Technical note

ASSESSMENT OF OBTAINING IDF CURVE METHODS FOR MEXICO

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Abstract

MANZANO-AGUGLIARO, F., ZAPATA-SIERRA, A., RUBÍ, J.F. & HERNÁNDEZ-ESCOBEDO, Q. Assessment of Methods to Obtain IDF Curves for Mexico. *Water Technology and Sciences* (in Spanish). Vol. V, No. 3, May-June, 2014, pp. 149-158.

This paper assesses the methods of obtaining IDF curves for the country of Mexico: modified Wencel, Chen, modified Chen, Témez and modified Témez. The data came from a total of 63 automated weather stations distributed throughout the country, recording data every 10 minutes for a minimum of 7 years. For the analysis, stations 50 km or less from the coast were identified as coastal and the remaining as inland. For each station, all of the parameters for the methods mentioned to calculate the IDF curves were evaluated for durations of 10 minutes to 24 hours, and return periods of 2 to 500 years. It was shown that when rainfall records for 10 minutes or less are used the Wencel method is recommended, and when the records are hourly the Chen method is recommended. When rainfall data are daily for durations under 2 h, the modified Temez method is required, and for durations of more than 2 h the best method is the modified Chen for inland areas and modified Temez for coastal areas.

Keywords: Mexico, IDF, extreme rainfall, coastal, inland, Wencel, Chen, Témez.

Resumen

MANZANO-AGUGLIARO, F., ZAPATA-SIERRA, A., RUBÍ, J.F. & HERNÁNDEZ-ESCOBEDO, Q. Evaluación de métodos de obtención de curvas IDF para México. Tecnología y Ciencias del Agua. *Vol. V, núm. 3, mayo-junio de 2014, pp. 149-158.*

En este trabajo se evalúan los métodos de obtención de curvas IDF para México: Wencel modificado, Chen, Chen modificado, Témez y Témez modificado. Los datos proceden de 63 estaciones automáticas (EMAS), distribuidas por todo el país, con registros cada 10 minutos y durante siete años como mínimo. Para el análisis se han diferenciado estaciones de costa cuando están a 50 km o menos de esa zona, y las demás como de interior. Se han valorado para cada una de las estaciones, todos los parámetros de los métodos de cálculo de curvas IDF mencionados, para duraciones entre 10 minutos y 24 horas, y para periodos de retorno de 2 a 500 años. Se ha comprobado que cuando se tienen registros de lluvia cada 10 minutos o menos, se recomienda el método de Wencel; cuando se tienen registros de lluvia horarios, se aconseja el método de Chen; cuando los datos de lluvia son diarios, para duraciones menores de 2 h, se necesita el método de Témez modificado; para duraciones de más de 2 h, el mejor es el de Chen modificado para las zonas del interior y Témez modificados para las zonas costeras.

***Palabras clave**: México, IDF, lluvia extrema, costa, interior, Wencel, Chen, Témez.*

Introduction

The dimensioning of hydraulic structures is based on the design flood (Singh and Hao, 2011). The level of desired performance is often determined by the potential damage and severity of weather hazards that could cause failure, malfunction or overflow structure in question (Soro *et al*., 2010). Thus, in the case of stormwater management, the dimension of various components of the infrastructure system (case of pipes and canals sanitation) is based on the return period of heavy rainfall events (Monhymont and Demarée, 2007; Segond *et al*., 2007). This information is often expressed as Intensity-Duration-Frequency (IDF) curves obtained from a statistical study of extreme events.

For the country of Mexico there is a map of IDF curves developed by the Secretaría de Comunicaciones y Transportes (SCT, 1990); in the literature are studies such as Campos (1990) who obtained IDF curves Cazadero, Zacatecas, applying the equations of Bell and Chen, widespread heavy rains; also Pereyra-Díaz *et al*. (2004) in a preliminary study, adjusted equations Sherman (1931), Wenzel (modified by Chow *et al*., 1988) and Koutsoyiannis *et al*. (1998) to the intensities of 11 severe storms recorded during the period 1999-2002. All of these studies show the need for continuous records of precipitation for major cities, to use extreme rainfall in urban design.

The aim of this paper is to assess the different procedures for obtaining the IDF relationships for Mexico, based on two approaches: the reference method and empirical method, in order to first determine whether there are differences in behaviour between coastal and interior geographical areas, and if so, which model is best suited to each zone, depending on rainfall data available.

Data and methods

Data

To assess the different methods for obtaining IDF ratios in coastal and inland areas, records were used from the network of automatic weather stations (EMAs) administered by the General Coordination of National Weather Service (CGSMN) with satellite transmission. This network has 133 automatic weather stations installed throughout the country. The age of the series of records of this network of stations is variable depending on the station, so 63 stations have been selected with record set which are limited between 1999 and 2008, see figure 1. The choice of these 63 stations have been allowed for this work with data sets a minimum period of 8 years for those 86%, increasing to 90% when the minimum age of the series is 7 years. Works realized in other countries also use short lengths of series to analyze these phenomena if they do not arrange of longer series, for example Lam and Leung (1994) in Hong Kong (China) or Zapata-Sierra *et al*. (2009) in Spain, that a similar length of the series gave similar results to longer series. For Mexico, Escalante y Reyes (2004), have observed that for records longer than 20 years, the R (ratio of rain for 1 h to 24 h) becomes stable, and Mendoza-Resendiz *et al*. (2013) use series of data of 7 years length for the calculation of synthetic rains.

Precipitation records used in this work are made by the height of precipitation (in mm) in 10 minutes (GMT) for each station, for each month and year of the study period. Thus, we have had a total of 105, 120 records per station and year. Table 1 lists the stations included in the study, and table 2 offers their classification in the coastal (C) or inland (I) zone and the period of data used. Figure 1 shows the spatial distribution of the 63 automatic weather stations on the country of Mexico.

Intensity-duration-frequency analysis

Some authors propose the use of double Gumbel distribution in areas where there is possibility of rain with two different generation mechanisms (Guichard-Romero *et al*., 2009). But since in the central regions of Mexico has found a better fit for the Gumbel distribution (Domínguez-Mora *et al*., 2013), and that in the case of short data series, Gumbel distribution gives good results (Tung and Wong, 2013), this one has been chosen. Figure 2 shows an adjustment to the Gumbel distribution for observed data (annual maximum) at Acapulco station. At each station, frequency analysis was carried out using the maximum annual rainfall for each of the rainfall durations selected, by fitting each series to a Gumbel distribution using the maximum-likelihood method (Zapata-Sierra *et al*., 2009).

For the return periods $T = 2, 5, 10, 25, 50$ and 100 years, the rainfall-height values, R_t^T, were obtained for each rainfall duration considered, t, and the corresponding intensities, r_t^T.

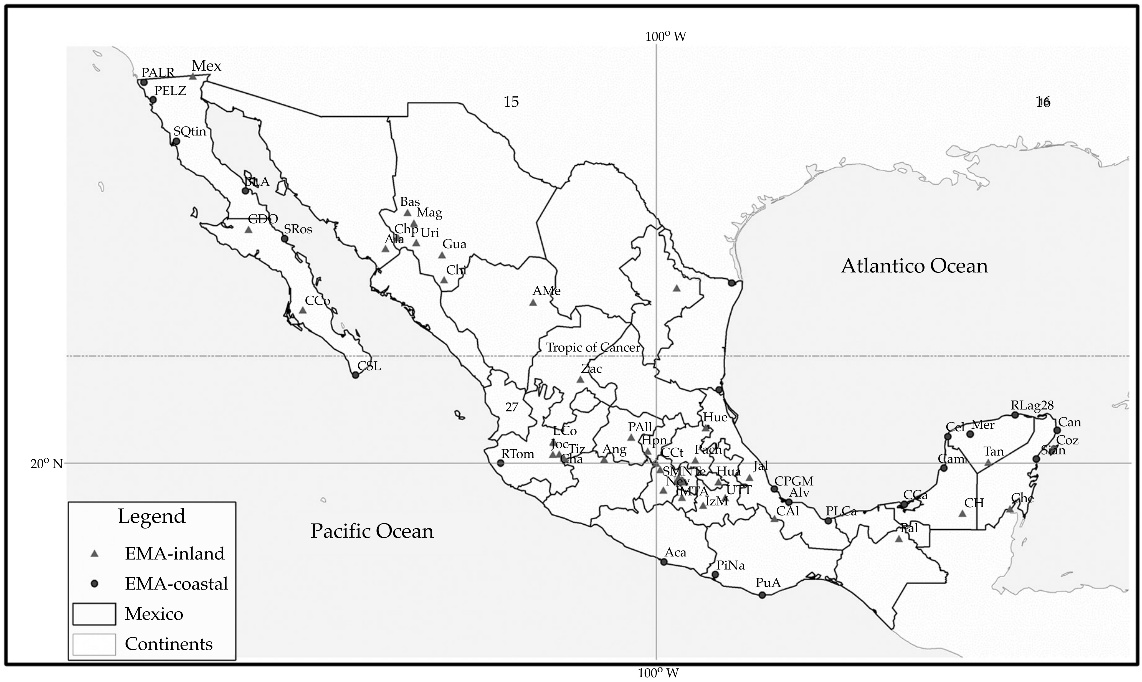

Figure 1. Location in Mexico of the rainfall stations (EMAs) studied.

Table 1. Values calculated for the parameters of the following equations: Wenzel, Chen, Chen modified and Témez modified.

	Wenzel (1)				**Chen (2)**			**Chen modified (3)**			**Témez modified (5)**	
Station	**a**	**b**	**c**	**d**	**a_1**	**b_1**	**c_1**	**a_{24}**	**b_{24}**	**c_{24}**	**α_1**	**β_1**
Acapulco	65.90	0.113	0.786	0.422	1.220	0.236	0.654	10.64	0.242	0.655	0.973	-0.222
Agustín	21.28	0.167	0.543	-0.125	1.040	-0.053	0.580	6.29	-0.054	0.578	1.005	-0.370
Álamos	60.78	0.124	1.135	0.533	1.922	0.691	1.225	41.60	0.637	1.159	0.980	-0.172
Altamira	112.85	0.136	1.044	0.997	2.067	1.040	1.047	29.16	1.032	1.041	0.955	-0.164
Alvarado	74.24	0.139	0.422	0.105	1.029	0.032	0.397	3.28	0.022	0.379	0.990	-0.297
Angamacutiro	49.61	0.139	1.241	0.404	2.223	0.663	1.433	82.59	0.648	1.410	0.995	-0.170
Atlacomulco	49.32	0.139	1.224	0.511	2.274	0.790	1.397	80.97	0.809	1.422	0.986	-0.164
Bahía Ángeles	12.40	0.232	1.016	0.145	1.239	0.134	0.976	27.61	0.134	0.977	1.006	-0.238
Basaseachi	41.79	0.157	0.955	0.268	1.252	0.238	0.927	21.81	0.237	0.926	0.992	-0.219
Cabo San Lucas	71.24	0.239	1.108	0.936	2.269	1.042	1.119	42.04	1.056	1.130	0.959	-0.158
Calakmul	119.01	0.097	1.215	1.119	3.841	1.619	1.429	89.46	1.629	1.436	0.957	-0.144
Campeche	95.12	0.082	0.800	0.716	1.251	0.468	0.694	8.44	0.391	0.618	0.958	-0.203
Cancún	131.39	0.204	0.615	0.696	1.173	0.319	0.495	5.10	0.311	0.487	0.956	-0.229
Cd. Alemán	147.15	0.084	1.043	1.332	2.277	1.348	1.027	23.31	1.202	0.937	0.945	-0.157
Cd. Constitución	36.08	0.149	0.625	0.343	0.891	0.112	0.477	5.01	0.109	0.473	0.974	-0.250
Cd. del Carmen	65.08	0.165	0.920	0.632	1.481	0.529	0.865	16.38	0.511	0.846	0.966	-0.191
Celestún	87.76	0.111	1.194	0.903	2.948	1.262	1.355	70.20	1.262	1.356	0.963	-0.151
Cerro Cat	39.63	0.117	0.793	0.692	1.258	0.450	0.692	9.87	0.454	0.695	0.959	-0.205
Chapala	54.09	0.169	1.221	0.470	2.317	0.730	1.393	72.39	0.719	1.379	0.989	-0.167

Table 1 (continuation). Values calculated for the parameters of the following equations: Wenzel, Chen, Chen modified and Témez modified.

Chetumal	69.68	0.138	0.721	0.488	1.150	0.274	0.629	7.32	0.249	0.597	0.967	-0.226
Chinatú	49.18	0.147	1.145	0.492	1.985	0.656	1.245	52.05	0.646	1.233	0.984	-0.174
Chinipas	98.40	0.150	1.306	0.903	5.279	1.643	1.703	198.91	1.684	1.738	0.967	-0.140
Cozumel	118.90	0.201	0.656	1.063	1.267	0.541	0.510	5.35	0.531	0.503	0.944	-0.212
CPGM	81.48	0.104	0.821	0.598	1.295	0.418	0.742	9.96	0.363	0.680	0.964	-0.206
ENCB	77.86	0.147	1.448	0.975	19.361	2.532	2.354	1 180.37	2.584	2.408	0.969	-0.127
Guachochi	47.88	0.131	1.005	0.522	1.541	0.520	0.999	24.77	0.515	0.993	0.976	-0.188
Gustavo DO	17.53	0.209	0.613	0.181	1.054	0.076	0.555	6.20	0.072	0.547	0.986	-0.271
Huamantla	83.01	0.160	1.337	0.594	4.234	1.210	1.759	186.42	1.161	1.704	0.985	-0.148
Huejutla	163.64	0.128	1.063	1.700	3.022	1.825	1.093	34.20	1.814	1.087	0.939	-0.150
Huimilpan	107.06	0.123	1.426	1.231	24.123	2.955	2.319	985.90	2.939	2.307	0.960	-0.124
IMTA	84.61	0.136	1.143	0.794	2.567	1.047	1.271	56.09	1.047	1.272	0.966	-0.159
Izúcar	130.50	0.219	1.323	1.439	7.681	2.367	1.688	275.13	2.509	1.776	0.952	-0.129
Jalapa	48.85	0.115	0.729	0.239	1.086	0.137	0.674	8.62	0.125	0.652	0.985	-0.250
Joicotepec	23.20	0.191	0.702	0.013	1.074	0.004	0.688	9.65	0.003	0.686	1.000	-0.309
Los Colomos	66.62	0.115	1.428	0.597	7.893	1.548	2.142	466.06	1.561	2.155	0.988	-0.140
Maguarichi	27.64	0.148	0.986	0.137	1.199	0.129	0.972	22.93	0.125	0.961	1.005	-0.244
Matamoros	119.93	0.160	1.259	1.165	5.260	1.862	1.574	147.19	1.902	1.602	0.957	-0.139
Mérida	101.20	0.121	0.906	0.587	1.420	0.484	0.855	13.82	0.412	0.773	0.968	-0.196
Mexicali	13.90	0.240	0.961	0.280	1.263	0.231	0.895	22.18	0.238	0.907	0.992	-0.217
Nevado	19.21	0.113	0.553	0.288	1.075	0.117	0.490	4.61	0.105	0.472	0.977	-0.264
Pachuca	25.87	0.161	1.017	0.225	1.299	0.227	1.011	24.35	0.204	0.959	0.999	-0.220
Palenque	102.30	0.211	0.983	0.693	1.675	0.642	0.943	24.24	0.646	0.948	0.965	-0.181
Pinotepa	129.17	0.183	0.941	1.137	1.873	0.992	0.880	15.86	0.920	0.830	0.947	-0.172
Psa. Abelardo	10.90	0.181	0.669	0.097	1.069	0.047	0.635	7.98	0.044	0.629	0.994	-0.283
Psa. Allende	25.91	0.157	0.741	0.037	1.100	0.019	0.722	11.65	0.015	0.709	1.000	-0.298
Psa. El Cuchillo	213.00	0.141	1.177	1.918	5.827	2.557	1.391	74.71	2.426	1.332	0.939	-0.137
Presa Emilio LZ	19.22	0.141	0.643	0.485	1.094	0.232	0.544	6.10	0.234	0.547	0.966	-0.237
Presa La Cangrejera	180.94	0.148	0.831	1.068	1.496	0.764	0.723	10.55	0.751	0.714	0.946	-0.187
Presa Madín	60.96	0.135	1.001	0.587	1.579	0.577	0.989	24.72	0.578	0.991	0.971	-0.184
Pto. Ángel	103.28	0.124	1.065	1.020	2.328	1.135	1.109	34.62	1.129	1.104	0.955	-0.161
Río Lagartos	246.83	0.215	0.880	2.162	2.114	1.691	0.752	10.92	1.613	0.720	0.929	-0.168
Río Tomatlán	123.85	0.114	0.944	1.004	1.808	0.898	0.901	17.37	0.861	0.873	0.951	-0.175
San Quintín	10.64	0.200	0.764	0.135	1.095	0.077	0.717	10.55	0.071	0.702	0.994	-0.266
Sian Kaan	41.90	0.118	0.226	-0.173	1.033	-0.033	0.259	1.87	-0.046	0.234	1.016	-0.334
SMN	97.80	0.123	1.361	1.078	10.937	2.282	2.003	371.11	2.214	1.963	0.963	-0.132
Sta. Rosalía	63.74	0.231	0.718	0.819	1.258	0.453	0.585	7.16	0.447	0.580	0.952	-0.210
Tantakin	78.95	0.194	0.797	0.674	1.261	0.430	0.686	9.78	0.424	0.680	0.960	-0.205
Tezontle	46.27	0.158	0.944	0.480	1.356	0.412	0.894	19.98	0.422	0.907	0.976	-0.198
Tizapán	37.70	0.177	0.724	0.306	1.144	0.172	0.655	8.68	0.167	0.648	0.979	-0.242
Tuxpan	322.25	0.176	1.413	1.925	31.190	3.884	2.186	853.75	3.689	2.124	0.946	-0.118
Urique	58.09	0.091	1.043	0.548	1.674	0.596	1.070	27.58	0.560	1.025	0.976	-0.181
UTT	41.74	0.156	1.339	0.447	3.273	0.920	1.708	156.39	0.911	1.698	0.996	-0.157
Zacatecas	68.35	0.206	1.508	0.817	28.599	2.509	2.628	1 216.78	2.184	2.342	0.978	-0.126

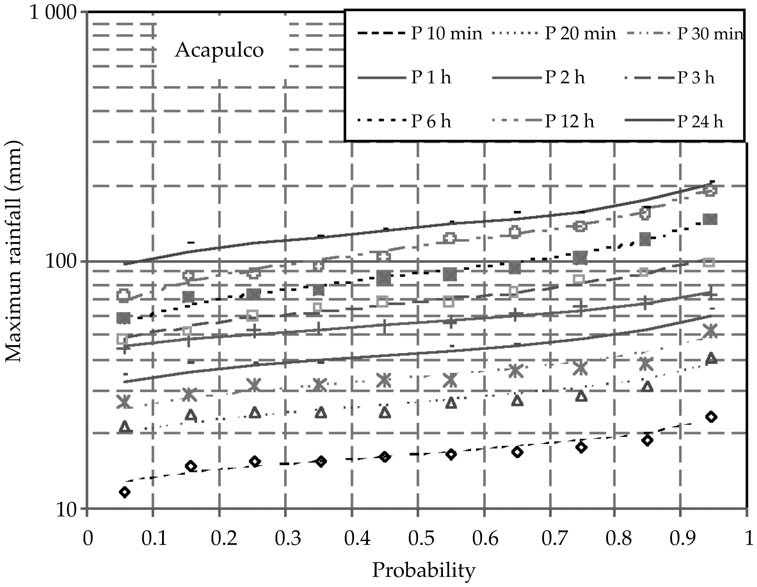

Figure 2. Example of measured maximum values (+) and Gumbel estimated data (---) for various durations, *versus* probability on Acapulco station.

Intensity–duration–frequency relationships

IDF relationship can be described mathematically by means of various expressions (Wenzel, 1982). The most common one, also called reference method, which groups the various intensity–duration curves for the various return periods in a single formula, is equation (1), which is applicable to locations with observatories keeping records for rainfall durations between 10 min and 24 h:

$$r_t^T = \frac{a\,T^b}{t^c + d} \tag{1}$$

where r_t^T is the mean intensity (mm h^{-1}) for the duration t (min) and the return period T (years), and a, b, c and d are parameters to be determined by fitting.

In cases where only 24 h rainfall data is available, regional rainfall characterization studies are carried out analyzing the ratios between short-lasting rainfall and rainfall over 1 h and/or 24 h (Bell, 1969; Chen, 1983; Froehlich, 1993 and 1995). Using isohyetal rainfall maps for large regions of the USA, Chen (1983) obtained a ratio between the rainfall height for 1 h and 24 h, regardless of the return period, (R_1^T/R_{24}^T), that varies very little according to the geographical location, ranging between values of 0.1 and 0.6, with an average value of 0.4.

The equations used in this work are, Chen (1983):

$$r_t^T = \frac{a_1 r_1^T}{\left(t + b_1\right)^{c_1}} \tag{2}$$

where $a = a_1 r_1^T$, $b = b_1$ and $c = c_1$. The fitting parameters a_1, b_1 and c_1 can be obtained from the known rainfall data from a given station by using optimization techniques and the least squares method.

Chen modified equation:

$$r_t^T = \frac{a_{24} r_{24}^{10} \log\left\{10^{2-x}\left[ln\left(\frac{T}{T-1}\right)\right]^{-(x-1)}\right\}}{\left(t + b_{24}\right)^{c_{24}}} \tag{3}$$

where $x = R_{24}^{100} / R_{24}^{10}$. These equations allow us to obtain the IDF ratios from 24 h rainfall data, Témez, 1987:

$$r_t^T = r_{24}^T \left(\frac{r_1^t}{r_{24}^T} \right)^{\frac{28^{0.1} - t^{0.1}}{28^{0.1} - 1}} \qquad (4)$$

where t is rainfall duration in h.

Témez modified (Zapata-Sierra *et al*., 2009):

$$r_t^T = r_{24}^T \left(\frac{r_1^t}{r_{24}^T} \right)^{\alpha_1 + \beta_1 ln\, t} \qquad (5)$$

where the coefficients α_1 and β_1 can be determined by using optimization techniques based on the observed intensity data.

Results

Each equation parameters studied was obtained by optimization techniques, being minimum square error for data from each station using the frequency analysis, here in after observed data.

First, Wenzel's equation (1) was fitted to the rainfall-intensity data obtained from each station by means of frequency analysis ("observed data"), obtaining values for the parameters a, b, c, and d expressed in table 1. We then proceeded to estimate the rainfall-intensity values for the different durations and return periods by applying Chen's equation (2) with the coefficients a_1, b_1 and c_1, determined by using optimization techniques; Chen's modified equation (3), applying the coefficients a_{24}, b_{24} and c_{24}; and Témez's equation (4) and its modified equation (5), optimizing the parameters α_1 and β_1. The values for the parameters in equations (1), (2), (3) and (5) determined by optimization are shown in table 1.

In order to compare the estimates made by each procedure, we defined a coefficient of variation (CV) as the ratio between the square root of the mean squared error and the mean of the rainfall values observed:

$$CV = \frac{\sqrt{\dfrac{\sum_{i-1}^{n} \left(x_{i0} - x_{ic} \right)^2}{n}}}{\dfrac{\sum x_{i0}}{n}} \qquad (6)$$

where x_{i0} are the values obtained for the rainfall heights of the different rainfall durations and return periods, x_{ic} are the rainfall heights calculated for the different durations (10 min to 24 h) and return periods (2 to 100 years), and n is the number of rainfall data employed for each equation.

The equations of Témez modified (5) and Chen modified (3) require the use of parameters calculated for a nearby area. This may be done using the parameters obtained in this work (table 1).

Table 2 shows the values of the coefficients of variation (CV) (in bold indicate the lowest CV obtained in each EMA) obtained with the different expressions to generate the complete set of 10 minutes to 24 h the heights of rain for different return periods. We observe that equations (1), (2) and (5) are those with a greater number of stations with minimum CV value. Témez equation (4) is the worst result offers, surpassing in some cases the CV values of 0.1.

The figures 3 and 4 show the average values of CV obtained at coastal and inland stations, obtained for the two periods studied, less than 2 hours and less than 24 hours. In all cases, seen as the Témez equation gets higher CV, and then it is not recommended for use without particularization proposed in equation (4).

The results obtained for durations between 10 minutes to 24 hours and for a return period between 2 to 500 years, due the length of data was 7 years, the supported validity for these estimates is limited to the duration of one series of data. But where there is no other information, here is provided some guidance for hydrological design.

Table 2. Summarized results (CV coefficient of variation) obtained for rainfall durations of less than 24 h. Highlighted in bold the lowest CV obtained in each EMA. Zone: C = coastal Station, I = Inland station.

Id	Station	Zone	Period	Wenzel (1)	Chen (2)	Chen mod. (3)	Témez (4)	Témez mod. (5)
Aca	Acapulco	C	1999-2008	**0.0102**	0.0276	0.0282	0.0119	0.0113
AMe	Agustín	I	2003-2008	0.0131	0.0092	0.0110	0.0721	**0.0056**
Ala	Álamos	I	1999-2005	0.0106	**0.0084**	0.0193	0.0526	0.0198
Alt	Altamira	C	1999-2008	**0.0088**	0.0131	0.0143	0.0546	0.0203
Alv	Alvarado	C	2000-2008	0.0111	0.0067	0.0245	0.0154	**0.0017**
Ang	Angamacutiro	I	2000-2008	0.0082	**0.0078**	0.0115	0.0563	0.0207
Aco	Atlacomulco	I	2000-2008	0.0097	0.0118	**0.0073**	0.0628	0.0217
BLA	Bahía Ángeles	C	2000-2007	0.0208	0.0181	0.0179	0.0184	**0.0101**
Bas	Basaseachi	I	1999-2008	0.0099	**0.0095**	0.0098	0.0111	0.0125
CSL	Cabo San Lucas	C	2000-2007	**0.0186**	0.0211	0.0196	0.0654	0.0227
Ckl	Calakmul	I	2003-2008	**0.0115**	0.0127	0.0119	0.0763	0.0238
Cam	Campeche	C	2000-2008	**0.0131**	0.0139	0.0338	0.0232	0.0135
Can	Cancún	C	2000-2007	0.0136	0.0137	0.0187	0.0098	**0.0097**
CAl	Cd. Alemán	I	2000-2008	**0.0128**	0.0165	0.0281	0.0557	0.0205
CCo	Cd. Constitución	I	2000-2007	0.0095	0.0408	0.0423	**0.0038**	0.0074
CCa	Cd. del Carmen	C	2000-2006	0.0136	**0.0095**	0.0159	0.0333	0.0162
Cel	Celestún	C	2000-2008	**0.0090**	0.0134	0.0133	0.0714	0.0229
CCt	Cerro Cat	C	2000-2007	**0.0091**	0.0123	0.0107	0.0223	0.0133
Cha	Chapala	I	1999-2008	0.0135	**0.0097**	0.0121	0.0603	0.0214
Che	Chetumal	I	1999-2008	**0.0086**	0.0110	0.0247	0.0108	0.0106
Chi	Chinatú	I	2000-2008	0.0081	**0.0074**	0.0102	0.0519	0.0199
Chp	Chinipas	I	1999-2008	0.0086	0.0116	**0.0077**	0.0875	0.0256
Coz	Cozumel	I	1999-2008	0.0138	0.0140	0.0185	0.0168	**0.0116**
CPGM	CPGM	I	2003-2008	**0.0060**	0.0062	0.0269	0.0220	0.0134
ENCB	ENCB	I	2001-2008	0.0115	0.0147	**0.0086**	0.1075	0.0285
Gua	Guachochi	I	2000-2008	0.0078	**0.0074**	0.0096	0.0372	0.0170
GDO	GustavoDO	I	2000-2006	0.0155	0.0167	0.0211	0.0149	**0.0051**
Hua	Huamantla	I	2000-2007	**0.0095**	0.0096	0.0142	0.0832	0.0249
Hue	Huejutla	I	2000-2008	**0.0125**	0.0129	0.0139	0.0591	0.0215
Hpn	Huimilpan	I	2000-2007	0.0126	**0.0100**	0.0111	0.1055	0.0282
IMTA	IMTA	I	1999-2008	0.0102	0.0063	**0.0061**	0.0636	0.0217
IzM	Izúcar	I	2000-2007	0.0170	0.0207	**0.0147**	0.0970	0.0278
Jal	Jalapa	I	2000-2008	0.0091	0.0077	0.0185	0.0079	**0.0077**
Joc	Joicotepec	I	1999-2006	0.0132	0.0118	0.0130	0.0517	**0.0007**
LCo	Los Colomos	I	2000-2008	0.0094	0.0062	**0.0057**	0.0938	0.0263
Mag	Maguarichi	I	1999-2006	0.0099	**0.0087**	0.0124	0.0209	0.0088
Mat	Matamoros	C	2000-2008	0.0100	0.0117	**0.0084**	0.0844	0.0254
Mer	Mérida	C	2000-2008	0.0074	**0.0058**	0.0277	0.0297	0.0153
Mex	Mexicali	I	2000-2008	0.0203	0.0210	0.0181	0.0136	**0.0135**
Nev	Nevado	I	2000-2008	0.0090	**0.0042**	0.0203	0.0069	0.0055
Pach	Pachuca	I	2000-2008	0.0126	**0.0088**	0.0212	0.0099	0.0126

Table 2 (continuation). Summarized results (CV coefficient of variation) obtained for rainfall durations of less than 24 h. Highlighted in bold the lowest CV obtained in each EMA. Zone: C = coastal Station, I = Inland station.

Pal	Palenque	I	2003-2008	0.0145	0.0141	**0.0128**	0.0433	0.0185
PiNa	Pinotepa	C	2003-2008	**0.0114**	0.0118	0.0236	0.0447	0.0187
PALR	Psa. Abelardo	C	2000-2007	0.0113	0.0111	0.0151	0.0275	**0.0037**
PAll	Psa. Allende	I	2000-2008	0.0108	0.0106	0.0160	0.0468	**0.0019**
PECu	Psa. El Cuchillo	I	2000-2007	**0.0080**	0.0091	0.0155	0.0733	0.0241
PELZ	Psa. Emilio LZ	C	2000-2008	0.0134	0.0128	0.0113	**0.0063**	0.0089
PLCa	Psa. La Cangrejera	C	2000-2007	**0.0098**	0.0115	0.0153	0.0317	0.0156
PMad	Psa. Madín	I	2000-2008	**0.0071**	0.0088	0.0081	0.0399	0.0175
PuA	Pto. Ángel	C	2000-2008	**0.0068**	0.0077	0.0090	0.0570	0.0207
RLag	Río Lagartos	C	2000-2008	**0.0149**	0.0171	0.0259	0.0393	0.0182
RTom	Río Tomatlán	C	2000-2008	0.0073	**0.0050**	0.0149	0.0425	0.0179
SQtin	San Quintín	C	2001-2007	0.0143	0.0143	0.0204	0.0230	**0.0059**
Sian	Sian Kaan	C	2000-2007	0.0154	0.0043	0.0391	0.0160	**0.0016**
SMN	SMN	I	1999-2007	0.0095	0.0075	**0.0068**	0.0960	0.0268
SRos	Sta. Rosalía	C	2001-2008	0.0172	0.0189	0.0212	0.0196	**0.0129**
Tan	Tantakin	I	2003-2008	0.0150	0.0174	0.0196	0.0230	**0.0138**
Tez	Tezontle	I	2000-2008	0.0100	0.0130	**0.0078**	0.0288	0.0154
Tiz	Tizapan	I	1999-2008	0.0105	0.0103	0.0143	**0.0044**	0.0089
Tux	Tuxpan	C	2000-2007	0.0134	0.0159	**0.0098**	0.1059	0.0290
Uri	Urique	I	2000-2008	0.0064	**0.0034**	0.0158	0.0421	0.0178
UTT	UTT	I	1999-2007	0.0128	**0.0085**	0.0087	0.0737	0.0235
Zac	Zacatecas	I	2000-2008	0.0162	**0.0160**	0.0214	0.1167	0.0301

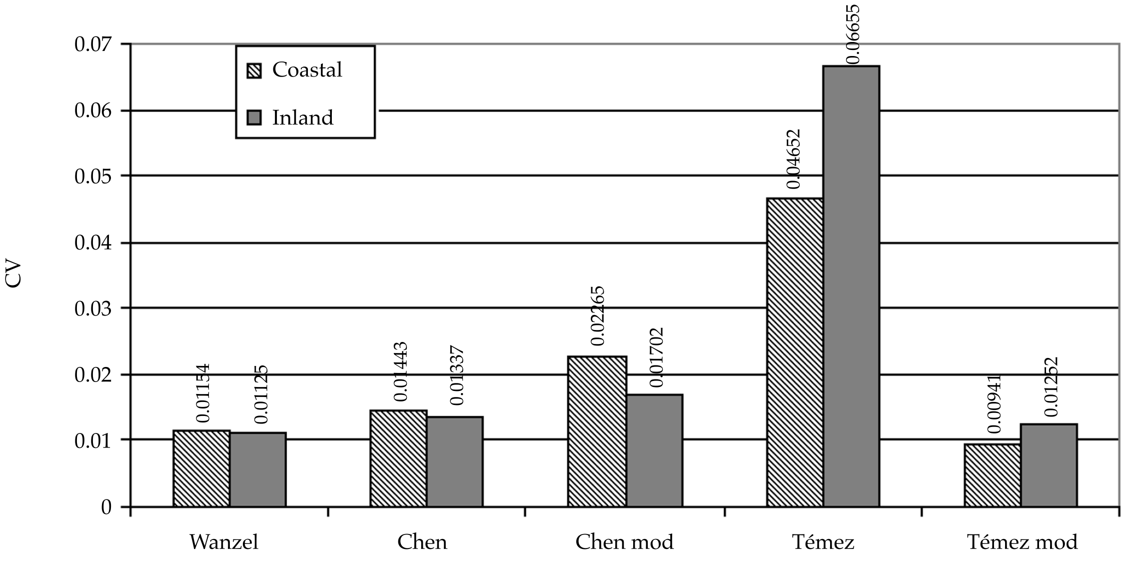

Figure 3. Coefficient of variation (CV) and Standard Deviation (sd) values obtained with the different equations for rainfall durations of less than 2 h at coastal stations studied.

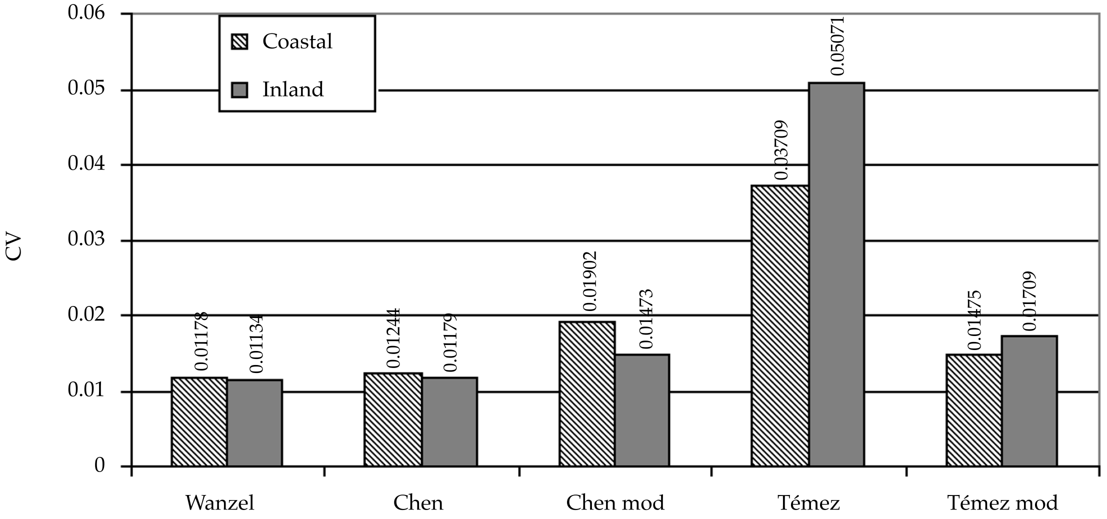

Figure 4. Coefficient of variation (CV) obtained with the different equations for rainfall durations of 24 h at inland and coastal stations studied.

Conclusions

The conclusions obtained in this work for data lengths of at least seven years were as follows:

Wencel´s method generally shows the best results as expected, which justifies their use when available short-term rainfall data such as every 10 minutes, which is not always possible. For these cases, this work shows that equations are more appropriate depending on the country's geographical area of Mexico, coast or inland, where rainfall data are available for longer.

Chen's equation gives very good results for rainfall durations between 2 h and 24 h, but requires data of maximum rainfall in one hour. This data can be more accessible but not widespread except for relatively modern stations. When only rainfall data available 24 hours, this is the most common situation, the estimation of rain of short duration (< 2 h) necessary to obtain IDF curves, then the best equations are Témez modified.

For durations longer than 2 h and for the coastal zone, the best equation is always Témez modified. While for the inland area depending on the duration of the rainfall to be estimated should be used: the equation Témez modified for durations less than 2 h and Chen modified for longer durations.

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