SPATIOTEMPORAL EVOLUTION OF RAINFALL REGIMES IN THE SANAGA BASIN-CAMEROON IN A DEFICIT CONTEXT

Amidou Kpoumié[1], Ngoupayou Jules Rémy Ndam[2], Eugen Rusu[3], Lucian Sfîcă[4], Pavel Ichim[5], Emmanuel Georges Eckodeck[6]

Key words: Rainfall regime, aridification, deforestation, ITCZ, climate variability, Sanaga-Cameroon.

Abstract. The study of the character of rainfall in the Sanaga basin (133.000 km^2) in Cameroon between 1950 and 2008 from monthly data obtained from 10 rainfall stations, show a generalized decrease of mean annual rainfall during the deficitory period. This decrease is about 66 mm with a reoccurrence in dry stations from 1977-1978, accompanied by a decrease of 20 days of rainfall yearly at the Edea station between 1983 and 2007 in response to the recent dryness occurring in West and Central Africa. Spatially, there is a SSW longitudinal tilting/sliding of mean interannual isohyets during this deficitory phase, quite common in the North of the Basin (about 150-200 km) above the zones where the main dams are located, as against 50 km in the South. This shows the important role that forests play in regulating rainfall partterns. This is also explained by the intensification of aridification in the northern part of the country, intensification of the convection of the ITCZ over the reliefs and to more local circulations, temperature variations at the surface of the Atlantic Ocean, and a modification of free convection above the equatorial forest due to deforestation.

Introduction

Subsaharan Africa is one of the regions which will be most affected by hydroclimatic disequilibrium that the earth has been experiencing for some decades now as compared to other regions of the world (IPCC, 2001). Recent studies show that West and Central Africa have been affected since the 1970s by a generalized

[1] Teach. Assist., Higher Institute of Sahel, University of Maroua, amidou27@yahoo.fr
[2] Prof. PhD., University of Yaoundé I-Cameroon
[3] Prof. PhD., University ,,Al. I. Cuza” Iasi, Romania
[4] Lect. PhD., Student, University ,,Al. I. Cuza” Iasi, Romania
[5] PhD., Student, University ,,Al. I. Cuza” Iasi, Romania
[6] Prof. PhD., University of Yaoundé I-Cameroon

decrease in rainfall accompanied by a decrease in discharges (Servat & al., 1999; Ardoin & al., 2003). This condition has consequences on the local population whose existence strongly depends on the water resources. Studies have been carried out to this effect (Servat & al., 1998, 1999; Ardoin & al., 2003) on the AMMA site (African Monsoon Multidisciplinary Analyses) in West Africa. Central Africa is one of the regions where studies are not carried out at a local scale on the characterisation and evolution of climate. Water resources are lagging because of lack of data and the acquisition of this data is more and more costly.

In Cameroon, many studies have been recently carried out on the vulnerability of water resources (Sigha Nkamdjou & al., 2003; Ngounou Ngatcha & al., 2005; Lienou & al., 2009; Dzana & al., 2011).

The River Sanaga which is about 920 km long is the main river in the Sanaga watershed. From the year 2000, low rainfall and discharge of streams has led to a serious repercussion on the Cameroonian economy. The Sanaga basin therefore is of prime importance to this economy in various domains including hydroelectric production, agriculture and animal breeding. These activities are today threatened by climate change which West and Central Africa has been experiencing since the 1970s.

The main objective of the present study is to precise the characteristics of rainfall regimes of the Sanaga watershed in Cameroon, their temporal evolution and their spatial distribution.

1. Study area

The Sanaga watershed (133.000 km^2) occupies the Central part of Cameroon in the forest-savannah contact zone. It is located between latitudes N3°22' and N7°22', and longitudes E 9°45' and E 14°57' (fig. 1). It covers about 28% of the total surface area of Cameroon (Dubreuil & al., 1975). It drains through a series of plateaus limited to the West by the Cameroonian dorsal and to the north by the Adamawa highlands. Some of the highlands extend towards the East in vast plateaus and are surrounded by volcanic massifs ranging from 1200 m to 1600 m altitude, thus providing a limit to this basin. The Bamilike and Bamoun areas which are very fertile constitute one of the most elevated parts of the Cameroonian dorsal. According to Olivry (1986), 6 out of the 8 main Cameroonian climatic units occur in this basin. They include: the altitudinal tropical climate of the Adamawa, the tropical climate, the equatorial climate, the coastal equatorial climate, the coastal tropical climate and the mountainous tropical climate of the West. This basin possesses a major surface water reserve ($65.3x10^9 m^3$/yr) (Sighomnou, 2004) leading to the construction of three regulatory dams between 1969 and 1987 (Mbakaou, Mape and Bamendjin) and two hydroelectric dams (Songloulou and

Edea). Presently, a fourth regulatory dam is undergoing construction at Lom Pangar.

2. Data and Method

Monthly rainfall data was obtained from the National Meteorology Directorate in Cameroon through a series of climatologic stations. The data is of variable quality and duration depending on the stations with some dating back to 1927 (Edea station). The choice of the stations was centred on three criteria: (1) sample size (data for 30 years according to the world meteorological organization (WMO); (2) the representativity of all the climates in the basin (tab. 1) and the homogenous

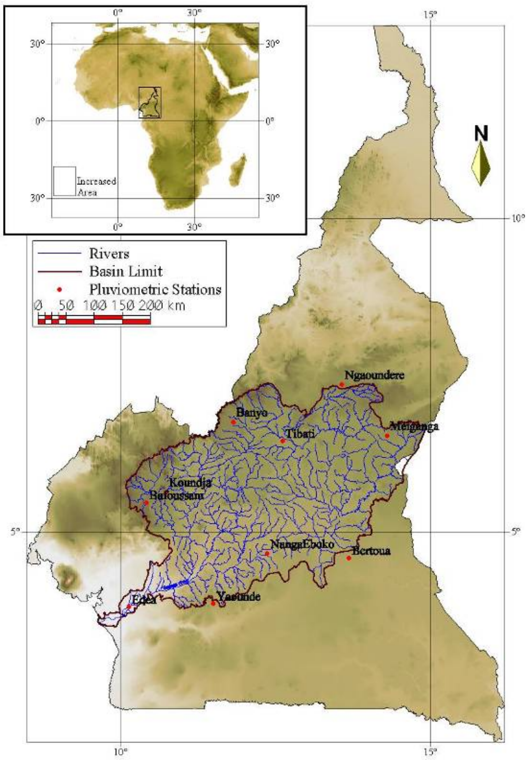


Fig. 1 - Location of the Sanaga basin in Cameroon and rainfall stations used

repartition of these stations within the basin (fig. 1); (3) and the data quality (absence of lacunes). The last criteria led to the choice of the period from 1950 to

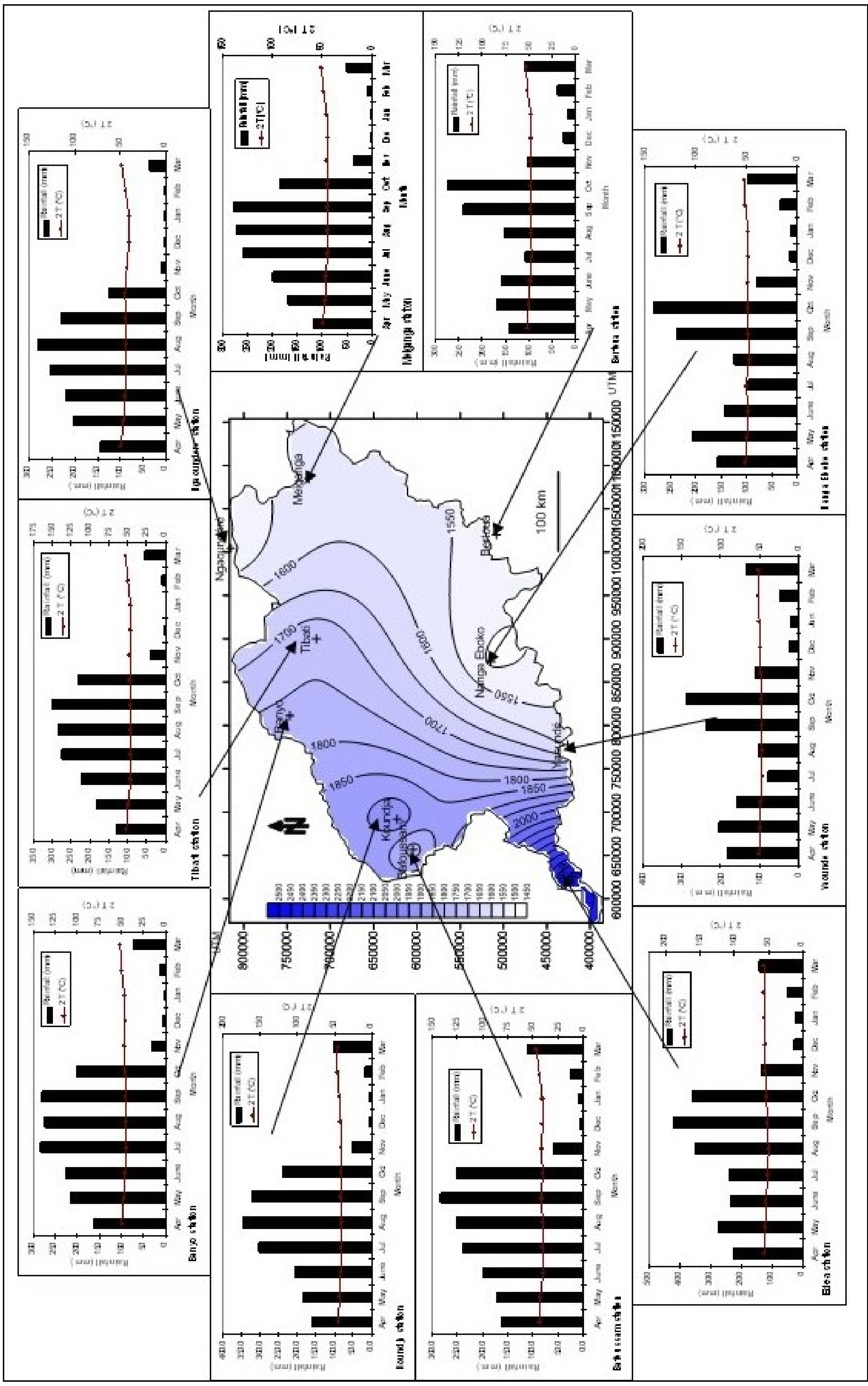


Fig. 2 - Mean annual isohyets and monthly distribution of rainfall (1950-2008) in the Sanaga basin in Cameroon

2008 as the reference period. The choice of the three climatologic stations (Yaounde, Bertoua and Ngaoundere) located out of the basin can be explained by their proximity.

This homogenized data have been treated by descriptive statistical analysis, analysis of straight lines with tendencies associated to the application of the rupture detection tests of Hubert (1989) and Pettit (1979), and calculations on deficits. The delimitation of the seasons has been done based on Bagnouls and Gaussen’s (1957) method. It uses monthly temperature data from 1979 to 2008. The spatialisation of data has been done by using the interpolation method by spherical kriging of the Sufer 9.0 and Arcgis 9.3 software programme, and then adapted to a reduced number of observation points.

Tab. 1 - Characteristics of chosen rainfall stations in the Sanaga watershed- Cameroon

<table>
<tr><th>Stations</th><th>Latitude (UTM)</th><th>Longitude (UTM)</th><th>Altitude (m)</th><th>Period of records</th><th>Climatic zone</th></tr>
<tr><td>Ngaoundere</td><td>774218.966</td><td>279054.111</td><td>1138</td><td>1929-2008</td><td rowspan="4">Altitudinal tropical climate of the Adamawa</td></tr>
<tr><td>Banyo</td><td>663608.575</td><td>721383.146</td><td>1110</td><td>1944-2008</td></tr>
<tr><td>Tibati</td><td>664114.162</td><td>167842.208</td><td>874</td><td>1940-2008</td></tr>
<tr><td>Meiganga</td><td>663305.531</td><td>389325.032</td><td>1027</td><td>1949-2008</td></tr>
<tr><td>Bertoua</td><td>442397.823</td><td>277943.617</td><td>668</td><td>1939-2008</td><td rowspan="2">Tropical and equatorial transition climate</td></tr>
<tr><td>Nanga Eboko</td><td>442736.253</td><td>166831.065</td><td>624</td><td>1939-2008</td></tr>
<tr><td>Yaounde</td><td>331796.292</td><td>722292.169</td><td>760</td><td>1943-2008</td><td>Equatorial climate</td></tr>
<tr><td>Koundja</td><td>552748.621</td><td>610859.927</td><td>1217</td><td>1950-2008</td><td rowspan="2">Mountainous tropical climate of the West</td></tr>
<tr><td>Bafoussam</td><td>552748.621</td><td>610859.927</td><td>1460</td><td>1944-2008</td></tr>
<tr><td>Edea</td><td>331643.938</td><td>611129.132</td><td>32</td><td>1927-2008</td><td>Coastal equatorial climate</td></tr>
</table>

3. Results

The annual and seasonal data of the different rainfall stations of the Sanaga basin for the last six decades are presented below:

3.1 Annual rainfall variation. Between 1950 and 2008, annual rainfall varies between 1626.10 and 3152.50 mm for an interannual mean of (2481.10±355.63) mm at the Edea station which is representative of the coastal equatorial climate. It varies between 1152.70 and 1842.80 mm for an average of (1500.17±166.41) mm at the Ngaoundere station; 1429.50 and 2847.80 mm for an interannual mean of (1763.17±228.32) mm at the Banyo station; 1182.60 and 2381.00 mm for an interannual mean of (1742.80±230.48) mm at the Tibati station and 1253.50 and 2073.60 mm for an arithmetic mean of (1583.04±202.95) mm at the Meiganga station representative of the altitudinal climate of the Adamawa. The data obtained from Bertoua and Nanga Eboko are representative of the tropical and equatorial transitional climate for the same period. It varies respectively between 1095.50 and 2210.00 mm for an interannual mean of (1537.26±235.00) mm; and 1019.00 and 1957.20 mm for a mean of (1491.48±237.01) mm. The equatorial climate (Yaounde station) shows rainfall varying between 1150.90 and 2179.80 mm for an interannual mean of (1592.19±222.85) mm (tab. 2).

3.2 Spatial and seasonal precipitation variations. Spatially, this basin is therefore characterized by a double decreasing South-North and West-East gradient with respect to the evolution of mean annual rainfall (fig.2). Monthly distributions and seasonal rainfall at all stations are shown respectively in Figure 2 and Table 3.

Tab. 2 - Annual rainfall variation domain in the rainfall stations of the Sanaga basin in Cameroon between 1950 and 2008.

Stations	Min	Max	Mean	S.D	Median	CV
Ngaoundere	1152.70	1842.80	1500.17	166.41	1521.90	0.11
Banyo	1429.50	2847.80	1763.17	228.32	1749.75	0.13
Tibati	1182.60	2381.00	1742.80	230.48	1757.80	0.13
Meiganga	1253.50	2073.60	1583.04	202.95	1557.70	0.13
Bertoua	1095.50	2210.00	1537.26	235.94	1509.90	0.15
Nanga Eboko	1019.00	1957.20	1491.48	237.01	1513.50	0.16
Yaounde	1150.90	2179.80	1592.19	222.85	1573.00	0.14
Koundja	1378.40	2563.10	1948.55	228.23	1961.90	0.12
Bafoussam	1306.80	2135.00	1769.70	181.55	1790.00	0.10
Edea	1626.10	3152.50	2481.10	355.63	2448.10	0.14

Min : Minimum ; Max : Maximum ; S.D : Standard Deviation; CV : Variation Coefficient

The number of rainy days at the Edea station varies between 149 and 217 for an interannual mean of (181.81±16.64) days between 1960 and 2007.

4. Discussion and Interpretation

Emphasis is going to be laid on the spatiotemporal variability of rainfall in the Sanaga basin in Cameroon, its present vulnerability state against the decrease in rainfall as well as the factors controlling its variation, variability and vulnerability.

The mean annual rainfall of the Sanaga basin is higher in the southern part as against the northern part. This is explained by the fact that the southern forest part is closer to the equator with an equatorial climate with four seasons consisting two rainy seasons (tab. 3). The northern part covered by savannah, is instead characterized by a tropical altitudinal climate of the Adamawa. The quantity of

annual rainfall is quite high at the coast (2481.10 mm at Edea) with a great convective activity in its southern part, but decreases as we advance towards the continent, reaching 1583.04 mm at Meiganga. This is related to the dynamic convection of orographic type due to the presence of the Cameroon volcanic line (CVL), Mounts Cameroon (4095 m) and Oku (3008 m), and from the Adamawa plateau, which influences the monsoon winds coming from the Atlantic Ocean. This double gradient is also due to the complexity of the Ocean-Atmosphere which generates rainfall due to its position in the two hemispheres (Lienou & al., 2005) and also due to the distancing with respect to the Atlantic Ocean which equally is a major homogenization factor of rainfall regimes (Servat & al., 1999). This orographic barrier role has been demonstrated by Sigha Nkamdjou & al., (2003) in the South Cameroon plateau where Mount Ngoazip and Nkongnam (1000-1200 m) which are situated at 100 km separate the Atlantic Ocean from Zoetélé.
This has equally been well demonstrated by Sall & al., (2007) for the Fouta Djallon in Guinea (West Africa) and Mount Cameroon (Central Africa). In Africa, the main mountainous areas are generally found to correspond to maxima of cloud cover (Sall & al., 1999; Mathon & Laurent, 2001).

Tab. 3 - Definition of dry and wet seasons in the Sanaga basin between 1950 and 2008

<table>
<tr><th>Stations</th><th>Jan</th><th>Feb</th><th>Mar</th><th>Apr</th><th>May</th><th>June</th><th>Jul</th><th>Aug</th><th>Sept</th><th>Oct</th><th>Nov</th><th>Dec</th><th>Total</th></tr>
<tr><td>Ngaoundéré</td><td colspan="3">38.58</td><td colspan="7">1451.92</td><td colspan="2">9.68</td><td>1500.17</td></tr>
<tr><td>Banyo</td><td colspan="3">88.51</td><td colspan="7">1639.77</td><td colspan="2">34.65</td><td>1762.93</td></tr>
<tr><td>Tibati</td><td colspan="3">62.95</td><td colspan="7">1629.89</td><td colspan="2">44.24</td><td>1737.08</td></tr>
<tr><td>Meiganga</td><td colspan="3">62.45</td><td colspan="7">1480.57</td><td colspan="2">40.02</td><td>1583.04</td></tr>
<tr><td>Bertoua</td><td colspan="2">55.68</td><td colspan="4">580.77</td><td>108.25</td><td colspan="4">766.61</td><td>26.02</td><td>1537.26</td></tr>
<tr><td>Nanga Eboko</td><td colspan="3">139.86</td><td colspan="3">504.80</td><td>95.84</td><td colspan="3">644.98</td><td colspan="2">92.36</td><td>1477.84</td></tr>
<tr><td>Yaounde</td><td colspan="2">201.02</td><td colspan="4">681.25</td><td>77.73</td><td colspan="3">743.88</td><td colspan="2">134.58</td><td>1592.17</td></tr>
<tr><td>Koundja</td><td colspan="2">125.2</td><td colspan="8">1864.80</td><td colspan="2">59.76</td><td>1948.7</td></tr>
<tr><td>Bafoussam</td><td colspan="2">34.6</td><td colspan="8">1668.7</td><td colspan="2">66.4</td><td>1769.7</td></tr>
<tr><td>Edéa</td><td colspan="2">74.36</td><td colspan="9">2379.21</td><td>27.53</td><td>2481.1</td></tr>
</table>

Dry season ; Wet season

Indeed, the rainfall regime in the region is mainly dominated by moist and cool monsoon air masses that generally follow the seasonal northward migration of the Inter-Tropical Convergence Zone (ITCZ). The ITCZ separates the moist and cool air masses (monsoon flow) coming from the equatorial Atlantic ocean to the warm and dry air masses (harmattan flow), coming from the Sahara desert (Olivry, 1986; Sigha Nkamdjou & al., 2003; Sighomnou, 2004).

The evaluation of indices against the mean interannual rainfall at the different rainfall stations between 1950 and 2008 shows an alternation of wet and dry periods (fig. 3) with a predominance of stations increasingly dry from 1977-

1978 (fig. 4). This shows the heterogeneous character of the rainfall decrease in the entire Sanaga basin.

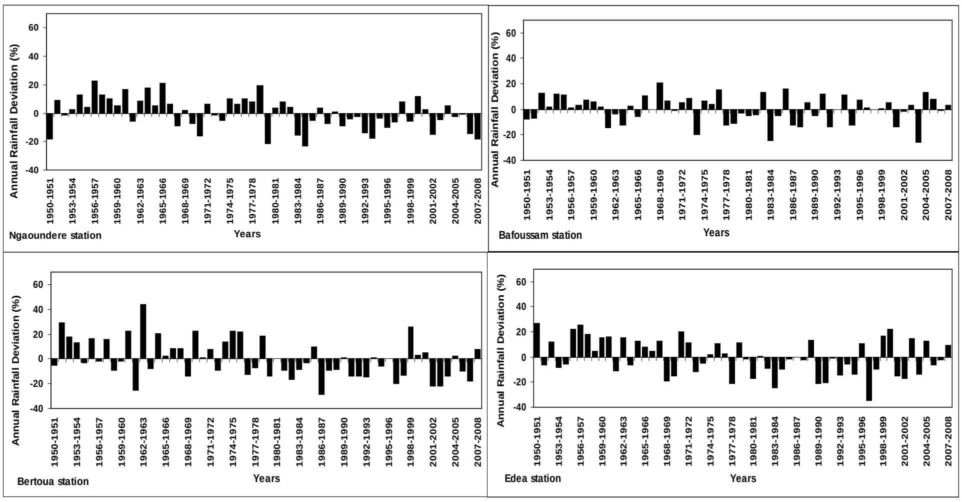


Fig. 3 - Interannual variability of precipitation in Sanaga basin calculated from deviation of annual precipitations to the mean annual rainfall at a few station for the 1950-2008 period

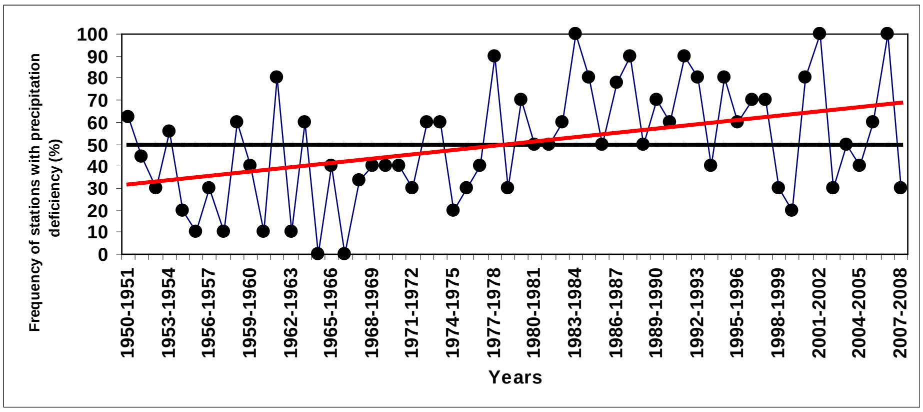


Fig. 4 - Percentage evolution of deficitory rainfall stations in relation to the interannual mean from 1950-2008

The application of Hubert (1989) and Pettit's test (1979) to the mean annual precipitation variable does not show ruptures for the Bafoussam and Tibati stations (tab. 4). This result does not show the regional behaviour in any way and does not signify that there is no precipitation variation with time. It shows that this variation is insignificant even if it exist (Kanohim & al., 2009).

Nevertheless, the Bertoua, Edea, Koundja, Nanga Eboko, Ngaoundere, Meiganga and Yaounde stations registered ruptures in the series between 1962-1963 and 1987-1988. Deficitory phases are noted preceded by wet phases (tab. 4). These last stations register decreases of 11.86; 13.50; 11.63; 9.75; 12.89; 9.99; 12.64 and 9.32% respectively (tab. 4). We have passed an average band of 1052 mm during the wet period to a band of 986.53 mm, thus revealing a decrease of 66 mm (fig. 5).

This variation is accompanied by a decrease of 20 annual days of rain between 1983-1984 and 2006-2007 (fig. 6) at the Edea station.

Tab. 4 - Variation rate of annual rainfall in the Sanaga basin in Cameroon after the application of the rupture tests of Hubert & al., (1989) and Pettit (1979)

Stations	Segmentation of rainfall	Rainfall before rupture	SD before rupture	Rainfall after rupture	SD after rupture	Inter-period ratios (%)
Bafoussam	No rupture	-	-	-	-	-
Tibati	No rupture	-	-	-	-	-
Banyo	1962-1963	1948.87	339.49	1717.78	168.05	- 11.86
Bertoua	1975-1976	1660.96	237.31	1436.76	183.52	- 13.50
Edéa	1967-1968	2697.50	294.82	2383.72	340.03	- 11.63
Koundja	1982-1983	2035.61	228.37	1837.12	176.45	- 9.75
Nanga Eboko	1975-1976	1603.90	239.68	1397.19	191.95	- 12.89
Ngaoundéré	1978-1979	1579.05	154.51	1421.29	140.06	- 9.99
Meiganga	1969-1970	1725.96	197.96	1507.82	162.71	- 12.64
Yaoundé	1987-1988	1645.03	212.44	1491.79	211.91	- 9.32

SD: Standard Deviation

All these stations in the basin therefore experienced the influence of the recent dryness and were not affected with the same intensity regarding the decrease in rainfall. This is in response to the recent dryness period in Central and West Africa since the 1970's.

The altitudinal tropical climate of the Adamawa, tropical and equatorial transition climate, equatorial and coastal equatorial climate are the most affected by the drop in annual rainfall with rates comprised between 11.4% and 13.4%.

When we compare the emplacement of isohyets of mean annual rainfall for the period before rupture and the period after rupture, it can be noticed that the isohyets of the deficitory period has been displaced longitudinally towards the ocean. This displacement is mostly towards the SSW direction. This tilting is greater towards the north of the basin (about 150-200 km); above the zones where the main dams of the region are located (fig. 7). In the South, there is a little displacement of about 50 km between the equatorial climate and the coastal equatorial climate. This also shows the important role that forests play in regulating rainfall partterns.

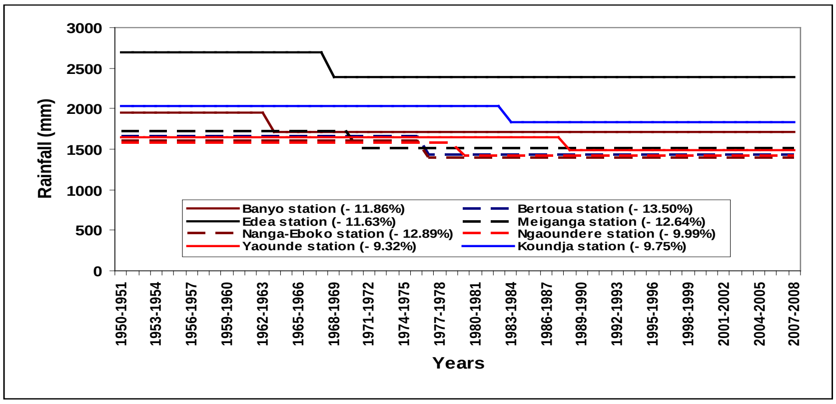
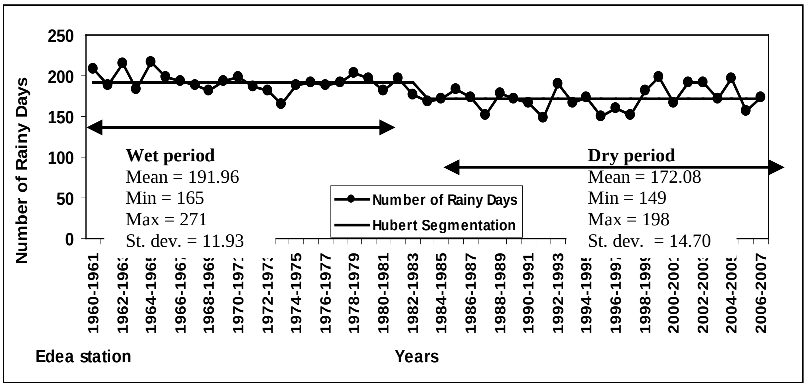


Fig. 5 - Hubert and Pettit's Segmentation of the rainfall of some pluviometric stations of the Sanaga basin-Cameroon between 1950 and 2008



Min : minimum ; Max : Maximum ; St. dev. : standard deviation

Fig. 6 - Hubert and Pettit's segmentations of number of rainy days at Edea pluviometric station between 1960 and 2007

Analysis suggests that the observed distributions are due to an intensification of the convection of the ITCZ over the reliefs and to more local circulations, notably slope wind, sea breeze, and monsoonal circulation generating low and middle clouds of convective and stratiform types (Sall & al., 2007). This is also explains by the high deforestation in many regions of the Gulf of Guinea (Paturel

& al., 1998) which influences evapotranspiration as well as free convection above the equatorial forest, space occupation by urbanisation and land cultivation. There is also industrialisation and increasing demographic pressure which does not respect environmental protection norms in big towns. The Ngaoundere and Banyo areas with a tropical altitudinal climate of the Adamawa, are more influenced by the intensification of aridification in the northern part of Cameroon, marked by displacement of isohyets towards the South by 100 km (Naah, 1990). The changes observed are finally explained by the interaction of the orbital factors, surface conditions of oceans (temperature variations at the surface of the Atlantic Ocean) (Gasse, 2006). The initial orientation of isohyets equally plays an important role in their displacement over time.

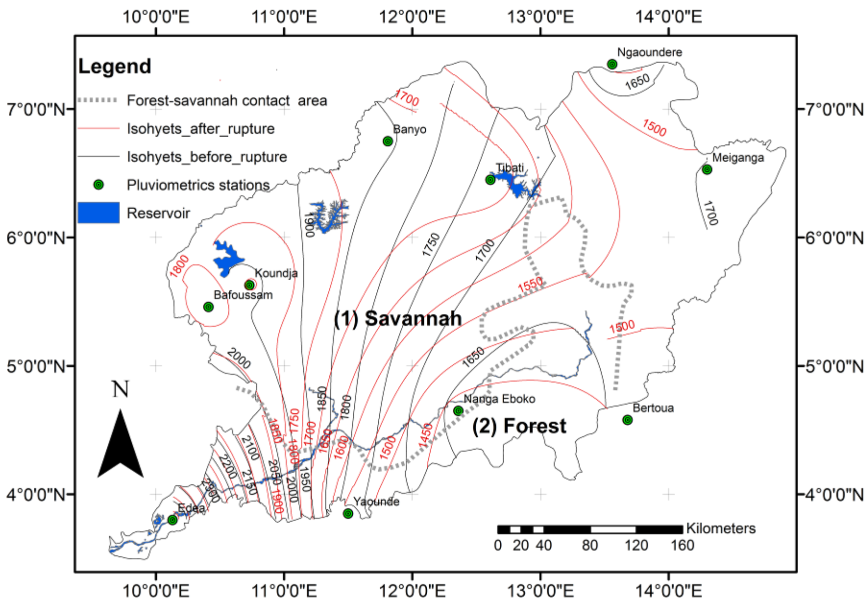


Fig. 7 - Evolution of interannual average isohyets rainfall between the periods before and after rupture of the Sanaga basin in Cameroon

This phenomenon of longitudinal tilting of isohyets toward the Atlantic Ocean was already observed in the Carcarana watershed in the Santa Fe Province of Argentina (Venencio & Garcia 2011), by comparing the mean annual isohyets of 1941-1970 and those of 1971 – 2000. In Cameroon, Sighomnou (2004) found an average tilting/sliding for mean annual isohyets in a North-South direction of about 250 km on average in the entire country. In Gourma, found in the Sahel, Label & al., 2003) noticed a North-South decreasing gradient with a rate of 1mm. km^{-1}.

Conclusion

This study brings out the evolution of annual rainfall regimes of 10 rainfall stations in the Sanaga basin in Cameroon between 1950 and 2008. This basin therefore presents a double decreasing evolution gradient of mean annual rainfall in a South-North and West-East direction. The application tests of Hubert (1989) and Pettit (1979) to the mean annual rainfall variable shows rainfall decreases from 9 to 13% corresponding to a band of 66 mm depending on each station. There is a decrease of 20 days of rainfall registered at the Edea station. The comparison of specialized data of mean annual rainfall before and after rupture shows a longitudinal tilting /sliding (SSW) of isohyets to about 150-200 km in the northern part of the Sanaga basin above the zones where the main dams are located, as against 50 km in the South forestory basin. This shows the important role that forests play in regulating rainfall partterns. This isohyets sliding is one of the causes of energy crisis in Cameroon since the 2000s. This is explained by the intensification of aridity in the northern part of the country, the variation of temperature at the surface of the Atlantic Ocean, and the modification of free convection above equatorial forests due to deforestation.

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