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ASSESSMENT OF REGIONAL EMPIRICAL IDF AND DDF MODELS IN SOUTHERN IRAN

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ABSTRACT

Aim of the study
This study aimed to evaluate and compare regional empirical IDF/DDF models, with particular focus on the Revised IMD (RIMD) approach, for estimating design rainfall in ungauged catchments in Iran.

Material and methods
Daily rainfall data from Baghmalek and Ahvaz were analyzed to determine the best-fit statistical distributions, develop DDF curves using four empirical methods, and assess performance using RMSE and Nash–Sutcliffe model efficiency coefficient, along with a sensitivity analysis of the IMD parameter *n*.

Results and conclusions
Results showed that the default IMD value ($n = 0.333$) was inaccurate over short time periods, whereas the calibrated values ($n = 0.39$ and 0.28) led to a significant improvement in agreement with the observations and produced more reliable runoff estimates.

Keywords: Ghahraman and Abkhezr, Ghahraman and Sepaskhah, IDF, IMD, Vaziri

INTRODUCTION

Estimating design floods is essential for planning and constructing hydraulic structures for flood control and storage. In gauged catchments, design floods are usually derived from statistical analysis of observed annual peak flows. In ungauged catchments, where discharge data are unavailable, indirect approaches must be applied, including empirical formulas and simple or conceptual rainfall–runoff models (Petroselli et al., 2019; Młyński et al., 2020). These models may be event-based or continuous. Event-based models transform a design storm of a given return period into a design flood of the same frequency (Petroselli et al., 2020; Gioia et al., 2021), while continuous models generate long synthetic rainfall and runoff series that are later analyzed statistically (Grimaldi et al., 2022).

Although continuous models offer several advantages (De Luca et al., 2020), event-based approaches are often preferred in small or ungauged catchments because they require fewer parameters and limited calibration (Piscopia et al., 2015). Their accuracy, however, strongly depends on the correct definition of the design storm, particularly rainfall duration and return period. Widely used methods such as the Rational Method (Mulvaney, 1851; Chow et al., 1988) rely directly on design rainfall to estimate peak discharge.

If high-resolution rainfall data are available, intensity–duration–frequency (IDF) curves can be directly derived. However, in many regions, including Iran, rainfall records are limited only to 24-hour totals (Mustafa et al., 2019; Mahmoudi et al., 2023; Abdolmanafi et al., 2025; Minh et al., 2022; Lau et al., 2022; Shamkhi et al., 2022), which requires the use of

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empirical depth–duration–frequency (DDF) relationships to estimate short-duration rainfall (Bell, 1969; Palaka et al., 2016; Rasel and Hossain, 2015; Rosbjerg and Madsen, 2019).

In Iran, notable contributions include the DDF equations of Ghahraman and Sepaskhah (1990) and Vaziri (1991), as well as the widely used IMD method. While Galoie et al. (2021) proposed a modified IMD approach (MIMD) and evaluated its applicability across different regions, this study focuses on assessing the standard and revised IMD (RIMD) method within Iranian context. Particular emphasis is placed on the local calibration of the parameter *n*, a comparison with established regional empirical equations, and an evaluation of its impact on design rainfall and the estimation of runoff.

Despite these efforts, the applicability and sensitivity of empirical DDF methods – particularly the IMD approach – remain insufficiently evaluated in Iranian context. This study addresses this gap by comparing existing DDF methods, assessing IMD performance, and analyzing the sensitivity of its parameter *n* on rainfall and flood estimates, thereby supporting improved flood design in data-scarce regions.

MATERIALS AND METHODS

The construction of the empirical IDF-DDF equations

Empirical IDF or DDF equations relate rainfall intensity or depth to return period and duration, where rainfall duration plays a critical role in defining the design storm. A key challenge in hydraulic design is selecting the correct rainfall duration, as guidance can differ depending on the rainfall–runoff model used. For example, the Rational Method assumes that the rainfall duration is equal to the catchment time of concentration. This means that the entire area contributes to peak discharge. In contrast, the NRCS (formerly SCS) method relates peak discharge and time to peak to excess rainfall and storm duration. For large catchments and critical hydraulic structures, such as spillways, the NRCS commonly recommends a 6-hour design storm (NRCS, 2008).

IDF equations are generally expressed as:

$$I = \frac{KT^a}{\left(t+c\right)^b} \tag{1}$$

where rainfall intensity I (mm/hr) is a function of return period T (years), rainfall duration t (hours), and regional coefficients a, b, c calibrated from short-duration gauge data using statistical distributions. Reliable calibration requires long, high-resolution rainfall records, which are often unavailable in regions where data is scarce. For this reason, simpler empirical approaches with fewer parameters are frequently adopted instead.

In many regions, including Iran, rainfall is recorded mainly as daily totals, from which monthly, annual, and maximum 24-hour values are derived. When short-duration data are unavailable, empirical DDF relationships are used to estimate sub-daily rainfall from 24-hour maxima or annual rainfall statistics. If even daily data are lacking, spatial interpolation methods such as regression analysis or inverse distance weighting (IDW) may be applied with data from nearby stations. Several empirical DDF equations developed for Iranian conditions are summarized in Table 1.

Table 1. Standard empirical DDF formulas in Iran

Name	Equation	Description	Number EQ
Bell (1969)	$T_t^T = \left[0.21\ ln\ T + 0.52\right]\left[0.54t^{0.25} - 0.50\right]R_1^{10}$ For $2 \le T$ (year) ≤ 100 & $5 \le t$(min) ≤ 100	T_t^T is the T-year and t-hour rainfall depth (inches), R_1^{10} is the 10-year and 1-hour rainfall depth (inches), t is the rainfall duration (h)	(2)
Chen (1983)	$I_t^T = \frac{aI_1^{10}\log\left(10^{2-x}T^{x-1}\right)}{\left(t+b\right)^c}$	T_t^T rainfall intensity (inches/hour), T return period (years), t storm duration (minutes), x is depth of frequency ratio (R_1^{100} / R_t^{10}), a, b and c = storm parameters that are dependent on regional ratio (R_1^{100} / R_t^{10})	(3)

Name	Equation	Description	Number EQ
Raudkivi (1979)	$I_t^T = C\frac{T^{0.20}}{t^{0.71}}\left(R_{24}^2\right)^{0.33}$	I is the rainfall intensity (mm/hr), t is the rainfall duration (hr), C is a constant having value 8.31 for the whole of the considered stations. R_{24}^2 (mm) is the rainfall depth having 2-year return period and 24 hr rainfall duration	(4)
Ghahraman and Sepaskhah equation (1990)	$P_T^t = \left(0.452 + 0.247\ln\left(T - 0.601\right)\right)$ $\left(0.371 + 0.6184t^{0.4484}\right)P_{10}^{60}$ $P_{10}^{60} = 2.2598P_{24}^{1.1374}P_{\text{year}}^{0.3072}$	P_{24} is the mean daily rainfall (mm), P_{year} is the mean annual rainfall (mm), t is the rainfall duration (hr)	(5)
Vaziri (1991)	$P_T^t = \left(0.41 + 0.26\ln\left(T - 0.44\right)\right) =$ $= \left(-0.24 + 1.245t^{0.0.267}\right)P_{10}^{60}$ $P_{10}^{60} = \left(3.114 - 0.61\ln\left(P_{24}\right)\right)P_{24}$	t is the rainfall duration (hr), P_{24} is the mean daily rainfall (mm)	(6)
Ghahraman and Abkhiz equation (2004)	$R_t^T = At^B\left[\alpha_1 + \alpha_2\ln\left(T - \alpha_3\right)\right]R_{60}^{10}$ $R_{60}^{10} = e^{0.291}\left(P_{1440}^2\right)^{0.694}$	t is the rainfall duration (min), P_{1440}^2 is the mean daily rainfall (mm)	(7)
Indian Meteorological Department (IMD)	$P^t = P^{24}\left(\frac{t}{24}\right)n$	P^t is the rainfall depth (mm) and t is the duration (hr), p^{24} is the daily rainfall value (mm)	(8)

Equation (8), proposed by the Indian Meteorological Department (IMD), estimates short-duration rainfall from 24-hour data. The IMD method recommends a default coefficient n = 1/3 = 0.333. However, this parameter depends on regional rainfall characteristics and should be locally calibrated. For example, Galoie et al. (2021) reported values of n ranging from 0.29 to 0.35 at stations in Australia, China, and Iran. One of the main objectives of this research is to use Equation (8) to compute the DDF. This equation can be written as follows:

$$P_T^t = P_T^{24}\left(\frac{t}{24}\right)n \tag{9}$$

In Equation (9), P_T^t represents the design rainfall depth for duration t and return period T, and P_T^{24} is the corresponding 24-hour design rainfall derived from the selected probability distribution. Most hydrologists estimate short-duration rainfall (ranging from 0.5 to 24 hours) using recorded 24-hour rainfall data, typically through the India Meteorological Department (IMD) equation.

Once these shorter-duration values are derived, statistical distributions – such as the Gumbel or Generalized Extreme Value (GEV) distributions, which effectively model maximum daily rainfall – are applied to generate DDF curves for various return periods across the selected durations.

In this study, P_T^{24} in Equation 9, referred to as the revised IMD (RIMD) method, is formulated based on the statistical distribution that best fits the region's daily rainfall data. While the Gumbel and GEV distributions are commonly used, other probability distributions may offer a better representation, depending on the regional rainfall characteristics. Selecting the most suitable distribution is essential for improving the accuracy of rainfall estimation in the RIMD method.

Software tools such as Easy Fit, SMADA, and HEC-SSP are commonly used to identify the most suitable statistical distribution for a given region's rainfall data. For example, the RIMD method has been derived using several distribution functions, including the GEV, Gumbel, Logistic, and Log-Logistic distributions. These equations are based on the quantile

Table 2. Depth data (mm) for DDF curves

a) Baghmalek station

Return period	Duration (min)						
(Year)	15	30	45	60	90	120	180
2	8.3	11.8	14.0	16.0	18.9	21.8	25.5
5	14.3	18.7	22.3	25.3	29.4	33.0	37.2
10	18.4	23.2	27.8	31.4	36.2	40.6	44.7
25	23.5	28.9	34.7	39.2	45.0	50.0	54.3
50	27.3	33.2	39.8	45.0	51.5	57.0	61.5

b) Ahvaz station

Return period	Duration (min)										
(Year)	15	30	45	60	90	120	180	360	720	1080	1440
2	9.1	13.3	15.2	17.0	19.8	21.2	22.5	26.4	31.2	32.4	36.0
5	14.2	20.0	23.0	25.8	28.5	30.2	32.7	39.6	45.6	48.6	52.8
10	17.2	23.8	27.4	31.0	33.9	36.0	39.3	49.8	56.4	59.4	62.4
20	19.9	27.1	31.3	35.5	39.2	41.6	46.2	61.8	68.4	72.0	69.6
25	20.7	28.1	32.4	36.8	41.0	43.4	48.3	66.6	73.2	75.6	72.0
50	23.1	31.0	35.7	40.7	46.2	49.0	55.8	81.6	87.6	86.4	76.8
100	25.3	33.5	38.7	44.2	51.8	55.0	63.6	99.6	104.4	97.2	84.0

functions (inverse cumulative distribution functions) of each distribution, allowing the method to be adapted for use with other statistical distributions as needed.

Parameters of the statistical distributions in aforementioned equations can be derived from basic statistics such as the mean and standard deviation of 24-hour rainfall data. Software tools such as Easy Fit can estimate the parameters for more than 50 probability distributions using daily rainfall records, which helps to identify the most suitable model for each dataset.

The case studies

The first study area, Baghmalek, is located in eastern Khuzestan Province, Iran (42°13′E, 31°31′N), at an elevation of 217 m. Analysis of maximum daily rainfall from 1975–2015 provides a mean of 68.1 mm and a standard deviation of 25.7 mm, with an average annual rainfall of about 562 mm.

The second area, Ahvaz, is located in southwestern Iran at the center of Khuzestan Province, in a flat region with a hot, arid climate. Average annual rainfall is roughly 229 mm, and mean annual air temperature is about 21°C. Maximum daily rainfall data from 1968–2011 show a mean of 36.5 mm and a standard deviation of 19.7 mm. Observed short-duration rainfall data from recording gauges were used as reference values for evaluating empirical methods (Table 2).

The following methods were used to compare the calculated design precipitation results with observations. Two widely used statistical metrics were applied: root mean squared error (RMSE) and Nash–Sutcliffe efficiency (NSE).

RESULTS AND DISCUSSION

Development of DDF for the cities of Baghmalek and Ahvaz

DDF curves for Baghmalek were developed using the methods described by Ghahraman and Sepaskhah (1990), Ghahraman and Abkhiz (2004), Vaziri (1991), and the RIMD method. Twenty-four-hour rainfall data from 1975–2015 were analyzed with EasyFit Professional, which tests over 50 distributions using

Chi-squared, Anderson–Darling, and Kolmogorov–Smirnov criteria. These tests were applied to perform a goodness-of-fit analysis. The results (not shown here for brevity) indicate that the three-parameter Weibull distribution provides the best fit for Baghmalek (Chi-squared = 0.71133; Anderson–Darling = 0.3899; Kolmogorov–Smirnov = 0.10695), while the Gumbel distribution was identified as the optimal model for Ahvaz based on the same criteria.

Furthermore, the parameter *n* in the RIMD method was calibrated in a sensitivity analysis by systematically testing values in the range 0.1–0.5. For each value of *n*, the resulting short-duration rainfall estimates were compared with observed data, and model performance was evaluated using the root mean squared error (RMSE) and Nash–Sutcliffe efficiency (NSE) indices. The optimal value of *n* was selected as the one that minimized RMSE while simultaneously maximizing

Table 3. 24-hour design rainfall (mm) for return periods of 2–100 years for both study areas

	Best distribution – T (years)	2	5	10	20	25	50	100
Baghmalek	Weibull (3p)	63.4	88.0	103.3	117.7	120.9	133.0	146.1
Ahvaz	Gumbel	33.2	50.6	62.2	73.2	76.7	87.5	98.2

Table 4. DDF values for Baghmalek using various empirical methods

Design Rainfall (mm) – Baghmalek City															
Calibrated RIMD *n* = 0.39 Time (min)								RIMD *n* = 0.333 Time (min)							
T	15	30	45	60	90	120	180	**T**	15	30	45	60	90	120	180
2	10.7	14.0	16.4	18.4	21.5	24.1	28.2	**2**	13.9	17.5	20.0	22.0	25.2	27.7	31.7
5	14.8	19.4	22.8	25.5	29.9	33.4	39.1	**5**	19.3	24.3	27.8	30.5	35.0	38.5	44.0
10	17.4	22.8	26.7	29.9	35.0	39.2	45.9	**10**	22.6	28.5	32.6	35.8	41.0	45.1	51.7
25	20.4	26.7	31.3	35.0	41.0	45.9	53.7	**25**	26.4	33.3	38.1	42.0	48.0	52.9	60.5
50	22.4	29.4	34.4	38.5	45.1	50.5	59.1	**50**	29.1	36.6	41.9	46.2	52.8	58.1	66.6
Ghahraman and Abkhiz (2004) Time (min)								Ghahraman and Sepaskhah (1990) Time (min)							
T	15	30	45	60	90	120	180	**T**	15	30	45	60	90	120	180
2	8.7	12.2	14.9	17.2	21.0	25.0	29.4	**2**	14.8	17.3	19.2	20.8	23.4	25.5	29.1
5	13.0	18.4	22.5	25.9	31.6	35.8	41.9	**5**	22.6	26.5	29.4	31.8	35.8	39.1	44.5
10	15.9	22.4	27.4	31.6	38.7	43.0	50.4	**10**	27.8	32.6	36.1	39.1	44.0	48.0	54.7
25	19.5	27.5	33.7	38.8	47.4	52.0	61.0	**25**	34.3	40.2	44.6	48.3	54.3	59.3	67.5
50	22.2	31.3	38.3	44.1	53.9	58.8	68.9	**50**	39.1	45.8	50.9	55.0	61.9	67.6	76.9
Vaziri (1991) Time (min)								Observed Time (min)							
T	15	30	45	60	90	120	180	**T**	15	30	45	60	90	120	180
2	11.6	14.9	17.1	18.8	21.5	23.5	26.7	**2**	8.3	11.8	14.0	16.0	18.9	21.8	25.5
5	17.7	22.7	26.1	28.8	32.8	36.0	40.9	**5**	14.3	18.7	22.3	25.3	29.4	33.0	37.2
10	22.0	28.2	32.4	35.6	40.7	44.6	50.7	**10**	18.4	23.2	27.8	31.4	36.2	40.6	44.7
25	26.1	33.4	38.4	42.3	48.3	53.0	60.2	**25**	23.5	28.9	34.7	39.2	45.0	50.0	54.3
50	27.4	35.1	40.4	44.4	50.7	55.6	63.2	**50**	27.3	33.2	39.8	45.0	51.5	57.0	61.5

Table 5. DDF values for Ahvaz using various empirical methods

Design Rainfall (mm) – Ahvaz City																							
Calibrated RIMD $n = 0.28$ Time (min)													RIMD $n = 0.333$ Time (min)											
T	15	30	45	60	90	120	180	360	720	1080	1440		**T**	15	30	45	60	90	120	180	360	720	1080	1440
2	9.3	11.3	12.6	13.7	15.3	16.6	18.6	22.6	27.4	30.7	33.3		**2**	7.3	9.2	10.5	11.5	13.2	14.5	16.6	21.0	26.4	30.2	33.3
5	14.1	17.1	19.2	20.8	23.3	25.3	28.3	34.4	41.7	46.7	50.7		**5**	11.1	14.0	16.0	17.6	20.1	22.1	25.3	31.9	40.2	46.0	50.7
10	17.3	21.0	23.6	25.5	28.6	31.0	34.7	42.2	51.2	57.4	62.2		**10**	13.6	17.1	19.6	21.6	24.7	27.2	31.1	39.2	49.4	56.5	62.2
20	20.4	24.8	27.7	30.1	33.7	36.5	40.9	49.7	60.3	67.6	73.2		**20**	16.0	20.2	23.1	25.4	29.1	32.0	36.6	46.2	58.1	66.5	73.2
25	21.4	26.0	29.1	31.5	35.3	38.3	42.9	52.0	63.2	70.8	76.7		**25**	16.8	21.1	24.2	26.6	30.5	33.5	38.4	48.4	60.9	69.7	76.7
50	24.4	29.6	33.2	36.0	40.3	43.7	48.9	59.4	72.1	80.8	87.5		**50**	19.1	24.1	27.6	30.4	34.8	38.3	43.8	55.2	69.5	79.5	87.5
100	27.4	33.2	37.2	40.4	45.2	49.0	54.9	66.6	80.9	90.6	98.2		**100**	21.5	27.1	31.0	34.1	39.0	43.0	49.2	61.9	78.0	89.3	98.2
Ghahraman and Abkhiz (2004) Time (min)													Ghahraman and Sepaskhah (1990) Time (min)											
T	15	30	45	60	90	120	180	360	720	1080	1440		**T**	15	30	45	60	90	120	180	360	720	1080	1440
2	4.5	6.3	7.7	8.9	10.9	12.9	15.2	19.9	26.2	30.7	34.4		**2**	9.8	11.5	12.8	13.8	15.5	16.9	19.3	24.4	31.5	36.7	41.0
5	6.7	9.5	11.6	13.4	16.4	18.5	21.7	28.5	37.4	43.9	49.1		**5**	15.0	17.6	19.5	21.1	23.7	25.9	29.5	37.4	48.1	56.1	62.7
10	8.2	11.6	14.2	16.3	20.0	22.2	26.0	34.2	44.9	52.7	59.0		**10**	18.4	21.6	24.0	25.9	29.2	31.8	36.2	45.9	59.1	69.0	77.1
20	9.6	13.6	16.6	19.2	23.4	25.8	30.2	39.7	52.1	61.2	68.5		**20**	21.7	25.4	28.2	30.5	34.4	37.5	42.7	54.1	69.6	81.2	90.8
25	10.1	14.2	17.4	20.1	24.5	28.3	34.5	48.7	68.6	83.9	96.7		**25**	22.7	26.7	29.6	32.0	36.0	39.3	44.7	56.7	73.0	85.1	95.2
50	11.5	16.2	19.8	22.8	27.9	32.1	39.3	55.4	78.0	95.4	110.0		**50**	25.9	30.4	33.7	36.5	41.0	44.8	51.0	64.6	83.2	97.0	108.5
100	12.8	18.1	22.1	25.5	31.2	36.0	44.0	62.0	87.3	106.8	123.1		**100**	29.1	34.1	37.9	40.9	46.1	50.3	57.2	72.5	93.3	108.9	121.8
Vaziri (1991) Time (min)													Observed Time (min)											
T	15	30	45	60	90	120	180	360	720	1080	1440		**T**	15	30	45	60	90	120	180	360	720	1080	1440
2	10.8	13.8	15.9	17.5	19.9	21.9	24.8	30.7	37.8	42.6	46.4		**2**	9.1	13.3	15.2	17.0	19.8	21.2	22.5	26.4	31.2	32.4	36.0
5	16.5	21.1	24.3	26.7	30.5	33.4	38.0	47.0	57.9	65.2	70.9		**5**	14.2	20.0	23.0	25.8	28.5	30.2	32.7	39.6	45.6	48.6	52.8
10	20.4	26.2	30.1	33.1	37.8	41.4	47.1	58.3	71.7	80.8	87.9		**10**	17.2	23.8	27.4	31.0	33.9	36.0	39.3	49.8	56.4	59.4	62.4
20	24.2	31.1	35.7	39.3	44.9	49.2	55.9	69.2	85.1	95.9	104.3		**20**	19.9	27.1	31.3	35.5	39.2	41.6	46.2	61.8	68.4	69.6	72.0
25	25.4	32.6	37.5	41.3	47.1	51.6	58.7	72.6	89.4	100.7	109.5		**25**	20.7	28.1	32.4	36.8	41.0	43.4	48.3	66.6	72.0	73.2	75.6
50	29.2	37.4	43.0	47.3	54.0	59.2	67.3	83.3	102.5	115.5	125.6		**50**	23.1	31.0	35.7	40.7	46.2	49.0	55.8	76.8	81.6	86.4	87.6
100	32.9	42.2	48.5	53.3	60.9	66.8	75.9	93.9	115.6	130.2	141.6		**100**	25.3	33.5	38.7	44.2	51.8	55.0	63.6	84.0	97.2	99.6	104.4

NSE, thereby guaranteeing the greatest possible agreement with the observed rainfall data.

Design rainfall for 2–100-year return periods is reported in Table 3. DDF results for five empirical methods are presented in Tables 4 and 5 for Baghmalek and Ahvaz, respectively.

Additionally, Figures 1 and 2 provide a graphical comparison of calibrated RIMD estimates and observed design rainfall depths for Baghmalek City and Ahvaz (Tr = 50 years).

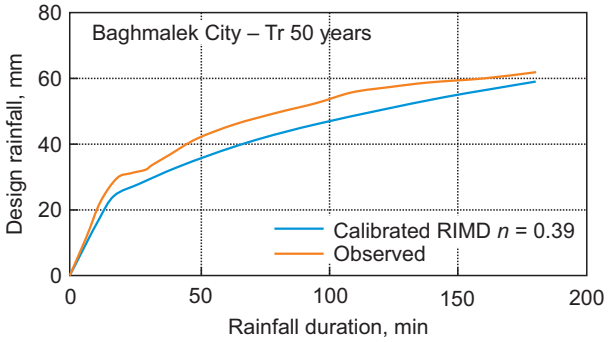

Fig. 1. Comparison of observed rainfall depths and calibrated RIMD estimates for Baghmalek at a 50-year return period (Source: Authors' own elaboration)

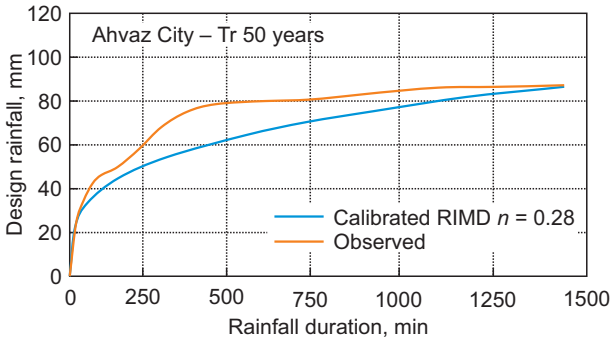

Fig. 2. Comparison of observed rainfall depths and calibrated RIMD estimates for Ahvaz at a 50-year return period (Authors' own elaboration)

Evaluation of the accuracy of different design rainfall methods

To assess the accuracy of the empirical methods, estimated short-duration rainfall depths were compared with observed data from recording rain gauges in Baghmalek and Ahvaz. Model performance was evaluated using root mean squared error (RMSE) and Nash–Sutcliffe efficiency (NSE), as presented in Table 6.

The IMD method (Equation 8) typically adopts a fixed coefficient $n = 0.333$; however, its performance varies regionally. Previous studies reported calibrated values between 0.28 and 0.35 (Galoie et al., 2021), raising concerns regarding the universal applicability of the default value.

Table 6. Performance metrics of the proposed methods for estimating design rainfall

	Baghmalek city		Ahvaz city	
Method	NSE	RMSE	NSE	RMSE
RIMD $n = 0.390$	0.89	2.61	0.85	6.79
RIMD $n = 0.333$	0.55	4.64	0.69	9.62
Ghahraman and Abkhiz (2004)	0.89	2.83	0.32	14.2
Ghahraman and Sepaskhah (1990)	0.07	8.6	0.78	8.25
Vaziri (1991)	0.8	3.18	0.38	13.81

For Baghmalek, RIMD with $n = 0.333$ shows relatively weak performance (NSE = 0.55; RMSE = 4.64). Ghahraman and Abkhiz (2004) provides the best results (NSE = 0.89; RMSE = 2.83), followed by Vaziri (1991) (NSE = 0.80; RMSE = 3.18). After calibration to $n = 0.39$, the RIMD method achieves comparable performance (NSE = 0.89; RMSE = 2.61).

For Ahvaz, Ghahraman and Sepaskhah (1990) performs best (NSE = 0.78; RMSE = 8.25). The RIMD method improves substantially after calibration, increasing from NSE = 0.69 (RMSE = 9.62) at $n = 0.333$ to NSE = 0.85 (RMSE = 6.79) at $n = 0.28$.

These results demonstrate that small variations in n (0.28–0.39) have a significant influence on short-duration rainfall estimates. Although the default value tends to underperform, regional calibration allows the RIMD method to achieve the accuracy comparable to the best empirical equations.

The difference in the calibrated n values for Baghmalek (0.39) and Ahvaz (0.28) reflects the contrasting climatic and topographic conditions of these regions. Baghmalek, located in a mountainous area, is influenced by more intense and variable rainfall patterns, particularly for short-duration events. In contrast, Ahvaz lies in a flat, arid lowland where rainfall is gener-

ally less intense and more uniform. These differences affect the temporal distribution of rainfall and consequently the scaling between 24-hour and short-duration rainfall, leading to different optimal values of *n*.

The effect of the coefficient *n* in the RIMD method on the rational method peak runoff

Peak runoff in urban basins is commonly estimated using the Rational Method:

$$Q_T = CI_T^t A / 3.6 \quad (10)$$

where:

I_T^t (mm/h) – the design rainfall intensity for duration t and return period T,
C – the runoff coefficient,
A (km^2) – the contributing area.

To evaluate the influence of *n*, a dimensionless flow rate (DFR) was defined as:

$$DRF = \frac{Q_p(n)}{Q_p(n-0.333)} = \frac{I(n)}{I(n-0.333)} \quad (11)$$

where:

$Q_p(n)$ – the peak discharge computed using a selected *n* value,
$Q_p(n = 0.333)$ – corresponds to the default IMD coefficient.

Table 7. Effect of parameter *n* on the DFR

	Time (min)											
n	5	10	15	30	60	90	120	180	240	300	360	720
0.1	3.7	3.2	2.9	2.5	2.1	1.9	1.8	1.6	1.5	1.4	1.4	1.2
0.15	2.8	2.5	2.3	2	1.8	1.7	1.6	1.5	1.4	1.3	1.3	1.1
0.2	2.1	1.9	1.8	1.7	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1
0.25	1.6	1.5	1.5	1.4	1.3	1.3	1.2	1.2	1.2	1.1	1.1	1.1
0.3	1.2	1.2	1.2	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1	1
0.333	1	1	1	1	1	1	1	1	1	1	1	1
0.4	0.7	0.7	0.7	0.8	0.8	0.8	0.8	0.9	0.9	0.9	0.9	1
0.45	0.5	0.6	0.6	0.6	0.7	0.7	0.7	0.8	0.8	0.8	0.9	0.9
0.5	0.4	0.4	0.5	0.5	0.6	0.6	0.7	0.7	0.7	0.8	0.8	0.9

The results show that the effect of *n* decreases as the duration of rainfall increases. At 720 minutes, the DFR varies only slightly (0.9–1.2) across the tested range of n. In contrast, at 30 minutes, the DFR ranges from 0.5 to 2.5, indicating high sensitivity to short-duration storms. These findings confirm that the default value of $n = 0.333$ may lead to substantial errors in small urban catchments where short-duration rainfall controls peak discharge.

The RIMD method was first applied using $n = 0.333$, and then *n* was varied between 0.1 and 0.5. DFR was computed for a 5-year, 88 mm rainfall event in Baghmalek (Table 7), and Figure 3 illustrates the sensitivity of peak runoff to *n*.

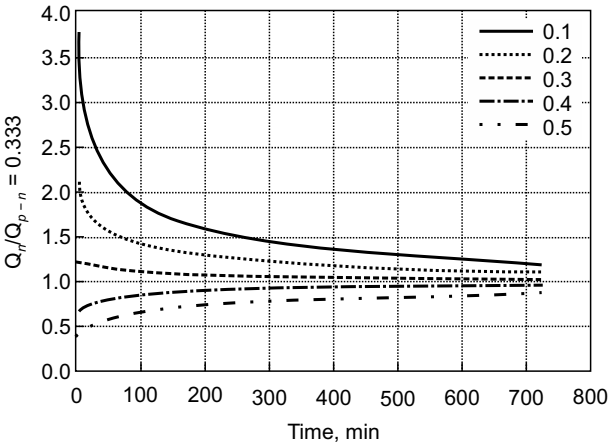

Fig. 3. Influence of *n* on the dimensionless flow rate (DFR) in Baghmalek for a 5-year return period rainfall (Authors' own elaboration)

The effect of the coefficient *n* in the RIMD method on the SCS method peak runoff

The SCS method is widely used for estimating catchment runoff, recommending a 6-hour rainfall duration if the basin's time of concentration is under 6 hours, or matching the actual concentration time if longer.

Table 7 shows that for durations ≥360 minutes (6 hours), the influence of *n* on the dimensionless runoff factor (DRF) diminishes. However, varying *n* from 0.1 to 0.5 still produces DRF values of 0.8–1.4. Calibration in this study yielded values of $n = 0.39$ for Baghmalek and $n = 0.28$ for Ahvaz, resulting in runoff variations of 10–20%, which is an acceptable margin. Thus, using the default value of $n = 0.333$ introduces minimal error and can be applied reliably in both cities.

In summary, careful calibration of *n* is crucial for short-duration rainfall, whilethe RIMD method pro-

vides accurate and dependable results even with the default coefficient for events of ≥ 6 hours.

CONCLUSION

This study assessed four regional empirical methods – Ghahraman and Sepaskhah (1990), Ghahraman and Abkhiz (2004), Vaziri (1991), and the RIMD method – for predicting design rainfall and DDF curves in the Iranian cities of Baghmalek and Ahvaz. The focus was on the practical RIMD method, which links short-term rainfall to maximum 24-hour rainfall via the parameter *n*, usually set to 0.333 by the India Meteorological Department.

The results show that the RIMD with $n = 0.333$ performs well for long-duration rainfall (6–24 hours) but it underestimates short-duration events unless *n* is regionally calibrated. Using limited short-term rainfall data, calibrated *n* values of 0.39 for Baghmalek and 0.28 for Ahvaz substantially improved accuracy, achieving efficiency and error metrics that were comparable to, or exceeded, those of other methods.

Peak runoff analysis via the Rational Method confirmed that *n* has a strong impact on short-duration runoff estimates, but a minimal impact on longer events. Within the calibrated *n* range, discharge variations remained within the manageable 10–20% error margin, which support the reliability of the RIMD method when it is properly calibrated.

The RIMD method provides a simple and practical approach for estimating design rainfall in urban catchments with limited data. While the default coefficient $n = 0.333$ is generally adequate for long-duration events (≥6 hours), accurate estimation of short-duration rainfall requires regional calibration. In ungauged or newly developed basins, further investigation and comparison with alternative empirical methods are recommended to ensure reliable hydraulic design.

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OCENA REGIONALNYCH EMPIRYCZNYCH MODELI IDF I DDF W POŁUDNIOWYM IRANIE

STRESZCZENIE

Cel badania

Celem niniejszego badania była ocena i porównanie regionalnych empirycznych modeli IDF/DDF, ze szczególnym naciskiem na zmodyfikowane podejście IMD (RIMD), służących do oszacowania projektowej intensywności opadów w zlewniach bez stacji pomiarowych w Iranie.

Materiały i metody

Przeanalizowano dane dotyczące dziennych opadów deszczu w Baghmalek i Ahvaz w celu: określenia najlepiej dopasowanych rozkładów statystycznych, opracowania krzywych DDF przy użyciu czterech metod empirycznych oraz oceny skuteczności za pomocą wskaźnika RMSE i współczynnika efektywności modelu Nasha–Sutcliffe'a, a także przeprowadzenia analizy wrażliwości parametru *n* modelu IMD.

Wyniki i wnioski

Wyniki wykazały, że domyślna wartość IMD (n = 0,333) była nieprecyzyjna przy krótkich przedziałach czasowych, podczas gdy wartości skalibrowane (n = 0,39 i 0,28) zapewniły znaczną poprawę zgodności z obserwacjami i pozwoliły uzyskać bardziej wiarygodne szacunki spływu.

Słowa kluczowe: Ghahraman i Abkhezr, Ghahraman i Sepaskhah, IDF, IMD, Vaziri