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The Dynamic Development of the Sebou Valley and Its Impact on the River Domain Between Oued Inaouene and Oued Bouchabel (Pre-Rif) Morocco

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Abstract: In this paper, we present the study's results of the fluvial erosion aspects in the Sebou valley, between River Inaouene and River Bouchabel in the Pre-Rif mountains. On the one hand, we analyzed the hydrodynamic factors interfering in the erosion, and on the other hand, we studied the types of banks exposed to the fluvial erosion processes and the degree of their deterioration. In order to achieve our objectives, this research was based on observation and interviews with the local population, fluvial erosion measurements, literature reviews, and the adoption of statistical series of precipitation and water flow for the Dar Al-Arsa station. As results, we found that despite the presence of the Allal El Fassi dam in the upstream of Sebou valley and the presence of the Idris I dam in the upstream of Inaouene valley, the water flow of Sebou between the Inaouene valley and the Bouchabel valley is characterized by important flood periods that erode the river banks, where the maximum flow in the studied field exceeds 400 m^3/s, as in the cases of 2008 and 2010. This results in a variety of erosive phenomena, either directly, by the erosion of the banks under the effect of the floods, or indirectly due to landslides of the marl slopes overlooking the main river, which causes a continuous degradation of the river banks, with a rate of 7m per year. These hydromorphological processes contribute to a significant dynamic evolution of the meanders within the alluvial plain. Therefore, we summarizing the recommendations in the tracking of the studied channel status and configure it for the hazard.

Keywords: Sebou, Floods, Banks Erosion, Geomorphological Impacts

1. Introduction

Lateral erosion of stream banks is one of the basic geomechanical methods of river formation, as well as other methods of transporting of materials from the high drainage basins to the lower ones [1-3, 8, 10, 14]. Typically, the bottoms of Moroccan valleys including Sebou valley reviewed in this article, are extremely fragile areas in which bank erosion is active due to the irregular annual and seasonal Mediterranean hydroclimatic conditions and the flowing water force during rainy phases.

The issue of this work lies in the study of the erosion aspects and its effects on the Sebou river banks to understand the resulting danger, in particular, the dragging of agricultural lands around the floodplain. As well as the diagnosis of the natural conditions and hydrodynamic factors that contribute to this erosion and the movement of the waterway in the short and long term. Therefore, the production of a database that can be adopted to guide the ways and means of preparation in order to mitigate the constraints of banks erosion along the Sebou valley.

2. Research Method

This work was based mainly on field work, we monitored and localized the erosion areas, we also used cartographic documents and satellite images (Google Earth), analyzed the hydroclimatic data and traced the morphological development of the stream from 1943 to 2016, and focused on the impact of the floods of 2008 and 2010 [14, 15]. In addition, we interviewed local residents and adopted questionnaires to study the effects of river erosion on agricultural land use in the Sebou Valley floodplain.

And we took pictures from the field, to track the danger of river erosion, bank collapse and slope slipping. We also measured side and vertical river erosion [4, 6, 7, 9, 11, 13], in a traditional way, in which we relied on manual work and walking on foot to measure side erosion between the top of the bank to oversee the stream and a known point, as well as measuring stream erosion. Perpendicular to the same bank between the top and bottom of the stream bank by the metre, as shown in Table 1.

2.1. Study Zone

This paper discusses riverbank erosion and its social and spatial impact in the central Sebou valley, which extends north of Fez city from the junction of the Sebou valley with the Inaoune valley, near of Douar Ben Haddan area, to its junction with the Bouchabel valley at Douar Ouled Ben Hammou area (Figurre 1). The study area is located between the two latitudes 34°05', 34°25' North, and the two longitudes 4°50', 5°20' West (topographic maps 1/50000, Fez East, Fez West, Qalaat Slass and Qariat Ba Mohamed).

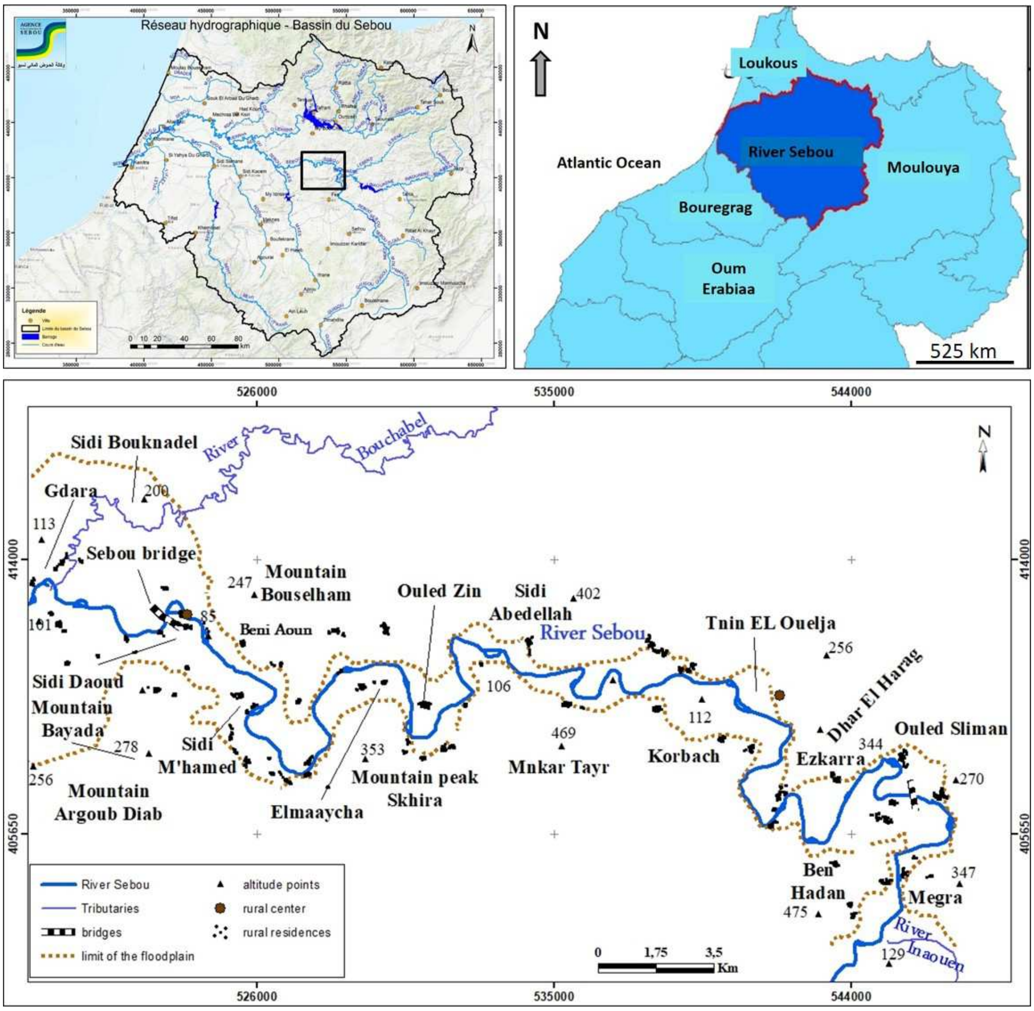


Figure 1. The location of the studied area.

Besides various crops in the riverine area (cereals, forage, vegetables and forestry), a natural vegetation cover extends on both sides of the river but only in some places. For example, the Tamarix plant extends on the eastern right bank at the intersection of Sebou and Inaoune valleys, south of Douar Magra area, also under the Sebou bridge, east of Douar Lala Arbia on the northern bank. On the opposite bank, the papyrus plant spreads east of the Douar Bin Hadan area. While the Siberian plant (Trèfles) spreads east of Douar Al-Fattah area, the Eucalyptus plant and the Salix mucronata plant extends to the southeast and north of Douar Karbach area in the western and southern left bank, And south of Douar Awlad El-Zein area on the north bank. In adittion, the spread of the Dactylon Cynodon plant along its banks, with the presence of the Phragmites frutescens plants and the cactus, Cyperus papyrus plants and Sidr (Jujube/Ziziphus Jujuba) plants, but otherwise, the planted vegetation is expanding.

This article aims to study the fluvial erosion events and their geomorphological and spatial impact in the banks of Sebou valley, by studying the hydrodynamic conditions controlling the river creation and tracking the evolution of the river course and its morphological variables over the last seven decades (for the years 1943, 1987 and 2016).

2.2. Hydrological Conditions Contributing to Fluvial Erosion

The hydrological system of the Sebou valley is the main driver of fluvial erosion activity. The valley drains an important river basin that extends to the Middle Atlas, It is generally characterized by water flows associated mainly with precipitations, as shown by the data of the Sebou River Basin Agency at the Dar Al-Arsa station (Figure 2 and Figure 3), in addition to the effect of snowmelt water during the winter and early spring. Depending on the rainfall system feeding the flow in the Sebou basin, the seasonal and annual heterogeneity of the flow contributes to moving the fluvial dynamics and activating the erosion of the stream banks, depending on the strength of the water currents during the tidal periods.

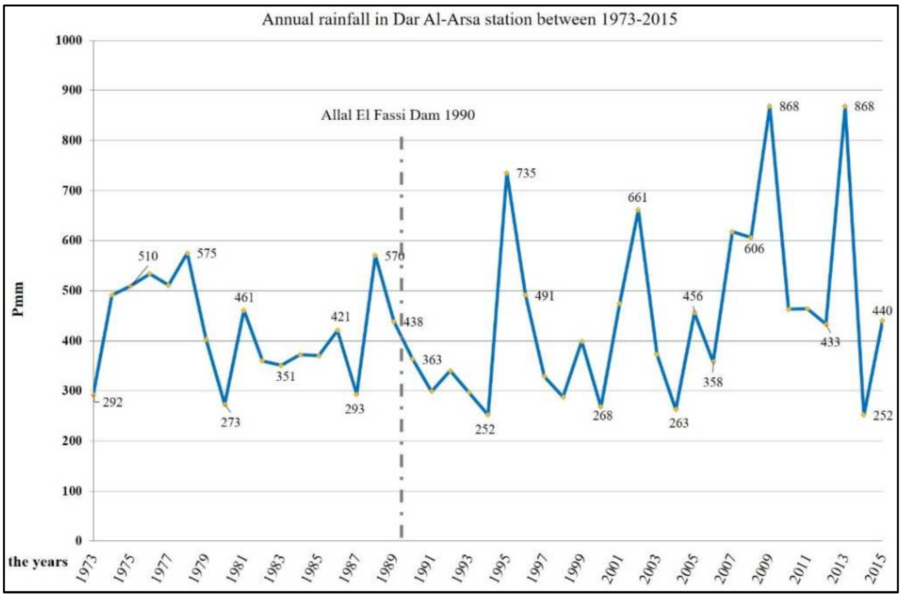


Figure 2. *Heterogeneity of annual rainfall in Dar Al-Arsa station between 1973 and 2015.*

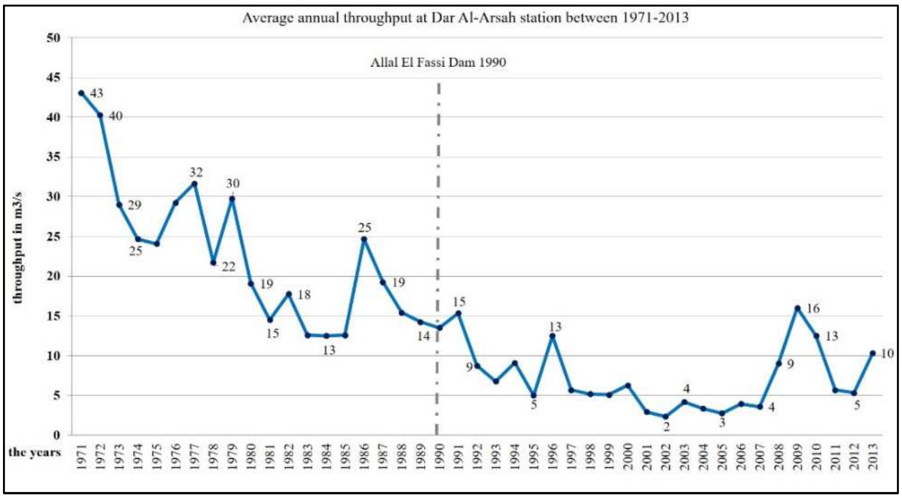


Figure 3. *Heterogeneity of the average annual throughput at Dar Al-Arsa station between 1973 and 2015.*

The rainfall registered at the Dar Al-Arsa station (between 1973 and 2015) was characterized by important fluctuations (Figure 2). It varied between 280 mm and 570 mm before the construction of Allal El Fassi dam in 1990, in Fez city, it did not exceed 600 mm, whereas it varied between 252 mm and 868 mm after the construction of the dam, and therefore it exceeded 600 mm several times, this confirms the increase in precipitation during this period, especially during the last ten years. While, the hydrological behavior of the Sebou valley has changed significantly after the construction of the dam, as shown in Figure 3, where the annual average flow at Dar Al-Arsa station varied between 10 m^3/s and 45 m^3/s before the construction of the dam, while it decreased significantly to reach between 2 m^3/s and 15 m^3/s after the implementation of the dam.

Fluvial erosion is closely related to the strength of eruption currents, which vary strongly at the bi-annual and monthly levels, as we show in Figures 4 and 5 through the heterogeneity of the maximum daily flow of Sebou valley among years and months.

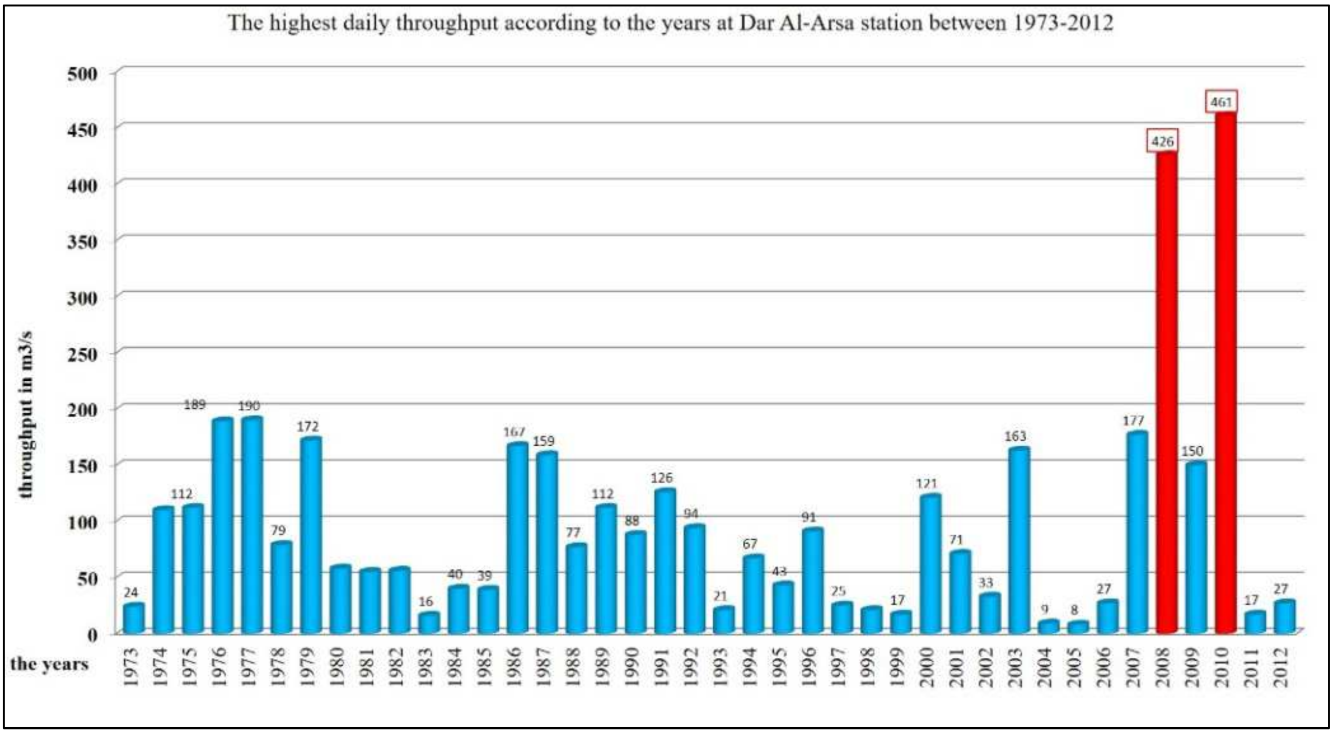


Figure 4. *Variation of the maximum daily throughput at Dar Al-Arsa station according to the years between 1973 and 2012.*

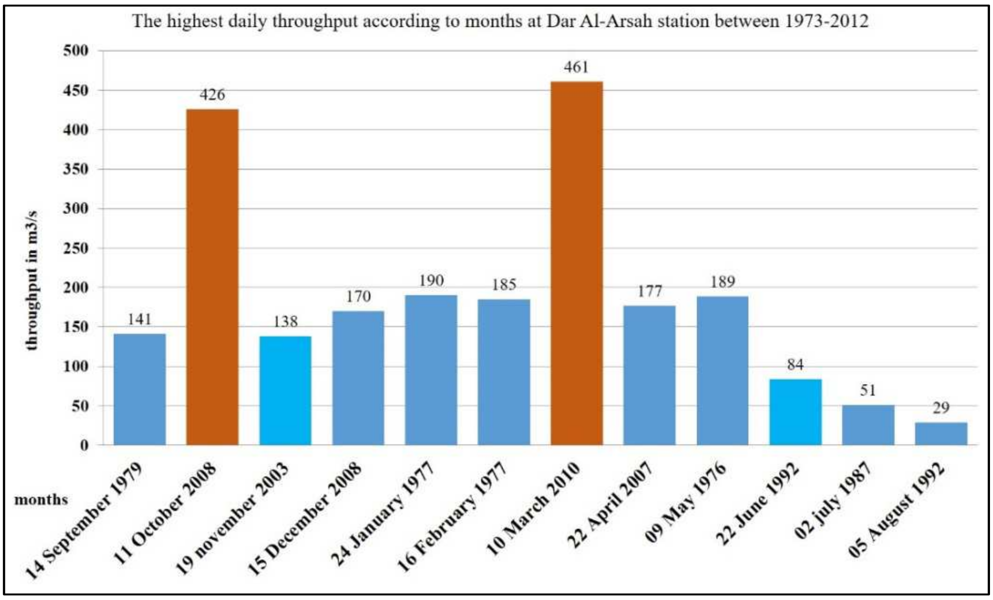


Figure 5. *Variation of the maximum daily throughput at Dar Al-Arsa station according to the months between 1973 and 2012.*

Figure 3 presents the fluctuation of the Sebou Valley stream flow before the construction of the dam in 1990 between 16 m^3/s in 1983 and 190 m^3/s in 1977, while after it varied between 8 m^3/s in 2005 and 461 m^3/s in 2010, Thus, the station of Dar Al-Arsa recorded an exceptional water flow during two exceptional years, which caused torrential floods in the floodplain and violent erosion of the banks, This was on December 15, 2008 at a flow of 426 m^3/s and March 10 at a flow of 461 m/s, as shown in Figure 5, indicating that all months of the study period have a significant water flow that can contribute to the erosion of the stream banks.

3. Results and Discussion

3.1. Fluvial and Bank Erosion Manifestations

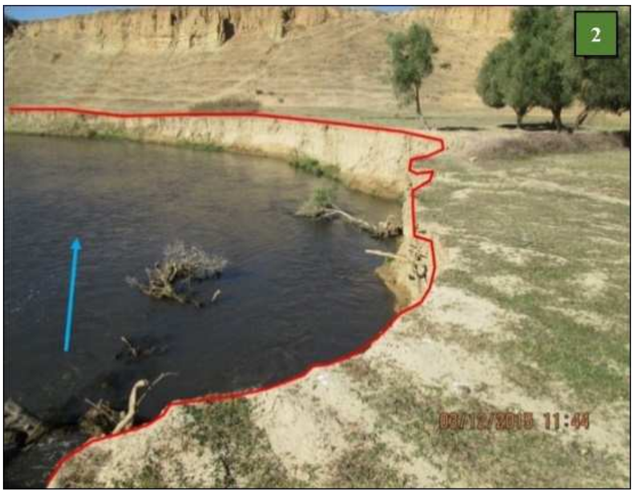
Based on fieldwork and satellite images, we have studied the erosion and the degradation of the banks in order to diagnose their spatial distribution along the Sebou valley and to assess its severity, and know the areas that have experienced the most degradation. In general, the forms and severity of fluvial erosion vary in the studied area, depending on the location, elements fragility, banks height, stream shape and the strength of the water current, the presence or absence of vegetation cover and its quality, as well as the human pressure through agricultural exploitation in the floodplain or the extraction of sedimentary materials from the floodplain or river sediments (sand quarries).

In general, it is possible to differentiate between lateral fluvial erosion or bank erosion, and lateral fluvial erosion of the clay slopes below the stream. Vertical erosions can be observed in the stream appearing in some areas.

3.1.1. Lateral and Bank Erosion

River banks are subject to strong lateral erosion due to the water current during eruptions, making the course of the stream in a continuous development, especially at the bottom of the curves, as shown in Figure 6, this provides examples of cases of bank erosion [2, 3, 6, 13, 14], as they are located in places faced with the water current, especially in the high flow stages, due to the fragility of the bank components and their low resistance to erosion, despite the presence of vegetation cover in some places.

1) - Bank erosion east of Zkara



2) - Bank erosion southwest of Ouled Zen

Figure 6. *Examples of lateral erosion in some banks of the Sebou River stream.*

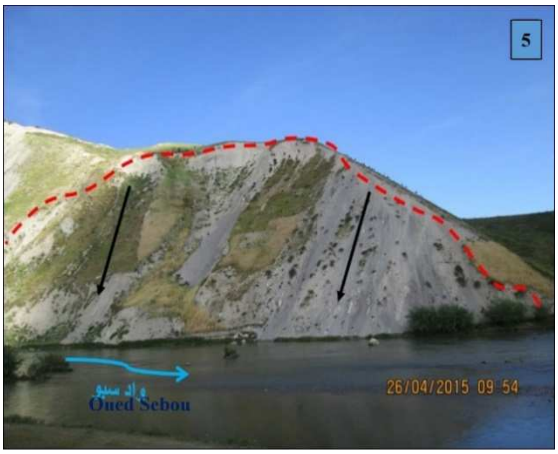
3.1.2. Bank Collapse

The strength and danger of fluvial erosion increases as we move from top to bottom, as a result, most of the banks are subject to collapse, as shown in the images of panel 2 in image 1 on the north right bank, northeast of Douar Ouled El Yamani area, at the beginning of the concavity, This entire bank collapsed, following the digging at its feet, and Figure 7 west of Douar Megra area shows that the bank collapsed for about 2.5 km on the north right bank, it appears that the latter is constantly collapsing, despite being parallel to the water current and despite its plant cover availability.

3) - The collapse of the banks, South of Douar Ouled El Yamani

4) - North of the Megra douar (view from the northeast)

Figure 7. *Some models of bank collapse in the studied course.*



5)- The eastern slope of Kodya Ghaouti, southeast of Dowar Korbash (view from the east)

6)- South slope to the south of Douar Ouled Baligh (view from the west)

Figure 8. *Models of some of the valley slopes slides.*

3.1.3. Slide of the Slopes of the Valley

When the stream reaches the valley slopes overlooking the stream, the stream is exposed to erosion at its feet [1, 5, 8], causing sliding of its marinade rocks, as we show in several points in image panel 3. Through image 1, we see an example of a landslide at the foot of Kodya Ghaouti, southeast of Douar Korbash area in the western slope overlooking the right side of the stream, where the bottom of this slope has been exposed to the excavation, which leads to its sliding always, whether the flow is normal or strong and fast. In Figure 8, we present an example of the sliding of the northern slope of the South slope to the south of Douar Ouled Baligh from the left side of the concave bank, as an effect of the force and speed of the water current.

3.2. Bank Erosion and Recession Evaluation

Through the forms of fluvial erosion to which the banks of the Sebou valley are exposed, we concluded that the river is permanently in a lateral movement that leads to erosion and recession of the banks, pushing us to research the decline rate. We have monitored and measured the erosion and recession of the banks, Table 1 represents the results we have found [14].

Table 1. *The results of measuring the lateral and vertical erosion of the banks of the Sebou Valley between 2016 and 2017.*

number station	Station location	21-22 May 2016 meter	21-22 May 2017 meter	the difference by meter
1	1) X= 545496,111; 2) Y= 403555,966; Z= 128 m 3) East of Ben Hadan	Height: 4.70 Distance: 3,90	- Height: 4,90 -Distance: 2,90	(+0,20) (-1)
2	1) X=545375,615; 2) Y= 404890,031; Z= 126m 3) East of Al-Fattah	Height: 4,90 Distance: 17,40	Height: 5,30 Distance: 11	(+0,40) (-6,40)
3	1) 34° X= 545556,359; 2) Y= 404096,595; Z= 125m 3) Northeast of Megra	Height: 4,80 Distance: 10,40	Height: 5 Distance: 6	(+0,20) (-4,40)
4	1) X=545771,531; 2) Y= 405139,63; Z = 124 m 3) A little east of Salfa	Height: 2,80 Distance: 10	Height: 3,10 Distance: 8,40	(+1,30) (-1,60)
5	1) X= 544041,55; 2) Y= 404136,423; Z= 121 m 3) East Zkarah	Height: 2,50 Distance: 38	Height: 2,80 Distance: 35,70	(+0,30) (-2,30)
6	1) X=541898,44; 2) Y= 407919,648; Z=116 m 3) East of Korbach	Height: 5 Distance: 18,30	Height: 4.40 Distance: 16,30	(-0,60) (-2)
7	1) X= 532000,542; 2) Y= 411646,422; Z= 103 m 3) Northeast of Ouled Zen	Height: 2,30 Distance: 22,30	Height: 2,30 Distance: 22,30	(did not change) (did not change)
8	1) X= 530554,588; 2) Y= 410286,537; Z = 93 m 3) West of Oulad Zen	Height: 4,80 Distance: 12,25	Height: 4.60 Distance: 5,25	(-0,20) (-7)
9	1) X= 523359,246; 2) Y= 412696,46; Z = 85 m 3) Northwest of the center of Sidi Daoud	Height: 3,50 Distance: 6.60	Height: 3,10 Distance: 6.10	(-0,40) (-0,50)

The results in Table 1 show that the majority of the banks studied are subject to erosion and recession: the bank of Station No. 8, for example, has decreased by 7 meters, and the bank of Station No. 2 by 6.40 meters over the course of only one year, and the bank of Station No. 3 by 4.40 meters... Excavations were also made at the bottom of some banks until the depth and height of the stream increased, indicating that the stream banks are completely unstable, with the exception of Station 7. It was under the influence of an annual flow for the same period, which reached 39.7 m^3/s at Dar Al-Arsa station, with an annual average of 3.1 m^3/s at the same station, which indicates the strength of erosion under the influence of these normal quantities, And perhaps low compared to years of water abundance and flood years such as 2008, 2009 and 2010, when the water current was strong, capable of causing severe erosion and rapid bank recession.

The field measurement over one year, as shown in Table 1, is of great importance, because it clearly shows what we talked about when analyzing the forms of erosion, and reveals to us the instability of the banks in this area., which confirms that the banks of the course of the Sebou valley and its floodplain are under the influence of fluvial erosion, and confirms The severity of erosion varies in importance depending on the conditions of the places (the nature of the bank, its height, the presence or absence of plant cover... etc), so that the distinction has become familiar between unstable banks, and semi-stable banks, while completely stable banks remain very few in the field studied.

3.3. Evolution of Sebou Valley Course and Morphology Between 1943 and 2016

As a result of hydrodynamic activity and the resulting lateral erosion, The Sebou valley path experiences kinetics and changes in the level of its flow path and the wideness or narrowness of its course.

Based on topographic maps at scale 1/50000 (East Fez, Qalaat Slas and Kariat Ba Mohammed) for the year 1943, Landsat satellite image 1987, and Google Earth image 2016, we have followed the evolution and measurement of morphometric variables of Sebou valley course between Inaoune valley and Bouchabel valley [12, 15], the results are summarized in Table 2 and Figure 5.

Table 2. *Evolution of morphometric variables of the Sebou River stream between 1943 and 2016.*

morphometric variable	Icons		year 1943	year 1987	year 2016
The real length of the stream	L		60 km	59,90 km	63,10 km
horizontal length	hl		36.16 km	35,62 km	36.11 km
inflection wavelength	Λ	max value	5077 m	5148 m	5148 m
		minimum value	972 m	740 m	975 m
		Average	3025m	2944 m	3062
The distance between the edges of the bend - turn extent	A	max value	2568 m	2550 m	2538 m
		minimum value	233 m	307 m	554 m
		Average	1401 m	1428 m	1529 m
turning ray	R	max value	1489 m	1503 m	1503 m
		minimum value	189 m	165 m	148 m
		Average	839 m	834 m	825 m
Turn indicator Is = L/ lh	Is		1,65	1,68	1,74

The results in Table 2 show that the stream morphometry has varied between the years 1943, 1987, and 2016, thus the actual stream length has changed in addition to changes in the shapes and number of bends in the river over this period. The stream length decreased between 1943 and 1987 by 0.1 km and then increased by 3.2 km between 1987 and 2016 and then increased by 3.1 between 1943 and 2016. A decrease in mean curvature wavelength was also recorded, by about 80 m between 1943 and 1987, then increased by 37.05 m between 1987 and 2016 by 117.64 m between 1943 and 2016. It shows the continuous dynamism of the river, since the average bending radius is constantly increased by 27.48 m between 1943 and 1987, 101.01 m between 1987 and 2016, and 128.49 m between 1943 and 2016 while decreased by 4 81 m between 1943 and 1987, by 8.44 m between 1987 and 2016, and by 13.25 m between 1943 and 2016. The Bend Index (which is the ratio of the actual length to the horizontal length of the creek) has increased from 1.65 in 1943 to 1.58 in 1987 to 1.74 in 2016.

The course of the Sebou Valley has undergone clear changes and developments along the course. A radical change occurred in the course of the flow between 1943 and 1987 and 2016, resulting in new flow path in some places along the course, and new bends formed and others developed, increasing their length or regressing (e.g., north of Douar Ouled al-Yamani and north of center Sidi Daoud), While between these stages, the dead arms. (For example, southwest of Douar ouled Suleiman and west of Douar Ghzzawna), in addition to the emergence of triangular and intersecting streams at various points of the river's meanders.

We note here that the morphological evolution of the Sebou valley between 1943 and 1973 was related to the natural change of the hydrological system, when the flow was normal before the construction of the dam Idris I 1973 on the tributary Inaoune, and since this year the development of the river deposit became under the influence of this dam, and since 1990, the hydrodynamic behavior of the Sebou valley was affected by the impacts of the Allal El Fassi dam, Which was established on Sebou, north of Fez, and this indicates that the development of the river field studied has become partially controlled by man since 1973.

4. Conclusion

Through this study, we have shown the fragility of the agricultural land distributed on the floodplain of the Sebou valley in front of the Rif land. These lands have been subject to dredging due to the erosion and recession of the stream banks, especially during the eruption periods, which varied greatly in their annual and semi-annual flow amounts. Despite the construction of the Allal El Fassi dam since 1990, the impact of major eruptions still clearly affects river dynamics and banks erosion. The exceptional floods of 2008 and 2010 are a great example.

In this work, we also showed the general morphological result of the fluvial dynamics influence on the stream kinetics in the floodplain, and the evolution of its flow path and morphology over the last seven decades. This is a result of the effect of climatic conditions and changes in flow quantities on the development of stream bank erosion to the detriment of floodplain lands.

In the absence of effective and real interventions to protect floodplains from erosion, and in view of the results of the study, we recommend first a precise cartographic study to classify and locate the danger of fluvial erosion along the banks of the Sebou valley. Secondly, the elaboration of a mechanical and biological preparation program of the Sebou riverbanks in the short and long term. Finaly, the effective application of all the laws programmed in the framework of the maintenance of the ecological balance of the riparian zones.

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