# Suspended sediment transport by rivers in the different climatic zones of Cameroon (Central Africa)

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**Abstract** Some watersheds representing the major climatic zones of Cameroon, in Central Africa, have been simultaneously investigated during the period 2002–2004. The patterns of monthly suspended sediment transport show a common form. In areas with a tropical climate, there is a hysteretic loop, with the maximum concentration preceding the flow peak. In these areas, the values of suspended sediment concentrations (up to 3000 mg $L^{-1}$) and specific sediment yields (>200 t $km^{-2}$ $year^{-1}$) are high. In contrast, in areas with an equatorial climate, the monthly concentrations increase regularly with the monthly flow and sediment concentrations are about 15 mg $L^{1}$ and specific sediment yields less than 10 t $km^{-2}$ $year^{-1}$. A comparison of recent results and historical data shows that in areas of dry tropical climate (Mayo Tsanaga) where flow rates have decreased by 50% since the late 1960s, average sediment concentrations increased from an overall average of 1050 to 2500 mg $L^{-1}$, with a maximum exceeding 3000 mg $L^{-1}$ in 2003. Conversely, in the equatorial zone (Ntem), the available data indicate no major change in sediment concentrations despite a decrease in flow rate of 19%.

**Key words** Cameroon; climate; drought; suspended sediment transport

## INTRODUCTION

Cameroon, a Central African country, is located between latitudes 2° and 13°N and longitudes 8° and 16°E. With a triangular shape, it extends over 1200 km from Lake Chad (north) to the Atlantic coast (south), covering an area of 475 000 $km^2$, with 402 km of coastline to the Atlantic Ocean in the Gulf of Guinea. The country covers a wide range of climatic conditions, reflecting its latitudinal extent, its exposure to the Atlantic monsoon flow and the main features of its relief. These oro-climatic influences are reflected by varied vegetation cover and diverse human activities, which in turn influence the processes of erosion and sediment transport.

Many measurements of sediment transport have been carried out in the rivers of Cameroon. The results of the first series of measurements were presented by Nouvelot (1972) and Olivry (1977). Subsequently, many measurement programmes have been undertaken and Liénou *et al.* (2005a) provide a synthesis of the existing information. This synthesis emphasizes that many of the measurement programmes were not synchronous, but were carried out for years with different hydrological conditions, during a period when the climate was changing. Use of the existing data to compare rivers and to identify key spatial patterns across the country therefore introduces many problems.

More recently, a measurement programme aimed at undertaking measurements simultaneously in rivers representative of the main climatic zones of Cameroon, using methods suitable for each river system, has been developed to address this problem (Liénou *et al.*, 2005b). This paper presents the results of this measurement programme.

## THE CLIMATIC ZONES OF CAMEROON AND THE STUDY RIVERS

### The climatic zones of Cameroon

The variation of climatic conditions within Cameroon reflects both the latitudinal extent of the country and the pattern of relief, particularly the location of highland areas. Stretching from the

Gulf of Guinea to Lake Chad, the country covers the five major climatic zones defined by L'Hôte *et al*. (1995). The topography of the country, and particularly the location of the high mountains, as well as its exposure to the Atlantic monsoon emphasise the north–south zonation of the climate. Eight climatic zones are described by Olivry (1986), and highlighted by Liénou (2007) (Fig. 1).

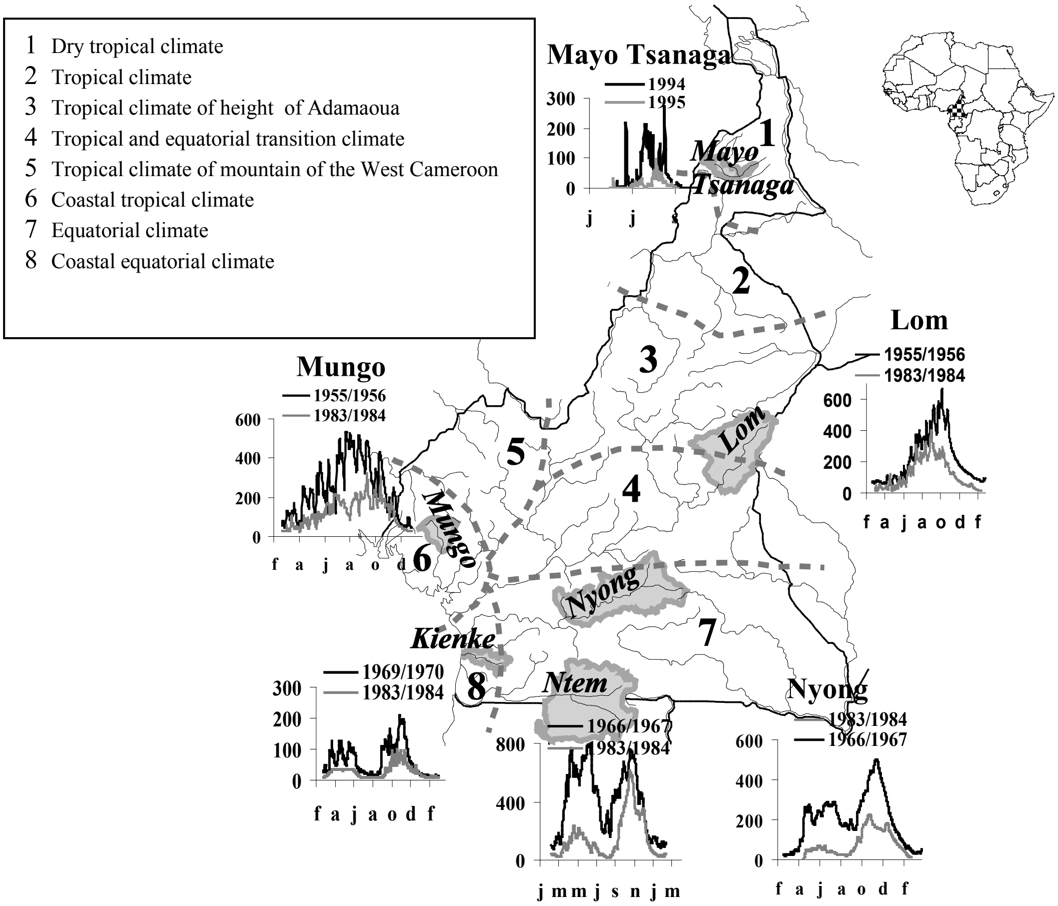



**Fig. 1** The climatic zones of Cameroon, the study rivers and their flow regimes (discharges in $m^3 s^{-1}$).

## The study rivers

The study rivers were selected by taking account of their ability to represent the different climatic units and the availability and quality of existing data on suspended sediment transport. Some stations, particularly those in the Sanaga basin, were among the oldest to have good quality data on suspended sediment transport. However, the subsequent construction of several dams upstream has had a significant impact on downstream suspended sediment loads and makes comparison of past and more recent data problematical. This impact is illustrated by the suspended sediment data collected from the measuring station at Goyoum (Fig. 2). The Goyoum station is situated downstream of the confluence of the Lom and Djerem rivers. The catchments of both rivers have identical characteristics. The Mbakaou Dam is situated on the Djerem River, but the Lom River has no dam. During the dry season (in January and March) suspended sediment transport reflects the mobilization of material from the bed of the river and the concentration is uniform across the measuring section (5 mg $L^{-1}$). In contrast, during the rainy season (in August and September), when sediment is mobilised from the catchment slopes, the suspended sediment concentrations are higher on the side of the river where the flow originates from the River Lom (72 and 52 mg $L^{-1}$) than on the side where the flow originates from the River Djerem (53 and 29 mg $L^{-1}$). The, six rivers finally selected for this study are shown in Fig. 1.

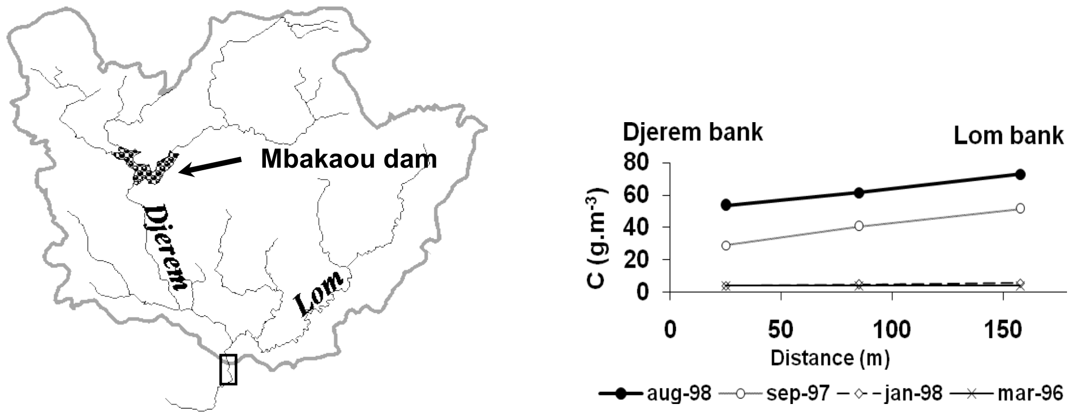



**Fig. 2** The impact of the Mbakaou dam on suspended sediment concentrations sampled at Goyoum.

The Mayo Tsanaga basin represents the dry tropical climatic zone, characterized by a dry season of six to seven months extending from December to May. The rain that falls from June to October generally occurs as isolated thunderstorms. The flow is torrential, consisting of intermittent floods corresponding to the rainfall events. The steppe type vegetation results in extensive areas of bare soil, which are susceptible to erosion.

In the tropical climatic zone, the Lom River is the only river where measurements of suspended sediment transport have been undertaken in the past and where the flow has not been influenced by more recent hydraulic structures. The rainy season is much longer in this zone, extending from April to October. The flow regime is of the humid tropical transition type, with more than 70% of the annual flow concentrated between June and November.

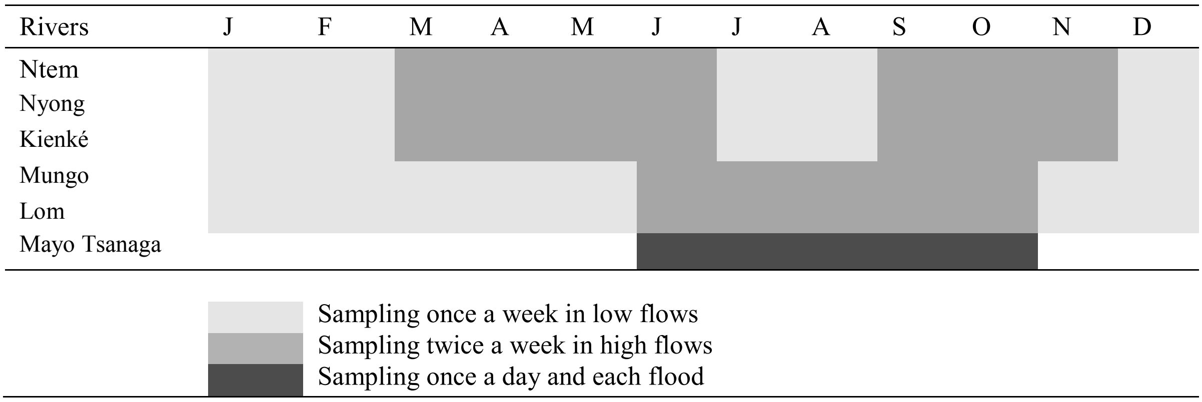
For the equatorial climatic zone, two river basins were selected, namely, the Nyong and the Ntem basins. The Nyong basin, is located on the northern edge of the equatorial climatic zone and is representative of the transition zone between savanna and forest, and is characterized by a fairly degraded and anthropogenically modified environment. The basin of the Ntem is covered by forest which is still relatively dense. The two basins have an equatorial flow regime, with the annual hydrograph divided into four periods: two periods of high water (March–June and September–November) and two low water periods (July–August and December–February).

The coastal areas of Cameroon, between the mouth of the Ntem and the Nigerian border, are represented, to the south, by the Kienke basin and to the north by the Mungo basin. These two basins differ in both rainfall and runoff. The Kienke River has an equatorial type regime, but the amount of rainfall makes it different from the Ntem, which is also located in the equatorial zone. The Mungo River basin receives close to the maximum rainfall in the southwest, but the seasonal distribution of the abundant annual rainfall does not show the pattern expected of the tropical climatic zone.

## METHODOLOGY FOR MEASUREMENT OF SUSPENDED MATTER

Measuring suspended sediment transport by rivers requires measurements of the sediment concentration in the cross-section at an appropriate frequency and combination of the resulting data with the record of water discharge. The implementation of continuous monitoring of suspended sediment concentration requires considerable human and material resources for gauging and sampling, and for subsequent laboratory analysis (filtration). A less intensive sampling procedure was therefore employed in the current study. Based on the approach proposed by Nouvelot (1972), a sediment sampling protocol was developed. Sampling frequencies were adapted to flow conditions (Table 1). In low water periods, where conditions are fairly stable and the magnitude of sediment transport is mainly related to the erodibility of the banks, samples are collected once per week. In periods of high water, it is necessary to relate the sampling frequency

**Table 1** Sampling frequencies employed in the study.




to the fluctuating flow and two samples are collected each week, with additional sampling on the rising part of the flood. In the case of the Mayo Tsanaga, more frequent sampling was required. Here sampling is performed daily during the period of flow, and more frequently during the intermittent floods.

Samples are filtered in the laboratory using Whatman millipore filters (cellulose acetate) with a porosity of 0.45 μm. The dry residue is weighed to establish the suspended sediment concentration of the sample.

## RESULTS AND INTERPRETATION

The characteristics of suspended sediment transport vary between the different climatic zones. In the tropical area (Fig. 3(a)), we find the classical hysteresis in the relationship between concentration and flow rate, widely reported by several authors (Nouvelot, 1972; Olivry, 1977; Bricquet *et al*., 1997; Picouet, 1999). Concentrations are much higher for the first flood of the hydrological year. These authors explain the elevated concentrations found early in the season as reflecting the mobilization by the first floods of readily available sediment remaining on the surface after the long dry season. Olivry *et al*. (1974) showed that the availability of sediment for mobilization increases with an increase in the length and severity of the dry season. The maximum concentration found at the beginning of the wet season is higher for areas with dry tropical conditions. Maximum concentrations ranging from of 3000 to 8000 mg $L^{-1}$ have been documented for the Mayo Tsanaga, whereas the equivalent values for the Lom are ~100 mg $L^{-1}$. After the initial flushing of readily available sediment, concentrations fall significantly, due to the development of the vegetation that protects the soil and promotes infiltration, and reduces the availability of easily mobilized material. In the equatorial area, however, concentrations are more directly related to the flow (Fig. 3(b)) and increase gradually during the wet season, from a minimum of around 10 mg $L^{-1}$ to a maximum of about 20 mg $L^{-1}$. This rather different behaviour may reflect the presence of a fairly constant vegetation cover throughout the year, which, despite its diversity, protects the soil against erosion.

The variation of specific suspended sediment yields and mean suspended sediment concentrations across the main climatic zones of Cameroon shown in Fig. 4 confirms the pattern described by Liénou *et al*. (2005). Overall, the lowest specific sediment yields (3–25 t $km^{-2}$ $year^{-1}$) and mean concentrations (12 and 17 mg $L^{-1}$) are found in the rivers of the equatorial area. However, coastal regions appear to produce more sediment than inland areas, probably because of the higher slope gradients and more erodible soils, especially in the volcanic region of the southwest.

Due to the reduced vegetation cover and the increased sensitivity of the soil to human activities, the tropical area produces more sediment. Sediment yields range from 32 t $km^{-2}$ $year^{-1}$ for the Lom to more than 250 t $km^{-2}$ $year^{-1}$ for Mayo Tsanaga, with values of average concentration of 66 mg $L^{-1}$ and more than 3000 mg $L^{-1}$, respectively.

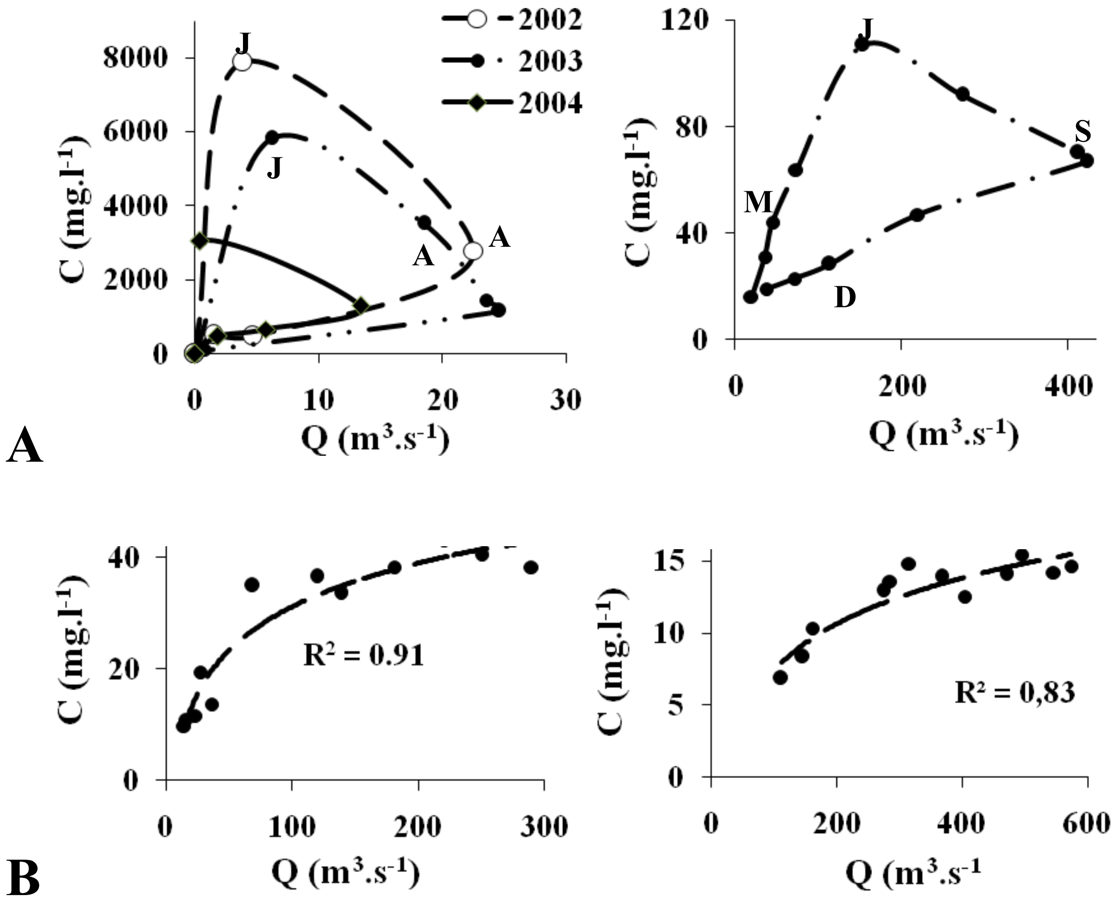



**Fig. 3** Relationships between suspended sediment concentration and discharge in the main climatic zones of Cameroon; (a) tropical climate, (b) equatorial climate.

A comparison of previous data for the Ntem (equatorial area) with that from the Mayo Tsanaga (dry tropical area) shows that the dynamics of sediment transport have not been greatly modified by drought conditions in the equatorial environment, despite a reduction in the flow by 19%. However, in the dry tropical area, reduced sediment yields (–22%) are paralleled by an increase in mean suspended sediment concentration from 1050 to 2500 mg $L^{-1}$. This situation may be related to the increased availability of sediment for mobilization, due to the reduction of the natural vegetation cover and increased anthropogenic pressure on soils, which have become more fragile (Liénou *et al*., 2009).

## CONCLUSION

Simultaneous measurements of suspended sediment transport by six rivers, representative of the six main climatic zones of Cameroon, have been used to establish the key features of the transport of suspended sediment by rivers in Cameroon. The spatial distribution of mean concentrations and specific suspended sediment yields across the six basins broadly follows the pattern described by previous work (Nouvelot, 1972; Olivry, 1977; Liénou *et al*., 2005a). Mean concentrations and specific sediment yields increase in areas with steep slopes and more erodible soils, and vary inversely with the density of the vegetation cover. Comparisons of the results with data from previous measurement programmes indicate an increase in mean concentrations in the watershed of the Mayo Tsanaga in the dry tropical area, probably because of increased soil degradation and loss of soil structure. For the Ntem (in the equatorial area), the magnitudes of concentrations and

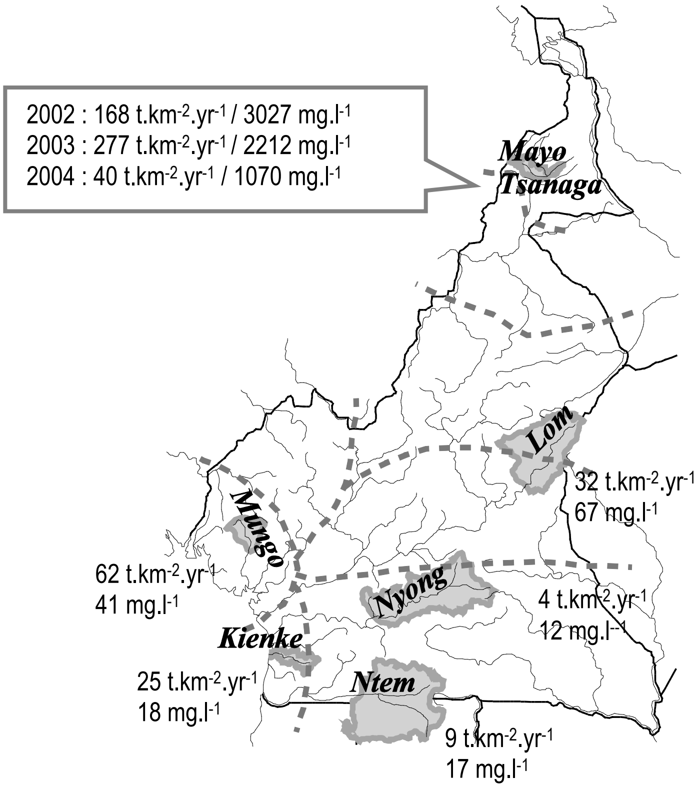



**Fig. 4** The variation of specific suspended sediment yields and mean suspended sediment concentrations between the study rivers.

sediment yields are almost identical to those documented by earlier studies, despite the reduction in flow. This implies that across a large area, changes in the forest vegetation cover have yet to impact on suspended sediment transport.

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