

Dynamics of the Physico-chemical Properties of Sediments along the Bandama River in the Department of Niakaramadougou, Northern Côte d'Ivoire

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

This work focuses on analyzing of physico-chemical properties of sediment affected by frequent floods along the eastern shore of the Bandama River in the department of Niakaramadougou. Sampling was from 4 excavated graves at two positions of studied area, one near the stream and the other one far away from the stream.. Samples collected were analyzed, including texture with granulometric analysis made by the Robinson pipette, and standard sediment analysis methods for measuring organic carbon (OC), nitrogen (N), and other chemical properties including pH, organic matter (OM), and C/N ratio. Statistical analyses were carried out to assess the differences between the physico-chemical parameters at different sampling areas. Differences are significant when comparing areas that are highly affected by floods and areas that are less affected by floods, especially for concentrations of OM, OC and nitrogen. Results show that successive floods are influencing directly the dynamic of physico-chemical properties of the sediments along the shore.

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1. INTRODUCTION

Recent decades have been marked by an increase in scientific work on hydroclimate change related to the anticipated impacts of climate change [1,2]. These changes brought about effects on river flow patterns and play a key role in stabilizing riparian ecosystems [3,4]. There is an increase in precipitation, flow levels flooding and a vertical increase in alluvial plains in active sedimentary areas affected by periodic floods [5]. Several studies describe the variability of physico-chemical properties of alluvial soils and sediments in different hydrological contexts [6,7,8,9,10]. The constant supply of alluvium transported by successive floods would have an impact on the physico-chemical properties of the sediments. These vary according to three large gradients. The longitudinal gradient (upstream-downstream), the horizontal gradient (channel distance) and the vertical gradient (depth) [8]. There should be marked differences between sediments near shore, which are therefore frequently flooded from sediments further away. Successive or periodic river floods are causing changes in riparian ecosystems [11]. This study attempts to highlight the impact of recurring flooding on the physico-chemical properties of river sediments based on the distribution of the physico-chemical parameters of the sediments away from the stream and comparing them with those of the near environment. Sediments are defined as continental or marine deposition consisting of particles from the alteration or disaggregation of pre-existing rocks and the precipitation of suspended materials that pass through the water column [12,13]. The particles that make up the sediments are more or less large and consist of organic and inorganic compounds [14]. The chemical composition of a sediment is specific to its environment and sources near the deposit area. However, the particles that make up the sediment will also undergo and/or induce bio-geochemical transformations which leads first to changes in physico-chemical composition and, second, to the formation of sedimentary rock [15]. These processes are primarily controlled by OM in the sediment column. After OM is buried in sediments, it will be progressively degraded through oxydo-reduction reactions controlled primarily by bacterial activity [16]. The study of the physico-chemical properties of sediments, including sediment organic matter in current environments, could be used as a basis for

paleoclimatic and paleoenvironmental interpretations [17]. Sedimentary organic matter consisting mainly of organic carbon and nitrogen has an impact on the sustainable functioning of ecosystems [18]. The main objective of this study is to assess the spatial distribution of the physico-chemical properties of the sediments along the shore of the Bandama River at Longo. This area was flooded recently after the Bandama River was removed from its bed.

2. MATERIAL AND METHODS

2.1 Location and Sampling

Four sampling points along the shore were predefined (Fig. 1) and were sampled from surface sediments at a depth of 10 to 150 cm. The various analyzes carried out in this study were carried out on the fine length part (< 2 mm), which was separated at laboratory a few weeks later after sampling.

These samples were analyzed to determine:

- The particle size (sandy, clay and lemon fraction), pH, total organic carbon, total nitrogen and organic matter.
- The analysis of each of these parameters involved specific methods as described below.

2.2 Physico-chemical Characterization of Sediment

Abbreviations used during analysis

- C1: surface layer
- C2: intermediate layer
- C3: depth layer

We compared positions (F10 (close) and F40 (far)) and compared layers

2.2.1 Physical parameters of sediments

2.2.1.1 Granulometry

It was determined by Robinson's Pipette method [19]. The application of this analysis allowed:

- to know the substances (OM and nitrogen) associated with the particle size contained in the sediment. It is used to determine whether they are in the fine, medium or coarse fractions;

- to reconstitute the conditions for transport and deposition of particles.

2.2.1.2 Texture

Triangular diagram of fine soils proposed by [20] was used. This type of diagram is particularly suitable for sediments because sediments can then be characterized according to the respective content of three particle size fractions (clay, silt and sand) [21,22].

2.2.2 Chemical sediment parameters

Also OC, OM, nitrogen and PH levels were determined.

pH of water was determined by measuring H_3O^+ ion activity using a pH meter [23].

Organic carbon of sediments was determined by Anne's method [24]. The carbon of the organic matter is oxidized by potassium bichromate in sulfuric medium.

The assessment of the organic matter content was made by quantifying its major constituent element, organic carbon, which represents almost 50% of this element [25]. The content of the OM was assessed based on the following conventional relationship: $OM = C \times 1,72$ [26].

Nitrogen in sediments was determined by the Kjeldahl method [20]. The principle is to transform the nitrogen of organic compounds from a finely crushed sediment sample into ammoniacal nitrogen under the action of concentrated sulfuric acid, which, when boiled, behaves as an oxidant. Organic substances are decomposed: carbon comes out as carbon dioxide, hydrogen gives water, and nitrogen is transformed into ammonia nitrogen. The latter is fixed immediately by sulfuric acid in the form of ammonium sulfate.

The C/N ratio is an indicator of sediment biological activity that provides information on the degree of organic matter evolution, biological activity, mineralization. The smaller the biological activity, the more difficulties encountered in mineralization. This reflects conditions of anaerobic, excessive acidity. The study of the C/N report is an approach to the problem of the origin, nature and evolution of organic matter [27].

2.2.3 Statistical analysis

Data analysis was done using variance analysis of different variables using SAS 9.4 software. The significance test is Fischer's distribution or "F test" at the 5% probability threshold. Correlation tests (Pearson) were also performed between variables (OM, pH, OC., N, texture). These tests allowed comparisons of different parameters according to the horizontal gradient (channel distance) and vertical (depth). Finally, a primary component (PCA) analysis was conducted to verify that there is a link between the different physico-chemical parameters, the layers and the positions close to or far from the stream. Units used were % to gkg-1 (international unit) for carbon, nitrogen and organic matter (OM).

3 RESULTS

3.1 Sediment Granulometry and Texture

Limon percentages increase with depth when close to the stream and decrease with depth away from the stream (Table 1, Fig. 2) The sandy fraction is greater in both study areas (Fig. 2). Particles increase in size. The texture is sandy-clayey close to the channel and sandy-limonous as you move away (Table 1).

3.2 Chemical Characteristics of Sediments

A decrease with the depth of organic matter (OM) in the layers of the two study areas was noted (Fig. 3). The surface layers

Table 1. Granulometry and sediment texture of layers according to positions

Layer	F10C1	F10C2	F10C3	F40C1	F40C2	F40C3
Clay (p.c.)	26,75	31,75	23	11,5	17	14,5
Fine Limon (p.c.)	5	1	2,75	4,5	3	4
Coarse Limon (p.c.)	14,6	17,2	26,1	26,3	24,65	22,6
Fine sand (p.c.)	33,4	36,1	29,35	35,1	32,5	29,3
Coarse sand (p.c.)	17,5	13,6	17,2	19,65	22,25	27,9
Texture	SA	SA	SL	SL	SL	SL

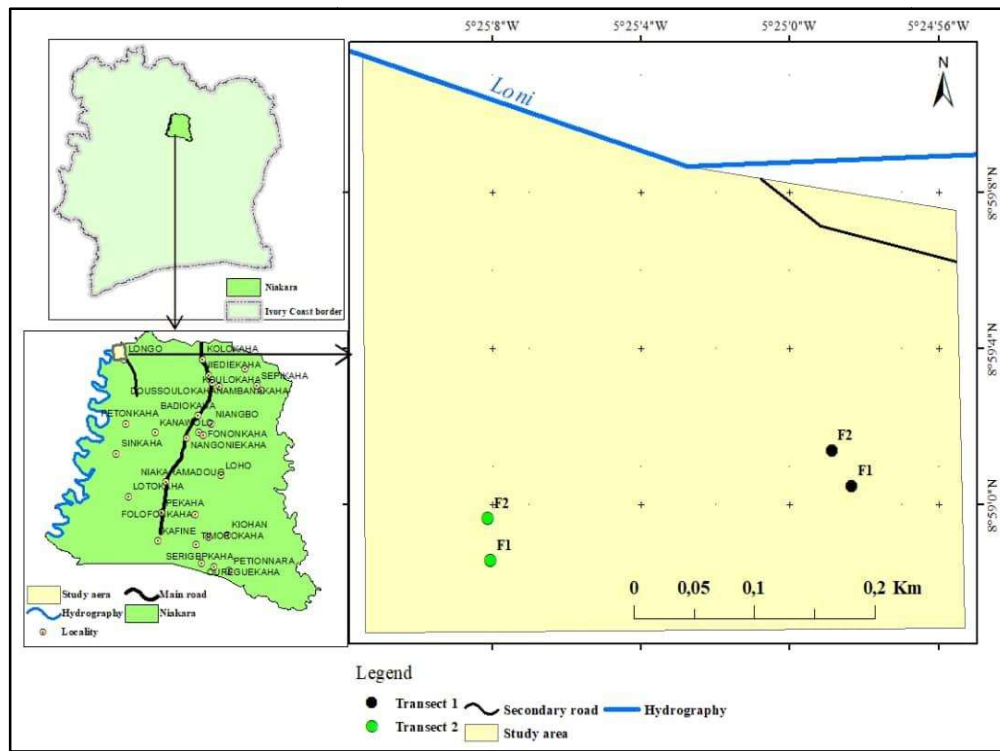


Fig. 1. Location map of the study area

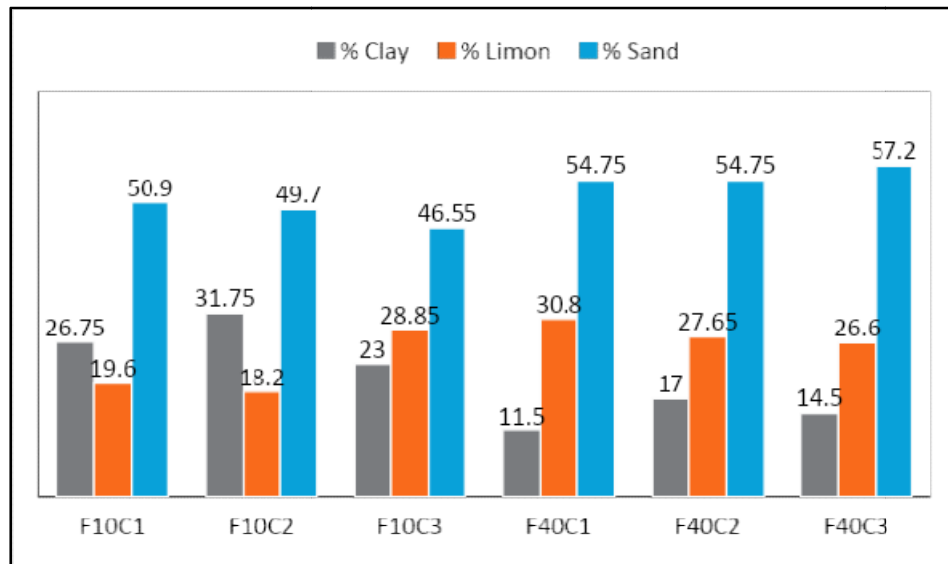


Fig. 2. Evolution of granulometry
F10 = pit near the river, F40 = remote pit

far from the stream are therefore more organic than the surface layers close to the main channel. The OM rate increases from 26.26 gkg⁻¹ on the surface to 7.35 (gkg⁻¹) deep when close to the channel and from 52.95 gkg⁻¹ to

5.67 gkg⁻¹ when far from the channel, respectively. Average organic matter (OM) levels in areas near and far from the stream range from 16.81 to 24.02 gkg⁻¹, respectively, as shown in Fig. 4. This low OM level near the watercourse is

believed to be due to the occasional flood and storm events that promote the transport of certain elements.

Analyzes show the gradual decrease with the depth of OC organic carbon in the layers, regardless of the sector (Fig. 5). The surface layers far from the stream are therefore richer in organic carbon (OC) than the surface layers close to the channel. The OC rate increases from 15.23 gkg⁻¹ on the surface to 4.27 gkg⁻¹ deep when close to the channel and from 30.71 gkg⁻¹ to 3.29 gkg⁻¹ when far from the channel, respectively.

A decrease is observed with the depth of nitrogen (N) in the layers (Fig. 6). The surface horizons away from the stream are therefore more nitrogen-rich (N) than those near the stream surface horizons. Nitrogen has the same

evolution as organic matter and carbon relative to the position near or far from the stream.

Analyzes revealed a decrease in C/N ratio from surface layers to depth layers near the stream (Fig. 7). This ratio ranges from 19.7 to 17.68. In layers far from the watercourse, the C/N ratio ranges from 26.62 to 16.5. The intermediate layer has a C/N ratio of 26.62, the increase of C/N in the intermediate layer reflects a faster degradation of the nitrogen compounds.

The pH generally decreases with depth (Fig. 8) except for the C3 layer near the stream, which has a value of 6.12. The pH is close to neutrality when you move away from the stream. It is between 7.09 and 6.09. Near the channel, it ranges from 6.12 to 5.87, thus low to medium acid.

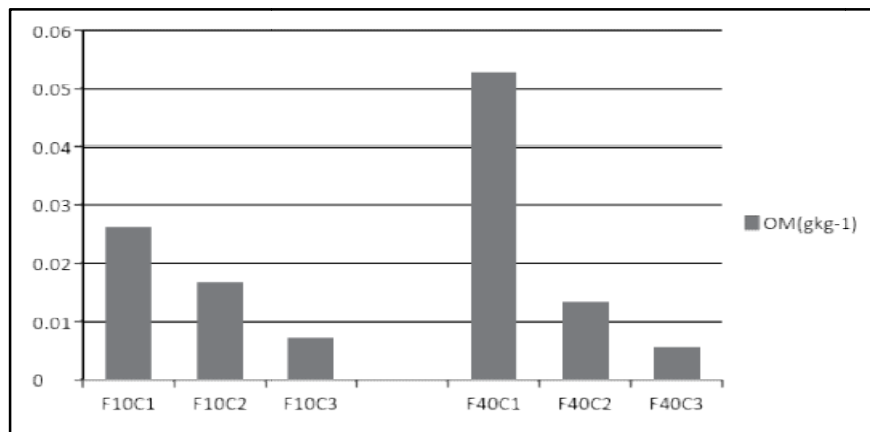


Fig. 3. Change in organic matter rate OM (gkg⁻¹) in horizons at the study area in relation to their position (near or far) to the shore

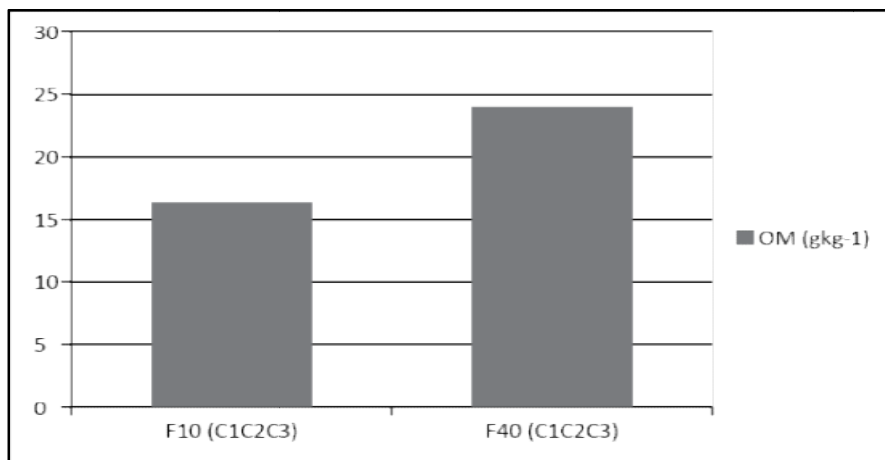


Fig. 4. Change in the organic matter rate of the study area relative to the position (close or far) to the shore

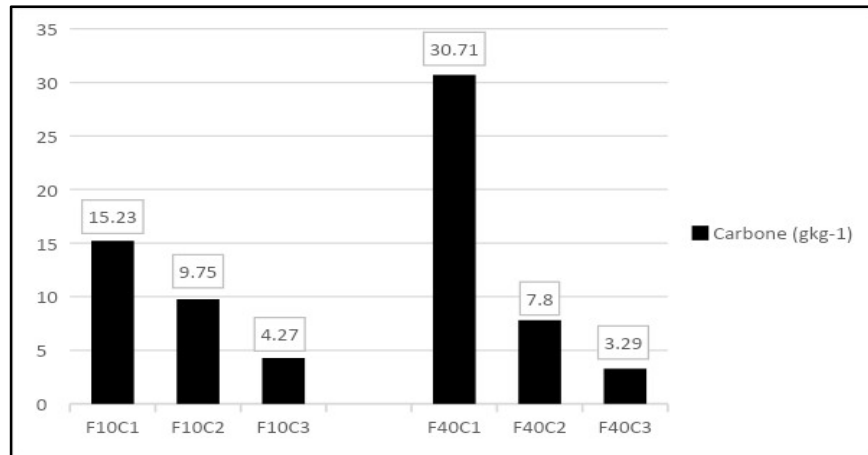


Fig. 5. Change in the organic carbon rate in the zone layers study with respect to the position (near or far) of the stream

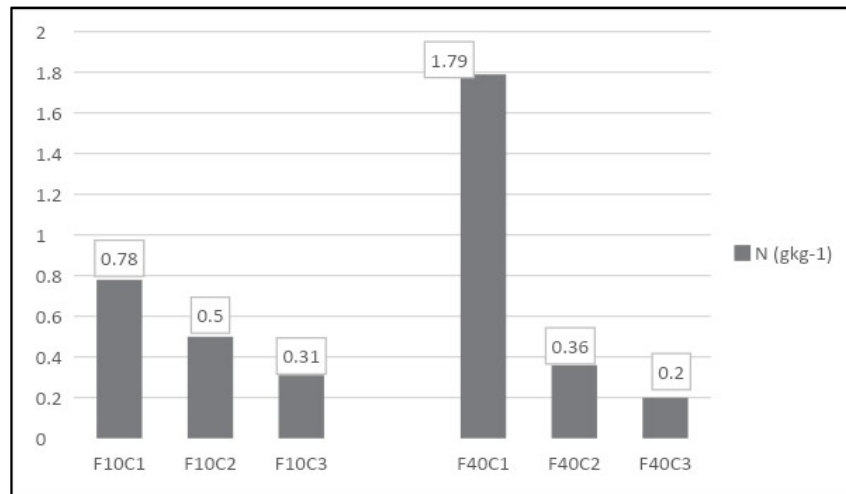


Fig. 6. Variation in nitrogen within layers in study area with respect to stream position (near or far)

3.3 Statistical Analyzes

Analysis of variance showed a significant difference between positions (near and far from the stream) for clay. For silt, sand and the proportion of physical elements, no significant differences were observed between the two positions (Table 2).

Analysis of variance showed no significant differences between layers for all clay, silt, sand and proportion of physical elements (Table 2).

Analysis of variance showed a significant difference between the positions (near the stream and far from the stream) for pH. For the other variables no significant differences were found (Table 3).

Variance analysis showed significant differences between layers for carbon and organic matter.

The Pearson correlation test showed a very good correlation between carbon and organic matter with a correlation coefficient, $r = 1$ and a probability, $P < 0.0001$. Also, the Pearson correlation test showed a good correlation between nitrogen and organic matter with a correlation coefficient, $r = 0.994$ and a probability, $P < 0.0001$, between carbon and nitrogen with a correlation coefficient, $r = 0.994$ and a probability, $P < 0.0001$. The pH was positively correlated with carbon with a correlation coefficient, $r = 0.812$ and a probability, $P = 0.050$, nitrogen ($r = 0.838$; $P = 0.037$) and organic matter ($r = 0.812$; $P = 0.050$) (Fig. 9).

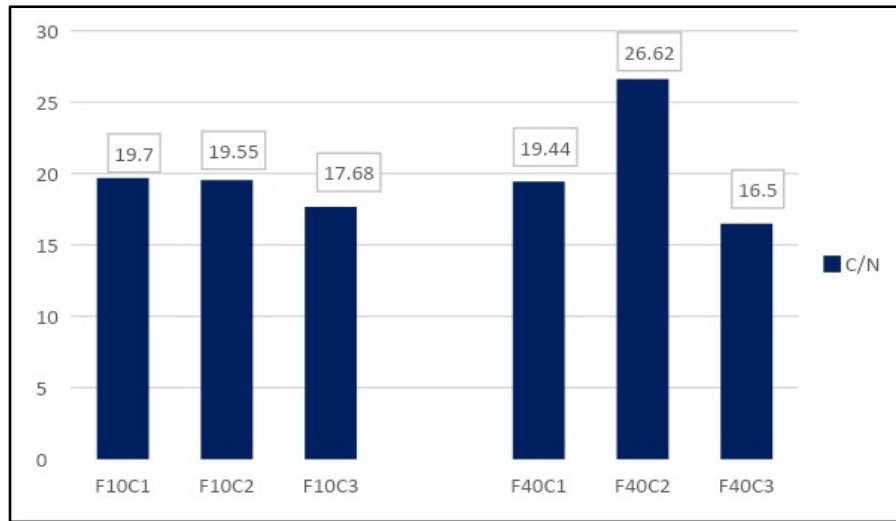


Fig. 7. Change in C/N ratio to stream position

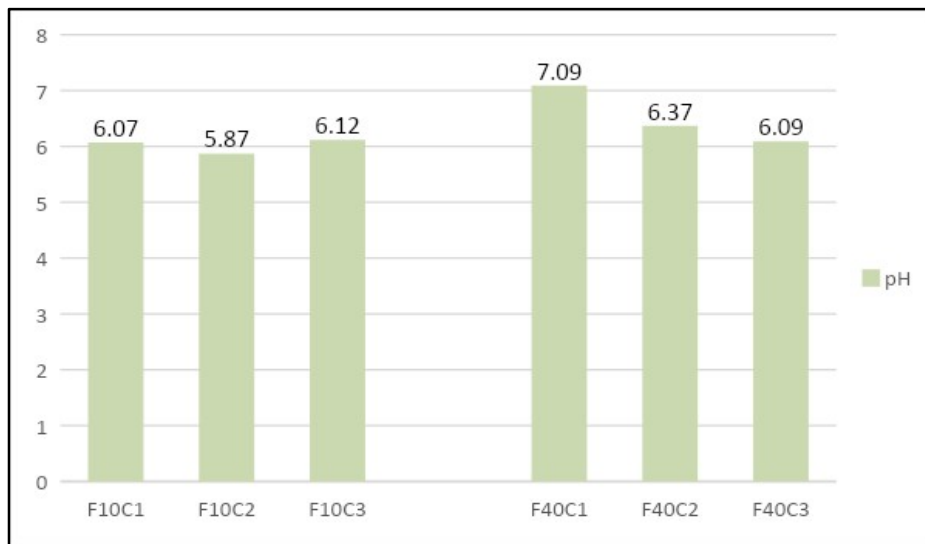


Fig. 8. Variation of pH in layers by position

Table 2. Comparison of physical soil characteristics between positions and layers

	% clay	% limon	% sand	% Physical elements
Position				
Near the river	20,13 a	27,05 a	50,63 a	9781 a
Far from the river	11,88 b	34,57 a	51,28 a	9772 a
Pr > F	0,0339	0,7338	0,3065	0,9927
Layer				
C1	16,38 a	31,00 a	48,51 a	95,89 a
C2	18,81 a	30,69 a	48,99 a	98,49 a
C3	12,81 a	30,74 a	55,36 a	98,91 a
Pr > F	0,1367	0,9973	0,5053	0,1574
Moyenne	0,16	0,31	0,51	0,98
C.V. (p.c.)	11,65	12,98	10,83	4,43

Nb: Means followed by the same letters in a column are not significantly different from the 5 p.c. threshold

Table 3. Comparison of chemical characteristics between positions and layers

	Carbon (gkg ⁻¹)	Nitrogen (gkg ⁻¹)	C/N	Organic matter (gkg ⁻¹)	pH
Position					
Near the river	9,750 a	0,53 a	18,98 a	16,81 a	6,02 b
Far from the river	13,93 a	0,78 a	20,81 a	24,02 a	6,52 a
Pr > F	0,8131	0,5870	0,4289	0,8111	0,0393
Layer					
C1	22,97 a	1,29 a	19,57 a	39,61 a	6,58 a
C2	8,78 ab	0,43 a	23,09 a	15,13 ab	6,12 a
C3	3,78 b	0,25 a	17,09 a	6,51 b	6,11 a
Pr > F	0,0449	0,0844	0,5634	0,0455	0,4023
Moyenne	11,84	0,66	19,92	20,42	6,27
C.V. (p.c.)	31,67	37,26	37,11	31,90	7,99

Nb: Means followed by the same letters in a column are not significantly different from the 5 p.c. threshold

	limon	sand	totals	carbon	Nitrogen	C/N	Organic matter	pH
clay	-0,607	-0,451	-0,038	-0,076	-0,134	-0,034	-0,076	-0,618
	0,201	0,369	0,943	0,887	0,800	0,949	0,887	0,191
limon	1.00000	-0,386	0,298	0,482	0,533	-0,020	0,482	0,756
		0,450	0,567	0,333	0,276	0,970	0,333	0,082
sand		1.00000	0,038	-0,683	-0,657	-0,028	-0,683	-0,309
			0,943	0,135	0,156	0,957	0,135	0,552
totals			1.00000	-0,555	-0,501	-0,264	-0,555	-0,352
				0,253	0,311	0,614	0,253	0,494
carbon				1.00000	0,994	0,056	1,000	0,812
					< 0,0001	0,916	< 0,0001	0,050
Nitrogen					1.00000	-0,012	0,994	0,838
						0,982	< 0,0001	0,037
C/N						1.00000	0,056	0,183
							0,916	0,729
Organic matter							1.00000	0,812
								0,050

Fig. 9. Correlation matrix (Pearson) of the following sediment characteristics positions and layers

Values in blue are different from 0 to a level of alpha=0.05 meaning

The data analyzed is represented by the F1 and F2 axes with 74.11 p.c. inertia. Clay was well correlated with the F2 axis with a square cosine of 0.912. Limon, nitrogen, pH, carbon, and organic matter are highly correlated with the F1 axis. Carbon and nitrogen are well correlated ($R^2 = 0.988$). Also, the main component analysis (PCA) showed that the F10mC3, and F40mC1 contribute to the formation of the F1 axis, respectively, with squares of 0.698 and 0.973; the F2 axis carried the information of the individual F10mC1. The carbon, nitrogen, pH, and silt variables were related to the individual F40mC1; Clay is related to F10mC1 and F10m C2; finally, a link between sand and total physical elements and F10mC3, F40mC3 and F40mC2 (Fig. 10).

4. DISCUSSION

The majority of soil samples analyzed in the study areas consist of sandy-limonous textures with a higher proportion of clay (about 20%) in the area closer to the stream. In contrast, in the area further away from the stream, the proportion of clay is about 10%. This slight variation at the level of the two zones would be due to hydromorphological conditions (erosion and sedimentation) which vary from one zone to another. The sedimentation rate is lower in the area far from the stream. For the area near the channel, this significant presence of finer particles or clay would be due to the deposition of fine suspended river sediments during floods. In the

area far from the stream, this very small proportion of clay is due to the fact that during floods, water containing fine suspended sediments reaches this area unevenly or rarely. Textural variability is due to the diversity of moveable deposits that make up land outside flood [28]. Depending on the origin of the sampling point, large particle size variations can be identified [29]. However, in some locations, the availability of sediment at source will influence the size distribution. If the only material available in the sedimentation basin is a material made of fine particles, the transport agent will not be able to carry particles more coarse than those available at source [30]. The results show a lower or lower level of OM in sediment. This decline is accentuated when you approach the channel. This low level of MO near the channel is due to occasional flooding and decoupling events that promote the transport of certain elements [31]. It is suggested that the erosion phases associated with the flood and storm events result in sediment reworking. This oxidizes the different elements and thus quickly remineralizes the OM, thus explaining the low levels of MO in the sediment. These results are consistent with the work done by [32] which shows that alluvial soils are also characterized by low concentrations of organic matter in their natural environment due to low or near absence of litter. Low amounts of organic

carbon are associated with different hydroclimatic changes [7]. However, higher concentrations of organic carbon are found in areas further away (5, 10, 20, 30 m) from shore which are less prone to flooding than areas directly affected by frequent flooding [33]. Also, the study of [8] shows that sediment organic carbon concentration increases significantly with distance from the main channel. They experience fewer disturbances from river bed overflows. The physico-chemical properties of the sediments vary widely depending on stream flow, sediment load, and the different patterns and patterns of flooding [8]. The frequency and duration of flooding has a real impact on the quality and quantity of sedimentation [34,35]. Numerous studies have shown the different impacts of this river phenomenon [36,37,1,38]. Floods and landslides can have beneficial or adverse effects on riparian ecosystems [39,27,40,41,42].

OC and N levels decrease with depth in both sectors. The study of [7] also shows that the concentration of nitrogen and organic carbon decreases with depth. Because the primary sources (organic matter) of these two parameters are generally within the first centimeters of soil, OC and N concentrations are therefore higher in the upper soil layers [43].

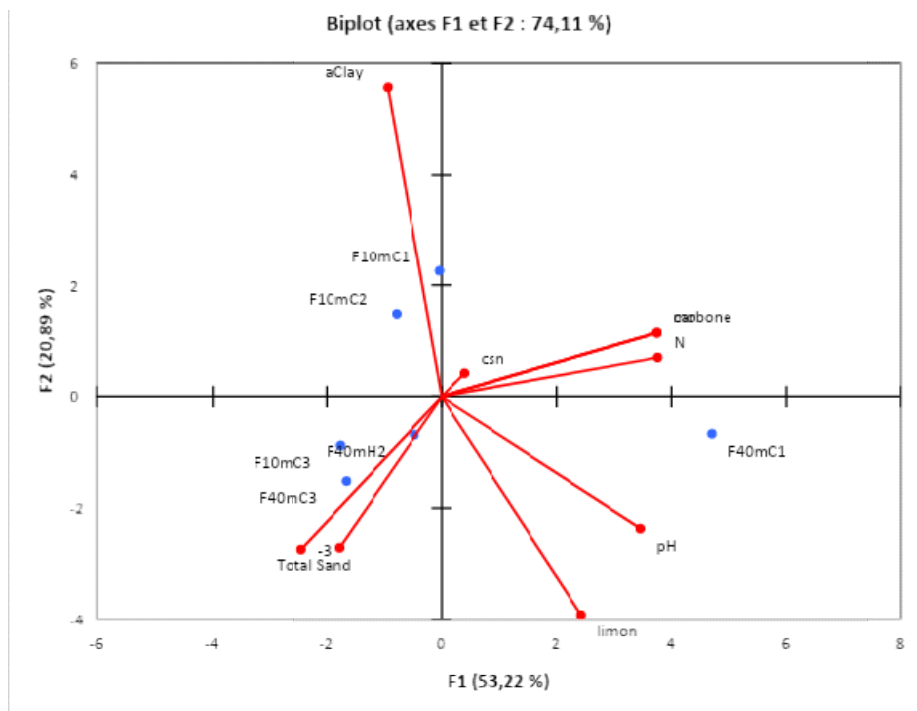


Fig. 10. Primary Component Analysis (ACP) on F1 and F2 axes for physico-chemical characteristics of sediments according to positions and layers

Results indicate that the proportions of clay are lower in depth. High levels of organic carbon are recorded in the upper layers with the highest proportions of clay. The organic carbon concentration is higher in fine matrix sediments than those with coarse matrix [44,7,8,45]. There is a significant correlation between organic carbon and particle size distribution [45]. A high concentration of organic carbon is often associated with a high proportion of clays in soils and sediments [46,47]. Organic matter is not evenly distributed in soil and sediment. It occurs not only in the different layers but also for the same layer in the different particle size classes with different physical, chemical and biological properties [48].

5. CONCLUSION

The objective of this study was to demonstrate the impact of floods on the physical and chemical properties of sediments along the shore. Results show that sediment texture varies more or less depending on the different alluvial areas studied. Generally a sandy-clay texture occurs close to the stream and a sandy-limonous texture away from it. Textural variability is due to the diversity of moveable deposits. Overall, the sediment load capacity of coarse particles (fine and coarse sand) is greater. Significant differences in sediment chemical parameters were measured between the different flood recurrence areas. Differences are significant when comparing areas that are highly affected by floods and areas that are less affected by floods, especially for concentrations of OM, OC and nitrogen. Lower values were recorded in areas subject to more frequent flooding. Average organic content in areas close to and far from the stream range from 16.81 to 24.02 kg⁻¹, respectively. This decrease in levels near the watercourse attributed to a change in the sedimentation environment. Relatively low levels are the response of successive flood-related disturbances as flooding plays an important role in this riparian area, causing significant effects on the physico-chemical properties of the sediments. This study provided a better understanding of the spatial distribution of the physico-chemical properties of sediments along the Bandama River bank in a climatic context of changes in which floods act as a major disturbance factor in the ecosystem.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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