AMMA2050
Technical notes #XX

Intensity-duration-frequency curves for the city of Ouagadougou: A tool for helping with the dimensioning of hydraulic structures

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02 may 2018

1. Intensity-duration-frequency (IDF) curves: what for?

1.1 Dimensioning of structures and design storm

Hydraulic structures to manage rainwater runoff are based on control of flow routing via channels, overflow limitation by dikes or temporary storage of flows before surface discharge or infiltration into the soil.

In both cases, the design of the structures is based on the definition of a design storm. Design storm is usually defined by a synthetic *hyetograph*[i] that represents the intensity of the rain over a given period of time. A statistical frequency, most often expressed as a *return period*[ii], is assigned to the design storm and depends on the targeted protection objectives (see Figure 1).

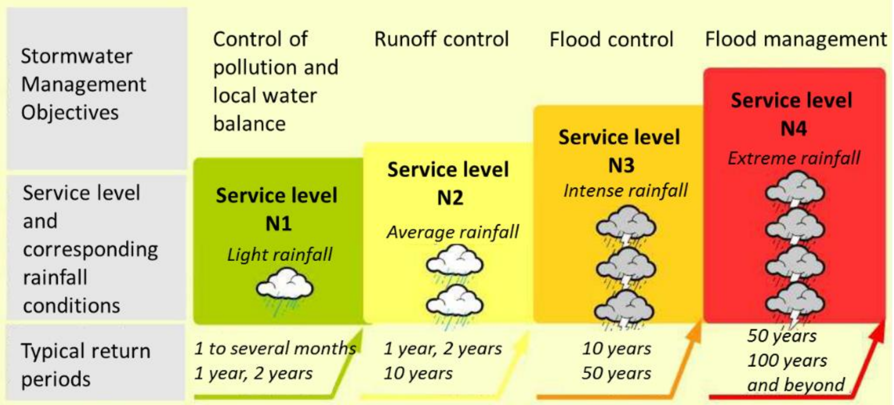

Figure 1 Stormwater management objectives and choice of precipitation return period for the design of hydraulic structures (adapted from DGALN, Cerema – Rejets d'eaux pluviales Principes généraux, 2014)

For a given frequency (or return period), the characteristics of a design storm depend on:

- the duration of the rain
- the maximum intensity of the rain
- the total height of the rain

The duration is generally fixed in relation to the time of concentration[iii] of the surface drained by the structure. This duration can be short (a few minutes to a few hours) for small rural watersheds and in urban areas.

The intensity or total height of the rain is usually determined from intensity-duration-frequency curves.

1.2 Curves intensity-duration-frequency (IDF)

The IDF (Intensity-Duration-Frequency) curves represent the evolution of the rainfall intensity $i_T(d)$ as a function of the duration *d* of the rain (generally from a few minutes to a few hours) and the return period *T* (often some values sampled between 2 and 100 years).

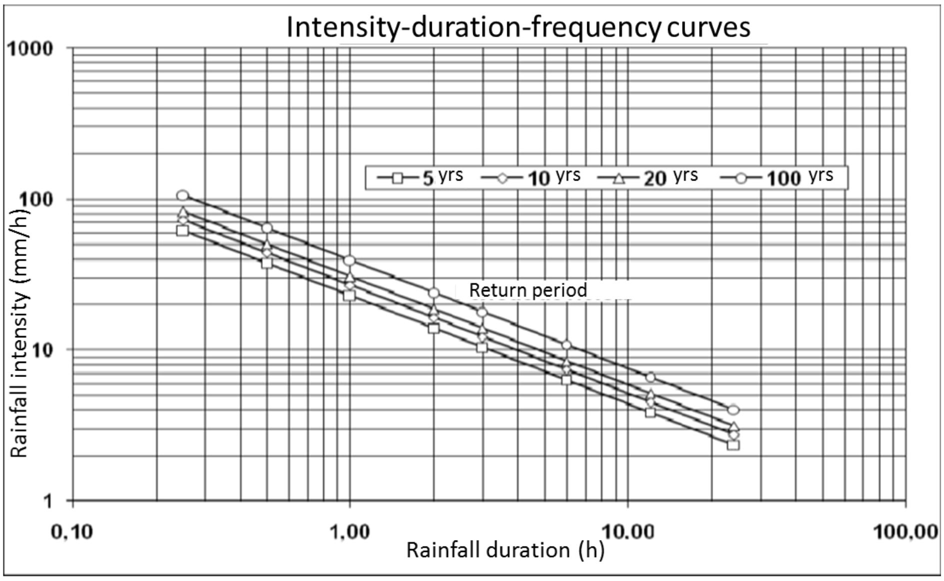

Figure 2 Exemple de courbes intensité-durée-fréquence

Several types of representation of information from IDF curves exist:

- Graph: The curves established as in the example of Figure 2, can be used to graphically evaluate the intensity of return period rain 10 years of duration 1h. The curves thus show that for a given return period, the longer the rain, the lower its average intensity.
- Tables of values: The tables can provide on a specific study area, for selected durations and return periods, the accumulated rainfall values over the duration (in mm) or the intensity of rain in (mm / h)
- Montana coefficient tables: The Montana empirical law is very commonly used to represent the evolution of rainfall intensity according to its duration according to the following formula:

$$i_T(d) = a_T d^{-b_T} \qquad \textit{Equation 1}$$

  where a_T and b_T are the Montana coefficients defined for a return period *T* and which may depend on the time range over which the IDF curves are adjusted.
  The Montana coefficient tables thus contain, for different time ranges and for different return periods, the values of the coefficients a_T and b_T intervening in the Montana formula.

The estimation of the IDF curves is based on a statistical analysis of the extreme rainfall intensities from series of rainfall measurements. In order to limit biases and provide a robust estimate, this analysis requires quality sub-daily data (not erroneous, with few gaps) recorded over a long enough period of time to sample rare events. Measurements from in-situ rainfall stations are, to date, the most likely to present these specificities and are therefore most commonly used to estimate IDF curves.

In some cases, the estimation of the rain intensity values is associated with the confidence intervals that make it possible to quantify the precision of the IDF curve adjustment, which can vary according to the rainfall information available on the location of interest. This accuracy is low if the rainfall series used to adjust the curves are too small. On the other hand, a too long rain series can introduce adjustment inaccuracies due to long-term climate variability. Different methods exist to improve the precision based on a use of several rainfall series around the area of interest (regional method) and the taking into account of the climatic evolution for the estimation of the parameters describing the IDF curves (climatic non-stationarity).

2. Development of intensity-duration-frequency curves for Ouagadougou

2.1. Context

Generally in the Sahel, two factors make the frequency analysis of the extremes and therefore the estimation of the IDF curves more difficult than in the temperate regions: (i) the very strong spatio-temporal variability of the rainfall systems which accentuates the effects of sampling, decreases the robustness of estimation of the IDF curves and increases the inaccuracies of estimation, (ii) the low availability or accessibility of long-term rainfall series at sub-daily scales.

These two constraints limit the simple possibility of estimating IDF curves or doing so robustly. Therefore, the quality of estimation of IDF curves in the region is largely conditioned by the possibility: (i) to collect sub-daily rainfall data over a sufficiently long period of time, (ii) to use statistical methodologies able to best reduce the sampling effects.

2.2. Methodology

As far as we know, there is no sufficiently long sub-daily rainfall series that could be used to adjust IDF curves in Ouagadougou. On the other hand, thanks to the maintenance of the national network operational by the General Directorate of Meteorology of Burkina Faso, very long daily rainfall records that make it possible to estimate at this time step relatively accurately the rainfall values for different return periods.

The development of IDF curves proposed by the AMMA2050 project is thus based on the combination of statistical analyzes from the daily rainfall records available in Burkina Faso including the city of Ouagadougou, and temporal scaling laws that describe the evolution of rainfall intensities at sub-daily scales estimated in other Sahelian study areas.

Our research indeed showed that the laws of change of temporal scales were very similar between different Sahelian regions (evaluated in Senegal and Niger) and that the IDF curves differed by a shift of intensity values which can be estimated, in first approximation, from daily data (Panthou et al., 2014b, Sane et al., 2017).

More specifically, the curves for Ouagadougou were developed through a three-step process:

(i) The estimation of daily rainfall intensities in Ouagadougou for different return periods:
   a. Data: daily data available in Burkina Faso.
   b. Method:
      - Use of a regional approach gathering information from several stations spread over Burkina Faso. This makes it possible to reduce the effects of sampling, and thus to gain in robustness, while keeping the possibility of having a local estimate in Ouagadougou of rainfall values of interest (Panthou et al., 2012).

- The theory of extreme values (Coles 2001) via the adjustment of a extreme value distribution (GEV distribution) applied to annual maximum daily rainfall values extracted from the daily rainfall series.

(ii) The estimation of the temporal scaling law in the Niamey region. The estimation method is based on:

a. Data: Rainfall data from the AMMA-CATCH Niger observatory (www.AMMA-CATCH.org) available at a 5-min time step over the period 1990-2016.

b. Method:

- Use of a regional approach gathering information from several stations.
- Joint use of the theory of extreme values and a simple scaling invariance approach (fractal theory, Menabde et al., 1999) to estimate the temporal scaling properties of rainfall intensities.

3. IDF curves for Ouagadougou

The IDF curves are delivered here in graphical format (Figure 3) and in table form (Table 1) where are reported the coefficients a_T and b_T of the Montana formula (Equation 1).

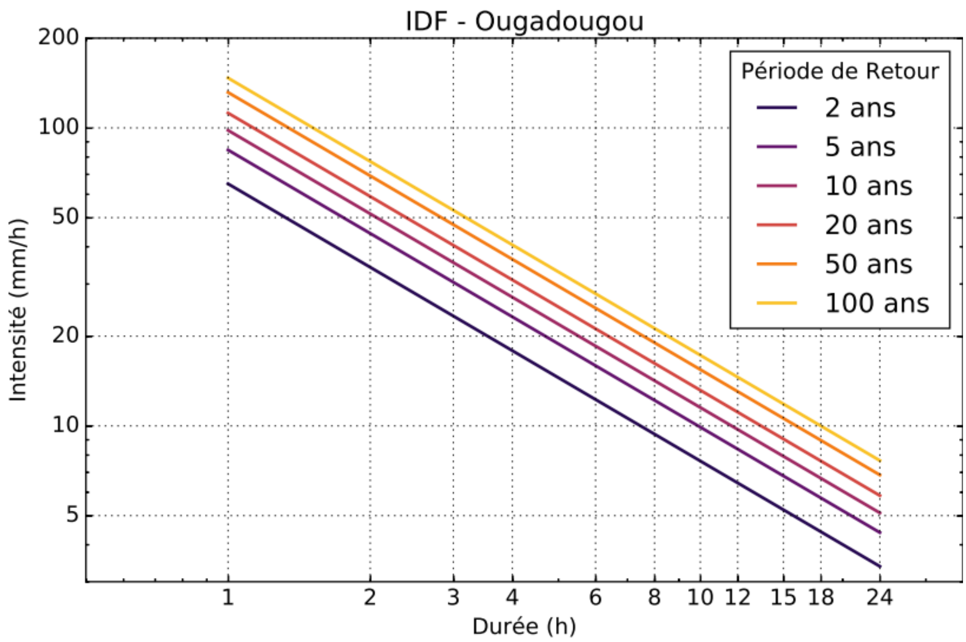

Figure 3 Intensity-duration-frequency curves for Ouagadougou

	b	$a_{T=2\ ans}$	$a_{T=5\ ans}$	$a_{T=10\ ans}$	$a_{T=20\ ans}$	$a_{T=50\ ans}$	$a_{T=100\ ans}$
Ouagadougou	0.93	64.92	84.31	98.13	112.17	131.55	147.03

Tableau 1 Montana coefficients for IDF curves in Ouagadougou with a duration in hours.

Note Bene 1: the coefficient b_T is in the case of the Sahel supposed to be independent of the period of return.

Note Bene 2: the values of the parameters a_T and b_T does not depend on the range of duration considered.

4. Precaution of use of IDF products

The frequency analysis of extreme rainfall is based on several assumptions that may have consequences on the estimation of the IDF curve in Ouagadougou. Some precautionary points of use are listed below:

- The IDF model (and the resulting curves) was estimated from point data (station), so $i_T(d)$ represents a point rainfall value. If this value can be used for small catchments (in the order of km^2), it may overestimate the rainfall of basins whose surface area is too large. In this case, the use of a spatial reduction factor (ARF) may be relevant (orders of magnitude of ARF can be found in Panthou et al (2014b).
- The method used does not allow to estimate the confidence intervals on the IDF curves in Ouagadougou. The values shown are expected values to be used as indicative quantities.
- The range of durations for which the curves provided are valid is 1h-24h. An analysis in progress suggests that extrapolation of IDF curves to smaller time steps could lead to a slight overestimation of sub-hourly intensities.
- Frequency analysis is based on the hypothesis of temporal stationarity of extremes. This hypothesis is very much open to criticism considering the strong decadal variability of the precipitation regime in the region. In particular, two recent studies (Panthou et al., 2014a, Taylor et al., 2017) show an increase in rainfall intensity in the Sahel since the early 1980s, including the most extreme rains. Over the period 1990-2016, rainfall intensities are estimated to increase by 2-4% per decade. The recent warming of the Sahara has been identified as the main cause of this trend as it favors weather conditions conducive to the emergence of intense storms. Being linked to global warming, there is every reason to believe that the intensification of rainfall in the Sahel is likely to continue in the coming decades. Research is underway within the AMMA2050 project to produce IDF curves under future climate conditions.

Glossary

[i] Hyetograph : curves of evolution of the intensity of rain over time.

[ii] Return period: value characterizing the frequency F of a random process expressed in average time T between two occurrences. The link between the frequency of occurrence F and the return period is F = 1 / T. For example, a rainfall of 10-year return period has 1 in 10 chance of being exceeded each year.

[iii] Time of concentration : The longest travel time to reach the outlet of a watershed. The most unfavorable rain for a watershed is the one whose duration is equal to the concentration time.

Online references

DGALN, Cerema – Rejets d'eaux pluviales Fiche n°3 – Conditions pluviométriques (V1 déc. 2014).

Scientific references

Coles, S., 2001: *An introduction to statistical modeling of extreme values*. Springer, London ;;New York,.

Menabde, M., A. Seed, and G. Pegram, 1999: A simple scaling model for extreme rainfall. *Water Resour. Res.*, **35**, 335–339, doi:10.1029/1998WR900012.

Panthou, G., T. Vischel, T. Lebel, J. Blanchet, G. Quantin, and A. Ali, 2012: Extreme rainfall in West Africa: A regional modeling. *Water Resour. Res.*, **48**, W08501, doi:10.1029/2012WR012052.

——, ——, and ——, 2014a: Recent trends in the regime of extreme rainfall in the Central Sahel. *Int. J. Climatol.*, **34**, 3998–4006, doi:10.1002/joc.3984.

——, ——, ——, G. Quantin, and G. Molinié, 2014b: Characterising the space–time structure of rainfall in the Sahel with a view to estimating IDAF curves. *Hydrol Earth Syst Sci*, **18**, 5093–5107, doi:10.5194/hess-18-5093-2014.

Sane, Y., and Coauthors, 2017: Intensity-Duration-Frequency (IDF) rainfall curves in Senegal. *Nat Hazards Earth Syst Sci Discuss*, **2017**, 1–30, doi:10.5194/nhess-2017-352.

Taylor, C. M., and Coauthors, 2017: Frequency of extreme Sahelian storms tripled since 1982 in satellite observations. *Nature*, **544**, 475–478, doi:10.1038/nature22069.