the watershed. The physical interpretation of the runoff coefficient for a watershed is the fraction of rainfall on that watershed that becomes storm water runoff; the runoff coefficient must have a value between zero and one.

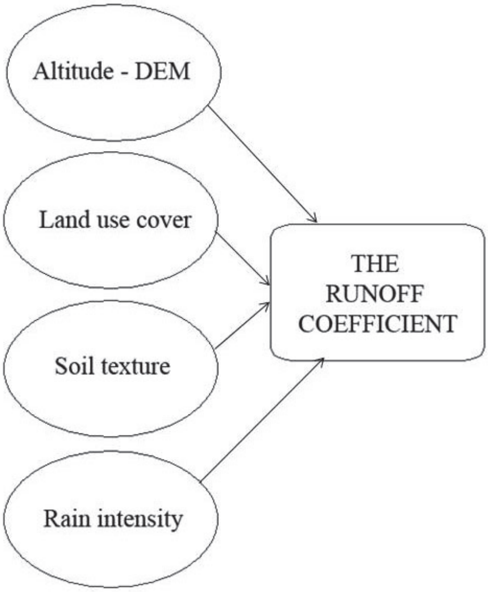

Fig. 3. The field-based spatial model used to calculate the runoff coefficient
Rys. 3. Przestrzenny model terenowy stosowany do obliczenia współczynnika odpływu

3. Results and discussion

The size of a hydrological basin, its form, and the morphometric features of the relief elements, have a particularly important role in producing hydrological phenomena, changing their variability in space and time.

The rational method lacks a physical loss model, yet initial abstraction exists and increases with watershed size (Asquith & Roussel 2007).

In the case of a hydrological basin reduced in size, such as Sebeş hydrological basin, the runoff trend closely follows the rainfall, the rain being felt immediately in the increase of the amount of water carried by that river, and a relatively short period of drought results in their depletion (Arba 2016).

The determination of the runoff in Sebeş hydrological basin, using ArcGIS software, could be performed by quantifying the computational elements (the delimitation of the hydrographical basin, the hydrographical river, the hypsometry, the slope etc.) (Fig. 4-5).

Fig. 4. Sebeș catchment – hydrographical network
Rys. 4. Zlewnia Sebeș – sieć hydrograficzna

The average altitude of a hydrographical basin has a great influence on the runoff. The hydrological basins located at high altitudes benefit from an increased amount of precipitation and a lower evaporation than the hydrological basins located at lower altitudes, therefore a hydrological basin located at high altitudes has a richer runoff than the one located at lower altitudes (Teodorescu 2003).

Another important element in the analysis of the runoff in Sebeş hydrographical basin is the slope influencing the water flow, both in terms of speed and in terms of the accumulation time. The slope leads to a lower or higher speed of the water movement on its slopes and a weaker or a heavier erosion and transport of solid particles on slopes.

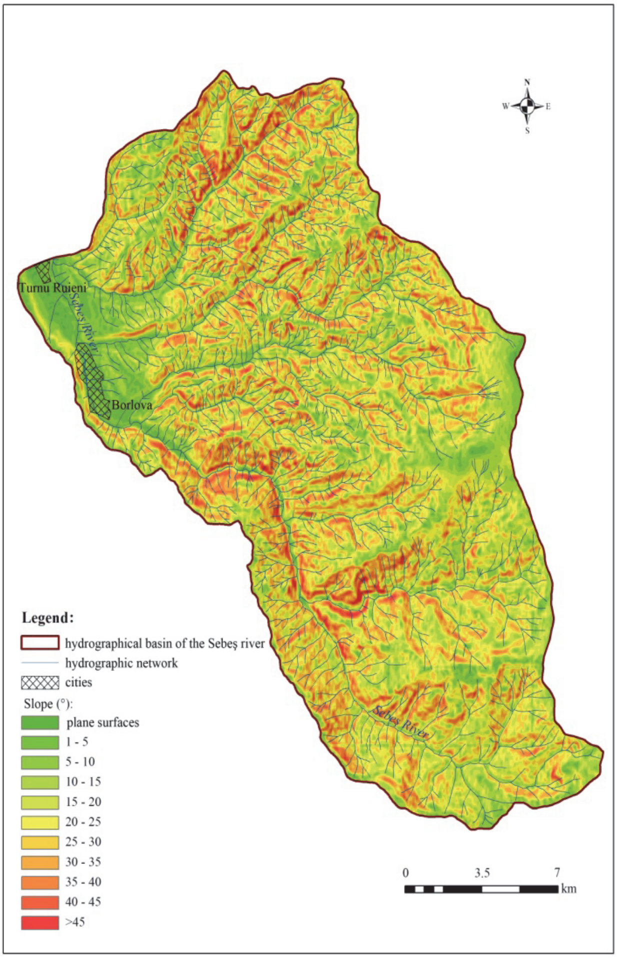

Fig. 5. Sebeş catchment – slope map
Rys. 5. Zlewnia Sebeș – mapa spadków

The physical and geographical features have a significant impact on the runoff, and cannot be neglected in the determination and the evaluation of the liquid flow. It is known that the surfaces of a hydrographical basin covered with forests contribute to the adjustment of the maximum flow, the reduction of precipitations on the ground etc. (Fig. 6-7).

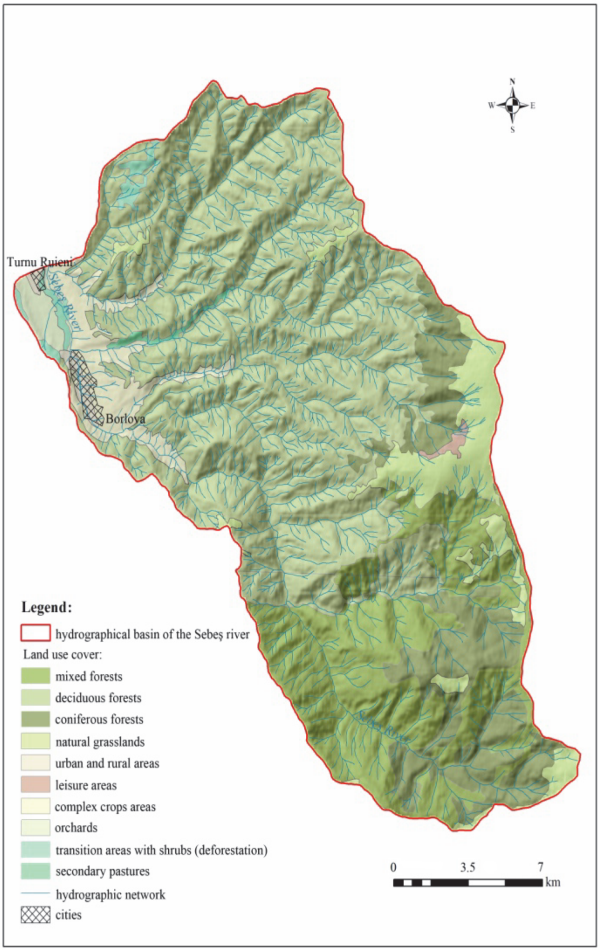

Fig. 6. Sebeş catchment – the land use cover
Rys. 6. Zlewnia Sebeş – zagospodarowanie terenu

The vegetation has a very important role in the formation of the runoff on Sebeş hydrographical basin, one the one hand, because it influences the formation of soil types, and, on the other hand, because it determines the size of water infiltration possibilities, the reduction of evaporation and the reduction of soil erosion.

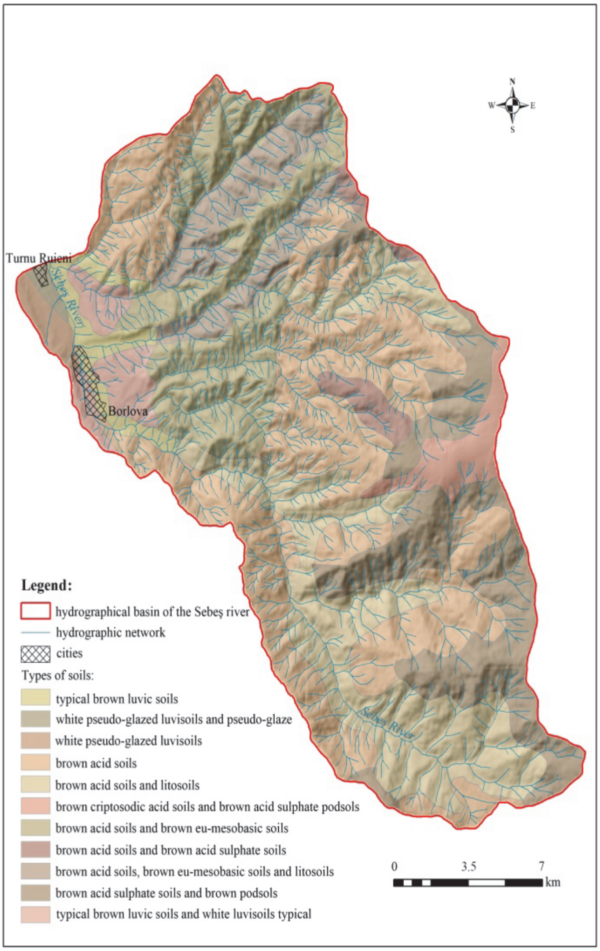

Fig. 7. Sebeş catchment – the soils type
Rys. 7. Zlewania Sebeş – rodzaje gleb

The influence of the vegetation on the runoff regime in the hydrological basin of Sebeş River occurs differently, according to the phyto-sociological groups and their extension.

The water coming from the precipitations is easily infiltrated in large quantities on the soil covered with vegetation, on extended basin surfaces, than on soils lacking vegetation, due to the fact that the vegetation-covered soil is loose and more structured, and the evaporation of the water from the soil is reduced.

For the hydrographical basin of Sebeş River, the runoff coefficient was determined based on the Frevert tables, integrating all the spatial values in a maximum flow model: topography altitude, slope, land use cover, soil features (class, type, texture) and rain intensity.

In this way we obtained the spatial distribution of runoff within the hydrographical basin of Sebeş River (Fig. 8).

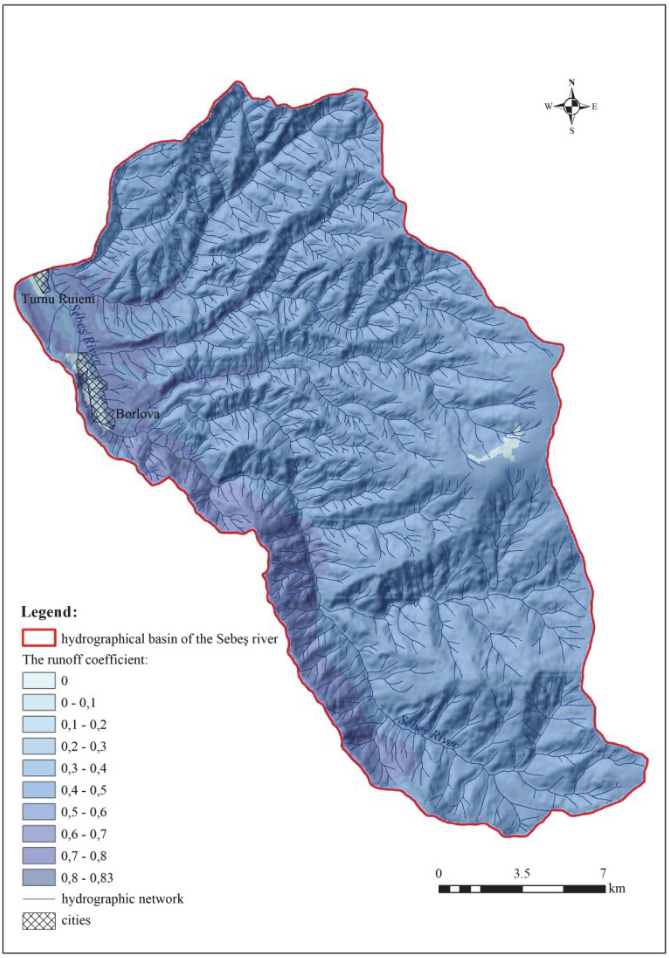

Fig. 8. Sebeş hydrographical basin – runoff obtained with the values of the runoff coefficient
Rys. 8. Dorzecze hydrograficzne Sebeş – odpływ otrzymany na podstawie współczynnika odpływu

Table 2. Runoff coefficient values and features of the Sebeş hydrological basin
Tabela 2. Wartości współczynnika odpływu i cechy dorzecza hydrologicznego Sebeş

Runoff coefficient	Localization	H (m)	Slopes (°)	Classes and types of soils	Soil texture	Land use cover
0.3	Everywhere except: the western and eastern side	variables	variables	variables	variables	variables
0.4	East South North-East North-West	450-600 > 900	< 15	podosoils (brown acid sulphate soils and brown podsols); ambisoils (brown acid and brown criptosodic acid and brown acid sulphate podsols);	medium medium medium	natural grasslands
0.5	Everywhere except: the western and eastern side	< 1500	< 20	ambisoils (brown acid and brown criptosodic acid and brown acid sulphate podsols); Argiluvisoils (typical brown luvic);	medium medium medium	all except urban, rural and leisure areas

Table 2. cont.
Tabela 2. cd.

Runoff coefficient	Localization	H (m)	Slopes (°)	Classes and types of soils	Soil texture	Land use cover
0.6	West	< 600 900-1050	variabile	ambisoils (brown acid); argiluvisoils (white pseudo-glazed luvisoils); Undeveloped soils (alluvial protosoils); Argiluvisoils (typical brown luvic);	hard medium medium medium	complex crops areas (crops and orchards), and deciduous and mixed forests
0.7	North-West	< 600	< 5	Undeveloped soils (alluvial protosoils); Cambisoils (brown acid); Argiluvisoils (white pseudo-glazed luvisoils); Argiluvisoils (typical brown luvic); Cambisoils (brown acid and brown eu-mesobasic);	medium medium medium medium	complex crop areas (crops and orchards) and secondary pastures
0.8	West	< 450	< 5 15-20	Cambisoils (brown acid);	hard	complex crop areas – agricultural crops

Analysing the spatial distribution map of the runoff along flow paths in Sebeş hydrographical basin, according to the runoff coefficient, we could distinguish many categories of surfaces, as shown in the Table 2.

The smallest values of the maximum runoff are recorded locally on the plan surfaces situated within Borlova and Turnu Ruieni localities and in the high area of Muntele Mic. These areas are the least vulnerable to high values of maximum runoff, so the risk of floods is low.

The runoff coefficient value of 0.3 resulted on surfaces that are situated everywhere within Sebeş hydrographical basin except: the western and eastern side and which have variable spatial values (altitudes, slopes, soils and land use cover).

The runoff coefficient of 0.4 was obtained in several areas located at high altitude (> 1200 m) in the eastern, southern, north-eastern and north-western part of the basin, with low slopes (< 15°), covered with natural grasslands and several types of soils with medium texture, within the category of spodosoils and cambisoils.

The runoff coefficient value of 0.5 resulted on surfaces that are situated everywhere within Sebeş hydrographical basin except: the western and eastern side. These surfaces have specific parameters as follows: high altitude (< 1500 m), high slope (< 20°), various land use cover (all except urban, rural and leisure areas), medium texture of soils and some characteristics classes and types of soil (cambisoils and argiluvisoils).

The runoff coefficient value of 0.6 was obtained in several areas with low and medium altitudes (< 600 m and 900-1050 m), located in the western part of the basin, with variable slopes, covered with complex crops (crops and orchards) and deciduous and mixed forests, with soils that have a heavy and medium texture belonging to the classes of: cambisoils, argiluvisoils and undeveloped truncated or rutted soils.

The runoff coefficient value of 0.7 resulted on surfaces situated in north-western part of the Sebeş hydrographical basin with low altitude (< 600 m), with low slopes (< 5°), covered with complex crops (crops and orchards) and secondary pastures and with medium texture of soils, which are part of the following classes: undeveloped, cambisoils and argiluvisoils.

The runoff coefficient of 0.8 was obtained in several areas located at low altitude (< 450 m), in the western part of the Sebeş hydrographical basin, with low slopes (< 20°), covered with complex crops (agricultural crops) and heavy textured soils from the cambisoil class.

The highest values of the maximum runoff occur in the western part of the basin, especially on both sides of Sebeș River, where is situated the two localities from the basin (Borlova and Turnu Ruieni). These surfaces are the most vulnerable to such a type of runoff, which is responsible for producing hydrological risk phenomena such as floods.

4. Conclusion

This article focuses on the determination of the maximum runoff within the representative and experimental hydrographical basin of Sebeș River, which is a small basin but responsible for producing hydrological risk phenomena like floods.

The maximum runoff occurring in this representative and experimental hydrographical basin was calculated based on the input data processed in GIS and then the model obtained was calibrate based on the scheme that includes optimisation of multiple objectives that measure different meteorological and hydrological aspects. Direct methods are based on the field-observed data from gauging stations, which are then evaluated by various statistical methods.

Especially, the role of digital elevation model (DEM) is important since its accuracy can significantly affect the resulting quality of runoff maps. The role of DEM and its quality is crucial for the results of surface runoff modelling.

The calculation equation for determining the maximum runoff of this small hydrographical basin used the physical and geographical features of the basin, namely: the relief altitude, the slope, the land use cover, the soil types, the rain intensity and their features.

From the analysis of the runoff spatial distribution within Sebeş hydrological basin, we may notice that various geomorphometric components have a higher or lower share in determining the runoff coefficient.

Runoff data are often matched to statistical distributions with known forms. Extrapolation can be made relatively simple where a good adherence to a statistical distribution can be found, but hydrological data may not conform, or different distributions may be more suitable in different geographical regions.

The smallest values of the maximum runoff are recorded locally on the plan surfaces situated within Borlova and Turnu Ruieni localities and in the high area of Muntele Mic. These areas are the least vulnerable to high values of maximum runoff, so the risk of floods is low.

The highest values of the maximum runoff occur in the western part of the basin, especially on both sides of Sebeș River, where is situated the two localities from the basin (Borlova and Turnu Ruieni). These surfaces are the most vulnerable to such a type of runoff, which is responsible for producing hydrological risk phenomena such as floods.

The ArcGIS software, used in this study to calculate the runoff coefficient, allows the spatial analysis of the maximum flow in a small hydrographical basin with a quite high accuracy.

The Rational Method which estimates peak flows is a simplified representation of the complicated process whereby rainfall amount and intensity, catchment conditions and size as well as human activity, determine runoff amount, but it is suitable where the consequences of the failure of structures are limited. The method is usually restricted to small watersheds and is based on the rainfall/runoff assumptions of the hydrograph below.

The main importance of the paper can be seen in the method used which can be replicable in other similar small catchments.

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Wyznaczenie maksymalnego odpływu w reprezentatywnym i doświadczalnym dorzeczu hydrograficznym rzeki Sebes (Banat, Rumunia)

Streszczenie

W kontekście zmian klimatycznych coraz poważniejsze stają się kwestie bardziej racjonalnego wykorzystywania zasobów wodnych i ekstremalnych zdarzeń hydrologicznych, takich jak powodzie, powodujące liczne negatywne skutki każdego roku. W małych dorzeczach hydrograficznych, takich jak dorzecze rzeki Sebeş (Rumunia), powodzie i ich destrukcyjne skutki zostały wzmocnione przez masowe wylesianie i niewłaściwe zagospodarowanie terenu. Analiza fizycznych i geograficznych cech dorzecza Sebeş pozwala ustalić reżim odpływu, także dla okresów o wysokim stanie wody i powodzi. Maksymalny odpływ występujący w tym reprezentatywnym i eksperymentalnym dorzeczu hydrograficznym został obliczony na podstawie danych wejściowych przetworzonych w GIS. Równanie obliczeniowe maksymalnego odpływu z badanego małego dorzecza wykorzystuje fizyczne i geograficzne cechy dorzecza, a mianowicie: wysokość wypiętrzenia, nachylenie, pokrycie terenu, typ gleby, intensywność opadów i ich cechy. Na podstawie analizy rozkładu przestrzennego odpływu w obrębie dorzecza Sebeş można zauważyć, że różne składniki geomorfometryczne mają większy lub mniejszy udział w określaniu współczynnika spływu.

Abstract

In the context of climate change, issues on more rational use of water resources and hydrological extreme events, such as floods, causing numerous negative effects every year, are becoming more acute. In small hydrographical basins, like the hydrographical basin of the Sebeş River (Romania), floods and their destructive effects have been and are amplified by the massive deforestation and the improper exploitation of surfaces. The analysis of the physical and geographical features of Sebeș hydrographical basin enables us to establish the runoff regime, including for the periods with high waters and floods. The maximum runoff occurring in this representative and experimental hydrographical basin was calculated based on the input data processed in GIS. The calculation equation to determine the maximum runoff of this small hydrographical basin used the physical and geographical features of the basin, namely: the relief altitude, the slope, the land use cover, the soil types, the rain intensity and their features. From the analysis of the runoff spatial distribution within Sebeş hydrological basin, we may notice that various geomorphometric components have a higher or lower share in determining the runoff coefficient.

Słowa kluczowe:
rzeka Sebeş, dorzecze hydrograficzne, odpływ, zagospodarowanie terenu, rodzaje gleb, współczynnik odpływu, GIS

Keywords:
Sebeș River, hydrographical basin, runoff, land use cover, soil type, runoff coefficient, GIS