Estimation of flow rate calculation errors on the example of five rapid response catchments in the Mecsek Hills

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Abstract

Today flash floods are one of the most significant extreme weather-related natural hazards. Due to the global climate change and altered land use, intense runoff and flash floods may exert catastrophic hydrologic impacts on developed areas. To measure and observe runoff-affecting environmental factors we have calculated characteristic flow values (CFV) with five empirical equations for five selected watersheds in the Mecsek Hills, SW Hungary. CFV's were then compared with measured characteristic Q_{max} values of 5, 10, 20, 33 and 100-year return period. From the empirical equations the Rational method was the most accurate while the largest differences between the calculated and measured values was observed for the Csermák-method. Nonetheless, determination of the input parameters for the Rational and Virág methods is rather challenging, thus, for practical applications, the Koris-method was found to be the most applicable equation to determine CFVs. Additionally, the median Koris errors showed a strong exponential correlation with the 5% specific runoff. If specific runoff could be estimated for any given outflow point, then error-specific runoff functions could be used to increase the accuracy of the Koris calculation method. To further increase the accuracy of CFVs for selected outflow points and cross sections, area and watershed-specific variables need to be included in the equation to account for topography, land use and soil properties.

Keywords: flash flood, runoff calculation, CFV, calculation error

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Introduction

Today flash floods are one of the most significant extreme weather-related natural hazards. Due to the global climate change and altered land use, intense runoff and flash floods may exert catastrophic hydrologic impacts on developed areas (Montenegro, S and Ragab, R. 2012). In Hungary, weather phenomena often cause disasters (hail storms, floods and mudflows) that subsequently generate considerable economic loss and may jeopardize human life.

The most severe natural hazards in the country are associated with atmospheric convections and storms (Horváth, A. 2005). Intense upward convection triggers various atmospheric phenomena ranging from small cumulus clouds to devastating super cells. Their devastation is further exacerbated by prediction challenges, as their magnitude and exact location varies considerably in space (Bartholy, J. and Pongrácz, R. 2010, 2013).

Convective processes develop rapidly and, with their associated features and consequences, may generate catastrophic damage. Typical observed hydrologic consequences and phenomena related to convective storms in hilly and mountainous regions are flash floods that are primarily characterized with short (less than 6 hours) response time and high flux (Horváth, E. 1999).

According to the report of the Environmental Protection Agency of the European Union, floods generate the largest economic loss in Europe (Lóczy, D. and Juhász, Á. 1996; Gaume, E. *et al*. 2009). Over the period of 1998 to 2002, about 100 devastating floods caused 700 fatalities, evacuation of 25,000 people and an economic loss of 25 billion Euros (Gaume, E. *et al.* 2009). Although the majority of the losses are caused by „conventional" large-river floods, over the past decades, floods more frequently occur on small streams located in small (10 to 100 km^2) mountainous watersheds (Marchi, L. *et al*. 2010; Mueller, E.N. and Pfister, A. 2011).

Flash floods are usually last for a few hours (in extreme cases up to a day) and due to their short time of concentration, prevention and evacuation effort are often challenging. In certain cases, however, snowmelt may also contribute to the generation of flash floods, hence low-intensity rainfall, amid ideal environmental settings may also trigger flash floods (Pirkhoffer, E. *et al*. 2008). A third, recently more frequent type of flash flood occurs in heavily urbanized areas, where paved surfaces are impervious and, in general, runoff is affected by various human factors (Gyenizse, P. 2009). This latter type of floods is called urban floods; however, some authors clearly differentiate them from typical flash floods (e. g. Georgakakos, K.P. 1986, 2006; Cobby, D. *et al.* 2008).

The majority of flash floods, at least in Hungary, occur between March and mid-October. Torrential, high-intensity precipitation caused significant economic loss in the hilly and low-mountain parts of Hungary. For example, a stream in North-West Hungary, the Által-ér inundated its valley following a

253 mm torrential rainfall on June 4, 1953 (Szilágyi, J. 1954). On June 27, 1987, several houses and part of the railroad were washed away in the Bükkösd Valley (Mecsek Hills, South-West Hungary) when 71 to 88 mm rain fell during a 6-hour period (Eszéky, O. 1987, 1992; Vass, P. 1997; Gyenizse, P. and Vass, P. 1998). Perhaps the largest economic loss was associated with flash floods in Mátrakeresztes, when a flash flood inundated the valley of the Csörgő and Kövicses Streams on April 18, 2005 (Horváth, A. 2005). Economic loss was estimated to reach 1 billion HUF (approx. 5 million USD) there (Koris, K. and Winter, J. 2000).

The city of Kaposvár was flooded by the Kapos Stream on August 21, 2008 (Hizsák, I. 2005) when 105 mm rain fell in 3 hours. According to insurance claim records, many of these torrential rainfall-associated floods in South-West Hungary occurred at and around the foothills of the Mecsek Hills on the catchments of the Kapos, Völgységi and Bükkösd Stream *(Figure 1).*

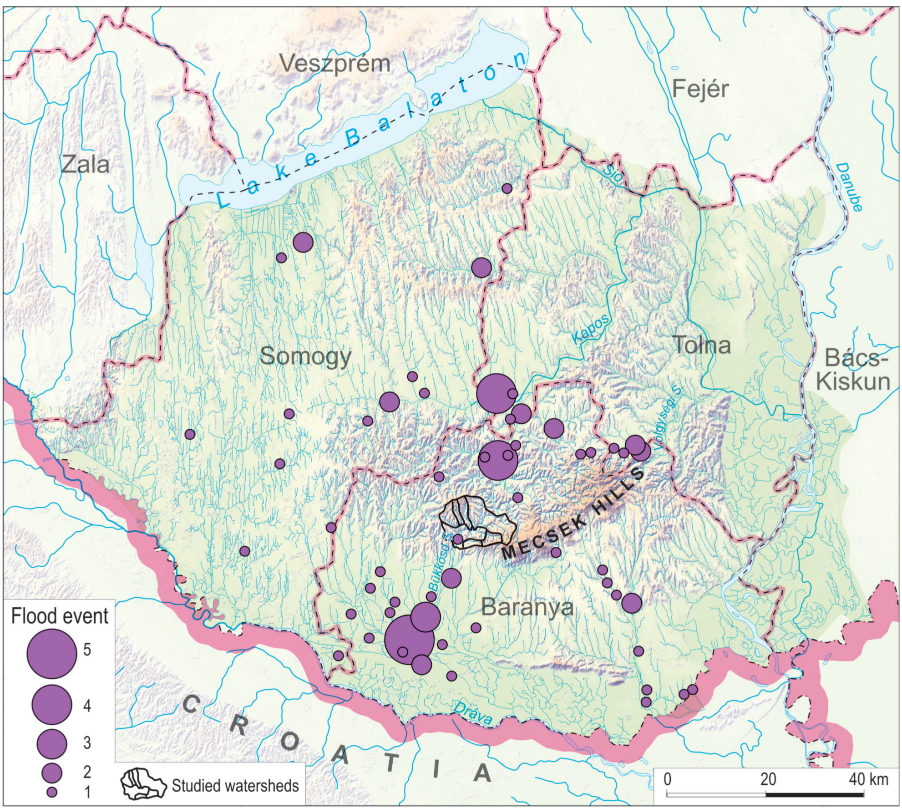

Fig. 1. Location of reported flood events in South-West Hungary between 1985 and 2005

Literature overview on the prediction methods usually applied in Hungary

Flash flood prediction is rather challenging, due to the large spatial and temporal variability of the convective rainfall events and the heterogeneous pattern of topography, land use and soil types (Yates, D.N. *et al*. 1999; Szlávik, L. and Kling, Z. 2007). In addition, prediction uncertainty is very high due to the available rainfall forecasting methods, and the localized characteristics of the precipitation (Szlávik, L. *et al*. 2002; Szlávik, L., Sziebert, J. and Zellei, L. 2002; Szlávik, L. 2003).

One way to estimate runoff and flow at the outflow point of the studied watershed is to use empirically derived equations. Equations of these types have been developed for small rapid-response watersheds located in Hungary. The most widely used equations employed by Hungarian researchers in the field of fluvial hydrology as well as the Hungarian Water Directorates include the *Koris*, *Csermák*, *Kollár*, *Rational* and *Virág equations* (estimation methods). Neither in the Introduction, nor in the Materials and Methods chapters of this paper it was not intended to describe these methods in full detail, instead a selection of literature was presented from which the reader could obtain further information about the calculation methodologies (e.g. Csermák, B. 1985; Zsuffa, I. 1996; Koris, K. 2001, 2002; Kontur, I. *et al*. 2003; Kaszab, F. 2009).

The basis of the calculations, with the exception of the Csermák rely on area-specific runoff (runoff calculated for a unit area, usually with a unit of m^3 km^{-2} s^{-1}) correlations (functions). Primarily based on topographic attributes, for the Koris equation Hungary is subdivided into broad runoff regions of about 15,000 to 25,000 km^2, each region having its own area-specific runoff correlation function (e.g. South-West Hungary, South Transdanubia Region). The other equations, however, do not differentiate unique runoff regions in Hungary.

The specific runoff value is then multiplied with the area of the watershed to obtain total runoff for a given recurrence time. Recurrence probability flow values calculated by the multiplication of the area and the specific runoff are discharge values of 5% and 10% probabilities for the Koris and the Kollár equations, respectively. The rational and Virág equations calculate a given probability runoff of $Q_{p\%}$ as a function of the flood-generating rainfall intensity with the same recurrence period ($i_{p\%}$). The Virág equation was primarily elaborated for large watersheds covering at least several 100s km^2 making it hard to accurately estimate runoff from minute watersheds.

The Csermák method considers an empirically generated map of runoff regions with a higher resolution than the aforementioned Kollár map. The individual runoff regions (classified from 1 to 5, 5 having the highest specific runoff) here are bordered by isohyets are the basis for determining the relative runoff attributes of the given watershed.

The rational method includes parameters that account for land use, soil and hydraulic properties (time of concentration).

Nevertheless, when compared with measured flow data, the output results of these equations are often burdened with significant errors when used for watersheds that were not included in the elaboration and calibration processes used during the generation of the given equations. To increase the accuracy of the equation, and to minimize the differences between the measured and calculated flow values, the equations need to be further improved by introducing modifying variables to account for the differences in topography, land use and soil properties among the individual watersheds.

Although these equations were developed in the 1970s and 1980s, there have not yet been fully adapted to digital, specifically to GIS-environment (see more details is VMS 1977a; 1977b, 1977c, 1977d, 1977e). Thus, a two-fold long term goal of the recently initiated research study of the flash flood research group of University of Pécs, Pécs, Hungary would be the improvement and adaptation of the runoff-calculating equations for a visual, watershed-based digital interface.

The short-term goal of the current paper is (a) to identify the most suitable runoff-calculation method to reproduce runoff from minute (1.7 to 12.13 km^2) watersheds of rugged topography that is characteristic for low-mountain conditions in Hungary and (b) to quantify the runoff calculation errors associated with individual runoff calculating equations when compared with the corresponding characteristic flow values of 5 selected watersheds from the Mecsek Hills.

Material and methods

Location and properties of the studied pilot catchments

To compare calculated and measured VFCs, five pilot watersheds were selected in Baranya County, SW Hungary. All watersheds are characterized by, at least under conditions typical in Hungary, with relatively high relief. Four selected watersheds, namely the Sás, Gorica, Sormás and Kán are tributary watersheds of the Bükkösd Stream Watershed that ultimately belongs to the drainage area of the Drava River.

For discharge value calculation and analysis, four pilot watersheds were selected – which are the tributary catchments of the Bükkösd Watershed – namely the Sás, Gorica, Sormás and Kán Watersheds. Each of the monitoring watersheds covers a relatively small land area (1.70 to 12.13 km^2) and topography of high relief. The four larger watersheds are dominantly undeveloped and are covered by deciduous forests, mainly beech and hornbeam.

For modeling purposes 5 rapid response-type catchments were selected in the Mecsek Hills, South-West Hungary, namely the catchment area of Kán, Gorica, Sormás, Sás and Bálics streams. The latter catchment is located on the Southern slopes of the Mecsek Hill within the administrative Borders of Pécs, with significant fraction of built-up areas (27%). The other four catchments are located in the North-Western part of the Mecsek Hills in predominantly forested areas (*Figure 2*). Catchment areas range between 4.0 and 12.1 km^2 while average slope values vary between 9.16 and 14.43 degrees (*Table 1*).

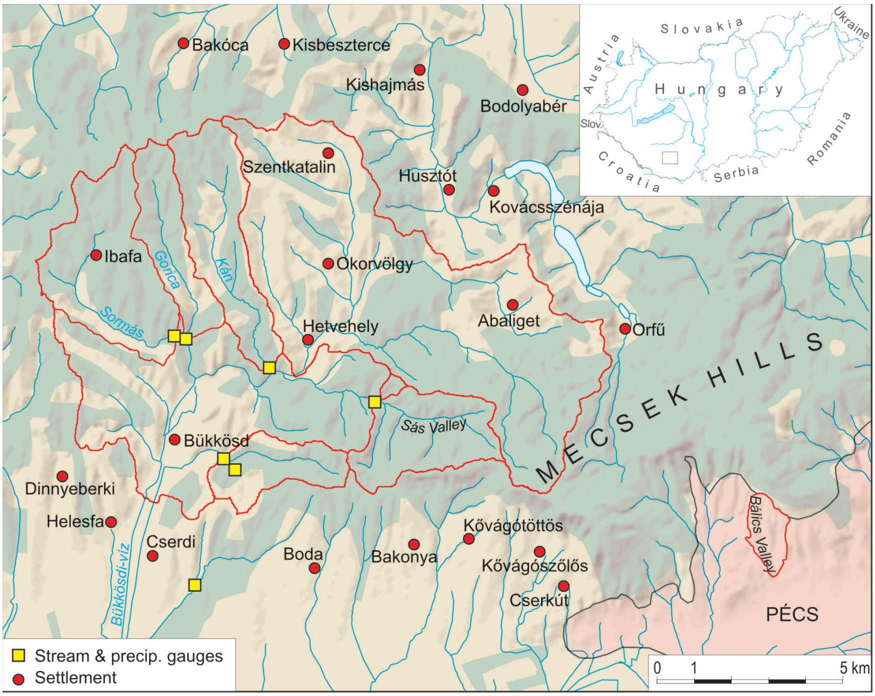

Fig. 2. Location of the studied watersheds (encircled by red lines) with the location of stream and precipitation gauges

Analysis of the selected runoff calculation methods and their comparison with measured characteristic flow values

Discharge measurements at the outflow point of the four undeveloped watersheds (Kán, Sormás, Gorica and Sás) were taken between January 1, 2005 and December 31, 2010 by the South Transdanubian Water Directorate (DDVIZIG) and the Mecsek Ore Company (Mecsekérc Zrt.). From the obtained data se-

Table 1. Land use and physical soil type characteristics of the studied watersheds

Indicator	Min	Max	Range	Mean	Std
Sormás Stream, 12.13 km^2					
Elevation, m	153.00	343.00	190.00	241.85	36.53
Slope, °	0.00	36.71	36.71	9.26	4.57
Aspect, azim °	flat	359.96	360.96	170.88	91.11
Gorica Stream, 5.84 km^2					
Elevation, m	151.00	355.00	204.00	255.56	43.03
Slope, °	0.00	35.41	35.41	11.02	5.32
Aspect, azim °	flat	358.60	359.60	174.74	90.91
Kán Stream, 9.58 km^2					
Elevation, m	154.00	356.00	202.00	248.88	43.63
Slope, °	0.00	35.16	35.16	10.00	4.86
Aspect, azim °	flat	359.78	360.78	160.82	88.04
Hetvehelyi/Sás Stream, 7.73 km^2					
Elevation, m	181.00	437.00	256.00	303.45	53.97
Slope, °	0.00	38.67	38.67	14.43	6.60
Aspect, azim °	flat	359.99	360.99	184.67	111.98
Bálics Stream, 1.70 km^2					
Elevation, m	166.00	390.00	493.00	262.11	28.47
Slope, °	0.00	36.15	36.15	10.72	7.15
Aspect, azim °	flat	354.80	355.80	183.20	99.24

ries, characteristic flow values (CFV) for 5 probabilities (1, 3, 5, 10 and 20%) were calculated for each watershed. Probability distributions were calculated with the Gumbel-probability function, widely used in hydrology. Hereafter these characteristic flow values are called the measured CFVs. For the Bálics Stream stage values were available for 2012 and until March 31, 2013, using an automated logger and the attached hydraulic head meter Dataqua (Dataqua Company, Balatonalmádi, Hungary). Stage values were then converted to discharge based on the Q-H function, which was generated with regular flow measurements. Due to the short measurement interval of this latter watershed, the reliability of the peak flows of long recurrence time is relatively low.

The CFVs (i.e. recurrence times of 5, 10, 20, 33 and 100 years) were calculated with 5 estimation methods being widely used by the Hungarian hydrological professionals. The employed runoff estimation methods are the following ones: Koris-, Csermák-, Kollár-, Rational, and the Virág-type discharge estimation. The calculated runoff (flow) values were then compared with the corresponding measured CFVs. The selected CFVs of 1, 3, 5, 10, 20% peak flow values (Q_{max}) values, are equivalent with recurrence periods of 100, 33, 20, 10, 5 years, respectively. For comparison, specific discharge values were also calculated by dividing the measured discharge values with the land area of the given watershed.

These Q_{max} estimation methods are standardized hydrologic methods in Hungary and have been developed for watersheds representative for Hungarian topographical conditions (lowlands and low-mountains). For these equations Q_{max} values are calculated as a function of watershed area and runoff characteristics (specific runoff, m^3 s^{-1} km^{-2}), while exclusively the rational-method considers precipitation as input parameter. Calculation methods of the five selected runoff-estimating techniques are briefly described below.

a) Koris estimation method:

$$Q_{p\%} = a_i q_{5\%} A, \tag{1}$$

where a_i is the probability multiplier which are 1.7, 1.2, 0.8 and 0.6 for the 1, 3, 10, 20% probabilities of discharge, $q_{5\%}$ is the specific flow rate estimated form the appendix (VITUKI, 1977) and A is the area of the pilot watershed (km^2).

b) Csermák estimation method (based on the Myer equation):

$$Q_{p\%} = rB_{3\%} F^n, \tag{2}$$

where r is a probability coefficient, $B_{3\%}$ is the 3% probability of peak flow occurrence estimated for the area, F is the area of the watershed, and n is a constant equals to 0.75, if the area is under 10 km^2; or 0.5, if the area is over than 10 km^2.

c) Kollár estimation method:

$$Q_{10\%} = q_{10\%} A, \tag{3}$$

where $q_{10\%}$ is a 10% probability of a specific peak flow occurrence (m^3/s km^2), and A is the extent of the watershed. Other than 10% probability estimation can be calculated with a multiplier factor based on the ratio of $Q_{p\%}/Q_{10\%}$.

For the Kollár and Koris methods, we used the median of the function range that accounts for the rainfall intensities (as well as topography and watershed shape) in the area-specific runoff correlation function. Here, when specific runoff is calculated using the lowest part of the range, low rainfall intensities and relatively flat topography (long time of concentration and storage coefficient) is assumed. When the upper boundary of the range is used for calculating specific runoff for the Koris and Kollár methods, 'torrential' conditions are assumed, referring to high-intensity rainfall events and topography, land use and soil types favorable for intense runoff.

d) Rational method (first applied by Mulvaney, T.J. in 1847):

$$Q_{p\%} = i_{p\%}\,\alpha A, \tag{4}$$

where $i_{p\%}$ is a $p_{\%}$ probability ($T = t$) rainfall intensity, α is the runoff coefficient, A is the area of the watershed.

e) Virág estimation method:

$$Q_{p\%} = Aq_{p\%}\,C_{p\%} \tag{5}$$

where A is the area of the watershed, $q_{p\%}$ is an estimated specific runoff, and $C_{p\%}$ is a specific correlation factor.

Results

Regarding their land use types and physical soil properties, the studied watersheds were divided into two main groups, an urban one and an undeveloped category. The Bálics Stream watershed is exclusively located within the administrative borders of Pécs, predominantly in the North-West part of the city (150.286 residents according to the 2010 census). This catchment is a highly developed urban area with a high proportion of impermeable surfaces favorable for intense runoff. The other four catchments are primarily covered by deciduous forest (beech and hornbeam) in 81.53 to 95.05%. In the undeveloped watersheds natural conditions dominate the land use, paved surfaces cover only insignificant proportion of these watersheds (*Table 2*). The proportion of the paved surfaces is highest in the Bálics Watershed covering 26.78% of the entire land area of the watershed. Similarly, the area of agricultural and horticultural areas was highest in the Bálics Watershed, with the dominance

Table 2. Land use and physical soil type characteristics of the pilot watersheds, in %

Land use, physical soil type	Sormás	Gorica	Kán	Sás	Bálics
	Watershed				
Agri/Horticultural areas	8.98	10.08	21.18	–	65.47
Artificial surfaces	–	–	–	–	26.78
Forests	81.53	89.91	76.93	95.05	7.73
Shrubs	9.48	–	1.87	4.95	–
Loam	100.00	–	0.83	1.27	–
Clayey loam	–	92.30	68.47	98.73	–
Clay	–	5.81	30.68	–	–
Coarse fragments	–	–	–	–	100.00

of grape, fruit trees, lawn and vegetable gardens. Forested areas within the Bálics Stream are only found in the northernmost tip of the watershed.

The predominant physical soil types of the undeveloped watersheds are loam and clayey loam according to measurements of Zalavári, P. (2008). Loamy soils are the sole soil physical soil types in the Sormás Watershed, while clayey loam cover the surface almost exclusively in the Gorica and Sás Watersheds (*Table 2*). The prevailing physical soil types of the Bálics Watershed are characterized by rocky and stony topsoils, primarily at higher elevations at the Northern tip of the watershed by field experiments, while, according to the AGROTOPO database, this soil type is the prevailing one within this watershed. Based on our field experiences and the former studies of Zalavári (2008), genetic soil types in the Bálics Watershed include rendzinas, carbonate-rich forest soils formed on carbonaceous parent material and forest soils with significant clay illuviation (FAO: Luvisols, USDA: Alfisols, dominantly Xeralfs).

CFV calculations and comparison of measured and calculated CFVs

For the five aforementioned watersheds we have calculated discharge values (a) at different recurrence periods (5, 10, 20, 33 and 100 years), and (b) with different estimation methods (Csermák, Koris, Kollár, Virág and Rational-type calculation). A total of 25 cases (five watersheds, five calculation methods) were analysed, i.e. for this many cases were the calculated and measured CFVs compared.

In the majority of the analyzed cases, calculated CFVs were larger than the measured values. Out of the 25 analyzed cases, calculated values exceeded the measured values in 21 cases. In general, the highest error was found for the Csermák-type calculations with a mean error of 695% between the calculated and measured values.

Best correspondence was observed for the Virág estimation method with a mean value of 102% (standard deviation, $\sigma = 80.3$). Error percentages ranged between 1.42 and 1641% for all cases (*Table 3, Figure 3*). Among all the 25 cases, the lowest error was found for the Sás Stream at a recurrence period of 5 years using the Virág equation. The highest error was found for the Sormás Stream at a recurrence period of 100 years.

When the five employed calculation methods were compared, the lowest error was found at the Virág-type estimation for the Sás and Kán Watershed (10.00 and 4.96%, respectively). The Sás Watershed has the highest mean slope (14.42%) among the five studied watersheds and also has the highest proportion of clayey loam soils. These two factors likely contribute to increased runoff. However, the Sás Stream has the highest proportion of forest cover within its watershed; this property, through the process of interception will

*Table 3. Calculated errors between the measured and calculated characteristic flow values of five recurrence time intervals **

Stream	Return period, years	Relative error of measured and specific Q	Error of calculated – measured Q, %				
			Koris	Csermák	Kollár	Rational	Virág
Sás	5	1.243	84.41	612.13	157.42	21.40	***10.00***
	10	1.410	115.27	693.54	192.70	14.14	35.63
	20	1.550	145.33	809.49	246.90	4.87	94.11
	33	1.640	179.10	879.84	317.44	3.56	118.10
	100	1.798	261.14	1,152.82	373.70	26.00	169.00
Gorica	5	0.843	123.21	*720.53*	184.30	15.00	18.58
	10	0.907	176.60	*870.67*	262.00	1.42	55.22
	20	0.955	228.34	*1,058.73*	346.86	13.77	131.38
	33	0.984	282.37	*1,177.80*	450.41	26.76	166.17
	100	1.035	415.18	***1,601.41***	550.37	60.63	241.78
Sormás	5	1.025	208.27	*927.43*	330.93	59.34	123.00
	10	1.228	242.84	*990.68*	392.37	65.81	161.96
	20	1.416	271.85	*1,089.75*	455.40	74.86	256.82
	33	1.546	308.60	*1,137.98*	533.76	83.81	287.30
	100	1.812	393.80	*1,378.55*	584.16	108.90	346.10
Kán	5	2.830	8.83	327.30	39.54	50.17	38.00
	10	3.726	7.67	313.07	29.26	52.77	33.68
	20	4.586	6.23	321.90	26.02	53.37	15.42
	33	5.200	0.91	322.20	29.47	52.86	11.71
	100	6.532	11.91	371.25	34.93	49.92	4.96
Bálics	5	2.770	39.22	121.60	11.74	91.62	74.17
	10	2.920	38.44	114.22	18.24	90.10	72.36
	20	3.030	37.48	118.80	20.29	88.40	64.76
	33	3.490	33.94	118.95	18.11	88.43	63.21
	100	3.720	25.38	144.40	14.66	85.54	60.40

* 5, 10, 20, 33 and 100 years. The maximum errors are marked with bold italics, the minimum values with italics.

delay and diminish throughfall and runoff as a direct consequence. The Kán watershed is slightly more developed than the Sás Stream Watershed, still, we found better correspondence between the calculated and the measured CFVs for this watershed using the Virág-type estimation method.

Relatively low errors were found for the Rational method, however, in this case time of concentration, as an input value was set in a rather arbitrarily fashion (and unrealistic values were found) to obtain the best correspondence between the calculated and measured values. Nonetheless, the time of concentration values did not always represent the actual (field-observed) values adequately. Calculated times of concentration are shown in *Table 4,* using the so-called Wisnovszky equation (Koris, K. 2003).These values, in many cases, are rather different from the observed data that was based on field monitoring between 2005 and 2010. This

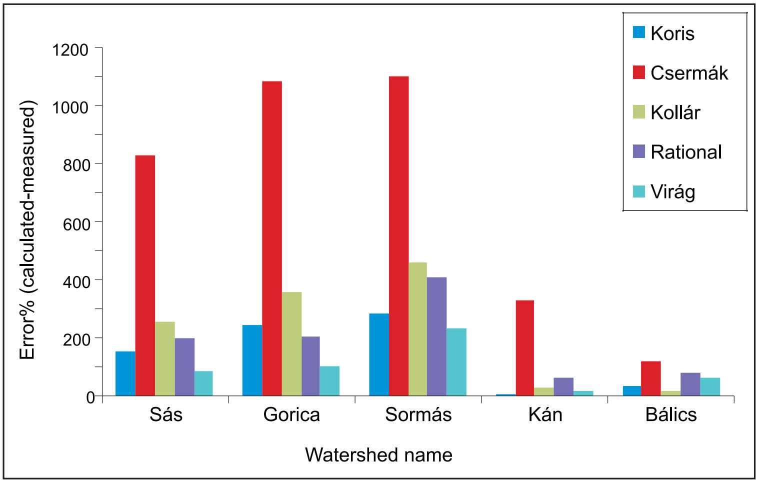

Fig. 3. Error percentages for the five selected CFV calculation methods for the five studied watershed

Table 4. Time of concentration values for the studied watersheds

Stream	Stream gauge loc.	Area, km^2	Calc. Tc, h	Number of events studied	Tc. used for best fit, h	Measured Tc., h		
						Min.	Max.	Mean
Bálics	Pécs	1.7	0.28	17	40.0	0.25	5.33	2.15
Gorica	Bükkösd	5.9	0.67	17	1.5	0.83	29.92	10.99
Kán	–	9.6	0.98	20	5.7	1.08	23.75	7.83
Sormás	Bükkösd	12.2	3.40	18	0.8	1.75	14.50	7.75
Sás	Hetvehely	7.7	1.83	22	2.0	1.25	32.25	12.12

way, through its arduous parameterization protocol (in respect of the calculation of concentration times), the Rational method is considered rather inadequate for direct runoff estimation for the five studied watersheds.

In general, the third lowest errors were obtained for the Koris method when the centerline (median) of the 5% probability range was use to estimate specific runoff (*Figure* 3). This way, in respect of parameterization accuracy, the Koris equation seems to be the most adequate method for estimating runoff among the presented five calculation methods.

If the mean values analyzed with respect to the individual watersheds, lowest errors were detected for the Bálics Stream (65%). Due to its environmental settings (topographical, land use and soil properties), the Bálics Stream has the highest runoff coefficient value. The Sás, Gorica and Sormás Streams are characterized by relatively high mean errors ranging between 306.4% and 498.9%, with standard deviations of 299.2 to 394.4 (*Table* 5).

Table 5. Mean error (differences between the calculated and measured CFVs) percentages relative to the corresponding measured CFVs

Stream	Koris	Csermák	Kollár	Rational	Virág	*Mean*	*St. dev.*
Sás	157.0502	829.5640	257.6320	14.00	85.3680	*268.72*	*291.77*
Gorica	245.1400	1,085.8280	358.7880	23.52	102.3035	*363.11*	*379.36*
Sormás	285.0720	1,104.8780	459.3240	78.55	235.0360	*432.58*	*357.44*
Kán	7.1100	331.1440	31.8440	51.82	20.7540	*108.90*	*128.80*
Bálics	34.8920	123.5940	16.6080	88.82	66.9800	*66.18*	*38.07*
Mean	*145.8528*	*695.0016*	*224.8392*	*51.34*	*102.0883*	–	–
St. dev.	*123.4172*	*446.5843*	*196.6012*	*29.37*	*80.3159*	–	–

The Kán Stream has the second lowest mean error when the corresponding calculated and measured CFVs are compared (91%). This behavior is unexpected, as the Kán Watershed, regarding its general environmental settings and its catchment area (see *Table 2* and *3*) is rather similar to the Sás, Gorica and Sormás Watersheds. Slight differences, nevertheless, are observed at the higher proportion of clay-rich soils and the deforested areas, both parameters being significant contributors to increased runoff.

Impact of runoff coefficient and specific runoff on the Koris median-derived CFV errors

As it was concluded above, the Koris median calculation method was proven to be the most adequate to directly estimate runoff for the five studied watersheds. Thus, in the current chapter we compared the impact of runoff coefficient (ratio of precipitation and outflow) and the specific area (runoff from a unit watershed area) on mean CFV errors that were obtained from the Koris median values.

By looking at *Table 4* two distinct groups of watershed types is identified. The first group consists of the Sás, Sormás and Gorica Watersheds, while the other group includes the Kán and Bálics Streams, two watersheds with rather different environmental settings and medium runoff coefficients, at least among the five studied watersheds. Highest runoff coefficient for the four undeveloped watersheds, based on the 2005 to 2010 flow and precipitation data, was found for the Sás Stream (0.4005). The Bálics Stream, which has the lowest mean error value among the five studied watershed, has a runoff coefficient value of 0.275 (second highest value) for the 5% probability discharge (*Table 6*) based over the period of October 1, 2012 to May 1, 2013 when 562 mm rain fell over the measurement period. Consequently, runoff coefficient, as a combined parameter that describes the general hydrologic behavior of a given watershed, does not readily influences the errors that appear between the calculated and measured CFVs (*Figure 4*).

Table 6. *Specific runoff and runoff coefficient values comparing to mean error values*

Stream	Mean	Max	$Q_{5\%}$ measured	Area, km^2	Specific runoff 5%, $m^3/s/km^2$	Runoff coefficient mean	Mean Koris error
	m^3/s						
Sás	0.0657	1.580	1.789	7.73	0.231	0.401	157.0502
Gorica	0.0250	1.000	1.150	5.84	0.195	0.202	245.1400
Sormás	0.0316	1.530	1.542	12.13	0.126	0.123	285.0720
Kán	0.0352	1.960	5.119	9.58	0.533	0.174	7.1100
Bálics	0.0025	0.548	0.964	1.70	0.567	0.275	45.8700

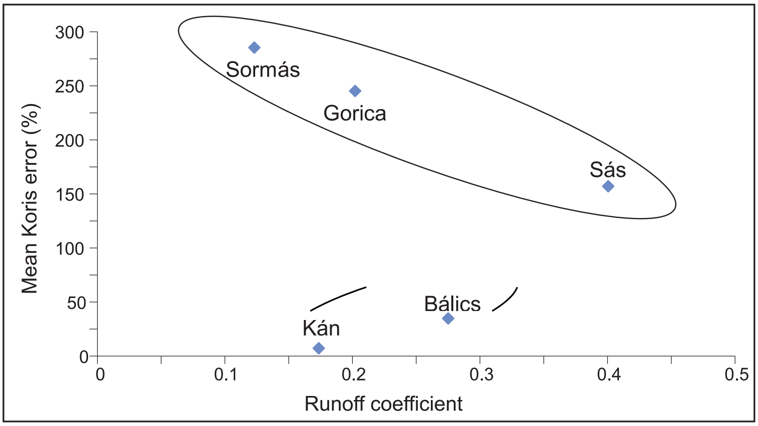

Fig. 4. Correlation between runoff coefficients and mean Koris estimation errors: two distinct groups are differentiated

Better results were obtained when correlation between specific runoff (another combined parameter that illustrates the overall hydrologic behavior of a given watershed) and measured CFV errors was analyzed (r^2 = 0.7643) (*Figure 5*). We need to emphasize that calculation errors are rather high for the Bálics Stream, firstly by the Q-H function calculation and secondly by the error arising from the short monitoring period used for the probability calculations of the CFVs, thirdly by the significant communal waste water input and (d) karstic environment and the flow and baseflow-buffering due to the underground water storage of the limestone aquifer. The Kán Watershed seems to be a good example to demonstrate the correlation between measured and calculated discharges for different estimation methods (*Figure 6*).

Generally, with increasing return period, the errors have also increased. When error percentages were analyzed as a function of the five studied recurrence periods (recurrence probabilities) we found increasing error percentages

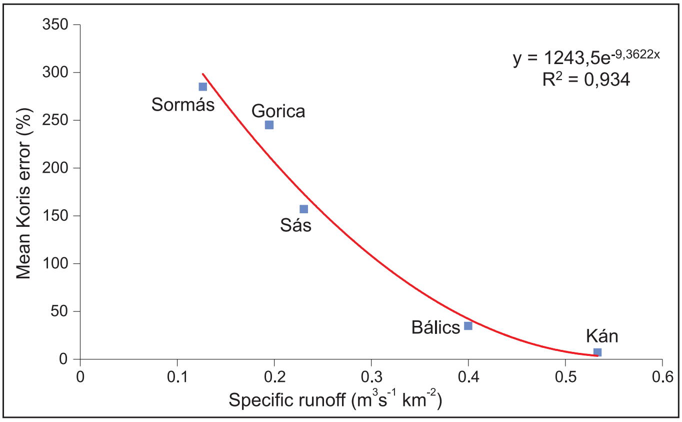

Fig. 5. Second degree polynomial correlations between the specific runoff and mean Koris estimation error

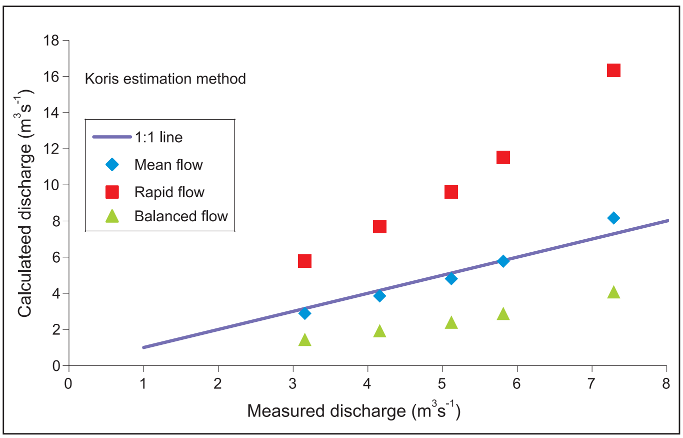

Fig. 6. Correlation between measured and calculated discharges for different estimation methods, at various return periods (5, 10, 20, 33, 100 years) for the Kán Watershed

with increasing recurrence times for the Sás, Gorica and Sormás Streams. Error percentages as a function of recurrence time remained relatively constant for the Kán and Bálics Streams. This way one could again differentiate two types of watersheds regarding their hydrological and hydraulic behaviors. When the Koris-, and the Virág-type estimation were used to calculate peak runoffs for the Kán Watershed, decreasing error percentages were found with increasing return period (*Figure 7*).

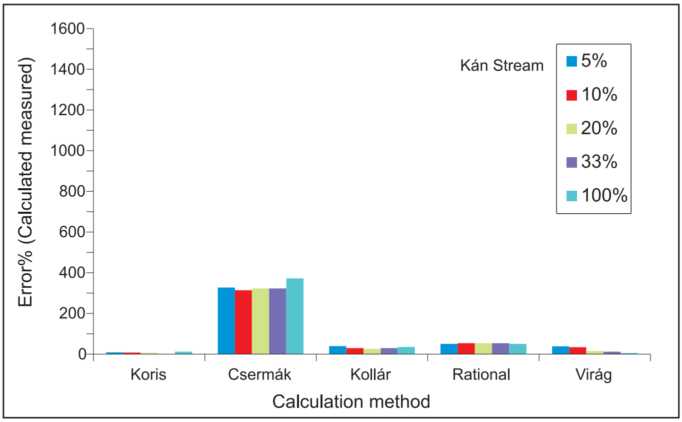

Fig. 7. Error values for the different estimation methods at different recurrence periods (for the five studied watersheds, in percentages)

Conclusion

During the course of the currently proposed research we investigated the appropriateness of 5 runoff estimation methods that are widely used in Hungarian hydrology were investigated for 5 selected watersheds in the Mecsek Hills, Baranya County. In general we claim that significant deviations were found between the measured and calculated CFVs for the five selected watersheds and all methods. Best results were obtained for the Virág and Rational methods, however, both methods are difficult to use due to the difficulties involved with input parameter estimation. Third lowest errors were associated when the Koris equation was used for the median of the area-specific runoff correlation range. Due to its easy parameterization and calculation methodology, this method was proven to be the most applicable with a reasonably accuracy to estimate runoff for the five selected watersheds.

Usually, for the Kollár and Koris-estimation methods, the lower boundary runoff character range within the area-specific runoff function gave the best results. This is likely explained in the light of climate change and the altered climatic conditions of today compared with the time when these estimation methods were developed, dominantly over the period of 1970s and 1980s. Secondly, the dominance of the lower boundary runoff character is explained by the fact, that, with a very few exceptions, both methods were predominantly developed by calibrating the model for large watersheds (several 100s km^2), rather than those used in the current study (around 10 km^2). Furthermore, each watershed behaves according to an individual rainfall-runoff pattern reflecting its unique topographic, land use and soil properties, in addition to the topography-induced meso-scale climatic differences and spatial rainfall patterns primarily due to the local orographic effects.

To overcome this watershed-specific problem, i.e. the uniqueness of each watersheds from the viewpoint of hydrography, hydrology and hydraulics, watersheds need to be categorized into selected classes according to their size, soil type, land use and topography. This way, based on the calculated flow correlations between the measured and calculated flow values, constants (being equal to the mean errors between calculated and measured CFVs) need to be developed to calibrate the various flow estimation methods in order to modify the currently available equations to obtain better correspondence with the measured values.

Specific correlation functions need also be generated to account for the aforementioned attributes of the watersheds. Such attempt is included in the rational method, however, this method needs to be automated and used in GIS-environment with subsequent calculations based on the available digital spatial databases (e. g. topography, land use and soil types).

By the automatization of the runoff calculations for selected cross-sections (outflow points) of the watershed of interest the CFVs could be calculated over a relatively short period of time (if sufficient calculation capacity is available). If pre-calculated inundation scenarios are available for the selected CFVs, the area of flooded terrain within the floodplains could be promptly determined, and warnings could be issued in advance with sufficiently long time lead. This way, residents of the affected areas could be evacuated in a short period of time, primarily in flash flood affected watersheds and in areas of rapid-response catchments. With increasing flood resilience, socio-economic consequences of torrential weather phenomena and disastrous hydrologic events could be diminished.

To develop an automated GIS-based method, correlations need to be found between the calculation errors and complex environmental parameters that expresses the topographic, land use and soil properties of a given watershed and readily expresses the hydrologic behavior of the individual watershed. In the present study the impact of two types of complex properties were analyzed: (i) runoff coefficient and (b) specific runoff. For the five studied watersheds no correlation was found between runoff coefficients and the Koris median- derived errors.

However, specific runoff exerts a strong impact on the Koris median-derived specific errors. In this case a relatively strong exponential correlation was found between the two parameters. This way, for any given cross-section along the watercourse relative error could be estimated for the Koris calculation method, and a correction constant could be introduced that accounts for the topographic, land use and pedologic properties of the watersheds located upstream from the selected cross section (or outflow point). In an ideal case, the correction factor would decrease moving upstream from the outflow points along the watercourse, as the headwater portion of any watershed would express increased runoff characters, i.e. increased specific runoff, where CFV errors are expected to be lower than in the vicinity of the outflow point of the watershed.

However, prior to generation of the correlation function between the upstream distance of the outflow point and the CFV errors, watersheds need to be classified into individual groups according to their runoff characteristics. In the present study, the five selected watersheds had very similar properties; nevertheless, two distinct watersheds were identified. This classification scheme is rater arbitrary, thus it provides significant challenges for reliable runoff prediction in watersheds of high relief. Hence, further studies are indispensable in order to increase the output accuracy of runoff calculations.

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