

Chemical Weathering and Mechanical Erosion of The Batéké Plateaus in Congo Brazzaville: Evaluation from Measurements Taken at Four Gauging Stations

Jean Bienvenu Dinga

National Institute of Research in Natural and Exact Sciences (IRSEN),
Ministry of the Scientific Research, the OUA Avenue Total market,
Baongo, Brazzaville, Congo, and Formation Doctorale en Sciences
De l'Environnement, Faculté des Sciences et Technique,
Université Marien Ngouabi, Congo

Monique Petitdidier

Université Versailles St-Quentin ; Sorbonne Universités,
UPMC Univ. Paris 06 ; CNRS/INSU, LATMOS-IPSL,
11 Boulevard d'Alembert, 78280 Guyancourt, France

Dominique Nganga

Formation Doctorale en Sciences de l'Environnement,
Faculté des Sciences et Technique, Université Marien Ngouabi, Congo

ABSTRACT

The Batéké plateaus, in Congo Brazzaville (Republic of Congo) is part of the Congo basin, in the longitude range from 14°30' East to 16°30' East and in the latitude range from 1°30' South to 4°30' South. Four stations were set up on the Alima, Léfini, Nkeni, and Djiri rivers, respectively. Those rivers are the main tributaries of the Congo River on its right bank. The measurements obtained at those stations permitted to study the seasonal, inter-annual variations and the annual budget of material transportation coming from those four tributaries. This work reports the results acquired during ten years of research (1998-2008) on the hydrological and hydrogeochemical plateaus Batéké in Congo Brazzaville. He aims to: to take stock of the outputs to the ecosystem of major outfalls (stations Djiri to Djiri of Mbouambé on Léfini of Gamboma on Nkeni and Tchikapika on Alima); specify the modes of transport minerals in rivers to recognize the operation of large entities upstream (rocks and forest ecosystems homogeneous) and define their contribution to the overall transport in the Congo River basin. Evaluation results indicate that mechanical erosion of 204.6 10³ tons per year and a chemical alteration of 731,6 10³ tons per year on all plateaus Batéké. The contributions of the entire ecosystem as a percentage in the Congo Basin are; Fluid intake: 9% of annual volume; Suspended solids: 8% of the total load, and Dissolved Solids: 7% of the total load.

Keywords: Hydrology, Hydrochemistry, Transportation of matter, plateaus Batéké, Congo Brazzaville

INTRODUCTION

Equatorial and tropical regions are characterized by periods of intense precipitations. The water level in the rivers increases and some inundations may occur (ref 2009). The rain that falls brings into rivers dissolved or suspended mineral and organic matters. A part may be disintegrated due to rain mechanical effect especially on mineral; this effect generating mechanical erosion. Organic and mineral matters may be dissolved and transported like dissociated ions by the river; this effect creating chemical deterioration of the environment.

Many studies have been carried on the Congo River and some of its tributaries. Molinier (1979), took from January 1978 to February 1979 monthly samples from the Congo River. He tried at the same time to diversify the sampled points along the measure sections. Different from what is observed in quiet rivers, his results show that along a vertical in the Congo River the concentrations of the suspended matter are decreasing from the surface to the bottom while the concentrations of dissolved material are more or less the same. Olivry et al. (1988, 1989) set up a program of systematic measurements of dissolved and in-suspension matters exported into the Congo River basin, got a long time series of data and then improved the estimations. During 11 years (1998-2008) the PEGI-BGP program (Programme d'Etude de la Géosphère Intertropicale -Opération Grands Bassins Fluviaux -URL), was devoted to the study of the inter-tropical geosphere with a specific emphasis on the large river basins (Moukolo, 1998). In the Batéké plateaus, in Congo Brazzaville (Republic of Congo), four stations were set up on the Alima, Léfini, Nkeni, and Djiri rivers, respectively. Those rivers are the main tributaries of the Congo River on its right bank. The measurements obtained at those stations permitted to study the seasonal, inter-annual variations and the annual budget of material transportation coming from those four tributaries. Several studies carried out on the Congo pouring basin, showed a weak mineralization of the water and provided an estimate of the different organic contributions (Moukolo et al., 1993). The measurement protocol implemented permitted to get a more reliable and precise set of data to estimate the concentrations of suspended material than the previous measurements. Furthermore, this unique long set of data will permit to find a relationship between the solid matter flux and the hydrologic regime.

This present study is focused on rivers in the area of the Batéké plateaus. This place is chosen as it is the location of the big river sources and is considered to be the water tower of the Congo Brazzaville, RC. As a consequence, one national plant of drinkable water supply and one hydro-electric plant are installed in the Batéké plateau area. Even if some estimations have been already done on the dissolved and suspended mineral and organic matters by using the PEGI-BGP data for the Batéké plateau rivers, there is no estimation of the transport of both mineral and organic matter, especially taking into account the organic dissolved carbon (DOC) and nitrogen (DON), obtained since 2005 by the Shimadzu method (Krupa et al., 2011). The estimation and analysis of the dissolved and suspended matter permits:

- to assess the geochemical characteristics,
- to quantify the erosion,
- to characterize the chemical deterioration,
- to understand the distribution of those materials inside various river flows and also

- to determine the quality of the water and its survey.

In part 2, a short description of the Batéké plateau area is given. Part 3 concerns the hydrological characteristics of the 4 selected basins, Alima, Léfini, Nkényi and Djiri basins averaged over 2 or 3 decades of observations. Part 4 is devoted to the methodology implemented to analyze the water samples and to characterize the dissolved matter. Part 5 gives the mineral and organic concentrations, the mechanical erosion and chemical weathering, and the hydrochemical facies relative to the 4 selected rivers. Finally, all the results lead to concluding remarks and future developments.

THE BATÉKÉ PLATEAU AREA

Geographical Location

The Batéké' plateaus are located in the Northern part of the Congo Brazzaville (RC) in the longitude range from 14°30' East to 16°30' East and in the latitude range from 1°30' South to 4°30' South (Figure 1). The Batéké plateau area is limited in the Eastern part by the Congo river, in the Western part by the Chaillu massif mountain range, in the Northern part by the Alima valley, and in the Southern part by the Djoué river. The whole Batéké plateau area is around 47,800 km² (Figure 1).

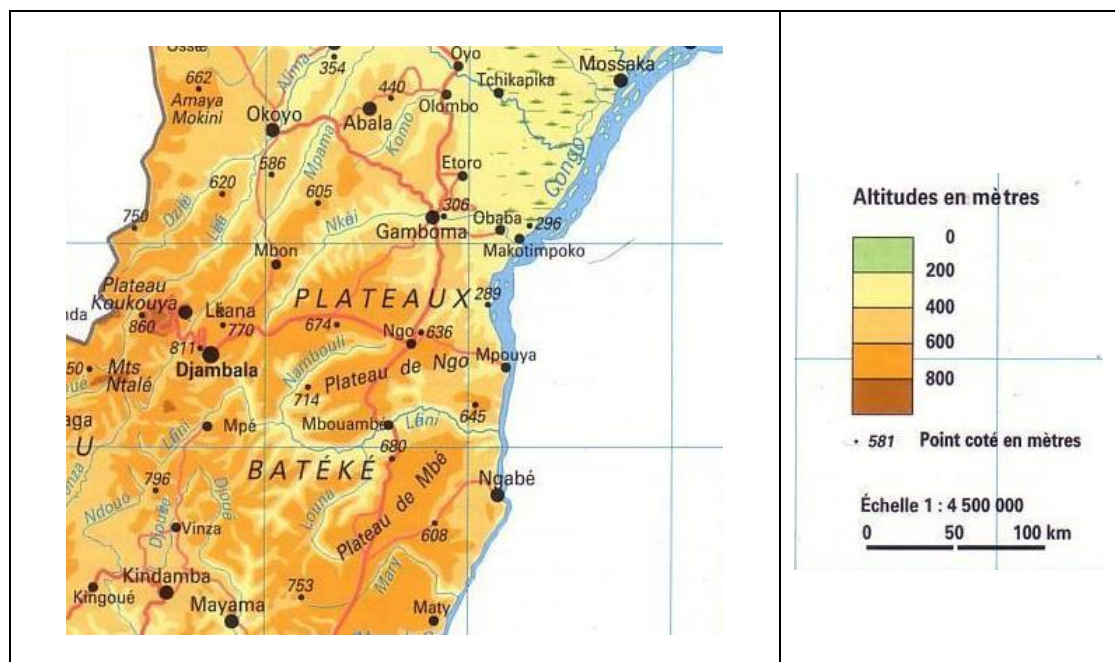


Figure 1: geographic situation of the batéké Plateaus (Vennetier et al, 2002)

This figure presents the topographic situation of the study site, it highlights the altitudes going up to 800 m, the watercourses represented in blue prove that the four sub-basins considered in this study (Djiri, Léfini, Nkeni and the Alima) have their sources in the Batéké plateaus and flow into the Congo River (in blue on the far right of the map)

The Djiri, Léfini, Nkényi and Alima rivers divide the plateau area in four big units, Mbé plateau, Nsa-Mpouya plateau, Djambala and Koukouya plateaus.

Physiographic Context

All the Batéké plateaus are formed of very porous sand with high capacity of water retention from the Kalahari Tertiary age, Series of the Batéké plateaus. The rivers flow at the bottom of deep valleys on the soft sandstones and the clays of the Stanley-Pool, series dated from Cretaceous.

The pedology is represented by the impoverished-iron and yellow soils, on sandy or sandy-clayey material. In some secondary valleys, we may find podzolic iron soils on sandy material. The main valleys are constituted of the mineral hydromorph soils with pseudo-Gley and Gley, under the vegetation of forest galleries sometimes very large.

Concerning the geomorphology, the four plateaus whose area varies from 450km² for the smallest one, the Koukouya plateau, to 13,000km², the largest one, the Mbé plateau, have an altitude in the 600-860m range. Their surface is lightly undulated including often closed depressions sheltering pools (Gatsou pool) or dry valleys. The plateaus are surrounded by abrupt sandy ledges, going on by the long slopes which are concave that ends at the bottom of the current valleys from 300 to 400 m. As a matter of fact, the Batéké plateaus are cut up into thousands of bare hills; among them a hydrographic system with temporary outflows taking place and drawing a real maze (Vennetier and al, 2001)

The typical vegetation of the Congo sub-basins is a savanna of *Loudétia demeusii*, that can turn on big spaces into *Hyparrhénia* and *Trachypogon* savanna. The vegetation in the river valley consists of mesophil forests.

Climate

The climate is humid tropical of the southern transition (Samba Kimbata, 1992). The meteorology is complex due to the large Congo basin, mountains around, and the influence of the inter-tropical convergence zone (ITCZ) moving Northwards up to 20°N in the boreal summer and back in the South in the boreal winter (Nganga and Samba, 2011). There are a dry season very marked from 4 to 5 months (June to September) and one rainy period (October to May). The most abundant rainfalls take place in November-December. During the rainy season in February-April, a small decrease of the rainfall is observed. The mean annual temperature is around 25°C; however, during the dry season the temperatures are around 12°C and around 35°C during the rainy season. The mean annual rainfall is around 1400mm; the mean annual relative humidity is in the 80% - 87% range.

HYDROLOGY OF THE POURING BASINS

Watershed under Study

The plio-quaternary series of the Batéké plateaus are mainly made of sand and soft sandstone. Those formations constitute the most important aquifers in the Congo Brazzaville (RC). The Batéké plateaus are considered as being the country's water tower. The big rivers such as the Niari, the Ogooué, the Djoué, the Djiri, the Léfini, the Nkéni and the Alima take their spring from there. The quantification of the mechanical erosion and the characterization of the chemical deterioration of the Batéké plateaus were done from the measurements achieved on the four most representative pouring basins, i.e., Djiri, Léfini, Nkéni and Alima. Table 1 indicates the geographical coordinates of the hydrometric stations at each river. We have series of data of more than half a century at the hydrometric stations, Djiri located at Djiri, Léfini at

Mbouambé, Nkéní at Gamboma, and Alima at Tchikapika. The measurements of the surface level and the flow are taken twice a day. A part of the data has been taken in the framework of the PEGI-BSG programme and afterwards completed by the GRSEN. Those long time-series of good data for those stations are in particular due to a regular survey and maintenance of the instruments permitted by the station locations close to a road. For this study only a part of this long time-series is taken in order to get consistent observations and chemical analysis.

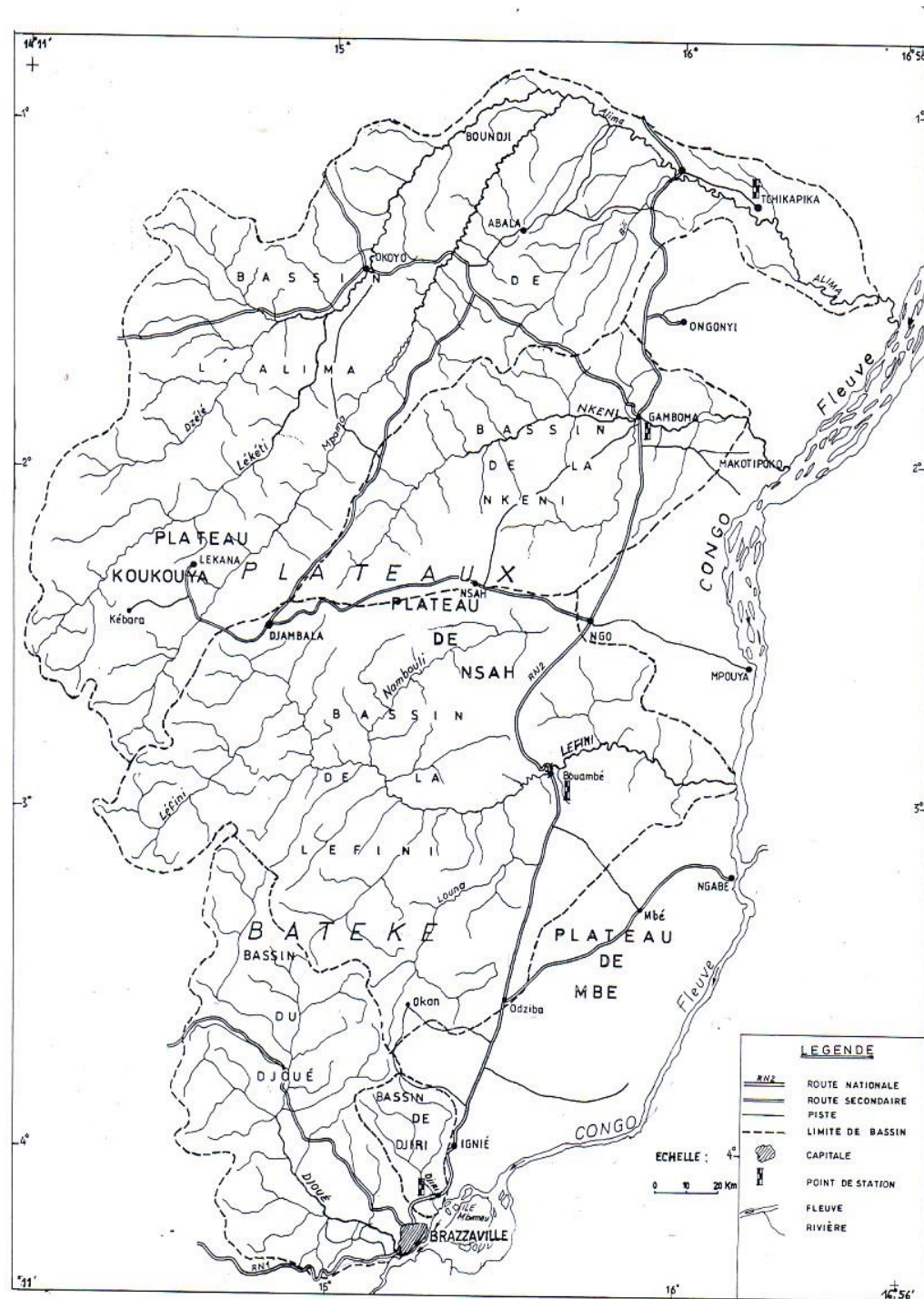


Figure 2: Situation of the pouring basins

Table 1: Geographical coordinates of hydrometric stations installed on the Alima, Léfini, Nkéni and Djiri rivers

Station	Tchicapika	Mbouambé	Gamboma	Djiri
River	Alima	Léfini	Nkéni	Djiri
Latitude	1°18' S	2°55' S	1°54' S	4°7' S
Longitude	16°10' E	15°38' E	15°51' E	15°18' E
Altitude	310m	310m	303.6m	278m

Table 2 summarizes the time period selected and the mean hydrological characteristics of each site. The basins are classified according to their area. The time series for the Djiri basin is shorter and, in some periods, data are missing (cf. Fig. 8.). The mean rainfall is more important in the Léfini basin than in the Nkéni and Alima basins. But in the Djiri basin the rainfall is only around 5% less than the ones in the other 3 basins. Even if the surface and the mean discharge are very different from one basin to the others – from 24.4 m³/s pour Djiri basin, 209m³/s pour Nkéni basin, 414m³/s pour Léfini basin and 537m³/s for Alima basin- the other parameters, listed on Table 1, are very close in a range less than 10%. It is explained by the fact that those rivers took their sources in the same, the Batéké plateaus and their basin substratum is very similar.

Table 2 Characteristics of the pouring basins (Moukolo et al., 1990)

Characteristics	Alima at Tchicapika	Léfini at Mbouambé	Nkéni at Gamboma	Djiri at Djiri
Area km ²	20070	13500	6200	853
Number of years (y)	1952-1982(31y)	1949-1982 (34y)	1952-1982 (31y)	25 years
Rainfall (mm)	1878	1917	1855	1800
drainage (mm)	931	999	1053	968
Flow shortage (mm)	947	918	802	850
Specific discharge (l.s ⁻¹ .km ²)	29.5	31.7	33.4	27
Flow Coefficient	49.6%	52.1%	56.8%	47%
Mean discharge (m ³ .s ⁻¹)	593	428	207	24.4 (1975/1980)

Flow Law

Figure 3 to Figure 6 represent the mean monthly variation of the mean flow in m³/s for each 4 stations over the whole set of data.

The mean monthly flow is similar for the Nkéni, Léfini and Alima basins. From January to March the mean flow is constant, a small increase is observed in April and May, from June a decrease is observed with minimum values in July August during the dry season, the mean discharge starts its increase in September to reach in November and December the highest values. For the Djiri basin the mean monthly flow is the same except in August, that may be considered as an “anomaly”, because it is relatively high.

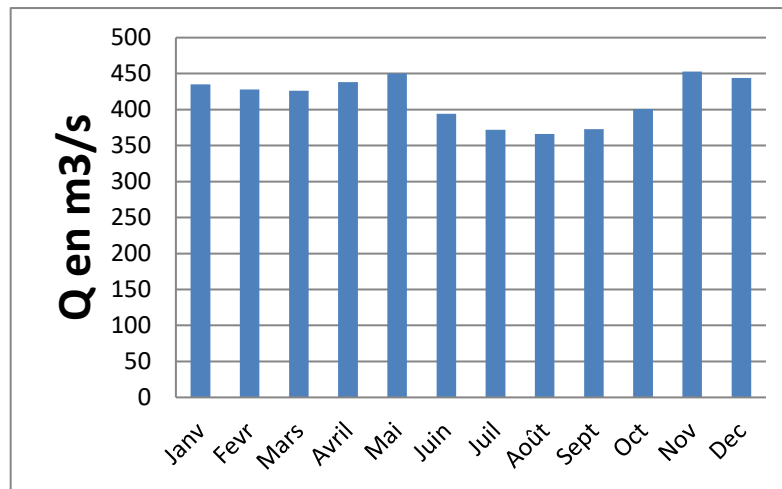


Figure 3: hydrologic law from the Léfini to Mbouambé (1951-2007)

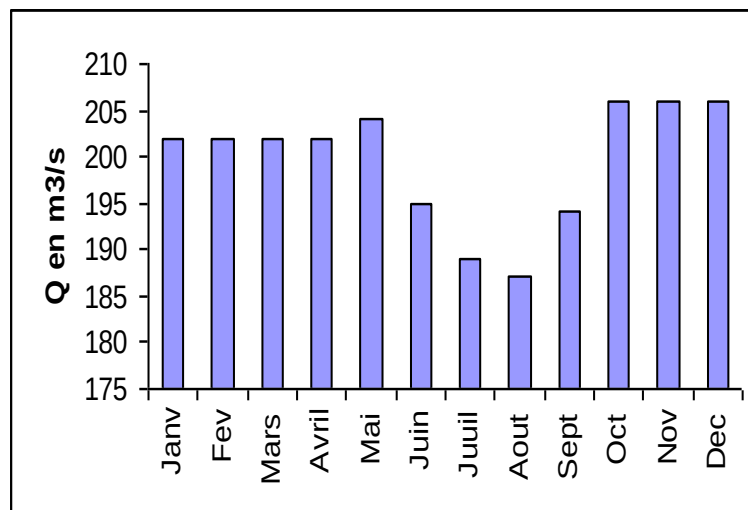


Figure 4: hydrologic law from the Djiri to Djiri (1983 - 2007)

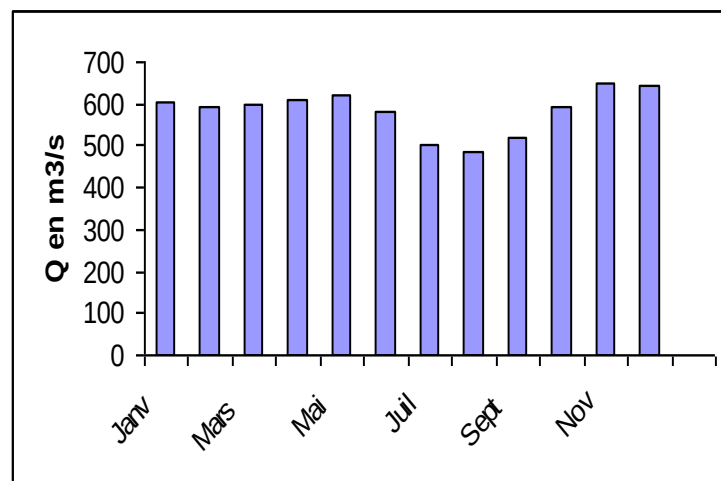


Figure 5: hydrologic law from the Alima to Tchikapika (1952 - 2007)

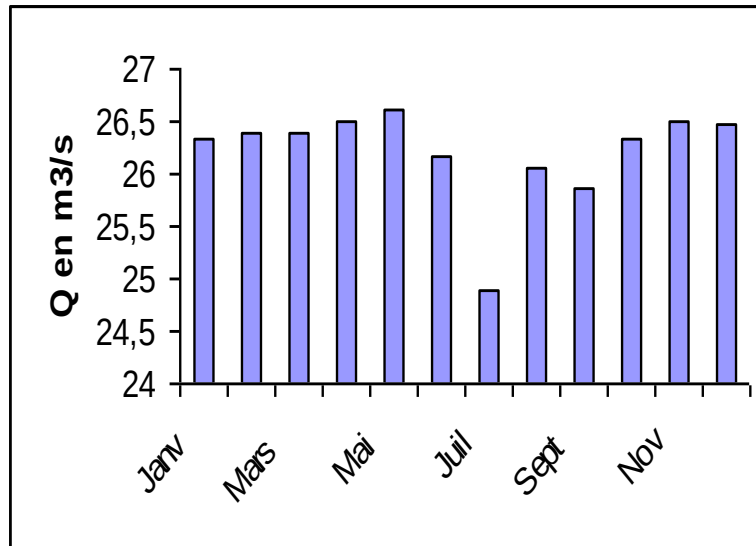


Figure 6: hydrologic law from the Nkény to Gamboma (1952 - 2007)

These figures present the histograms of the evolution of the average monthly flows according to the months, the histogram of figure 3 shows that the average monthly flows of the Lefini at Bouambé vary very little, this gives the Lefini river its hydrological stability compared to the other tributary rivers (right bank) of the Congo River.

The impact of the main rainy season is observed on the mean monthly flow variation with its maximum in November and December. The impact of the rainfall increase in April-May is also observed on the mean monthly flow variation with the increase in April and May. The dry season is clearly observed with a minimum of the mean monthly flow in July and August for the Nkény, Lefini and Alima Basins. As noted previously in the Djiri basin in August the mean flow is relatively high, different from the behaviour of the other basins.

The Nkény, Lefini and Alima Basins are located in the upper part of the Batéké plateaus while the Djiri basin is in the lower part of the Plateaus. Furthermore, the Djiri basin is relatively close the Congo River, that it is not the case of the other basins. Then one possible explanation of this fore-mentioned “anomaly”, is that it may be due to a flow coming from the Congo River.

Except this “anomaly” in the dry season, the flow variation is in agreement with the rainfall one.

Inter-Annual Variability of The Flow

The flows (figures 7 to 10) are very regular for those streams whose water supply is mainly insured by the drainage of the deep layer inside the Batéké sands. The coefficient of inter annual irregularity K_3 , the ratio between the mean annual discharge maximum and the mean annual discharge minimum, is equal to 1.1 for the Lefini basin, the most regular stream of this area.

The coefficients of variation have been estimated and found to be around:

- 6% around an average of 584.3 m³/s for the Alima
- 16% around an average of 414 m³/s for the Lefini, ;
- 9% around an average of 204.5 m³/s for the Nkény;
- 2% around an average of 26 m³/s for the Djiri;

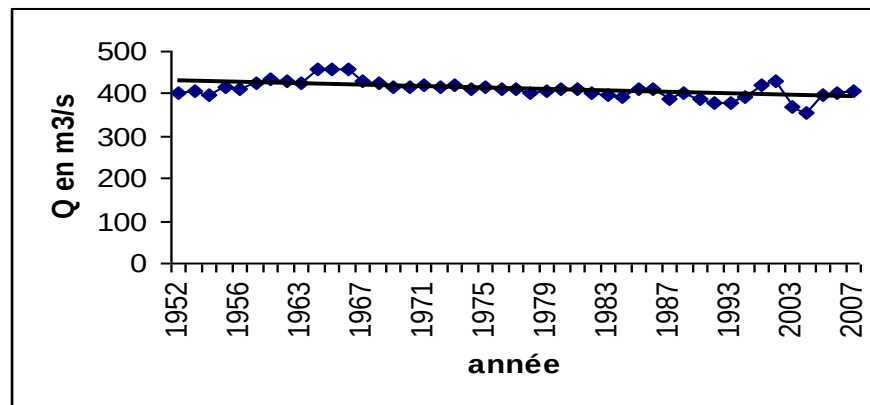


Figure 7: Interannual variability of the flows (resort from Léfini to Mbouambé)

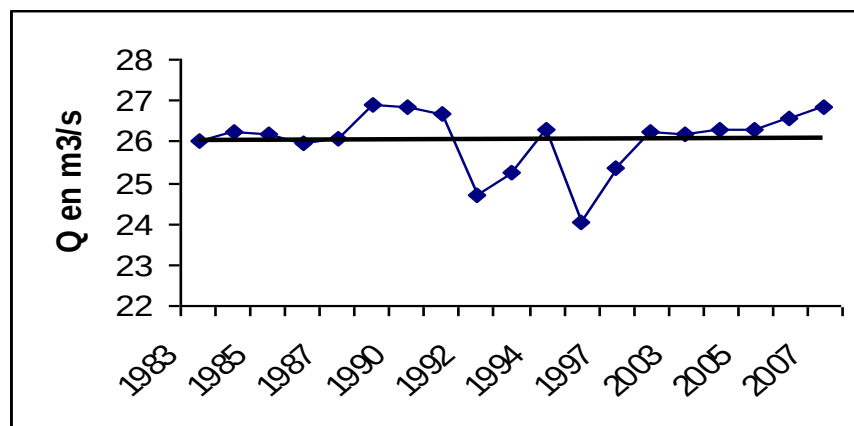


Figure 8: Flows interannual variability (resort from Djiri to Djiri)

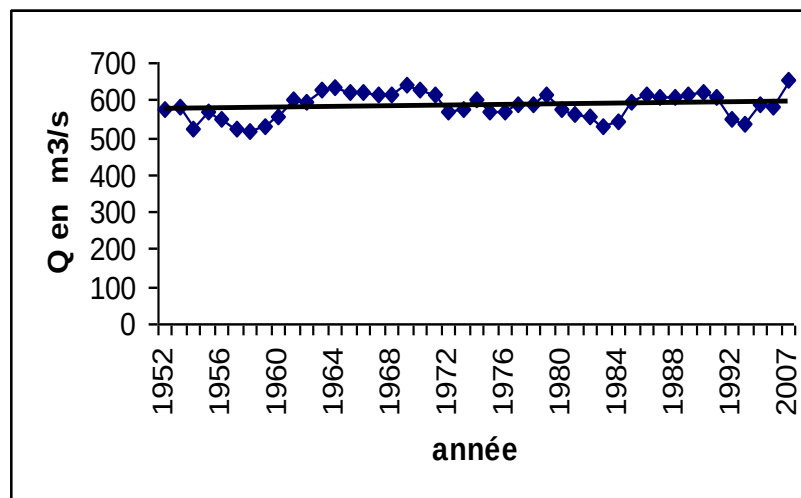


Figure 9: Flows interannual variability (Alima to Tchikapika)

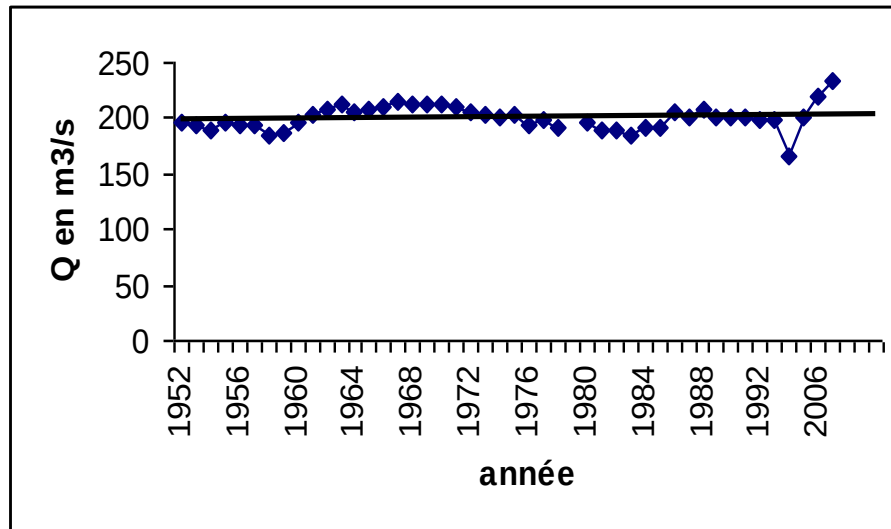


Figure 10: Flows interannual variability ((Nkényi to Gamboma))

Conclusion

The streams that take their sources in the Batéké plateau area have the most regular regime among all the streams of the Congo basin right bank as the coefficients of variation, less than 20% for all 4 Batéké plateau rivers, point it out. The drainage of the underground water, the only alimentation of those rivers, may be the explanation of such a behavior. The flow regime is according to the precipitation one.

ANALYSIS OF MINERAL AND ORGANIC MATTERS

The previous results on the Congo River were obtained without enough accurate measurements and rigorous sample treatment protocol, especially to determine the matter in suspension. Concentrations were very often determined from samples only taken at the surface and also not at regular time. Many data were time extrapolated in the past with few knowledge of the precise date and on the depth level of the samples. This explains the highly variability of the published results. As a consequence, among the previous time-series a 10-year (1998-2007) data set was selected to estimate the dissolved and suspended organic and mineral matter. The estimation of the dissolved organic carbon (DOC) and nitrogen (DON) is recent and the data set covers only 3 years (2005-2007).

Methodology

Samples have been made at a quarterly frequency from 1998 to 2001, then at a monthly frequency from 2002-2007.

The most rigorous method to get a flow estimation of the solid charge consists of estimating the concentration, C , of the suspended matters and the rate of the current, V , by sampling in N points along X verticals on the transversal section of the stream. By double integration of the CV product (on the verticals and on the width of the section), we obtain the solid rate:

$$Q_s = \int_0^l \int_0^p C_i V_i dldp \quad [1]$$

where C_i and V_i are the concentration and the rate at the point i , l is the abscissa of the section, p the total depth of a given vertical. The solid rate Q_s allows obtaining from the liquid rate Q , the average concentration in the section.

$$C_m = \frac{Q_s}{Q} \dots [2]$$

The parameters, liable to be modified by the transportation- such as the pH, the temperature, the conductivity, the alkalinity and the dissolved oxygen- are measured in the field immediately after collection when conditions allow it. Otherwise, they are measured as soon as the samples arrive at the laboratory.

After the field experiment the samples are analyzed in the laboratory in order to separate the solid and dissolved phases. The implemented protocol consists of three stages:

- (1) sifting of the samples at $50\mu\text{m}$, to isolate the suspended sand component (Sand) ;
- (2) filtering on $0.45\mu\text{m}$ acetate filter, to isolate suspended matter component (S.S) ;
- (3) centrifugation at 0.11 micron and dry residue at 105°C , to isolate the dissolved matter component (TDS).

One difficulty of this “full gauging of solid rates” method is the time needed to carry out the whole sampling in the field due to the width of the rivers, the number of measured profiles and of points along of a profile, and the analysis of all the samples in the laboratory due to their very large number. Equilibrium has to be found between the scientific impact of a very large number of samples and their relatively high technological cost.

Characterization of the Dissolved Matters

Protocol:

The protocol did not include a special conditioning for the water samples devoted to chemical analyses. The mixtures of the other elements are made in laboratory on the water collected after centrifugation (cut at 0.1 micron).

Three analysis techniques are used:

- **Titration**
We use standard kits, “kit individuel”, to determine the bicarbonates. The titration was made manually to the color turning point of the indicator.
- **Colorimetry**
The following ions: Cl^- , SO_4^{2-} , SiO_4^{4-} , Al^{2+} , NH_4^+ , and the total iron, Fe, are determined through the photometer (type?) with filter allowing some measurements of transmission and of optical density. Samples and standards are mixed to some reagents forming a specific complex of proportioned element. The absorption of the light caused by the complex, at a given wave length is transformed in linear electric potential compared with the concentration.
- **Spectrophotometry**
The cations, Ca^{++} and Mg^{++} , are determined by atomic absorption, the Na^{++} and K^+ are determined by flamespectrometry.

Characterization of the dissolved organic Carbon and Nitrogen:

Water samples are filtered with a Millipore 0.45µm filter. After filtering, a portion of each sample reaches the room temperature at 25°C and is analyzed for UV-Visible absorbance from 200 to 800 nm in a 10 mm quartz bowl via a Shimadzu UV-1700 spectrophotometer. The remaining filtered sample was stored frozen (-20 °C) in the dark. The DOC (Dissolved Organic Carbon) concentration is measured on acidified samples (pH=2 with 12N HCl) with a Shimadzu TOC-V_{CSH} analyzer via the non-purgeable organic carbon method (Krupa et al; 2011).

ESTIMATION OF THE DISSOLVED AND SUSPENDED MATTERS

Matter Evaluation

Table 3 provides averaged results obtained in the 4 selected basins of the Djiri river, Nkeni river, Lefini river and Alima river.

Table 3 summarize, relative to those 4 rivers, physical parameters- temperature, pH and conductivity- and the concentrations and fluxes of dissolved and in suspension matters. For all 4 rivers the temperature and pH are very close. pH always close to 5 indicates light-acid water. The conductivity is always under 20µS/cm that indicates a weak mineralization and increases from Alima river to Djiri river by a factor 2.2; the factor being 1.32 between Nkéné river and Alima river, and 1.07 between Léfini and Alima rivers.

Table 3: mean physical and chemical parameters deduced from the set of data for each river T is the temperature of the water; EC: Electric Conductivity at 25°C, pH: pH<7 acid trend of the water, Q: Discharge; Sand: concentration of sand, S.S: Concentration of matter in suspension, TDS: Concentration of the dissolved matter; S. Flux: Particle flux; D. Flux: flux of dissolved matter

Rivers	T (°C)	EC µScm ⁻¹	pH	Qmoyen m3 s ⁻¹	Sand mg, l ⁻¹	S.S mg, l ⁻¹	TDS mg, l ⁻¹	S Flux kg s ⁻¹	D Flux kg s ⁻¹
Alima	26.3	11.6	5.2	537	3.17	2.6	28.3	3.1	15.19
Léfini	25.9	9.5	4.9	414	3.4	2.4	21.2	2.4	8.78
Nkéné	25.9	8.8	5.2	209	5	3.6	20.4	1.79	4.26
Djiri	26.9	19.8	4.4	24.4	2.45	2.6	40	0.12	0.98
Total			4,93		14.02	11.2	109.9	7.41	29.21

The sand and suspended matter concentration decreases from 5mg/l for the sand and 3.6mg/l for suspended matter in the Alima river to 2.45. mg/l for the sand and 2.6mg/l for the suspended matter in the Djiri river. The concentration of dissolved matters is far more important than the matter in suspension and the sand. The concentration of dissolved matter is more important in Djiri river than in the other rivers that may be explained by a water more acid (pH=4.4).

The flux of solid and dissolved matters depends on the river discharge and it is why the values in the Alima river are higher than in the others.

Non-Organic Dissolved Matter

Table 4 gives the mean concentrations in major ions, silica and iron. All the rivers are slightly mineralized that explains the small electricity conductivity. The Nkéné river contains a higher concentration of iron because it is flowing in a zone with iron mines in higher altitude. Alima

river contains more Na^+ and Djiri river more K^+ .

Table 4: mean chemical composition of the non-organic dissolved matters; EC: Electric Conductivity at 25°C. the next 10 columns Concentrations expressed in mg l^{-1}

River	pH	EC $\mu\text{S/cm}$	SiO_2 mg l^{-1}	Fe_{tot} mg l^{-1}	Ca^{++} mg l^{-1}	Mg^{++} mg l^{-1}	Na^+ mg l^{-1}	K^+ mg l^{-1}	HCO_3^- mg l^{-1}	Cl^- mg l^{-1}
Alima	5.13	12.57	3.25	0.09	0.41	0.18	0.70	0.27	3.15	0.87
Léfini	5.33	8.70	5.16	0.05	0.44	0.10	0.10	0.18	4.19	0.66
Nkéni	5.03	8.68	5.07	0.05	0.38	0.10	0.07	0.25	3.63	0.62
Djiri	4.98	17.40	5.18	0.06	0.35	0.09	0.13	0.36	4.03	0.68

The scarcity of dissolved mineral salt of the Batéké rivers is caused by the drainage of the sand and the silicious sandstones, matter with low solubility.

Dissolved Organic Carbon and Nitrogen

Table 5 gives the mean concentrations of dissolved organic carbon (DOC) and dissolved nitrogen (DON) expressed in mg. l^{-1} of the 4 selected rivers, Alima, Léfini, Nkéni and Djiri, and their flux expressed in kg. s^{-1} .

**Table 5: Concentration of the Dissolved Organic Carbon and Nitrogen (DOC; DON)
T: Water temperature; EC: Electric Conductivity expressed at 25°C; Q: discharge; DOC: Concentration of dissolved organic carbon; DON: Concentration of dissolved organic nitrogen.**

Rivers	T°C.	EC μScm^{-1}	pH	Qmoyen $\text{m}^3. \text{s}^{-1}$	DOC mg. l^{-1}	DON mg. l^{-1}	Flux DOC kg.s^{-1}	Flux DON kg.s^{-1}
Alima	26.3	11.6	5.2	382.1	5.421	0.26	2.00	0.1
Léfini	25.9	9.5	4.9	244.4	2.927	0.17	0.72	0.04
Nkéni	25.9	8.8	5.2	182.4	2.056	0.12	0.38	0.02
Djiri	26.9	19.8	4.4	21.9	1.684	0.09	0.04	0.002

The concentration in organic matter, C and N, is relatively negligible. The carbon and nitrogen concentrations are increasing from the savannah areas to the forest ones.

The maximum value of the DOC is 1kg/s and of DON is 0.05kg/s , those values being also observed in the Alima river (Tableau 5).

The pH is decreasing from the savannah to the forest. A pH around 5 i.e. acid, favors the organic matter dissolution except in the Léfini river ni qui a la plus grande valeur de la pluviométrie (Tableau 2).

Mechanical Erosion and Chemical Weathering

The specific flows of the dissolved and particulate matter are related to the pouring basin areas. Drains undergone by all the plateaus are obtained making the total and they are numbered as indicated in the table 6. The mechanical erosion and the chemical weathering are more important in the Djiri basin than in the other selected basins; followed by the Léfini pouring basin. The two mechanisms have small impact on the Nkéni basin.

Table 6: Average matter amount per year due to mechanical erosion and chemical deterioration. and drained into the Congo River. In parenthesis the mechanical erosion and chemical weathering determined during the PIRAT-GBF programme.

Pouring basin	Mechanical Erosion Tg year ⁻¹	Chemical Weathering Tg year ⁻¹
Alima	97.74 (121.1) 10 ³	478.94 (462.6)10 ³
Léfini	75.67 (127) 10 ³	276.83 (236.8)10 ³
Nkéni	56.44 (35.9) 10 ³	134.44 (155.4)10 ³
Djiri	3.78 (3.5) 10 ³	30.89 (12.7)10 ³
Total	233.63 (286.5) 10³	921.1(867.5) 10³

The chemical weathering is preponderant compared with the mechanical erosion, i.e., 731.6 10³ Tg/year versus 204.6 10³ Tg/year

Geochemical Classification

During the period 1998-2008, we carried out 1116 physico-chemical measurements and 987 chemical titrations.

Insights to the geochemical nature of the water is revealed by plotting the concentrations of major cations and anions in the Piper trilinear diagram (**fig. 12**) which shows the dominance of CaHCO₃ in the 4 selected rivers, Alima, Léfini, Nkéni and Djiri, and also in two other rivers from the same area, Nkomo and Kouyou rivers. CaNaHCO₃ is also observed that indicates an ion exchange reaction between Ca⁺⁺ and Na⁺ due to the clayey minerals present in the lithograph of each basin. Few Alima river samples indicate the presence of NaHCO₃ which points out an evolution of the Alima river hydrochemistry. In few samples of the Nkéni and Djiri rivers, NaCl facies are present.

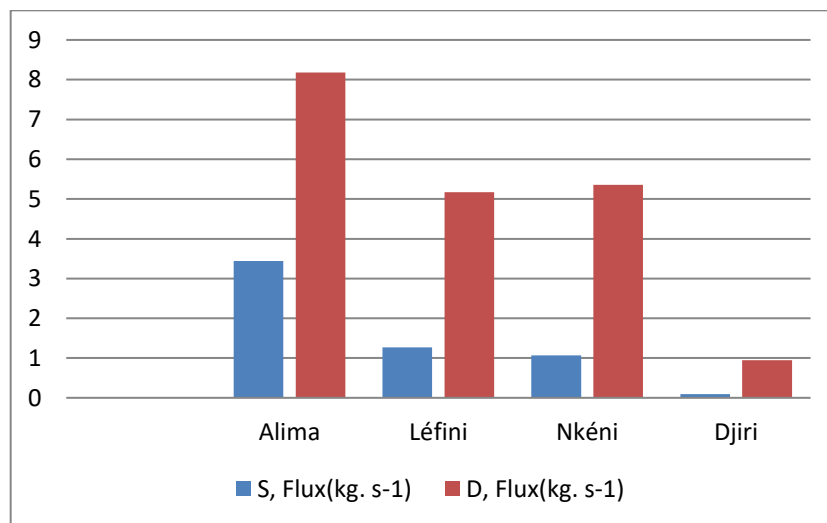


Figure 11: Transport of solid and dissolved suspensions in Alima, Lefini, Nkeni and Djiri suspensions is very high compared to that of dissolved suspensions The rivers in the Batéké Plateaux transport in dissolved

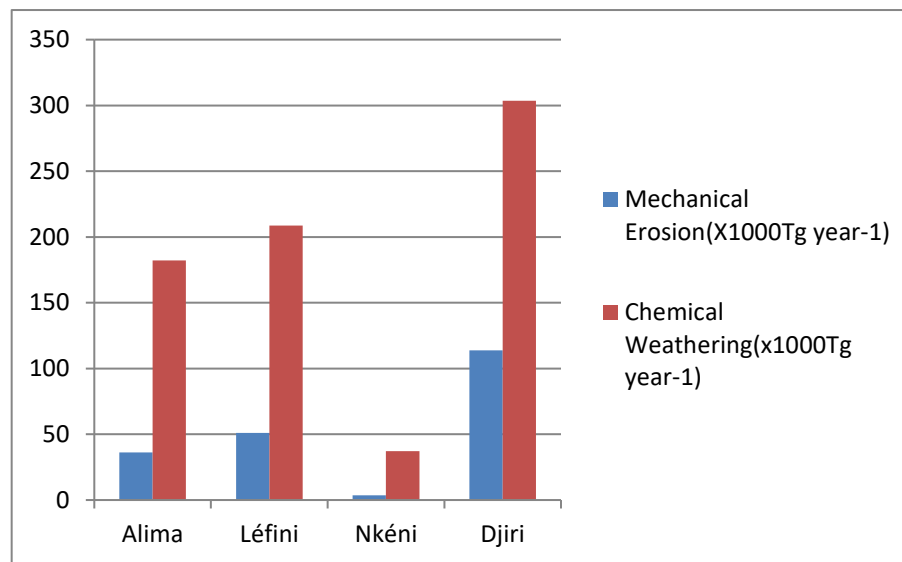


Figure 12: Mechanical Erosion and Chemical Weathering in the the Batéké Plateaus

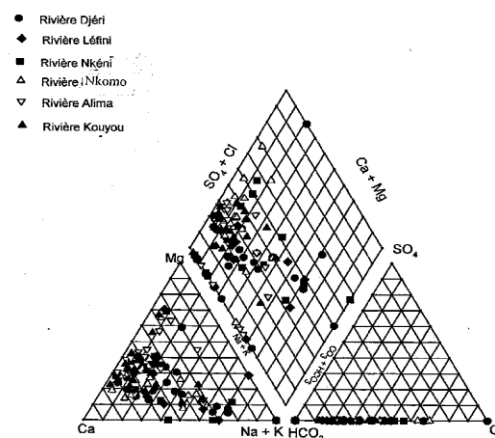


Figure13: Piper Diagram of water samples

From this diagram the major hydrochemical facies have been identified and they are 1) $\text{Ca}^{2+}\text{HCO}_3^-$ type and 2) Mixed $\text{Ca}^{2+}\text{Na}^+\text{HCO}_3^-$ type; other facies have been detected in a few samples the mixed $\text{Na}^+\text{HCO}_3^-$ type in the Alima river and Na^+Cl^- type in the Nkényi and Djiri rivers.

It is an overall characterisation of the major hydrochemical facies of 4 Batéké plateau rivers. A characterisation by season is planned in order to determine the role of the rainfalls on the chemical composition of the water.

CONCLUDING REMARKS

- This study shows that the evaluation of the matters transported by the rivers and the streams of the Batéké plateaus in Congo Brazzaville constitutes a preoccupation for the researchers working in the field of water in Congo. Because the contribution of the Batéké plateaus to mechanical erosion, i.e., the transport of solid matter, is 0.2 GTg per

year and 0.73 GTg per year of chemical degradation, i.e. the transport of dissolved matter (Table 6). By comparing these results with those of the Congo River obtained within the framework of the PIRAT project (Moukolo; 1993); 61. 1GTg.year-1 of transport of dissolved matter and 30.6GTg of transport of solid matter, in sum the contributions of the Batéké plateaus (for the four rivers chosen) represent only less than 1% of the contributions in the Congo River.

- b) Some important results have been obtained during the implementation of this program. Some of them raise up at present a certain number of interrogations, notably the hydro chemical study of the samples made to the four resorts of measurements shows that about the dissolved matters,
- c) it does not exist the obvious correlation between the contents of the balanced elements and liquid flows. And yet, it is certain that the importance of the bringing is related to the quantity of drained water. This absence of precise relation between contents and flows would be linked to the very complex alimentation mode of whole hydro system.
- d) At last some information enough precise on the transportation in solution and in suspension in the Batéké plateaus rivers are currently available. It comes from all these evaluations that to the scale of the Congo river basin, the Batéké plateaus located on the right side represent:
 - hydric bringing about 9% of the annual volume;
 - suspended matters 8% of the total charge;
 - dissolved matters 7% of the total charge.At last, the results of the hydrochemical analyses have shown a slight mineralization of the waters (biostatic law in damp equatorial area).
- e) we have chosen to quantify in addition to the mineral fraction that of the organic fraction in order to attract the attention of the public authorities of Congo-Brazzaville in charge of water supply facilities.

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