Rainfall Variability along the Southern Flank of the Bambouto Mountain (West-Cameroon)

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ABSTRACT

This paper presents the rainfall variability along the southern flank of the Bambouto mountain. Data were collected from rain gauges, while spatial variability was estimated through daily recorded data. Monthly and annual data were used to draw isohyetes via the triangular method, with linear interpolations between observation points. Results show that rainfall is highly variable along the slope. Daily rainfall amounts range from 0.1 mm to 120 mm. Mean yearly rainfall is 1918.1 mm. Rainfall amount does not have a linear relationship with altitude. Dschang is characterised by abnormally high rainfall. Following a North-South direction, rainfall decreases from Dschang to a Melang-Loung-Djuttitsa axis. From this axis, the gradient reverses as rainfall increases rapidly towards the Mélétan mountain. The existence of the relatively dry zone within the hillside seems to be due to the influence of two air masses. The first is cold and very wet which moves from the Mamfe basin to the summit zone where it starts to warm up as it flows towards Melang and Loung where temperature increases. The second comes from the south to south-east monsoon which is also impoverished during the ascension to higher altitudes. It is also likely that a third air mass from the dry harmattan is involved depending on the position of the ITCZ.

Key words: rainfall, spatial variability, gradient, slope, mountain.

RESUME

Une étude a été entreprise dans le but de mettre en évidence la variabilité pluviométrique à petite échelle sur le flanc sud des Monts Bambouto où les altitudes varient de 800 m dans la plaine des Mbo à 2740 m au Mont Mélétan. Quinze postes pluviométriques ont été relevés sur la période s'étendant de novembre 2002 à octobre 2003. L'étude de la variabilité met en œuvre le tracé des isohyètes mensuelles et annuelles basé sur la méthode des triangles, avec interpolation linéaire pour tous les segments. Il en découle une définition et caractérisation du gradient pluviométrique tant avec l'altitude qu'avec la distance. La pluviométrie est très variable sur le versant. La pluie journalière varie de 0,1 à 120 mm. La pluie annuelle moyenne a été de 1918,1mm. Suivant un axe S-N, à partir de Dschang, le gradient pluviométrique est négatif jusqu'à un axe de faible pluviométrie (Loung-Melang-Djuttitsa) et redevient positif vers la zone sommitale. De nombreux courants d'air tels que l'harmattan venant du nord-est et les vents humides venant du sud-est ou du sud-ouest, associés à des interférences de phénomènes multiformes (latitude, continentalité ou orientation des pentes) occasionnent cette grande complexité spatiale autour du massif dont la conséquence est la grande variabilité des précipitations.

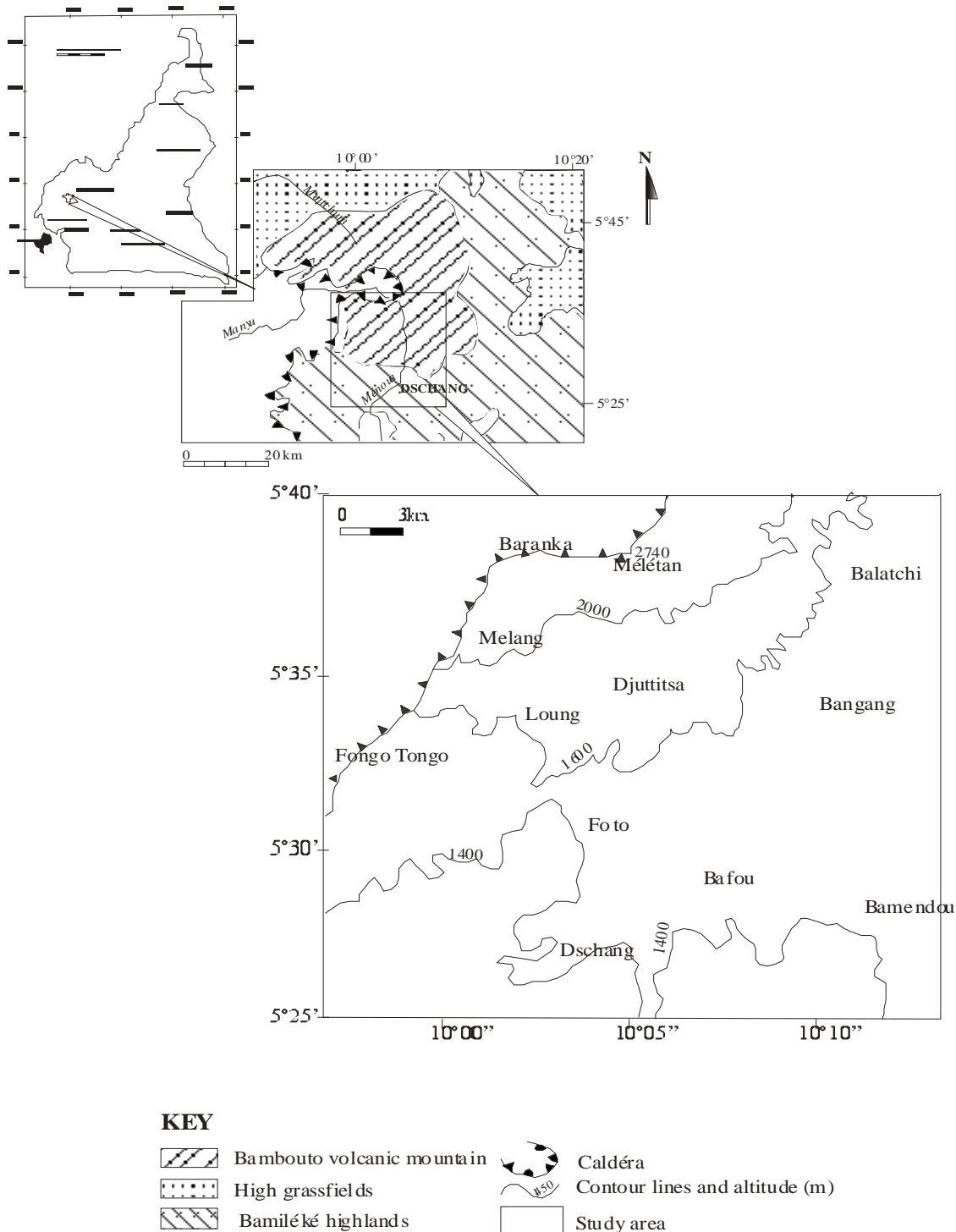**Mots clés :** pluviométrie, variabilité, gradient, massif.

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INTRODUCTION

As any natural phenomenon, rainfall is subject to great spatial and temporal variation, due to the general circulation pattern and local factors (Chow *et al.*, 1974). At a small scale, variations are due to the local relief or nature of the landscape, the effect of continentality and the exposure to wind (Richardson *et al.*, 2004). These factors are present in the Bambouto mountain where a great dissymmetry can be observed from the northern to the southern flank (Morin, 1988). The southern flank constitutes the "bread basket" of the country and most of her neighbours, based on crop and livestock production which sometimes results in the conflict over soil and water use. Water resources are essential in the efficient use of soil by vegetation. They constitute the major climatic risk of agrarian

KEY

▨ Bambouto volcanic mountain		⬡	Caldéra
⋮⋮⋮ High grassfields		⌇₅₀	Contour lines and altitude (m)
▧ Bamiléké highlands		▭	Study area

Fig. 1: Location and topography of the study site

systems. It is in the framework of characterizing the variability at a small scale that studies have been undertaken along this flank. In the past, stations were set up for the estimation of general climatological data at the meteorological station of Dschang town. The meteorological station of Djuttitsa was for local industrial needs of CTE - Cameroon Tea Estate, (former CDC - Cameroon Development Corporation). Data from these stations have provided some basic hydrologic information such as water balance, flow regime or rainfall regime (Olivry, 1986). Valet (1985) reported a particular climate in the region compared to those situated at the same altitude. Other local climatic conditions have been stated by Ngoufo (1988) and Tsalefac (1999) who suggested, despite the lack of numerical data, a decrease of rainfall with elevation. Lack of precise information can be attributed to the dearth of appropriate climatic data for all the different elevations.

The present theme is focused on the study of the spatial variability of rainfall, using numerical data recorded at different locations within the Menoua river watershed which validly represents the southern flank of the Bambouto mountain. Altitude ranges from 800 m to 2740 m a.s.l. This difference in altitude brings about many microclimates which account for the diversity of agricultural activities in the area. The study intends i) to appreciate rainfall variability along the slope, ii) to determine the altitudinal and distance rainfall gradients and to, iii) to find out the directions of air masses found along the slope.

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MATERIALS AND METHODS

Experimental site
The study area is located within the West Cameroon Highlands and occupies the southern slope of the Bambouto mountain (figure 1). The surrounding region is a part of a complex structure known as "The Cameroon Line". The region is dominated by a Precambrian granito-gneissic basement complex covered by various volcanic rocks (Tchoua, 1974). Intensive agriculture is predominant with scarce fallow lands dominated by *Pteridium aquilinum, Rafia vinifera, Eucalyptus grandis, Imperata cylindrica, Pennisetum purpureum* and the crops cultivated include maize, beans, potatoes
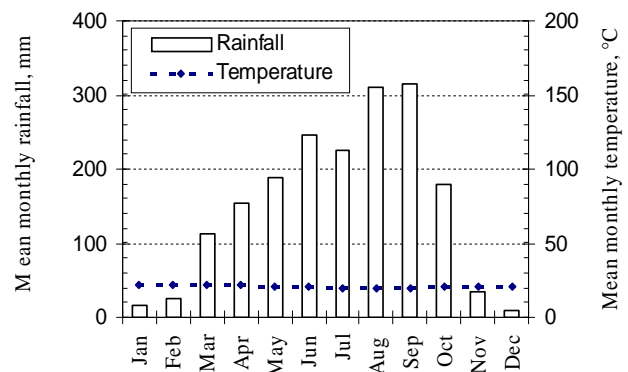
Fig. 2: Climagraph at Dschang meteorological station

and tea (Kuété, 1999 ; Morin, 1988). The intensive cattle breeding constitutes an additional stress in the upper zone, where conflicting use of water and land resources is often observed.

The study area comprises the Menoua river watershed that extends to over 655 km^2. This watershed is drained by a fifth order stream (*Ménoua*), through the contribution of many streams that take their rise from the high elevation zone. The altitude ranges from 800 m to 2740 m a.s.l. Three successive morphological domains separated by more or less pronounced escarpment starting from the summit of the flank are: the upper zone (higher than 2000 m), the mid elevation zone (from 1600 m to 2000 m) and the lower zone (from 1400 m to 1600 m) (Morin, 1988). The landscape is characteristic of the West Cameroon Highlands.

The climate is characterized by the alternation between a wet and a dry season of variable intensity (figure 2). The mean annual rainfall calculated from 1910 to 2000 records at Dschang meteorological station is 1873.2±208.9 mm. The temperature is fairly constant throughout the year, the mean air temperature is 18.9°C, with the highest monthly mean of 23.4°C between March and April and the lowest (14.3°C) in December.

Data measurements
The only viable approach for characterizing rainfall variability in this environment is the collection of data using appropriate instrumentation, because phenomena combine and interact to influence the local meteorology and especially rainfall and its spatial distribution (Vetter, 2004). Daily rainfall data were collected using 10 rain gauge network installed along the slope, according to the recommendations of the manufacturers. Rain gauges were of two types : three of them had a reception surface of 400 cm^2 (Dschang Météo, IRAD, Djuttitsa) and the others had 113 cm2 surface area. Both had a
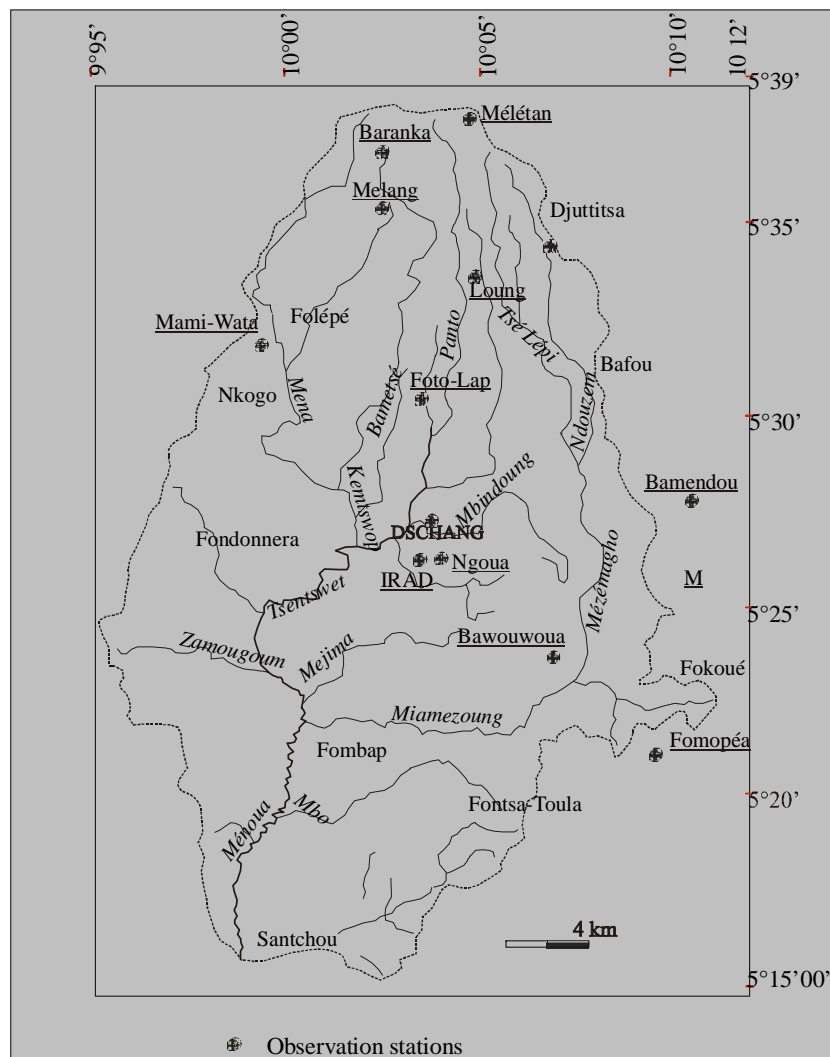
Table I : Location of Rain Gauge stations

Stations	Symbol	Geographic coordinates		Elevation (m)
		latitude	longitude	
Mélétan	MLT	5⁰38'08"	10°04'43"	2608
Melang	MLG	5°35'26"	10°02'24"	2232
Loung	LNG	5°33'26"	10°04'59"	1838
Djuttitsa	DJU	5°35'00"	10°05'02"	1890
Mami-Wata	MMW	5°32'44"	09°59'44"	1626
Dschang	MDS	5°27'08"	10°03'46"	1400
Bamendou	BMD	5°26'35"	10°10'43"	1568
Ngoua II	NGO	5°26'20"	10°04'13"	1445
IRAD	IRA	5°25'00"	10°04'00"	1390
Bawouwoua	BWW	5°23'40"	10°07'13"	1536

graduated measuring glass tube that allowed direct reading of the amount of daily rainfall. Their position and elevation are shown in table 1 and figure 3. It is noteworthy that the network was dense enough, at least 1 rain-gauge per 47 km², compared to minimum standards given by the WMO for mountainous area i.e. 1 rain-gauge per 250 km² (Cosandey and Robinson, 2000).

Spatial variability

Spatial variability was estimated through monthly and annual data computed from rainy days and daily records. The mean values were calculated, with corresponding standard deviations and eventually the coefficient of variation. The monthly and annual data were then reported on a map. Although geostatistical methods exist like kriging to map rainfall by the use of elevation (Phillips et al., 1992 ; Goovaerts, 2000), we drew isohyetes using the triangular method, with linear interpolations between observation points. Isohyetes were drawn in the heart of the rainy season as times series were incomplete at Mami-Wata from November to May. Our approach considers that the rainfall amount at any position is influenced by the relief and this provides the necessary information for drawing the rainfall maps (Cosandey and Robinson, 2000). From the maps, we also derived rainfall gradient as a function of the distance or difference of elevation between stations.

Fig. 3: Location of rain gauge stations in Menoua watershed
Underlined names indicate stations installed by the authors specifically for the study

Table 2: Statistics on daily rainfall on the southern flank of the Bambouto Mountain

		MLT	MLG	DJU	LNG	MDS	BMD	NGO	IRA	BWW	AVG	STD	Min	Max
Number of rainy days		**160**	**148**	**165**	**134**	**190**	**119**	**144**	**174**	**156**	**154.4**	**21.3**	**119**	**190**
Daily rainfall	MIN	0.4	1.0	0.1	1.0	0.2	0.3	0.1	0.2	0.2	0.4	0.4	0.1	1.0
	AVG	15.6	11.5	10.6	13.1	10.6	14.2	14.4	10.3	12.3	12.5	1.9	10.3	15.6
	MAX	120.0	55.0	50.3	78.4	76.2	64.6	77.6	80.9	81.9	76.1	20.1	50.3	120.0
	STD	17.3	9.1	10.8	12.9	11.2	13.6	15.5	12.9	13.7	13.0	2.5	9.1	17.3
	CV	1.1	0.8	1.0	1.0	1.1	1.0	1.1	1.3	1.1	1.0	0.1	0.8	1.3
% Days of rainfall														
under 5mm		26.9	20.3	39.4	26.1	36.3	30.3	34.7	45.4	39.1	33.2	7.9	20.3	45.4
5 – under 15mm		36.3	52.7	32.7	44.8	42.1	31.1	29.2	30.5	27.6	36.3	8.5	27.6	52.7
15 – under 30mm		24.4	22.3	21.8	18.7	14.2	22.7	5.6	18.4	26.3	19.4	6.3	5.6	26.3
30 – under 45mm		7.5	4.1	4.8	6.7	5.3	13.4	25.0	2.9	3.8	8.2	7.0	2.9	25.0
45 – under 60mm		2.5	0.0	1.2	2.2	1.6	1.7	2.8	1.7	0.6	1.6	0.9	0.0	2.8
More than 60mm		2.5	0.7	0.0	1.5	0.5	0.8	2.8	1.1	2.6	1.4	1.0	0.0	2.8
% Daily rainfall														
under 5mm		4.4	4.6	7.2	5.5	8.4	3.6	5.9	8.3	6.2	6.0	1.7	3.6	8.4
5 – under 15mm		23.4	38.7	26.6	30.8	36.0	19.7	18.3	25.3	19.8	26.5	7.3	18.3	38.7
15 – under 30mm		32.3	42.2	43.6	29.5	27.0	33.1	6.5	39.3	46.4	33.3	12.1	6.5	46.4
30 – under 45mm		17.0	11.3	17.2	18.1	17.3	33.7	45.8	9.7	11.0	20.1	12.0	9.7	45.8
45 – under 60mm		7.8	0.0	5.5	8.1	7.6	6.1	9.6	9.6	2.4	6.3	3.3	0.0	9.6
More than 60mm		15.2	3.2	0.0	8.0	3.8	3.8	13.8	7.9	14.2	7.8	5.5	0.0	15.2

AVG : Mean value ; STD : Standard deviation ; CV : coefficient of variation ; MIN : minimum ; MAX : maximum

RESULTS

Data were collected from November 2002 to October 2003.

### Days of rainfall and daily rainfall variability

On the flank, the average annual number of rainy days was 154.6 (21.3) which represents 42% of the number of days in the year (table 2). The maximum was observed in Dschang town (190 days) and the minimum in the eastern part at Bamendou (119 days). There were 160 days of rainfall (DOR) at the summit zone of Mélétan. Rainfall values lower than 15 mm are the most dominant (69.5 6% days of rainfall), while exceptional values (higher than 60mm) accounted for 1.3 1.1%. The maximum daily rainfall was highly variable having a standard deviation of 20.1mm. The highest value was recorded at Mélétan (120 mm) and the lowest at Djuttitsa (50.3mm). Rainfall lower than 5mm, although frequent (33.1 7.2% DOR) represented only 6.0 1.7% of annual rainfall. 80% of the rainfall ranged from 5mm to 45mm.

Table 3: Monthly and annual rainfall (mm) on the southern flank of the Bambouto Mountain

Mois	MLT	MLG	DJU	LNG	MMW	MDS	BMD	NGO	IRA	BWW	AVG	STD	CV
Nov	56.6	112.0	34.2	44.1		33.3	31.5	52.6	33.3	38.2	48.4	25.5	0.5
Dec	0.0	0.0	5.9	0.0		6.6	23.9	91.7	0.9	1.8	14.5	29.9	2.1
Jan	0.0	0.0	0.0	0.0		8.8	0.0	9.2	6.9	16.0	4.5	5.9	1.3
Feb	37.3	0.0	39.1	62.5		63.3	99.5	6.9	37.4	80.0	47.3	32.4	0.7
Mar	16.6	6.5	20.7	13.2		81.8	76.0	38.1	76.0	85.6	46.1	33.3	0.7
Apr	142.8	87.0	202.7	141.2		133.0	101.3	160.9	119.3	168.0	139.6	35.3	0.3
May	177.8	131.2	141.7	164.5		240.2	167.0	188.6	156.6	148.4	168.4	32.2	0.2
Jun	306.1	230.0	258.9	235.6	324.7	281.9	122.6	262.6	242.8	190.8	236.8	53.9	0.2
Jul	718.4	292.0	282.9	291.0	561.4	328.1	279.9	209.0	260.0	247.6	323.2	151.9	0.5
Aug	485.0	377.0	345.1	346.8	536.2	332.8	226.0	440.3	309.8	301.4	351.6	76.5	0.2
Sep	297.3	272.6	270.4	282.2	488.6	259.8	238.5	313.8	285.4	303.4	280.4	23.2	0.1
Oct	269.4	200.0	163.0	178.5	246.4	259.9	352.6	296.4	262.5	342.2	257.2	67.3	0.3
Total	**2507.3**	**1708.3**	**1764.6**	**1759.6**		**2029.5**	**1718.8**	**2070.1**	**1790.9**	**1923.4**	**1918.1**	254.9	0.1

AVG : Mean value ; STD : Standard deviation ; CV : coefficient of variation ; MIN : minimum ; MAX : maximum
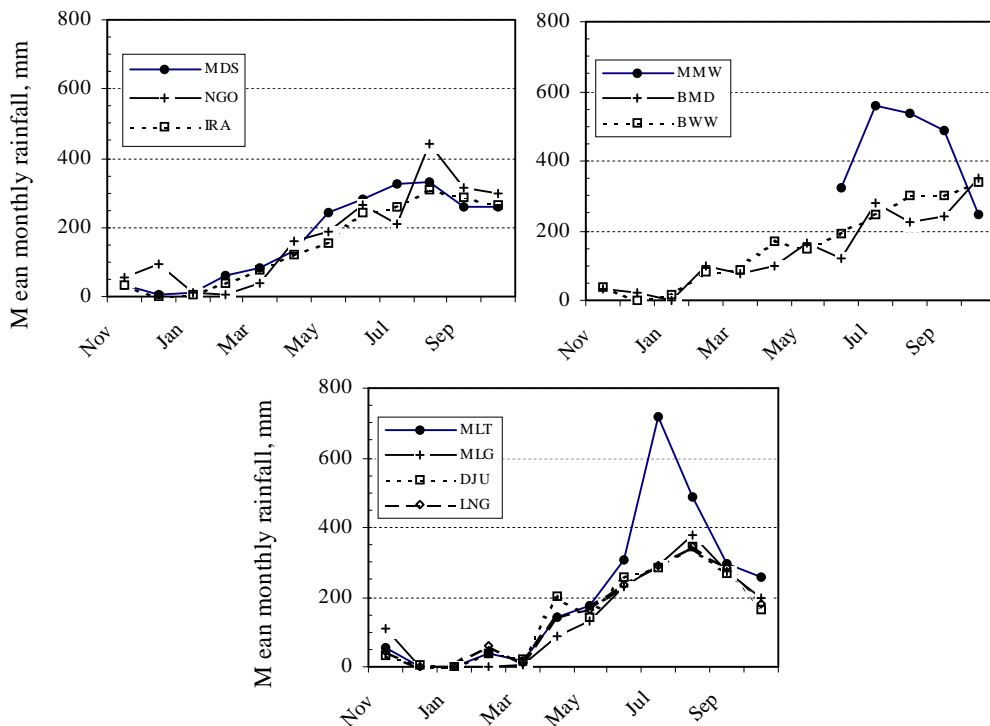
MLT : Mélétan ; MLG : Melang ; LNG : Loung ; DJU : Djuttitsa ; MDS : Dschang meteorological station ;
MMW : Mami-Wata ; BMD : Bamendou ; NGO : Ngoua II ; IRA : IRAD ; BWW : Bawouwoua

Fig. 4: Monthly rainfall at different stations

Monthly rainfall and monthly isohyetes
Monthly rainfall is presented in table 3 and shows that rainfall is insignificant in December and January (less than 19mm) as recorded in all the stations. February and March are also dry months at higher altitudes (Djuttitsa, Loung, Melang and Mélétan). The variability is low in the dry season but this rises in the heart of the rainy season (standard deviation 151.9mm). Taken individually (figure 4), Mami-Wata and Mélétan attained the maximum in July, Bamendou and Bawouwoua in October, while the others had their maximum in August.

The spatial distribution showed that rainfall is always high at Mélétan, Mami-Wata and Dschang town (figure 5). The lowest values are encountered at Melang, Loung, Djuttitsa (and sometimes Bamendou) which correspond with the mid elevation zone.

Annual rainfall and annual isohyetes
Times series were incomplete at Mami-Wata from November 2002 to May 2003. An attempt to complete these data from correlation techniques failed, as coefficients of determination were lower than 0.8 and could not provide good results. Annual rainfall at that station was used as an indication which is however an underestimation of rainfall gradients since a significant part of the data was missing. At a yearly scale, mean rainfall was 1918.1 mm with a high standard deviation

of 254.9 mm. Higher values were recorded at Mélétan summit zone (2507.3mm). Mami-Wata, Dschang and Ngoua II showed values higher than 2000 mm. Dschang and Ngoua II are situated at the lower elevation zone (table 3). On the other side, Melang was the dryer station (1708.3 mm), as well as Djuttitsa, Loung and Bamendou. On the map (figure 6), these stations show a zone of least rainfall from the north west to south east. From this zone, rainfall increases both to the north and to the south.

DISCUSSION
Although the records covered a short time duration (November 2002 to October 2003), the results show the dynamics of rainfall in this mountainous watershed. On the average, we found 154.4 21.3 days of rainfall, with a maximum of 190 days in Dschang town. The maximum daily rainfall was 120 mm at Mélétan at the summit zone and 80% of the rainfall ranged from 5 to 45 mm.

Monthly rainfall was highly variable along the slope. Whatever the station, two seasons are distinct. Monthly rainfall is negligible from December to February when the continental powerful harmattan flux predominates while the maritime monsoon flux is inexistent. However, March is still dryer in the mid and higher elevation stations (MLT, MLG, DJU, LNG) which makes them
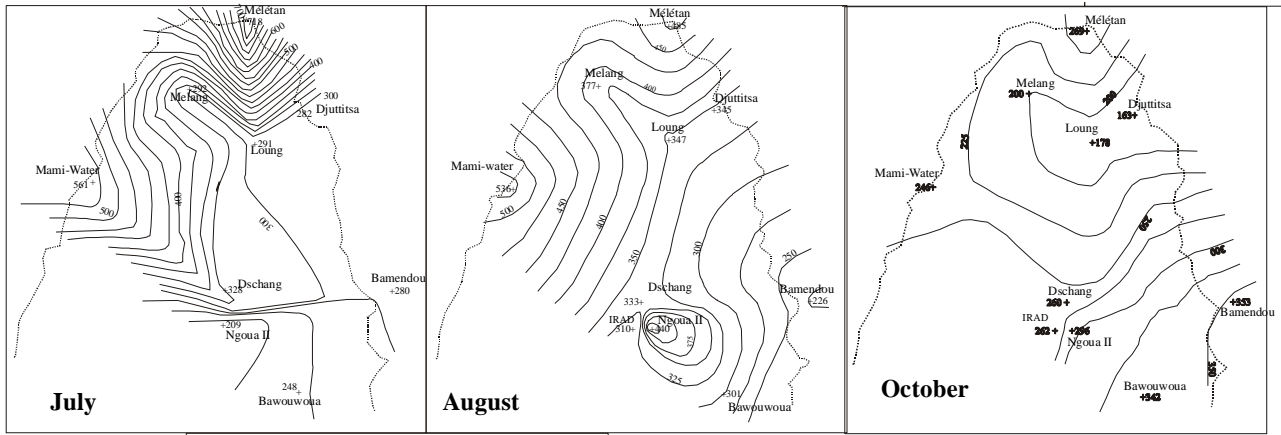
Fig. 5: Monthly isohyetes

to have a longer dry season compared to the rest of the stations on the flank.

On the southern flank, rainfall is high in Dschang town, compared with the neighbouring stations at the same elevation. This situation has been described earlier (Ngoufo, 1988), as a consequence of the local landscape. The general landscape is made up of a hollow alveolar in the centre which is elevated at the borders. This situation entraps air inside that is warmed-up and creates rising movements leading to local rainfall. It would seem the increasing population of the town contributes to the phenomenon. This kind of rainfall generally does not extend laterally because the average wind speed is barely 2m/s based on local data (Olivry, 1986).

Mélétan at the summit is the wettest station. It is also the zone where frequent tornadoes are encountered, which can explain why despite its long dry season, annual rainfall is high. The atmosphere here is very cloudy towards the caldera. Rainfall from this station decreases sharply, as well as the elevation in the southern direction, up to the relatively dry zone along the Melang-Loung-Djuttitsa axis. The rainfall gradient varies from 90 mm/km to 130 mm/km distance. From this axis, rainfall increases slowly to Dschang or probably sharply to Mami-Wata. The gradient here ranges from 20 mm/km to 40 mm/km.

The relation between rainfall and elevation is not distinct. A simple linear regression of rainfall and elevation is not significant (figure 7). Rainfall variability is the conjunction of multiform interferences between factors, such as latitude, altitude, continentality, air masses conflicts and even slope orientation. The position of
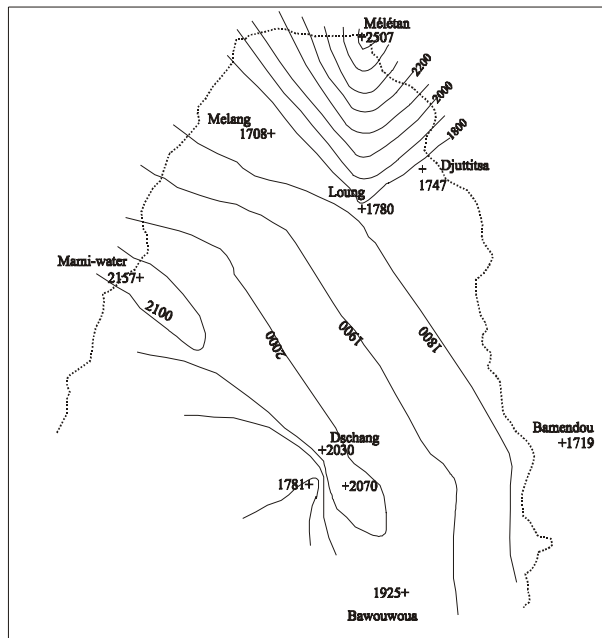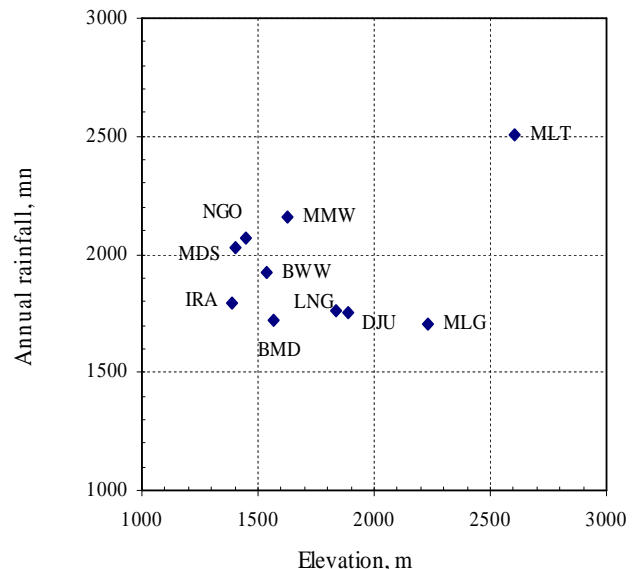

Fig. 6: Yearly isohyetes

Fig. 7: Relation between rain gauge elevation and annual rainfall

the relatively dry zone within the hillside seems to come from the existence of two air masses. The first is wet and moves in from Mamfé basin to the borders of the caldera. The cold clouds originate from the Atlantic monsoon from July, when the intertropical convergence zone (ITCZ) is high in latitude. Since rainfall is abundant, forest cover is permanent in the valley. This air reaches the border at the northern part of the flank where 2507.3 mm are recorded at Mélétan. From records, it is likely that Mami-Wata is influenced by the same air flux with more than 2200 mm of rainfall. While blowing down on the hillside, air becomes hot and dry due to temperature increase which accounts to the rapid decrease of rainfall. That's why little rainfall is recorded at Melang, Loung and Djuttitsa. It would also seem that the dry harmattan from the north-east hits the northern hillside of the Bambouto Mountain and comes along side the southern flank as a dry wind which is responsible for the rainfall deficit, as suggested by Tsalefac (1999). The other air masses come probably from oceanic winds which are slowly and successively impoverished during the ascension of the highlands. This is responsible for the gentle rainfall gradient recorded.

CONCLUSION

Although the records cover a short time duration (November 2002 to October 2003), the available results show the dynamics of rainfall on the watershed. The southern flank of the Bambouto mountain exhibits substantial rainfall variations over small distances. Spatial variability is evidenced through annual and monthly isohyetal curves drawn using the triangle method. The approach considered that rainfall heights at any position depend on the relief that is implicitly taken into account while drawing the isohyete maps. A simple linear regression of rainfall and elevation was not significant. Our results confirm previous uncertainties (Tsalefac, 1999 ; Ngoufo, 1998) that rainfall varies along the slope, with additional information that a relatively dry zone exists at the middle of the slope in the zone. The map developed from the study can enable one to determine rainfall amount at any given point in the slope. In summary, the variability of rainfall in the slope is due to the effects of relief, the distance from the sea and the exposure to wind.

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