Extreme Rainfall and the 14 October 2019 Flooding at the IRAD Multipurpose Station Foumbot (IMSF): West Region of Cameroon

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ABSTRACT

This study analyses the influence of extreme precipitation and flood amplification on the spatial and temporal level at the IRAD Multipurpose Station of Foumbot (IMSF) from a hydro-climatic and anthropogenic approach. The processing and analysis for 20 years of rainfall data allowed the measurement and the extent of the phenomenon in the study area. Thus the topographic configuration of the IMSF, particularly the valley bottom with flat topography, predisposes it to the risk of flooding. Heavy rainfalls from July to September contributed to the floods. During the first decade in the month of October, there is an increase of the River Noun bed of 5 m and its main branch Momon of 1 m considerably. The areas flooded on a recurrent basis, were most often crop plots having a flat relief located near the River Noun. There was also the absence of main drain dredging, the anarchic occupation of flood areas and the under sizing of the drainage channels for runoff water. As a result, a significant quantity of water had stagnated between the ridges in the cultivation plots, contributing to the complete destruction of the plants. More than one hectare of hybrid maize seeds, 8 ha of tomatoes were destroyed, and more than 15 ha of beans completely flooded. This situation underlines the need to take into account climate change adaptation policies and numerical climatic predictions for better flood risk management.

Keywords: *drainage, flooded land, inundation, river beds, torrential rains*

I. INTRODUCTION

In its third report published in 2007, the Intergovernmental Panel on Climate Change (IPCC) noted that the world will face a greater frequency of extreme rainfall events in the coming years. According to the World Health Organization, every year, natural disasters kill around 90 000 people and affect close to 160 million people worldwide. Natural disasters include earthquakes, tsunamis, volcanic eruptions, landslides, hurricanes, floods, wildfires, heat waves and drought. Thus, in 2014, 250,000 people have been affected by the extreme rainfall event in recent decades [4].

Since the year 2000, at least 12 major floods have been recorded in Cameroon affecting several thousand people and property. Several scientific works carried out have highlighted the role of rainfall in the occurrence of flood disasters [16]- [7]. The results of the study carried out by [15] show a normality of rainfall patterns, accompanied by an increase in the vulnerability of societies. Meteorologists claim that over the past 40 years, monthly rainfall has been increasingly peaking, with some months being excessively wet. This is particularly the case with the humidity, which was the cause of many floods in 2012, 2013 and 2015 with catastrophic flooding of rivers in the northern part of the country. Between 2000 and 2010, in Douala alone, floods caused more than 100 deaths and significant material and human damage [23]. In June 2015, unusual rains caused severe flooding in the city of Douala, affecting more than 1,500 families and killing three people. There are between 5 and 10 floods per year and 5 to 10 deaths per year [20]. Floods due to torrential rains have caused disarray and tears in recent years.

However, IRAD the Multipurpose Station of Foumbot (MISF) is no less affected. Based on the origin of the flood, there are two main types of flooding at the IMSF: floods caused by overflow of the minor bed and floods due to stagnation in the flat areas. Indeed, during the flooding periods, the minor bed is unable to carry all the water away from the runoff and the plain is submerged. It should be noted that in the lowlands, lack of planning and lack of proper dredging for drainage aggravates flooding. The flooding due to stagnation in the flat area, the drainage of water is very difficult because of the low slopes.

The IMSF is located in an agricultural production area and has an important land domain developed in a varied pattern. This is the case of test plots, seed production plots and those allocated to projects. Over the last decade, they have experienced an increase in flooding with disastrous consequences. Many studies were conducted on flooding in urban areas in Cameroon. Few studies were carried out on floods in rural areas and their impact on agriculture. Hence the present study carried out on the floods observed in the IMSF, presented extreme rainfall as a key factor to the increase of floods at the MISF and their consequences on agriculture.

II. MATERIALS AND METHODS

A. Study site

The IMSF is located in the Foumbot Sub-Division, precisely in the *Mangoun* village (Fig. 1). It covers a surface area of about 465 ha. The morphology of the Foumbot multipurpose station is flat, surrounded by a set of hills varying between 1062 m and 1190 m. The topography presents a flexible slope of between 0 and 20%. These observed forms are the result of a long and complex volcanic activity which took place in this area several million years ago. On the slopes of these hills there is an intensification of agricultural activities. This is most often linked to the fertility of the soils in the area (very fertile volcanic soil), but also and above all to the scarcity of cultivable areas. The reasons for the choice of the study area are based on the fact that agricultural activity and its spatial distribution is one of the objectives of the structure. In addition, the station's lowland area has been intensively exploited in recent years. The soils are formed from rock outcrops which then bear the name of parent rock whatever the nature of the materials.The soils are essentially young soils derived from loose volcanic rocks.They come from various rocks, especially acid and grainy. This is the case with volcanic ash from volcanic eruptions in the quaternary. These soils are grouped around the emission centers located near Foumbot and Baleng which are the main emission centers for pyroclastic materials. The transport by wind dispatches thinner materials towards the West, sometimes very far and as far from the center of origin. From Foumbot to Noun, the ashes are quite coarse, while on the west bank of the river, they are generally very fine. Andosoils are found, which are young soils with a homogeneous profile, developed on basic volcanic formations and generally associated with raw and poorly evolved mineral soils. Light andosols contain a large amount of organic matter, very favorable for cultivation but subject to erosion. Foumbot station in its spatial configuration is located near the Noun river. This large river follows the limits of the station throughout its western part. One of its main tributaries name *Momon*, passes through the station. It is used on the one hand as an element for delimiting plots and on the other hand as a raw material in the cultivation of off-season speculations (market gardening, cereals). It should also be noted that, the passage of this watercourse favored the development of a traditional irrigation system given the demand for water from vegetable crops (F**ig)**.

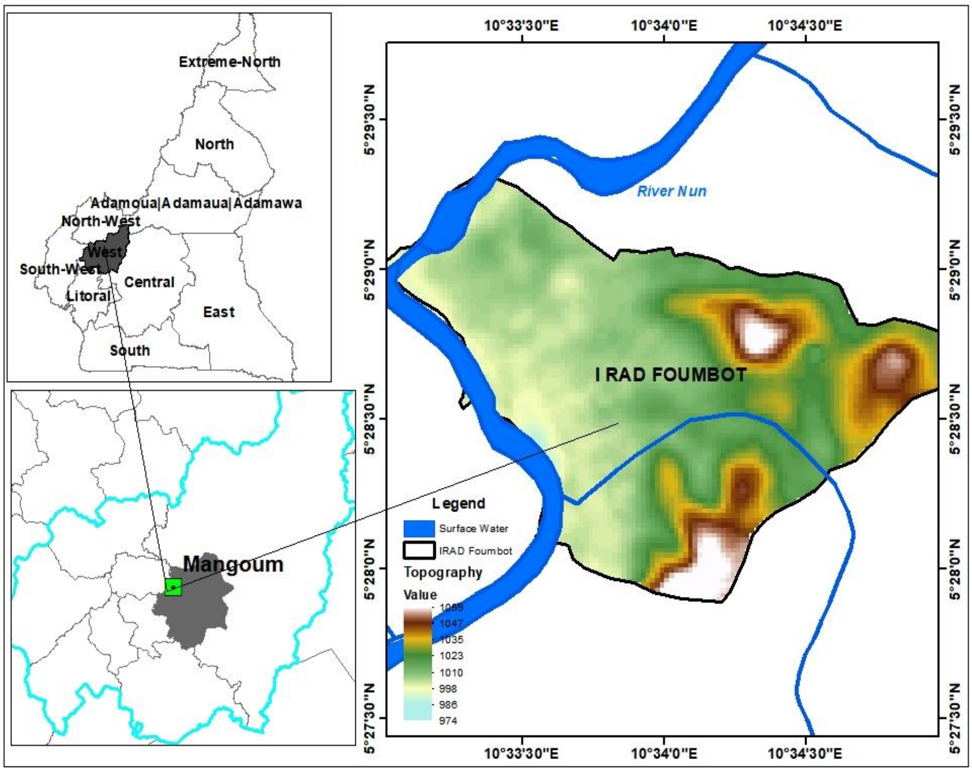


Fig. 1. Study area. Source: NIC Cartographic Database (2011)

B. Land use at the IRAD Multipurpose Station of Foumbot (IMSF)

A multitude of plots with particular shapes can be seen on the agricultural landscape of the IMSF (Fig. 2). Pulses (annual legumes) and cereals dominate the agricultural area of the IMSF. This is linked to the fact that these crops alternate on the same plots according to the agricultural calendar. In particular, cereals are cultivated from March to July while pulses are grown from late August to December. These two types of crops are the most produced due to a growing demand on the market. In addition, market garden crops are generally produced in wetlands. This is the case of tomato, vegetable, carbage.

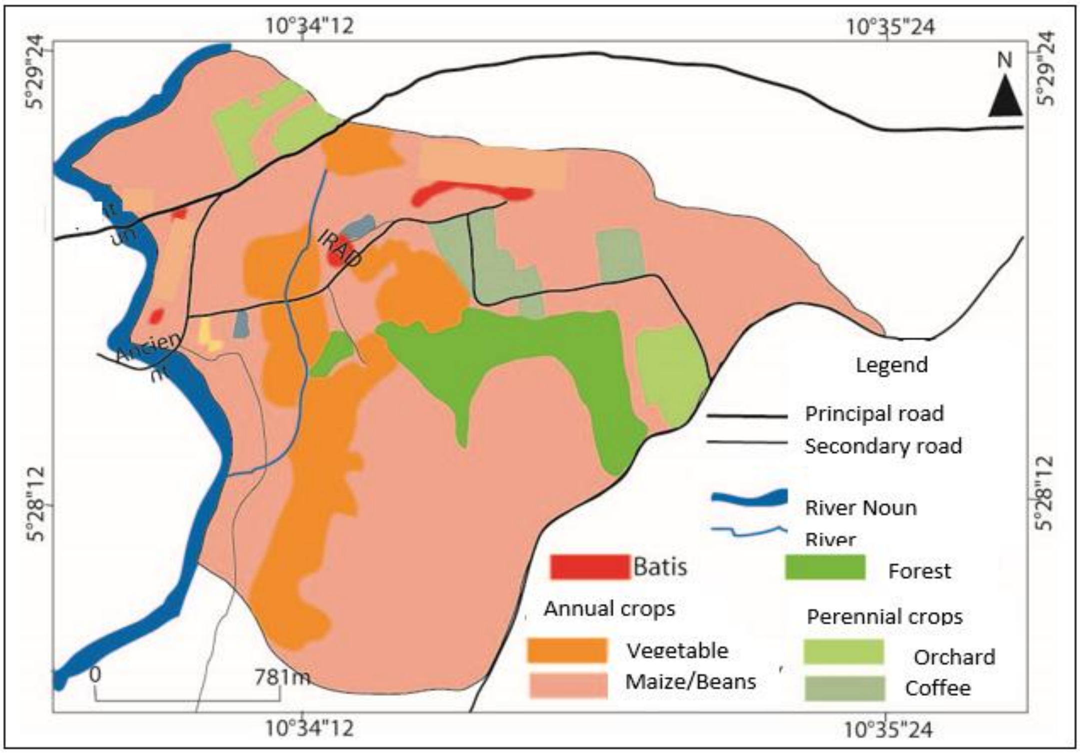


Fig. 2. Land use mapping in the IMSF

The map also shows the presence of orchard fields and coffee which are classified as perennial crops. At the IMSF, there is a forest gallery in the form of an island with the presence of a few emerging trees that dominate all the strata. It is located around or near the swampy areas.

C. Data Collection

Climatic data, particularly daily rainfall (1997-2019), comes from the rain gauge of the IMSF (x=5˚28 42 y= 10˚33 47 and z= 1009m). These data are composed of rainfall heights and the number of rainy days.

It is difficult to retrieve reports of known flooding at the IMSF. However, interviews and questionnaires were carried out in order to better understand the rationales and methods of use of the cultivated plots. The survey was administered to 54 peasants occupying the low land rivers bed at the IMSF. The questionnaires were focus on the growing techniques, flood-related losses and destruction.

The measurement of the river depth was established by the private energy company name ENEO using the graduated ruler at three levels (from 10 to 20m, from 20 to 30m and from 30 to 50m). During the floods, all the graduated ruler put in place for the measurement was covered by the water. Due to the floods, it was not possible to measure the additional water in the major and minor beds of the river. ENEO teams used the data for the Bamendjin dam. Therefore, when the river went back in his normal bed; a graduated bamboo cane was used to estimate the height of the additional submerged water.

Fig. 3: Measurement instrument

D. Methods of analysis of flood risk indicators

The standardized precipitation index (SPI) was developed as a drought index but it has been suggested to be used as an indicator of the progress of soil saturation conditions conducting to floods [18]-[19]. Following [12] an important characteristic of the SPI is a possibility of analyzing both dry and wet periods. According to [5], there are concerns that current climate changes may intensify floods and droughts. In this context flood risk indicators are an indispensable tool for watershed management, monitoring, risk assessment, and civil protection. The Standardized Precipitation Index (SPI), developed by [12] may be a tool for identification of these events.
The SPI which were developed in 1993 by [12] is a very important index, and simple to calculate. This index is calculated by the following formula:

$$\boldsymbol{SPI} = \frac{xi - \bar{x}}{s}$$

With,
xi the value of the annual rainfall,

$\bar{x}$ the inter annual mean value of the study period (1998 to 2019);
S = standard deviation.
Positive SPI values (Table 1) indicate precipitation above the median while negative values indicate precipitation below the median. Since the index is normalized, it is possible to represent wet and dry climates condition in the study area.

Table 1. SPI values index and their signification

SPI index values	Drought category
2.0 and more	Extremely wet
1.50 à 1.99	Very wet
1.0 à 1,49	Wet
-0.99 à 0.99	Normal
-1.0 à -1.49	Moderately dry
-1.50 à – 1,99	Severely dry
-2.0 and less	Extremely dry

E. Extreme rainfall analysis

The Rclimdex was used to analyze the daily rainfall. It is a Microsoft Excel based program that provides an easy software package for the calculation of indices of climate extremes for monitoring and detecting climate change. Among the indices provided by the program, those related to the analysis of extreme rainfall have been selected (***Tab.2***).

Table 2: Climate indices

ID	Indicator name	Definitions	UNITS
SDII	Simple daily intensity index	Annual total precipitation divided by the number of wet days (defined as PRCP>=1.0mm) in the year	Mm/day
R10	Number of heavy precipitation days	Annual count of days when PRCP>=10mm	Days
R20	Number of very heavy precipitation days	Annual count of days when PRCP>=20mm	Days
CDD	Consecutive dry days	Maximum number of consecutive days with RR<1mm	Days
CWD	Consecutive wet days	Maximum number of consecutive days with RR>=1mm	Days
R95p	Very wet days	Annual total PRCP when RR>95th percentile	Mm
R99p	Extremely wet days	Annual total PRCP when RR>99th percentile	mm
PRCPTOT	Annual total wet-day precipitation	Annual total PRCP in wet days (RR>=1mm)	mm
RX1day	Max 1-day precipitation amount	Monthly maximum 1-day precipitation	Mm
Rx5day	Max 5-day precipitation amount	Monthly maximum consecutive 5-day precipitation	Mm

F. Analysis of the return period

There are several steps in this analysis:

Step 1: Organize the data from the smallest to the largest.

Step 2: Determine the probability of occurrence [6]-[10]

$$FA\ (\%) = \frac{[2(n-1)]}{2y} * 100$$

with

n: actual or event number,

y: the total number of the event.

Step 3: Return period = $\frac{100}{FA}$

Gumbel's law (1958) was applied to monthly rainfall depths to characterize the return periods. The return period of an event is defined as the inverse of the annual probability of exceeding this event [14]. A rainy event is qualified as very exceptional if its Return Period (RP) is beyond 100 years; exceptional if RP is in the range of 30 to 100 years; very abnormal if RP is between 10 and 30 years; abnormal if RP is between 6 and 10 years old and normal if RP is less than 6 years old.

G. Cartographic data analysis and processing

Processing operations based on mapping have been made possible through a varied range of software including ArcGIS 10.5 and QGIS 3.10. The drawing of the various maps of the IMSF was possible with the use of the GPS receiver in the collection of field data. Aster Dem images with the resolution of 30 meters were used. A cartographic repository of the National Institute of Cartography (INC) of 2011 was also used.

III. RESULTS

A. Determination of flood risk period

Monthly evolution of rainfall at the IRAD Multipurpose Station of Foumbot (IMSF), is characterized by a raining months having a high susceptibility to the flood event. The diagram shows that September has a rainy peak. However, the flood always occurred during the second decade of the month of October. So flood observed in October is related to the amount of rain registered in September (Fig. 4).

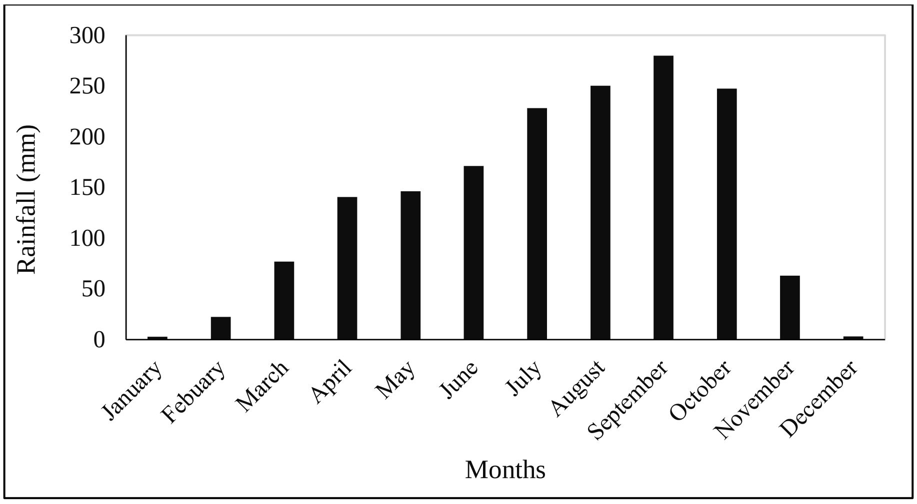


Fig. 4. Monthly rainfall

It can be seen that from July to October (growing period), the rainfall increases to more than 50 mm every month. This is a transitional phase between the first rainy season and the second. The gradual increase in rainfall from July to September will rise in river flows and generate the flooding observed in October.

The standard precipitation index brings out the dry (negative value) and wet (positive value) months (Fig. 5). SPI satisfactorily explained the development of circumstances leading up to major peak flow events related to the wet condition and the flood occurrence.

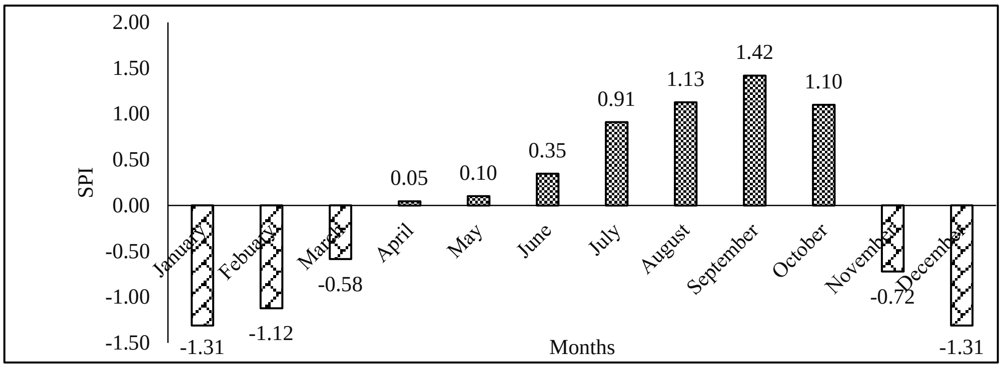


Fig. 5. **Monthly SPI of Foumbot**

The study area has five dry months (November to March) and seven wet months (April to October). Table 3 shows the drought levels according to each month's indices. It shows that the second rainy season is very wet, especially in September. The high humidity in this month was a trigger factor for flooding in October.

Table 3. Drought levels according to each month's indice

SPI index values	Drought category	Months
2.0 and more	Extremely wet	-
1.50 à 1.99	Very wet	-
1.0 à 1,49	Wet	August, September, October
0.0 à 0.99	Normal humidity	April, May, June, July
-0.99 a 0.0	Normal drought	March, November
-1.0 à -1.49	Moderately dry	January, February, December
-1.50 à – 1,99	Severely dry	-
-2.0 and less	Extremely dry	-

B. Return period analysis

The second season shows an increase in rainfall from July to October, then the succession of heavy amount of monthly rains with the peak in September explains the water overflows observed in October.

The occurrence of flooding in the study area is strongly correlated with the September peak rainfall (Fig. 7).

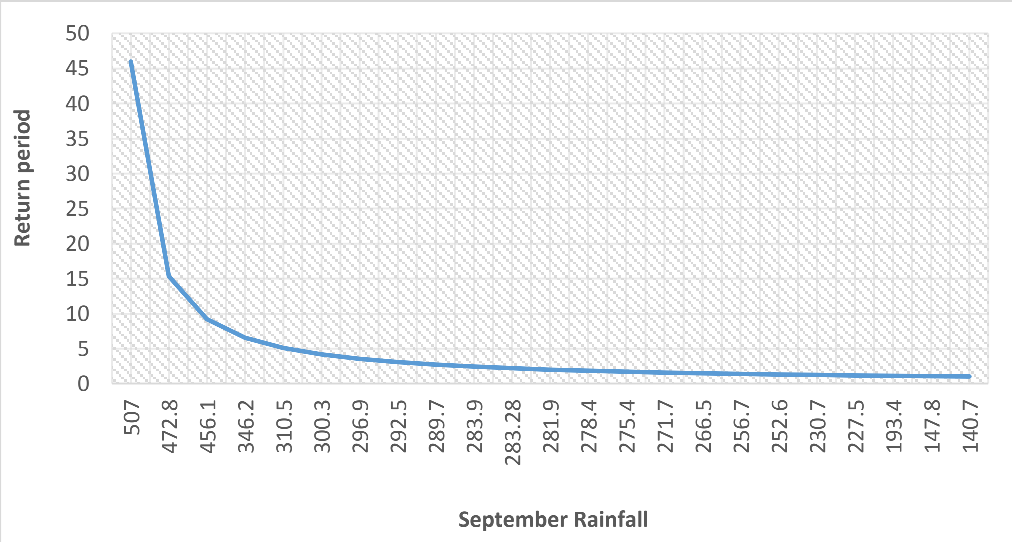


Fig. 7. Return period

The analysis of the September rainfall returns periods from 1997 to 2019 permits the detection of the return period of extreme rainfall amounts. September in the year 2019 was excessively wet with a monthly total of 507 mm. The return period of this amount of rainfall is exceptional (the range is between 30 to 100 years) according to the Gumbel's law. September 2018 had also shown a very abnormal situation with its return period value between the range 10 to 30 years. From 2017 down to 2010, the months of September had presented a return period value migrating from an abnormal situation to a normal situation. In addition, the accumulation of such rainfall during the month of September always led to the increase the flood during the first and second decade of October 2016, 2017, 2018 and 2019.

C. Trend of rainfall index

This index is obtained by the number of wet days divided with the annual total precipitation (defined as PRCP>=1.0mm) in the year. It shows the variation of the daily rainfall intensity with an increase in slope of 0.349 each year. The amount of daily rainfall is growing from 2010 to 2019. From 2016 to 2019, the simple daily intensity index of rainfall was more than 16/year with the maximum observed in 2017 and 2019.

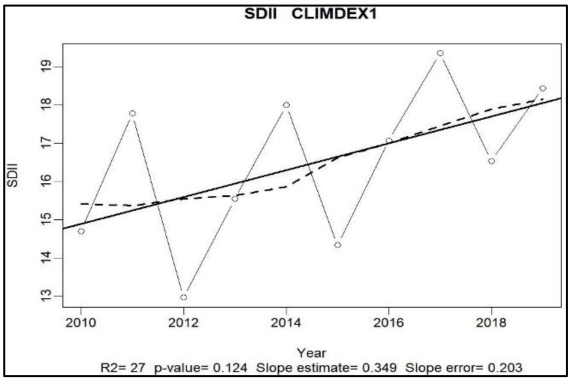


Figure 8: Simple daily intensity index

The indices on the figure indicated an increase in daily rainfall within a month. There is a non-significant variation in the maximum of five or one consecutive day precipitation each year. Therefore, there is a general increase in daily precipitation rate at Foumbot.

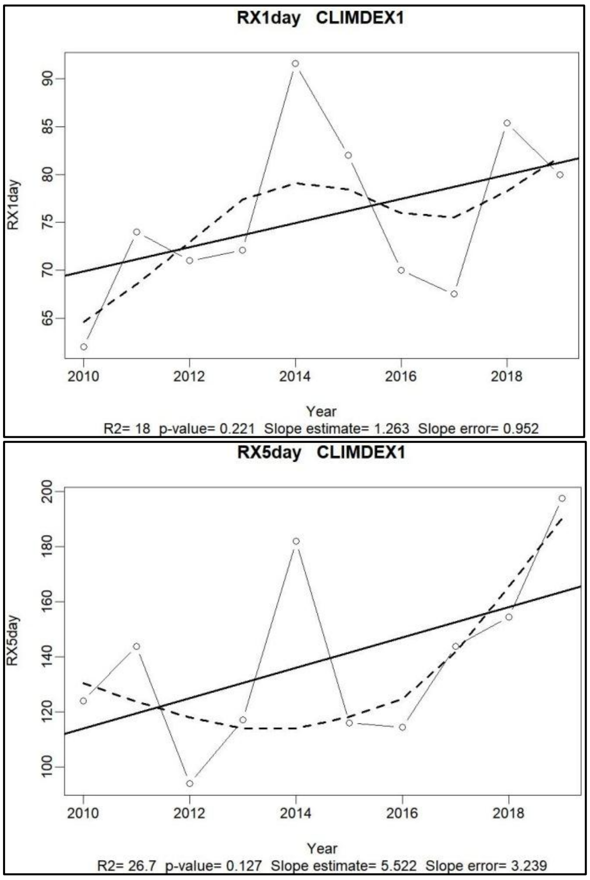


Figure 9: a) Monthly maximum 1-day precipitation b) Monthly maximum consecutive 5-day precipitation

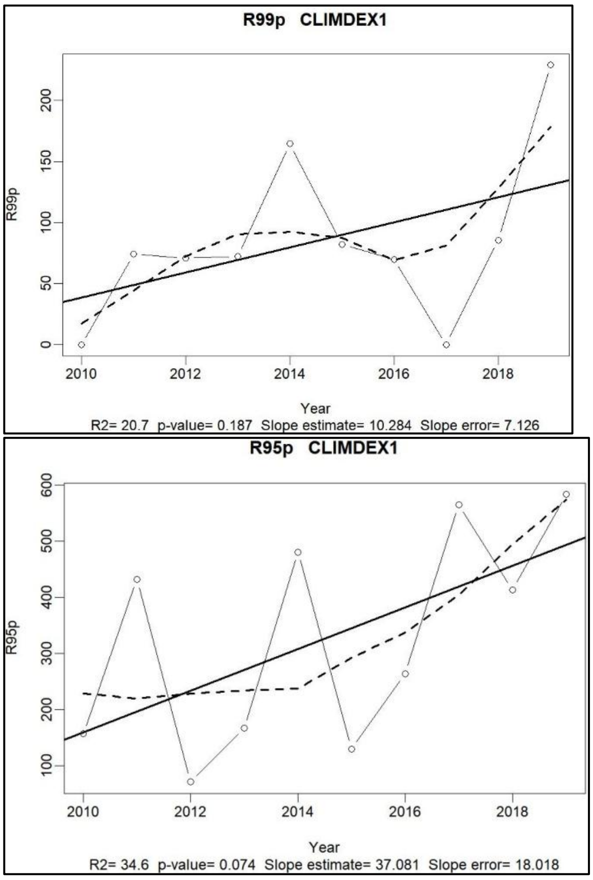
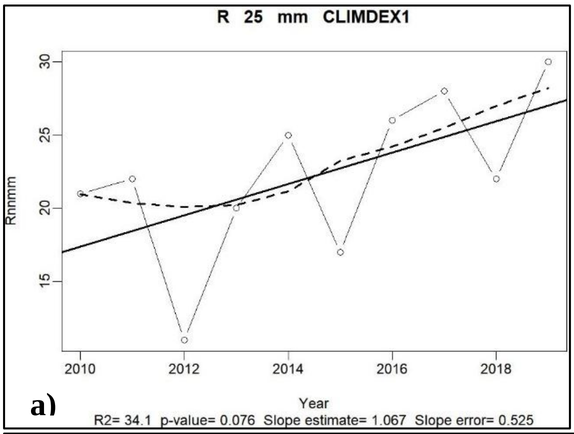
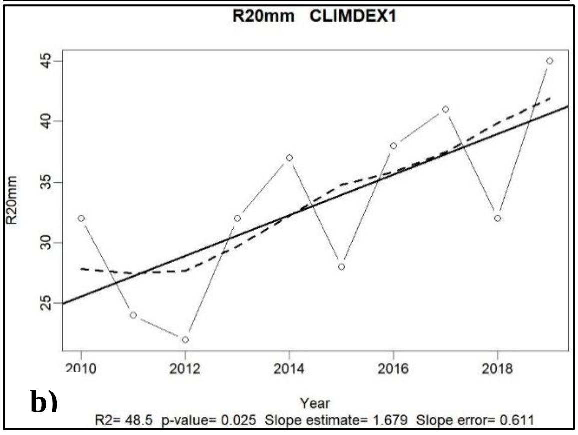


Figure 10: a) Extremely wet days b) Very wet days Annual

Furthermore, the total PRCP when RR>95th percentile and the annual total PRCP when RR>99th percentile describe the wet days at Foumbot. From 2017 to 2019 the extremely wet day's increase to more than 200 days while from 2015 to 2019, there is an increase in the annual very wet days. Both situations contributed in the amplification of inundation in the study area. Wet condition leads to abundant precipitation. The accumulation of heavy precipitation will increase the water level and through runoffs, the surrounding area will be covered with water.

Three daily rainfall amounts have been chosen to describe their contribution in the flood; 10 mm, 20 mmm and 25 mm. The highest number of rainfall with 10 mm, 20 mmm and 25 mm is observed during the year 2019. It is an exceptional year because the quantity of rainfall was above the normal. Also the amount of rain registered has never been recorded during the last 40 years. The intensification of days with more than 25mm of rainfall are the main causes of the floods. The days with this amount of rainfall are always experienced from September to October.





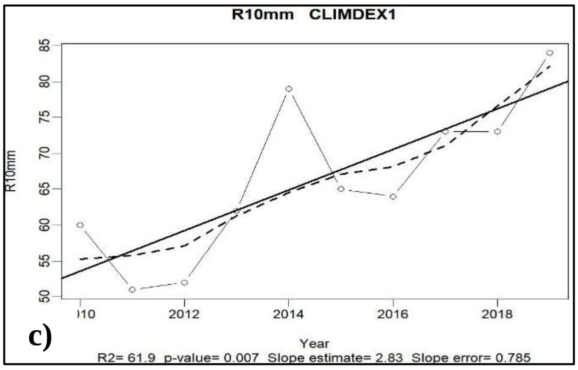


Figure11: The annual count of days when precipitation (PRCP) a)PRCP>=25mm; b)PRCP>=20mm; c)PRCP>=10mm;

Flooding in the IMSF area is mostly caused by great amounts of precipitation. Apart from precipitation which is considered as one of the main factors of floods, they are other factors which contribute to the intensification of flooding.

The IMSF has a flat topography, surrounded by a series of hills varying between 970 m and 1 190 m (Fig. 12). These natural topographic shapes of the IMSF, predisposed the area to the stagnation of water. The land use pattern and the growing demand for arable land, materializes the presence of crop plots in the floodplain of the Noun River, which has often been subject to flooding. Flooding becomes a problem when, in addition to the valley, other neighboring areas reserved for crops or habitat are flooded.

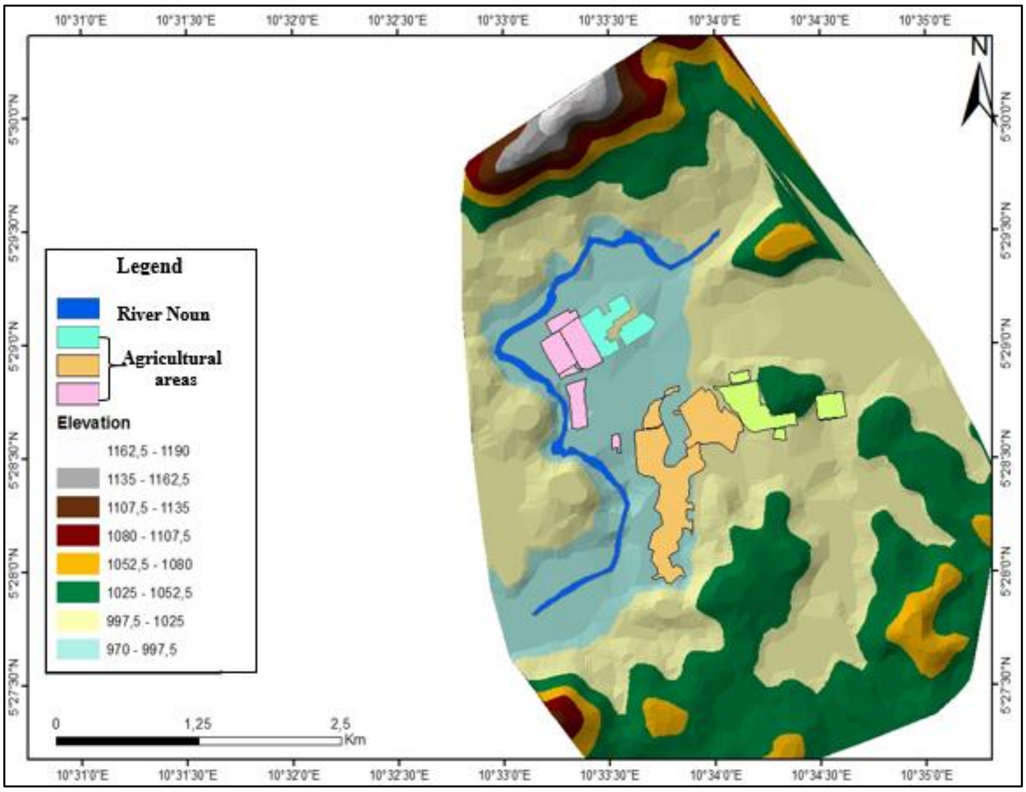


Fig. 12. Topography and flood area

In the study area is influenced by two types of flooding by overflow of the minor bed of the Noun River and flooding by stagnation of water from runoffs (Fig. 13).

Fig. 13. Water stagnation (left) and overflowing of the flat minor bed (right)

The overuse of agricultural land, the under sizing of drainage structures and the lack of regular cleaning are some anthropogenic factors that have an undeniable impact on flooding at the IMSF. During the construction of the trail leading to the IMSF, the drainage conduits for runoff water were undersized. It was built with aluminum and cement nozzles with smaller dimensions. Due to the high flow rate of the watercourse, the runoff water overflows onto the road from one side to the other, degrading the road as a result of erosion activity (Fig. 14).

Fig. 14. Submerged nozzle and the main road covered with water

In addition, the main river beds of the Nun branch that flows at the IMSF have not been cleaned up since the 1990s. The drains are overloaded with sediment deposits that reduce the width and depth of the drainage channels. There is a progressive colonization of the vegetation cover on the deposited sediments. All of this also contributes to amplifying the flooding phenomenon because it reduces the size of the bed river.

The study area is a vegetable production basin. This explains the extent of land aggression by farmers. Due to the strong growth in the demand for arable land by the indigenous and non-indigenous population, the anarchic occupation of the lowland will modify the hydrographic design of the area. This situation makes water drainage difficult because of the disturbance in the orientation of the ridges in the cultivation plots. Consequently, it contributes to the aggravation of the flooding (Fig. 15).

Fig. 15. Inappropriate disposition of the ridges in the plots

The first plots have ridges oriented vertically from the road to the Nun River while the second plot has horizontal ridges. This situation makes it difficult to evacuate the flood waters towards the main stream (Nun).

D. Socio-economic consequences

On the social level, the site occupied by the IMSF has fertile land favorable to agricultural practices and production. Every year, the IMSF is subjected to a high concentration of agricultural populations from various backgrounds. Even the floodplains subjected to flooding are exploited by peasant farmers. This situation in the study area has raised the level of vulnerability of crop and producers. In this way, the floods contribute to aggravating the poverty of producers. This is a serious blow to people's food livelihoods.

Floods promote the leaching of insecticides, fungicides and herbicides that contaminate the water. People who use this chemically polluted water are exposed to water-borne diseases and infections (fig16).

Fig.16. Exposure of population to infections and diseases

Flooding also promotes the spread of water-borne diseases such as cholera, dysentery, and itchy feet and toes. The permanent presence of water during floods also favors the multiplication of vectors of diseases such as malaria.

Economically, the flooding of plantations has led to the destruction of crops (Fig. 17).

Fig. 17. Destruction of crops by flooding

Field surveys have revealed enormous damages caused by the overflow of the Nun and its main outlet, which passes through the IMSF. Based on different type of crops, an economic loss assessment was conducted over a distance of about 2 km on either side of the Nun River. The losses were evaluated as follows: field preparation, seed purchase, field letting, sowing labor, fertilizers. The sum of all these steps gives the total expenditure by crops type (Table 4).

Table 4. Economically estimated losses

Types of crops	Area destroyed by water (ha)	Total Costs (FCFA)
Corn	1	250,000
Bean	10	2, 000,000
Tomato	More than 8	4, 500,000

Sources: Field investigation IRAD-Foumbot 2019

IV. Discussion

The moist and wet condition in September and October justifies the intensification of rainfall during those months and the flooding at the IMSF. This result corroborates with those of [3] which was a study conducted in Douala on floods, showed that the heavy rains of June and July especially, generally prepare the field for floods. Indeed, variations are increasingly observed in the quantity and frequency of rainfall in Cameroon [21]. This lead to flooding [16]- [22] and the destruction of infrastructure and crops [13]. More often than not, heavy or torrential rains are the cause of floods.

The discharge of runoff waters depends on the topography of the environment. In the study area, the relief has a valley bottom morphology with a flat topography and a wide variation in the gradient observed, especially on the banks of the Nun River. However, according to [23] the areas most exposed to flooding are mostly located in lowland areas, close to sea level (mangroves, swamps). The proximity of the study site to the Nun River and the swamp causes flooding by overflow in the minor bed over a distance of 100 m on either side of the banks, and flooding by water stagnation.

Some of the human activities have been noted as a factor of flood amplification in the study area. The rapid overflow of this tributary of the Nun River is linked to an aggression of the minor bed by a plant cover that has grown over the sediments deposited in the river bed. This has contributed to the decrease in the size of the riverbed. This situation was described by [11] in Cap Cameroon. According to him, unsuitable human activities and interventions appear to be an intensifying factor of floods in Cap Cameroon and other neighboring localities including Toubé, Kangué, Mboko. One of the main factors increasing the vulnerability of the populations of Cape Cameroon to flood risks is the anarchic and inappropriate occupation of the waterfront.

V. Conclusion

Overall, extreme rainfall is the major factor that explains flooding in the IMSF. There is an increase of more than 50 mm of rainfall between the first and second rainy seasons. The humidity in the months of August to October contributes to the flooding phenomenon in October. Also the wet condition of September lead to heavy rainfall observed during September which increase the runoff and the water content in the *Nun* River and its branch *momon*. The overflow of the rivers due to the excess of runoff water will cover experimental plot of the station and destroy the plants in the neighboring peasant plantation. The extension of flood is associated with the relief, which has the shape of a valley bottom with a flat topography that favors the stagnation of water in the plots of land, thus destroying the crops. In addition, the under sizing of the canals and the anarchic occupation of the plots of land owners have contributed to the overflowing of floods on the agricultural installations. Consequently, a significant damage was observed on crops and an exposure of population to some illnesses due to the use of polluted water.

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