RECONSTRUCTING EXTREME RAINFALL FIELDS IN HAITI

RECONSTRUIRE DES CHAMPS DE PLUIE EXTREME EN HAÏTI

RECONSTRUCCIÓN HISTÓRICA DE LOS CAMPOS DE LLUVIA EN HAITÍ

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Abstract

A description of the main objectives of urban drainage works in the environmental and hydraulic aspects is presented. It is mentioned the corrective actions related to the optimal operation of a rainwater management system, as well as the importance of having the intensity-duration and frequency curves for the design of works and hydraulic utilization. Employ 24-hour maximum rainfall data from 43 climatological stations, satellite images and in particular from nine stations with extensive records from 1997 to 2003, the intensity-duration and return period curves are calculated. Using the formulations proposed by Sherman and Bell, maps of intensities are created for periods of return of 10, 25 and 50 years; Taking into account durations of 10, 30, 60, 120 and 240 minutes. The results of this work present a collection of maps that allow knowing the spatial distribution of precipitation intensities throughout the country, which can be used in the design of works and in the reconstruction of the country's infrastructure.
Key words: Intensity-duration and return period curves; satellite images, precipitation intensity.

Résumé

Ce document montre une description des principaux objectifs qui ont des travaux de drainage urbain dans les aspects environnementaux et hydrauliques. Nous commentons les mesures correctives liées à l'exploitation optimale d'un système de gestion des eaux pluviales a également l'importance qu'elle représente ont des courbes intensité-durée et période de retour (IDF) pour les travaux de assainissement et des ouvrages hydrauliques. En utilisant l'information de précipitation maximale dans les 24 heures à partir de 43 stations météorologiques, Image satellite et en particulaire neuf stations météo avec des donnes depuis 1997 à 2003, les courbes d'intensité-durée et période de retour on a été calculés. En utilisant les formulations proposées par Sherman et Bell on a cartographié (cartes IDF) des camps de pluie pour des périodes de 10, 25 et 50 années et pour les durées de 10, 30, 60, 120 et 240 minutes. Les résultats de cette étude montrent une collection de cartes qui offrent un aperçu de la cartographie spatiale des intensités des précipitations en Haïti, qui peut être utilisé dans le travail d'évaluation des ouvrages hydrauliques et de reconstruction des infrastructures.
Mots clé: Courbes intensité-durée et période de retour ; Image satellite ; intensités des précipitations.

Resumen

Se presentan una descripción de los principales objetivos que tienen las obras de drenaje urbano en el aspecto ambiental e hidráulico. Se comenta sobre las acciones correctivas relacionadas con la operación óptima de un sistema de manejo de aguas pluviales, asimismo se menciona la importancia que representa contar con las curvas de intensidad-duración y periodo de retorno para el diseño de obras y de aprovechamientos hidráulicos. Empleando información de lluvia máxima en 24 horas proveniente de 43 estaciones climatológicas, imágenes de satélite y en particular de nueve estaciones con registros extensos de 1997 a 2003, se calculan las curvas de intensidad-duración y periodo de retorno. Utilizando las formulaciones propuestas por Sherman y Bell se crean mapas de intensidades para periodos de retorno de 10, 25 y 50 años; tomando en cuenta duraciones de 10, 30, 60, 120 y 240 minutos. Los resultados de este trabajo presentan una colección de mapas que permiten conocer la distribución espacial de las intensidades de precipitación a lo largo del país, los cuales pueden ser empleados en el diseño de obras y en la reconstrucción de infraestructura del país.
Palabras claves: Curvas de intensidad-duración y periodo de retorno; imágenes de satélite, intensidad de precipitación.

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INTRODUCCIÓN

One of the most important and important projects in the work of a civil engineer is undoubtedly the elaboration of a Master Plan Rector of Urban Drainage. If we understand the urban drainage as the set of works built to dislodge rainwater and industrial and domestic waste, it would be necessary, especially in these times, to add the component of respect for the environment. In photograph 1, it can be observed the negative impact created by inadequate management of rainwater in urban areas, both in the environmental and hydraulic aspects. It can be said that an urban drainage system is built to achieve three fundamental objectives: (i) to avoid to the maximum the possible damages that the pluvial and domestic waters can cause to the people and their goods; (ii) guarantee the normal development of people's daily lives and traffic of vehicles during the occurrence of rainfall; and (iii) To evacuate in an economical and ecological way the surplus waters of an urban zone. These objectives are related to specific actions that are systematically carried out for the optimal operation of an urban drainage system. These actions can be of the preventive or corrective type. *Corrective actions* in the strictest sense are considered all actions that involve the construction or modification of a hydraulic work; among the most common can be mentioned the construction of dam dissipating works of canalization/rectification, works of regulation/temporary reservoir, settlers, culverts and conduits in general. *Preventive actions* include conservation of tributary watersheds, territorial planning, acquisition of priority areas for conservation (one of the tasks proposed by the *Action Plan for National Recovery and Development of Haiti* in 2010 in the metropolitan area of the city of Puerto Principe, Haiti), regulation and regulation in the use of land routes and of course all actions of information and education to citizens. In all these actions a fundamental concept is implicit that we must not forget those who plan, design or construct hydraulic works; and is the concept of "degree of protection". That is, to define the acceptable level of risk of occurrence of damages or discomfort resulting from the management of rainwater and domestic waters of a city. The degrees of protection will always be associated with the first two objectives mentioned above; being the protection of people and property the main. This degree of protection is translated, for example in the case of floods, in the definition of the level of maximum permitted waters, before the impact of people, goods and road infrastructure (Planos, 2013). Likewise, this maximum permissible water level or height must be related to a probability of occurrence or to a value expressed in years that is commonly known as the return period (the probability of occurrence is the inverse of the return period).This leads us to define for each of the hydraulic works, a design event associated to a critical probability of occurrence from which, the considered event would begin to cause damages. Since the return period is defined as the average time elapsed for a certain phenomenon to recur within a time series of events recorded annually (for example, annual maximum runoff in some river or annual maximum rainfall recorded within a hydrological basin).

Image 1. Environmental impact that generates in an urban area a channel of discharge of rainwater combined with black waters, Prince Port, Haiti. (Photographer: Alfonso Gutiérrez 2005)

METHODOLOGY

To characterize a rainy event it is used to detail its behavior defining what is known as: "the regime of an event"; That is, the magnitude and frequency of a hydrometeorological phenomenon (in this case precipitation).In this way the magnitude of a storm is defined by its intensity (i) and its frequency will be defined by its probability of occurrence or period of return (Tr).The mathematical construction of this relation was presented by Sherman, in 1931 and modified by Bernard, in 1932; Is an equation of the type:

$$i = \frac{k \cdot {T_r}^m}{d^n}$$

where:

i	is the intensity of precipitation, in mm/h
T_r	is the period of return of the event, in years
d	is the duration of the storm, in minutes
k, m, n	are coefficients that are determined by a regression analysis

It is important to note that the intensity and duration of a storm are inversely related and that "m" is a dimensionless parameter that is constant and independent of duration. The characterization of a region is given by the parameters that define this equation. The curve obtained by plotting this equation for different return periods is referred to as intensity-duration-frequency (IDF) curves. The data used to construct these IDF curves come from pluviograph records. However, in many countries of Latin-American and the Caribbean information is not always available for precipitation records to allow the development of such curves. In Mexico, as in other countries, this type of rain-gage is scarce and there are few studies that use these registers (Campos and Gómez, 1990, Campos, 2010).At present Satellite Images, there is an alternative for the estimation of these curves.

The rainfall records that are obtained from conventional stations, which have on average records from 1997 to 2003. The relationship of stations is shown in Table 1. Table 2 shows the precipitation intensities for different storm durations and various return periods; the reference values correspond to Damien station located in the urban area of Puerto Principe (Gutierrez-Lopez and Olvera, 2011). Their parameters k, m and n were obtained by means of a cross-correlation between stations, in addition to comparing the values obtained, with those presented by the Analyse Géotechnique, *Hydrologique et Hydraulique de la Clinique de Soins D'urgence à Delmas 40b, Port-Au-Prince developed for the reconstruction of houses in Haiti* (Mora et al., 2012)

A hydrological model based in satellite images calibrated their parameters k, m and n. These type of models are used for resolutions of latitudes and longitudes of approximately 0.5° as well as to parameterize physical atmospheric processes. They are able to simulate regional climate characteristics, such as orographic precipitation (Frei *et a*l., 2003), extreme events (Fowler *et al*., 2005; Frei *et al*., 2006) and regional or climatic anomalies, Such as those associated with the El Niño southeastern oscillation (Leung *et al*., 2003). However, the model's abilities depend heavily on the presence and influence of regional phenomena such as orography and vegetation cover. Studies in the western United States, China, Europe and New Zealand, where the effects of topography on temperature and precipitation are strong, have always been reported acceptable and consistent results with values of precipitation intensities obtained from images of Satellite and regional meteorological models (Wang *et al*., 2004).

Recent research highlights the use of remote sensing systems and the access to the public of different databases for the development of early warning systems, such as; Flood risk maps in tropical areas and prone to both material and human damage and/or loss in the tropics. Bozza *et al*. (2016) use such tools for the Quinte River near Gonaïves Haiti.

Rainfall estimation using satellite imagery is mainly based on the use of data from IR spectrum images as well as on passive microwave radiation values. These techniques that interpret the IR images additionally require complementary empirical methods that infer quantitatively the rainfall, such methods start from the supposition that the clouds with deep convection can generate precipitation.

The most used Methodologies around the world are listed below:

- Arkin's technique (Arkin, 1979)
- The GPI index of GOES precipitation (Arkin and Meisner, 1987)
- The GWT Griffith-Woodley technique (Griffith *et al*., 1978)
- The NAWT Negri-Adler-Woodley technique (Negri *et al*., 1984)
- The convective-stratiform technique (Adler and Negri, 1988)
- The PERSIANN artificial neural network technique (Hsu *et al*., 1997)

In general, it can be said that the estimation of precipitation by satellite images is based on the clear relation that keeps the temperature of the cloud formations with the place, time and intensity of the storms.In addition, there is a practically linear relationship between the brightness of the clouds and their temperature. Vicente *et al*., 1998 have proposed to estimate rainfall through IR satellite images in the band 10.7 μm (channel 4), from the GOES-8 and GOES-9 satellites, in particular for events related to the summer season and deep convection. This is a potential adjustment between instantaneous rain estimates made by surface radars and temperatures at the top of the clouds obtained by satellite, both for equal time and space (the authors worked with data from May to June 1995 for the central zone Of the Great Plains, USA). The expression is as follows:

$$I=1.1183x10^{11}e^{(-0.036382\ T^{1.2})}$$

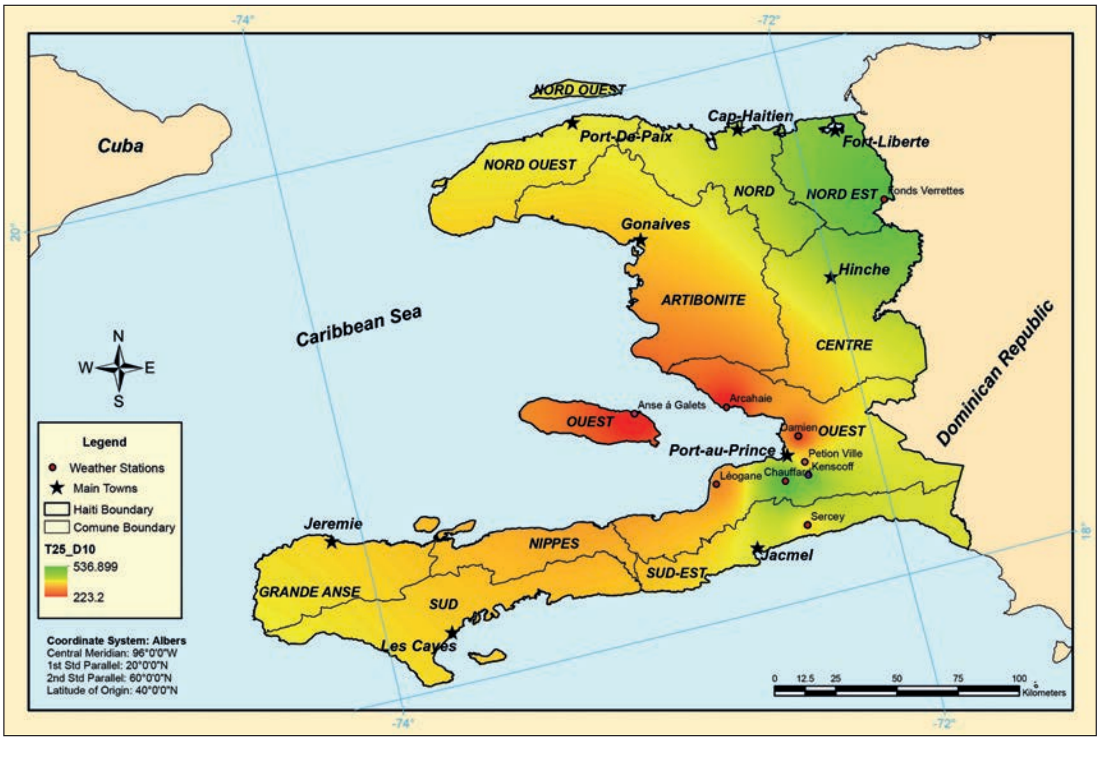
where I is the intensity of precipitation, in mm/h and T is the temperature at the top of the clouds, in °K (degrees Kelvin), for the range $195 < T < 260$ °K. For a better estimation, the above equation is corrected by factors such as humidity, cloud growth and gradient temperature. The moisture correction is related to the amount of precipitable water, Pw (in inches) and relative humidity, Hr (as fraction), whose product is indicative of a dry or wet environment depending on whether the result is less or greater than one, respectively. Such correction is applied to the adjustment equation as follows (Vicente *et al*., 1998):

a. If T > 210 °K and Pw Hr <1.0, it means that the ambient humidity is low and, in such case, the intensity R must be multiplied by the factor Pw Hr; otherwise, the calculated value is left unchanged.
b. If T <200 °K, the precipitation rate should be limited to 72 mm/h, which is the maximum intensity observed in the study area (central area of the EU), for a resolution with 4 km pixels per side. It is important to identify the maximum rainfall recorded in each of the meteorological stations in some Latin American and Caribbean countries and to be able to establish this limit.

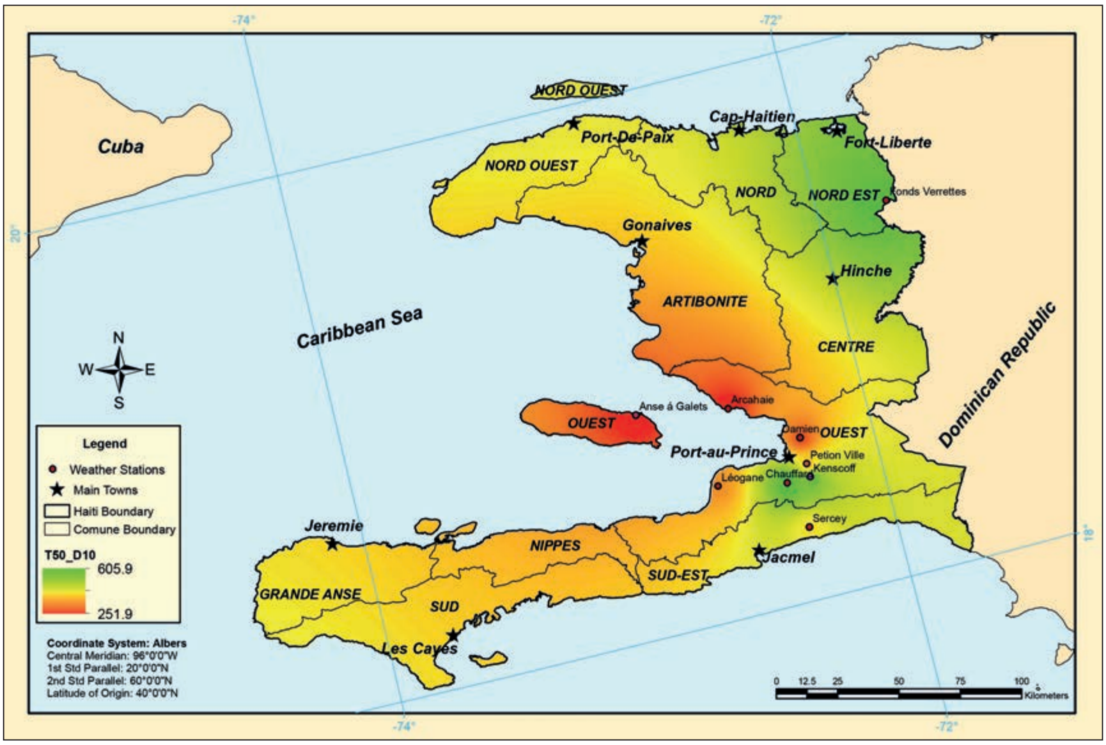
Once the parameters k, m and n of the intensity Shermann´s equation are obtained, it is possible to construct the IDF maps, as shown in figure 1. In this figure we can observe the maps for different probabilities of occurrence, and in table 2 data from 10 to 50 years of return period. Recent studies have shown that these equations must be corrected by geographic position and topographic relief for greater accuracy in the estimation of design events (Olvera, 2012). The practical way of using these IDF curves or characteristic equations of storms is associated, as already mentioned, to the degree of protection of a works or to define the acceptable level of risk of occurrence of damages that can cause an extreme hydrometeorological event on a hydraulics work.

Table 1. Rain gage stations used in the study

Number	Station	Latitude	Longitude
1	Anse á Galets	18.83	-72.87
2	Arcahaie	18.77	-72.52
3	Damien	18.60	-72.28
4	Léogane	18.50	-72.63
5	Sercey	18.27	-72.33
6	Petion Ville	18.50	-72.28
7	Chauffard	18.45	-72.37
8	Kenscoff	18.45	-72.28
9	Fondsverrettes	19.37	-71.73



(a)



(b)

Figure 1. Precipitation intensity-duration-frequency (IDF) map for 10 minutes duration of rainfall and 25 years (a); 50 years (b) return period

Table 2. Intensity-duration and return period curves for Haití (mm/h)

Station	Latitude	Longitude	Alt	T10D10	T10D30	T10D60	T10D120	T10D240	T25D10
Anse á Galets	18.83	-72.87	5	185.9	102.8	67.5	43.3	27.4	223.9
Arcahaie	18.77	-72.52	10	185.3	102.5	67.3	43.2	27.3	223.2
Damien	18.60	-72.28	18	213.5	118.1	77.5	49.7	31.4	257.2
Léogane	18.50	-72.63	18	257.4	142.4	93.5	60.0	37.9	310.1
Sercey	18.27	-72.33	430	297.1	164.3	107.9	69.2	43.7	357.9
Petion Ville	18.50	-72.28	390	276.9	153.1	100.5	64.5	40.7	333.6
Chauffard	18.45	-72.37	1300	445.7	246.5	161.8	103.9	65.6	536.9
Kenscoff	18.45	-72.28	1400	410.9	227.3	149.2	95.8	60.5	495.0
FondsVerrettes	19.37	-71.73	560	442.9	245.0	160.8	103.2	65.2	533.6

Station	T25D30	T25D60	T25D120	T25D240	T50D10	T50D30	T50D60	T50D120	T50D240
Anse á Galets	123.9	81.3	52.2	33.0	252.7	139.8	91.8	58.9	37.2
Arcahaie	123.5	81.1	52.0	32.8	251.9	139.4	91.5	58.7	37.1
Damien	142.3	93.4	59.9	37.8	290.2	160.5	105.4	67.6	42.7
Léogane	171.5	112.6	72.3	45.6	349.9	193.6	127.1	81.6	51.5
Sercey	198.0	130.0	83.4	52.7	404.0	223.5	146.7	94.2	59.4
Petion Ville	184.5	121.1	77.7	49.1	376.5	208.2	136.7	87.7	55.4
Chauffard	297.0	195.0	125.1	79.0	606.0	335.2	220.1	141.2	89.2
Kenscoff	273.8	179.8	115.4	72.8	558.7	309.0	202.9	130.2	82.2
FondsVerrettes	295.2	193.8	124.4	78.5	602.2	333.1	218.7	140.4	88.6

Alt= = altitude in meters
T= duration in minutes
D= return period in years

RESULTS AND DISCUSSION

The use of satellite images in this study was of great importance because of the scarce precipitation data available in Haiti, it was necessary to estimate some events through the technique of the hydroestimator. Once you have the values of the parameters of the Shermann equation, you can create the IDF maps. These curves or maps can be used as a reference for the design of hydraulic work. In this aspect of design it is important to mention that each country, state and also municipality has, in some cases, its own specifications regarding the regulations of design of hydraulic works, for example, for the state of Querétaro, la *Comisión Estatal de Aguas* (CEA) selects the return periods associated with different levels of risk and expected life of the works it builds. Although for practical purposes and considering that a large part of the storm drainage system of the small towns is carried out by surface, the CEA establishes as a period of return for the analysis and design of its pluvial works of water supply and conduction a Tr = 10 years and for head-works Tr = 25 to 50 years (CEA, 2011). This means that using figure 1a or the values quoted; For example, a storm drainage work associated with a storm duration of 30 minutes and a return period of 25 years should be designed (or revised) with a precipitation intensity of approximately 142.3.7 mm/h (also obtained from the Table 2). Some other important values that we must keep in mind are for example 25 to 100 years for the design of road bridges (depending on the population); From 500 to 1000 years for channeling works in rivers in large populations and from 50 to 100 years for diversion dams in large areas of agricultural irrigation. Now it is interesting now to ask what magnitudes have been presented in our state and in Puerto Principe metropolitan area in recent years. To mention some interesting data last year, several important extreme events were monitoring since 2014 for www.redciaq.uaq.mx using a *Hidroestimador* presented for analysis (figure 2). For example on August 2013, where the storm began in Dominic Republic area at 15h00 GMT, it became widespread throughout the island at 15h30 GMT, and finished at 21h20 GMT. In this event, a maximum intensity of 85 mm/h(in one hour) was estimated in the Damien and Chauffard station cover area. If we look at table 2, we can conclude that this maximum intensity event is associated with a return period of just over 20 years. Also, during that event the maximum estimated rainfall high was 121 mm in 40 minutes. In this way we can only wonder if our hydraulic works in urban areas are designed for this type of events or we must review them. Finally, it should be mentioned that in recent years precipitation intensities have increased in Haiti as a result of climate change, so for the next rainy season it is recommended to monitor the evolution of the storms.

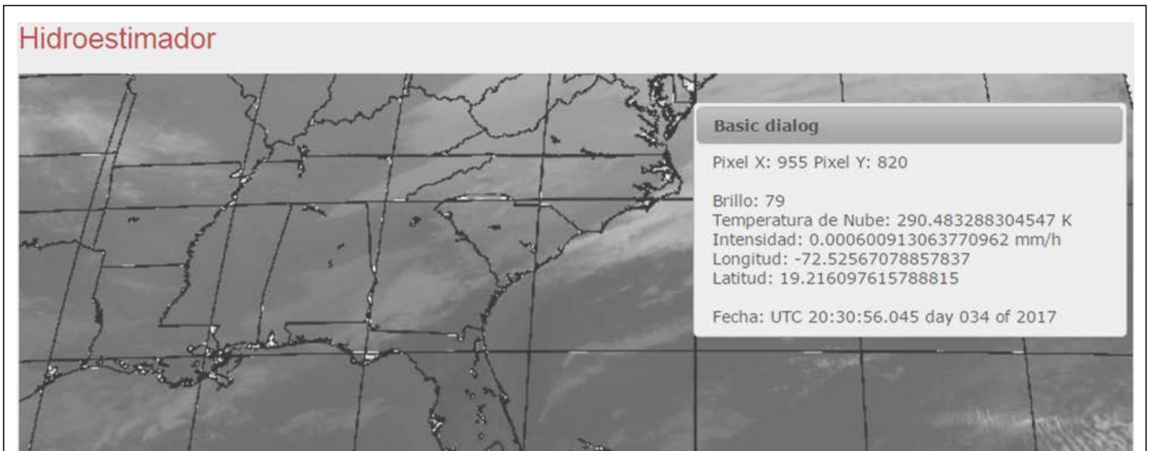


Figure 2. Screen view oh hidro-informatic tool called *Hidroestimador* in www.redciaq.uaq.mx

CONCLUSIONS

The historical reconstruction of the rainfields in Haiti was successful. The few rainfall data that were available were the basis for knowing the maximum rainfall in 24 hours, however, it was necessary to use the technique of the hydroestimator that consists of using satellite images to determine the temperature of the clouds and this way to find the intensity of precipitation. Some estimations of intensities were realized with the use of these satellite images to obtain the instantaneous intensities; from them the parameters m and n of the Shermann formula were obtained and in this way supplement the daily rainfall records to obtain as shown in Figure 1 and Table 2 different values associated to different storm durations and return periods. These maps now allow us to use them for the design of hydraulic works in Haiti. They also allow to know intensities of short duration which could not be obtained from daily records; That is to say the frequency of the satellite images that are taken every 15 minutes allows to obtain events for short duration and therefore to construct reliable IDF curves.

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