Response of Basin Morphometric Properties to Deforestation In Upland Watersheds Of Volcanic Regions: Example Of Mount Cameroon

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***Abstract*-The paper focuses on the problem of deforestation and resulting degradation of water yields in volcanic upland drainage basins. It argues that most studies have tended to concentrate on the effects of land use changes on the discharge from drainage basins, ignoring the impact of deforestation on drainage basin areal properties. In order to link hydro-geomorphology and environmental concerns, this study investigates the implications of deforestation and forest conversion to crop plantations, rural and urban settlements on the morphometric properties of these upland drainage basins and the consequences on flood peaks. The paper used a combination of primary and secondary data to establish the impact of deforestation from 1970 to 2006 on the number of stream segments, stream lengths, drainage density, stream frequency, drainage intensity and bifurcation ratio. The study concludes that there were marked spatio-temporal variations exhibited by these parameters in response to deforestation and land use change. Between 1970 and 2006 all drainage basin morphometric properties exhibited a drop which was manifested in the drying up of most 1st, 2nd and 3rd order streams and an increase in flood risks. The study also emphasized the role of forests in influencing the regulatory characteristics of drainage basins composed of very permeable, faulted and jointed geological formations such as volcanic rocks.**

I. Introduction

Forests play an important role in conserving soil and water resources. Several researchers have investigated efforts in the study of drainage basins as physical and biological units. The processes of water transfer in drainage basins have been described and quantified by Kori (1976). Ndenecho *et al.*, (1984) assessed the hydrological implications of land use change on discharge and flood peaks. Danjuma (2003) like Amawa (2001) used descriptive statistics to link drops in water yields from drainage basins in the Bamenda Highlands. Acho-chi (1998) on his part related variations in climate, geology and the rate of forest degradation on spatial and seasonal variations in water yields. Bailey *et al.*, (1979) assessed man's impact on the hydrological cycle. McVean and Lockie (1969) focused on the ecology and land use in uplands. Newson and Robinson investigated the effects of agricultural drainage on upland stream flows. Amawa (2001) examined the effects of deforestation on water yields in granitic upland drainage basins.

The above mentioned studies have tended to focus on the impact of land use change on the stream discharge. The consensus is that with increasing land drainage, conversion of forests to pastures and farmlands and general deforestation, water yields in streams will fall while flood risk increase. These studies largely ignore the morphometric parameters of drainage basins. This study therefore focuses on the effects of forest destruction and conversion of farmlands and human settlements on drainage basin morphometric properties such as number of stream segments, stream length, drainage density, stream frequency, drainage intensity and the bifurcation ratio as an aid to the design of drainage basin management strategies for water conservation in upland watersheds found in mountain regions.

II. The Study Area

The study area is located between latitudes 4015'N and 4040'N and longitudes 9000'E and 9035'E. The drainage basins identified for study constitute the northern and north western slopes of the Mount Cameroon (Figure 1). The basins cover a land surface area of 2048km2. Principal morphological units include volcanic hills, plateaux and sedimentary basins. The climate is equatorial. It is very wet and hot. Rainfall is continues and abundant and ranges from 2000 to 2500mm per year. The drought season lasts less than 3 months. Atmospheric humidity in the wet season is about 85%. Rainfall maxima occur in June, July and August. Mean annual temperatures average 260c with a mean annual range of 2.80c.

The climax vegetation is rain forest. It is situated between 200 and 800m above sea level. This forest over the years has been intensively degraded by timber exploitation, plantations of cocoa, oil palm, Robusta coffee, plantains, food crop fields and urban development. Letouzey (1985) established a quantitative description of the forest.

Primary forests; 39% of the land surface area;Secondary old forest; 50.6% of the land surface area;

Secondary young forest; 0.05% of the land surface area; and Food crop plantations and multi-storey home garden plots; 10.35% of the land surface area.

The forest is fragmented by agro-industrial plantations (rubber and oil palm), food crop farms, rural settlements, urban centres, and commercial exploiters of timber and non-timber forest products. It is a landscape of steep slopes in the middle slope segments with a series of valleys and

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streams, mountains ridges of volcanic origin and deeply dissected slopes with gradients more than 25%. At 30 to 300m elevation above sea level the gradients range from 5 to 8%. These slopes constitute important watersheds. They are source regions for several streams, rivers and springs which support villages and towns. The major river basins are: Yoke, Mandese, Mbo, Meme and Iloani.

The study investigated these watersheds in terms of changes in drainage basin morphometry in response to land use changes from 1970 to 2006. Documented data reveals a progressive degradation of the climax vegetation of rainforest by anthropogenic activities over the years. Figure 2 and Figure 3 present the extent of rainforest degradation between 1970 and 2006. The destruction of the forest is alarming (Courade, 1973; Etuge 1979; Kamanda, 1994; Balgah, 2001; Effange 2006; and Ewane, 2006).

III. RESEARCH METHODOLOGY

Data on relief and drainage, vegetation and land use were established for 1970 and 2006 based on topographical and land use maps at scales of 1/200.000 (Douala / Buea NB – 32 – IV: 1970) established by the National Geographic Institute in Yaounde and the Mount Cameroon Project. The 2006 maps were updated by field observations and the work of Nkemasong (2006). The quantitative investigations of morphometric parameters involved the use of aerial photographs and topographical maps of the area from the National Geographic Institute. These were equally complemented by field observations and the use of the Global Positioning System. The main parameters investigated were:

- Stream frequency (Fs): According to Horton (1945);

$$F_s = \frac{Total\ number\ of\ stream\ segments}{Ba\sin\ area}$$

- Drainage density (D_d): According to Horton (1945):

$$D_d = \frac{Sum\ of\ stream\ lengths}{Ba\sin\ area}$$

- Drainage Intensity (I_d): It is the combined textural effect of the drainage density and stream frequency of the basin. According to Faniran (1975): $I_d = D_d \times F_s$. This index gives a more comprehensive assessment of the extent to which the surface has been dissected by agents of denudation.
- The study also examined some linear properties of drainage basins. These are stream orders and the bifurcation ratio (B_f). Stream ordering or ranking was done after Strahler (1964).

$$B_f = \frac{N}{N+1}$$

Where: N is the number of stream segments of one order, and N + 1 those of the next higher order. This is a measure of the branching within a drainage network.

The above investigated parameters are related to three of the four Hortonian Laws of fluvial morphometry: the law of basin areas, the law of stream length and the law of stream numbers (Whittow, 1984). The unit of data collection is the drainage basin. Ten 5th order drainage basins were studied. The above data were generated for two dates, that is, 1970 and 2006 respectively. The analysis of the data employed descriptive and inferential statistical techniques in order to establish the implications of land use changes on drainage basin aerial properties.

The investigations faced some limitations. Among these were the rough terrain and the largely inaccessible nature of the study area.

IV. DATA PRESENTATION AND DISCUSSION

Table 1: The response of stream numbers and stream length to deforestation

S/N	Name of Basin	Surface Area (Km^2)	*Average Elevation (m)	Number of streams			Total stream length (km)		
				1970	2006	% change	1970	2006	% change
1	Yoke	484	530	262	63	-76	216	180	-16.7
2	Mandese	52	65	44	13	-70.5	44.8	25	-44.2
3	Mbekeke	38	65	21	4	-81	32	16	-50.0
4	Kendongue	96	180	59	16	-72.9	83	50	-39.8
5	Kumba	104	236	54	9	-83.3	90	42.6	-52.7
6	Mambanda	68	121	32	5	-84.4	70	24	-65.7
7	Malende	40	109	46	6	-87	38	10.6	-72.1
8	Mbo	140	305	78	17	-78.2	80	51	-36.3
9	Meme	976	628	376	137	-63.3	406	323	-20.4
10	Iloani	50	10	17	14	-17.6	42	36	-14.3

Average elevation above sea level

Table 1 presents data on the response of stream numbers and stream length to deforestation. The drainage basins experienced a marked drop in the number of streams between 1970 and 2006. From the table, 705 streams or 71.3% of the streams have dried out. From planimetric estimates, 75% of primary forest was degraded during the period. The disappearance of the streams can therefore be attributed to deforestation. The drying up of streams varies with drainage basin. Most streams in the Malende basin (87%), Mambanda basin (84.4%), Kumba basin (83.2%), Mbekeke basin (81%), Mbo basin (78.2%), Yoke basin (76% and Kendonge (72.9%) dried up. These basins have emerging towns such as Kumba, Muyuka, Mbalangi and Ekondo-Titi. The primary forest in these basins has also been reduced by extensive agro-industrial tree-crop plantations. The basins that experienced relatively lower rates of stream disappearance include Iloani (17.6%), Meme (63.3%) and Mandese (70.5%). These basins harbour large areas of protected forests and are mostly occupied by rural settlements practising multi-storey agroforestry farming systems. The visible evidence of the disappearance of streams is the increasing number of dry valleys and abandoned potable water collection points in the Bakundu, Mbonge and Bafaw settlements. The drying up of streams has affected the total length of streams (table 1). Total stream length dropped from 1101.8km in 1970 to 748km in 2006. In 36 years 533.6km of stream length disappeared.

Table 2: The response of drainage density and stream frequency to deforestation.

S/N	Name of Basin	Surface Area (Km^2)	*Average Elevation (m)	Drainage Density (D_d in km/km^2)			Stream Frequency (F_s)		
				1970	2006	% change	1970	2006	% change
1	Yoke	484	530	0.5	0.4	-20	0.5	0.1	-80.0
2	Mandese	52	65	0.9	0.5	-44.4	0.9	0.3	-66.7
3	Mbekeke	38	65	0.8	0.4	-50	0.6	0.1	-83.3
4	Kendongue	96	180	0.9	0.5	-44.4	0.6	0.2	-66.7
5	Kumba	104	236	0.9	0.4	-55.6	0.5	0.1	-80.0
6	Mambanda	68	121	1.03	0.4	-61.2	0.5	0.1	-80.0
7	Malende	40	109	0.95	0.3	68.4	1.2	0.2	-83.3
8	Mbo	140	305	0.6	0.4	-33.3	0.6	0.1	-83.3
9	Meme	976	628	0.4	0.3	-25	0.4	0.1	-75.0
10	Iloani	50	10	0.8	0.7	-12.5	0.34	0.28	-06.7

**Average elevation above sea level*

Table 2 presents data on the response of the drainage density and of stream frequency to land use changes. For all drainage basins the density of streams dropped as most streams dried up. The stream frequency or the average number of streams per unit area of drainage basin dropped by 45.6%, that is, from 0.8km2/km to 0.4km/km2. These changes can largely be attributed to the desiccation of the basins following deforestation. The drop is highest in the Malende basin (68.4%), Mambanda (61.2%), Kumba (65.6%) and Mbekeke (50%), but lower for Iloani (12.5%), Yoke (20%), Meme (25%) and Mbo (33.3%). The high drop in stream density is largely as a result of the high rate of drying up of stream

Table 3: The response of drainage intensity and bifurcation ratio to deforestation

S/N	Name of Basin	Surface Area (Km^2)	*Average Elevation (m)	Drainage Density (I_d) = (D_d x F_s)			Bifurcation Ratio		
				1970	2006	% change	1970	2006	% change
1	Yoke	484	530	0.25	0.04	-84.0	2.7	2.7	0
2	Mandese	52	65	0.81	0.15	-81.5	3.6	1.6	-55.6
3	Mbekeke	38	65	0.48	0.04	-91.7	1.7	3.0	+76.5
4	Kendongue	96	180	0.54	0.10	-81.5	4.0	4.1	+2.5
5	Kumba	104	236	0.45	0.02	-95.6	2.7	1.6	-40.7
6	Mambanda	68	121	0.50	0.04	-92.0	3.0	4.0	+33.3
7	Malende	40	109	1.14	0.06	-94.7	2.2	2.0	-9.1
8	Mbo	140	305	0.36	0.04	-88.9	2.3	2.4	+4.3
9	Meme	976	628	0.16	0.03	-81.3	2.3	2.1	-8.7
10	Iloani	50	10	0.24	0.19	-18.3	2.4	1.8	-25

*Average elevation above sea level

Table 3 presents the changes in the drainage density and bifurcation ratio between 1970 and 2006. The drainage density dropped in all basins. The drop was generally above 80% for all drainage basins except for Iloani where it was as low as 18.3%. This is because this basin experienced the lowest drop in drainage density (12.5%) and stream frequency (6.7%). The high drop in values of the other basins can be explained in terms of their high drops in stream frequency as a result of the destruction of primary forest and urbanization. Field observations point to low water discharges during the short dry season and floods during the rainy season in the highly degraded drainage basins. Deforestation results in an increase in storm runoff, with a consequent liability to increase storm flow peaks downstream. This affects the volume of rainfall received in drainage basins and available as throughflow, soil moisture storage, groundwater storage and base flow necessary for recharging the streams. Lower order streams are most affected. Table shows high space-time variations in stream orders and therefore the bifurcation ratio. From the table, the number of streams per rank and highest rank per drainage basin changed between 1970 and 2006

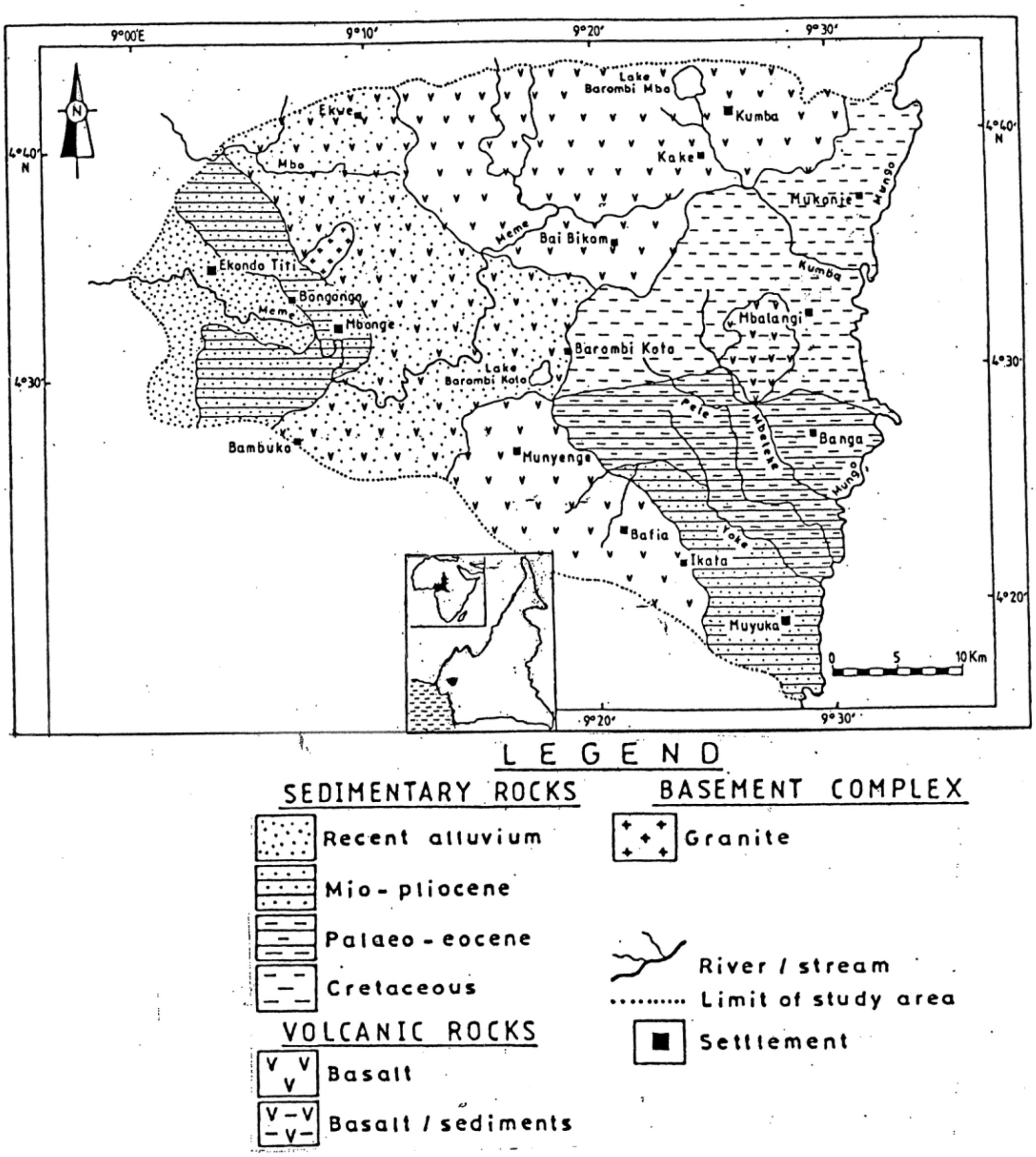

Figure 1: The location and geology of the Northern slopes of Mount Cameroon (Dumort,1968)

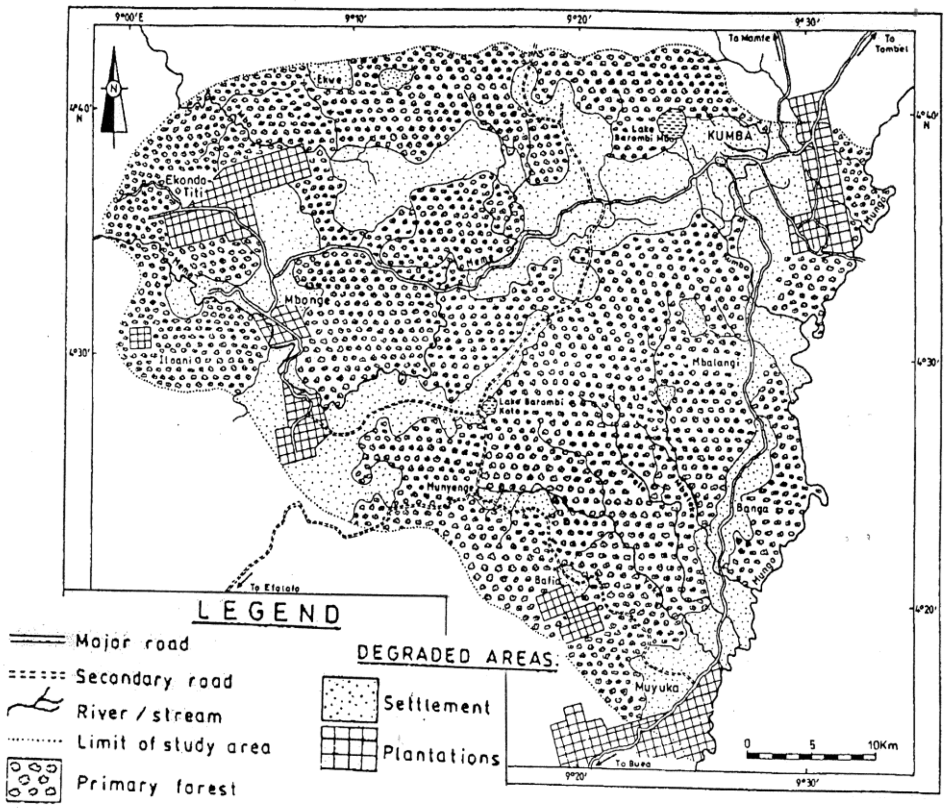

Figure 2: The 1970 land use pattern of the northern slopes of Mount Cameroon Source: National Geographic Institute, Yaounde.

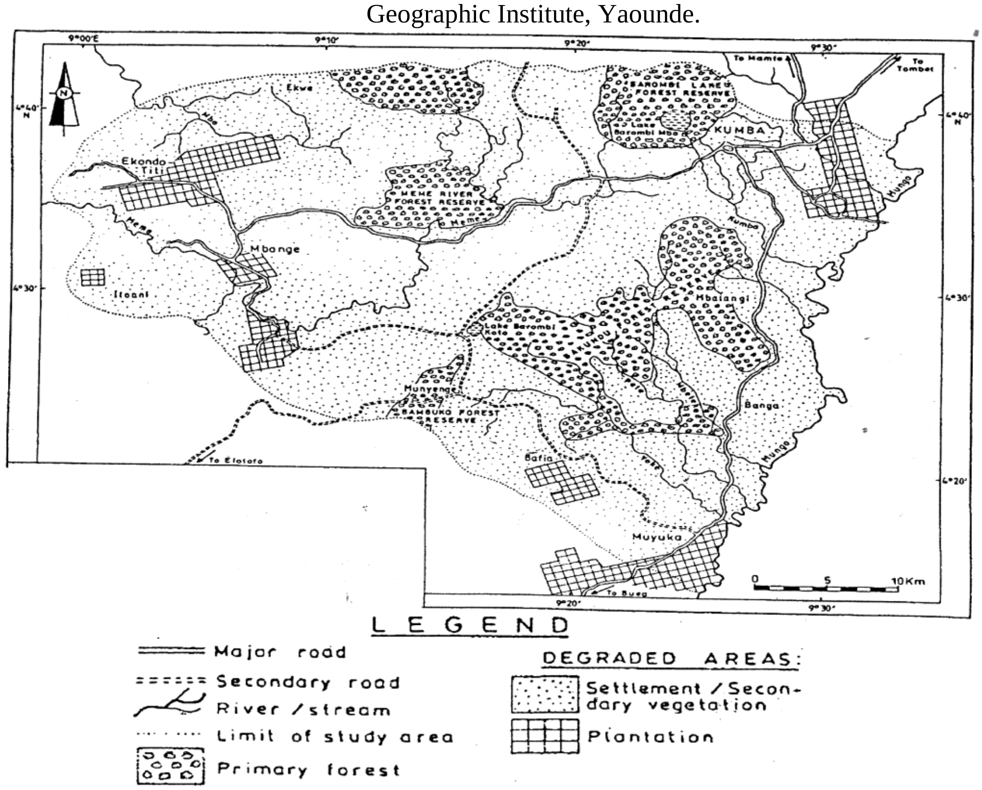

Figure 3: The 2006 Land use pattern of the Northern Slopes of Mount Cameroon (Nkemasong, 2006)

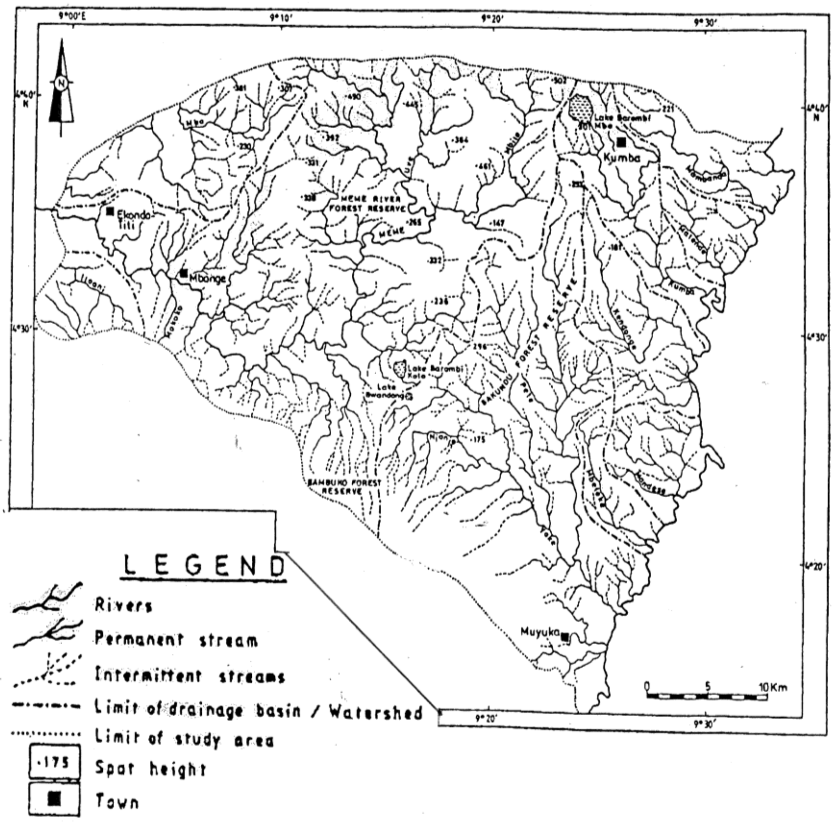

Figure 4: The 1970 drainage network of the northern slopes of Mount Cameroon Source: National Geographic Institute, Yaounde.

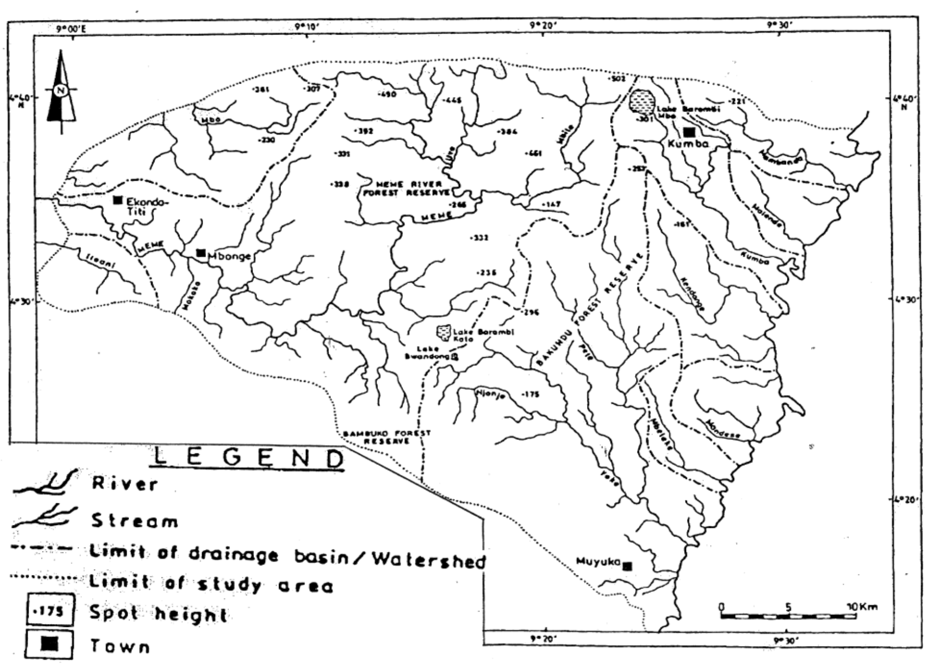

Figure 5: The 2006 drainage network of the Northern slopes of Mount Cameroon Source: Nkemasong, 2006.

Table 4: Changes in stream ordering in response to deforestation

S/N	Basin Name	Basin size (Km^2)	Number of streams / Order									
			Year: 1970					Year: 2006				
			1	2	3	4	5	1	2	3	4	5
1	Yoke	484	142	75	24	17	4	35	18	8	17	4
2	Mandese	52	25	11	7	1	-	8	5	-	1	-
3	Mbekeke	38	11	6	4	-	-	3	1	-	-	-
4	Kendongue	96	35	19	3	2	-	8	7	1	2	-
5	Kumba	104	34	15	5	-	-	5	3	1	-	-
6	Mambanda	68	21	4	7	-	-	4	1	-	-	-
7	Malende	40	28	12	6	-	-	4	2	-	-	-
8	Mbo	140	43	19	6	4	-	11	4	2	4	-
9	Meme	976	262	112	61	27	14	69	35	24	27	14
10	Iloani	50	11	3	3	-	-	9	5	-	-	-
	Total	**2048**	**612**	**276**	**126**	**51**	**18**	**156**	**81**	**36**	**51**	**18**

From table 4, between 1970 and 2006 the number of 1st order streams dropped from 612 to 156 streams (74.5%), 2nd order streams dropped from 276 to 81 streams (70.6%); the number of 3rd order streams changed from 125 to 36 streams (83.2%). Many 1st, 2nd and 3rd order streams have disappeared. The changes in drainage network are presented in figures 4 and 5. Amawa (2001) studied the response of water yield to deforestation in granitic, upland watersheds in the Mbum Plateau of Nkambe. The process of drying up of streams in a drainage basin, he concluded, starts with 1st order streams, followed by 2nd and 3rd order streams.

One of the most important functions of the forests is their effect on regulating the distribution of precipitation reaching a watershed. This effect is the major factor in managing watersheds for stream flow regulation. If the forest cover is destroyed, the multiple benefits of soil and water conservation, flood and land slide prevention are jeopardized. The benefits from a forest are the functional inter-relationships of many natural variables operating within the forest-functions, yet unquantified by science, but generally understood from the results of empirical research and experience. The study made a statistical analysis of changes in morphometric parameters in response to deforestation.

Table 5: Quantitative analysis of changes in morphometric parameters in response to deforestation

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PARAMETER	RANGE		MEAN		VARIANCE		STANDARD DEVIATION		C.V. %	
	1970	2006	1970	2006	1970	2006	1970	2006	1970	2006
Number of Streams	359	12	98.9	28.4	144499.4	1749.9	120.4	41.8	121.8	147.2
Stream Length	374.0	312.4	110.2	75.8	1364.9	9891.5	116.7	99.5	105.9	131.3
Drainage Density	0.6	0.4	0.8	0.4	4.3	1.3	2.2	1.2	275	289.8
Stream Frequency	0.9	0.2	0.6	0.2	6.5`	8.1	2.6	2.8	433.3	1400
Drainage Intensity	1.0	0.2	0.5	0.7	0.7	0.3	2.9	0.6	580	85.7
Bifurcation Ratio	2.3	2.5	2.7	2.5	0.5	0.8	0.7	0.9	25.9	36.0

Table 5 summarizes the results of the quantitative analysis of the changes in morphometric parameters between 1970and 2006. The coefficient of variability for stream numbers changed from 121.8% in 1970 to 147.2% in 2006. Stream lengths equally showed a high coefficient of variability. The direct relationship between stream length and basin size as predicted by Horton's law on basin area and stream length shows that spatial variations in basin sizes and the geology remain the most important factors in explaining the variation of stream length between basins. However changes over the years show that within 36years 353.6km of stream segments disappeared. All the other parameters investigated showed high coefficients of variability. The drainage intensity showed the greatest drop between 1970 and 2006, both in terms of the mean (86%) and the C.V. (58%to 85.7%). The bifurcation ratio did not show marked variations. The range of 2.5 and C.V. of 36% attest to this.

The low drainage density in 2006 indicates that the lag times in stream discharge peaks are subdued. This fact is also proven by bifurcation ratios of 2.5 for 50% of the drainage basins. Apart from Yoke, Mbeteke, Kendongue, Mambanda and Mbo basins, the other basins have experienced marked drops in bifurcation values (generally below 2.5). The implication is a reducing lag time and increasing flash flood peaks (Collard, 1988). The Kumba basin suffers from severe floods while floods in the Mandese and Iloani are a common occurrence.

V. Conclusions

The study showed that there are marked space-time variations exhibited by morphometric properties of drainage basins in volcanic areas. In response to the deforestation or conversion of primary forests to farmlands and human settlements. Moreover, volcanic mountain watersheds in the area exhibit volcanic "karst" drainage characteristics (Underground drainage and high seasonal fluctuations in water yields). This can be attributed to the high permeability of basalts and the presence of faults and joints in rocks. Between 1970 and 2006, all the drainage basin aerial properties experienced a drop in all parts of the study area. Greatest changes were recorded in stream numbers and bifurcation ratios. These changes resulted in a fall in water yields and increased flood risks. The study demonstrates that forests can significantly influence the regulatory characteristics of drainage basins in volcanic areas. However, their influences are complex and inter-related. For example, trees have a function of intercepting part of precipitation. Fallen leaves and the branches retain water which gradually infiltrates the soil. Forest, therefore, create deep storage for soil water. A forest cover and its litter detain surface runoff and allow more time for infiltration. Forest shed reduces surface evaporation and delays runoff. In some instances forest can increase the water available to the watershed by condensing atmospheric moisture. Deforestation does not only cause a reduction in drainage basin discharge as illustrated by previous studies, but also provokes a drop in drainage basin morphometric parameters. The study, apart from linking hydro-geomorphology with anthropogenic processes, also demonstrates that deforestation is one of the causes of desertification. The management of upland watersheds in volcanic regions must therefore strongly consider the maintenance of the indigenous forest cover and its rehabilitation where it has been degraded.

VI. References

1. Acho-Chi, C. (1998) Improved water management systems in the Kano close- settled zone: problems and possibilities. Journal of Applied Social Sciences, Vol. 1, No.1 University of Buea p. 71-80.
2. Amawa, G. (2001) Variations in spring discharge on the Mbum Plateau of the North West Province of Cameroon In: C.M Lambi and E.B. Eze (eds) Readings in Geography. Unique Printers, Bamenda p. 127-141.
3. 3.Bailey, F. et al. (1981) Effect of improved land drainage on river flood flows. In: Flood Studies Report, Institute of Civil Engineers, U. K.
4. Balgah, S. N. (2001) Exploitation and conservation of biological resources in the Mount Cameroon Region, Cameroon, In: C.M. Lambi and E.B. Eze (eds) Readings in Geography. Unique Printers, Bamenda p. 310 - 324.
5. Collard, R. (1988) The physical geography of landscape. Unwin-Hyman. U.K.
6. Courade, G. (1973) Regional Atlas West 1: Commentary and Explanatory notes. ORSTOM, Paris.
7. Danjuma, I. S. (2003) An analysis of watershed degradation in Bamendjim Catchments area and its impact on the landscape. Unpublished Msc. Thesis, Department of Geography, University of Buea.
8. 8.Effange, E. G. (2006) The involvement of local population in protected area management in Cameroon: the case of Bamboko Forest and Bayang-Mbo Wildlife Sanctuary in the South West Province of Cameroon. Unpublished Msc. Thesis, Department of Geography, University of Buea.
9. Etuge, N. J. (1979) The development of Agriculture in Kumba Division: 1910 to 1960 a socio-economic appraisal. Unpublished postgraduate diploma thesis. Department of Geography, University of Yaounde.
10. Ewane, B. E. (2006) Optimizing the management of dynamic ecosystems: The case of the Southern Bakundu Forest Reserve in the South West Province of Cameroon. Unpublished Msc. Thesis, Department of Geography, University of Buea.
11. Faniran, A. (1975) Rural water supply in Nigeria's basement complex: A study in South Western Nigeria. The Nigerian Geographical Journal Vol. 25, No. 1-2, p. 205-209.
12. Hollis, G.E. (1979) Man's impact on hydrological cycle in the United Kingdom Geo. Abstract Ltd. Norwich.
13. Horton, R.E (1945) Erosional development of streams and their drainage basins: hydrophysical approach to quantitative morphology. Bulletin of the Geological Society of America, No. 56 p. 275-370
14. Kamanda, B. (1994) The Southern Bakundu Forest Reserve Project: The rural economic survey, preliminary Draft. ITTO/ONADEF, Yaounde.

15. Kori, K. (1976) Managing forests for water supplies and resource conservation. In: Hydrological techniques for Upstream conservation. F.A.O. Rome p. 1- 12
16. Letouzey, R. (1985) Notice de la carte phytogeographie du Cameroun. Vol. 2 - 5. Institut de la carte International du Toulouse, Toulouse.
17. Mevean, D. N. and Lockie, J. P. (1969) Ecology and land use in upland Scotland, Edingurgh University Press, Edinburgh.
18. Ndenecho, E. N; Barnes, I; Hundy, P, et al (1984) land use changes in the Afon Garno catchment area and their hydrological implications. Unpublished Msc. Field Project. Silsoe College, Cranfield Institute of Technology, Bedford.
19. Newson, M.D. and Robinson, M. (1983) Effects of Agricultural drainage on upland stream flow: case studies in Mid Wales. Journal of Environmental Management, Vol. 17 p. 333-348.
20. Nkemasong, N.A. (2006) Hydro-climatic variations and impacts on the population of adjoining Northern Slopes of Mount Cameroon. Unpublished Msc. Thesis, Department of Geography, University of Buea.
21. Strahler, A.N. (1964) Quantitative geomorphology of drainage basins and channel networks. In: V.T Chow (ed). Handbook of applied hydrology, section 4. 11. McGraw-Hill, New York.
22. Whittow, J. B. (1984) The Penguin Dictionary of physical geography. Penguin Books, Britain.