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GENERATION OF RAINFALL INTENSITY-DURATION-FREQUENCY CURVES

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Abstract: Intensity - Duration - Frequency (IDF) relathionships are essential for the design of hydraulic structures, for future planning and management, as well as for urban drainage systems. The objective of this study is to establish this type of relationship for Turnu Ruieni hydrometric station located in the Sebes River Basin. Based on 45 years of maximum annual rainfall data, IDF curves and rainfall intensities for durations ranging from 3 to 24 hours were generated. The analysis was performed using Gumbel probabilities distribution function.
Keywords: rainfall, IDF, standard deviation, Gumbel, frequency factor

1. INTRODUCTION

Floods are one of the main natural hazards with major impact on the environment, posing a threat to human lives and their properties, and causing significant economic losses.

The main objective of this study is to develop the Intensity-Duration-Frequency (IDF) curves by establishing statistical relationships among rainfall intensity, duration and frequency (return period). This relationships are highly important in design hydrology, being used to determine maximum design discharges from small catchments, or in designing the urban drainage systems. The design rainfall intensity for a given duration and rainfall frequency is estimated from a set of statistically derived IDF curves, calibrated for a specific region. It is useful to have a long historical series of observations in order to determine the statistical properties of maximum annual rainfall.

IDF curves were developed for shorter durations and various return periods in different regions [1] and are included in numerous hydrological research studies [2]. When such long timeseries are not available, extrapolations are used with statistical tools to estimate the rainfall depths corresponding to the desired return period.

The present study aims to derive the Intensity-Duration-Frequency (IDF) curves for the Sebes Representative Basin, based on a 45-year record of maximum annual rainfall, to support hydrological design and regional rainfall analysis. Representative basins are small catchments whose characteristics regarding geophysical factors and rainfall regimes are also found across large catchments within their respective regions.

Sebes Representative Basin is one of the 14 representative basins of the National Administration “Romanian Waters”, and it is managed by the Banat River Basin Administration. The main purpose of a representative basin in the hydrometric activity is to provide an understanding of the mechanism of liquid and solid runoff formation in initial phases on small-scale surfaces. This fact gives them a very important role in early-warning forecasts of extreme hydro-meterological events.

IDF curves stand as a starting point in establishing rainfall hyetograph, the most essential input in pluvial or stormwater modelling of urban and rural inhabited areas. Therefore, IDF curves connect extreme rainfall data to design choices or to river basin management. Also, they are part of the instruments used in evaluating the flood risk, mostly in flash flood prone areas. Hence, measures can be proposed to reduce the flood risk, such as stormwater management plans.

2. THE CASE STUDY

Situated in the northwestern sector of the Muntele Mic Mountains, within the Tarcu Mountains range, Sebes river is a right-bank tributary of the Timis river at Caransebes city. Its river basin encompasses a total area of 142 km² at its confluence. The Sebes Representative Basin, monitored at Turnu Ruieni hydrometric station on the main course of the Sebes river, covers 124 km².

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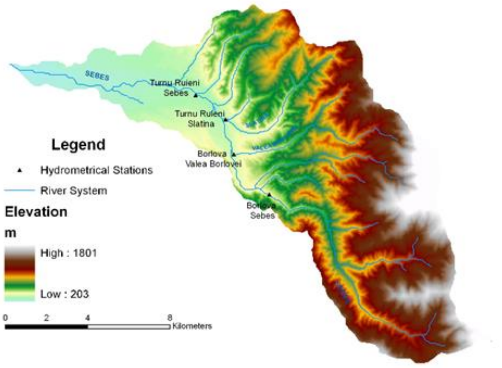

Figure 1. Location map of the study area

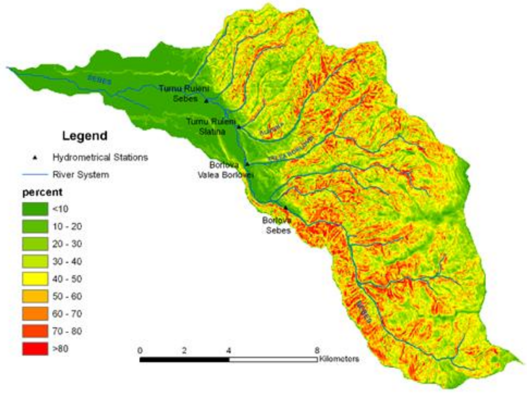

Figure 3. The slope map of Sebes River Basin

Sebes Representative Basin has an elongated shape in the SE-NV direction. The main ridge of Muntele Mic massif branches into several ridges that decrease gradually in altitude towards north-west, west and south-west and they separate the main subbasins.

Figure 2. The land cover map of Sebes River Basin

The land-use map from Figure 2 shows the spatial distribution of the main classes of land use and land cover. Therefore, in the eastern part of the catchment at elevations exceeding 1400 m, there are secondary mountain meadows or pastures on small areas where species as windgrass, red fescues predominate alongside blueberry bushes. This vegetal cover works as a sponge after the rainfall begins, and facilitates water drainage. The lower altitudinal level is occupied by coniferous forest, where spruce and fir prevail. This level goes down to 1100 m altitude. In case of low intensity rainfall, the conifers retain an important quantity of water, while during a torrential downpour create favourable conditions for a higher runoff compared to other types of forest. Deciduous or broad leaved forest occupies most of the catchment, where beech, ash, pedunculate oak and hornbeam predominate. This type of forest can retain up to 60% of the rainfall due to its dense forest canopy.

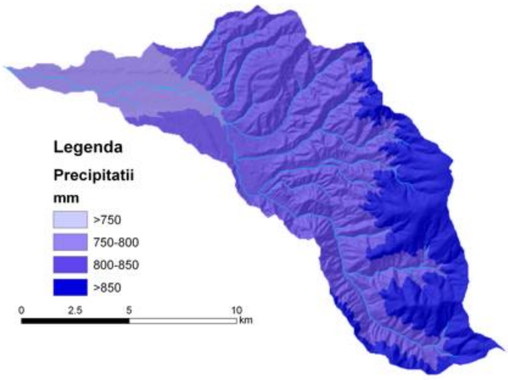

Figure 4. Mean multiannual rainfall of River Sebes

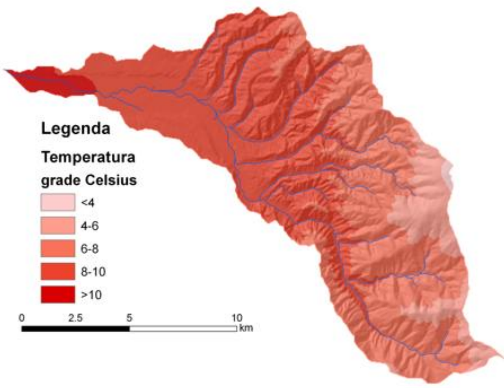

Figure 5. Mean multiannual air temperature – Sebes River Basin

Maps from Figures 4 and 5 display spatial distribution of mean multiannual rainfall and air temperature across Sebes Representative Basin. A spatial variability of pluviometric and thermal regimes is observed: rainfall reaches higher values in mountainous areas and lower values in lower-lying relief zones, while mean air temperatures increase as altitude decreases. These variations illustrate how orographic and geographic factors influence the local climate of the river basin.

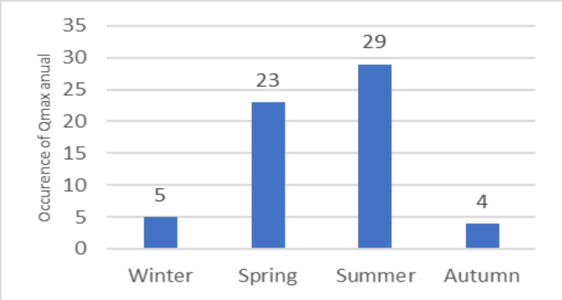

Figure 6. Seasonal distribution of maximum runoff for Turnu Ruieni hydrometric station (1964-2024)

Regarding seasonal distribution of annual extreme maximum discharges, a prevalence of these values is observed in the spring and summer seasons. The values of the maximum annual discharges are mostly associated with the months of April and June, according to the observations and measurements carried out at Turnu Ruieni hydrometric station. In contrast, the autumn and winter seasons exhibit a low incidence of maximum annual discharges, indicating a limited role of hydrological processes to the occurrence of extreme maximum discharges.

3. RESULTS AND CONCLUSIONS.

The maximum annual rainfall values recorded over a 45-years period at Turnu Ruieni hydrometric station were used to develop the graphical representation of the IDF curves. These data form the maximum annual rainfall timeseries. The recorded values of rainfall were adjusted and the statistical parameters of the distribution (mean, standard deviation and skewness coefficient) were determined with Gumbel method (Table 1).

Table 1. Statitstical parameters

Period	3H	6H	9H	12H	18H
Average	25.50	32.13	36.78	40.48	46.34
Standard deviation	9.02	11.36	13.00	14.31	16.38

Subsequently, based on the calculated parameters, the rainfall intensity corresponding to a specific return period is determined. Since shorter rainfall durations of less than 24 hours (0.5 hours, 1 hour, 2 hours, etc.) are of major importance for water resources management, these values were determined for this study. The maximum annual series was obtained from daily rainfall values and calculated for shorter durations using the reduction formula.

In Table 2 are presented these values obtained by extrapolating the maximum values for Turnu Ruieni hydrometric station.

Table 2. Extrapolation of maximum rainfall

Year	Max of 3H	Max of 6H	Max of 9H	Max of 12H	Max of 18H
1980	31.00	39.06	44.71	49.21	56.33
1981	21.15	26.65	30.50	33.57	38.43
1982	13.90	17.51	20.05	22.06	25.26
1983	43.70	55.06	63.03	69.37	79.41
1984	17.10	21.54	24.66	27.14	31.07
1985	17.40	21.92	25.10	27.62	31.62
1986	24.60	30.99	35.48	39.05	44.70
1987	16.00	20.16	23.08	25.40	29.07
1988	17.05	21.48	24.59	27.07	30.98
1989	39.30	49.51	56.68	62.38	71.41
1990	24.90	31.37	35.91	39.53	45.25
1991	22.60	28.47	32.59	35.88	41.07
1992	16.50	20.79	23.80	26.19	29.98
1993	23.40	29.48	33.75	37.15	42.52
1994	22.55	28.41	32.52	35.80	40.98
1995	21.15	26.65	30.50	33.57	38.43
1996	29.25	36.85	42.19	46.43	53.15
1997	22.90	28.85	33.03	36.35	41.61
1998	38.65	48.70	55.74	61.35	70.23
……	……	……	……	……	……
2018	26.85	33.83	38.72	42.62	48.79
2019	30.55	38.49	44.06	48.50	55.51
2020	45.65	57.52	65.84	72.46	82.95
2021	22.70	28.60	32.74	36.03	41.25
2022	14.95	18.84	21.56	23.73	27.17
2023	28.15	35.47	40.60	44.69	51.15
2024	14.70	18.52	21.20	23.33	26.71

An extrem event (X_T) can be determined using probability distribution functions [2], based on the following equation:

$$X_T = \overline{X} + K_T \times \sigma_T \quad (1)$$

Where: X_T - value of the variation (maximum rainfall) corresponding to a specific return period T; X - mean of the observed hydrological variate data; σ_X - the standard deviation of the observed hydrologic variate data; K_T - frequency factor.

The Gumbel frequency factor K_T is a dimensionless parameter used to calculate extreme values, and in the present study, for rainfall intensity corresponding to a given return period T (Table 3).

Table 3. Extreme rainfall values in relation to the frequency factor

K_T	Return Period	3H	6H	9H	12H	18H
0.164	2	24.0	30.3	34.6	38.1	43.6
0.720	5	32.0	40.3	46.1	50.8	58.1
1.305	10	37.3	47.0	53.8	59.2	67.7
2.045	25	43.9	55.4	63.4	69.8	79.8
2.594	50	48.9	61.6	70.5	77.6	88.8
3.138	100	53.8	67.8	77.6	85.4	97.8
4.397	500	65.1	82.1	94.0	103.4	118.4
4.938	1000	70.0	88.2	101.0	111.2	127.2

It links the basic statistics of rainfall timeseries (mean and standard deviation) and the probability of occurrence of a rare event.

Figure 6 illustrates that for a given duration, rainfall amounts increase with the return period, events with a 100-year return period produce higher rainfall than those with a 2-year return period. This spacing between curves is directly determined by the Gumbel frequency factor (K_T).

The Figure 5 shows that as the duration increases, the total amount of rainfall increases, while the intensity generally decreases. An inflexion is evident for 24-hours duration, suggesting a possible shift in the rainfall regime or a transistion from convective to frontal rainfall events.

The slope of the IDF curves from Figure 7 is determined by the standard deviation, whereas their vertical position is influenced by mean of the maximum rainfall values.

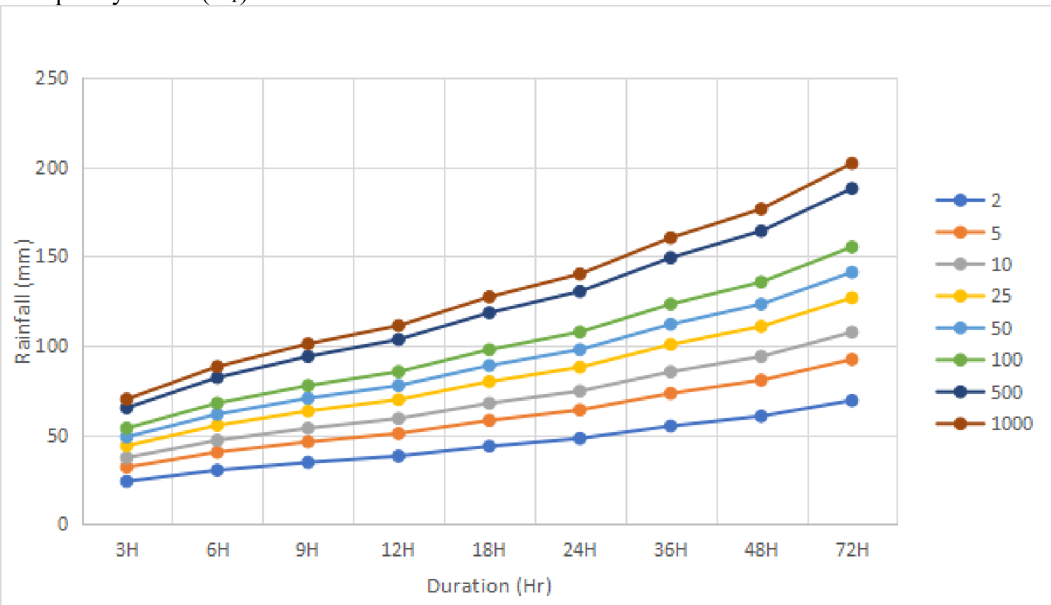

Figure 6. DDF Curves (Depth-Duration-Frequency)

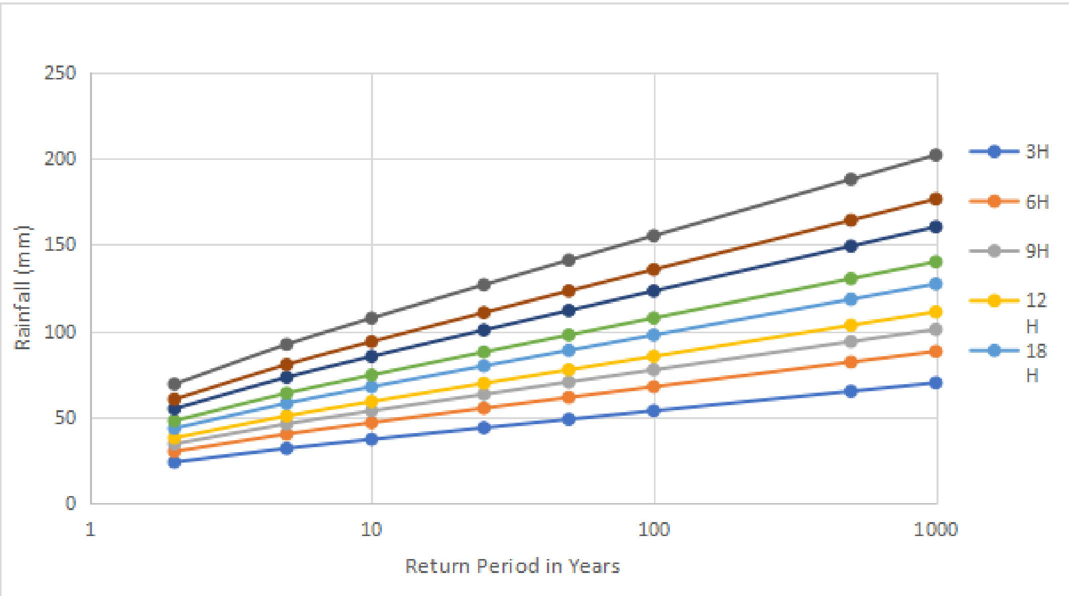

Figure 7. IDF Curves (Intensity-Duration-Frequency)

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