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# DISCHARGE LIQUID, VECTOR OF TOTAL SUSPENDED SEDIMENT (TSS) OF MAYO TSANAGA AT MAROUA (FAR NORTH CAMEROON)

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## Abstract

Mayo Tsanaga is the Cameroonian part of the Lake Chad Basin ungauged. The knowledge of discharge is essential for the design of hydraulic structures and for hydrological risk prediction. The objective of this study is to evaluate discharge, total suspended sediment and the deduction of the specific sediment yield. The exploration of velocity fields and the differences in the pre and post filtration filter weights were adopted as a methodology. The results revealed that annual discharges of Mayo Tsanaga at Maroua from 2012 to 2014 are respectively 1.94 ± 0.38 $m^3$ /s, 2.18 ± 0.43 $m^3$/s and 0.89 ± 0.17 $m^3$/s. Mayo Tsanaga discharge will be used when sizing the second bridge on this river. Mayo Tsanaga's daily mean concentrations of TSS are respectively 429.384 mg/L ± 12.88 for the year 2013 and 17.45 ± 0.52 mg/L for the year 2014. The corresponding specific sediment yield (SSY) of Mayo Tsanaga are 34.92 $t.km^{-2}.year^{-1}$ in 2013 and 0.57 $t.km^{-2}.year^{-1}$ in 2014. The SSY expresses the amount of ground lowering for the whole catchment.

***Keywords:*** Watershed; Discharge; Total Suspended Sediment; Specific Sediment Yield.

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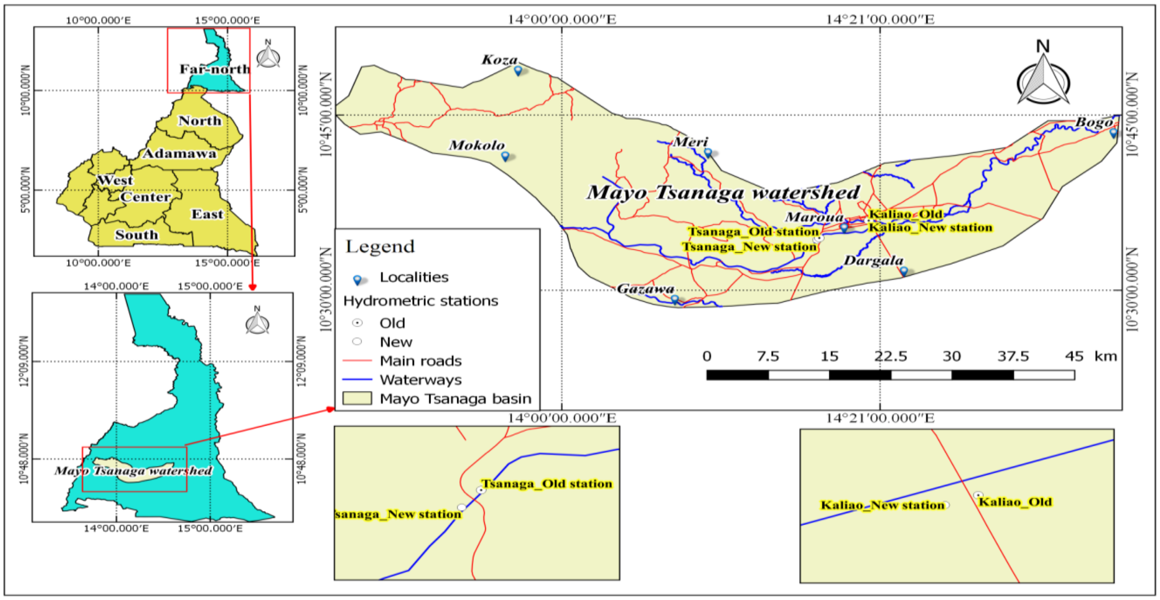
## 1. Introduction

From the elemental runoff on the slopes to the fluvial flow, running water was a powerful specific sediment yield agent, acting mainly by ablation and transport. Rivers carry the evidence of degradation of the slopes they drained. These were total suspended sediment (TSS) and total dissolved solid (TDS). The estimation of these river TSS concentrations, coupled with their discharge, led to the determination of the specific sediment yield rate and chemical alteration in the basin considered. In countries where hydrological services operated normally, discharge data and other physicochemical parameters of water such as TSS were measured continuously and published annually in hydrological yearbooks. The discharge data thus collected were of vital importance as they were essential for the design of hydraulic structures (dams, bridges, dykes) and hydrological risk forecasts such as floods, which threatened recurrently the watershed of Mayo Tsanaga. Total suspended sediment data were equally important in that they allowed the assessment of the specific sediment yield on the slopes of the basin, to evaluate qualitative aspects of water resources, to study the diffusion of pollutants*[1]*; *[2]*. In the long term, these sediments yields could also be indicators of a possible change in environmental conditions, including the climate *[3]*. Larger research programs aimed at understanding the erosive processes and material balances (solid and dissolved) transported at the scale of major river basins had been developed in the southern part of the country. Unfortunately, in the far north of Cameroon, where the study area was located, total suspended sediment and discharge were no longer measured after the departure of the colonizers in the 1970s.

This work was therefore part of a context characterized by a complete lack of hydrological data, an absence of hydrological services, a context in which each researcher managed with his own resources for work whose results were of national interest. In such an environment, any research undertaken even punctual was essential. Measurements of suspended solid transport were too often limited to the duration of the program that generated them in the southern part of the country, whereas such studies required a long follow-up. The history of all previous punctual work carried out in the watershed *[4]*, *[5]*, *[6]*, *[7]* showed that all were realized at the basin outlet and yet it was important that discharge and TSS measurements were made throughout the basin in accordance with the WMO *[8]*.

## 2. Study area



Sources: Hydrosciences Monpellier, GPS survey and SOGEFI 2017 data base

The Mayo Tsanaga is located in the Cameroonian part of the Lake Chad basin in the Far North Cameroon in the Sahelian zone between 10 ° 30 'and 10 ° 52' north latitude and 13 ° 43 'and 14 ° 37' east longitude. It was a contrasting basin with an upstream western half distinguished by its mountainous and inselberg massifs, which rose to 1400 m, formed of crystalline and volcanic rocks and an eastern half downstream in the Logone Plain, a tributary of Lake Chad. The hydrographic network was made up of Mayo Tsanaga and its numerous tributaries, the most important of which were on the left bank the Mayo Kaliao, the Mayo Fogom, the Mayo Bao and on the right bank the Mayo Goudoulou and the Mayo Mododrof *[9]*.

This watershed was subject to a dry tropical climate alternating with a long dry season (October-May) when the intertropical front was further south and a rainy season (June-September) when it was in the North. Mean interannual rainfall was 792.13 mm for a 70-year long data series (1927-2013). It oscillated between 530.1 mm for deficit years (1984) and 1333 mm for surplus years (1991). The number of rainy days fluctuated between 91 days (1954) and 38 days (1990) for an average of 59 days. The geological characteristics made it possible to distinguish the massifs and inselbergs formed of crystalline rocks (granites of anatexie and syntectonic granites) more or less old. The Mount of Maroua was made up of green volcanic rock. The formations of the Piedmont area consisted of loose rocks of detritic origin originating from the erosion of the massifs *[10]*.

Soils in the Mayo Tsanaga watershed were very diverse *[11]*. In the highest parts, between Mokolo and Gazawa, we found the mother rock, unaltered, with its detrital arenas and lithosols little evolved, poor in clay and organic matter but essentially sandy (80%). Between Gazawa and Maroua, there were little evolved soils along the valley of Mayos Tsanaga and Kaliao. These were soils derived from soft materials (alluvium or pediments), sandy-clayey with almost always quartzose gravel. There were also piedmont soils at the beginning of evolution: they were sub arid gray soils. Finally, other piedmont soils were vertisols, evolved, consisting of dark clays, calcareous or not, and slightly sandy.

## 3. Methodology

The methodology adopted consisted of three components namely: the exploration of the speed fields, the differences of the weighings of the filters before and after filtration and the calculation of the hydrometric indices.

Mayos discharge gauging was done by float for heights less than 30 centimeters on the gauge scale. The Mayo gauging station was divided into several sections and then the water velocity in each section was measured using the float.

The discharge at the station was calculated by the sum of the discharge of different sections according to the following formula: $Q = \sum_{1}^{n} V_n \times S_n$ where Q is discharge at the measuring station, Vn: water velocity in section n, Sn: Water surface at the water section n. When the water level at the gauge was greater than 30 centimeters, the velocity fields were explored using the curent meter. The speed of the Mayo varied from the left bank to the right bank and from the surface to the bottom, several verticals had been retained for the measurement of average speeds along the cross section. At the same time, the measurement of the depths and the distance between two consecutive verticals made it possible to calculate the elementary surface using the medium section method. The product of the average velocity and the elementary surface gave the elementary discharge. The sum of the elementary discharge from the left bank to the right bank allowed the discharge of Mayo. The field studies consisted of taking water samples daily after a rain event during two successive hydrological years 2013 and 2014. The water samples were generally taken at the same vertical where the speeds of the water nets were the most important. Indeed, in Cameroon's major rivers, this rather simple and practical sampling technique gave satisfactory results and was quite close to the full gauging method *[12]*, [*13]*.

In the laboratory, the different water samples were filtered with cellulose acetate 0.45 μm membranes using a polycarbonate Millipore filtration unit. The particulate fractions retained on the filter were dried in the oven at 105°C and, after cooling in a desiccator, weighed on a Mettler type balance. The TSS concentration was calculated from the weight of the sediment and the volume of filtered water. The determination of the TSS contents was done by difference of weight of the loaded filter and the virgin filter brought back to the volume of water taken *[14]*. Quantitation of the TSS fluxes required knowledge of both the concentrations of suspended solids and the volumes of water flowing.

Mean TSS concentrations were calculated using the equation:

$C_{x,p}$ (mg.l$^{-1}$) $= \sum_{i=1}^{n} CiVi / \sum_{i=1}^{n} Vi$ where $C_{x,p}$ (mg.l$^{-1}$) = average concentration weighted by water volumes; Ci = instantaneous concentration of MES during sampling; Vi = volume of water flowing during period i separating two successive withdrawals.

The suspended sediment yield (SY) exported annually from a drainage basin was usually calculated from the volume weighted mean concentration and the total volume of flow ($V_{TY}$) for the year as follows:

SY (t.year$^{-1}$) = $C_{x,p}$ (mg.l$^{-1}$)* $V_{TY}$(L)
The specific sediment yield (SSY) characteristic of the physical denudation rate was obtained by the relation: SSY (t.km$^{-2}$.year$^{-1}$) = SY/A(km$^{2}$).

The indices studied here measured the differences between the variables studied compared to an average over a long period. They made it possible to differentiate the years when the flow was deficient or surplus. The indices of annual discharge or hydrometric indices were calculated according to the formulas proposed by *[15]*: $X_{ij} = (Q_i – m_i) /S_i)$, where $Q_i$ is an average annual discharge of station i; $m_1$ is the inter-annual average of the discharge at station i over the reference period; Si is the annual standard deviation of discharges and Xij is the annual average index of discharge at station i for year j.

## 4. Results and Discussions

### 4.1. Mayo Tsanaga’s Discharge at Maroua

The gauging data allowed drawing the calibration curve of the figure 1. In this figure the data of water level collected during three hydrological years 2012, 2013 and 2014 at the frequency of three times a day to minimize the losses of the hydrological information were projected.

From the projection on the rating curve, the daily discharge were deducted which made it possible to have the monthly and annual discharges. Thus, the average monthly discharge in 2012 for August and September were respectively 8.52 $m^3/s$ and 14.81 $m^3/s$, the annual discharge was 1.94 $m^3/s$. For the year 2013, the average monthly discharge in July, August and September were respectively 3.83 $m^3/s$, 7.04 $m^3/s$ and 15.30 $m^3/s$. The 2013 annual discharge was 2.18 $m^3/s$. The average monthly discharge in 2014 for the months of August and September were 5.41 $m^3/s$ and 5.32 $m^3/s$, respectively. The annual discharge was 0.89 $m^3/s$. Thus the flows on this watershed were marked by an interannual variability characteristic of the tropical dry zone to which it belonged. Since these annual discharges were lower than the different discharges obtained during the work of *[16]* and *[17]*, the hydrometric deficits of the eight years that Mayo Tsanaga in Maroua was gauged in its history were evaluated.

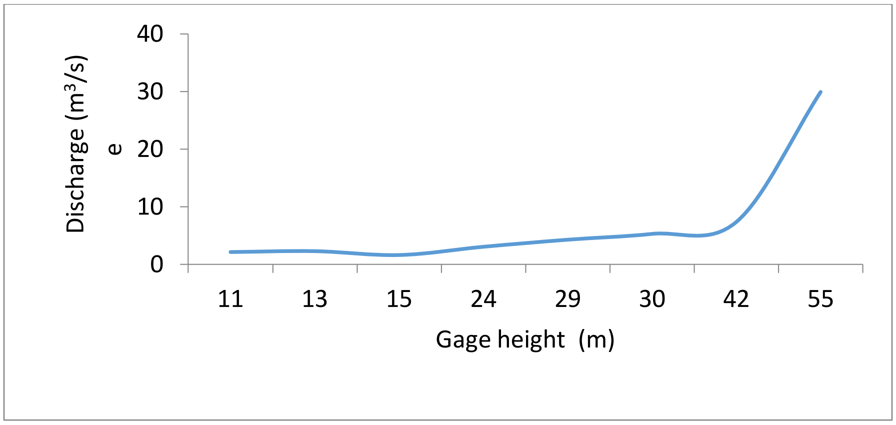


Figure 1: Calibration curve of Mayo Tsanaga in Maroua (low water) in 2013

Comparing the flows of the years 2012, 2013 and 2014 with those of the years gauged by the colonizers (period 1954-1977 with gaps), we recorded the annual hydrometric deficits that appeared in table 1. These hydrometric deficits had a close correlation with the rainfall deficits obtained by *[18]* in the Sudano-Sahelian zone of Cameroon during the last five decades.

Table 1: Hydrometric deficits of Mayo Tsanaga

| | **Hydrometric deficits** | | |
|---|---|---|---|
| Years | 2012 | 2013 | 2014 |
| 1954 | -2,76 | -2,35 | -7,21 |
| 1955 | / | / | / |
| 1966 | -1,73 | -1,43 | -4,95 |
| 1967 | -2,89 | -2,46 | -7,48 |
| 1968 | -2,4 | -2,02 | -6,41 |
| 1969 | -2,04 | -1,70 | -5,62 |
| 1970 | -1,83 | -1,52 | -5,17 |
| 1977 | -2,51 | -2,12 | -6,62 |

Flow monitoring was done for three hydrological years, 2012, 2013 and 2014 at the Mayo Tsanaga Maroua station. The annual hydrographs of instantaneous discharge were representative of the Sahelian regime with fast floods more or less close together. The start date of the flows varied widely from one year to the next. Runoff started at the end of July for the years 2012 and

2014 whereas in 2013 runoff started in late June. The annual hydrographs of Mayo Tsanaga daily discharge (figures 2) were representative of the Sahelian regime with fast floods more or less close together. In 2012, the hydrograph showed a single peak corresponding to the day when runoff and overflow floods were observed (03 september) in the watershed. The 2013 hydrograph showed five peaks that corresponded to the highest discharge of the year that generated the runoff floods. During the 2014 low water year, only one peak was recorded, which also caused runoff flooding. The start date of the flows varied widely from one year to the next.
The flows began at the end of July for the years 2012 and 2014 whereas in 2013, the flows began at the end of June and they lasted two or three months depending on the speed of the hydrological response But according to the work of *[19]* the flows of Mayo Tsanaga at Maroua were slightly earlier in 1954, 1968 and 1969. Once the flow started, the flow was permanent across the width until the end of the season unlike Mayo Kaliao.

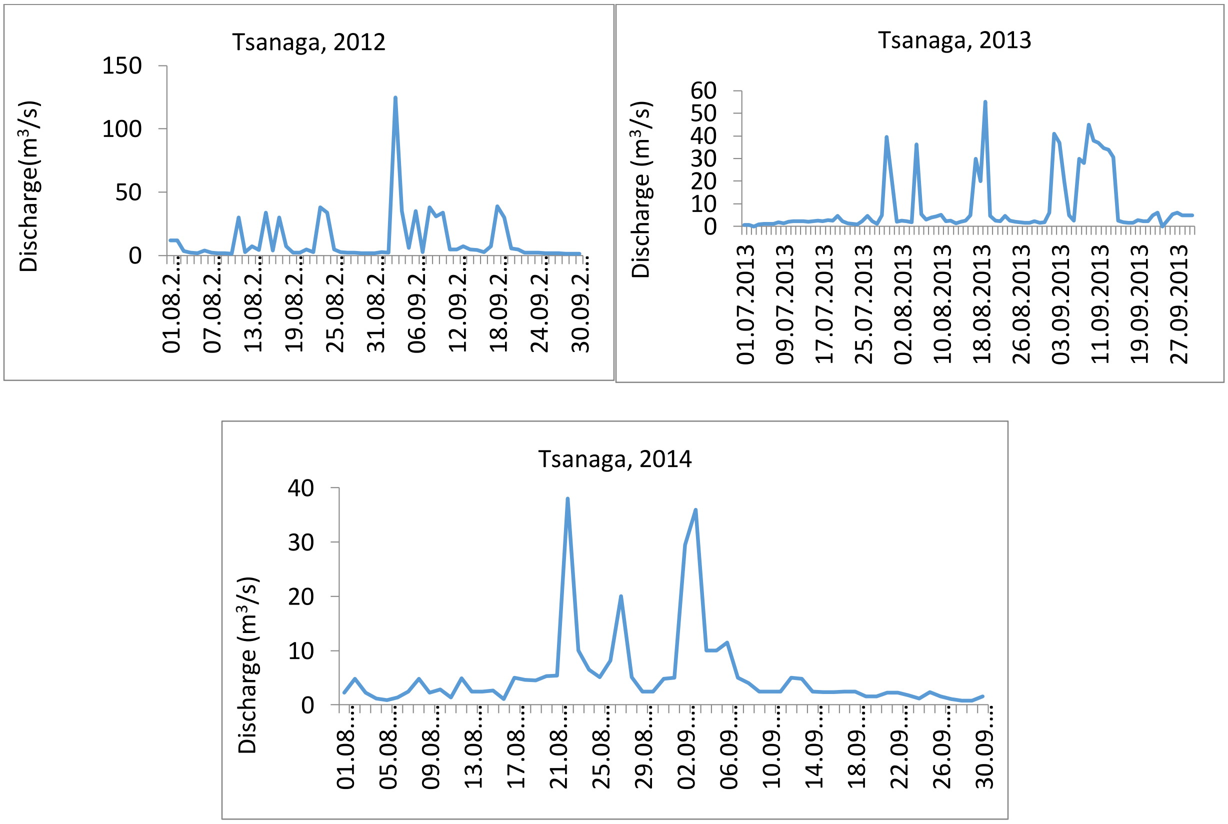


Figure 2: Annual hydrographs of instantaneous discharge of Mayo Tsanaga

### 4.2. Mayo Kaliao's Discharge at Maroua

Mayo Kaliao gauged and collected water level data were also used to plot the Mayo calibration curve (figure 3). The average monthly discharge of the month of July 2012 was 2.68 $m^3/s$, it varied between 24.5 and 0.1 $m^3/s$. The monthly discharge of the month of August of the year 2012 oscillated between 125 and 0.1 $m^3/s$ for an average discharge of 10.30 $m^3/s$. In September, the discharge fluctuated between 230 and 0.2 $m^3/s$, the average discharge was 13.03 $m^3/s$. The annual flow in 2012 was 2.16 ± 0.32 m3 / s. For the year 2013, the average monthly discharge of the month of July was 6.75 $m^3/s$, the maximum being 23.5 $m^3/s$ and the minimum 0.11 $m^3/s$. The

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August discharge oscillated between 195 and 0.11 $m^3/s$, the average discharge was 24.71 $m^3/s$ and in September the average discharge was 7.97 $m^3/s$ and it varied between 31 and 0.2 $m^3/s$. The 2013 annual discharge was 3.28 ± 0.49 $m^3/s$. The average monthly discharge of the month of July 2014 was 6.4 $m^3/s$, it varied between 74 and 0.1 $m^3/s$. The average in August 2014 (9.03 $m^3/s$) fluctuated between 72 $m^3/s$ and 0.2 $m^3/s$. The annual discharge in 2014 was 1.67 ± 0.25 $m^3/s$.

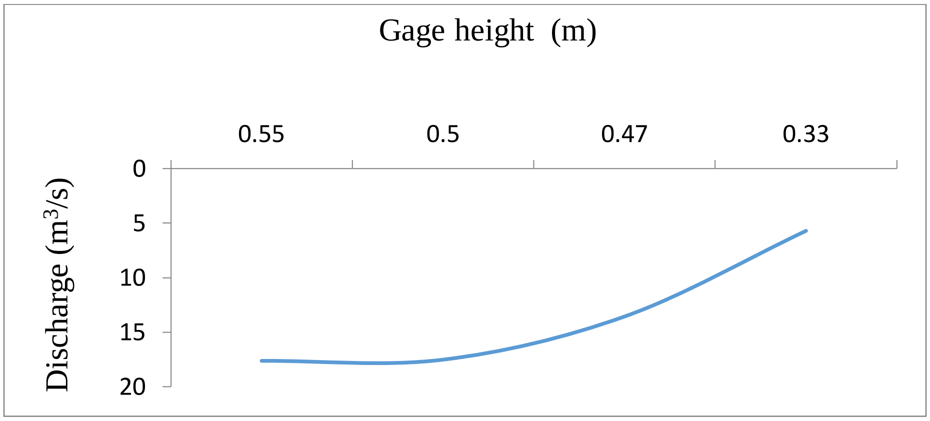

Figure 3: Calibration curve of Mayo Kaliao in Maroua (low water) in 2013

The annual hydrographs of daily discharge of Mayo Kaliao (figure. 4) showed two peaks in 2012, the largest of which corresponded, as for Mayo Tsanaga, to the runoff and overflow floods that were observed (03 September) in the watershed. The hydrograph of 2013 showed a peak and that of 2014 two major peaks. Mayo Kaliao flows generally began in late June for the three years of study.

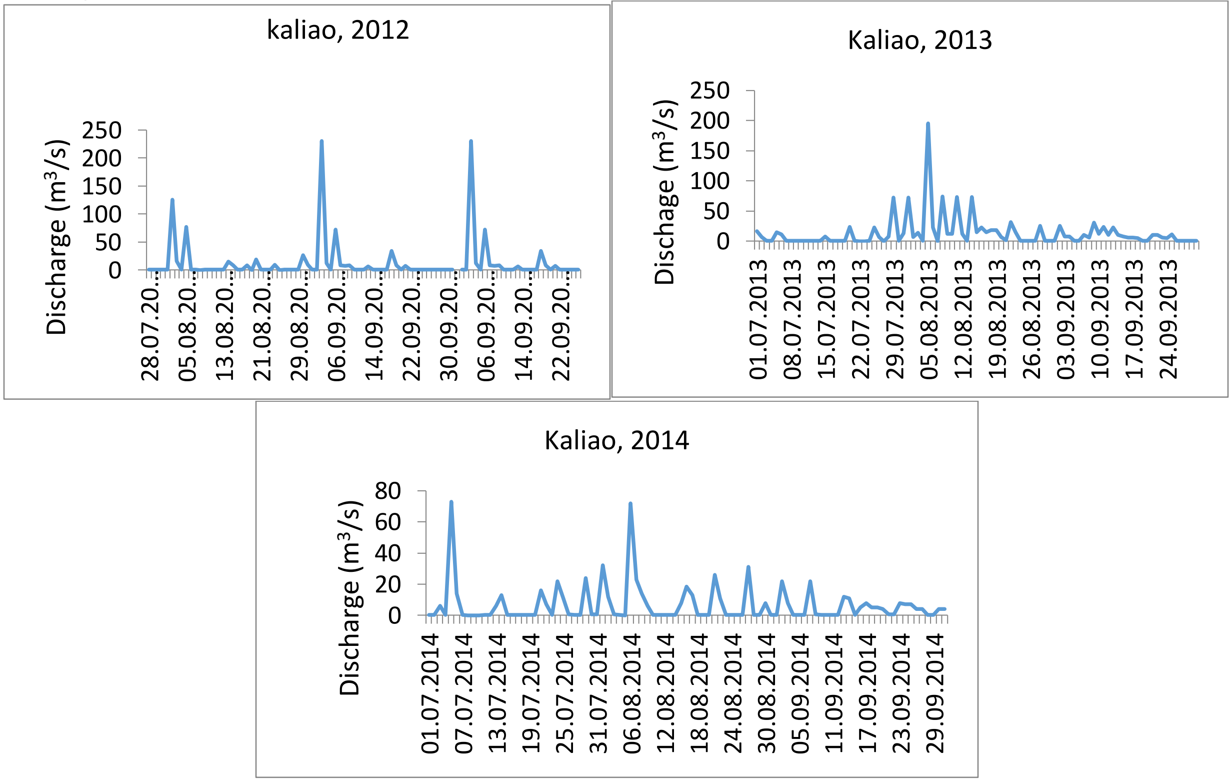

Figure 4: Annual hydrographs of instantaneous discharge of Mayo Tsanaga

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### 4.3. Hydrometric Surpluses and Hydrometric Deficits of Mayo Kaliao at Maroua

The discharge of the period of study were compared to the modules of the period 1966-1970, the only years whose Mayo was gauged in its history in Maroua. Two deficit years and three surplus years were recorded, unlike the Mayo Tsanaga where hydrometric deficits had been recorded exclusively (table 2**)**. These hydrometric surpluses and deficits of Mayo Kaliao were of the same order as those obtained by *[20]*. The hydrometric surpluses of Mayo Kaliao were in contradiction with the results of *[21]* who estimated that rainfall had decreased in the Sudano-Sahelian zone of Cameroon over the last five decades. However one could explain these hydrometric surpluses by the phenomenon of urbanization which waterproofs the ground thus increasing the flow since the sub-basin of Mayo Kaliao was strongly urbanized.

Table 2: Hydrometric Surpluses and Deficits of Mayo Kaliao

| | **Hydrometric surpluses** | | |
|---|---|---|---|
| Années | 2012 | 2013 | 2014 |
| 1966 | + 0.51 | + 0.60 | + 0.28 |
| 1967 | + 0.14 | + 0.29 | - 0.37 |
| 1968 | +0.51 | + 0.60 | + 0.28 |
| 1969 | + 0.40 | + 0.51 | + 0.041 |
| 1970 | +0.36 | + 0.48 | - 0.017 |

### 4.4. Daily Variations of the TSS of Mayo Tsanaga and Kaliao

The results obtained from the daily point samples allowed to calculate the daily mean and extreme concentrations of the two Mayo during two hydrological years 2012/2013 and 2013/2014. Samples were generally very charged just after the rain event in the case where the hydrological response was positive. As time passed, the turbidity decreased due to the dilution and the lack of water supply. For Mayo Kaliao, daily TSS concentrations ranged from 0 to 920 mg/L, an average concentration of 270 ± 8.1 mg/L for the 2013 hydrological year. The highest concentrations were recorded at the beginning of the season (figure 5) which suggested that the main origin of the TSS in this Mayo was the erosion of the soils of slopes and soils valley bottom. These high concentrations were due to the mobilization of soils, made pulverulent by the long dry season, and by the prolonged trampling of animals. Subsequently, the concentrations decreased gradually over the rest of the rainy season, due, among other things, to the development of the vegetation, which was then sufficiently dense thus playing a protective role in reducing the mechanical action of the raindrops on the ground. The soil whose erodibility had been appreciably diminished after the first. For the 2013/2014 hydrological year, the average Mayo Kaliao TSS concentration was 98.56 mg/L, ranging from 10 to 1343.6 mg/L. These results were consistent with those obtained by *[22]*. For Mayo Tsanaga, daily TSS concentrations in 2013 ranged from 180 to 926 mg/L, an average concentration of 429.384 mg/L ± 12.88 for the 2013 hydrological year. The year 2014 was a low-water year therefore the consequence was the small number of samples taken. This year had an average SS concentration of 17.45 ± 0.52 mg/L, the extreme concentrations being 8.8 mg/L for the minimum and 51.2 for the maximum.

The maximum concentrations of Mayo Kaliao SS for the year 2014 was higher than that of Mayo Tsanaga certainly because of the early start of the rains upstream of the basin where the altitude was high thus generating the precipitation that pushes the plant cover that protected the slopes.
The highest concentrations of TSS were recorded in late July and August (figure 5). Thus the main origin of the Mayo Tsanaga TSS was the erosion of the channel, erosion of the banks and the bottom of Mayo. In late July and August, the Mayo already had enough water, its bed was no longer in equilibrium with the conditions of the flow. The physical action of water caused the removal of material from the banks when current velocity and turbulence developed an erosive power capable of overcoming particle weight and cohesion. Mayo's bed was no longer in equilibrium with the conditions of the flow.

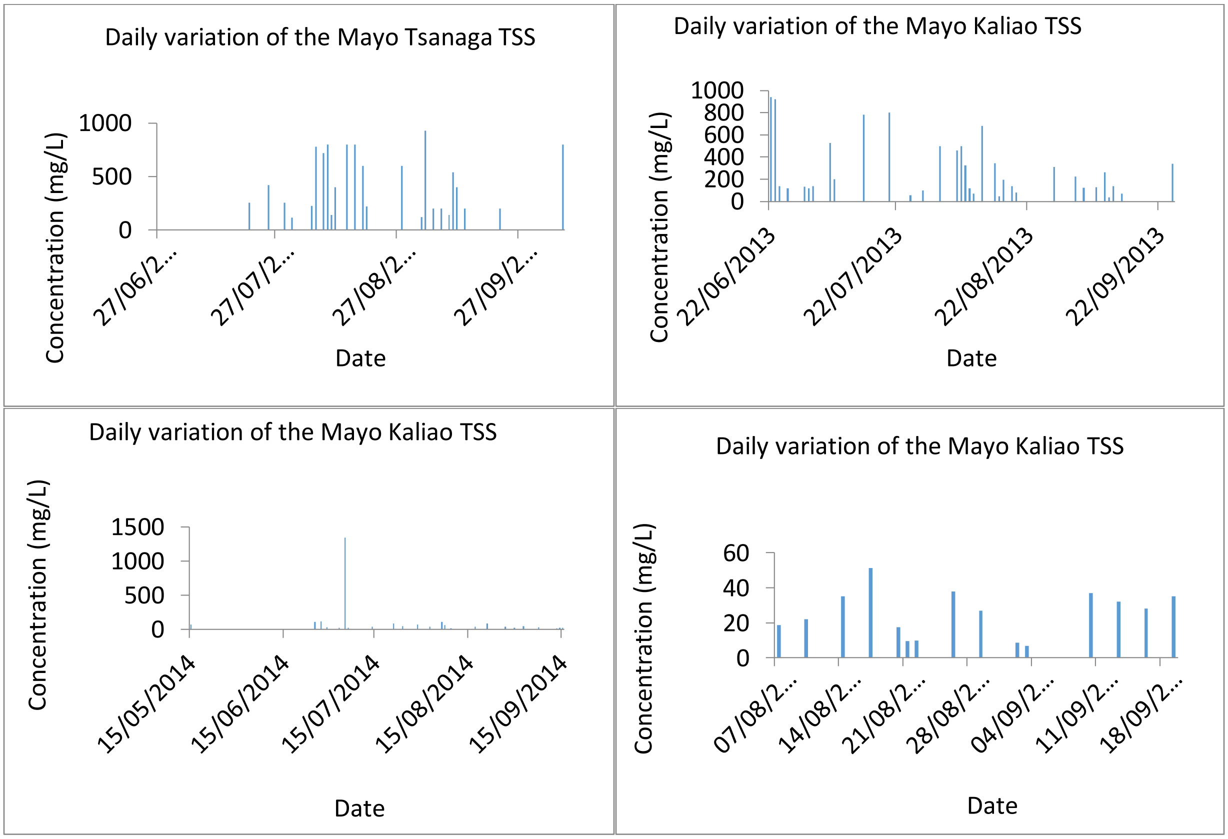

Figure 5: Daily variation of Mayo Tsanaga and Mayo Kaliao TSS

### 4.5. Annual Balance of Exports of Mayos Tsanaga and Kaliao in Maroua

The suspended sediment yield (SY) in a section of a river was defined as the amount (mass) of TSS passing through this section over a unit of time *[23]*. It could be calculated at a time t (instantaneous solid discharge) or over periods of variable duration depending on the objectives pursued (flood, day, month, year). For the two years of study of Mayo Kaliao total suspended sediment, the annual suspended sediment yields (table 3) were respectively 27931.11 $t.year^{-1}$ for the year 2013 and 2517.82 $t.year^{-1}$ for 2014. The specific sediment yield (SSY) was 18.91 $t.km^{-2}.year^{-1}$ in 2013 and 5.08 $t.km^{-2}.year^{-1}$ in 2014. This specific sediment yield was of the same order as the results obtained in comparable morpho-climatic contexts by *[24]* in the upper Niger and its main tributary Bani. The very low water quality of the year 2014 would explain why the specific sediment yield of this year was one third of that of 2013.The specific sediment yields of Mayo Kaliao at Maroua in 2013 was 355 km$^2$ and was greater than that obtained by *[25]* in the Sanaga to Ebebda with an area of 76 817 km$^2$ in 1995, 1996 and 2005 because the basin of Mayo Kaliao was in Sahelian zone where the vegetation cover was weak so the soil was little protected than the basin of Sanaga was in zone of dense forest.

Table 3: Suspended sediment yield and specific sediment yield of Mayo Kaliao at Maroua

| **Years** | **Discharge (m$^3$/s)** | **Runoff depth (m)** | **TSS (g.L$^{-1}$)** | **SY (t.year$^{-1}$)** | **SSY (t.km$^{-2}$.year$^{-1}$)** |
|---|---|---|---|---|---|
| 2013 | 3.28 | 0.19188 | 0.09856 | 27931.11 | 18.91 |
| 2014 | 1.67 | 0. 29137 | 0.01745 | 2517.82 | 5.08 |

The suspended sediment yield (SY) of Mayo Tsanaga were respectively 80859.51 t.year$^{-1}$ for the year 2013 and 1341.83 t.year$^{-1}$ for 2014. The corresponding specific sediment yield (SSY) were 34.92 t.km$^{-2}$.year$^{-1}$ in 2013 and 0.57 t.km$^{-2}$.year$^{-1}$ in 2014 (table 4). This specific sediment yield (SSY) remained low compared to those obtained at the basin outlet in Bogo by *[26]*. This SSY was of the same order as the results obtained in comparable morpho-climatic contexts by *[27]* in the Upper Niger and its main tributary Bani. As for the Mayo Basin, the very low rainfall of 2014 with very little rainy event would explain why this year's specific sediment yield was insignificant.

Table 4: Suspended sediment yield and specific sediment yield of Mayo Tsanaga at Maroua

| **Years** | **Discharge (m$^3$/s)** | **Runoff depth (m)** | **TSS (g.L$^{-1}$)** | **SY (t.year$^{-1}$)** | **SSY (t.km$^{-2}$.year$^{-1}$)** |
|---|---|---|---|---|---|
| 2013 | 2.18 | 0.08135 | 0.4293 | 80859.51 | 34.92 |
| 2014 | 0.89 | 0.03321 | 0.01745 | 1341.83 | 0.57 |

## 5. Conclusion

The Mayo Tsanaga Basin is the Cameroonian part of the Lake Chad Basin where discharges were not measured even total suspended solids. In short, it was a hydrologically abandoned watershed since the departure of the colonizers in the 1970s. The final objective of this work was the determination of the specific sediment yield of Mayo Tsanaga and its tributary Mayo Kaliao at Maroua from discharge and total suspended solid.The exploration of velocity fields using the current meter and the differences in the weighing of the filters before and after filtration were adopted as a methodology to achieve this objective. The gauged results showed that annual discharges of Mayo Tsanaga at Maroua were respectively 1.94 ± 0.38 m$^3$/s in 2012, 2.18 ± 0.43 m$^3$/s in 2013 and 0.89 ± 0.17 m$^3$/s for the year 2014. Annual discharges of Mayo Kaliao at Maroua were 2.16 ± 0.32 m$^3$/s in 2012, 3.28 ± 0.49 m$^3$/s in 2013 and 1.67 ± 0.25 m$^3$/s in 2014. There were two deficit years and three surplus years, unlike Mayo Tsanaga where only the hydrometric deficits had been recorded.For Mayo Tsanaga, daily total suspended solid concentrations in 2013 ranged from 180 to 926 mg /L, an average concentration of 429.384 mg/L ± 12.88 for the 2013 hydrological year. An average concentration of total suspended solid was recorded in 2014 17.45 ± 0.52 mg/L, extreme concentrations being 8.8 mg / L for the minimum and 51.2 for the maximum.The corresponding specific sediment yield of Mayo Kaliao at Maroua were 18.91 t.km$^{-2}$.year$^{-1}$ in 2013 and 5.08 t.km$^{-2}$.year$^{-1}$ in 2014. The specific sediment yields of Mayo Tsanaga at Maroua were 34.92 t.km$^{-2}$.year$^{-1}$ in 2013 and 0.57 t.km$^{-2}$.year$^{-1}$ in

2014. The very low runoff of the year 2014 would explain why the specific sediment yield of this year was one third of that of 2013.

The highest concentrations of total suspended solids were recorded at the end of July and in August, when the Mayo already had sufficient water, its bed was no longer in equilibrium with the flow conditions. Thus, the main source of Mayo Tsanaga suspended solids concentrations was channeled erosion, bank erosion and Mayo bottom erosion. For its Mayo Kaliao tributary, the highest concentrations were recorded at the beginning of the season, suggesting that the main source of suspended solids concentrations in this Mayo was erosion of the slope soils.

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