An approach to the vulnerability analysis of intensive precipitation in Cuba

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Abstract Hydrological analyses typically use a strict probabilistic approach to predicting extreme hydrological phenomena and analyse the vulnerability of regions to intense precipitation. Although it is well known that probabilistic approaches have weaknesses, when this method is complemented with the physical analysis of precipitation and the analysis of how meteorological systems interact with geomorphology, it can be successfully used to characterize the hydrological vulnerability of regions. This paper presents a methodological approach for the regional analysis of the vulnerability due to intensive precipitation. The methodology uses: (a) probabilistic and stochastic analysis; (b) local geographical scale characterization; (c) regional Intensity-Duration-Frequency graphs; (d) regional relations between the depth of precipitations of different durations; (e) maps of the return periods of maximum precipitation; (e) stochastic maps and (f) graphs of stochastic security. A case study that uses the methodology in Eastern Cuba is presented.

Key words intensive precipitation; probability; frequency; stochastic; vulnerability

INTRODUCTION

In Cuba, an intensive precipitation is considered to be an event that reaches or surpasses 100 mm in 24 hours. One of the most remarkable characteristic of the meteorological systems that produces these precipitations is that in a few hours they can produce rainfall that is close to or even greater than annual precipitation. When these events occur their hydrological impacts often cause lamentable disasters.

The hydrological analysis of this kind of phenomena typically includes a group of deterministic, parametric, probabilistic and stochastic procedures that are used to determine regional generalizations and relations between hydrological variables (OMM, 1994). Extraordinary advances have been made in diagnosing and forecasting dangerous meteorological and hydrological situations. Today, most applied hydrological studies have an integrated vision of the hydrological and meteorological phenomena. Nevertheless, there are limitations in the use of common techniques because certain natural processes are not yet sufficiently described and they are too complex to be defined mathematically. Furthermore, in many cases the analysis is exclusively statistical, the synoptic scale is not well considered, and the geographical conditions are not properly analysed. Therefore, many hydrological characterizations only describe a statistical space and do not include adequate meteorological and geographical analysis. This paper presents a methodology for the regionalization of the intense precipitations and the development of regional vulnerability analysis that is based on a physical-geographical interpretation and probabilistic and stochastic analysis.

DATA

The results presented in this paper are based on two detailed investigations of intense precipitation in Cuba: Planos (2000) and Limia & Planos (2004). This data was based on data collected between 1970 and 1990 in a raingauge network of 835 pluviometers and 135 pluviographs. The density of the raingauge network used in the analysis is consistent with those of the Cuban hydrological network: 8 pluviometers in 1000 km^2, an average of 14 km between pluviometers, and a spatial interpolation error of between 9.5 and 11.5% (Huerta *et al.*, 1977). This design insures that the spatial distribution of the precipitation is well represented.

METHODOLOGY

Analysis of the chronological series

The homogeneity and randomness of the series of annual absolute maxima precipitations were examined with the Helmert test of homogeneity and the Autocorrelation Test. Both tests gave satisfactory results for most of the stations. The Langbein-Dalrymple test (Stedinger, 1995) was also used to evaluate the regional homogeneity of the probabilistic values that were generated. In this test the series were grouped according to altitude, distance between instruments and the coefficient of variation of the series.

Probabilistic analysis of the intensity of the precipitation

To analyse the intensity of Cuban precipitation a method that is widely used internationally was used. This included: (a) the selection of series of annual absolute maxima values of daily precipitation organized by intervals of time 5, 10, 20, 30, 40, 60, 120, 720 and 1440 minutes; (b) probabilistic distribution analysis; (c) development of local and regional graphs of Intensity-Duration-Frequency; (d) determination of regional values of maximum precipitation, for each interval of time in given probabilities; (e) construction of regional graphs of non-dimensional probabilities of maximum precipitation for different time intervals.

The probabilistic estimations were calculated using the Gumbel distribution function and validated with the Kolmogorov-Smirnov test. The probabilistic analysis itself is an evaluation of the hydrological risk and is expressed in terms of return periods. While this probabilistic technique is widely used, the analysis has many weaknesses, including the short duration of the data series available and the inherent uncertainty in the method. Fortunately, by using the concept of stochastic risk (Díaz Arenas, 1982) that is based on the calculation of the probability that one event will occur after a specific number of years, it is possible to get a more objective evaluation of the danger than can be analysed with the distribution functions alone. In this paper the binomial distribution was used to estimate the probability that a depth of rainfall equal to or bigger than 100 mm would occur in the next 2, 5, 10 and 20 years.

Analysis of the vulnerability

The integrated valuation of Threat, Vulnerability, and Risk should be an integral part of the evaluation of the natural threats in a region. While this is a valuable concept, in practice it is usually simplified when individual maps of hydrological risks are produced. Using the experience of the authors, this paper offers this wider vision for the methodological analysis of the intense precipitation. The methodology used in this paper is based on the integral analysis of: (a) regional IDF graphs; (b) regional graphs representing the relation between the depth of precipitation over different time intervals; (c) maps of return periods; (d) maps of probability that the precipitation of 100 mm be equalled or more in 2, 5, 10 and 20 years; (e) graphs of stochastic security, and (f) an integral map of vulnerability for impact of intense precipitations.

RESULTS

To characterize the behaviour of the precipitation in Eastern Cuba at different time intervals, transfer functions of precipitation over different intervals were developed from statistical relationships between the total event precipitation relative to the precipitation that occurred in 60 minutes (Fig. 1). The linear correlation coefficients of these relationships are good (>0.70). This is partly because the most intense rain is reached in the second and third quartiles of storms that had more that 50 mm of rainfall in one hour (Planos, 2000; Limia & Planos, 2004). The results of similar correlations between precipitations with durations of less than one hour are not as strong. This is apparently because they are caused by a diverse group of meteorological situations. This is especially true of intense precipitations with durations of less than 40 min and rainfalls less than 50 mm (Planos, 2000; Limia & Planos, 2004).

The final transfer functions used in the geographical analysis were based on the pluviographs that had error estimations less than 10%. The average error of the estimation with these equations oscillates between +/– 0.1 and 7%, an excellent value for this type of procedure.

Vulnerability analysis

Using the regression based transfer functions described above, the amount of precipitation over different time intervals was calculated for return periods of 100, 50, 20, 10, 5 and 2 years. As part

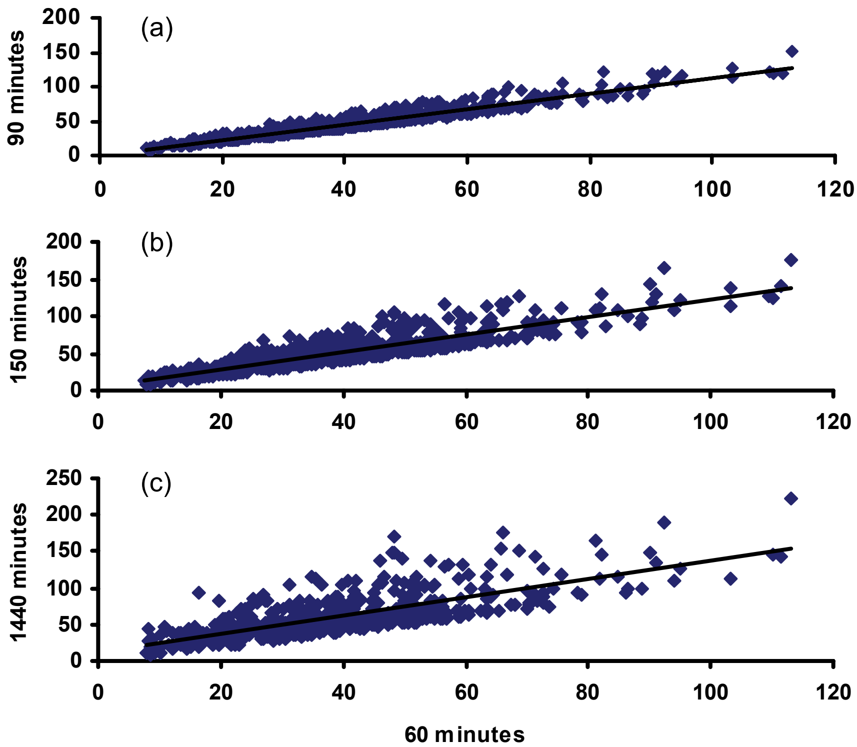

Fig. 1 Relationship between depths of precipitation for different intervals of time: (a) 60 min/90min; (b) 60 min/150 min and (c) 60 min/1440 min.

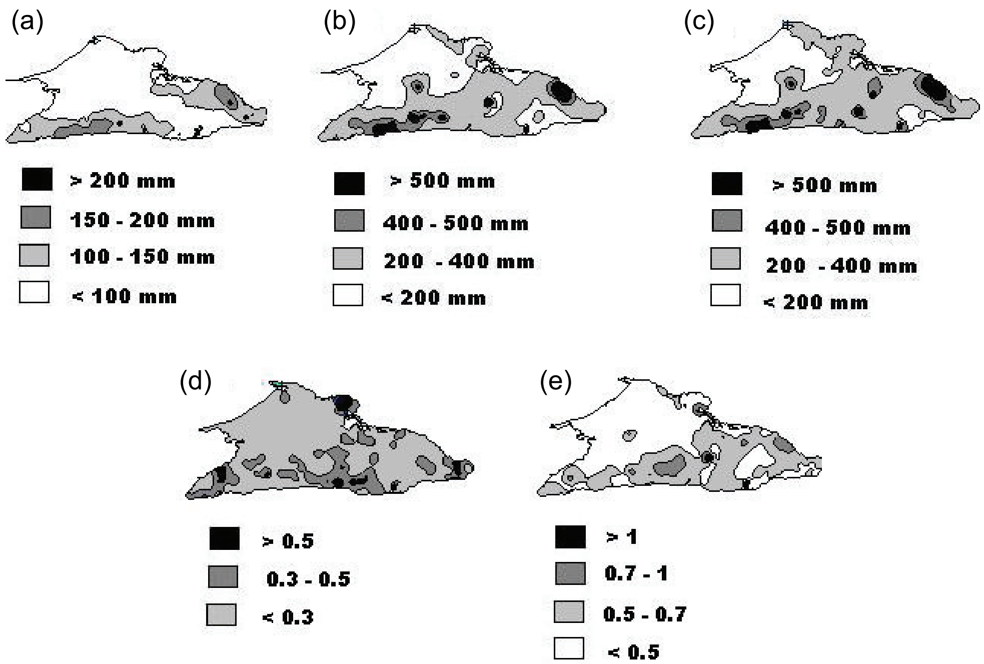

Fig. 2 Cuba Eastern Region. Distribution of statistical parameters associated with intense precipitation: (a) average of annual maximum precipitation in 24 hours; (b) maximum absolute precipitation in 24 hours; (c) 100-year 24-hour maximum precipitation; (d) probability of surpassing the 100 mm depth of precipitation in 2 years; and (e) Coefficient of variation of series of maximum precipitation in 24 hours.

of this analysis the following maps were prepared (Fig. 2): (a) maps of average of maximum precipitation depth; (b) coefficient of variation of the data series, (c) maps of absolute maximum depth of precipitation, (d) maps of 100, 50, 20, 10, 5 and 2 years of return period; (e) maps of 20, 10, 5 and 2 years of probability of surpassing 100 mm of depth of precipitation.

These maps have a structure that clearly reflects major influences on the spatial distribution of the intense precipitation in Cuba (Koshiasvili, 1972; Planos, 2000; Limia & Planos, 2004). In this sense, Planos (2000) and Limia & Planos (2004) determined a strong relationship between the distribution of the maximum values of precipitation, the relief, and the trajectory of the meteorological systems that produce the intense precipitations. Many of which were tropical hurricanes.

Integral map of vulnerability

Independently of the valuable information each of the mentioned maps has for disaster studies, it is more useful to have an integral and mappable valuation of the danger of intense precipitations. To achieve this, maps were developed (Fig, 3) using three levels of danger that were defined using the elements and ranking categories explained in Table 1. These three regions of danger were defined below and their average hydrological and geographic characteristics are presented in Table 2.

Low danger (AI): areas where the average of annual depth of maximum precipitation is less than 100 mm; the frequency of precipitation greater than 100 mm in 24 hours is 0.20%; the probability that a depth of precipitation of 100 mm be surpassed in 5 years is 0.34% and the maximum depth of absolute annual precipitation is less than 200 mm.

Moderate danger (AII): areas where the average of depth of maximum precipitation is less than 200 mm; the frequency of precipitation greater than 100 mm in 24 hours is 0.42%; the probability that a depth of precipitation of 100 mm will be surpassed in 5 years is 0.53% and the maximum depth of absolute annual rain is approximately 250 mm.

Higher and high danger (AIII): areas where the average of depth of maximum precipitation is greater than 200 mm; the frequency of the precipitation greater than 100 mm in 24 hours is 0.46%; the probability that a depth of precipitation of 100 mm be surpassed in 5 years is 0.58% and the maximum depth of absolute annual rain is bigger than 300 mm.

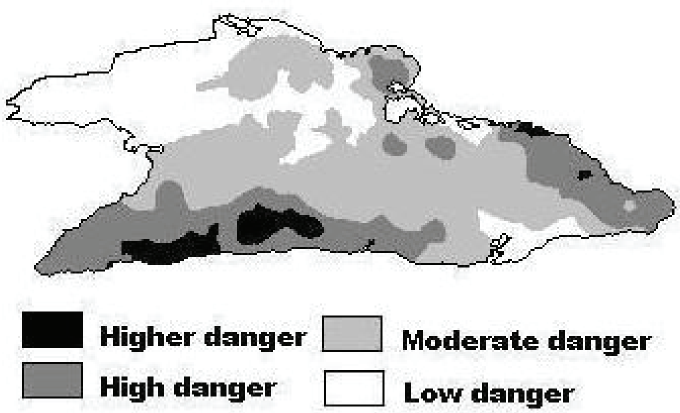

Fig. 3 Map of danger for intense precipitation impact. Cuba Eastern Region.

Table 1 Indicators and category ranking for classification of the vulnerability to intense precipitation impact.

Indicators	Range	Category	Indicators	Range	Category
Average of maxima precipitation	<100	1	Maxima absolute precipitation	<100	1
	101–125	2		100–199	2
	126–150	3		200–299	3
	151–200	4		300–399	4
	>200	5		>399	5
Frequency precipitation =>100 mm	<0.2	1	Probability 100 mm surpassed in 2 years	<0.5	2
	0.2–0.29	2		>0.5	4
	0.3–0.39	3	Danger category according the indicators range	<1	Low
	0.4–0.49	4		2–3.9	Moderate
	>0.49	5		4–4.5	High
				>4.5	Higher

Table 2 Statistical and hydrological characteristic parameters from the areas of danger in the Eastern Region of Cuba.

Average of statistical and geographical attributes	Higher / High danger areas	Moderate danger area	Low danger area
Altitude (m)	220	173	90
Average Annual maximum precipitation (mm)	115	103	80
Frequency of precipitation > 100 mm	0.46	0.42	0.20
Data series coefficient of variation	0.52	0.50	0.42
Annual maximum absolute precipitation (mm)	324	243	172
Precipitation of 100 years of period of return	345	294	225
Probability precipitation = 200 mm	0.58	0.40	0.15
Probability 100 mm precipitation be equalled or surpassed in 5 years	0.58	0.53	0.34

CONCLUSION

The analysis of intense Cuban precipitations was related to the determination of the most severe impacts in the rain by incorporating the analysis of stochastic risk. In the case of Cuba, three levels of danger were defined on the basis of the intensity of the precipitation. Each of these regions had its own identity, expressed through the parameters associated to the intensity of the precipitation and relationships between its statistical parameters, which allows us to define them as homogeneous regions.

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