Testing of mapping approaches for estimation of 100-year maximum daily precipitation totals in the upper Hron River basin

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A b s t r a c t: The 100-year maximum daily precipitation totals for rainfall-runoff studies and estimating of flood hazard were mapped. The main objective of this study was to discuss the quality and properties of maps of design precipitation with a 100-years return period. Four approaches to the preprocessing of annual maximum 24-hour precipitation data were used. The first method was the direct mapping of at-site estimates of distribution function quantiles. In the second method, the daily measurements of the precipitation totals were interpolated into a regular grid network, and then the time series of the annual maximum daily precipitation totals in each grid point of the selected region were statistically analysed. In the third method, the spatial distribution of the design precipitation was modeled by quantiles predicted by regional precipitation frequency

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analysis using the Hosking and Wallis procedure. Homogeneity of the region of interest was tested, and the index value (the mean annual maximum daily precipitation) was mapped using spatial interpolation. Quantiles were derived through the dimensionless regional frequency distribution estimated by using L-moments. The kriging interpolation method was applied in all of these three approaches. The mapping approaches were tested on the daily precipitation measurements at 23 climate stations from 1961-2000 in the upper Hron basin in central Slovakia.

In the forth method, the estimation of 100-year maximum daily precipitation at 557 stations in Slovakia was the basis for the construction of expert's hand drawn isohyets of design maximum daily precipitation totals. The part of the map for the upper Hron basin was selected and compared with previous mapping approaches.

Key words: 100-year maximum daily precipitation totals, design precipitation mapping, regional frequency analysis, L-moments, expert's hand drawn map

1. Introduction

Design precipitation values are in particular especially needed and estimated for engineering and urban hydrology in order to provide a hydrometeorological input for design flood estimation and urban flood management. For the design of hydrotechnical projects in ungauged watersheds, the flood flow is usually estimated by various methods which demand the estimation of rainfall of a particular critical duration and return period. For medium-sized and large basins, storms causing flood flows usually have a duration of at least 24 hours (e.g., *Loukas et al., 2001*).

Recently, intensive efforts to develop complex statistical and spatial interpolation methods for estimating design rainfalls have been reported in the literature and also by several national authorities and meteorological offices in the world. As a result, hydrological maps of design and extreme precipitation have been produced for national hydrological atlases.

The problem of mapping the spatial distribution of extreme precipitation involves a statistical description of the properties of extremes locally at site and a process of translating the point information registered at different climatic stations in a region in the form of a spatially continuous variable. Both steps can be approached by a number of methods. The statistical analysis of extreme precipitation has a well-established theoretical background, but it will not be treated here in detail. As a result of this analysis different variables can be used to describe the at-site behavior of extreme precipitation, e.g., the median, the mean, various quantiles, distribution parameters or absolute maxima (*García-Ruiz et al., 2000*).

Next, these variables estimated locally are mapped using spatial interpolation techniques. Spatial interpolation can be undertaken through the use of various algorithms. In climatological applications besides simple methods like the inverse square distance method, kriging methods without the use of an external variable and kriging methods making use of a secondary variable, such as factorial kriging, kriging with an external drift and cokriging, (*Carrera-Hernandéz and Gaskin, 2007; Pecušová et al., 2004*) are often used.

The evaluation of the performance of these and other methods has been addressed in a large number of studies; among them (*Tabios and Salas, 1985; Borga and Vizzaccaro, 1997; Dubois, 1998; Goovaerts, 2000; Jarvis and Stuart, 2001; Weisse and Bois, 2001; Brown and Comrie, 2002; Hofierka et al., 2002; Lloyd, 2005; Watkins et al., 2005; Begueria and Vincente-Serrano, 2006; Daly, 2006; Carrera-Hernández and Gaskin, 2007; Casas et al., 2007; Cooley et al., 2007* and *Wallis et al., 2007*).

For the Landscape Atlas of Slovakia, *Šamaj et al. (1985); Faško et al. (2000)* and *Gaál et al. (2004)* estimated the design rainfall for different return periods and subjectively drew (expert's hand drawn) isoline maps (isohyets) over the entire region of Slovakia supported by classical subjective reasoning. In *Parajka et al. (2002, 2004)*, annual and seasonal maximum daily precipitation depths were used, and the N-year values of the maximum daily precipitation depths were estimated at site using several distribution functions and parameter estimation methods. In order to interpret the spatial variability of the design maximum daily precipitation depths, contour and grid maps of the mean value, standard deviation, 100- and 2-year maximum annual and seasonal daily precipitation depths were derived using various interpolation methods such as Thiessen polygons, kriging, cokriging and the inverse weighting distance method.

The choice of statistical methods for estimation of design precipitation totals is wide. While the use of the regional L-moment algorithm with a GEV distribution has became more or less a standard in hydrology for the statistical frequency analysis, the recommendation on the choice of spatial interpolation method is not so obvious. Many aspects can be taken into consideration, ranging from the field of application of the resulting map through the constraints imposed by the data availability, the time and the available resources to the selection of a physically adequate model for the given settings. Among these, consideration of the secondary variables seems to be the most important, for details see (*Wolfson, 1975; Asli and Marcotte, 1995; Faulkner and Prudhomme, 1998; Goovaerts, 2000* and *Wotling et al., 2000*).

These studies did not provide a clear answer as to whether the use of elevation (altitude) as a secondary variable always improves the spatial interpolation of daily rainfall. Some authors consider that although the use of elevation as an auxiliary variable improves the spatial interpolation of monthly rainfall data, the relationship between rainfall and elevation is less useful when interpolating daily data (*Carrera-Hernández and Gaskin, 2007*). On the other hand, assimilation of other climatic variables, including those from weather models, seems to improve the mapping performance.

In this study we propose to compare a combination of four different approaches to the mapping of 100-year annual maximum daily precipitation totals.

The first method is the direct mapping at site estimates of 100-year design values. For the second method we have proposed an approach, which to the best of our knowledge, has not yet been used for this purpose. First, the daily measurements of the precipitation totals were interpolated over a regular grid network in a catchment, and then the time series of the maximum daily precipitation totals in each grid point of the selected region were statistically analysed at site. The major advantage of the proposed algorithm in comparison to the direct mapping of design precipitation values is that, if a physically adequate interpolation is used and adequate data are available, it enables the estimation of design values at ungauged sites for an interpolated time series, which may better reflect the physical and regional properties of the precipitation extremes, as well as the description of the seasonal variations of the extreme daily precipitation totals over the selected region.

In the third method, the spatial distribution of the design precipitation was modeled by quantile (percentile) values as predicted by a regional precipitation analysis. For this purpose the Hosking and Wallis procedure was adopted; the homogeneity of the region of interest was tested, and the dimensionless regional frequency distribution derived by using L-moments and the index value (the mean annual maximum daily precipitation) was mapped using spatial interpolation (instead of the more usual regional regression).

In all of these three methods, the kriging interpolation method was applied and the daily precipitation measurements at 23 precipitation stations from 1961-2000 were used in the upper Hron basin in central Slovakia.

For the purpose of comparison, in the fourth method the map of 100-year maximum daily precipitation totals were constructed by Faško and Lapin (*Faško et al., 2000*), using the design precipitation values estimated by the Pearson III method at 557 stations in Slovakia according to the data from the 1950-2000 period (*Gaál et al., 2004*). From the design precipitation values at 557 stations in Slovakia the expert's hand drawn map of design precipitation isohyets was constructed. This method enables to assess isohyets also in the area without regular precipitation measurements, because these experts have experience with extreme precipitation analysis longer than 20 years. The comparison of radar data and measurements at regular precipitation network in Slovakia proved that the expert assessment can be very close to the real precipitation field at selected extreme events.

2. Data

The upper Hron River basin with an area of 1766 km^2 was selected as a pilot area. It is located in central Slovakia, and it was chosen as representative of mountainous regions in Slovakia (Fig. 1). The minimum elevation of the basin is 340 m a.s.l.; the maximum elevation is 2004 m a.s.l.; and the mean elevation is 850 m a.s.l. The digital elevation model of the basin and the location of the climatic station used in this study are in Fig. 2.

The climate conditions of the upper Hron River basin are described by mean temperature, precipitation and evaporation, summarised in Table 1 for the valleys and mountainous slopes of the region separately. The mean annual precipitation within the study area decreases from the western slopes of the Starohorske Mountains (1000 mm), to the Hron River valley (700 mm)

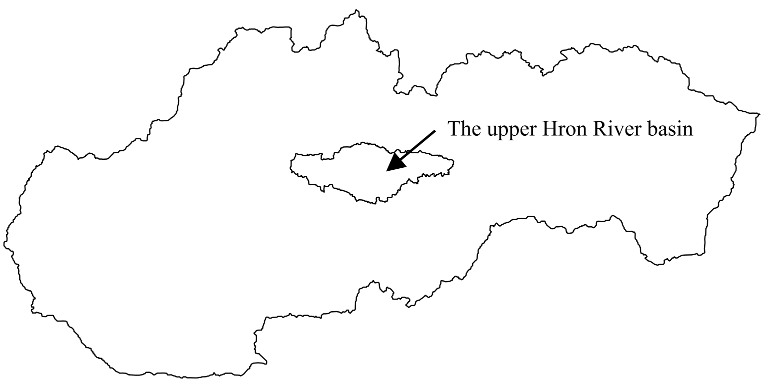

Fig. 1. Location map of the upper Hron River basin in Slovakia.

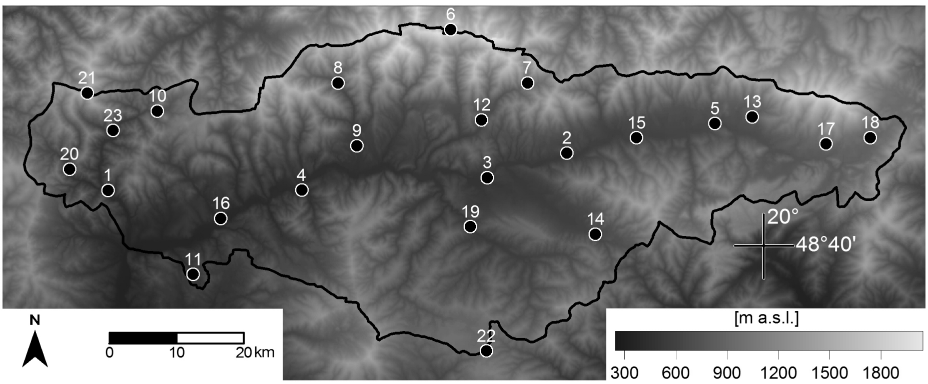

Fig. 2. Topography of the upper Hron River basin with the location of the precipitation stations.

and increases again up to 1500 mm, at the highest altitudes of the Low Tatras.

In the study the annual maximum 24-hour precipitation totals are analysed, which is the greatest amount of precipitation in a 12-month period for a 24-hour duration measured from 7 a.m. to 7 a.m. (MLT) of the next day and associated with the date of the previous day. The calendar year was used for determining precipitation annual maxima for 24-hour's in this

Table 1. Values of selected climatic characteristics of the upper Hron River basin in 1951-1980

Climate characteristics	Valleys	Mountainous slopes
Mean air temperature [°C] – January	(-4.0) – (-5.5)	(-3.5) – (-9.0)
Mean air temperature [°C] - July	18.0 – 14.5	18.0 – 7.0
Mean annual precipitation [mm]	600-850	700-1500
Mean annual precipitation in warm season (April-September) [mm]	350-550	400-800
Mean annual precipitation in cold season (October-March) [mm]	300-400	300-700
Mean annual evaporation [mm]	400-450	450-200

study, and the data were obtained from the precipitation records of the Slovak Hydrometeorological Institute.

The selection of the climatic stations aimed at covering the whole region uniformly with stations which have a complete series of observations during the period 1961-2000. The final dataset included 23 precipitation stations (6 of them are also climatologic stations), their spatial distribution is shown in Fig. 2, and a list with their elevations is summarised in Table 2.

Table 2. The list of analysed precipitation stations

Station	Elevation (m a.s.l.)	No. of station	Station	Elevation (m a.s.l.)	No. of station
Banská Bystrica	398	1	Mýto pod Ďumbierom	634	12
Beňuš	542	2	Pohorelá	764	13
Brezno	490	3	Pohronská Polhora	618	14
Brusno	406	4	Polomka	586	15
Heľpa	657	5	Slovenská Ľupča	372	16
Chopok	2008	6	Šumiac	887	17
Jarabá	892	7	Telgárt	901	18
Jasanie na Kyslej	705	8	Čierny Balog – Krám	530	19
Jasenie	492	9	Dolný Harmanec	481	20
Motyčky	688	10	Krížna	1570	21
Môlča	459	11	Lom nad Rimavicou	1018	22
			Staré Hory	483	23

Annual maximum daily precipitation totals occur predominately in the summer months as a result of several different storm mechanisms. They may occur due to convective activity associated with cyclonic synoptic weather systems. In such a case, the 24-hour annual precipitation maxima are embedded within rains of a longer duration. They may also occur due to intense convective activity not associated with an organised cyclonic weather system, but with thunderstorms in instable air masses in the late spring, summer and early autumn. These are of significantly shorter duration than one day, occur mainly in the late afternoon, and have limited areal coverage. The mean annual number of thunderstorm days is about 30 in the upper Hron River basin; some stations can also have more than 35 days an average. The number of thunderstorm days does not show any significant altitudinal dependence.

3. Methods

3.1. Estimation of design maximum precipitation totals

The steps in traditional design precipitation estimation are as follows:

1. Choose an appropriate distribution on the basis of some criterion.
2. Estimate the parameters of this distribution.
3. Determine the design value with a selected return period. For annual maximum values it holds that the given exceedance probability is $q = 1/T$, where T is the return period.

Unfortunately, our prior knowledge of hydrologic and meteorological processes is not sufficient for the choice of an appropriate theoretical distribution. The extreme value theory can be of help in a broader sense since the data itself may not provide a straightforward answer to the question of which theoretical distribution is the best one for a specific problem (*Cunnane, 1985*). Similar studies have also favored the use of such distributions, e.g., the EV1 - Gumbel distribution, or GEV - General extreme value distribution (*Geiger et al., 1986; Lang et al., 1998; Loukas et al., 2001; Casas et al., 2007; Wallis et al., 2007*). The GEV is to be generally considered a very suitable distribution (*Hosking and Wallis, 1997*). In the present study the GEV distribution was selected to be tested as a candidate both for at site and a regional frequency analysis.

In order to increase the information content in the data, it is recommended to merge observations from the individual observation points (*Hosking and Wallis, 1997*) which come from a homogeneous region, and to analyse not just individual series but to use also regional data. The method adopted here is based on the so-called index flood method, which was developed by *Dalrymple (1960)* and put into a new theoretical framework by *Hosking and Wallis (1997)*, which has the following steps:

1. Scaling of each observation series by means of a parameter of the central tendency (mean, median, mode) – the so called index flood – here, the mean is used.
2. Estimation of the representative quantiles across the scaled regional sample and establishing the form of the distribution function and its parameters on the basis of the total regional data sample.

Homogeneity implies that a scaled data series has the same theoretical distribution. Clearly it seems unreasonable to believe that such an assumption would ever be entirely true. However, if only limited records are available at the sites in question, this is a reasonable approximation to make (*Stedinger, 1983*). Recently, the main emphasis has been on the development of statistically robust regional estimators of frequency distributions, the so–called L-moments (*Hosking, 1990; Vogel and Fennessey, 1993*).

The time series of annual maximum daily precipitation totals in each station were analysed using L-moment statistics. The three parameters of the GEV distribution were estimated, the appropriateness of using the GEV distribution was tested in each station; and 100-year values of the annual maximum 24-hour precipitation was computed.

The identification and formation of homogeneous regions is an iterative process. Here it was anticipated that the upper Hron region would not require sub-division to meet the homogeneity criteria. Based also on results from *Gaál (2006)*, who performed a regional frequency analysis for 56 precipitation stations covering the whole territory of Slovakia, also including stations from the upper Hron River basin, the whole region was selected a priori as homogeneous. According to *Gaál (2006)* the stations from the region belong to a homogeneous sub-region of Slovakia; the analysis was based on the similarity of physiographic and climatic characteristics determined by K-means clustering and confirmed by the test of *Hosking and Wallis (1997)*. The convective characters of the 24-hour annual maximum precipitation and its weak altitudinal dependence also support this decision.

Hosking and Wallis (1997) proposed to test the homogeneity of pooled sites by a measure based on L-moment ratios, which compares the between-site variation in sample L-Cv (coefficient of a variation) values with the expected variation for a homogeneous pooling group. This method fits a four-parameter kappa distribution to the regional average L-Cv ratios. The estimated kappa distribution is used to generate 500 homogeneous pooling groups with population parameters equal to the regional average sample L-Cv ratios. The properties of the simulated homogeneous pooling group are compared to the sample L-Cv ratios as

$$H_1 = \frac{V_1 - \mu_V}{\sigma_V}, \tag{1}$$

where μ_V is the mean of the simulated V_1 values, and σ_V is the standard deviation of the simulated V_1 values. For the sample and simulated pooling groups, respectively, V_1 is calculated as

$$V_1 = \sqrt{\frac{\sum_{i=1}^{N} n_i (t^{(i)} - t^R)^2}{\sum_{i=1}^{N} n_i}}, \tag{2}$$

where N is the number of sites, n_i is the record length at the site i, $t^{(i)}$ is the sample L-Cv at site i, and t^R is the regional average sample L-Cv.

According to the L-moment used in the definition of the statistics V, (H), Hosking and Wallis defined three heterogeneity measures: H_1 (V_1) – when L-Cv (t) is used and H_2 (V_2) – if the $L - Cs$ (t_3) is used and H_3 (V_3) – if the $L - Ck$ (t_4) is applied. Pooling groups are usually classified as acceptably homogeneous if $H_i < 1 (i = 1, 2, 3)$, possibly homogeneous ($1 \leq H_i \leq 2$) and heterogeneous ($H_i > 2$). In the case of additional variability in the data H_1 less than 2 may be accepted as homogeneous for 24-hours precipitation (*Wallis et al., 2007*). According to the test, where the H_1 value was calculated to be equal to 1.94; the whole region was found to be acceptably homogeneous.

One of the primary tasks in the regional analyses was to identify the best probability distribution for describing the behavior of the annual maxima data. Plots of the regional L-Skewness and L-Kurtosis values for the Hron region with a 24-hour duration are shown in Fig. 3. In order to select the appropriate regional frequency distribution function the L-moment ratio diagram was used. The closeness of the regional mean and the at site data to the GEV distribution is clearly evident.

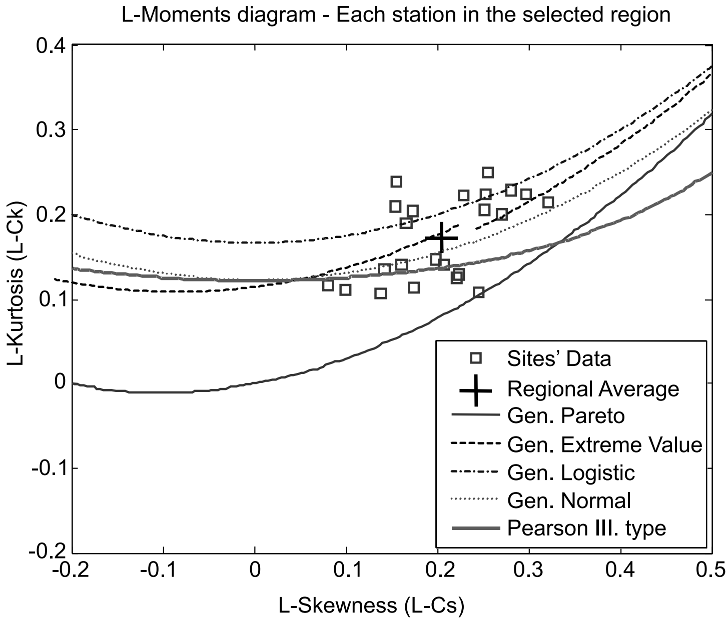

Fig. 3. L-moment ratio diagram for the precipitation stations in the upper Hron River region.

Accordingly, a goodness-of-fit test statistic (*Hosking and Wallis, 1997*) was computed for use in identifying the best three-parameter distribution. An acceptable distribution function should achieve a value of $|Z^{DIST}| \leq 1.64$ (for details see *Hosking and Wallis, 1997*). The results of the Z^{DIST} goodness-of-fit measure presented in Table 3 show the three accepted distribution functions – General Logistic, General Extreme Value (GEV) and General Normal. The lowest value of Z^{DIST} achieved the GEV distribution.

Table 3. Results of the Z^{DIST} goodness-of fit measure

Distribution function	General Logistic	General Extreme Value	General Normal	Pearson Type III.	General Pareto
Z^{DIST} **value**	1.60	-0.84	-1.44	-2,68	-6,45

Due to the location of the regional L-moment ratios (see Fig. 3) and also to the results of the test (Table 3), the GEV distribution function was selected as the regional one. Table 4 contains the values of the quantiles of dimensionless regional frequency distribution – GEV.

Table 4. Values of the quantiles of the dimensionless regional frequency distribution – GEV.

Probability of exceedance	0.900	0.800	0.500	0.200	0.100	0.050	0.020	0.010
Quantile estimates	0.673	0.751	0.941	1.210	1.397	1.584	1.837	2.034

3.2. The kriging interpolation method

The general form of the equation for interpolation in the $z(x, y)$ plane at point z_0 *(Meijerink et al., 1994)* is:

$$z_0 = \sum_{i=1}^{n} w_i z_i, \tag{3}$$

where:
z_0 is the estimated value of the process at any point x_0 and y_0,
w_i is the weight of the sampling point i,
$z_i(x_i, y_i)$ is the observed value of the attribute at point x_i, y_i,
n is the number of sampling points considered.

The ordinary kriging was applied in this study. It is a stochastic interpolation approach, which is designed to give the best linear unbiased estimate (B.L.U.E) of the variable of interest. The best means that the weights w_i are assessed by minimizing the variance of the interpolation error using a statistical relationship (spatial autocorrelation) between values at sampled points. The term linear means that the estimation of mapped variable in ungauged sites is based on a weighted linear combination of observations in neighborhood and the term unbiased refers to the zero bias of interpolation errors. More detailed description of the algorithm is available in geostatistical literature (e.g. in *Isaaks and Srivastava, 1989*).

Elevation has often been used as a secondary variable in some studies. In order to support the choice of kriging interpolation method used in this study, the relationship between an elevation and the mapped variables was also investigated.

The relationship between the daily precipitation totals and the catchment elevation was tested on each day in the period 1961-2000. As expected and as also reported in the climatological studies (e.g. *Lapin et al., 2002*) and due to the convective character of the 24-hour annual maximum precipitation in the region, the correlation was not significant in general and did not exhibit a uniform tendency – both positive and negative correlations were observed. The mean values of the correlation coefficients were low and oscillated around a value of 0.2 (Fig. 4). Next, the 100-year annual maximum daily precipitation values were plotted against the station elevation; these plots are shown in Fig. 5. The associated R^2 coefficients are 0.02, respectively.

4. Results

In this chapter different mapping approaches to design 100-year annual maximum daily precipitation totals are compared and discussed. The first approach comes from the direct mapping of at site estimates of 100-year maximum daily precipitation totals by the kriging interpolation. The second approach is based on the interpolation of daily precipitation totals over a regular grid network in a catchment. In this method, the design annual maximum daily precipitation totals were estimated from the time series of the annual maximum daily precipitation totals in each grid point of the selected region. In the third method, the spatial distribution of the design precipitation was estimated by quantile values as predicted by a regional precipitation analysis. For this purpose the Hosking and Wallis procedure

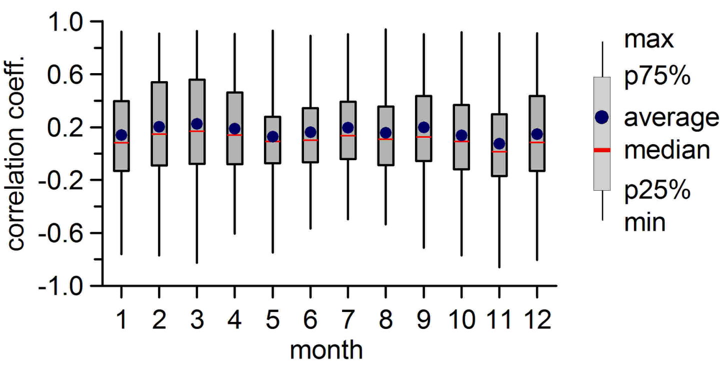

Fig. 4. Distribution of the correlation coefficient between the daily precipitation totals and the elevation in each month.

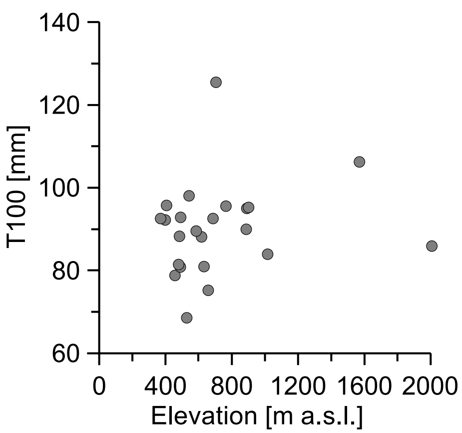

Fig. 5. Relationship between the estimated design 100-year daily maximum precipitation totals calculated at the stations and the elevations.

was adopted; the homogeneity of the region of interest was tested, and the dimensionless regional frequency distribution derived by using L-moments and the index value (the mean annual maximum daily precipitation) was mapped using spatial interpolation. For all these 3 mapping approaches the kriging interpolation method was used.

In the fourth approach, the estimation of design maximum daily precipitation totals at 557 stations in Slovakia with complete data series in 1950-2000 was the base for the subjective isohyets construction by Lapin and Faško (*Faško et al., 2000; Gaál et al., 2004*). The isohyets of 100-year maximum daily precipitation totals have been hand drawn in the map with the scale of 1 : 750 000 with taking into account similarity of conditions in each topographically homogeneous part of Slovakia. This method enables to construct isohyets also in the areas without any long-term observations. More than 20 year experience with the elaboration of such maps and comparing them with radar and satellite observations proofed the high reliability of this expert approach. This analysis is also based on a good knowledge of dynamic climatologic characteristics and air circulation conditions at different localities in the country.

In Fig. 6 maps of design maximum daily precipitation totals are illustrated. Regardless of a low correlation between annual maximum daily precipitation totals, as well as between their design values with an elevation, local effects of the terrain represented by orography are apparent here. The lowest values of the design annual maximum daily precipitation totals in maps A, C and D are resulting from the rain shadow effect for the leeward sites. On windward slopes the raising effect of the maximum daily precipitation is evident. In map B, the design annual maximum daily precipitation totals are generally lower in comparison with the previous maps, especially

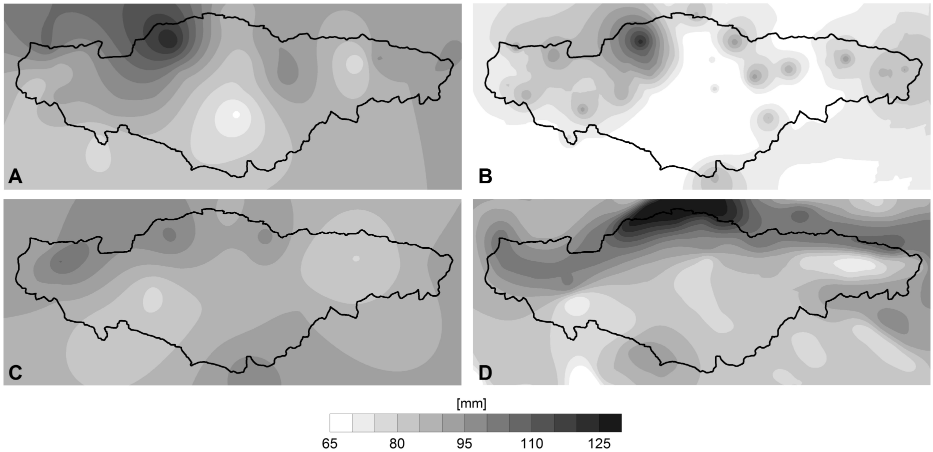

Fig. 6. Maps of 100-year maximum daily precipitation totals derived by different mapping approaches (A = at site, B = interpolation of daily precipitation, C = regional estimation, D = Lapin and Faško).

on areas with the low density of stations. These results are caused by the smoothing effect of interpolations for daily precipitation totals, especially in the case of the occurrence of local extremes with a high degree of differences in their spatial distribution during convective atmospheric events.

In Fig. 7 a comparison of percentage differences between maps of the design maximum daily precipitation totals derived by A, B and C mapping

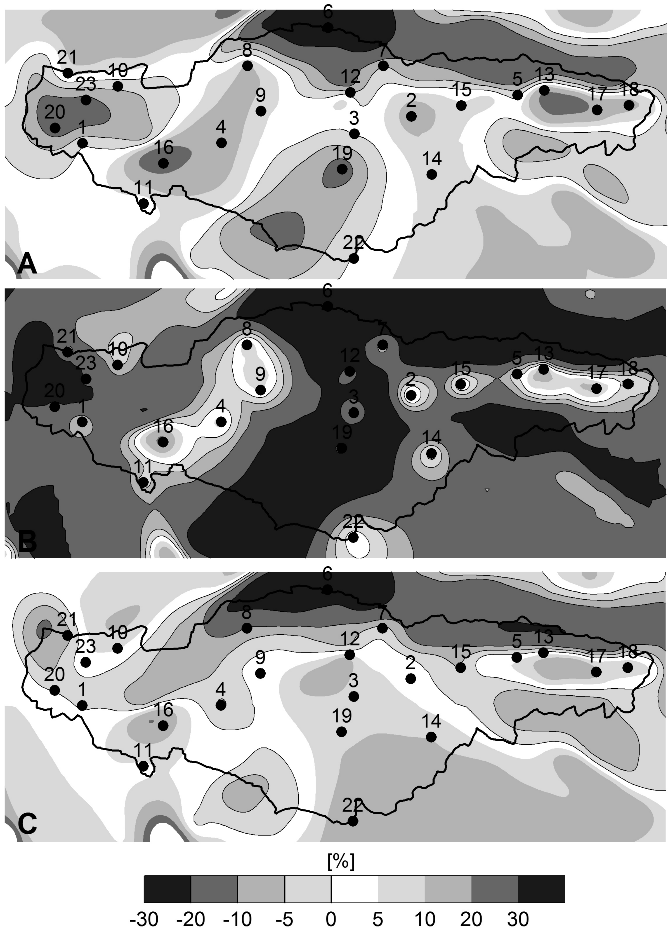

Fig. 7. Percentage differences between maps of 100-year maximum daily precipitation totals derived using the kriging interpolation method and the map derived by Lapin and Faško (A = at site, B = interpolation of daily precipitation, C = regional interpolation).

approaches using the kriging interpolation method and the expert's hand drawn map D is presented. In Table 5 areas of the upper Hron River basin with the same category of the percentage differences of A, B and C maps from D map are compared.

Table 5. Comparison of the catchment area in [%] belonging to the certain range of percentage differences between the maps of 100-year maximum daily precipitation totals derived using the kriging interpolation method and the map derived by Lapin and Faško.

Category of differences [%]	Percentage of the basin's area [%]		
	A at site	B interpolation of daily precipitation	C regional interpolation
less then -30	0.2	8.0	0.3
(-30) – (-20)	1.7	30.1	2.9
(-20) – (-10)	11.7	33.7	8.5
(-10) – (-5)	17.7	10.6	13.2
(-5) – 0	16.9	8.4	21.1
0 – 5	21.7	5.0	22.5
5 – 10	16.5	3.0	18.3
10 – 20	11.2	1.0	13.0
20 – 30	2.4	0.1	0.0

From the comparison in Table 5 it can be seen that for A and C mapping approaches the differences from the expert drawn map D are less than ±20% on the most of the basin's area. Differences in the category from 0 to ±5% take 38.6% of the basin's area for A map and 43.7% of the basin's area for C map, and only 13.6% of the basin's area for B map. Differences in the range of ±5 to 10% are on 34.2% of the basin's area for A map and 31.5% of the basin's area for C map, and only 13.6% of the basin's area for B map. Differences in the range of ±10 to 20% are on 22.9% of the basin's area for A map, 21.5% of the basin's area for C map and 34.6% of the basin's area for B map. Differences higher than 20% take 4.3% of the basin's area for A map, 3.3% of the basin's area for C map and 38.3% of the basin's area for B map.

From the comparison it follows that mapping approaches based on interpolation of at site and regionally estimated design precipitation (A and C) are rather consistent with the expert based approach (D). Some differences can be seen in areas where local topographical effects are apparent, especially in the case of low stations density. Such inconsistency comes from the used interpolation method which does not consider these topographical effects in the region with a complex orography. In spite of this the very work intensive interpolation method D can be replaced by quite reliable method C based on the regional estimation. Some improvement of methods A and C is possible after detail topography conditions being included into the interpolation.

The greatest differences in the comparison with the subjectively constructed D map were found for the method B based on daily estimation of extremes. Under the specific regime dominated by thermal (convective) and frontal (cyclonic) heavy precipitation events, the potential advantage of using mapping of daily precipitation series as a basis for quantiles estimation was not shown. This method also does not suit for the estimation of the design maximum daily precipitation totals at areas with low stations density.

5. Conclusions

The purpose of the study was to produce and compare maps of 100-year daily precipitation as extreme rainfall indexes, which could be used in engineering hydrology for rainfall-runoff studies and estimating flood hazard. In follow up investigations the mapped information could be further processed by engineering hydrologic methods such as temporal disaggregation and/or the spatial reduction of the design precipitation values.

Four approaches to the preprocessing of data to be mapped were used and three interpolation methods employed. Combinations of the respective results were described and compared with a special emphasis on the spatial patterns introduced by each processing and mapping approach to the final maps. The study was not aimed at finding the best method; it was intended more to comment on the quality and properties of the final products (maps of design precipitation with a given return period) with respect to the expectations of the end user community.

Daly (2006) suggests, that complex regions, such as those that have significant terrain features, and also significant coastal effects, rain shadows, or cold air drainage and inversions, are best handled by sophisticated systems that are configured and evaluated by experienced climatologists. That might well also be the case for the upper Hron River basin, where in addition to the synoptic spatial scale, both Mediterranean and continental effects mix their influence. Such a complex approach can hardly be taken into consideration in engineering projects.

Two solutions can be suggested for such conditions, in principle. One is to initiate and conduct countrywide studies of mapping extremes such as that described in *Wallis et al. (2007)* and supported by extensive background data and knowledge. In small scale studies the use of one of the available versions of the regional frequency approach could be recommended as a suitable method to account for spatial variability. It is well described in the literature and supported by appropriate software. The drawbacks of the approach lie in the problem of solving discontinuities on the borders of regions (which were avoided here by the suggestion that the whole region be taken as homogeneous area) and in subjective decisions that are to be taken when delineating regions, which require a high degree of skill from the analysts. By trading space for time it overcomes the data shortage problem, and through the expected and quantitatively underpinned spatial homogeneity, it also offers a solution to the problem of inadequate spatial coverage and sampling of the precipitation fields by the gauging network.

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