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ASSESSMENT OF BASIN RAINFALL GRADEX OVER 1 TO 7 DAYS FROM POINT DAILY GRADEX IN 67 RHONE SUB-CATCHMENTS

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Abstract

Basin rainfall gradex over 1 to 7 days in 67 sub-basins of the Rhône catchment are assessed from point daily gradex available at more than 500 raingauges. Estimates being used beyond the present study for evaluating peak discharges of the Rhône tributaries, their reliability has to be asserted. The analysis is composed of 2 steps based upon 2 types of datasets: daily rainfall time series at 243 stations over the 11 main sub-catchments and daily seasonal gradex at 325 (recording) raingauges over the whole Rhône catchment. From the first type of data series, daily rainfall is interpolated over each of the 11 main sub-catchments by a kriging system. Weighting coefficients which are attributed to raingauges take into account the average range over a basin of extreme daily rainfall exceeding a threshold on average three times a year. The basin gradex over the 7 durations are determined by fitting the Gumbel distribution to monthly basin rainfall maxima during the high risk season. Results point out the areal reduction factor applied to point gradex. Secondly, daily rainfall time series being not available at a sufficient number of raingauges for assessing gradex values over 1 to 7 days in the 67 Rhône sub-catchments, a relation between the gradex of the 11 main basins estimated over the 7 durations and the daily seasonal point gradex available for all sub-basins is carried out. Basin gradex are function of the weighted mean of point daily seasonal gradex and of the basin area according to rainfall duration. The validation of the model, performed with a test sample composed of 3 sub-catchments, shows the less accurate estimates are included within a $\pm 20\%$ interval with regard to 'true' gradex and concern sub-catchments characterized by heavy Mediterranean rainfall. The comparison between the weighted mean of daily point gradex and daily basin gradex for all sub-catchments displays an areal reduction factor which becomes more significant with high gradex values.

Keywords: Extreme rainfall data; High risk season; Gumbel distribution; Basin gradex; Areal reduction factor; Validation test

1. INTRODUCTION

Within the context of a global hydrological and open-channel hydraulics study directed by the Rhône-Saône Institute (IRS) and aiming to reduce flood risks over the Rhône Valley (France), the University of Nice Sophia Antipolis was in charge to provide hydrological parameters necessary for studying peak discharges of the Rhône tributaries. The parameters to assess are the basin gradex (exponential gradient) during the high risk season for cumulative rainfall over 1 to 7 days and related to the 67 main and secondary sub-basins of the Rhône River. The sub-basin areas defined from nearly 1000 hydrologic units, range from 100 to 30000km², the whole catchment area upstream to the Rhône Delta being about 96500km².

Concerning the 11 main sub-basins, the value of the gradex over 1 to 7 days can be evaluated from daily rainfall time series available at 243 stations from 1948 to 1999. But concerning the 56 other sub-basins, this raingauging network density is too low to give reliable evaluation of basin gradex. Nevertheless recently, Djerboua (2001) produced results about daily seasonal gradex calculated at more than 550 raingauges and recording raingauges (325 used in this study) located in the Rhône catchment (observation period between 1901 and 1995). Consequently it was expected to identify a relation between the gradex assessments of the 11 main basins over the 7 durations and the daily seasonal gradex available for all sub-basins. This relation might enable to provide rather accurate estimates of the seasonal gradex over 1 to 7 days for the 56 secondary basins.

Firstly, basin rainfall over 1 to 7 days during the high risk season and their gradex values are calculated over the 11 main sub-catchments. Secondly the 67 sub-basin gradex over 1 to 7 days are evaluated from the previous assessments and from the point daily gradex available over the whole Rhône catchment.

2. ASSESSMENT OF BASIN RAINFALL AND GRADEX OVER MAIN SUB-CATCHMENTS

The spatial spreading of the 243 raingauges providing daily rainfall time series is not homogeneous over the 11 main sub-catchments, which are characterized by mountainous regions (the Alps, the Massif Central) influenced by temperate and Mediterranean climates. In their first works, Lebel and Laborde (1988) underlined the relevance of analysing the spatial structure of extreme rainfall in order to derive the areal statistics from point statistics. Thus, in order to assess the mean areal rainfall over a basin, weighting coefficients (rather than uniform weights) are attributed to raingauges and are computed by solving a kriging system. The basin gradex over the 7 durations are determined by fitting the Gumbel distribution to monthly areal rainfall maxima during the high risk season.

2.1 INTERPOLATION OF POINT DAILY RAINFALL OVER A BASIN

The analysis of the spatial correlation structure of extreme daily rainfall allows to define their average range over each basin. Extreme rainfall events which are taken into account are those exceeding a threshold on average three times a year (rather than annual maxima daily rainfall). This approach minimizes the bias involved by eventual errors in data series.

At each raingauge a correlogram with an exponential theoretical model depending on distance h (pairing of one point with all other measured locations) is established and enables to determine the average range of extreme daily rainfall within the neighborhood of a gauge. Point values of average ranges (varying from 10 to 50km) are spatially interpolated over the whole Rhône basin by the Spline method. From this mapping the average range (or decorrelation distance) of extreme daily rainfall over each basin, noted R , is assessed. It represents the distance from which rainfall data series are independent from one another over the basin.

For a given basin, the covariance function can be approached by Eq. (1) and at any point \vec{x}_o in the basin, daily rainfall $R(\vec{x}_o, \omega)$ that occurred on day ω is estimated from observed rainfall $R(\vec{x}_i, \omega)$ at \vec{x}_i raingauges by Eq. (2):

$$\hat{C}(\vec{x}_i, \vec{x}_j) = Var \frac{h_{ij}}{R} \tag{1}$$

$$R(\vec{x}_o, \omega) = \sum_{i=1}^n \lambda_i R(\vec{x}_i, \omega) \tag{2}$$

The kriging system can be written in a matrix form by Eq. (3), which produces the weights λ_i by resolving the system given by Eq. (4):

$$\begin{pmatrix} C(\vec{x}_1, \vec{x}_1) & C(\vec{x}_1, \vec{x}_2) & \dots & C(\vec{x}_1, \vec{x}_j) & \dots & C(\vec{x}_1, \vec{x}_n) & 1 \\ C(\vec{x}_2, \vec{x}_1) & C(\vec{x}_2, \vec{x}_2) & \dots & C(\vec{x}_2, \vec{x}_j) & \dots & C(\vec{x}_2, \vec{x}_n) & 1 \\ \dots & \dots & \dots & \dots & \dots & \dots & \dots \\ C(\vec{x}_i, \vec{x}_1) & C(\vec{x}_i, \vec{x}_2) & \dots & C(\vec{x}_i, \vec{x}_j) & \dots & C(\vec{x}_i, \vec{x}_n) & 1 \\ \dots & \dots & \dots & \dots & \dots & \dots & \dots \\ C(\vec{x}_n, \vec{x}_1) & C(\vec{x}_n, \vec{x}_2) & \dots & C(\vec{x}_n, \vec{x}_j) & \dots & C(\vec{x}_n, \vec{x}_n) & 1 \\ 1 & 1 & \dots & 1 & \dots & 1 & 0 \end{pmatrix} \begin{pmatrix} \lambda_1 \\ \lambda_2 \\ \dots \\ \lambda_i \\ \dots \\ \lambda_n \\ \mu \end{pmatrix} = \begin{pmatrix} C(\vec{x}_1, \vec{x}_o) \\ C(\vec{x}_2, \vec{x}_o) \\ \dots \\ C(\vec{x}_i, \vec{x}_o) \\ \dots \\ C(\vec{x}_n, \vec{x}_o) \\ 1 \end{pmatrix} \tag{3}$$

$$[\lambda_i] = [C_{i,j}]^{-1} [C_{i,o}] \tag{4}$$

The parameters λ_i are calculated at every node \vec{x}_o of a regular grid covering the Rhône catchment. The mean of λ_i values associated to \vec{x}_o points determines the weight of the raingauge \vec{x}_i used in calculating mean areal rainfall over a sub-catchment. Therefore weights depend both on extreme daily rainfall spatial structure and on distances between locations.

For a given basin, all raingauges located within its boundaries as well as those in immediate proximity are used in order to compensate for possible non instrumented areas or for a too low number of gauges, particularly in small catchments. Furthermore, raingauges are not systematically characterized by a common and complete observed period. Lacks in data series are tolerated only if at least 80% of raingauges have information on day ω . Lacks are filled in by whether the observed value at the nearest point or the arithmetic mean of observed data. Daily rainfall over the 11 main Rhône sub-catchments are assessed during a period of about 40 years, and cumulative rainfall over 1 to 7 days are calculated.

2.2 FITTING THE GUMBEL DISTRIBUTION TO MONTHLY BASIN RAINFALL MAXIMA DURING THE HIGH RISK SEASON

In order to produce statistical parameters characterizing extreme basin rainfall, it seems relevant to exclude from the analysis the numerous and non significant rainfall events occurring during the low risk season. The high risk season is defined both by considering the period of major flood events and by the analysis of gradex values of monthly basin rainfall maxima, the Gumbel distribution being widely used in extreme rainfall analysis, as demonstrated by Bontron and al. (1999). Regarding monthly basin gradex values over 1 to 7 days in the 11 main sub-catchments, the high risk season is assumed to be in autumn from September to November. Fig. 1 shows the example of the Eyrieux sub-catchment where high values occurred during these 3 months. This assumption remains consistent with Djerboua's results which determined the same high risk season concerning point daily rainfall.

For the 11 main sub-catchments, seasonal gradex over 1 to 7 days are assessed by fitting the Gumbel distribution to monthly basin rainfall maxima during the high risk season. Thus, the probability law is assumed to be stationary during the 3 months of the high risk season. This statistical approach allows to produce more robust estimates than if only seasonal maxima were retained. The samples varying from 37 to 44 with the basin are consequently multiplied by 3.

Table 1 gives values of seasonal basin gradex over 1 to 7 days ('true' values) and concerning daily rainfall it compares seasonal basin gradex with the arithmetic mean of seasonal point gradex and with the weighted mean of the last ones (weighting coefficients determined in 2.1.). Results point out the areal reduction factor applied to point gradex, the relative differences ranging from 8 to 36%. Sub-catchments being classified according to their confluence sequence with the Rhône River from the Northern (temperate) to the Southern (Mediterranean) parts, results moreover show high gradex values characterize sub-catchments with heavy rainfall (exceeding 600mm over 48 hours) occurring in Mediterranean climatic conditions.

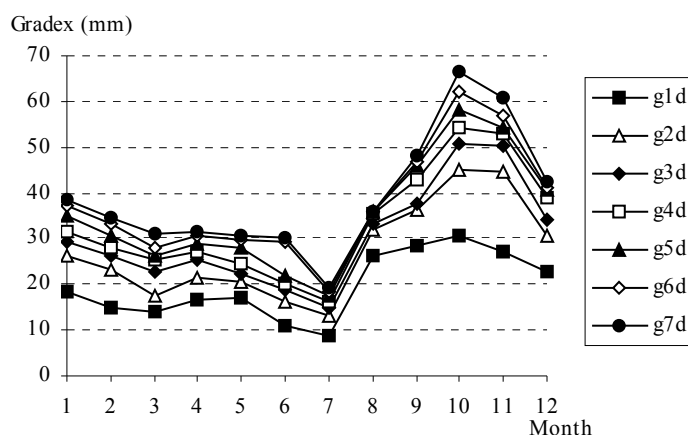


Fig. 1 Gradex of monthly basin rainfall maxima of the Eyrieux catchment (1958-1998)

Table 1. Recapitulative table of seasonal basin gradex over 1 to 7 days in the 11 main Rhône sub-catchments

Sub-Catchment (in confluence sequence with the Rhône River)	Area (km ²)	Observation Period	Number of raingauges	Seasonal Gradex from September to November (mm)											
				Mean g1d	Mean gw1d	g _B	g _B 1d	Relative difference with Mean g1d	Relative difference with Mean gw1d	g _B 2d	g _B 3d	g _B 4d	g _B 5d	g _B 6d	g _B 7d
ARVE	2083	1958-1997	15	12.8	12.6	'true' estimated	11.5 11.2	10% 12%	8% 10%	16.0 14.8	19.0 17.4	22.4 19.6	25.0 21.4	27.1 23.0	29.2 24.5
FIER	1443	1958-1994	14	13.8	13.4	'true' estimated	12.1 12.1	12% 12%	10% 10%	16.2 16.0	20.2 18.8	23.5 21.1	26.2 23.1	28.2 24.8	30.5 26.4
AIN	3765	1961-1998	20	13.9	14.4	'true' estimated	12.4 12.1	11% 13%	14% 16%	16.0 16.0	19.1 18.8	22.3 21.1	24.9 23.0	27.1 24.8	29.2 26.4
SAONE	29437	1961-1998	51	10.8	10.6	'true' estimated	7.6 8.4	29% 22%	28% 21%	11.0 11.1	12.7 13.0	14.4 14.6	16.1 16.0	17.5 17.2	18.7 18.2
ISERE	11897	1958-1997	51	14.7	14.3	'true' estimated	10.2 11.2	31% 23%	29% 21%	13.8 14.8	16.2 17.5	18.2 19.6	20.5 21.4	22.3 23.0	23.9 24.5
EYRIEUX	890	1958-1998	6	35.1	34.2	'true' estimated	29.7 26.4	16% 25%	13% 23%	43.7 34.8	48.7 40.9	52.4 45.9	54.7 50.2	58.0 54.0	60.9 57.4
DROME	1665	1961-1998	9	17.2	16.7	'true' estimated	12.9 14.4	25% 17%	23% 14%	17.0 18.9	18.7 22.3	20.7 25.0	22.5 27.3	24.4 29.4	27.3 31.3
ARDECHE	2381	1955-1998	13	38.6	39.4	'true' estimated	29.1 27.8	25% 28%	26% 29%	47.0 36.7	53.1 43.2	57.0 48.5	59.2 53.0	62.5 57.0	66.9 60.7
CEZE	1365	1955-1998	9	35.3	32.1	'true' estimated	23.1 24.5	35% 31%	28% 24%	33.8 32.3	37.2 38.0	39.2 42.6	40.2 46.6	42.4 50.1	44.8 53.3
DURANCE	14369	1958-1998	48	15.5	15.2	'true' estimated	11.4 11.7	26% 25%	25% 23%	16.6 15.4	18.9 18.1	21.7 20.3	23.5 22.2	25.7 23.9	27.9 25.4
GARD	2003	1955-1998	14	37.0	34.5	'true' estimated	23.6 25.3	36% 32%	32% 27%	36.2 33.4	40.7 39.3	42.7 44.1	43.5 48.2	45.6 51.9	48.2 55.2

3. ASSESSMENT OF BASIN GRADEX OVER 1 TO 7 DAYS FOR SECONDARY SUB-CATCHMENTS

Daily time series being available at a non sufficient number of raingauges for assessing gradex values over 1 to 7 days in secondary sub-catchments, a relation between basin gradex over the 7 durations and daily point gradex in main sub-catchments is put forward. This assumption will enable to estimate seasonal gradex over the 7 durations for all Rhône sub-catchments. The validation of the process is performed in order to ensure the reliability of estimates.

3.1 RELATION BETWEEN BASIN GRADEX OVER 1 TO 7 DAYS AND DAILY POINT GRADEX

From the previous results obtained in main sub-catchments, different modelling attempts show that the basin gradex g_B (seasonal) over a duration t can be explained by the expression:

$$g_{B(t)}^* = a^* g_{w1d}^{\alpha} * A^{\beta} * t^{\gamma} \quad (5)$$

where $g_{w_{1d}}$ is the weighted mean of point daily gradex (seasonal), A the basin area and t rainfall duration (from 1 to 7 days). The coefficients a , α , β and γ are evaluated by the least squares method and are respectively equal to 2.35, 0.8, -0.06 and 0.4.

Fig. 2 compares ‘true’ gradex (calculated from basin rainfall) with those estimated by the assumed model over the 11 main sub-catchments (for the 7 durations). The relative difference from ‘true’ values reaches 20% at the maximum (20% interval represented by dashed lines) and concern the Ardèche catchment and the Cèze catchment, which are located on the right bank in the downstream part of the Rhône River and submitted to a Mediterranean climate (plotted with a red colour).

Concerning these two catchments, Fig. 3 shows that estimates refer to values of daily ‘true’ gradex and increase with rainfall duration according to the Montana law (power functions) induced by Eq. (5). If the process is regionalized by calculating distinct coefficients (a , α , β and γ) according to climatic regions, deviations are not significantly reduced. All values of estimated basin gradex are given in Table 1.

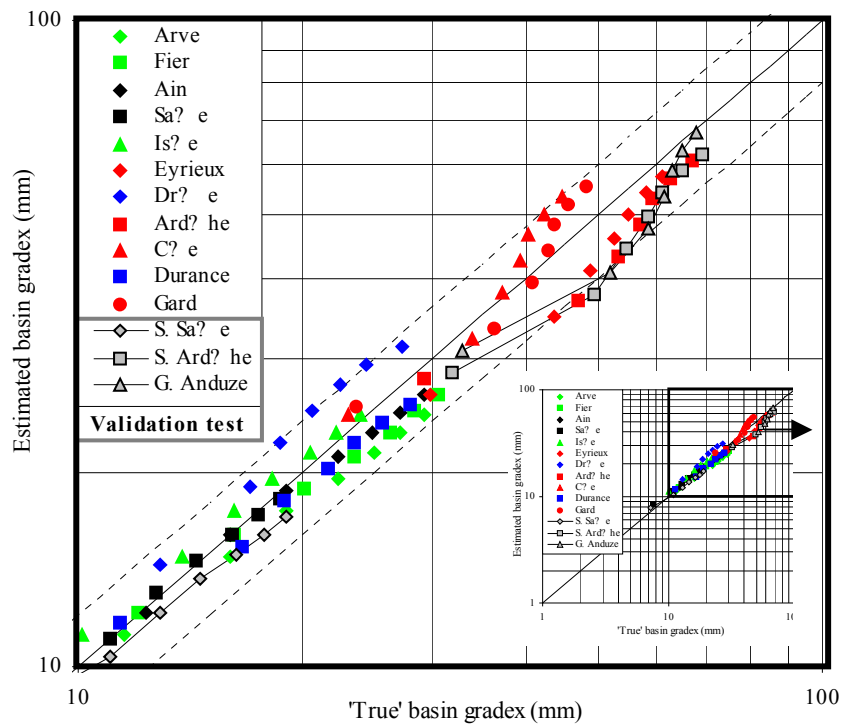


Fig. 2 Comparison between ‘true’ basin gradex and estimated basin gradex over the 7 durations in the 11 main sub-catchments – sub-basins located both on the same bank of the Rhône River and in the same part (Northern/Southern) are plotted with the same colour – and Validation test

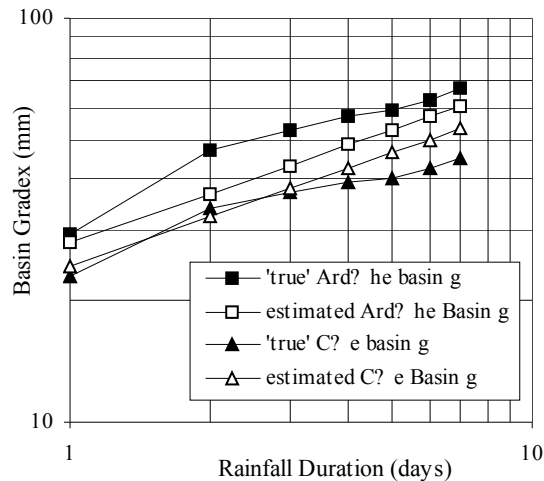


Fig. 3 Evolution of the basin gradex values of the Ardèche catchment and the Cèze catchment with rainfall duration

3.2 VALIDATION PRINCIPLES

The validation of the process is performed with a test sample composed of 3 sub-catchments which areas, locations and climatic characteristics differ and which were not used for the model calibration. One of them is selected because of the lower (but reasonable) rainfall data availability. Basin gradex values are plotted in Fig. 2 with a grey colour. One basin displays very accurate estimates. Gradex values of the two other basins (under Mediterranean influence) are less accurate but remain within a relative difference of 20%.

Furthermore a cross validation is carried out with the reference sample composed of the 11 main basins. This approach demonstrates that the successive removal and re-input of each basin do not provide significant changes.

3.3 ASSESSMENT OF SEASONAL BASIN GRADEX OVER 1 TO 7 DAYS FOR ALL SUB-CATCHMENTS

In order to assess seasonal basin gradex over 1 to 7 days for all sub-catchments, two types of daily seasonal gradex are available at raingauges: those estimated in the previous steps of the study and those estimated by Djerboua. Among the last ones, Weiss correction (which divides gradex values by a coefficient equal to 1.14) is applied to recording raingauges which operate on a 24 hour clock (daily rainfall at raingauges being measured from 6:00 to 6:00 UTC).

The average ranges of extreme daily rainfall over secondary sub-catchments are estimated and rainauge weights are evaluated. The weighted mean of point gradex (seasonal daily gradex) becomes available for all of the 67 basins. Thus, from the relation previously defined, seasonal basin gradex over 1 to 7 days are assessed for the 67 Rhône sub-catchments. Basin gradex estimation is carried out only if at least 3 raingauges are available within a small catchment (below 300 km²) and if the medians of Thiessen polygons are convergent within its boundaries.

Fig. 4 compares the weighted mean of daily point gradex with daily basin gradex for all sub-catchments. The graph underlines the effect of areal reduction factor which becomes more significant concerning high gradex values.

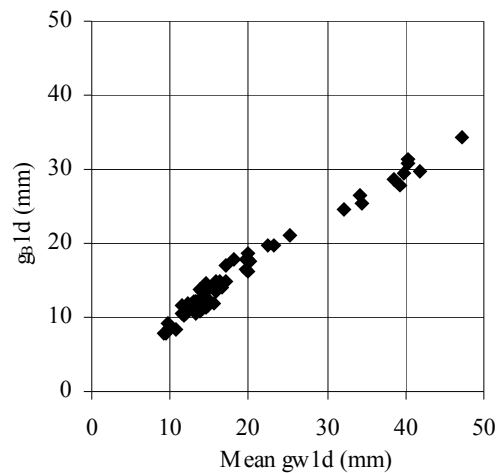


Fig. 4 Comparison between the weighted mean of daily point gradex and daily basin gradex in the 67 Rhône sub-catchments

3. CONCLUSIONS

The necessity to conduct a policy of reduction of flood risks in the Rhône Valley and the low availability of hydrometric information over the whole river catchment lead to use a raingauging network and point daily parameters for estimating basin gradex over 1 to 7 days in the 67 main and secondary sub-basins. The statistical approach becomes reliable under the two following conditions.

First, areal statistics (basin rainfall) are derived from point statistics by weighting raingauges taking into account the spatial variability of rainfall events over each basin, which is expressed in this case by the average range of extreme daily rainfall exceeding a threshold on average three times a year. Secondly, scale parameters (gradex) of basin rainfall over the 7 durations, which are used to calibrate the final equation, are evaluated from a robust statistical analysis (with large samples), by fitting the Gumbel distribution to monthly basin rainfall maxima during the high risk season.

The assessment of basin gradex over 1 to 7 days in all sub-catchments, is performed from an empirical formula which is function of the weighted mean of point daily seasonal gradex and of the basin area. Results point out the areal reduction factor applied to point gradex. The model validation process shows estimates are included within a $\pm 20\%$ interval with regard to 'true' gradex. It emphasizes the difficulty to ensure a very satisfactory outcome concerning regions characterized by heavy rainfall and flash floods within a Mediterranean climatic context.

REFERENCES

- Bontron, G., Menez, G., Duband, D., Gautier, J.N. (1999). Gradex method application to large watersheds: the case of the Loire at Bec d'Allier (32,000 km²). *La Houille Blanche*, n° 6, pp. 29-36.
- Djrboua, A. (2001). *Predetermination of extreme rainfall and floods in the Alps*. Ph.D, LTHE-INPG, Grenoble University (France), 212 p.
- Lebel, T., Laborde, J.P. (1988). A geostatistical approach for areal rainfall statistics assessment. *Stochastic Hydrology and Hydraulics*, n° 2, pp. 245-261.