Geomorphological Evolution And Inundations In The Déhita Valley, Important Witnesses Of Climate Change In The Peripheral District Of The Bouaflé City (Central-west Of Côte d'Ivoire)

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Abstract

In Bouaflé town, the valley of Déhita is on front frontline facing global warming. It undergoes inundations, as they occur more and more regularly, which threaten human life and installations.

There is a real difficulty in isolating these crises from the effects of the revival of morphogenetic processes due to global warming. Thus, how does geomorphological evolution links to the current climate, imply the inundations, which threaten the populations in the Déhita valley ? Objective is to study impact of geomorphological evolution in the inundations in the Déhita valley. Hypothesis is that the inundations depend on deficiency of isostatic compensation of products of erosion in the valley. Direct measurements of erosion and solid flows in the river have been carried in the valley. Results show enormous disproportion between latent loads at edge of the of the river and the minimal capacity of the latter, that undergo inundations in the Déhita valley.

Keywords: Déhita, geomorphological evolution, climate change, inundations

L'évolution Géomorphologique Et Les Inondations Dans La Vallée De Déhita, Marqueurs Importants Du Changement Climatique Dans Le Quartier Périphérique De La Ville De Bouaflé (Centre-Ouest Ivoirien)

Résumé

Dans la ville de Bouaflé, la vallée de Déhita est en première ligne face au réchauffement climatique. Elle subit des inondations comme elles sont produites de plus en plus régulièrement, qui menacent la vie et les installations humaines riveraines. Ces inondations rejoignent la question climatique dans ses rapports avec l'évolution géomorphologique actuelle. Comment, alors, l'évolution géomorphologique, en relation avec le climat actuel, implique-t-elle les inondations dans la vallée de Déhita ? Cette étude vise à étudier le rôle de l'évolution géomorphologique dans les crises d'inondation dans la vallée de Déhita. On part de l'hypothèse des inondations dues à la déficience de compensation isostatique des produits de l'érosion climatique dans la vallée. La méthodologie repose sur la comparaison des mesures de l'étalement, dans la vallée, de la charge arrachée au versants par abatage d'une part, et des débits solides du cours principal, d'autre part. On note une énorme disproportion entre les charges de matériaux latents déposés au bord du marigot et la minime capacité de ce dernier. Ce qui est la principale cause des inondations dans la vallée de Déhita.

Mots-clés : Déhita, évolution géomorphologique, changement climatique, inondations

Introduction

Global warming (+0.85°C on average worldwide since the industrial era) is a reality whose magnitude is still limited (Janicot et *al*., 2015). Awareness of global warming and its consequences has so far not been able to reduce the incidence of the phenomenon.

Bouaflé is on the front line in the face of global warming. In this city, the Dehita Valley is experiencing flooding, as it is occurring more and more regularly, which threatens life and human settlements along the river. There is a real difficulty in isolating this phenomenon from the climate question in its relationship with geomorphological evolution.

We are therefore trying to find out how geomorphological evolution, in relation to the current climate, involves flooding in the Dehita valley?

The objective is to study the role of geomorphological evolution in flood crises in the Déhita valley.

This general objective can be broken down into three levels of specific objectives: to measure the importance of the factors of geomorphological evolution in the Déhita valley; to characterize the topography of the colluvial and alluvial aquifer in the basin; to show the role of hydrodynamic behaviour in the flooding of the Déhita valley.

The study is based on the postulate of flooding due to the lack of isostatic compensation of the products of climate erosion in the valley.

1. Data and methods

1.1. Geographical framework of the study

The city of Bouaflé is the capital of the Marahoué region, named after the tributary of the Bandama River that crosses it. It is located in the central-western part of Côte d'Ivoire between latitudes 6°57'-7° N and longitudes 5°45'- 5°47' W (fig. 1).

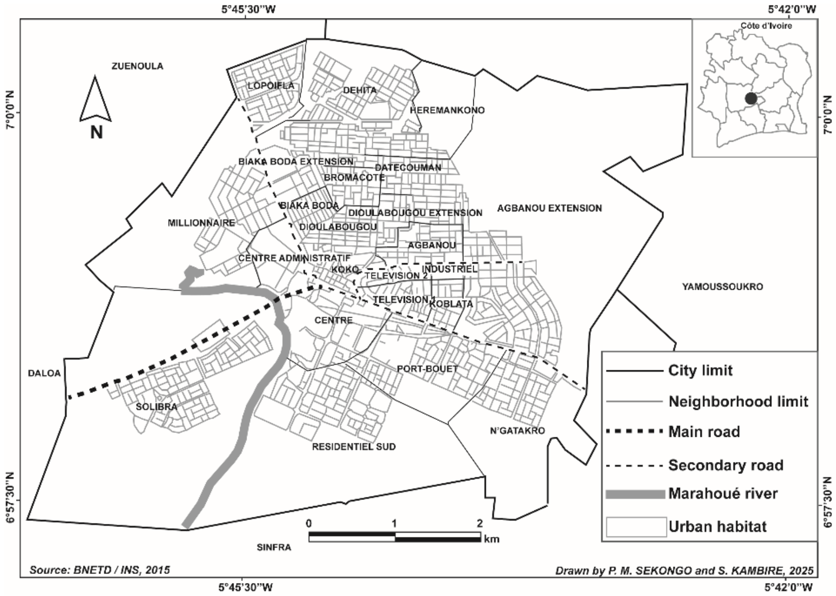


Figure 1: Presentation of the study area

The area investigated includes the valley of the Déhita district, in the north of the city, and the immediate interfluves. In fact, transverse and lateral dynamics (alluvial and colluvial) collaborate in the shaping of the valley, which subordinates the form to the interfluve.
The climatic regime is of the attenuated transitional equatorial type (Baoulean climate). It is marked by rainfall of less than 1700 mm with at least two to three dry months. The humidity is never below 50% (Adjanohoun, 1964).
The geological bedrock is formed by the granites of the median massif rejuvenated by the Eburnean cycle. It belongs to the granito-gneiss domain of the old Ivorian Precambrian basement. Rare intrusive Birrimian schist outcrops - in particular, the flysch and associated sediments (Eburnean facies of the Birrimian) - penetrate the central granite massif and give significantly different landscapes. But the general appearance is that of a poorly dissected peneplain, with an average altitude of around 260 m (Riche, 1967).

1.2. Data collection methods and techniques

A sequence of operations and methods is implemented. A first operation concerns the mapping of the topographical facets of the city of Bouaflé. The aim is to reconstruct the conditions of shaping and geomorphological evolution offered by the relief and topography. The mapping of the landscape is based on the interpretation of aerial photographs from the HAUTS-MONTS INC-CIV-96 aerial mission.
Thanks to the stereoscopic montage of triplets of neighbouring shots, all the slope break lines and all the slope inflection lines visible in the aerial photographs are systematically drawn. These obvious discontinuities delimit the topographical facets. These are distinguished by their cross-sectional profile, their position in the topography, the length of their slope, and their plan design.
A second operation consists of the direct measurement of erosion. On the converging slopes, there are areas of concentrated runoff. There are individual beds, small wadis with sandy bottoms, and unstable channels dug between banks of sand and pebbles. At the contact zone of each bed and channel with the valley, an experimental plot is established. It is a rectangular surface (10 metres by 5 metres), elongated across the valley in the direction of flow towards the major bed.
A ditch delimits the width of the plot facing the high topographies, and another delimits its length facing upstream of the valley. These two ditches collect, the first, the colluvium that runs down the slopes, and the second, the alluvium from the upper basin. These materials will not be considered in the concentration assessment of solid transport. A third ditch was installed at the limit of the length of the plot facing downstream of the backwater, then a fourth was established at the limit of the width facing the backwater. These gutters make it possible to collect colluvial deposits due to erosion and which will be the subject of the measurements.
The surface of the plot is covered with a large bag that isolates the anterior alluvium and colluvium, and the gutters are equipped with tanks.
After each rainfall event, the load of material torn from the slopes is deposited on the surface of the bag and in the two collection tanks. It is emptied and measured on the Roman scales.
A third operation concerns the analysis of the topography of the aquifer at the scale of the elements (texture), essentially crystalline and ferruginous, and at the scale of its overall architecture (structure). It provides evidence of current or sub-current climates in fluvial morphogenesis. The analysis is based on observations of soil profiles dug in the valley.

A fourth operation encompasses some aspects of surface hydrology.
First, the analysis focuses on the solid flows of the major course of the valley. The aim is to assess the relationship between the latent charges at the edge of the backwater and the capacity of the latter. But we start by studying the liquid flow and the current of the backwater. Only then will we be able to evaluate its solid flows. Secondly, the analysis refers to the influence of the pressure of the water table head on the sedimentary mantle.

Liquid flow and current measurement

The reel gauging method and the so-called "point-by-point gauging" technique of this method are applied.
Flow measurement involves the determination of a sufficient number of point velocities in cross-sections of the watercourse. A reel, a device equipped with a propeller, is used. The number of revolutions made by the propeller at several points, in cross-section of the river, makes it possible to establish the flow: this is the gauging.
The speed of the current at the points chosen for sampling will be determined by means of a gauging system with a 25 kg salmon, a measuring winch and a cantilever, mounted on a rubber dinghy.

Measuring of suspended load

At a given point in the watercourse, the suspended solid flow (Qs), by the principle of gauging, is a function of the concentration of solid matter (C), the velocity of the current (V) and the surface element considered around this point (S):
$Qs = C \times V \times S$
From a practical point of view, and at the various points of measurement of the previous liquid flow, samples are taken. The containers used are of the "demijohn" type, gauged by 10 litres by means of a nozzle, which is fixed on the metal rod of a salmon so that it is always parallel to the current, and by a "Japy" type pump placed near the measuring winch on the overhang. The containers are made of glass and protected by a plastic basket that provides effective protection during transport and quick removal.
At the end of the sampling operation, each container is meticulously calibrated and numbered, the volume marked by an indelible line. Then the samples are subjected to the evaporation of the supernatant liquid in the containers by simple exposure to the sun. The deposition of suspended particles is obtained. The concentration of the solid load at the sampling point (in g or kg/m3) is given by relating the weight of dried sediment to the volume of water at the origin.

Measuring of the bed load

The sediment pit method has been applied, which gives good results in the case of small basins of about 1 km^2 in areas where erosion is active.
The sediment pit consists of a concrete reservoir built into the riverbed itself. It was replaced by a calibrated weir for the measurement of liquid flows. The advantage of the pit is to minimize the velocities for suspended sediments to settle. The load deposited is then measured by samples taken at the outlet of the spillway. The volume of the bedload is measured by means of the volumetric containers when emptying the pit. Finally, the evaluation of the concentration follows the same procedure as that of suspended transport.

Hydrostatic pressure

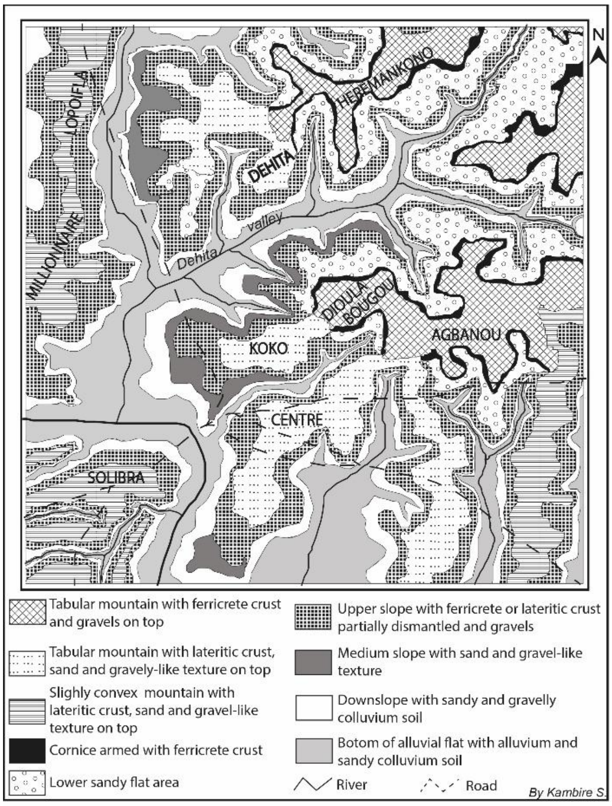
We clarify how to measure hydrostatic pressure. A manhole two metres in diameter is placed at ground level in the watershed. At some point, this manhole is filled with water up to 0.5 meters above ground level. The water level is therefore 0.5 metres above the ground. The hydrostatic pressure, at ground level, would be 0.5 meters. It should be noted that, in this scenario, the hydrostatic pressure represents the net force due to groundwater on the groundwater topography (alluvial mantle and colluvium). And that the total amount of water is not taken into account in the calculation, nor is the diameter of the pipe. Only the height of the water above the ground counts. As long as there is no water above ground level of the groundwater topography, there is no hydrostatic pressure.
Thus, 12 manholes are installed at regular intervals in the upper parts of active sumps, making it possible to measure the extent of the drawdown of the water table around catchment points.
A final operation, finally, is that of the socio-economic survey. It makes it possible to reconstruct the characteristics of the floods in the Déhita valley and to describe the damage of the particularly catastrophic flood of 2023.

2. Results

2.1. Conditions of geomorphological evolution

2.1.1. Conditions offered by the relief and topography

The appearance of the summit slope makes it possible to differentiate three types of forms (fig. 2).



Source: Aerial photographs Hauts-Monts 96

Figure 2: Landscape units and segments of the city of Bouaflé

The most common landscape is the tabular mountain (plateau, extensive area of flat upland usually bounded by an escarpment (i.e., steep slope) on all sides but sometimes unclear cornices (scarps).

Tabular mountains with a ferricrete crust (iron incrusted tabular mountains) and/or gravels on top are among the best developed. They settled in the north-eastern quarter of the city.

The indurated material (the ferricrete crust or plintite) is very widespread and effectively arms the interfluve summit. Most often, however, this ferricrete crust is weakly or patially dismantled. But the summit margins are less and less protected from regressive erosion (Fig. 4).

The summit slope is very low, often straight (hardly more than 2%). But weak concave or regular monocline lines (3% to 1.8%) are also observed. The vertex represents nearly 40% of the development of the model.

The limit of the summit surface is marked by a sudden break in the slope, which initiates a real continuous cornice (scarp) armed with a ferricrete crust. The sharpness of the cornices emphasizes a vigorous escarpment (with a slope of 30% to 45%) offering the appearance of a small vertical wall that is cut into orthogonal blocks of ferricrete crust. But, very locally, the cornice continues with a slope of cuirass (plintite) scree or ends up being no more than a short-accentuated convexity.

At the foot of the cornice, there is a vast arenaceous (sandy) flat, which occupies nearly a quarter of the surface area of the model. The slope rarely exceeds 3%.

The fraction of the shape that returns to the slope is about 16%. Generally, a middle slope is interspersed between a high slope and a low slope.

The upper slope, 200 m long on average, is inclined from 6% to 4% and most often slightly concave. It bears ferruginous gravel and a few indurated outcrops on regolith at a height of more than one meter. The middle slope is of the same magnitude as the high slope. But the slope weakens (2% to 4%), and surface convexities dominate. It is covered with sand and gravel, sometimes indurated on regolith at a depth of about 2 meters. This induration is as much, and often much more, a concentration of iron oxides in the cuirass (ferricrete crust or plintite) as an accumulation of oxides in the lateritic crust. But ferruginous gravel still dominates.

The lower slope is 150 m long. The slope is steep (between 5% and 8%) and, once again, the surface concavities prevail. The colluvial sands are more abundant, but patches of induration in the lateritic crust are observed. Contact with the valley is sometimes made by a series of sandy stair steps, with a steep slope (between 7% and 20%), always short (about thirty meters on average), concave or convex, or rectilinear.

The tabular mountains with a ferricrete crust are extended, in the same interfluve, by pisolitic and saprolited tabular mountains. These constitute the second type of landscapes. The lateritic crust and the ferricrete crust are extremely rare.

The pisolitic and saprolited convex mountains (low hill, extensive area of convex upland sometimes enclosed by a discontinuous and unclear cornice (scarp)) represent the third type of landscapes. They extend to the west and the south of the city. These convex mounds are, in fact, tabular mountains. But they justify their name of convex mounds by the absence of summit sectors with a rectilinear profile and by the development of a general convexity. However, the general slopes fall within the same average range of the slopes of the tabular mountains (1% to 3% in the summit, 2% to 20% in the slope) and the share of the summits in the model is equivalent to what is noted for all the tabular mountains (around 40%).

The shape and pedological content that characterize the segments differ from those of the previous trays only by a very indistinct and discontinuous cornice, as well as the rarity of the cuirass.

In the south-east and west of the city, on the contrary, it is a landscape of lateritic convex mountains and pisolitic or saprolited tabular mountains that settle in. The shape is not very extensive in the test area and is generally short. 300 to 600 m separate the summit from the thalweg. The differences in altitude are around twenty meters and the average slopes are between 5% and 8%. The summit part represents only 20% of the shape developed by the interfluve.

These pisolitic or saprolited tabular mountains are little or not "indurated in a lateritic crust". The lateritic crust and vacuolar ferricrete crust are marked in the topography only by a very short cornice, a few meters high and very discontinuous. The ferricrete crust (plintite) is exceptional at the summit. When they exist, these cuirasses (ferricrete crust or lateritic crust) mark this summit with stairs or convex plates of a few decimeters to a metre in altitude. It is therefore a thick layer of sand and/or gravel, on regolith at more than 2 meters, that covers the summit surface.

A high slope is developed on a regolith indurated in a lateritic crust.

In the lower slope, a strongly sandy and incoherent deposit develops. But colluvial sand sometimes gives a truncated horizon (a lesser fraction of sand on regolith and colluvial sand in places indurated in a lateritic crust).

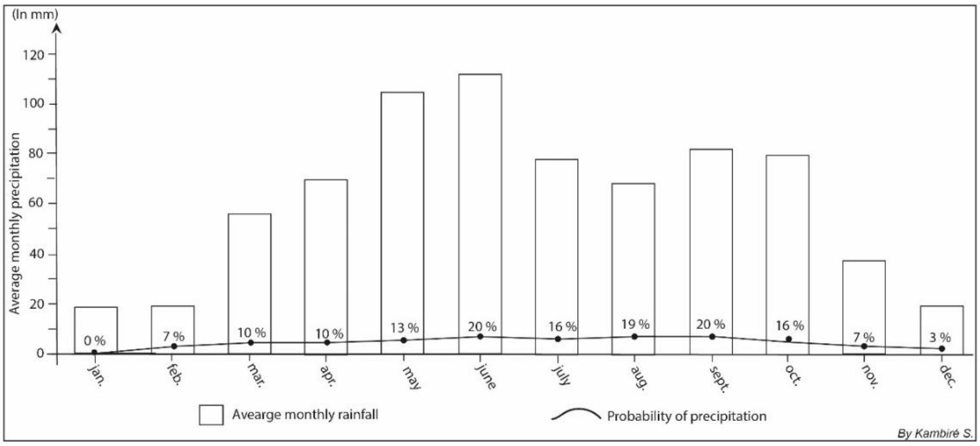
In the valley, a low terrace is marked by old bank ridges and small intermediate levels of alluvial and colluvial sand and gravel. Silica materials predominate, but the petrographic nature is variable.

The landscape of the Déhita district presents the same type of general evolution as that of the city of Bouaflé as a whole. However, we can insist on one particular point: the meeting of converging slopes of a different pedological nature, which form the extreme heads of the Déhita valley.

This valley is bounded by the interfluves with a ferricrete crust on top of Hérémankoko district (to the north) or Dioulabougou district (to the south) and their extensions in tabular mountains with a lateritic crust or pisolitic or saprolited convex mountains to the west. Generally, low lying terrace landscapes (lower sandy flat areas) are developed at the bottom of the cornices of the iron incrusted tabular mountains. The valley is then bordered, to the west, by the extension of the convex mountains with a lateritic crust from the Millionaire district to the Lopoifla district. The next feature that emerges is the tiering of the trays, with the indurated surfaces in a ferricrete crust higher than the surfaces with a lateritic crust or a pisolitic or saprolited soil that follow them. Rather than a single plan, the landscape is made up of a superimposition of these individualized surfaces, one in relation to the other. The slopes in front of them are a minor form. Finally, topographic slopes are more escarpments than slopes, because their development is sometimes minimal and their profile abrupt.

The high probability and torrential nature of some rainfall events suggest a period of climatic transition, characterized by abundant rainfall and erosion that develops easily as a result of the intensity of runoff.

The distribution of rainfall (fig. 3) is, however, more interesting to consider for its role in morphogenesis than the overall volume of precipitation. The analysis in Table I sheds light on this aspect.



Source: SODEXAM data

Figure 3: Average total precipitation over the month (period 2021 - 2024)

The heavy showers opening the rainy season did not provide the highest amounts of rain. But they may have been of greater importance in the exercise of erosion by runoff.

This erosion is especially active at the beginning of the rainy season. In March and April, erosion removed, and then spread out in the valley, between 29 kg/s and 51 kg/s of material from the tabular mountains indurated in a ferricrete crust on top with lower sandy flat areas and the convex mountains with a lateritic crust or a plintite weakly or patially dismantled. At the same time, the quantity of material from pisolitic and saprolited tabular mountains or pisolitic and saprolited convex mountains was estimated at between 71 kg/s and 96 kg/s.
But erosion depends, to a large extent, on the superficial soil materials on which it is exerted. The materials transported from the tabular mountains indurated in ferricrete crust with lower sandy flat areas to the valley were between 2 kg/s and 51 kg/s. While the sandy or clay textures and rock residues torn from the pisolitic and saprolited tabular mountains or pisolitic and saprolited convex mountains and accumulated in the valley were measured between 3.2 kg/s and 96 kg/s.
On the other hand, erosion is based on violent downpours. Thus, a rainy downpour at the beginning of the rainy season of less than 60 mm/h carried away, and accumulated in the valley, 29 kg/s of material from the tabular mountains indurated in a ferricrete crust on top with lower sandy flat areas and the convex mountains with a lateritic crust or a plintite weakly or patially dismantled. This quantity of material from pisolitic and saprolited tabular mountains or pisolitic and saprolited convex mountains was estimated at 71 kg/s. Under a downpour of intensity greater than or equal to 60 mm/h, these accumulations from the tabular mountains indurated in a ferricrete crust on top with lower sandy flat areas were increased to 51 kg/s, and those from pisolitic and saprolited tabular mountains or pisolitic and saprolited convex mountains reached 96 kg/s.
The immediate effects of the heavy showers at the beginning of the rainy season on the interfluves with a pisolitic and saprolited soil and on the mountains indurated in a ferricrete crust (fig. 4 and 5) are to influence the processes of geomorphological evolution of the valley.

Table I: Spreading of the load torn from the slopes in the valley (in kg/s)

Landscape, rainfall Intensity (i) in and Flows/Period	Tabular mountains indurated in a ferricrete crust on top with lower sandy flat areas and convex mountains with a lateritic crust		Pisolitic and/or saprolited tabular mountains or convex mountains	
	i < 60 mm/h	i ≥ 60 mm/h	i < 60 mm/h	i ≥ 60 mm/h
December - February	1,4	2	2,5	3,2
March - April	29	51	71	96
May - October	27	38	57	71,3
November	4	7,3	11,4	19

Source: Field measurements in tropical downpour conditions (2021 to 2024)

A B

Fig. 4 A: traces of diffuse runoff at the top of a tabular mountain indurated in a ferricrete crust and sweeping of the concentrations of quartz and ferruginous gravel in a dripping sheet give evidence of the iron incrusted interfluves resistance to erosion. **Fig. 4 B**: but the cuirass is also a material that is attacked by erosion: blocks of cuirass loosened on the cornice (*photos Kambiré S., 2023*)

Figure 4 : Resistance of the ferricrete crust to erosion on iron incrusted interfluves

A B

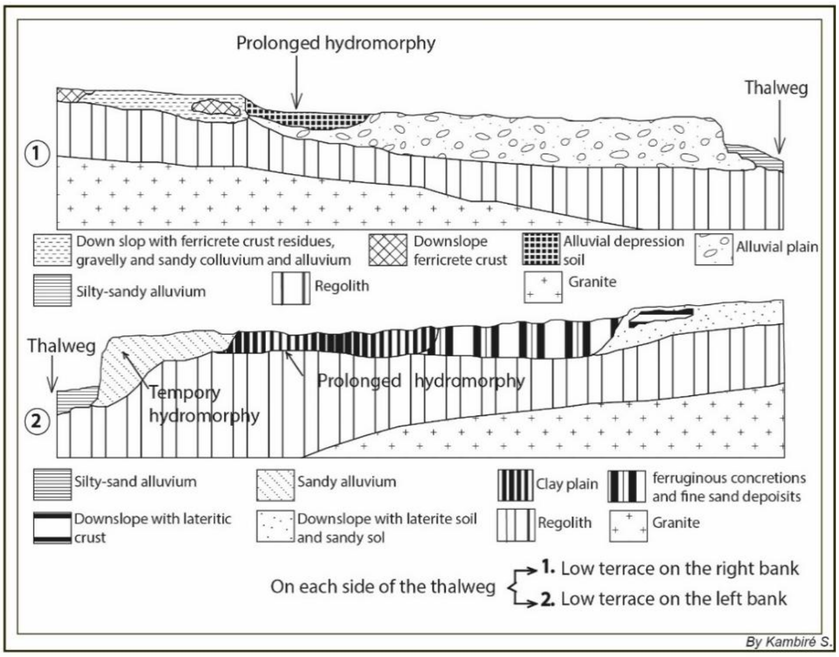
Fig. 5 A: Traces of anastomosing runoff processes on the top of the pisolitic and saprolited interfluve and scanning of sand and quartz concentrations. **Fig. 5 B**: deep bites from the concentrated runoff on a low lying sandy terrace area in a tabular mountain with a ferricrete crust on top. This runoff types give evidence of a very active erosion in all the interfluves of the Déhita district (*photo Kambiré S., 2023*)

Figure 5: Action of erosion on sandy, pisolitic and saprolited environments in the Déhita district

2.2. Characteristics of the topography of solid materials accumulated in the Déhita valley by erosion

2.2.1. General scheme

More or less steep slopes bound the valley. This is the domain of a powerful concentration of incoherent materials (fig. 6).



Source: fieldwork

Figure 6: Topography of the layer of materials accumulated in the Déhita valley

The mantle of accumulated products can be roughly divided into three zones.

On the alluvial terrace influenced by the indurated interfluves (tabular mountains with a ferricrete (plintite) weakly or patially dismantled on top and tabular or convex mountains (low hills) with a lateritic crust), the valley has a layer of products of very coarse colluvial and alluvial origin at depth. These materials are often referred to as "under bank gravel" by mining researchers and prospectors. These are coarse, more worn gravels which are, in fact, in some cases, very good diamondiferous placers, gold-bearing placers, or radioactive minerals. They are homogeneous over several metres or alternate with lenses and beds of gravel and sand.

On the contrary, on the terrace of the valley immediately subordinated to the non-indurated interfluves (pisolitic and saprolited tabular mountains or convex hills (convex mountains)), sandy colluvium and ferruginous concretions dominate the coarse gravels. Scoriaceous shells formed from sand and, incidentally, silt are mixed with it.
In these first two concentration zones, the layer of gravel and pebbles, of various qualities, is crisscrossed by a series of "stone-lines". Their deposit describes a scalloped, undulating line in the spreading sheet.
In the notch of the watercourse, it is a cover of sandy and clay-silty alluvium. However, small-caliber gravel in lentils appears, most often not very worn.
However, it is worth mentioning another characteristic feature of the valley. It consists of an individualization into alluvial depressions, clayey settling basins, or reaches in which a layer of coarse alluvium is deposited.

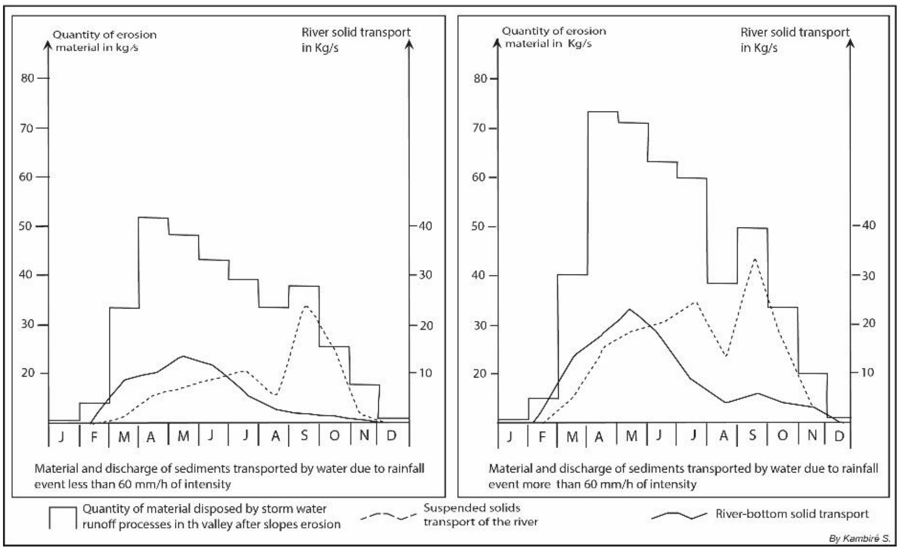
2.2.2. Characteristics of the soil profile

Sections, over a distance of at least 5 m, made in the rock table of the valley show the following profiles:
- from 0 to 2 metres, a bed of sand, coarse gravel and free ferruginous gravel and barely cemented gravel is developed. These materials bear no signs of wear. Siliceous materials dominate. The whole rests on a shell of slag formed from sand and, incidentally, from silt. But this armour or carapace is not very thick and discontinuous. Stone lines snake through this superficial layer. They are, most often, in-depth and have a marginal position.
- from 1.8 to 3 metres, it is a more homogeneous bed of small-calibre gravel, in lenses, little worn. They have inclinations of the order of 25° and dominate old quartz pebbles, more or less worn.
- From 2.8 metres, much more worn coarse gravel alternates with lenses and beds of gravel and sand.

2.3. Hydrodynamic behaviour and flooding

2.3.1. Flow dynamics and solid flows

Figure 7 presents, over the period 2021-2024, the results obtained in the study of the quantities of materials spread out in the Déhita valley and the solid flows of the main river.
Over the four years of observations, colluvial deposits in the valley exceeded 50 kg/s after each rainfall of intensity less than or equal to 60 mm/h and 70 kg/s after each rainfall of intensity greater than 60 mm/h. 60% of the deposits are produced between March and May, at the beginning of the rainy season. These deposits decrease as the rainy season progresses.
Over the four years of observations, the maximum value of bed load (bottom solid materials transport of the river) is also noted between March and May, at the beginning of the rainy season. However, the value of these larger sediments which are transported by saltation, rolling, and dragging on the riverbed is worth only one-fifth of the value of the colluvial deposits in the valley.



Source: fieldwork

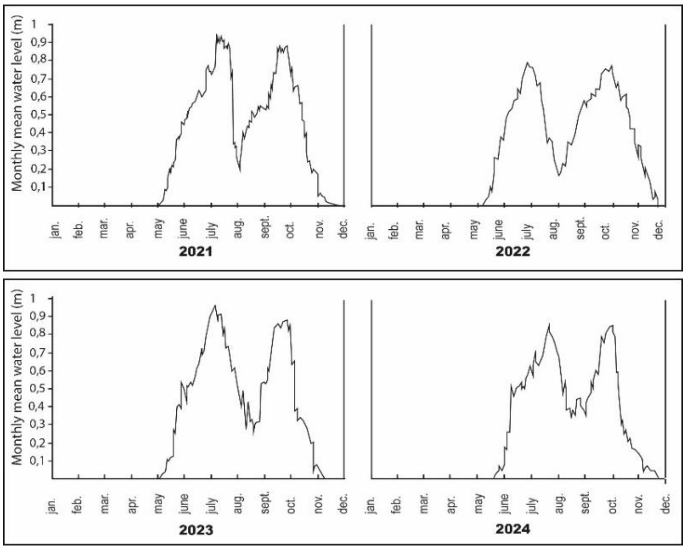
Figure 7: Situation of the load torn from the slopes and accumulated in the valley and the solid matter transported by the river (in kg/s)

Indeed, between March and May, this bed load is estimated, on average, at 10 kg/s during rainfall of less than 60 mm/h and in the order of 20 kg/s during rainfall events of intensity greater than 60 mm/h. At the same time, the mass of colluvial inputs in the valley reaches 50 kg/s during rainfall of less than 60 mm/h and 75 kg/s during rainfall of more than 60 mm/h. Then, forward in the wet season, bed load represents only a quarter of the colluvial deposits in the valley.

In contrast to long-distance transport, it is in the early wet season that suspended load (the middle layer that consists of the smaller sediment that' suspended) is most important in the river. But also at this time, the values they present are only one-tenth, on average, of the colluvial deposits in the valley.

2.3.2. Hydrostatic pressure

The hydrostatic pressure control is carried out over four years, from 2021 to 2024 (fig.8).



Source: fieldwork

Figure 8: Measuring of hydrostatic pressure in the Déhita valley

Over this period, it shows a certain consistency. The maximum pressure is observed in the rainy season. It increases sharply in June-July and September-October during the two main rainy seasons (about 0.9 metres) and reaches its minimum in the short dry season.

2.3.3. Relationship between floods and geomorphological evolution in the Déhita valley

Studies of colluvial deposits and hydrodynamic behaviour in the valley are of great interest. They showed that the current morphology of the topography of the material sheet derives from the incision and dismantling of interfluves. The erosion was so severe that it washed away and deposited large quantities of coarse sand and gravel in the valley. In return, there is a clear deficiency in the transport of these materials by the currents of the backwater, resulting in waterlogging of the valley and chronic flooding.

Floods, with catastrophic consequences, have already been observed in the Dehita valley. They are characterized by the sudden rise of the waters that come out of their beds. The example of the November 2023 flood is quite poignant. On the night of Wednesday, July 5, to Thursday, July 6, in an area already bruised, this time again, the water rose higher and faster. The historical record for the June 2020 flood had just been beaten.

The waters spread over a distance of 0.6 km in the valley and covered the bridges. The streets are gutted. Hundreds of damaged houses (up to 2 metres high), had their feet in the water (fig.9).


A


B

The feet of the walls were still darkened by the rising waters at the time of the shooting, which took place five days after their removal (**figs. 9 A and 9 B**). As for this inhabitant (**fig. 9 B**), pointing to the actual level reached by the waters on the night of the flood, the houses are almost half swallowed up by the water (*photos Kambiré S., 2023*).

Fig. 9: Water level mark on residential walls five days after removal in July 2023

After 1 to 3 hours of heroic efforts, 7 men, imprisoned by the water, managed to dig a hole in the roof and take their households out alive. Amateur rescuers managed to rescue 86 people from the water, but at least 3 others died.
For a week, hundreds of people had to leave their homes surrounded by water.

3. Discussion

3.1. Seasonal morphogenic crises and slope dynamics

The erosion phenomenon is triggered and develops in different ways, depending on whether it affects different types of materials.
Ferricrete crust (ferruginous cuirass) has an important geomorphological influence. These materials are capable of freezing landforms. Thus, the cuirass plays a role comparable to that of a resistant rocky bank and truly arms the landscape. But cuirasses are also materials that can be attacked by erosion. At the top of the indurated interfluves (tabular mountains with a ferricrete crust or a plintite weakly or patially dismantled), an area of diffuse runoff begins with coalescing pools during heavy downpours. This runoff then passes to a sweeping a dripping sheet. In general, there is a concentration of quartz and ferruginous gravel on the surface that can be moved.
In non-indurated landscapes (the pisolitic and saprolited tabular mountains or convex hills (convex mountains)), erosion will not take the same form and will not have the same activity. Erosion in the channel is characteristic of non-indurated slopes. It is likely to carry away much more grain and accumulate a layer of ten to fifty centimeters of coarse sand, clay, silt, coarse gravel, pebbles, or quartz veins, etc. in the valley.
It is now important to clarify the geomorphological role of the heavy showers opening the rainy season. These may have been of greater importance in the exercise of erosion by runoff, according to the results of this study.
Indeed, the dominant granite soils, particularly poor in clay in urban areas in the Déhita area, are very sensitive to degradation. As soon as the rainy season is over, the soils dry out. This is the time of the greatest temperature variations. These characteristics of the soil become more pronounced as one progresses through the dry season. Finally, the first showers, of high intensity, of the following rainy season, were triggered on very poorly protected ground. No material is likely to attenuate the kinetic energy of water droplets. These lead to the rebound of fine particles ("splash effect") or the bursting of clods of soil by rewetting. In the second case, the clods melt by water saturation and lead to micro-detachment of particles.
The water saturation of the soil surface can drop below 2 mm/h. The soil loses the stability of its structure. When the clods are melted to the soil surface, subsequent rainfall, even if of low intensity, will generate runoff and solid transport. This mechanical process is carried out by the loosening and detachment of the particles, by turbulence of runoff water, in the crust of battance (surface made up of the molten clods).
Then, as the soil gradually gets wet, it is subjected to much less variation in humidity. The soil regains structural stability and becomes less suitable for solid transport. This explains why, from July to November, the load of materials torn from the slopes decreases by more than half, compared to its value at the beginning of the rainy season.

3.2. Evidence of geomorphological evolution and current climates

The results showed, in the topography of the rock sheet of the Dehita valley, a stratigraphic succession. From 0 to 2 metres deep, sand, coarse gravel, and gravel, free, unworn, and gravel barely cemented on a slag shell were observed. This is followed, 1.8 to 3 metres thick, by small-calibre gravel, not very worn, in lenses. Above 2.8 metres deep, coarser, more worn, homogeneous gravels alternate with lenses and beds of gravel and sand.
Overall, the petrographic nature is variable, indicating significant colluvial inputs into the valley. This implies, on the one hand, a predominance of mechanical erosion over chemical erosion in the immediate interfluves, and on the other hand, a significant geomorphological evolution of the valley by the transport of layers of coarse elements falling in large sections into the basin.
The problems posed by the quality of materials have hardly been addressed in Côte d'Ivoire. But the wear of the gravel in the two earlier strata of the valley's soil profile suggests, like the stratigraphic arrangement, an alternation of wetter and drier climates. This spent gravel is then placed in a paleoclimatic context.
Schematically, the loosening and detachment of the particles were done during a period of active erosion. Then, a drier period must have interrupted their transport to the valley. Then the strong temperature variations must have developed diaclases (cracks), by thermoclasty, on certain stones and certain elements of the coarse gravel. The process results in the total isolation of the gravel balls wrapped in concentric scales of rotten rock and embedded in a soil that is already deeply evolved. Finally, another wetter period arrives. Solid particles whose integrity has already been damaged must have worn out, partly during transport, by impact or corrosion. At the extreme, these balls must have ended up altered and appear as fragments within the accumulation horizons.

But the varying degree of material wear observed in the two anterior layers of the solid product sheet may have another explanation. It must have been related to a different isostatic pressure depending on the position of the stratum in the profile.

The study also showed that the materials making up the superficial stratum of solid deposits (0 to 2 metres deep) show almost no signs of wear. This assumes a current or similar climate system, characterized by strongly contrasting seasons and violent rainfall.

The dry season is when the soil dries out due to strong temperature variations. This leads to the loss of stability of their structure. The first showers of the rainy season that are coming cause a real morphogenetic crisis. The soil, which is dried out and protected to a minimum, is particularly suitable for the formation of a crust of beating (surface determined by the melted clods of soil) as a result of the water saturation of the earth. This crust facilitates the loosening and detachment of the particles by turbulence of the runoff water, which is transported to the valley.

A non-interruption of solid transport for a very long time, due to the intervention of a dry climate, reduces the time of its transit on the slopes and the risk of wear and tear.

This superficial layer of coarse elements in the valley is certainly functional. This profile shows the current existence of a transit of iron oxides from the depths of the valley to the surface and their trapping in the zone where the water table beats (an area concerned by the rise of groundwater). This can only be the partial justification for the beginning of the cementation of the ferruginous gravel and gravel as well as the formation of the slag shell that can be observed in this superficial layer of the solid water table. This functional character of the surface layer of colluvial debris supports the evidence of the formation of this table in the current climate system.

In addition to these direct proofs that the formation of this superficial layer of the aquifer took place under the present climatic conditions, some indirect evidence can also be advanced.

They concern the "stone-line". These "rubble lines" are developed deeper than on the surface in the surface water table of materials, and more in the margins of the valley than in the centre.

As a result, it is not certain that they correspond to a single climatic phase. But a link with current climates is obvious.

The problem posed by the climatic context of this "stone-line" has hardly been addressed by the current work in Côte d'Ivoire. However, Riou (1965) found fine examples in pre-forest savannahs in Côte d'Ivoire. But Avenard, J. M. (1971); Vogt (1968) encountered others in Côte d'Ivoire, Upper Guinea, and Upper Volta, and Leneuf (1964) in tropical regions. The climatic conditions, in relation to these materials, given by these authors, seem to apply perfectly to the case of the valley of Dehita.

Rougerie (1950) hardly considers the paleoclimatic aspect. Leneuf (1964), in a brief note, observes "this accumulation of gravel and pebbles of various qualities". But he is talking about inherited materials, from ancient surfaces or quartz veins, outcropped in earlier periods. He does not specify further.

Riou (1965) seems to place these lines of rubble in a climatic context without really having elucidated it perfectly. He points out that the study of the elements of the stone-line aquifer shows that "this aquifer is not the result of a purely pedological process, but that it is the witness of a major erosion phase that separated two different pedogenesis". Between the domains of extension of this "stone-line" layer, there is almost always a more or less thick layer of coarse elements. And the author continues: this arrangement of the stone-line aquifer, on either side of a more or less thick sheet of coarse elements, underlines "a system of erosion with strongly contrasting seasons and violent rainfall" (characteristics of the current climatic regime); Their varied petrographic composition implies "a period of active erosion with a dry nuance" (paleoclimate).

It is the observations of Avenard, J. M. (1971), on the alluvium of Côte d'Ivoire and Upper Guinea, and of Vogt (1968), on the current processes in the savannah valleys of the borders of Côte d'Ivoire and Upper Volta, which seem to have best placed the "stone-line" in a current climatic context. "In particular, the weakness of alluvial transit, as well as the torrential character" of the rivers, suggests a "period of climate transition". It is "characterized by abundant rainfall and very sparse vegetation that develops only with difficulty due to the destruction of the soil". In this diagram, the stone line would be a line of rubble corresponding to the unaltered materials related to the current erosion system.

3.3. Floods or crisis phenomena of disruption of equilibrium

It is possible to place floods in a context of profound natural imbalance. The results of this study showed that there is a huge disproportion between the loads of colluvial debris collected at the edge of the backwater and the minimal capacity of the latter. The erosion of the slopes, therefore, seems to provide more material than the backwater evacuates, hence a total waterlogging of the valley floor.

This congestion of the basin makes it a world, on the whole, anarchic, which presents the following aspects (fig. 10):

A

B

10A: solid load torn from the slopes and accumulated in valley. Further on (**10B)**, talweg almost blinded *(photos Kambiré S., 2023).*

Figure 10: Topography of colluvial product slicks, disorganization, and blinded talweg.

- almost always the existence of a very thick layer of coarse elements: quartz pebbles, more or less worn, and ferruginous gravel;
- particular topography where the congestion by colluvial products takes precedence over the clearing of the valley by running water.
- confusion, disorganization, swampy areas, and blinded or dead talwegs in places.

As a result of the overflow of its course out of the talweg, during periods of high water, the valley loses less than a fifth of the accumulated solid inflows.

Topography of the layer of materials accumulated in the Déhita valley, superimposed on the sandy, silty, and gravelly embankment, explains the floods. In the rainy season, the drainage is defective, as a result of the filling or blinding of the talweg, the water floods the valley. The waters rise easily and abruptly above the depression.

It must be seen that the structure of the topography of the layer of materials accumulated does not prevent water infiltration. But this infiltrated water goes shallow and feeds the water tables. These are at such a shallow depth that they form emergences that then inflate the level of the stream in the valley. Hydrostatic pressure, due to the relatively high-water table in the heart of the basin, is also a source of imbalance and flooding.

Conclusion

The upper stratum of the topography of the layer of solid materials accumulated in the Déhita valley can only be explained on the basis of mechanical processes on more or less indurated surfaces. The petrographic nature and the varied quality of the accumulation products show that this topography of the layer of materials accumulated in the valley is in fact, only the result of the continuation of a geomorphology dynamic under the current climatic conditions. These are marked by an active erosion system, contrasting seasons, and violent showers.

This erosion system provides large quantities of solid materials to the valley while the solid transports of the main river, in particular the bed load, suspended load and floating matter, amount to only one-tenth of the colluvial inputs.

Therefore, ther is an enormous disproportion between the solid charges deposited at the edge of the river and the minimal capacity of the latter to evacuate them (bed load and suspended load very weak). It follows that the topography of the layer of solid materials accumulated in the valley presents itself as a world of blurred forms buried under a mantle of accumulation products. It is a world of disorderly appearance, from which there is sometimes no harmonious hierarchy of flow, and in which precarious waters seem to have difficulty evacuating. This is the cause of repeated flooding. But the importance of hydrostatic pressure should not be neglected.

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