Developing of the rainfall intensity-duration-frequency curves for the Kosice region using multiple computational models

A Repel 1

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Abstract. There are several formulated methods for determining of calculative stormwater flow rates in the sewage system. Three basic characteristics can be attributed to rainfall, i.e. duration, intensity and frequency. The flow rate in storm drainage network is mainly dependent on the intensity of the rain. The main parameter in the IDF curves is rainfall intensity, which is a measure of rain falling in a given time. Extremeness of a rainfall event depends on the duration of rainfall. For this reason, Intensity–Duration–Frequency (IDF) curves are extensively used in water resources engineering. This paper is focused on developing new IDF curves using three models: Dub model, Blaszczyk model and Reinhold model in the Kosice region. From the calculated values of intensities, it is clear that the relations used in Slovakia and Germany have brought very similar results of intensities, but intensity calculated according to Blaszczyk model, used in Poland equals to quarter amount.

1. Introduction
Rainfall, and its duration, intensity and frequency are very important in urban hydrology, for example in designing of sewerage or drainage system is cities. Extremeness of a rainfall event depends on the duration of rainfall. For this reason, Intensity–Duration–Frequency (IDF) curves are extensively used in water resources engineering for planning and designing [1]. IDF curves provide estimates of return levels for the continuum of durations and return periods. The problem of creating IDF curves is that they need more than a hundred years of data collection, while the series that are available are mostly much shorter. Estimating the 100-year return level, for example, relies then on extrapolating using some statistical model. Uncertainty is inherent to this estimation because no model is perfect. This is particularly true for extreme value estimation – such as the 100-year return period – because it is based on few data, so a subsequent variability is induced by sampling. Risk evaluation should account for this uncertainty to avoid over-optimistic results [1]. Since current infrastructure dealing with flooding and precipitation (e.g. dams or dikes) are based on IDF curves, ignoring uncertainty may result in sharp underestimation of flood risk and failure risk of critical infrastructures [2].

The main parameter in the IDF curves is rainfall intensity, which is a measure of rain falling in a given time. The rainfall intensity is usually expressed by the height of the rainfall layer per minute (mm/min) or as the specific rainfall intensity in liters per second on one hectare (l/s·ha). The intensity of the precipitation, its duration and the area it has affected have fundamental importance in determining the outflow from the area and therefore there are very important in hydrology [4]. Between rainfall intensity expressed in mm/min (i) and specific rainfall intensity in l/s·ha (i’ ) applies equation \( i = 0.006i’ \) [5]. In general, the greater the intensity of rainfall is the shorter length of time it
continues. In other words, shorter the rain is, the greater is its intensity. For a particular location, it is possible to draw a series of curves showing the probabilities of various intensities of rainfall occurring at that place in given periods. These curves are called IDF curves, which were mentioned above [6]. Proper selection of storm sewers geometry requires the determining of the duration of calculative stormwater flow, during which the established precipitation intensity will bring to a certain stormwater runoff from the catchment to the sewage system. There is a number of formulated methods for determining of calculative stormwater flow rates in sewage systems. Precipitation belongs to random events, and virtually every one of them has a different course in time and space. However, when comparing the rains observed over a long period of time, it can be noticed a certain relationship between them [7].

2. Material and methods
There are several methods of calculation, on the base of which the establishing of calculative stormwater flow in sewage system is carried out, taking into account a number of parameters characterizing mainly the catchment and accepted level of reliability of the designed sewage system, associated with the frequency of gravitational operating, action under pressure of the occurrence of flooding from network [7]. The following part of the paper presents different models for calculation specific rainfall intensity. This study is focused on developing IDF curves using three different empirical models, which are used in Slovakia, in Germany and in Poland. First empirical model is Dub model, which is using in Slovakia, second is Blaszczyk model used in Poland and second is Reinhold model, which is using in Germany.

2.1. Rainfall intensity according to Dub
In Slovakia, a relationship based on professor Dub's knowledge, and based on rain data processed by Šamaj and Valovič, is used to calculate the intensity. This relationship was developed by Urcikán and Horváth (1979) [5] and is described by equation (1).

\[ q = K \times (t^a + B)^{-1} \]  

where:
- \( q \) – specific rainfall intensity \((\text{l/s} \cdot \text{ha})\),
- \( K, B, a \) – local parameters for 68 ombrographic stations in Slovakia,
- \( t \) – duration of precipitation \((\text{min})\).

2.2. Blaszczyk model
In Poland for determining of calculative stormwater flow rate when dimensioning of drainage and combined sewage systems the formula of Blaszczyk model is commonly used for more than 50 years. Blaszczyk model was developed in 1954 and coming out from 67 years of observations. On the territory of Poland for the dimensioning of drainage infrastructure Blaszczyk model is mostly used. It is described by the equation (2) [7].

\[ q = \frac{6.631 \times \sqrt[3]{H \times C}}{t_{dm}^{2/3}} \]  

where:
- \( q \) – specific rainfall intensity \((\text{l/s} \cdot \text{ha})\),
- \( H \) – average annual amount of precipitation from multi-year period \((\text{mm})\),
- \( C \) – frequency of calculative rainfall occurrence for storm drainage system dimensioning \((\text{years})\),
- \( t_{dm} \) – calculative time of rain \((\text{min})\).

The use of this model is also possible in Slovakia because of similar latitudes. The average annual precipitation amount from the multi-year period for the territory of Slovakia has a value in the range of \( H = \) from 500 mm to 2000 mm in high altitudes in High Tatras [8].
2.3. Reinhold model
In Germany, the calculative rainfall intensity for the purposes of drainage systems dimensioning in urban areas the Reinhold model is often used. This model was published in 1940 and it is presented by the relationship described by equation (3) [7].

\[ q = q_{15.1} \times \left( \frac{3B}{t+9} \times \left( \frac{1}{\sqrt{p}} - 0.3684 \right) \right) \]  

where:  
- \( q \) – specific rainfall intensity (l/s·ha),  
- \( q_{15.1} \) – reference rainfall intensity of duration \( t = 15 \) minutes and frequency \( C = \) one year (l/s·ha),  
- \( p \) – the probability of precipitation occurrence (-),  
- \( t \) – duration of precipitation (min).

The value of \( q_{15.1} \) can be read out from the Atlas of rains developed in Germany and depends on the geographical location of the canalized catchment. This reference value varies from 90 to 170 l/s·ha.

3. Results and discussion
Each of these three empirical models (Dub, Blaszczyk and Reinhold) were used to calculating of rainfall intensity in the city of Kosice for periodicity \( C = 5 \) years (one time per five years) or probability \( p = 0.2 \), which is the same. Although not every model was developed for the area of Slovakia (only one of them is specially used in Slovakia), their use is possible as they have been developed under similar morphological conditions. Each model was used to calculating rainfall intensity for rain with probability 0.2 and with durations from 5 minutes to 120 minutes. The results of calculated rainfall intensities for rains with durations from 5 to 120 minutes by three models are in Table 1.

|       | 5 min | 10 min | 15 min | 30 min | 60 min | 80 min | 100 min | 120 min |
|-------|-------|--------|--------|--------|--------|--------|---------|---------|
| DUB   | 367.33| 257.86 | 199.87 | 120.75 | 68.45  | 53.39  | 43.86   | 37.27   |
| BLASZCZYK | 298.98| 188.35 | 143.74 | 90.55  | 57.04  | 47.09  | 40.58   | 35.93   |
| REINHOLD | 342.59| 252.44 | 199.85 | 122.98 | 69.51  | 53.89  | 44.00   | 37.18   |

The highest values of rainfall intensities are when Dub model is used for empirical calculation. It means bigger dimensions of pipes when designing rainwater sewage systems, then when using Reinhold or Blaszczyk model. Values of rainfall intensities calculated by Dub and Reinhold are very similar. The lowest rainfall intensities are, when Blaszczyk model is used. From the calculated rainfall intensities, IDF curves were developed (Figure 1). IDF curves are graphical representation of table 1, where rainfall intensity is on vertical axis, duration of the rain is on horizontal axis, and computational methods are distinguished by different colors. These IDF curves shows rainfall event with periodicity 5 years, which is the same that probability 0.2.
4. Conclusion
One of the most important parameter used to calculate design flow in designing urban sewerage and drainage systems is rainfall intensity, which is the main parameter of IDF curves. In this paper, rainfall intensities were calculated using three empirical models, and after that IDF curves for Kosice were developed. From the calculated values of intensities, it is clear that the relations used in Slovakia (Dub model) and Germany (Reinhold model) have brought very similar results of intensities, but intensity calculated according to Blaszczyk model, used in Poland equals to quarter amount. The highest values of rainfall intensities are when Dub model is used.

5. References
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