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The Morphological Evolution of the Alluvial Terraces of El Alam (Central Tunisia) After the Installation of Nebhana Dam: Typology of Forms and Influence of Anthropogenic and Hydrodynamic Factors

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ABSTRACT:
To study the typology of alluvial terraces in the region of Sisseb El Alem after the establishment of Nebhana dam, this work proposes the use of cartographic, geomorphological and sedimentary approaches. The use of the GIS tool makes it possible to identify the evolution of shapes between the different dates. This tool also allowed us to compare profiles between different dates too. Field prospecting also allows a good mapping of shapes and facilitates their differentiation. By adopting a study of the sediments of the various terraces upstream and downstream of the dam, we were also able to identify the erosive dynamics that were at the origin of the deposits of sediment inputs. We could compare the different shapes of alluvial terraces. Towards the end, we were able to emphasize the anthropogenic contribution in the degradation of the alluvial terraces and their preservation. Finally, we ended up with some recommendations to better control anthropogenic action and limit erosive action

Keywords: Alluvial terraces, Anthropogenic action, Central Tunisia, Geomorphological forms of terraces, Plain of Sisseb-El Alem.

I. INTRODUCTION

The geomorphological evolution of alluvial terraces is conditioned by the interferences between the dynamics of rivers and external factors such as the deformation of the underlying geological substrate, variations in hydrological and sedimentary flows linked to the climate or more recently the anthropic activity. In these plains, rivers often change course laterally, erode their banks, transit and form sandy banks, overflow during floods and can suddenly change course by drawing a new line and clearing abandoned channels (ref). Alluvial terraces are often made up of detrital materials such as pebbles, sands, silts and clays. They have a flat top corresponding to the old flood bed and a steep rim shaped by the incision. Alluvial terraces are often shaped and highlighted by river digging. Since the end of the Tertiary, there have been several phases of incisions and backfilling, which has given rise to more or less complex forms of terraces: either stepped if the substratum appears between the layers, or nested if the latter does not surface. . From their formation, the terraces undergo the action of erosion which contributes to their brutal or progressive destruction (Larue, 2001).

The study of the morpho-sedimentary functioning of the Wadi Maarouf basin, the main tributary of Nebhana, has enabled us to describe and explain the main factors behind the formation of recent terraces (Lahmar, 2010). It is in this context that this study falls under the example of El Alam to study the processes of destruction of the terraces, the conditions favorable to their conservation and to classify the resulting forms.

II. PRÉSENTATION OF THE STADY AREA

The 'El Alem' plain is the last hydrologic unit before 'Sebkha Kelbia' which is the final outlet of the 'Wadi Nebhana- El Alam' watershed, which is approximately 855 km^2.

The study area belongs to the superior arid climate. The climatic conditions are very varied with clear daily and seasonal variations. There are mainly two seasons: A dry season from April to September

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characterized by high temperatures and almost no rains, especially in summer. The second one is rainier from September to April.

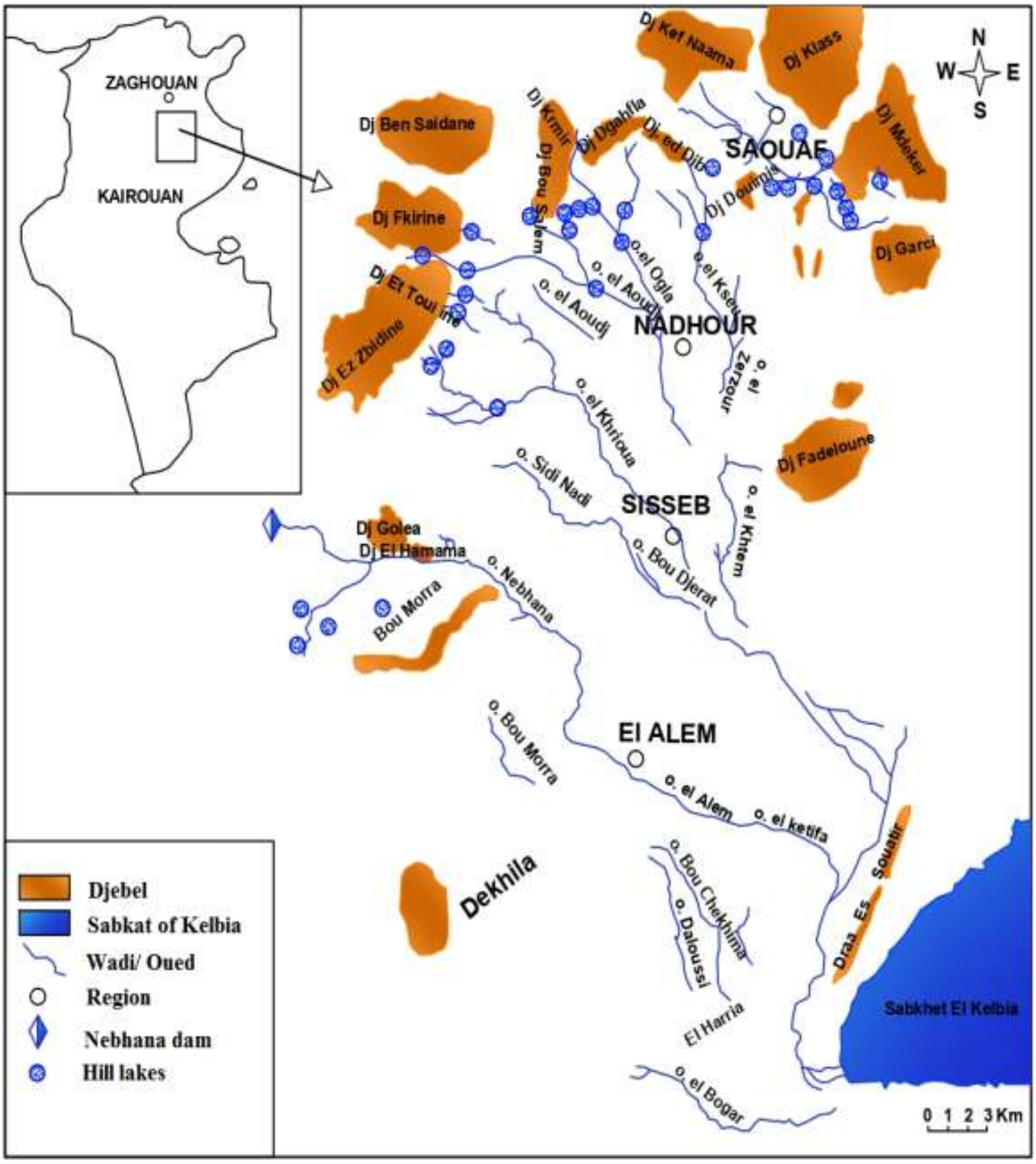

Figure 1: Localization of the study zone

Overall, the Kairouan region is classified as less rainfall zone (Fig 2). In fact, the average precipitation presents large irregularities which are distinguished both in time and in space. The average value is around 250 mm, of which 120 mm is in autumn. The strongest cumulative rainfall is recorded during the months of February and March (CRDA Kairouan, 2015).

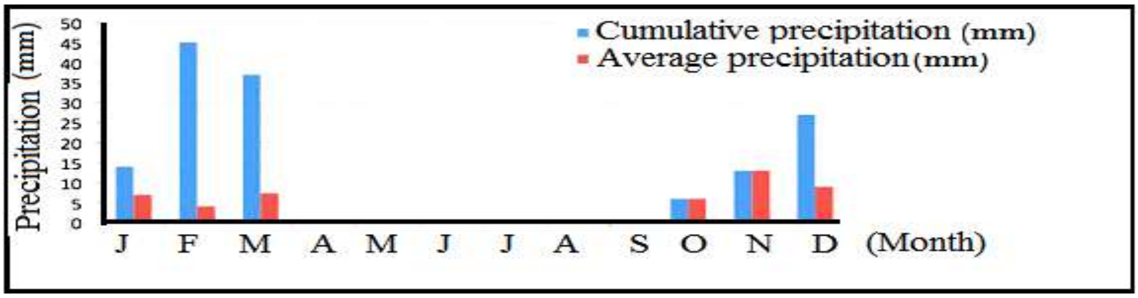

Figure 2: Distribution of cumulative and average precipitation.

The most frequent prevailing winds are from the northwest, north and north-northwest in winter and from the northeast and south in summer. Cold winter winds generally are originate from the northwest while hot dry summer winds (sirocco) blow from the south to the west.

The mean annual temperature in the study area is 18 ° C. The average maximum for the hottest month (July) reaches 38 ° C while that of the minimum for the coldest month (January) is 11.1 ° C. As with rainfall, the region's temperature is characterized by great variability between seasons.

PEDOLOGICAL AND GEOLOGICAL DATA

The Sisseb-El Alem plain is characterized by a slow mineralization of organic matter in salty soils. The average content is less than 2%. The soils are generally stratified, clayey on the surface with mainly montmorillonite mixed with kaolinite, illite and quartz in trace amounts. Clays are inherited from alluvium. Three main pedological units can be identified: poorly developed soils with low salinity upstream, saline soils with a calcium complex in the center of the plain and saline soils with a sodium complex in the low positions. In the 1980 year's, before the completion of a large hydro-agricultural development such as the Nebhana dam, the Sisseb plain was frequently flooded.

The Sisseb-El Alem basin is made up of sedimentary series ranging from the Triassic to the Quaternary with a subsiding synclinal ditch north of Kairouan (Fig3). The Sisseb plain is characterized by a very varied morphology between the edges of the plain where erosion processes dominate and the plain itself where eroded materials accumulate in varying grain sizes. There are three very distinct formations: Lake and marine alluvium, recent alluvium from wadi Nebhana and a fold covered with sandy deposits.

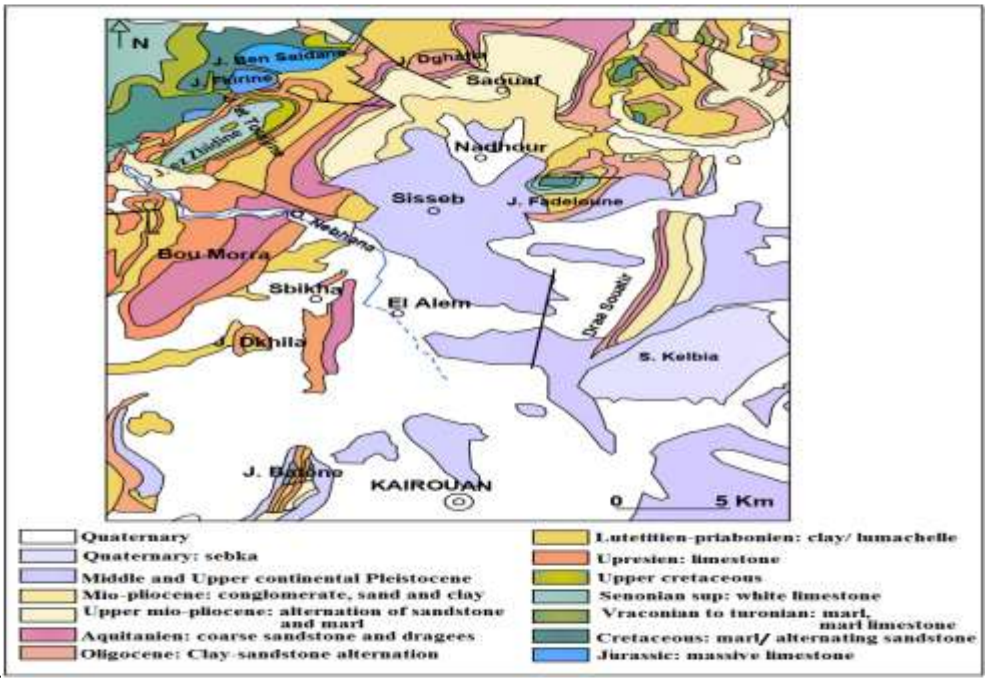

Figure 3: Geological map of the Sisseb El Alaam region

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METHODOLOGY AND WORKING TOOLS:

The diversity of geological and environmental data of the study region allows their integration into a Geographic Information System (GIS). In the present work, we took as cartographic support such as the topographic map (1/50000) of Jbibina and Sbikha-El Alam. The tools were used to locate the study area. They also allow the positioning of the region, the presentation of hydrographic data, access paths, vegetation... With regard to paper documents, the acquisition mode is done by digitization in ArcView ... then processing (creation of topology and cleaning). The development of the GIS tool has enabled us to display and query spatial data, access the different types of maps, synthesize and organize them geographically (topographic, land use, etc.), manage the digital model of the terrain and automatically extract the topographic profile and level curves.

Complementary approaches have been carried out in parallel. Firstly, the sedimentary filling of abandoned channels was sampled, in particular along the tributaries of Nebhana- El Alam. This work will make it possible to characterize the filling of the channels but also to measure the physical properties of the content of the channels and alluvial terraces. Secondary, the factors controlling the geometry of channel infills and their impact on the geomorphological evolution of alluvial plains were tested to draw longitudinal profiles and do a modeling. The impact of the dynamics of channel abandonment on the distribution of infill facies is therefore proven. Apart from the geometric shape of the profiles, the sedimentary study of the different identified has made it possible to identify the speed of erosion and accumulation in the course and on the terraces of Sisseb El Alam after the installation of the Nebhana dam.

III. RESULTS

The use of the GIS tool made it possible to process LandSat images (2018) and Google Earth images. The result obtained made it possible to draw the longitudinal section of Wadi Nebhana at the level of its lake (dam) not far from Henchir Lekrachoun (Fig 4). The first remark is that the trajectory of Wadi Nebhana has experienced a significant shift towards the north-west. This change in trajectory is due to a strong accumulation of matter. This over-sedimentation was undoubtedly accentuated by the construction of the dam in 1969.

THE EVOLUTION OF THE LONGITUDINAL PROFILE AT THE LEVEL OF THE NEBHANA DAM

By adopting the same approach to construct another longitudinal profile of this zone but we used the topographic map at 1/50000 of 1956 and the aerial photos of the 2000 mission. We were able to obtain a new profile which made it possible to make a comparison between the two situations: the current form of wadi Nebhana and that of the fifties (Fig4).

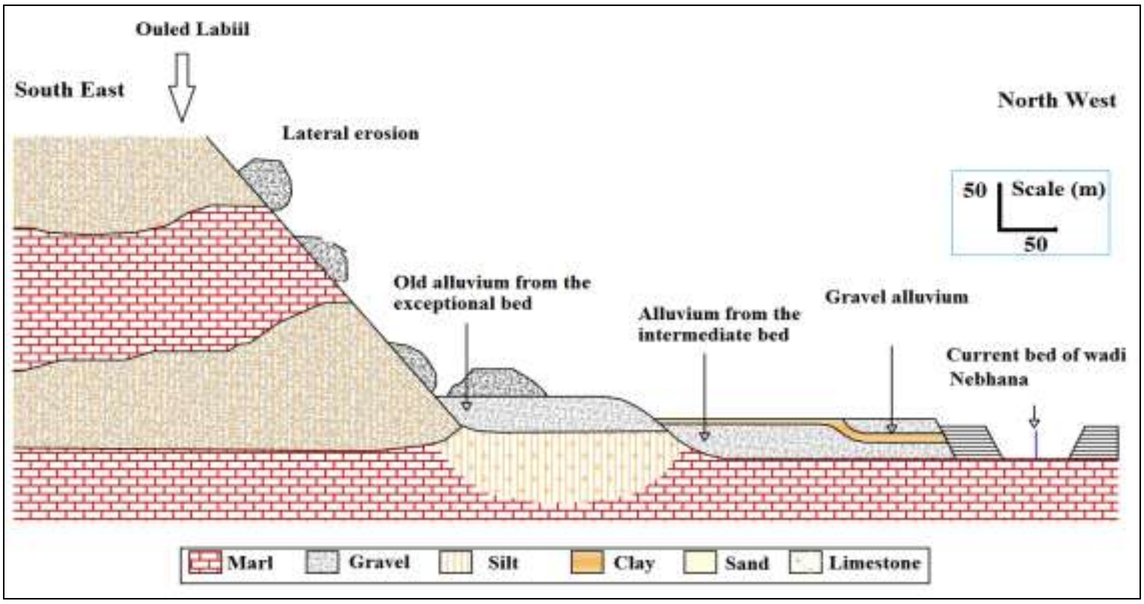

Figure 4: Cross section of the left bank of the Nebhana wadi at Oled Labiil (data of 2018)

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The first differences between the two profiles are mainly focused on the level of the minor bed, average bed and the exceptional bed. We notice a widening of the minor bed of the Nebhana wadi in its current form with the formation of a significant sediment supply in its upstream part, then an elevation of the minor bed and a gain in material deposited in the exceptional bed (Fig 4 and 5).

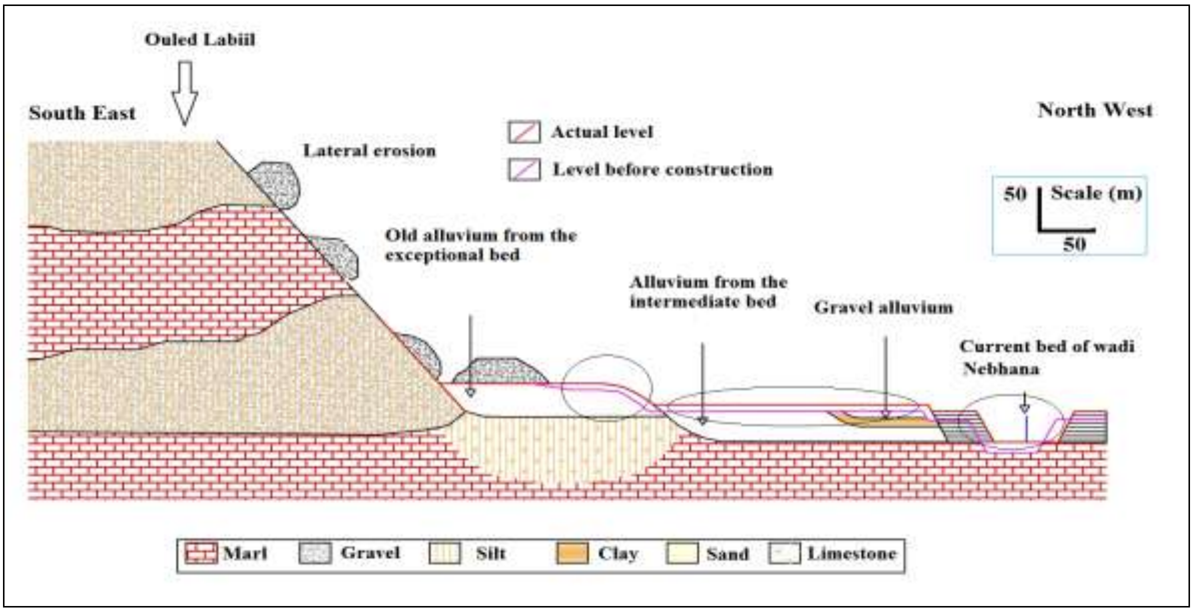

Figure 5: Cross section of the left bank of the Nebhana wadi at Oled Labiil (data before construction of the dam)

To compare the two situations: the one that preceded the installation of the dam the other that succeeded it, we tried to superimpose the two profiles. Result shows that the sediment input must have increased since the 1970s (Fig 6). The thickness of the new sedimentary layer varies between 70 cm and 130 cm, with an average of 1.4 and 2.6 cm per year. The analysis of the sediments show that the kinetic speed of the transited matter decreased. The diameter of the average particles also decreased. An important dynamic was recorded, in its upstream part, after the installation of the dam.

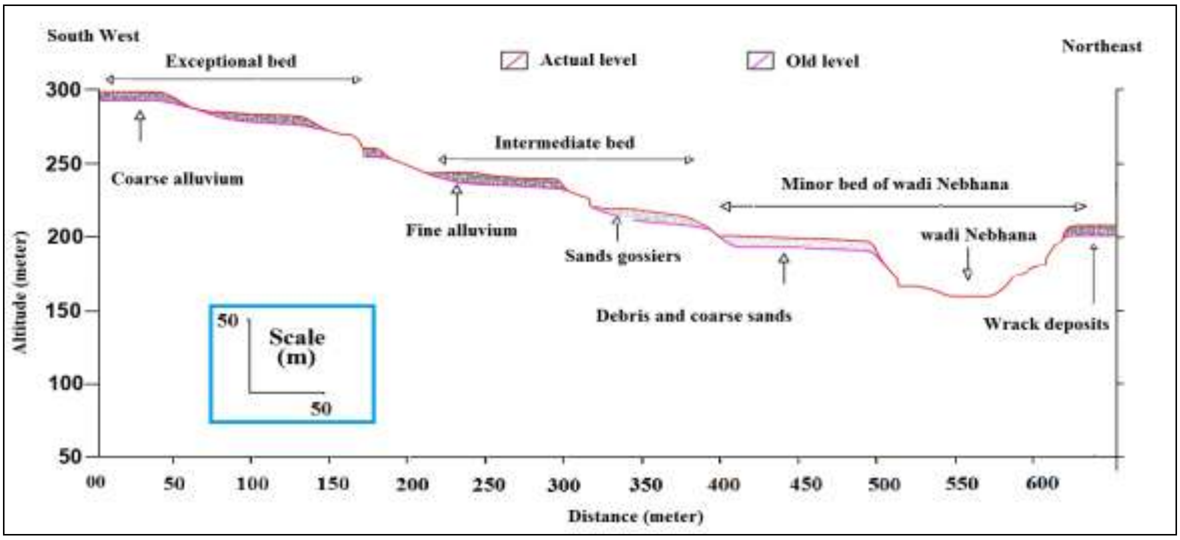

Figure 6: Result of the superposition of the two sections

We can deduce that the establishment of the Nebhana dam allowed the supply of the surrounding alluvial terraces (Henchir El Krachoun and Oled Atia), with detrital matter. The sediment input has become important and sometimes trapped by the construction walls. It is very important at the minor bed level, less important at the middle bed and low in the major bed. The grain size also changes between the three levels of the stream depending on the energy it was responsible for setting it up.

MORPHOLOGICAL EVOLUTION OF THE SURROUNDINGS OF NEBHANA DAM

The slowing down of the speed of abundant water by the construction of water control tools increases sediment inputs in refuge areas and upstreams of the constructions (Kotti et al 2016; Vorosmarty, 2003). The establishment of the Nebhana dam proves it. The study of the evolution of adjacent areas of the dam shows a gain in land (Lahmar, 2016). The results obtained emphasize the role that the dam played in stopping a significant sediment supply in its upstream part. The lowering of the kinetic energy of the water combined with the softening of the slopes promotes over-sedimentation and the accumulation of the transited water (Fig 7).

Figure7: Image of recent dynamics around Nebhana

The summary image of the land use of Lake Nebhana and these limits shows that 92.76% is formed by a wetland; 4.75% is formed by pebbles and blocks which often form natural low walls (Table 1). The vegetation cover that has grown around the lake and the bare soil space together make up almost 2% (Lahmar, 2010).

Tableau 1: Land use at Lake Nebhana

	Humid zone	Stony ground	Bare ground	Vegetation
(%) of the surface	92,76	4,75	1,80	0,68

SHAPES OF SISSEB EL ALEM TERRACE

The downstream of Lake Nebhana (Region of El Alem) is often formed by alluvial terraces of different ages and separated by an erosion surface. We were able to detect three levels of terraces (1), (2) and (3) which are stepped and sometimes nested according to their topographical location (Fig 8). The basal unit consists mainly of sands with an often fine grain size. The upper unit, on the other hand, is of a carbonate facies rich in bioclasts, with in particular conch. These two other units therefore correspond to two distinct phases of sedimentation and the dynamics of which it was at the origin of their deposits is not the same. In general we can say that terraces in the study area are organized firstly by a system of interlocking

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terraces. Then, we can also find a stepped terrace system (Fig 8). Within the same terrace system, all these characterizations coexist and show the different fluvial dynamics during the formation of different aquifers (Camille, 2005).

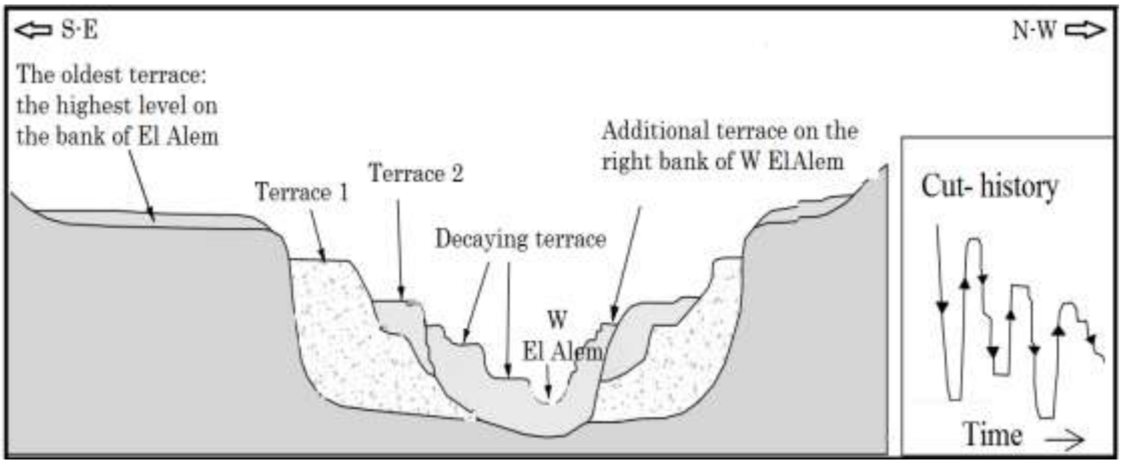

Figure 8: The forms of terraces identified on the El Alem wadi at the Oled Bou Morra level

THE TERRACES KEPT IN THE STUDY AREA

The morphological study of the terraces of different ages in El Alem shows that despite the effectiveness of the erosion agents (ablation and transit), they remain in more or less continuous shreds depending on the sector. However, can we identify the factors favorable to the conservation of alluvium on the terraces of the study area?

THE WELL-PRESERVED TERRACES

The study area is characterized by a structure of glacis and terraces. The gradual sinking of the Nebhana wadi, sometimes with low kinetic energy, results in the spreading of several terraces. Hillsides appear successively towards the watercourse: the plateau sheltered from alluvium placed before the digging of the valleys, the high terrace, the middle terrace, the low terrace, the low plain or recent alluvial plain liable to flooding (Ghyselinck-Bardeau et al. , 2007). They form extensive alluvial banks sometimes in the form of stairs that can be followed over great distances along the course of the wadi Nebhana and then the wadi El Alem. They form different edges and slopes in strong proportionality with the degree of ablation or the sudden evolution

THE TERRACES WITH MARKED EDGES

After the establishment of the Nebhana dam, the dynamics of the wadi experienced a sharp decrease. As a result, the terraces of El Alem were weakly attacked by water erosion. The tributaries had to dig to connect with the current major bed of the main course of Nebhana. The topographically clear edges have a command which varies from 12 meters upstream, in the area of Oled Bou Morra to 2 or even 3 meters in the lower level, that is to say at the level of the alluvial plain of Bou Morra (Fig 10). The rim has a convexo-concave profile, intersecting a slope ranging from 15° to more than 25° depending on its position relative to the current trajectory. Where the low terrace sometimes doubles, the slope limiting the highest level (10-12 meters above sea level) is less sloping (Fig 10). The basal concavity is explained by the accumulation of debris torn from the alluvium and not passed through the wadi Nebhana, already weakened by the construction of its dam. The terraces (1) and (2), shown in Figure 10, whose rim has been rejuvenated by strong human action, form levels at Oled Bou Morra, downstream from the dam. However, they are dissected by small tributaries whose heads of ravines are very affected by suffusion. The same phenomenon exists all along the course of Nebhana in the downstream part of the dam until reaching Sabakt El Kalbia. In general, the rim remains more personalized than the lithological difference between the alluvial material and the substratum.

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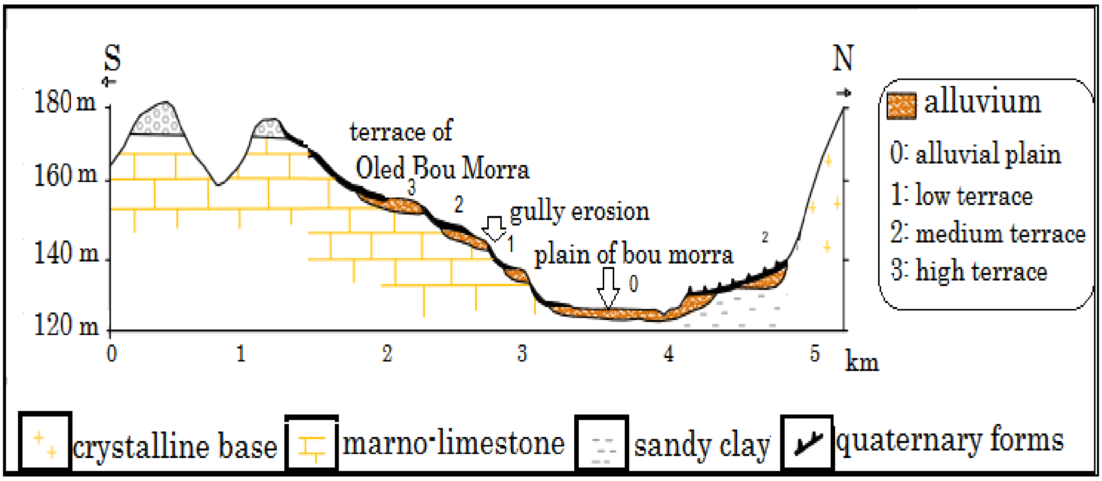

Figure 9: The terraces with marked edges in the plain of El Alem

EDGED TERRACES MITIGATED BY EROSION

The repetitive action of solifluxion and runoff transforms the edges of old terraces into softer shapes. The terraces of El Alem (downstream from Nebhana) are often in the form of storeys, connected to each other by a very low slope although no functional glacis has intersected them. Section 1 in Figure 11, transverse over the Nebhana wadi, to the right of Oled Bou Morra, made up of several tiered terraces, ranging from 120m to 160m. The layers of alluvium vary in thickness. They are formed mostly of pebbles, sands, coarse sands and a sandy clay matrix. The thickest layers of the reworked material are located at the foot of the edges, while on the horizontal top of the terrace close to the edge; the alluvium in place is little masked. Section 2 of Figure 11 shows that the slope of the edges gradually decreases with age: 10 to 12° for the lower terrace of El Alem, 8° for the upper one. It also varies according to the nature of the substratum, so the edges are less clear in the zones of thalweg filled by sediments of the sandy clay type and which sometimes turns into dead arms.

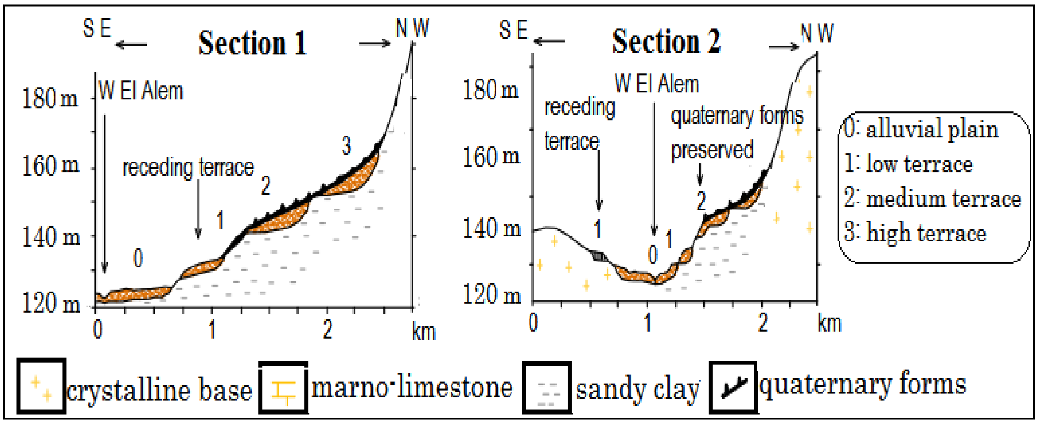

Figure 10: Terraces with edges mitigated by erosion upstream of Oled Bou Morra

OTHER FORMS OF TERRACES AND GLACIS IN THE STUDY AREA

Other forms of terraces can be found in the El Alem area. Each Jebel presents on its foothills a set of glacis such as Jebel El Hamama, Jebel Dkhila and Jebel El Golea. Both feature a highly developed glacis system that can extend up to 20m in width and 60m in length. They are also found downstream from Lake Nebhana. For the rest of the glacis also located downstream of the dam, we find the very dissected terraces (Fig 10). The latter are personalized by mounds, forms of plateaus, hills and sometimes in the form of veneer-flats. Moreover, one can find terraces intersected by glacis. This phenomenon is noticed at the level of Ain Bou Morra. These are very fragile lands and form a very accessible area for agricultural exploitation and sand mining trafficking often used

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for the construction of uncontrolled habitats. But we can also identify forms of glacis. The ancient glazes are fossilized by a large conglomerate crust. The dominant soil type on the Lutetian bar is rather lithosols. The recent glacis are formed by stony alluvium cemented by a soft encrustation or a very calcareous silt. Culture has greatly degraded its structure and the organic matter content is low (Cointepas et al, 1967).

MAPPING OF GRAIN SIZE INDICES FOR THE CHARACTERIZATION OF TERRACES: THE EFFECT ON THE NATURE OF THE SEDIMENTS

The study and mapping of sediments from alluvial terraces in the Nebhana region provide additional information on the chronology of the phases of aggregation and incision on the downstream part of this watershed (Fig11: A and B). We can also deduce the passage between an aggregation stage and that of an incision of the terracing systems in the region. In addition, the dates obtained make it possible to characterize the rate of alteration of the various water tables as a function of time based on different weathering criteria but also to quantify the rate of incision of the stream The particle size mapping allowed us to identify the dynamics that were at the origin of the sedimentation in the upstream and downstream part of Wadi Nebhana. For this we could make two profiles: the first is upstream of the dam and the second is downstream. The results obtained showed that the dynamics must have changed since the 70 year's. Figure 11 shows that other than the nature of the grain deposited, we can say that the speed of sedimentation has experienced a strong decrease after the setting of Nebhana Dam. We are therefore witnessing a bulk deposit. Water no longer has the same power to transit matter. The mobilization of deposits does not come from the same contribution. Currently the deposits are very rich in organic matter. This proves our motivating postulate that the wadi Nebhana has lost its kinetic energy to transmit the torn matter very far. The average particles size also presented a marked increase. This proves the dynamics of Nebhana's water no longer have the same kinetic speed.

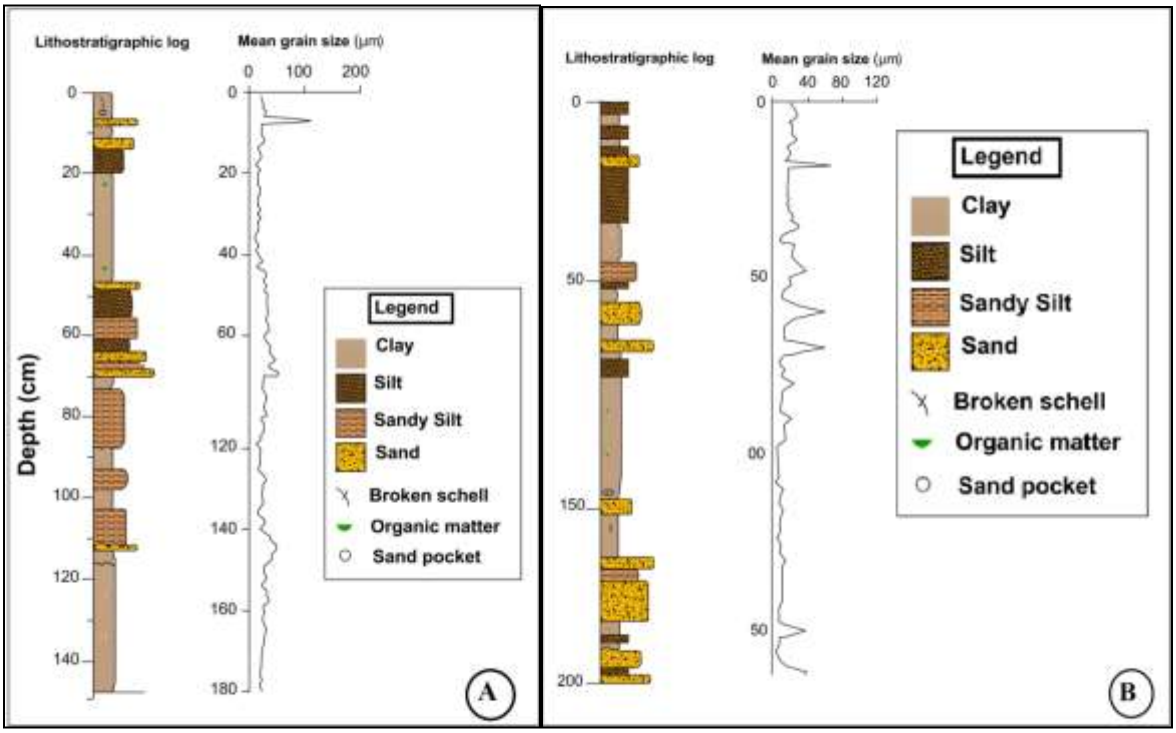

Figure 11: Particle size mapping upstream (A) and downstream (B) of Nebhana

It can therefore be concluded that the sedimentary filling of abandoned channels and the spatial distribution between clay and sand elements can in turn influence the development of rivers, in particular by offering varying resistance to erosion. The distribution of sedimentary facies is a determining factor in the circulation of the waters of Nebhana. Disturbances are observed in the studied sediments of the Nebhana terraces. These are layers of loose sediment. This seems a little

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strange and especially when it corresponds to deep sediments. This phenomenon is linked to biological activity. It amounts to a movement of particles by soil fauna, mainly ants and insects.

IV. DISCUSSION

It is now a question of providing new explanations on the geometry, shapes and degradation of the terraces in the alluvial plains of Nebhana- El Alem. Then we give a typology of the factors that participated in the modification and destruction of the terraces. The classification mainly gives anthropogenic, natural and other agro-pastoral factors.

The Role Of Hydraulic Arrangement In The Fragility Of Alluvial Terraces

The study site shows that the Nebhana wadi trajectory passes from multiple channels before the establishment of the dam, to a single channel (Dai et al, 2019). The area was under a very accelerated dynamics brought about by the reached system and suffusion. This fragility was proved by the floods of 1969 which must have modified the panoramic view of the region and a general change in the landscape. The sedimentary processes combined with the low kinetic velocity of Nebhana especially after the establishment of its dam which helps in the fixation of the channel. This could also help its artificialization by hydraulic developments. The hydraulic works in the region, which began in the 1950 year's, had the effect of permanently dividing the minor bed of Nebhana. They caused its almost complete staging and caused a general decrease in flow velocities (El Aoula et al, 2021). This situation, by slowing down sediment transport, favored sedimentation upstream of the structures and in the floodplain (Beauchamp et al, 2017).

Influence Of Anthropogenic Factors

Ballais (1992), Fehri (2003), Neboît (1979) and Larue (2001) have shown the importance of human factors in morphogenesis. Man voluntarily contributes to the destruction of terraces by exploiting detrital materials such as sands or gypsum and indirectly by catalyzing mechanical erosion. In our field study, we found a plastic bag near the terrace of Oled Bou Morra (Fig13). The index found is 72 cm in depth (Fig 12) testifies to a strong anthropization affecting the region.

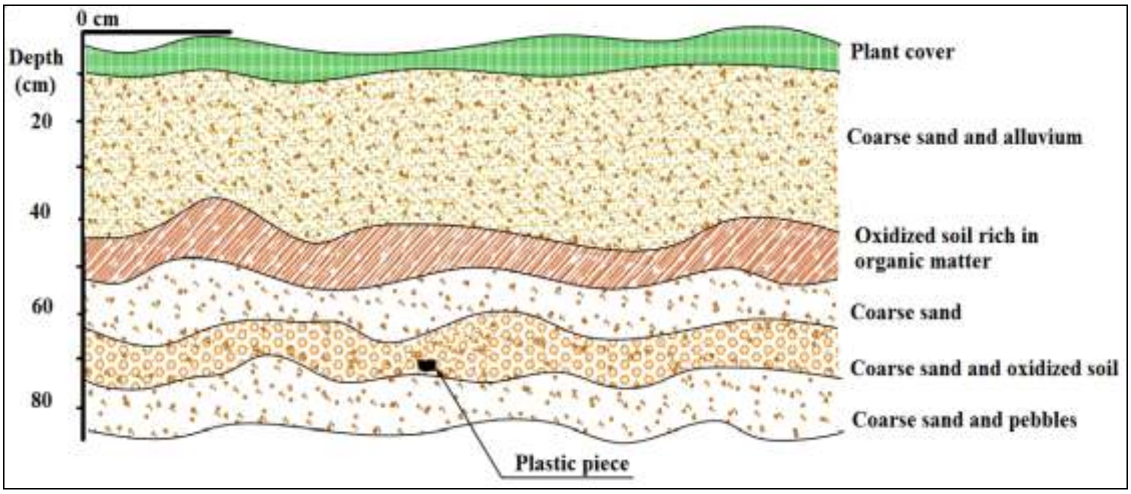

Figure 12: A plastic piece found at a depth exceeding 70cm in a terrace in Oled Bou Morra

The extraction of sands mainly affects recent alluvial formations due to the slight deterioration of the material (Larue, 1982). It can result in the partial removal of a terrace such as for example the low terrace of Henchir Elkrachoun at the level of the Kseub wadi, where the excavations end up joining and give way to bodies of water called the local "guelta" scale. The old alluvium is exploited by the construction of buildings, cement factories, tile factories and brickyards, for example in El Alem south at the level of the Kelifa wadi and at the level of Ain Bou Morra downstream of Lake Nebhana. The walls of the abandoned quarry recede by landslide, which ends in the formation of a scree slope going at 30°.

Figure 13: The evolution of current sediment inputs

AGRO-PASTORAL ACTIVITIES

The water from the Nebhana dam will be used to irrigate existing agricultural land with an area of approximately 700 hectares.

The man encourages runoff on the terrace edges. Plowing in the same direction as the slope promotes runoff concentrated in the furrows. An abundant downpour carries the fine elements down the slope, which gradually reinforces the concavity of the base of the profile and accelerates the erosion of the heads of the ravines ... We have also observed that the accumulation in Sisseb El Alem is very accelerated where the edges of the middle and lower terraces initially undergo a strong activity in channels between the lines of the recently established shrubs, these incisions are sometimes erased by the successive plowing. When the land is grazing, the trampling of the herds who use the same paths to move, activates erosion on the slope of the embankments. When the soil is dissected from water, the animals compact the earth and enhance the mobilization of matter and its displacement downstream of the relief. However, this erosion could be mitigated by the growth of vegetation because the latter combines a root system capable of blocking the development of the heads of ravines. The creation of new irrigated perimeters in the area of Sisseb El Alem has been able to strengthen the traditions of the residents occupied by arboriculture. But the agricultural lands irrigated by Wadi Nebhana are strongly threatened by illegal and non-compliant constructions.

V. RECOMMANDATIONS

The climate change scenarios predict an increase in aridity accompanied by torrential rain which manifests itself in a significant erosive action. According to Bates et al (2008), Hungtintion (2006), sediment transport in rivers controls environmental problems often related to observed changes in the hydrological cycle. To deal with the worsening of this phenomenon, we propose a comparison of two situations. A first zone is cultivated and the second zone is completely deforested. The hydraulic dynamics are deferent in the two zones. In the deforested area, abundant water gains speed, obstacles are therefore rare and water is capable of pulling out soil particles and therefore capable of modifying geomorphological shapes. For the reforested area, the water opposes obstacles that favor over-sedimentation. They help to form significant sediment inputs and the formation of alluvial sponges. Figure 14 compares the two situations. The shapes resulting from the dynamics of the water are proportional to the development and the plant cover in the upstream part of the watercourse. In order to preserve the soil of the alluvial terraces in the region of Sisseb El Alem, it is recommended to better develop, reforest and control the pastoral activity in the region.

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The obligation of setting up the Nebhana dam is driven by at least two reasons: protecting the downstream areas from flooding and providing the area with irrigation water. Now, after 50 years of the construction of the Nebhana Dam, we will have to look for other methods to preserve the environmental ecosystems downstream. This protection aims to fight against erosion and protect geomorphological forms in situ such as alluvial terraces.

Controlling the clandestine use of some of the region's resources remains essential. Uncontrolled drilling depletes groundwater and weakens alluvial terraces. Then the use of the bottom sands of the wadi only mobilizes the material and facilitates its transition from upstream to downstream. All of these recommendations require a broad common environmental knowledge and good awareness.

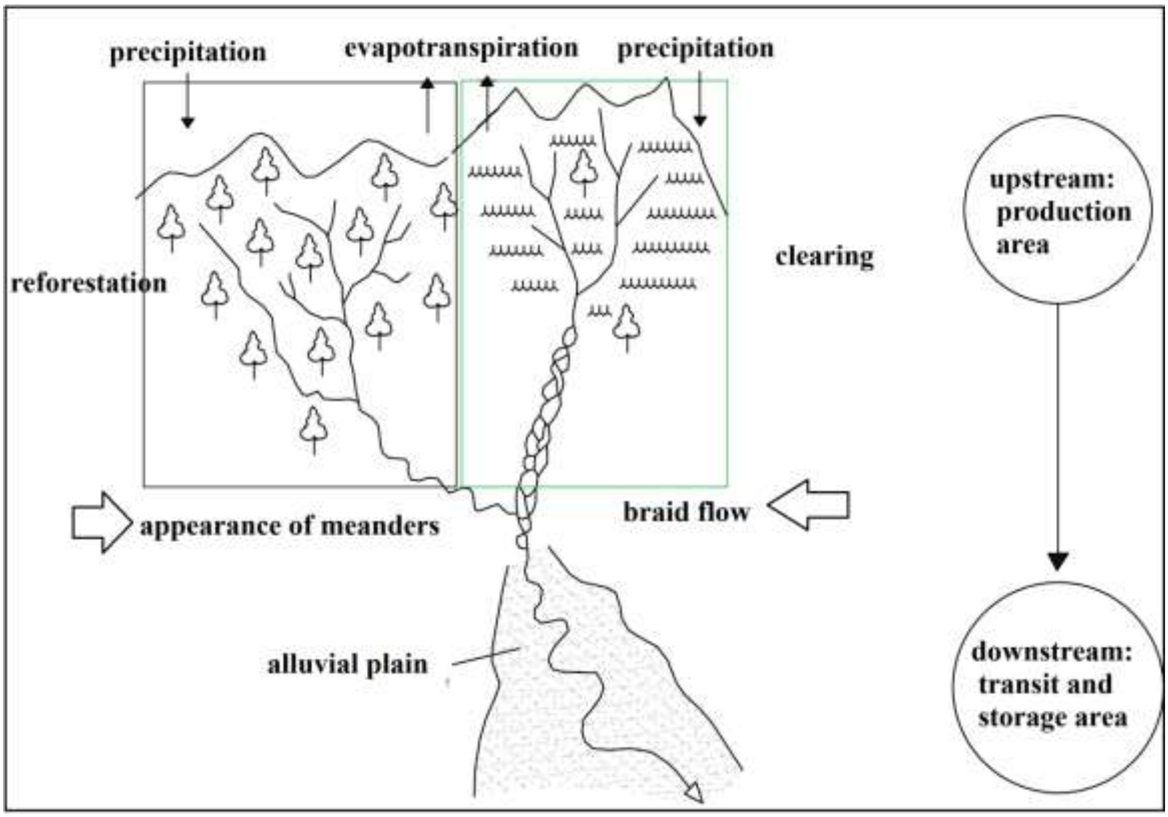

Figure 14: Comparaison des formes induites des clearing and reforestation.

VI. CONCLUSION

The results obtained in this article show that the alluvial terraces in the region of Sisseb El Alam are fragile constructions that change abruptly under the influence of mechanical, anthropogenic erosion and chemical weathering in the adjacent areas of Sabkhat Elkalbia. it is the periglacial phases of the Quaternary which control morphogenesis. Most of the forms are inherited from these cold periods where river dynamics, runoff and solifluxion played an active role. The temperate environment nowadays brings little detail: slow weakening of the edges of terraces and linear incision by small tributaries. We also note that human action remains very decisive in the destruction of these forms of terraces. Uncontrolled action as well as heavy exploitation can only worsen water erosion and induce a strong transition of matter. The destruction of the edges of terraces by the action of (sometimes deep) plowing catalyzes the erosive dynamics. Moreover, the forms of terraces preserved in the region of Sisseb El-Alem are the most protected forms: either against erosion in its various forms or against excessive anthropic action.

Note:
The results of this article come from a thesis carried out in the laboratories of the University of Paris-Est and Meudon on the hydro-geomorphological dynamics of small watersheds.

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