# IDF curves Impact Case Study for the AMMA2050 extension

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## Introduction

Adapting to the effects of climate change is a major challenge of this century, especially for developing countries whose means of action are limited. Although in West Africa climate disruption manifests as an overall decrease in rainfall, Sahelian countries, such as Senegal, face intense rainfall episodes during the West African monsoon period. These extreme events, coupled with poorly controlled urban planning, cause major flooding almost every year.

According to the United Nations Office for the Coordination of Humanitarian Affairs, "torrential rains in 2005, which lasted from August to early September, caused flooding in Dakar, leading to 46 deaths, a cholera epidemic and the evacuation of 60,000 people. In 2009, floods again destroyed 30,000 homes in Dakar, affecting more than half a million people and resulting in USD 44.5 billion in damages and losses. In 2012, another catastrophic flood devastated already fragile public infrastructure and contaminated more than 7,700 drinking water sources" (Agence Française de Developpement, 2017). These events therefore have adverse economic, social and health effects, paralyzing entire areas of the country over a period of several months.

Due to global changes and population growth, people are increasingly exposed to hydrometeorological hazards such as torrential rainfall and flooding [IPCC, 2012; Mechler and Bouwer, 2015]. In order to produce practical tools for flood risk management, hydraulic infrastructure and hydrological models have long addressed the issue of assessing the probability of extreme precipitation events at different scales. For this purpose, intensity-duration-frequency (IDF) curves of precipitation are commonly used, as they provide estimates of the return levels of precipitation over a range of durations.

The implementation of IDF curves faces two main difficulties. The first relates to the information problem inherent in (i) the analysis of the frequency of extremes, which requires a long series of precipitation data, and (ii) the need to have precipitation records on sub-daily time scales. The second difficulty arises from the variability of complex precipitation at all scales (from cloud microphysics to synoptic scales) which results from the non-linear interaction of different atmospheric processes [Schertzer and Lovejoy 1987].

In this impact case study, a model of intensity-duration-frequency curves (IDF) for Senegal is proposed in order to provide a tool to assist in the design of hydrological and hydraulic structures.

The results obtained have opened up prospects for application to other sites and cities in West Africa.

## I - Background to the study

In the Sahel, the last two decades have seen an exponential rise in flood-related damage in a region that is better known for drought. The Sahelian populations are increasingly vulnerable to floods due to population growth and rapid urbanization, where populations are often residing in informal settlements situated in flood-prone areas (Tarhule 2005; Di Baldassarre et al. 2010; Tschakert et al. 2010). But there is also a proven increase in the frequency and intensity of intense thunderstorms in the region (Panthou et al. 2013; Taylor et al. 2017) which, together with soil degradation (Descroix et al. 2018), accentuate local and river flooding (Wilcox et al. 2018).

Flood preparedness has therefore become a major issue for Sahelian decision-makers. IDF curves are part of the climate information currently available to inform flood risks appropriately inform infrastructural developments.

There are two principal tools for reducing flood risk: regulatory management which aims, through the implementation of prevention plans, to reduce the exposure of populations and structural management which aims, through hydraulic works, to reduce the effects of the natural hazard linked to heavy rainfall and floods. In Senegal, structural management is constrained by the lack of data and tools to help design hydraulic infrastructure.

ANACIM benefited from capacity building in the development of IDF curves, supported by the AMMA-2050 project and project partners, which was then used to support specific infrastructure development initiatives.

This case study identified the benefits of using IDF curves and provides examples of the where ANACIM has developed IDF curves for specific government and private sector infrastructure development projects. The case study then documents feedback and lessons learned on the usefulness of IDF curves from the institutions that requested ANACIM to produce these.

## II - Socio-economic benefits of using IDF curves

### II-1 Sizing of structures for projected rainfall

Hydraulic structures to manage stormwater runoff are based on the control of runoff via channels, the limitation of overflow by dykes or the temporary storage of runoff before surface discharge or in the soil by infiltration. In each case, the design of the structures is based on the definition of a design storm. Design storm is defined by a synthetic hyetogram (graph of the temporal variation of the water flow rate, measured on the ground) which represents the intensity of the rainfall over a given duration. A statistical frequency, usually expressed in return period, is assigned to the projected rainfall and depends on the protection objectives.

For a given frequency (or return period), the characteristics of a design storm depend on the duration, the maximum intensity and the total height of the rainfall. The duration is generally set in relation to the time of concentration of the watershed drained by the structure. This duration can be short (a few minutes to a few hours) for small rural catchments and in urban areas.

### II-2 IDF curves

IDF curves represent the evolution of the rain intensity as a function of the rain duration (generally from a few minutes to a few hours) and of the rain frequency expressed in return period (between 2 and 100 years). They are based on the statistical analysis of extreme rainfall intensities from rainfall measurement series. In order to limit the biases and provide a robust estimate, this analysis requires good quality (non-erroneous, with few gaps) sub-daily data recorded over a sufficiently long period to sample rare events.

Measurements from in-situ rainfall stations are, to date, the most likely to have these specificities and are therefore the most commonly used to estimate IDF curves.

Generally speaking, two factors make the frequency analysis of extremes and thus the estimation of IDF curves more difficult in the Sahel than in temperate zones: (i) the very high spatio-temporal variability of rainfall systems, which accentuates sampling effects, decreases the robustness of the estimation of IDF curves and accentuates estimation inaccuracies, (ii) the poor availability or accessibility of long rainfall records at sub-daily scales.

These two constraints limit the possibility of simply estimating the IDF curves or of doing so in a robust manner. Therefore, the quality of IDF curves estimation 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 capable of absorbing sampling effects.

## II-3 The advantages of IDF curves

IDF curves hold many advantages. Firstly, there are a lot of demand for hydrological studies.

Secondly, the curves are estimated in a very robust manner because they are based on long rainfall series available over the period 1950-2005 in Senegal. They result from the application of the most recent and efficient statistical methodologies in this field.

They also have certain limitations that must be borne in mind. Firstly, they are based on an assumption of stationarity of the climate over their calibration period 1950-2005. Secondly, their validity for the design of multi-decadal structures may be questionable because of the recent increase in rainfall intensity, which is likely to continue over the coming decades

AMMA2050 researchers are working on the development of adaptive IDF curves. Meantime existing IDF curves, which are capable of taking climate trends into account, can be used as a first estimate of the orders of magnitude of rainfall values to be used for hydrological and hydraulic design studies.

## III - Some lessons learned

The methodology developed can be applied to estimate the IDF curves for other localities in West Africa for which long daily rainfall series are available. Dependence on this data for the development of IDF curves highlights the importance of continuing to promote long-term observation of precipitation at sub-daily scales.

Initiatives in this direction carried out within the AMMA-CATCH Observatory or within national meteorological services show that a substantial effort in instrumentation, monitoring, data storage and digitization can meet important needs in hydrological engineering (Sane et al. 2018).

A key point for improving the IDF curves is currently focused on addressing the assumption of stationarity of extremes. This assumption is highly questionable given the high 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, particularly impacting the most extreme rains. Over the period 1990-2016, rainfall intensities are estimated to have increased by 2-4% per decade.

With global warming there is every reason to believe that rainfall intensification in the Sahel is likely to continue in the coming decades. Research is underway within the AMMA-2050 project to produce IDF curves under future climate conditions.

## IV - Testimonials/quotes from stakeholders on the use of IDF curves

We collated feedback from the users of ANACIM-generated IDF curves, including the Ministry of Water and Sanitation, the NGO GRET (www.gret.org) and Espace Ouakam Dakar. Key informant responses are summarized below:

**Why were the IDF curves necessary?**

Following the occurrence of extreme weather events in 2020, there is a recognized need to calculate the occurrence of this type of event and determine the flow generated by watersheds. The IDF curves informed hydraulic studies for infrastructure project, for example, enabling the design of stormwater facilities for 2-year and 10-year return periods.

**Why IDF curves produced by ANACIM were sought (e.g., quality, detail of information provided or other)?**

ANACIM is the nationally-mandated agency for meteorological information and users of IDF curves included established as well as newer ANACIM partners. It is the only organization in Senegal that has stations in a large part of the country. Users recognized ANACIM as a trusted, citable source, recognizing the quality and reliability of the data it provides. More specifically, ANACIM stations were closer to one of the user's study areas and therefore considered more reliable.

**How have the IDF curves been used? And the resulting impacts observed to date?**

The IDF curves were used in hydraulic design calculation. The flows calculated with the IDF curves were used to quantify the volumes of water in the low points and, on this basis, size stormwater networks, including the pipes, stormwater drainage and storage structures.

The IDF curves are recognized as a very important tools as they synthetize rainfall information useful to hydraulic engineering. They make it possible to determine the Montana coefficients of a given zone. However, there are big differences in the IDF curves for the same region. Several reports are found with different IDFs and therefore with widely varying Montana coefficients. This makes it very difficult to verify the reliability of the calculations.

**Requirements that could not be fully met in the current IDF curve format (e.g., IDF curves for future climate or for a specific period not yet available)?**

IDF curve users noted the need for full country coverage. Moreover, the process of accessing data is slow, with delays in obtaining recent data. One user highlighted that the fundamental importance of the reliability of the curves, noting the differences in different projects undertaken by different offices in the same area.

## Conclusion

Within the framework of the AMMA-2050 project, ANACIM and the Institut des Géosciences de l'Environnement (IGE) have developed IDF curves for Senegal. These value-added products are operational and marketed at ANACIM. This collaboration with IGE has strengthened the capacity of ANACIM who are now able to independently supply IDF curves and Montana coefficients. Thus, many state projects have used these IDF curves to size stormwater structures and drainage networks. Feedback from users of the IDF curves highlight the need for national coverage, the reliability of the curves, area and the slowness of the procedures to access the data. Other shortcomings concern the temporal resolution because many projects wish to have information of 10, 15 and 20-minute intervals while current products are only available at 1hour to 24-hour intervals.

ANACIM is working with the Université Cheikh Anta Diop (UCAD), Senegal, to provide IDF curves at 15, 20, 30 minutes. Moreover, future or adaptive IDF curves using data from the latest convection-permitting climate model data will be developed in collaboration with UK Centre for Ecology & Hydrology (UKCEH) and IGE.

## Examples of flooding cases in Senegal

Dakar Wakhinane school in 2020

River flooding in Ballou, 2019

The visit of Aly. G. Ndiaye (minister of the interior) to Linguere in 2019

flood in Daarou Marnane, 2018

flood in Dakar in 2018

**Figure 1 :** Example of flooding cases in Senegal in 2019 and 2020 (**source :** Direction de la Prévention et de la Gestion des Inondations **DPGI** Cité Keur Gorgui Immeuble Y1d 5ème étage Dakar-**Sénégal**)

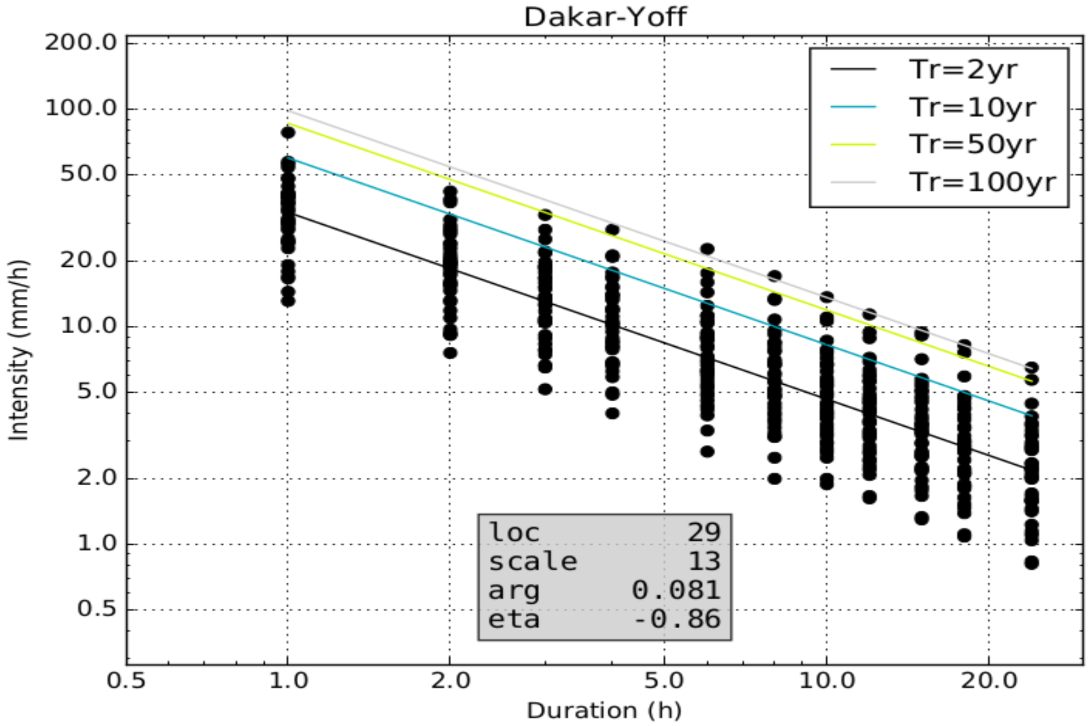


**Fig.2** Dakar IDF curve

The IDF curves (Intensity–Duration–Frequency) represent the evolution of the intensity of the rain according to the duration of the rain (generally from a few minutes to a few hours) and the frequency of the rain expressed as a return period (often a few values sampled between 2 and 100 years). IDF curves are established on the basis of the analysis of showers recorded at a station over a long period. The curves obtained can therefore be constructed analytically or statistically.

| **Function/Structure** |
|---|
| Eiffage/CSE/YM Consortium |
| Egis Eau |
| EIFFAGE ENERGIE |
| Design office (03) |
| EIFFAGE Group |
| SIAT Group |
| SETEC Group |
| Diamniadio/CSE |
| SAR |
| Integrated Flood Management Project in Senegal |
| Company (03) |

| |
|---|
| Technical Manager GRET |
| Student |
| Hydraulics (ENGEES) |

**Table 1:** Institutions requesting IDF curves from ANACIM

# References


**Descroix Luc. (2018).** Processus et enjeux d'eau en Afrique de l'Ouest soudano-sahélienne. Paris: EAC, 320 p. ISBN 978-2-8130-0314-0.

**Di Baldassarre G., Montanari A., Lins H., Koutsoyiannis D., Brandimarte L. Blösch G., 2010** Flood fatalities in Africa: From diagnosis to mitigation. Geophysical Research Letters, 37, L22402, doi:10.1029/2010GL045467.

**IPCC:** Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation**,** Technical report Intergovernmental Panel on Climate Change (2012)

**Panthou G., Vischel T., Lebel T.**, 2013 From pointwise testing to a regional vision: an integrated statistical approach to detect non stationarity in extreme daily rainfall. Application to the Sahelian region. Journal of Geophysical Research, 118: 8222-8237

**R. Mechler, L. Bouwer:** Understanding trends and projections of disaster losses and climate change: is vulnerability the missing link? Climatic Change, 133 (1) (2015), pp. 23-35

**Schertzer and Lovejoy:** Multifractal simulation and analysis of clouds by multiplicative process, Atmospheric Research, volume 21; Issue 3-4, May 1988, Pages 337-361

**Tarhule A**., 2005 Damaging rainfall and floodings: the other Sahel hazards. Climatic Change, 72: 355-377. doi: 10.1007/s10584-005-6792-4

**Taylor C M, Beluši´c D, Guichard F, Parker D J, Vischel T, Bock O, Harris P P, Janicot S, Klein C and Panthou G** 2017 Frequency of extreme Sahelian storms tripled since 1982 in satellite observations Nature 544 475–8

**Tschakert P., Sagoe R., Ofori-Darko G., Codjoe S. M**., 2010 Floods in the Sahel: an analysis of anomalies, memory, and participatory learning. Climatic Change, 103: 471-502. doi: 10.1007/s10584-009-9776-y.

**Wilcox C, Vischel T, Panthou G, Bodian A, Blanchet J, Descroix L, Quantin G, Cassé C, Tanimoun B and Kone S** 2018 Trends in hydrological extremes in the Senegal and Niger Rivers J. Hydrol. 566 531–45