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# FLOODS RISKS IN THE MFOUNDI UPSTREAM DRAINAGE BASIN IN YAOUNDE: A RESPONSE TO CLIMATIC MODIFICATIONS OR TO HUMAN IMPACTS?

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**Keywords**: floods risks, Mfoundi upstream, rainfall, urbanization, Yaoundé.

**Abstract**. Located at 217 km of the estuary of the Wouri, the city of Yaoundé is exposed to seismic risks, to mass movement and mainly to flood risks. From 1980 to 2008, 128 floods have been counted and caused important material damages and more than 70 deaths. The main goal of this paper is to show the role of climatic and human factors in the triggering and the expansion of flooding in the city of Yaoundé in general and in the Mfoundi upstream drainage basin in particular. In fact, it has been noted that although the annual rainfall has decreased from 60 mm after years 1980, we observed a tiny increase of rainfall during dries months, explaining therefore unexpected floods observed in the dry season. The urbanization of the drainage basin and its consequences (waterproofing, obstructions of gutter, bridge etc.) aggravate this phenomenon over the time.

## Introduction

Built on a hilly site and valleys, the city town of Yaoundé (Fig. 1A) is exposed to many natural hazards (mass movements, seismic hazards) amongst which floods are the most common and the most damaging since three decades. Its position in the South Cameroon plateau between forest and savannah exposed it to a subequatorial Guinean climate with eight months of rainy season and four months of dry season. The analysis of rainfall over the past three decades shows a decrease of annual precipitation and paradoxically an increase of rainfall during the dry season leading to unexpected floods. In addition to these climatic modifications, human impact plays a key role in the amplification of flooding. Indeed urban sprawl has also increased since the beginning of 1980 due to an explosive growth of the population (650,935 in 1987 and 1,456,420 in 2001, SDAU 2001), which has resulted in a soil sealing by asphalt and buildings, leading to a rapid concentration of water flow in the main rivers of the watershed of Mfoundi.

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Fig. 1A-Location of the study area in Yaounde

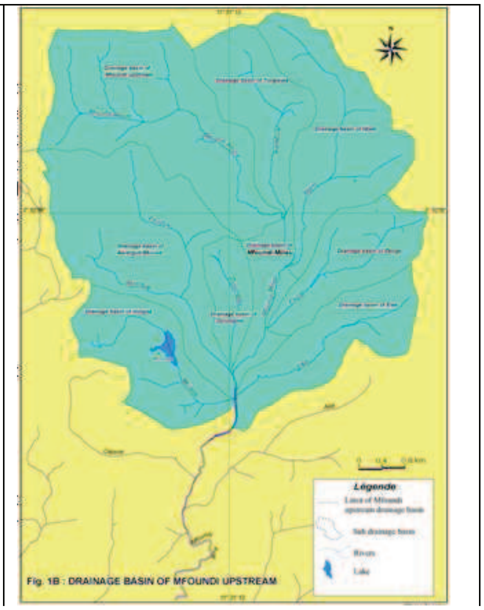

Fig. 1B – Drainage basin of Mfoundi upstream

Facing such situation, the central interest of our analysis is to know the contribution of climatic and human factors in the genesis and amplification of flooding in the drainage basin of Mfoundi upstream.

## 1. Data and Methodology

**1.1. Rainfall and flood frequence.** *Rainfall.* Rainfall analysis was based on precipitation data extracted from Monthly Climate Tables (MCT) of National Meteorological Center of Douala. Their treatment was facilitated trough Excel. To have an idea of the general distribution of annual rainfall amongst the drainage basin of Mfoundi upstream, we based our reasoning on the map of annual isohyets of Yaoundé produced by Kiet Srang in 1971. This map was georeferenced in Mapinfo to facilitate the overlaying of other information in the same projection. system We digitized the isohyets crossing the watershed of Mfoundi. With Vertical Mapper, we converted polylines (isohyets) in points; these points were exported to Surfer for a better modeling process.

*The frequency of flooding.* The method of gathering information consisted to exploit the archives of national newspapers (Cameroon Tribune, Messager etc...) reports of the Civil Protection on the risks, theses and dissertations. These sources were completed by broadcasted information, surveys in flood area and field observations. The year 1980 was considered as a starting point because of the scarcity of the hazard before that date and the exponential growth of the city from the 1980s. Like rainfall, flood data have been incorporated into a spreadsheet and then treated to establish correlations between floods and rainfall.

**1.2. Cartographic treatment and GIS contribution.** *Nature and source of map data***.** Our study was based on several maps such as:

-Arial photographs of 1951 and 1980 respectively at 1/10000 and 1/8000,
-We also benefited from the National Institute of Cartography a numeric database map of Yaoundé. This database is stored in DXF was updated in 2005. The database is organized into four categories. Topographic data including contour of 5 meters of equidistance and 50,000 heights point. The land use data contains houses, roads, vegetation and hydrographic features. The database is georeferenced in GAUSS KRUG North projection system.

*Treatment related to GIS.* Through MapInfo, ArcGIS and SURFER, we built a Digital Elevation Model (DEM) for a better visualization the relief and floodplains of the watershed of Mfoundi upstream. Several layers of information such as hydrography, vegetation and land use have been overlaid on the DEM to better understand the urban sprawl in the watershed. GIS facilitated the calculation of the rate of soil occupation by human activities useful to assess the waterproofing of watershed. In general this tool of decision support has allowed us to answer questions such as: where are localized low areas prone to flooding? What areas do they cover? Where are located the populations most exposed to flooding? How many houses are in these areas?

## 2. Analysis and discussion

**2.1. Decreasing rainfall toward ever-increasing flood.** Located at the foothills of Mbam Minkom, the city town of Yaoundé benefits from a subequatorial guinean climate hot and humid, with average annual temperature of 23.5°C. The capital city has an annual bimodal climate made up of four seasons, two wets and two dries organized as follows: a long rainy season from mid-august to mid-November, a long dry season from mid-November to February, a short rainy season from March to June and a short dry season from July to August (Fig. 2). In the decades 1980-1990 and 1990-2000, the climate of Yaoundé experienced a remarkable modifications, especially concerning rainfall which has slightly reduced. Precipitation dropped to 1610 mm compared to years 1950-1970 where it was around 1700 mm, thus a minimum gap of 30 mm and 90 mm maximum. Studies carried out by Hervé Defo (2008) confirm a real decline of rainfall of about 30 to 50 mm during 1926 to 2006.

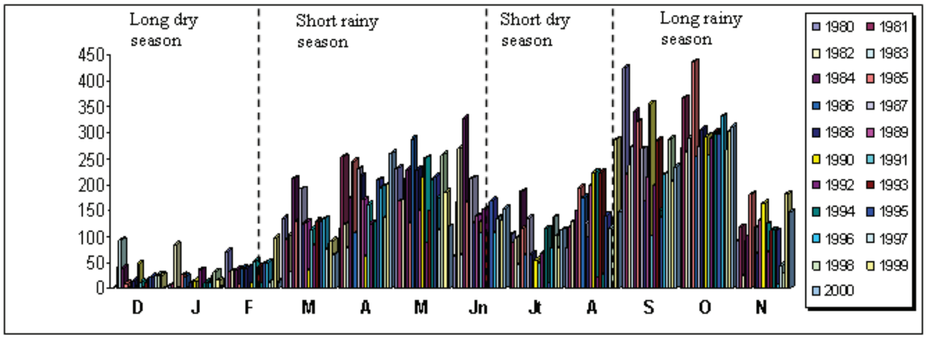

Fig. 2 - Monthly rainfall in Yaoundé from 1980 to 2000

Fig. 3 - Flood of February 8, 2000 (A) in central town of Yaoundé (B)

Fig. 3 - Flood of May 29, 2007 in central town of Yaoundé (B)

Although rainfall is decreasing, it must still be emphasized that it evolves in saw tooth, the years 1984, 1985 and 1999, respectively recorded 2028.5 mm, 1964.8 mm and 1806 mm, about 300 mm above the average. In contrary, the years 1983, 1992 and 2001 recorded a drastic decrease with 1212.1 mm, 1114.4 mm and 1270.4 mm. Despite this lack of rainfall, there is a paradoxical slight increase of precipitation during the two dry seasons. For example, the months of February and November recorded a slight increase from 15 to 20 mm compare to decades 1950-1970. This increase is partly responsible for the unexpected flood in dry season. It is the case of the flood of the 8th February 2000 which caused huge damage in the stores central town (Fig .3 A) and the night flood of 23th February 2003 in the Biyemé Valley which made four deaths and the partial and full destruction of twenty houses.

Apart from the unexpected floods of dry seasons, the main flooding period remains the long rainy season which covers the months of September, October and November. During this time the monsoon extends at maximum in latitude. It is thick from about 3000 to 4000 meter. The sky is permanently covered by cumulonimbus and stratocumulus, and disrupted by thunderstorms and squall lines. This season covers an average of 65 rainy days for an amount of 750 to 800 mm of water. October is the wettest month with 25 days of rain on average. In contrast to the small rainy season, this season is marked by frequent rainfall (5 to 6 days of rain per week) and their intensity.

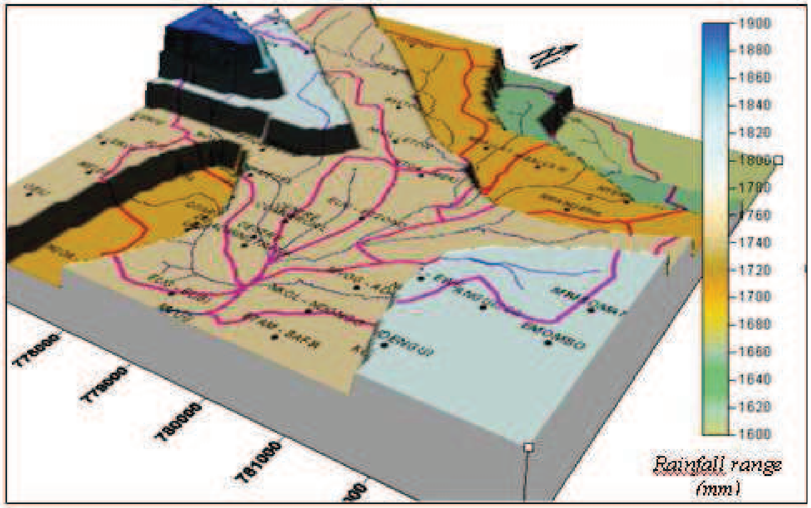

Fig. 4 - Digital Elevation Model of annual rainfall in three dimensions combined with the upstream Mfoundi watershed

The annual rainfall of Yaoundé has not changed radically after thirty years, the isohyets map of Yaoundé carried out by Kiet Srang in 1971 remains best support to assess the distribution of rainfall in the capital city and in the watershed of Mfoundi. This is due to the abundance of stations that have made it possible. Although it does not account for the entire phenomenon, it remains a powerful tool for assessing the distribution of precipitation. In general, rainfall is abundant along the North-west and South-east axe, while it significantly drops in the Northeast and Southwest. By overlaying hydrographic and sub watersheds map of Mfoundi upstream on the rainfall map, we see that the watershed of the Abiergué-Ekozoa is the wettest in its northern part; it is crossed in the north-west by isohyets ranging from 1700 mm to 1900 mm. The abundance of rainfall in this watershed has a close relationship with the relief which is also accentuated at the same place. This area of heavy precipitation corresponds to the altitude of 850 m to 880 m where we observe the Mount Messa and the peaks surrounding the Congress Palace, Ntougou, etc. In this watershed floods are very common. Is it the consequence of this heavy rainfall?

In fact, in the north-west of Yaoundé stands a huge mountainous massif that obstructs the flow of monsoon from the sea coast. During its departure from the coast, the monsoon is thick. It pours the major quantities of its water while crossing the Yaoundé's massif made of Mbankolo, Febe and Messa Mountains, The center, which is in a shelter position receives only remnants of rain. This is even more pronounced as the station of Nkolbisson records 2050 mm per year against 1700 mm for the administrative center and 1550 mm for the north east of the city where is found the watershed of the Ntem and quarters of Mballa I, Mballa III and Etoudi. To better visualize this unequal distribution of rainfall, we have developed a Digital Elevation Model of Precipitation (DEMP) in three dimensions (Fig. 4.) on which were overlaid rivers, watershed of Mfoundi and quarters of the area of study.

This cartographic representation more detailed and simplified facilitates the observation and identification of annual ranges of rainfall without suffering enough. Thus we see that after the drainage basin of Ekozoa, the watershed of Ewé is the wettest with 1800 mm of water per year. As in the catchment area of the Ekozoa, people surveyed reported that floods were frequent here. What about the really the evolution of floods since the 1980s?

**2.2. Evolution of flooding in Yaoundé from 1980 to 2008.** 128 floods have been recorded between 1980 and 2008. An effort of correlation between rainfall and associated flooding was made when it was possible. From 1980 to 2003, two major periods of flooding emerge:

- the first decade from 1980 to 1991. During this period, the years 1981 and 1984 recorded the greatest frequency of flooding with 6 cases each. This is probably linked to the high rainfall for the year 1984 which recorded 2028.5 mm of rain in 177 days, while 1981 accumulated 1679 mm in 161 of rainy days. The histograms of flooding disappear totally in 1992 and restart in 1996. This decrease is mainly due to the lack of information during the years 1992, 1993, 1994, 1995 (Fig. 5).
- the second decade is from 1996 to 2008. This period contains the highest frequency of both decades. The years 2000, 2007 and 2002 showed respectively 12, 10, and 07 floods. Contrary to what one might think, the observation of rainfall showed a real decrease while the frequency of flooding increased. This implicitly implies the presence of another factor aggravating the frequency of the

phenomenon. It is the human factor acting through urbanization and its consequences in the watersheds of the city.

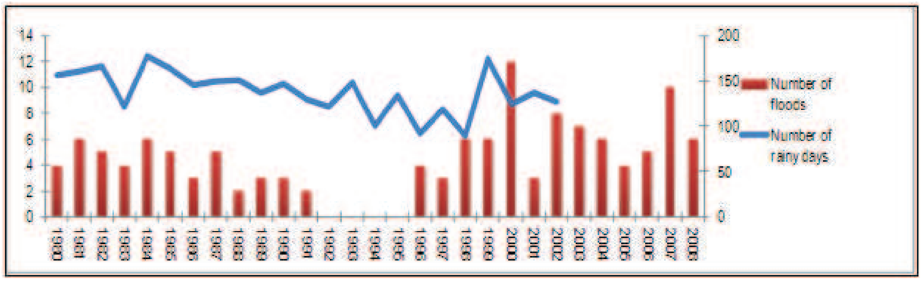

Fig. 5 - Annual frequency of floods and number of rainy days from 1980 to 2008

The monthly observation of floods shows a close relationship between rainfall and periods of flooding. Two periods of floods hidden on the two main rainy seasons emerge. The first is from February to June with an average of 11.4 floods per month where the peak is found in May and June (16 and 14 floods) and the minimum in February. However, we must not forget that it was in February 2000 and 2003 that occurred some of the most damaging floods of the past 10 years. The second period covers the months of August, September and October with an average of 17 floods. The month of high prevalence of flooding here is September with 21 cases with an average of 22 rainy days.

Amongst the 128 floods surveyed, 47 were related to their volumes of rainfall. In these 47 floods, 19 were caused by slides of water between 25 and 81 mm, 17 by rainfall oscillating between 24 and 11 mm, and 11 with rain less than or equal to 10 mm. In total these floods have caused enormous material damage (demolition and burial of houses, destruction of some equipment in the city center), environmental damages (destruction of riverside crops, roads and vehicles as in the Fig 3B May 29, 2007, growth of water-borne diseases and malaria in the lowlands) and especially the loss of human life. Indeed, if we confine ourselves only to floods which have been reported, the loss of human life would exceed 70 dead, because it should not be forgotten that the national newspapers, magazines and even some media are only interested to the most spectacular and dramatic floods, but the reality on the field is quite different. Are these deadly floods only linked to rainfall and to natural factors? What is the responsibility of the Man in the genesis of these catastrophic floods?

**2.3. The human impact in the genesis of floods.** Since fifty years, the population of Yaoundé has experienced an explosive growth. Between 1957 and 2002, it was multiplied by 25 ranging from 58099 to 1456420 inhabitants (SDAU, 2001). This spectacular growth of the population has had an impact on the spatial evolution of the town which itself has been multiplied by 09 between 1956 and 2000 (from 1740 to 15900 ha). Spatial dynamic of the city at the expense of existing forest has contributed to increase the frequency of floods in the city center and in some pericentral areas. In fact we recorded 46 floods in the 1980s against 61 for the period 2000-2008. At the same time the area of the city has tripled between 1981 and 2001 from 5300 to 15900 ha. The consequences of this urbanization are visible through the increase of impermeable surfaces (buildings and tarred roads) in the entire watershed of Mfoundi upstream and especially in flood areas.

***2.3.1. Evolution of houses in the drainage basin of Mfoundi upstream.*** The drainage basin of Mfoundi upstream covers an area of 3754 hectares (37.54 square kilometers) and a perimeter of 27.72 km. The occupancy rate by houses increased successively from 6.21% in 1951 to 17.27% in 1980 to 21.70% in 2005. The surface waterproofed by the houses was 233.2 ha (2.33 km $^2$) in 1951, 648.14 ha in 1980 and 814.59 ha in 2005. This corresponds to 10,543 houses in 1951, 29,149 in 1980 and 38,260 in 2005. However, these values are far from being identical when considering the dynamic of land occupation by sub-watershed.

***2.3.2. Overview of the evolution of the houses in flood areas.*** Flood-prone areas occupy 25.86% of the total area of the drainage basin of Mfoundi upstream, thus 970.96 ha (9.7 km$^2$). The evolution of buildings in these areas has been relatively rapid. In 1951, 2,254 houses were built in the valleys, corresponding to a built area of 58.13 ha making 5.99% of the coverage rate of these areas (Fig. 6). In 1980, the number of houses reached 7230 for an inhabited area of 158.66 hectares and a coverage rate of flood zones of 16.34%. In 2005, demographic explosion increased the number of houses at 10,118 for inhabited area of 158.66 ha and a rate of 21.93% of waterproofing. If we consider a number of 3 persons living in a household, we can multiply this minimum value by the number of houses and estimate the population at risk of flooding. On this basis, the population at risk in 2005 was 30,354 inhabitants.

***2.3.3. Evolution of tarred road and vulnerability of hydraulic structures.*** Apart from the growth of housing, urbanization of the city was also accompanied by the increase of asphalted surfaces which further contributed to the growth of runoff. This was caused by the increase of impermeable surfaces. In 1951, the rate of waterproofing of the drainage basin of Mfoundi, by the bitumen was 2.73% which was equivalent to 102.33 hectares or 1.02 km$^2$ of asphalted surface.

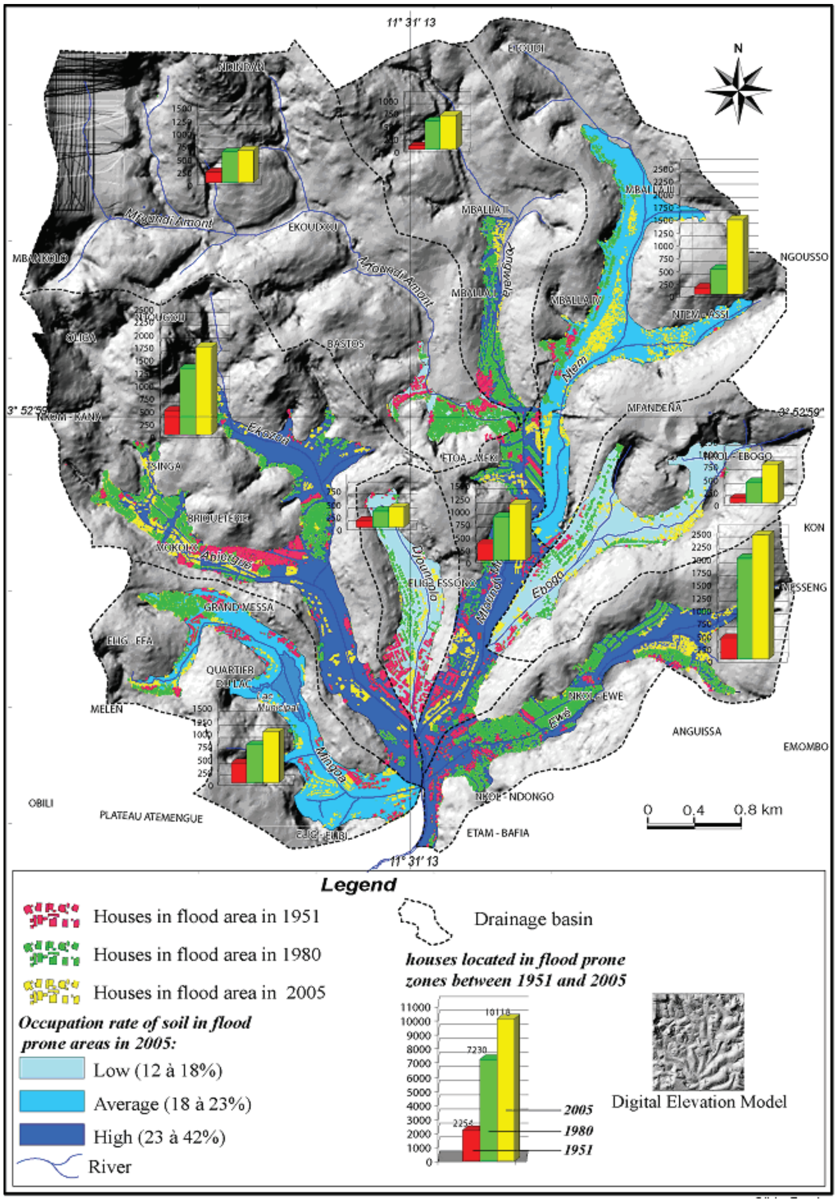

Fig. 6 - Evolution of soil occupation and houses growth in the watershed of Mfoundi between 1951 and 2005

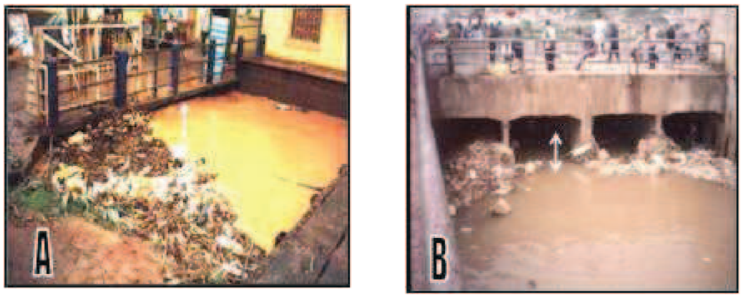

Fig. 7 - Fragility and vulnerability of hydraulic equipments

In 1980, the asphalted area is estimated at 132.78 ha. This increases the rate of waterproofing of the watershed to 3.54%. In 2005 the surface of the drainage basin will rise to 201.2 ha (2.01 km ²) and reach and a rate of 5.3% of waterproofing of the entire the drainage basin of Mfoundi, during this period, the state and municipality separately contributed to the improvement of road network of the city. The length of the road network in general, increased from 505 km in 1978 to 696 km in 1998 (Mougoué Benoît, 1998). This has caused the reduction of the hydrological response leading to a rapid concentration of water flow in the main rivers of the watershed. During the construction of roads in the drainage basin of Mfoundi upstream, several culverts, gutters, sewers, and artificial channel were built along the Mfoundi. With urbanization, they are now very old and vulnerable. Their execution was often done without taking into account the basic hydrological parameters (heights and extreme discharges of rivers). We measured the dimensions of some culverts and gutters in the field. At the Rue Mfoundi, the heights of bridges and culverts varied between 11 cm to 150 cm, while the height of garbage pile usually exceeds 160 cm during floods (Fig. 7). The nozzle and gutter are also very undersized and especially in precarious materials. We must notice that the age of the hydraulic equipment which date to many decades increases their vulnerability and especially when their maintenance is being questioned. All these deficiencies indicate the responsibility of public authority in the genesis of floods. Logically a suitable construction of hydraulic equipment should allow at long-term drainage of rainwater, but it is the contrary, they contain the runoff and supply flooding, causing traffic jam. The burial of river Ekozoa under 20th May Boulevard up to the confluence with the Mfoundi is a good illustration.

## Conclusion

Throughout this discussion, we intended to determine the impact of climatic factors and human activities in the genesis of floods. We started from the hypothesis that climate modifications have led to a decline in rainfall while flooding increased. Through GIS applications, field surveys, and statistical processing, we found that climate modifications are not responsible of the increased of flood risks although it declined from 30 to 90 mm. We observed a link between urban growth and the high frequency of floods. We recorded 46 floods in the 1980s against 61 for the period 2000-2008. Meanwhile, the area of the city has tripled between 1981 and 2001 ranging from 5300 to 15,900 ha. However due to the complexity of the phenomenon we are not able to quantify the real values exerted by climatic and human factors in the process of flooding. This is just because these different factors are combined and linked together to cause exceptional floods. The effective management of flood risks should pass through a joint awareness of public authorities and local populations.

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