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Hydro-sedimentary and geochemical dynamics of the Agnéby River (Côte d'Ivoire): Implications for coastal systems and the blue economy

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ABSTRACT: This study investigates the hydro-sedimentary and geochemical functioning of the Agnéby River, a tropical coastal basin in southern Côte d'Ivoire, based on the combined analysis of suspended sediments (TSS) and dissolved constituents (TDS) during the 2020 hydrological year. TSS concentrations and fluxes exhibit a strong dependence on river discharge, with sediment export largely controlled by flood events. More than 50% of the annual suspended sediment load is transferred within a short period, reflecting an impulsive transport regime typical of medium-sized tropical catchments. Water chemistry is dominated by bicarbonates and alkaline-earth cations, indicating a geochemical signature primarily governed by chemical weathering of basement rocks under humid tropical conditions. Seasonal variations in TDS reveal dilution effects during high-flow periods and enhanced water–rock interactions during low-flow conditions. The TSS/TDS ratios, ranging from 0.08 to 0.30, highlight a transition from weathering-dominated conditions during baseflow to a mixed regime increasingly influenced by mechanical erosion during floods. Comparison with larger Ivorian river basins, such as the Bandama and Comoé rivers, shows that the Agnéby River differs markedly by its rapid hydrological response and limited sediment storage capacity, whereas larger systems exhibit more progressive seasonal sediment transfer. These findings emphasize the significant contribution of small and medium tropical coastal rivers to sediment and solute fluxes toward lagoonal and coastal environments, with important implications for coastal sediment budgets and the sustainability of the blue economy.

KEYWORDS: suspended particulate matter, dissolved load, weathering processes, seasonal variability, sediment yield.

1 INTRODUCTION

Tropical rivers play a major role in transferring water, sediments, and dissolved constituents from continents to the oceans, thereby strongly influencing coastal ecosystem functioning and global biogeochemical cycles. At the global scale, these systems contribute disproportionately to fluvial fluxes of suspended particulate matter and dissolved loads due to climatic conditions that promote both intense chemical weathering of rocks and mechanical erosion of soils [1], [2]. In humid tropical regions, the seasonality of rainfall and river discharge represents a key control on hydro-sedimentary transfers. Suspended particulate matter (TSS) is primarily associated with mechanical erosion and runoff processes, whereas dissolved constituents mainly result from chemical weathering of geological formations within the catchment. The joint analysis of these two compartments provides insight into the dominant functioning mechanisms of river basins and allows assessment of their sensitivity to hydroclimatic variability. The TSS/TDS ratio is therefore widely used as a synthetic indicator of the relative control between mechanical erosion and chemical weathering in fluvial systems [3], [4].

In West Africa, despite the importance of coastal basins for continental inputs to lagoons and estuarine environments, studies simultaneously addressing suspended sediment and dissolved load transport remain relatively scarce, particularly for medium-sized basins. These systems are often characterized by strong seasonal hydrological variability, increasing anthropogenic pressures on vegetation cover, and heightened sensitivity to extreme rainfall events, all of which may intensify erosion and sediment transfer processes.

The Agnéby River, the main coastal river in southern Côte d'Ivoire, drains a humid tropical catchment and discharges into the Ébrié Lagoon, a lagoonal ecosystem of major ecological and socio-economic importance. Fluvial inputs from the Agnéby River largely control turbidity, sedimentation, and nutrient availability in coastal and lagoonal environments, with direct implications for fisheries, aquaculture, navigation, and, more broadly, the regional blue economy. In a context of increasing climatic variability and growing anthropogenic pressures on watersheds, understanding the hydro-sedimentary and geochemical dynamics of the Agnéby River is therefore essential.

The objective of this study is to analyze the hydro-geochemical functioning of the Agnéby River using hydrological data and measurements of suspended particulate matter and dissolved constituents collected in 2020. Specifically, the study aims to (i) characterize the seasonal variability of discharge, TSS, and dissolved elements, (ii) quantify suspended sediment fluxes and annual export, (iii) assess the coupling between mechanical erosion and chemical weathering using the TSS/TDS ratio, and (iv) discuss the implications of these fluvial inputs for coastal ecosystems and blue economy-related issues in Côte d'Ivoire.

2 Materials And Methods

2.1 Study Area

The Agnéby River is a coastal river located in southern Côte d'Ivoire, draining a catchment situated in a humid tropical zone. The river originates at Agoua in the Bongouanou hills in the central-eastern part of Côte d'Ivoire, at an elevation of approximately 250 m. It flows southward through the Agboville region and discharges into the Ébrié Lagoon near Dabou [5]. The climate of the basin is characterized by an alternation of rainy and dry seasons, resulting in strong seasonal variability in river discharge, which exerts a major control on the hydrological and sedimentary regimes of the river [6]. The geological formations of the basin are dominated by crystalline and crystallophyllian basement rocks, overlain by ferrallitic soils. The selected monitoring station is located at Agboville, in the downstream part of the basin, a position that is favorable for integrating hydrological and geochemical inputs from the entire watershed (Fig. 1).

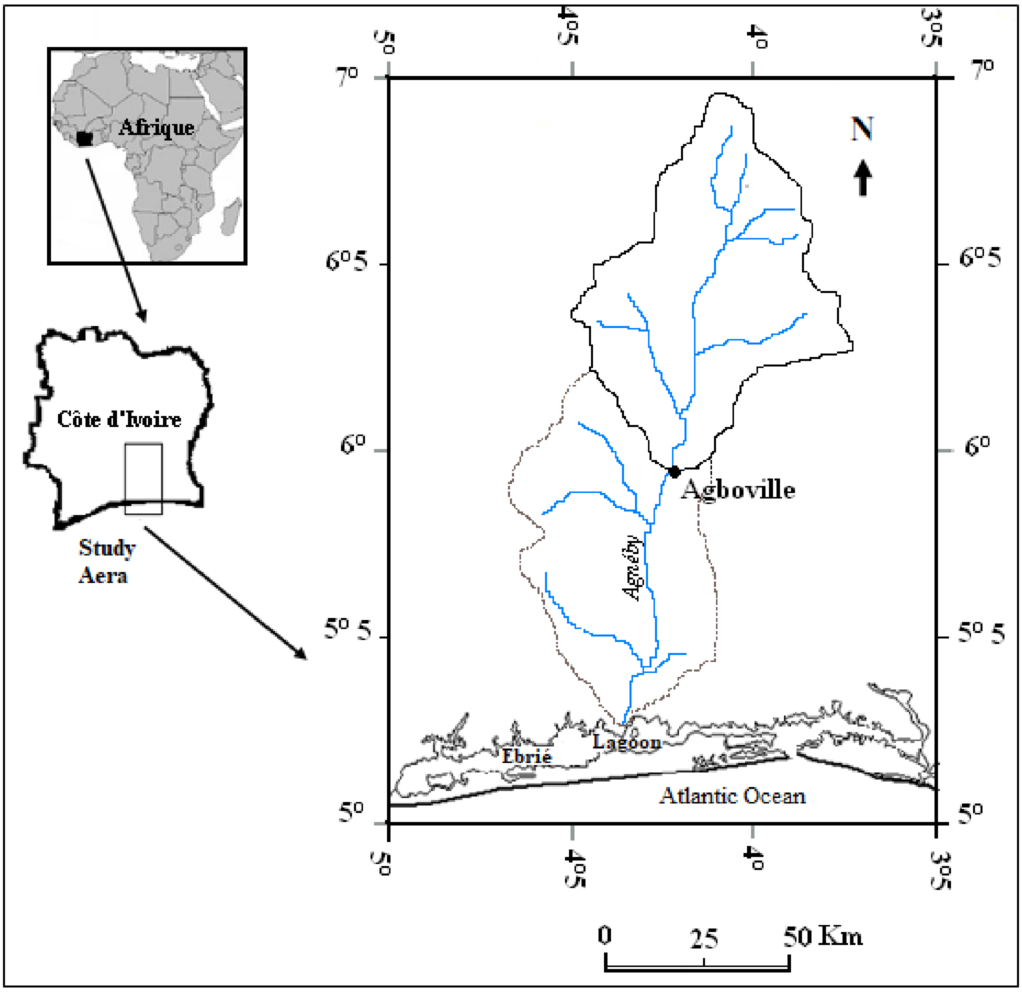

Fig. 1. Study area and hydrometric station of the Agnéby River basin, southern Côte d'Ivoire

2.2 Hydrological Data

Discharge data used in this study were obtained from the national hydrological services and correspond to daily measurements aggregated at the monthly scale for the year 2020. Monthly water volumes were calculated from mean monthly discharge values and the corresponding time periods. These data were used to compute suspended sediment fluxes and to estimate monthly solid exports.

2.3 Sampling And Physico-Chemical Parameters

Water sampling was conducted at the Agboville monitoring station using a frequency adapted to the analyzed parameters. Samples for suspended sediment analysis were collected on a daily basis from January to December 2020, whereas samples for chemical analyses were collected weekly during January, June, September, and October of the same year, as dissolved element concentrations exhibit lower variability than suspended sediment concentrations [3]. Suspended sediment fluxes were estimated using water sampling, a method widely applied in fluvial hydrology [7], [8]. Surface water samples were collected using a 2-L NISKIN bottle, following an intermediate approach previously applied in tropical environments [9]. The relative error associated with surface sampling is less than 10% compared to full vertical integration [10]. During each sampling campaign, pH, water temperature, and electrical conductivity were measured in situ using calibrated portable probes. Water samples were stored in polyethylene bottles previously rinsed with river water. Samples intended for chemical analyses were kept at 4 °C until laboratory analysis.

2.4 SUSPENDED SEDIMENT (TSS) ANALYSIS

Suspended sediment concentrations (Total Suspended Solids, TSS) were determined by filtration of a known volume of water sample through pre-weighed glass fiber filters (Whatman GF/C, 0.45 µm pore size). After filtration, the filters were dried at 105 °C until constant weight. TSS concentrations (mg·L^{-1}) were calculated from the mass difference of the filter before and after filtration, normalized to the filtered volume. Bedload transport was not considered in this study, as it is generally negligible in downstream sections of large river basins characterized by low channel slopes [4]. TSS concentration was calculated as follows:

$$TSS = \frac{P2 - P1}{V} \ (E1)$$

where P1 is the filter mass before filtration (mg), P2 is the filter mass after filtration and drying (mg), and V is the filtered volume (L).

2.5 DISSOLVED ELEMENTS ANALYSIS

Concentrations of major dissolved elements (HCO_3^-, Cl^-, SO_4^{2-}, NO_3^-, Ca^{2+}, Mg^{2+}, Na^+, K^+, and SiO_2) were determined using standard analytical methods described by [11]. Bicarbonates were measured by acid-base titration, while major cations and anions were analyzed by spectrometric and ion chromatography techniques, depending on the parameter considered. Total dissolved solids (TDS) were calculated as the sum of the measured ionic concentrations.

2.6 FLUX CALCULATIONS AND TSS/TDS RATIO

Monthly suspended sediment fluxes were calculated using mean monthly TSS concentrations and corresponding river discharge values. Monthly solid export was estimated by integrating these fluxes over the duration of each month. The TSS/TDS ratio was calculated from monthly mean TSS concentrations and total dissolved solids and was used as an indicator of the relative dominance of mechanical erosion versus chemical weathering processes within the river basin. Inter-basin comparisons were conducted using published data from major tropical river systems, allowing the Agnéby River to be positioned within a broader regional and global hydro-sedimentary context.

2.7 STATISTICAL ANALYSES AND GRAPHICAL REPRESENTATION

Hydrological and chemical data were statistically processed to determine monthly means, seasonal variability, and potential correlations between discharge and TSS or dissolved element concentrations. Graphical representations and summary tables were used to illustrate seasonal trends, flux variability, and the coupling between suspended and dissolved loads, thereby facilitating interpretation of riverine transfers in the context of coastal dynamics and blue economy challenges.

3 RESULTS

3.1 PHYSICO-CHEMICAL PARAMETERS OF RIVER WATER

The physical parameters of the Agnéby River measured at the Agboville station are presented in Table 1. Water pH values range from 6.40 to 6.93, with a mean value of 6.63, indicating slightly acidic to near-neutral waters throughout the study period. The lowest pH values were recorded in September and June, whereas the highest value was observed in January. Electrical conductivity exhibits marked seasonal variability, with values ranging from 115.7 µS·cm^{-1} in June to 253 µS·cm^{-1} in January. The mean conductivity is 170.93 µS·cm^{-1}. Higher conductivity values occur during low-flow periods, while a noticeable decrease is observed during high-discharge conditions. Water temperature shows limited seasonal variation, ranging from 24.8 °C in October to 27.3 °C in June, with an annual mean of 26.3 °C. This narrow thermal amplitude reflects the tropical climatic conditions of the region.

Table 1. Physical water parameters of the Agnéby River at Agboville (2020)

Date	pH	Electrical conductivity (µS·cm⁻¹)	Temperature (°C)
January	6.93	253	27.1
June	6.45	115.7	27.3
September	6.40	180	26.0
October	6.72	135	24.8
Mean	**6.63**	**170.93**	**26.3**

3.2 HYDROLOGICAL VARIABILITY AND SUSPENDED SEDIMENT CONCENTRATIONS (TSS)

Mean monthly discharges of the Agnéby River show strong seasonal variability, typical of a tropical hydrological regime. The lowest values occur during low-flow periods, particularly in January, February, and December, with discharges below 2 $m^3 \cdot s^{-1}$. In contrast, the highest discharges are recorded during the rainy season, with maxima in June (38.30 $m^3 \cdot s^{-1}$), July (36.95 $m^3 \cdot s^{-1}$), and October (35.13 $m^3 \cdot s^{-1}$) (Table 2). Monthly suspended sediment concentrations range from 6.18 $mg \cdot L^{-1}$ in January to 68.71 $mg \cdot L^{-1}$ in October, indicating pronounced intra-annual variability. The highest concentrations are observed during high-flow periods, particularly in April, May, September, and October, whereas the lowest values generally correspond to periods of low discharge. The relationship between mean monthly discharge and suspended sediment concentration is illustrated in Fig. 1. The scatter plot highlights substantial data dispersion and a weak linear correlation ($R^2 \approx 0.09$), indicating that mean monthly discharge explains only a limited fraction of the variability in suspended sediment concentrations.

Table 2. Monthly suspended sediment characteristics of the Agnéby River (2020)

Month	Discharge ($m^3 \cdot s^{-1}$)	TSS ($mg \cdot L^{-1}$)	TSS flux ($kg \cdot s^{-1}$)
January	1.48	6.18	0.01
February	1.55	8.80	0.01
March	4.37	12.65	0.06
April	6.51	30.00	0.20
May	7.06	40.00	0.28
June	38.30	17.00	0.65
July	36.95	10.52	0.39
August	4.84	12.00	0.06
September	8.41	21.33	0.18
October	35.13	68.71	2.41
November	10.82	33.39	0.36
December	1.58	29.68	0.05

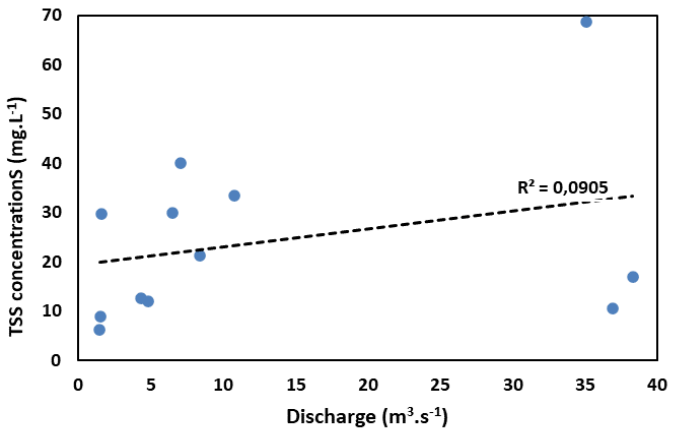

Fig. 2. Relationship between mean monthly discharge and suspended sediment concentration (TSS) in the Agnéby River. The solid line represents the linear regression, and R^2 is the coefficient of determination

3.3 Monthly Suspended Sediment Fluxes And Annual Export

Monthly suspended sediment fluxes, calculated from river discharge and suspended sediment concentrations, exhibit strong seasonal variability (Fig. 3). Fluxes remain very low during low-flow periods, with values below 0.05 kg·s^{-1} in January, February, and December. In contrast, they increase sharply during flood periods, reaching maximum values in October (2.41 kg·s^{-1}), June (0.65 kg·s^{-1}), and July (0.39 kg·s^{-1}). The annual suspended sediment export is estimated at approximately 12,346 tonnes. This export is largely concentrated over a limited number of months. October alone accounts for more than 50% of the annual suspended sediment export, while June, July, and November also contribute significantly to the total flux. Conversely, low-flow months make only a marginal contribution to the annual suspended sediment export. These results highlight a strongly pulsed hydrosedimentary regime, characterized by a pronounced temporal concentration of sediment transfers during high-flow periods.

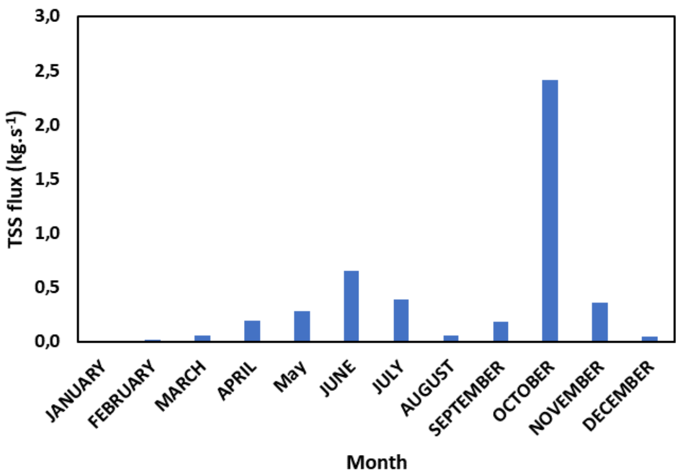

Fig. 3. Monthly suspended sediment flux

3.4 Chemical Composition And Dynamics Of Dissolved Elements

Monthly concentrations of the main dissolved constituents measured in the Agnéby River are presented in Table 3. Total dissolved solids (TDS) range from 136.53 mg·L^{-1} in October to 185.44 mg·L^{-1} in September, with an annual mean value of 166.09 mg·L^{-1}. The ionic composition is dominated by bicarbonates (HCO_3^-), which represent the main anionic species, followed by chlorides. Among cations, calcium and sodium are the dominant elements, whereas magnesium and potassium occur at more moderate concentrations. Sulfate and nitrate concentrations remain low throughout the year. A clear seasonal variability in dissolved concentrations is observed, with generally higher values during low-flow periods and a relative dilution during high-flow conditions, particularly in October. Dissolved silica also exhibits seasonal variations, with higher concentrations during low-flow periods.

Table 3. Monthly concentrations of major dissolved elements in the Agnéby River (2020)

Month	HCO_3^-	Cl^-	SO_4^{2-}	NO_3^-	Ca^{2+}	Mg^{2+}	Na^+	K^+	SiO_2	TDS ($mg.L^{-1}$)
January	83.00	23.0	0	8.90	14.04	6.56	15.7	6.30	23.90	181.40
June	85.64	14.7	1	5.70	13.23	2.19	18.5	3.75	16.30	161.01
Sepember	114.00	16.0	2	0.201	23.00	7.00	16.0	4.00	3.24	185.44
October	63.44	18.0	1	2.50	16.04	4.62	12.0	5.23	13.70	136.53

3.5 TSS/TDS RATIO

The ratios between suspended sediment concentrations (TSS) and total dissolved solids (TDS) are presented in Table 4. The TSS/TDS ratio exhibits strong seasonal variability throughout the year, with a minimum value of 0.034 observed in January and a maximum value of 0.503 recorded in October. Intermediate values are observed in June (0.106) and September (0.115). The mean SS/TDS ratio over the study period is 0.19.

Table 4. Monthly MES/TDS ratios in the Agnéby River (2020)

Month	TSS ($mg \cdot L^{-1}$)	TDS ($mg \cdot L^{-1}$)	TSS/TDS ratio
January	6.18	181.40	0.034
June	17.00	161.01	0.106
September	21.33	185.44	0.115
October	68.71	136.53	0.503
Mean	—	—	**0.19**

4 DISCUSSION

4.1 HYDRO-GEOCHEMICAL FUNCTIONING AND CONTROL OF SUSPENDED AND DISSOLVED TRANSPORT

The results show that the hydro-geochemical functioning of the Agnéby River is closely controlled by the hydrological regime, which simultaneously governs the transport of suspended sediments (TSS) and dissolved elements. SS concentrations and fluxes generally increase with discharge, highlighting the key role of flow conditions in the mobilization and transfer of solid particles. Maximum fluxes occur during high-flow periods, confirming that sediment export is mainly driven by flood events, as commonly observed in humid tropical river basins [3]. At the same time, the chemical composition of Agnéby waters, dominated by bicarbonates and alkaline-earth cations (Ca^{2+}, Mg^{2+}), indicates a mineralization pattern primarily controlled by chemical weathering of basin rocks, which is typical of humid tropical catchments in West Africa [3]. The low concentrations of sulfates and nitrates suggest a limited anthropogenic influence on water chemistry. Seasonal variability in total dissolved solids, characterized by lower values during high-flow periods, reflects a dilution effect associated with increased discharge, whereas higher concentrations observed during low-flow conditions result from longer water residence times and enhanced water–rock interaction. Dissolved silica concentrations further confirm the dominant role of silicate mineral weathering in shaping the geochemical signature of the Agnéby River. However, the relationship between discharge and TSS concentration is not strictly linear (Fig. 2), indicating a partial decoupling between concentrations and solid fluxes. High fluxes may be associated with moderate concentrations during periods of high discharge, whereas high concentrations may correspond to lower fluxes during low-flow conditions. This variability reflects the combined influence of sediment availability, pedological and geological characteristics of the watershed, vegetation cover, and anthropogenic pressures. It highlights the need for an integrated approach that simultaneously considers suspended and dissolved transfers to properly interpret the hydrosedimentary functioning of the Agnéby River [4].

4.2 COUPLING BETWEEN MECHANICAL EROSION AND CHEMICAL WEATHERING AND REGIONAL COMPARISON

The combined analysis of suspended sediment and dissolved element fluxes reveals a seasonal alternation between periods dominated by chemical weathering and periods dominated by mechanical erosion. The low TSS/TDS ratios observed during low-flow conditions indicate efficient chemical weathering, favored by reduced discharge and increased water residence time. In contrast, the high TSS/TDS ratios recorded during flood periods reflect the predominance of mechanical erosion, driven by intense runoff and the mobilization of surface particles and sediments stored in the riverbed. Overall, these results demonstrate a clear seasonal alternation between chemically dominated processes during low-flow periods and mechanically dominated processes during flood events. This coupled hydro-geochemical functioning is summarized in the conceptual diagram presented in Fig. 4.

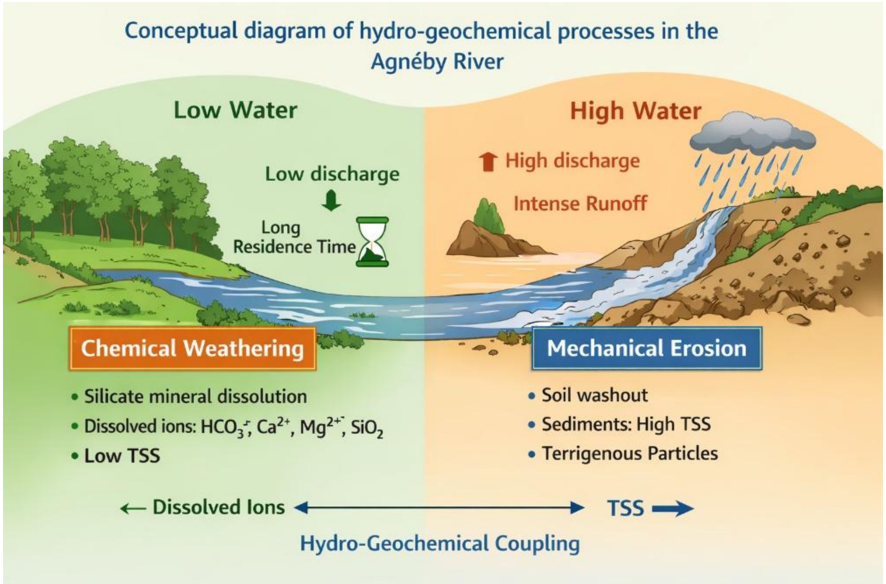

Fig. 4. Conceptual diagram illustrating the coupling between dissolved load dynamics (chemical weathering) during low-flow conditions and suspended sediment transport (mechanical erosion) during high-flow periods in the Agnéby River

The updated comparison highlights marked contrasts in suspended sediment dynamics between the Agnéby River and larger river basins in Côte d'Ivoire (Table 1). The Agnéby River, a medium-sized tropical coastal catchment, exhibits an impulsive sediment transport regime, with more than 50% of the annual suspended sediment export concentrated within a single month. This behaviour reflects the limited sediment storage capacity of the basin and the strong influence of short-duration high-flow events on sediment mobilisation, a characteristic commonly observed in small to medium tropical catchments [4], [3]. In contrast, larger river systems such as the Bandama and the Comoé display a more progressive seasonal distribution of suspended sediment transport. In the Bandama River, recent measurements conducted at the Bafécao hydrometric station during the 2019–2020 hydrological year indicate very low mean suspended sediment concentrations (~9 mg L^{-1}) and an annual suspended sediment export of approximately 8×10^4 t yr^{-1}. This reduced sediment yield is primarily attributed to sediment trapping by the Kossou and Taabo reservoirs, which significantly attenuate downstream sediment fluxes and redistribute sediment transport over several months of the rainy season [12]. Similar effects of reservoir regulation on suspended sediment fluxes have been widely documented in large river basins worldwide [4]. The Comoé River, despite its large drainage area, also exhibits a progressive hydrological control on sediment transport, with suspended sediment fluxes distributed over the rainy season rather than being dominated by a single extreme event. This behaviour reflects the buffering effect of channel and floodplain storage typical of large tropical basins, which dampen short-term hydrological variability [13], [14]. At the regional scale, studies conducted in the Sassandra watershed highlight a strong seasonal hydrological variability, with sediment mobilisation enhanced during flood periods but generally spread over the rainy season rather than concentrated within a single peak month [15]. The consistency between hydrosedimentary and geochemical indicators further supports these interpretations. In the Agnéby River, TSS/TDS ratios ranging from 0.08 to 0.30 indicate a transition from chemically weathering-dominated conditions during low-flow periods to a mixed regime increasingly influenced by mechanical erosion during high-flow events [16], [14], [4]. In contrast, the Bandama River shows a much lower relative contribution of suspended solids, with suspended sediments representing only about 12% of the total exported matter, confirming the dominant role of dissolved loads under regulated flow conditions [12]. These contrasts emphasise the combined influence of basin size, hydrological regulation and sediment storage capacity on suspended sediment dynamics in tropical river systems

Table 5. Comparative hydrosedimentary and geochemical characteristics of the Agnéby River and selected tropical river basins

Basin	Basin type	Annual suspended sediment export	Contribution of peak period	Mean / max TSS (mg L^{-1})	Dominant sediment transport regime	References
Agnéby (Côte d'Ivoire)	Medium-sized tropical coastal basin	~1.2×10^4 t yr^{-1}	> 50% (Oct.)	Mean ~30 / Max ~70	Impulsive, flood-dominated	This study
Bandama (Côte d'Ivoire)	Large tropical basin, regulated	~8.0×10^4 t yr^{-1} (MES)	Seasonal, multi-month	Mean ~9	Strongly regulated by dams	[12]
Comoé (Côte d'Ivoire)	Large tropical basin	10^4–10^5 t yr^{-1}	< 40%	60–150	Progressive hydrological control	[13]
Sassandra watershed	Humid tropical basin	Order of 10^4–10^5 t yr^{-1}	Seasonal	High during flood events	Flood-enhanced mobilisation	[15]
Upper Niger	Very large tropical basin	> 10^6 t yr^{-1}	< 30%	100–300	Storage–remobilisation dominated	[14]
Tropical forest basins (general)	Humid tropical basins	10^3–10^5 t yr^{-1}	Variable	50–150	Mixed discharge–concentration control	[4], [16]

4.3 IMPLICATIONS FOR COASTAL ECOSYSTEMS AND THE BLUE ECONOMY

The hydro-sedimentary dynamics identified in this study have direct implications for the coastal and lagoonal ecosystems located downstream of the Agnéby basin. Large inputs of suspended sediments during flood events contribute to increased turbidity and sediment accumulation in estuarine environments, which may negatively affect primary productivity and aquatic habitats. Conversely, dissolved matter inputs, which are more evenly distributed throughout the year, play a key role in sustaining the natural fertility of coastal ecosystems. These processes directly influence blue economy activities, including fisheries, aquaculture, navigation, and the management of port and lagoonal infrastructures. The results therefore highlight the importance of an integrated watershed–coastal management approach aimed at reducing upstream erosion while preserving the ecological functioning of coastal zones. In a context of increasing climate variability, such an approach appears essential to reconcile environmental sustainability with socio-economic development in Côte d'Ivoire.

5 CONCLUSION

This study highlights the central role of hydrological variability in controlling suspended sediment and dissolved matter transfers within the Agnéby River basin. The coupled analysis of TSS and TDS reveals a contrasted hydro-geochemical functioning, with chemical weathering dominating during low-flow conditions and mechanical erosion becoming increasingly significant during flood events. The strong temporal concentration of suspended sediment fluxes, with a large proportion of the annual export associated with a limited number of high-flow events, reflects an impulsive transport regime typical of medium-sized tropical coastal basins. Moderate suspended sediment concentrations combined with relatively low TSS/TDS ratios indicate that, despite the importance of floods in sediment mobilisation, chemical weathering remains a key process structuring the geochemical behaviour of the basin. Regional comparison shows that this response differs markedly from that of larger Ivorian river systems, such as the Bandama and Comoé rivers, where hydrological regulation and greater sediment storage capacity dampen seasonal variability and promote a more progressive redistribution of sediment fluxes. The Agnéby River thus appears highly sensitive to hydroclimatic variability, and its solid and dissolved inputs play a significant role in sustaining sediment supply to the Ébrié Lagoon and adjacent coastal environments. In the context of ongoing climatic changes and increasing anthropogenic pressures, these results underline the need for strengthened hydro-sedimentary monitoring of tropical coastal basins to improve the understanding and management of land–ocean fluxes and to support the sustainable development of the blue economy in Côte d'Ivoire.

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