Mini Review

Quantification of Water Erosion and Statistical Modeling of Solid Transport in the Faleme River Basin (Senegal, Mali and Guinea)

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Abstract

This work aims at quantifying the phenomenon of hydric erosion and at modelling solid transport and its variability in Falémé River basin over a period 1965-2015. Methodological approach is to establish a relation of regression between the data of liquid discharge (Ql) and solid discharge (Qs), from which, calculation of regression allowed to establish a model of type power $Qs = 0.09Ql^{0.97}$.

Keywords: Quantification; Modelling; Hydric Erosion; Transport Solid; Falémé River Basin; Pollution; Senegal River Basin; Suspended Solids; Solid Discharge ; Liquid Discharge; Concentrations; Water Erosion; Rivers; Sediments; High-Water Periods

Introduction

In West African tropical zone, characterized by very irregular and often intense precipitation, climatic factors have a considerable influence on the detachment of soil particles. The latter, transported by runoff into basins, will eventually settle in the reservoirs causing their siltation or discharge to the sea causing its pollution [1]. The research carried out in the field of erosion and solid transport, show that specific degradations, tropical watersheds are important and variable.

Mobilization of transported sediments is related to the role of stormwater, favored by steep slopes and lack of protective vegetation cover [2]. This mobilization of materials results from mechanical and water processes. It is sometimes a real impregnation of the soil and weathering mantle by rainwater, sometimes of superficial or sub-surface runoff. The fine materials are driven by diffuse and then concentrated runoff, while active runoff evolving towards the gully carries mobilizable materials. Process of transporting suspended solids in watersheds is complex. It occurs mainly during floods and is closely related to rainfall intensity, watershed configuration, and hydraulic features of the watercourse [3]. To understand the process of transporting suspended particles in rivers, in the Sudano-Sahelian tropical climate, Falémé watershed was chosen. In the upper Senegal River Basin, watercourses such as Bafing and Falémé are characterized by presence of numerous rapids and falls due to rocky sills which fix the levels of the intermediate reaches.

The rare suspended solids (SS) concentration data in Faleme come from a study of SLII [4] during the high-water period (18 July to 14 November 2010) and are still very partial. Through these measurements, SLII [4] reported a significant runoff and a high concentration from August, contrary to the end of the rainy season when a decrease in concentration is noted. However, in Faleme, as in many tropical regions, lack of data is a major handicap in evaluation of these contributions [2]. This has led many researchers to propose general forecast models (for a set of basins) and specific models (specific to a given basin). Our work fits into second category of widely used models in the world. It aims to know this solid discharge-liquid discharge relationship in Falémé River basin in order to quantify water erosion and solid transport.

Materials and Methods

Data

Falémé, a tributary of the Senegal River, rises at an elevation of 800 m at the foot of Fouta Djalon. Its watershed is between latitudes 12° 11’ and 14° 27’ N and longitudes 11° 12’ and 12° 15’ W. It covers an area of 28,900km^2, or 10% of the total area of the Senegal River watershed, which is the last major tributary, 625km long [5]. Study is based on the instantaneous values of discharge flows (Ql) given in m^3/ s measured at Gourbassi station at latitude 13° 24’ North and longitude 11° 38’ West, which drains a basin of 17100km^2. To certain measurements carried out in 2010, was evaluated the load of the corresponding suspended matter given in g / l and obtained from samples of water taken with Gourbassi taken by SLII [4]. All available data cover the period from 1965-66 to 2014-15 for daily average liquid discharge at the Gourbassi station and part of 2010 for instantaneous couples (liquid discharge). These liquid discharge (Ql) and solid (Qs) data used were obtained from the database of the Organization for the Development of the Senegal River (OMVS).

Méthods

From measured concentrations of suspended solids concentrations and associated flow rates selected for this study, suspended solid discharge is then calculated. To be able to develop models of solid discharge, we used approach proposed as early as 1895 by Kennedy [6]. The power relationship between solid discharge and liquid discharge has been verified for most rivers in the world. In this work, water erosion is evaluated based on the annual, monthly or seasonal flow of suspended matter crossing the section of stream. Solid discharge in tonnes or million tonnes, As (106t or MT) and specific inputs in tonnes per square kilometer per year, For this study, it will be evaluated at 30% of the total load, against 70% from slopes and soil erosion. These sediments located in river beds and from slopes are transported by floods to be deposited either on alluvial plains with low slope, or in barrels of dam or transported to the sea.

Results and Discussion

The power relationship of measured suspended solids concentration pairs and associated flow rates selected for this study indicates a highly significant correlation between runoff volume and solid transport, as evidenced by a coefficient of determination of 0.84. The computation of the regression allowed us to establish a model of the type power $C= 0.09Ql^{0.97.}$ This relationship makes it possible to determine the solid contribution of each discharge.

The Falémé River basin at Gourbassi station annually drains (on average) 7.3 million cubic meters of water and transports 0.2 million tons of sediments, ie a water erosion of around 12 t km^{2-1} $year^{-1}$. Average solid discharge is estimated at 6.6 kg s^{-1} over the period 1965-66 to 2014-15. Erosion and solid transport in the basin show significant interannual variability with a coefficient of variation of 0.49 for solid discharge, which is high. In fact, solid discharge recorded a maximum value of 0.49 million tonnes of sediments for the year 1967-68, i.e, a water erosion of around 29 t km^{2-1} $year^{-1}$ for a minimum value of 0.05 million tonnes of sediments in 1983-84, ie water erosion of the order of 3 t km^{2-1} $year^{-1}$. This can be explained by the fact that abundance of suspensions exported by a basin is a function of the volume of water available.

At seasonal scale, evolution of erosion and solid transport indicates a clear difference between periods of high and low water. If during high-water periods (August, September and October), river (on average) drains a flow of 451m^3 s^{-1} and carries 0.03 million tonnes of sediment, ie an average water erosion of around 2 t/km^2 / year, during low water periods (November to July), average flow rate is only 10.6m^3 s^{-1} for an average solid discharge of 0.001 million tonnes and a specific average degradation of 0.1 t / km/ year. In basin, the period of high water (with monthly flow rates greater than 1) thus records almost all solid discharge (86.3% of total inflows). On the other hand, during periods of low water in basin, solid discharge load decreases regularly (13.7%) as a function of relatively low flow of recession.

On a monthly scale, variability of water erosion and solid transport is most important of scales (CV = 1.93). An important part of erosion (38.9% of annual total) is observed during the month of September (month of maximum of flow and erosion) whose contributions in suspension are estimated at 0.08 million. tonnes of sediment for a specific degradation of order of 5 t km^{2-1} $year^{-1}$, which is huge. This month is followed by August (30.2% of contributions) and October (17.2%). However, in May (minimum flow and erosion), inputs are only 5 tons of sediment, a water erosion of the order of 2 g km^{2-1} $year^{-1}$. The months of May (0.01%) and April (0.02%) therefore record almost zero frequencies.

The Faleme River basin, with a Sudano-Sahelian climate, is characterized by irregular seasonal and interannual rainfall. This irregularity has a direct impact on erosive action and in particular on solid transport in suspension. The latter depends on several factors including aggression of showers, situation of soil and turbulence of flow. Floods of rainy season are responsible for the bulk of the solid transport in basin and amount of suspended load it generates depends on rainfall intensity, most of which is caused by storms in basin. . However, frequency of severe thunderstorms also largely explains lack of correlation between suspended load and rainfall totals on the one hand, and variability of this load on the other hand, observed at annual, seasonal and monthly scales [7].

Average annual sediment load recorded at Gourbassi station is estimated at 0.2 million tonnes per year. This value is very different from those used in studies carried out in the Upper Senegal Basin, which was first reported in 1969 Senegal Consult study, i.e. 0.9 million tonnes per year, or 45 million m^3 of siltation. 50 years old [4]. In addition, power-type model used shows that flood-scale parameters (a = 0.09 and b = 0.97) are far removed from those found by many researchers who have worked mainly in semi- arid as Oued Sebdou [8]. Finally, share taken in estimating thrust versus suspension load is 12.5% in this study, while it can be much larger, for example in Sahelian zone where it varies between 10 and 80% in total transport according to superficial state of basin [9,10].

Conclusion

This work constitutes a first contribution to quantification of erosion phenomena and modeling of solid transport in the Falémé River basin (tributary of the Senegal River). It provides many basic elements for a search for hydrological models, governing relationship between surface flow and suspended solid transport in this basin. On the basis of few measurements made in Gourbassi site (from July 18th to November 14th, 2010 by SLII) [4], we selected a few pairs and determined a power type relation between liquid discharge and solid discharge through which erosion and transport solid are quantified. These estimates indicate that erosive action and sediment transported by basin vary widely from year to year. Sediment concentrations based on liquid discharge are highest during high water period, which accounts for 97% of inflows. Over this period, the month of September alone accounts for 49.5% of annual contributions.

The sediments transported during flood come mainly from river bed, but also from banks and tributaries. In any case, this annual, seasonal and monthly variability depends on frequency of thunderstorms and their period of occurrence. Indeed, it is these storms that generate most of suspended load. To this temporal variability is added spatial variability of soil erosion rate in basin. This disparity is result, according to some authors [9], mainly of difference in lithology, vegetation cover, slope and size of the watershed.

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