REGIONALIZATION OF HURRICANE RAINFALL IN THE FORESTS, PROTECTED AND RESERVED ZONES OF MEXICO

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Abstract

Hurricanes are extreme phenomena that affect the coasts of Mexico every year. The economic and biodiversity losses caused by these extreme events are extensive. However, little is known about the effects that these severe weather incidents have on Mexico's forest conservation and protected areas. A hydrological characterization and regionalization of the storms caused by the rain fields generated by all the hurricanes that touched the Mexican coast from 1966 to 2017 were carried out. Adimensional Huff Curves are proposed to get precipitation hyetograms from which the erosion factor of a storm is obtained; using the Universal Soil Loss Method (USLE). The results made it possible to get the typical precipitation hyetograms in the forests and protected areas, before, during, and after the impact of a hurricane. The proposed hydrological regionalization made it possible to estimate the rainfall intensity in 30 minutes to characterize the start of rain erosion. The method proposed in this research was applied in the 177 Natural Protected Areas (25628239 ha), as well as in the 370 voluntarily designated areas for Conservation

(399643 ha), in Mexico. It is concluded that, with the regionalization and the proposed equations, it is possible to get typical hurricane precipitation hyetograms, which would allow us to detail the forest management plans in forests, ecological reserves, and protected areas of Mexico.

Key words: conservation forests areas; forest management; storm erosive; Huff Curves; regionalization; Mexico

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Introduction

Mexico is a country with great diversity in natural protected areas; however, this biodiversity is exposed to a great number of meteorological and anthropological hazards that disturb the environmental processes year after year. Due to the fragility of these processes and their limited resilience, in Mexico, the General Law of Ecological Equilibrium and Environmental Protection, as well as its Regulations (LGEEPA), provides for the promulgation of conservation orders that allow for the protection of these Natural Protected Areas. In fact, in Mexico, there are limited detailed studies about the impact of hurricane storms over reserve areas and the most important forests. In many cases, there are weather stations in the urban centers, but they are scarce in the forests and protected areas. For this reason, studies are being carried out to empirically find the temporal distribution of precipitation in these areas of Mexico (Gomez-Tagle et al. 2015). Unfortunately, the little information available about the intensity and duration of storms before, during, and after hurricanes made it difficult to characterize this kind of extreme event (Pielke and Landsea 1998). On the other hand, in Latin America and the Caribbean, meteorological networks are scarce and the culture of measuring and monitoring hydrometeorological variables is being progressively lost. For this reason, understanding changes in the temporal variability of rainfall are very important both for climatological monitoring and hydrometric gauging (Gonzalez-Reyes and Muñoz 2013). In contrast, in developed countries, investment in measurement is increasing and technology is advancing in radar and meteorological satellites (Simpson 1998; Elsner 2003; Kwon and Frank 2005). While most developed countries do not have the problem of hurricanes, in Latin America and the Caribbean, hurricane rains are a destructive force with great erosive and destructive power. In the case of ecologically fragile areas, such as protected areas, reserves and forests in general, any rainfall of more than 45 mm per hour and wind speeds of more than 105 km per hour have a significant impact on soil loss (Xie et al. 2016). Hurricane rains and winds easily cause these extreme conditions; such as, Hurricane Katrina in 2004 was catastrophic not only in resource losses but also in the degradation of coastal ecosystems (Knaff et al. 2003; Mctaggart-Cowan et al. 2006; Ewing et al. 2006). In the case of Mexico, its history is a tragic one, hurricanes that exceed 250 km/h wind speeds, known as category V hurricanes, have caused serious disasters. In the Atlantic Ocean area, the most important hurricanes were Emily 2005, Wilma 2005, and Dean 2007. Within this same scale of hurricanes, in the Pacific Ocean area hurricanes, Rick 2009 and Patricia in 2015 are the most important, the last-mentioned being, according to the National Hurricane Center, National Oceanic and Atmospheric Administration (NOAA), the most intense tropical cyclone ever observed in the western hemisphere in terms of atmospheric pressure, and the most intense globally in terms of maximum sustained wind. For example, during the impact of Hurricane Patricia, the ecosystems of the Chamela region, which connects the ports of Manzanillo and Vallarta on the Mexican Pacific, were affected (Castillo y Paz 2015). If the ecosystems of the forested areas of any country are considered a true treasure and universal heritage, it is important to have detailed studies of the typical storms that cause soil loss and erosion in these regions and to (Knighton and Walter 2016). Pizarro et al. (2003) correctly remark that rainfall is one of the climatic components that most influences the stability of nature, the economy and the production of products and services in a region. Its temporal and spatial distribution also conditions the agricultural and forestry cycles, as well as the development of the main plant and animal species. At present with modern telemetry techniques, either at an annual level or on hourly time scales, precipitation distribution must be studied in detail (Huber and Iroume 2001; Wallis et al. 2007; Dunkerley 2010). The concept of understanding the temporal distribution of rainfall is not a new one and has been the focus of specialized studies for a long time, many of which are now considered valid and obligatory reference (Huff 1967; Huff 1970b; Trump and Elliott 1976; Bonta and Shahalam 2003; Bonta 2004; Al-Rawas and Valeo 2009). Two goals can be identified from the above: (i) to have access to climate monitoring networks, close to forests and reserves, that allow a measurement of precipitation at a time scale in minutes and; (ii) with these rainfall data at a time interval of less than one hour (hyetograms); to qualify the loss of soil in the forests and conservation areas that are vital for a country. By having a measured or theoretical precipitation hyetogram it is possible to know the erosive factor of rainfall (Bagarello et al. 2009), since the Universal Soil Loss Formula (USLE), such as, allows us to know the energy that comes from precipitation and that has a direct effect on soil erosion (Lin et al. 2005; Lee and Heo 2011; Kinnell 2014). This paper proposes to use the rainfall information from Automatic Meteorological Stations (EMA) in Mexico, collected every ten minutes, to characterize with Huff Curves the rainfall regime due to hurricanes (Koutsoyiannis et al. 1998). Under the hypothesis that some hydrological regionalization techniques using the parameters of the IDF curves, will allow characterizing the spatial distribution of storm type within hydrological homogeneous regions (Bonta and Rao 1989); cartography with zones of the similar temporal behavior of the precipitations will be generated. Then, in each of these homogeneous regions, Huff Curves are generated (Huff 1968; Huff 1975), which will allow us to know the temporal pattern of rainfall during the hurricane season in Mexico (Elsner 2003; Ewing et al. 2006). The method proposed in this work is applied in the 177 Natural Protected Areas (25,628,239 ha), as well as in the 370 areas voluntarily dedicated to Conservation (399,643 ha), in Mexico.

Materials and methods

For the first goal, it is proposed to use the monitoring network of the National Water Commission, Mexico, which has 188 EMAs with real-time data transmission (every 10 minutes) in all the Mexican country (https://smn.cna.gob.mx/es/emas). These EMA stations offer climatological data on temperature, rainfall, wind speed and direction, solar radiation, humidity, and atmospheric pressure. With the information available from 1999 to December 2017 of precipitation, the curves (IDF) are constructed. According to the parameterization proposed by Sherman (1931) and Chen (1983) we have:

$$i = \frac{k\,T^m}{d^n} \qquad [\,1\,]$$

where

i	rainfall intensity in (mm/h)
d	storm duration in minutes
T	return period, en years

The k, m, n coefficients are parameters obtained from the historical sample of rainfall data for the EMA. Ramirez (2011) presents the characterization of the precipitation regime in Mexico, according to the formulation of equation (1) for all EMA stations until 2011. In this work, these curves were reviewed and updated until December 2017.

For the second goal, the hydrological regionalization theory is used, to reduce the uncertainty in this transfer of climatological information to a site with scarce or no data (Bonta and Rao 1989). The heterogeneity of climatic regions represents a great problem when a study of the spatial and temporal distribution of precipitation is required (Gutierrez-Lopez et al. 2004), as transferring hydro-climatological information from one region to another can generate errors if these regions do not have the same climatic behavior. In order to carry out a hydrological regionalization, it is first necessary to (i) know, discriminate, and rank the variables that will allow delimiting the homogeneous regions. Then, it is necessary to (ii) use proximity techniques, aggregation rules, and a representation of the clustering of regions with similar climatological behavior; such as, with a hierarchical classification (Gutierrez-Lopez et al. 2004). The last step of regionalization is (iii) to create transfer equations that allow the transfer of data from one site to another with the minimum uncertainty; that is, to have hydrological data transfer equations that allow the transfer of data within a region subdivided into sub-regions with hydrological homogeneous behavior (Kachroo et al. 2000; Fill and Stedinger 1995).

Hydrological regionalization

The identification of representative characteristics of a region is certainly a fundamental step in a hydrological regionalization study. Creutin and Obled (1982) suggest using not only climatic characteristics but also physiographic, statistical, hydrological, and environmental ones. Hence, climatological data collected from EMA stations, geographic position data from each station (latitude, longitude, and elevation), parameters from the Sherman equation, and precipitation intensities calculated for different combinations of storm durations and return periods were used. Table 1 shows the 12 combinations of characteristics proposed to carry out the hydrological regionalization technique.

Table 1. Combination of characteristics used in the regionalization technique to delimit hydrological homogeneous regions

At this point, it is necessary to use the different combinations of hydro-climatological variables proposed (table 1) to produce an analysis of homogeneity and get an ideal regionalization (Lin and Chen 2006). De Araujo and Gonzalez-Piedra (2009), propose that once this regionalization is carried out, typical storm patterns can be generated with different climatic conditions, such as Huff Curves.

Universal Soil Loss Formula

The second aim of this work is to calculate the volume of sediments that can be erosion in the watershed and that will eventually be transported. Therefore, we propose to use a simple formulation such as the Universal Soil Loss Formula (USLE). The general formulation for estimating soil loss is a function of the erosive force of raindrops that impact the soil, the length and slope of the main channel, the vegetation cover, and the type of soil. A very important component is that it is related to the soil and crop conservation activities carried out within the basin (Wischmeier and Schmidt 1958). The general expression of this procedure can be written as:

$$A = R\ K\ SL\ C\ P \qquad [\,2\,]$$

where

A	Annual soil loss, (kg/m^2) year
R	Erosive factor of rain, (N/h) year
K	Soil type factor, (kg h/N m^2) o (ton h/N ha)
SL	Length factor and terrain slope, dimensionless
C	Vegetation coverage factor, dimensionless
P	Soil Conservation Factor and Crop Practices, dimensionless

It is important to mention that the Universal Soil Loss Formula estimates soil erosion values (A) by quantifying the material that is set in motion during a storm in a certain period, usually one year (Gottschalk 1964; Gracia 1997).

Rain erosion factor (R)

This concept takes into account the kinetic properties of raindrops that cause soil particles to fall. It is known that maximum detachment happens for a typical storm characterized by an intensity of 30 minutes, which is known as EI30 or also as Wischmeier's Index. It is important to consider that when the duration of the typical storm is less than 30 minutes, it is used as an indicator I30 equal to two times the rainfall. The expression shown below was obtained for single storms and is originally given in units EIu per year which are equivalent to 100 (ton/acre) (in/h). To use the results in the metric system (N /h) per storm, it is necessary to multiply by 1.702

$$R = 1.702 \frac{\left[\sum \left(1.213 + 0.890 \log I_j\right)\left(I_j T_j\right)\right] I_{30}}{173.6} \qquad [3]$$

where

R	Rain erosion factor, in (N/h) by storm
Ij	Rainfall intensity for a selected time increment, in mm/h
Tj	Selected time increment, in h
I_{30}	Maximum intensity of a 30-minute storm, in mm/h

Results

The data collected from the 188 EMA stations, represented in the form of IDF equations, made it possible to carry out a hydrological regionalization as detailed in the previous section. Based on the characteristics and combinations of analyses presented in table 1, the regions considered to be hydrological homogeneous were found. Figure 1 shows the mapping resulting from this procedure. In order to name each of the regions in a simple manner, letters were used. Region A, contains 3 homogeneous sub-regions, which are A-PA (Pacific Coast), A-GO (Gulf of Mexico), A-GOS (Southern Gulf of Mexico and Southern Pacific). Region B contains 4 homogeneous sub-regions, which are B-NO (North of the country), B-PA (Pacific Coast), B-PAS (South Pacific Coast and Gulf of Mexico), B-PE (Yucatan Peninsula). And region C, contains 4 homogeneous sub-regions, which are

C-NO (North Mexico), C-PA (Pacific Coast), C-PAS (South Pacific Coast) and C-CE (Central Mexico).

Figure 1. Hydrological regionalization (hydrological homogeneous regions) of the Mexican Republic, based on climatological, hydrological and physiographic variables

The daily rainfall records for the 188 EMAS stations were then processed, considering 24-hour time periods with measurements every ten minutes. In this way, the temporal distribution of rainfall for the homogeneous regions was obtained. Bonta and Rao (1989), propose an adjustment for the Huff Curves of the polynomial type, specifically of tenth degree. While this is a precise adjustment, it is not considered practical for comparing coefficients between regions. It is not practical to have ten coefficients for each curve, from each homogeneous region. Therefore, a logistic type equation is proposed, because it is considered similar to Sherman's formulation and it has only three adjustment parameters. It is important to mention that, in forest management plans in forests, ecological reserves and protected areas in Mexico, the value of the total maximum rainfall in 24 hours is used as a reference, that is, the daily rainfall height; however, this value do not allow us to know the erosive power of rainfall. For this reason, we propose a logistic distribution where the sheet can be obtained in 24 hours, where the precipitation sheet can be obtained at any interval of time. The 24-hour rain gauge records are the most extensive in forests, ecological reserves, and protected areas in Mexico; with the proposed Huff Curves, this daily rainfall can be disaggregated into a temporal rainfall at the required time interval. In the case of using the rainfall erosion factor, the intensity in 30 minutes is used, according to equation (3). The logistic type curves proposed to adjust the Huff Curves are shown below.

$$hp_{24h} = hp_t(a + b t^c) \quad [4]$$

$$hp_{24h} = hp_t(1 + b e^{-ct})/a \quad [5]$$

where

hp_{24h} Daily rainfall height, in (mm)
hp_t Rainfall height for a time t, in (mm)
t Time, in hours

Figures 2 and 3 show an example of the result when applying the cited procedure. The data measured in the EMA of the A-GOS (southern Gulf of Mexico and southern Pacific) and B-NO (northern) regions are presented as points, as well as the proposed fit for the Huff curve types. From table 2, the coefficients of the equations to characterize the Huff Curves can be obtained, in each hydrological homogeneous region. It is important to note that these curves were constructed with the complete rainfall record, so they include the hurricane record. This means that the presence of several Huff Curves does not refer to percentile as proposed by Azli and Rao (2010). The 100% percentile is used with the original proposal of Huff (1977). Thus, one curve represents the temporal distribution of the rainfall pattern as the hurricane approaches the coast, and the other represents the distribution over time as the hurricane hits or moves away from the study site.

Region A has two curves characteristic for each sub-region, these behaviors are attributed to the proximity of the hurricane to the coast, which correspond to the regions A-GO, A-GOS, and A-PA. For region B, there are three curves characteristic of sub-regions B-PAS and B-PE; these areas are those most affected by hurricanes during most of the season and three curves indicate, before, during, and after the passage of the phenomenon over the study site. Sub-region B-NO has two typical curves due to the fact that this area is not affected by hurricanes. There is a B-PA sub-region in which it was not possible to determine these graphs because there is no EMA with which to create its Huff curve.

In the case of region C, four sub-regions were identified, one of which is not on the coast of the country, but in the center of the Mexican Republic, covering part of the State of Mexico and the Federal District. Although this sub-region is not directly affected by hurricanes, they do cause storms that enter the national territory, affecting it to a lower degree.

Figure 2. Historical data and proposed Huff Curves for the A-GOS region

Figure 3. Historical data and proposed Huff Curves for the B-NO region.

Table 2. Coefficients of the equations to characterize the Huff Curves in each hydrological homogeneous region

Validation

In order to validate the proposed formulation for the construction of the Huff Curves, data from the EMA-Matamoros station in the state of Tamaulipas was used when Hurricane Erika passed through from August 14th to 17th, 2003. The site of this station belongs to the B-NO region, which has two rain behaviors. Curve 1 refers to the distribution of rainfall in the time before the hurricane hits the coast. Curve 2 describes the temporal distribution of precipitation when the hurricane moves away from the study area. Figure 4a shows the EMA station data for August 14th, when a total rainfall of 13.15 mm was recorded in 24 hours. Figure 4b shows the rainfall data for the station mentioned above, on August 16th, 2003, where 33.52 mm of total rainfall was recorded in 24 hours. Figures 5a and 5b show the theoretical rainfall hyetograms, proposed during the track of Hurricane Erika (a) Huff curve 1 and (b) Huff curve 2, in the hydrological homogeneous region B-NO.

Figure 4. Rainfall hetograms recorded over the track of Hurricane Erika (a) 14th and (b) 16th August 2003, at the EMA Matamoros station, Tamaulipas, Mexico

Figure 5. Theoretical rainfall hetograms during the track of Hurricane Erika (a) Huff curve 1 and (b) Huff curve 2, in the hydrological homogeneous region B-NO

In order to illustrate the Huff Curves proposed in this paper, a case study is presented for the calculation of the erosion factor in a site where there are no hourly rainfall data: Marismas Nacionales Nayarit, in the state of Nayarit, which is located in the hydrological homogeneous A-PA region.

Study case

The study site is located on the Pacific Ocean coast northwest of the state of Nayarit, Mexico. One of the most important sites in the country is in this area; the Marismas Nacionales Nayarit Biosphere Reserve. It was created by Decree on May 12th, 2010, and includes the municipalities of Santiago Ixcuintla, Tuxpan, Rosamorada, Tecuala, and Acaponeta. With 133,000 hectares it is the area that protects one of the most important wetland systems in Mexico: the wetlands and mangroves. The problem of sediment inflow from the highest point of the watersheds is such that in 2013 a system was implemented to monitor the effects of sediment loading and transportation on the lagunar ecosystem. "*This wetland protects 20 percent of the country's total mangrove area, it is considered one of the most productive in the northwest, and is classified nationally and internationally as an important area for the conservation of birds and wetlands*" (SEMARNAT 2013). Even with the importance of this site, until 2003 there were no EMA stations in the area; only conventional rain gauges were accessible. Six stations are located within a 250 km radius: Ahuacatlan station (code 18002/ 234 km from the site); Capomal, Stgo Ixcuintla (18004/125); Compostela (18006/193); Cucharas (18007/57); Huajicori (18012/56) and Huajimic (18013/196). The villages of Cucharas and Huajicori, where the rain gauges are located, are sites on the banks of the Acaponeta River, the main tributary in the contribution of sediments to the lagunar ecosystem. The year 2003 was an active year in the development of hurricanes for the Mexican Pacific. The most intense were: Ignacio (August 22-27th), Jimena (August 28-30th), Marty (September 18-24th), and Nora (October 1-9th), all categories II on the Saffir-Simpson scale. As mentioned above, unfortunately, there are no records of the time distribution of any of these events. However, the total daily rainfall was recorded on conventional rain gauges. For example, in 24 hours at the Cucharas station 180 mm (Kevin) and 190 mm (Linda); at the Huajicori station 192 mm (Marty). To calculate the erosion factor of Hurricane Marty's precipitation from the record of the total maximum rainfall in 24 hours, we do as follows. Figure 6 or table A1 in Annex A, shows the proposed hydrological regionalization for forests, ecological reserves, and protected areas. This is the location of the study area, which is in the A-PA sub-region. With the coefficients of this region in table 2 and with equation (5), we proceed to disaggregate the rainfall in ten-minute intervals. Table 3 shows the results of this procedure. Only the interval of maximum precipitation in 70 minutes is shown.

Table 3. Hyetogram for rainfall generated by Hurricane Marty at Huajicori station

Figure 6. Hydrological regionalization (hydrological homogeneous regions) for forests, ecological reserves and protected areas in Mexico

To illustrate the procedure, the calculation for 07:00 is shown. It should be recalled that the intensity is estimated for 30 minutes (0.5 hours) as:

$$\text{¿}((5.62+5.69+5.72))/0.5=34\,mm/h$$

From the above it is concluded that the maximum intensity that happens in 30 minutes is I30 = 34.2 mm/h and using equation number 3 it is obtained that:

$$[1.213+0.890\log(32.94)](32.94 \text{ x } 0.167)=14.10$$

$$[1.213+0.890\log(33.63)](33.63 \text{ x } 0.167)=14.45$$

$$[1.213+0.890\log(34.07)](34.07 \text{ x } 0.167)=14.66$$

$$[1.213+0.890\log(34.24)](34.24 \text{ x } 0.167)=14.75$$

$$[1.213+0.890\log(34.16)](34.16 \text{ x } 0.167)=14.71$$

$$[1.213+0.890\log(33.84)](33.84 \text{ x } 0.167)=14.55$$

$$[1.213+0.890\log(33.30)](33.30 \text{ x } 0.167)=14.28$$

$$[1.213+0.890\log(32.56)](32.56 \text{ x } 0.167)=13.92$$

$$\sum 115.41$$

$R=\frac{(115.41)34.23}{173.6}=22.75$ EIu; in the metric system (1.702 x 22.75) R=38.73 N/h storm

The above represents the condition of one storm. For the mean annual condition of the 2003 hurricane season: 16 storms, we will then have: R=619.6 N/h year.

Discussion

The parameters of the mathematical expressions that describe the RTD curves are used to carry out hydrological regionalization. The result of the regionalization of Mexico was congruent with the techniques proposed to find temporal patterns of similar behavior in climatological records (Meadows 2016). Traditionally, the Huff Curves proposed by the United States Natural Resources Conservation Service (NRCS, old Soil Conservation Service, SCS) are used in Latin America (Hershfield 1961; Huff 1970a; Frederick et al. 1977; USDA 1986). The cartography presented in figures 1 and 6 is the first of its type in Mexico. The analysis made in this research was carried out with more than 20 thousand storms in 188 EMAS stations in an annual mean of 30 years of data records. These values are overly high compared to the 49 storms used by Huff for his original proposal. Another important point is the use of a logistic equation, which allows simple management of the coefficients (Nojumuddin et al. 2015).

About the Universal Soil Loss Formula, while modifications to the original formulation have been proposed, it is clear that in any of the cases it is not possible to obtain results if we do not have precipitation data in 30 minutes (Bagarello et al. 2018). Therefore, the proposal of Huff Curves for extreme events conditions is vital in the conservation of protected areas. Annex A shows the details of the protection and reserve areas in the Mexican Republic, associated with the proposed hydrological homogeneous regions. A comparison of the results obtained from the theoretical Huff Curves (figure 5) with the real records of the storms that happened during Hurricane Erika (figure 4); they follow similar temporal behaviors. The shape of the hyetograms is suitable considering that there is no data on when and how the rains happened during Hurricane Erika. It is important to highlight the coincidence in the times of occurrence. There is a small-time lag between the start and end of the storms. However, the Huff Curves proposed in this work are not dimensionless on the time axis; therefore, the occurrence is obtained at a time between 0:00 and 24:00. In any case, several types of curves can be used to estimate different phenomena (before, during and after the passage of a hurricane); where the regionalization of hydrological homogeneous regions becomes very useful. The case study presented in the Marismas Nacionales in the state of Nayarit is not random; the importance of sediment contribution is a matter of national security in Mexico. At the time of publication of this paper, the volumes of sediment inflow into this important conservation area had not been quantified. The scarce monitoring makes management programs and payments for environmental services deficient, due to the non-definition in the rainfall regime of conservation areas where monitoring is scarce or null. The events of 2003 were so important that the Federal Government installed an EMA station in Acaponeta (a village) near to Marismas Nacionales on December 21st, 2003. Also, on December 8th 2012, an EMA was installed directly in the Marismas Nacionales area. These findings make it possible, such as, to estimate the risk of the erosive power of hurricane rainfall.

Conclusions

The Huff Curves presented in this paper allow to disaggregate the total maximum rainfall in 24 hours into hyetograms of a duration of less than one hour. The importance of understanding the temporal distribution of rainfall when a hurricane approaches the coast is useful for taking preventive measures and reducing human or material losses due to floods, which are frequent in areas of the country when extreme rainfall events caused by cyclones and hurricanes happen. The results of this research highlight the need to check the effects of sediment transport and deposition in wetland ecosystems. In this sense, an important role is given by the climate which is hot and sub-humid, with rainfall ranging from one thousand to one thousand five hundred millimeters per year, which clearly brings about a process of washing into the soil, the age of the plain, and the light texture of the sediments. The quantification of the contribution of sediments in the highest parts of a watershed requires disaggregated rainfall in time intervals of less than 30 minutes. In Mexico, there were no ready Huff Curves, since the North American curves were used for years without considering that the behavior between a tropical zone and North America are very different. With respect to hydrological regionalization, it was found that the Euclidean distance and Ward's rule of aggregation provided results similar to those presented by the Center for the Prevention of Disasters in Mexico, with respect to the cartography of vulnerability to extreme events in Mexico. Although there are many regionalization techniques, the identification of hydrological homogeneous regions according to the behavior of hurricane storms is very useful for Mexican engineering. Likewise, the environmental contribution of being able to get a temporal disaggregation of storms from rain data in 24 hours is critical in the formulation of forest and reserve zone conservation plans.

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