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CHANGES IN RIVER BANK MORPHOLOGY IN A SMALL MEANDER OF EL ABID RIVER, ATLAS MOUNTAINS, MOROCCO

SUMMARY

This paper presents initial findings stemming from an extensive and first-hand field monitoring endeavour that delves into the erosion of a fluvial section in the downstream part of Oued El Abid. This river, situated within the Central High Atlas, holds particular prominence as the primary tributary of the big Oum-Err-Bia River. The hydrological behaviour of the El Abid River follows a snow-rainfall pattern, characterized by an average monthly precipitation of 82 mm. The main purpose of the current study is to investigate how the El Abid River responds to the forces of fluvial dynamics, particularly in the downstream segment near the Bin El Ouidane dam, by employing a methodology cantered on Geographic Information Systems (GIS) and Google Earth imagery spanning from 2016 to 2022. The findings of the study reveal a significant metamorphosis and ongoing dynamism within the targeted meandering section at the river's outlet. The period of research from 2016 to 2022 has witnessed pronounced alterations driven by lateral activities and a spectrum of fluvial processes: erosion, transportation, and deposition. This continual fluvial erosion has culminated in substantial soil loss from the riverbanks. Inevitably, these transformations intensify the sedimentation and siltation processes downstream, directly impacting the Bin El Ouidane reservoir as an outcome of the El Abid River’s discharge dynamics.

Keywords: Fluvial erosion; Morphology; El Abid river bank; Atlas Mountain; Morocco

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INTRODUCTION

In recent times, there has been a noticeable surge in research attention directed towards the dynamics of fluvial bank erosion (Konsoer *et al*., 2016). This trend can be attributed, in part, to several factors: (i) An increasingly heightened recognition of the pivotal role that bank erosion plays in influencing the dynamics of fluvial sediment transport, the sediment yields within basins, and the creation and destruction of floodplains (Billi and Spalevic, 2022); (ii) A growing emphasis on studies pertaining to channel stabilization, within which the analysis of bank failures holds a central position; (iii) Notable advancements made within the last decades in models (Darby and Thorne, 1996) and monitoring techniques (Lawler, 1991, 1994). These advancements have significantly contributed to addressing some of the persisting challenges (Coulthard *et al.*, 2012) and challenges include understanding the dynamics of bank erosion events, pinpointing the mechanisms driving bank retreat, defining intricate combinations and sequences of processes, with establishing connections between the supply of sediment from the banks and the transport of sediment within the channel (Lawler *et al*., 1999). Experiences of similar studies are identifying usually five distinct approaches used to examine the progression of meandering channels (de Vente *et al*., 2008; Gao, 2008; Milewski *et al.*, 2020; Vojtek *et al*., 2019), including three categorized as methodologies concentrating on meander morphology (Magdaleno and Fernández-Yuste, 2011). These methodologies involve scrutinizing the channel's characteristics over a specific time period. The other two approaches are focused on directly observing alterations experienced by the river's planform (Hooke, 1984). Consequently, given the extensive array of environmental and historical changes in processes within a basin's evolution, it becomes unfeasible to precisely predict or possess complete knowledge regarding the alterations experienced by a channel (Constantine *et al.*, 2009; Duan and Julien, 2005).

Several research endeavours have pointed out the limitations of traditional hydraulic viewpoints, such as regime theory or other geometric geomorphic approaches, in accurately predicting the consequences arising from changes in the environment within river systems. Factors like the scale of operations, the degree of alterations, and the spatial arrangement and spread patterns emphasize that the hydrological response and behaviour of river systems don't solely depend on external factors, or at least are not limited to them entirely (Latron *et al*., 2009; Latron and Gallart, 1995). Instead, it hinges on the landscape and the structural arrangement of the system, shaped by its geomorphologic history. This, in turn, reveals a non-linear aspect of how river systems react to modifications in extraneous conditions (Downs and Gregory, 2004).

The objective of this study is to continuously monitor the evolution of the morphology of a meander in the downstream part of the Oued El Abid River within the Central High Atlas of Morocco with an assessment of the meandering process that has been monitored since 2016 to investigate the impact of fluvial erosion on the river bank of the studied section.

MATERIAL AND METHODS

Study area

Positioned within the Central High Atlas of Morocco, Oued El Abid River emerges as a significant tributary of the Oum Err Bia River, as presented in Figure 1. Administratively, this river belongs to the region of Beni-Mellal - Khenifera, and the province of Azilal (Ouakhir *et al.,* 2022).

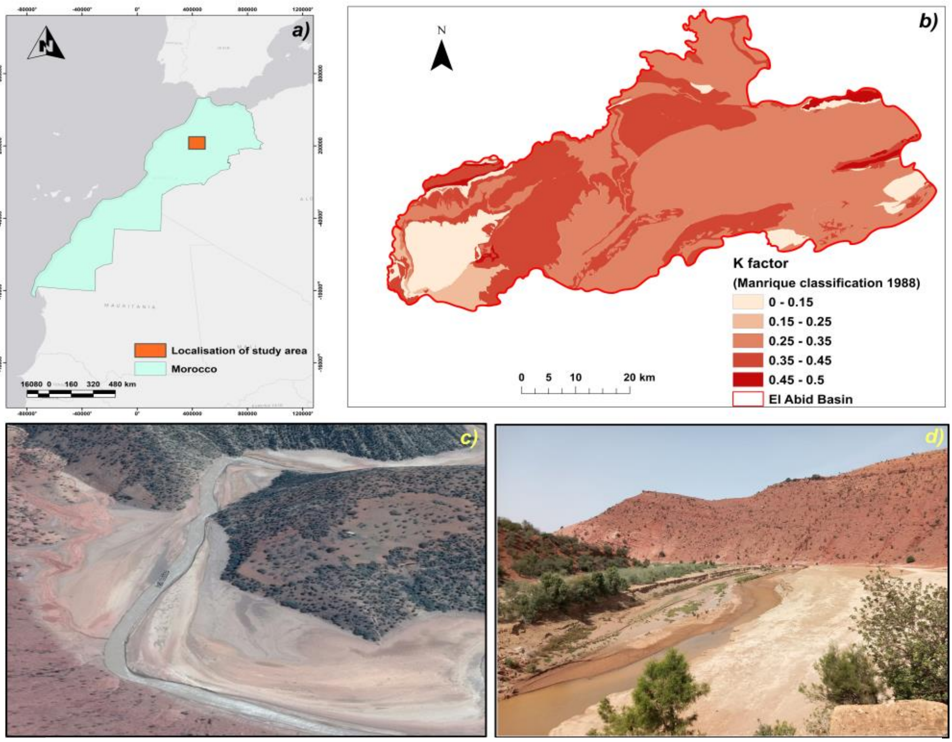

Figure 1. a) Position of Morocco in the North Africa, b) El Abid River basin with presentation of Erodibility factor (K); c) the Google Imagery of 2016 ®, and d) photo from the field of the studied meander of El Abid river (Source: Original, 2023).

The climate in the upper part of the basin leans towards semi-arid, characterized by the concentration of precipitation during the autumn and winter seasons. This climatic attribute yields a torrential regime that accelerates sediment transport and leads to silt accumulation downstream, affecting the Bin El Ouidane dam (Ouakhir *et al.*, 2023), as presented in Figure 1 b, c. Temperatures reach 35°C in August, while a low temperatures of –5°C are documented in January (Karroum *et al*., 2019). The geographical area of El Abid basin is nestled between the mountainous northern coastline: The Rif Mountains; and the interior: the Atlas Mountains (Karaoui *et al*., 2017). This territory is bordered by wide plateaus interspersed with valleys and fertile coastal plains. The mean elevation of this terrain stands at 909 m a.s.l, with the highest altitude being Jebel Toubkal at 4165 m a.s.l. Limestone, marl, and clay outcrops constitute the prevailing lithology of the basin, coupled with a substantial quaternary deposit evident along the banks of the El Abid river (Ouakhir *et al*., 2019).

El Abid basin holds a mountainous character, adorned with meadows and pastures. Notably, the frequency and intensity of floods have experienced a noteworthy upsurge in the study area over recent decades (Cherifi and Loudiki, 1999). This surge can be attributed to a combination of factors, including heightened rainfall intensity, alterations in land use (urbanization, vegetation changes, deforestation), and the rugged topography typified by steep slopes (Barakat *et al*., 2016). The analyzed basin's K factor (Figure 1b) demonstrated a significant vulnerability of soil to detachment and erosion because of the intensity of rainfall and runoff (Ouakhir *et al*., 2022). Furthermore, the spatial arrangement of mean soil erosion within the El Abid river basin between 2000 and 2022 exhibited a consistently elevated pattern in terms of annual average soil erosion, surpassing 20 t ha^{-1} yr^{-1} and covering 62.6% of the entire area. Notably, fluvial erosion held a particularly prominent role in this scenario (Ouakhir *et al.,* 2022).

Material

Total topographic station was used to take the topographic profiles in order to monitor the fluvial dynamic and detect the change in river banks of the studied section (Figure 2).

Figure 2. Total topographic station used for extracting topographic sections

This sophisticated surveying instrument used combines the functions of a theodolite and an electronic distance measuring (EDM) device, allowing us to accurately measure angles and distances in three dimensions (horizontal, vertical, and slope) to create detailed topographic maps and profiles. This allows us to record measurements directly into the instrument and process the data later on a computer to create maps, profiles, and other graphical representations; provided geodetic coordinates (latitude, longitude, and elevation) for surveyed points. This was crucial for creating accurate topographic maps and for precise positioning of objects or features on the surface of the studied region.

Methods and data

The investigation into the downstream meandering of the Oued El Abid River has commenced since 2016, focusing on the comprehension of the interactions and dynamics of fluvial erosion processes. To achieve these aims, distinct profile sections were surveyed using topographical stations throughout 2016, 2017, 2018, and 2022. Additionally, a historical methodology was applied to trace the progressive changes in the meandering pattern. Google earth imagery spanning four timeframes (2016, 2017, 2018, and 2022) was also analysed to quantify the change in the morphology of banks and explain the features of the meanders in their natural state before significant human settlement and development occurred (as presented in Table 1).

Table 1: Utilized Google Earth Images for Analyzing spatial and temporal change in meandering patterns

Year	x	Y	Elevation (z)	
			Max	Min
2016	32° 08’ 27.14” N	6° 17’ 43.92” w	869	811
2017	32° 08’ 25.48” N	6° 17’ 39.46” w	872	810
2018	32° 08’ 28.30” N	6° 17’ 47.04” w	892	817
2022	32° 08’ 29.20” N	6° 17’ 43.40” w	893	819

The climatic data of Tizi N’Isli and Tilouguit gauging stations (1980 /2022) were used to determine the hydrological response of the Oued El Abid River. These gauging stations were managed by the Hydraulic Oum Err Bia Agency (HOERBA). Besides, table 2 presents different details of these gauging stations.

Table 2:Detailed of used hydroclimatic data

Station name	Number	x	Y	Z	Serie of data	Mean rainfall
Tizi N’Isli	8500	432300	139600	1595	1975/2019	444.19
Tilouguit	8228	422670	158500	1100	1983-2019	362.13

RESULTS AND DISCUSSION

Hydroclimatic characteristics of the studied period. The climatic context of the studied years can be analyzed and interpreted based on the data presented in table 3. The river’s flow discharge (Q) and the amount of precipitation ® exhibit noticeable variations across the years.

Table 3: Hydro climatic context of the studied years

Studied year	**Q (m^3s^{-1})**	**R (mm^{-1})**
2016	175.13	613.32
2017	92.41	484.65
2018	57.62	338.87
2022	56.78	331.56
MEAN	**95.49**	**442.10**
Max	175.13	613.32
Min	56.78	331.56
SD	55.632	134.167

Source: HOERBA 2022

In 2016, both the flow discharge and precipitation were relatively high, with Q at 175.13 m^3s^{-1} and R at 613.32 mm. In the subsequent years, there was a significant decline in both parameters, particularly in 2017, where Q dropped to 92.41 m^3s^{-1} and R decreased to 484.65 mm^{-1}. This trend of reduced values continued in 2018 and 2022. The average values over the studied years indicate a mean discharge of 95.49 m^3s^{-1} and mean precipitation of 442.10 mm^{-1}. The maximum values occurred in 2016, while the minimum values were recorded in 2022. The standard deviation reveals notable variability, with Q showing a standard deviation of 55.63 m^3s^{-1} and R with a standard deviation of 134.16.

These climatic variations are likely to exert a significant influence on the fluvial dynamics of the studied river. Higher precipitation and flow discharge in 2016 might have led to increased water levels and stronger currents, potentially resulting in greater erosion and sediment transport (Ouakhir *et al*., 2021). The subsequent years' decrease in these parameters could have led to reduced water flow, impacting sediment transport rates, and potentially altering the river's channel morphology. The lower precipitation and discharge levels could contribute to sediment deposition and reduced erosional activity, potentially affecting the meandering patterns and overall river dynamics. The observed fluctuations in the climatic context highlight the importance of considering climatic variables in understanding the changes in fluvial systems over time.

Dynamic and changing of river channel within the studied meander. The climatic context of the studied years, as analyzed in table 3, has implications for the fluvial dynamics in the studied river basin. Table 4 presents the dynamics of erosion process mechanisms observed in the El Abid river meander during the different studied years. Three main erosion processes are observed: fluvial erosion, transport processes and deposition, each expressed as a percentage of the total erosion activity for the respective year. Fluvial erosion shows a gradual decline from 25.30% in 2016 to 18.90% in 2022.

Table 4: Dynamic of erosion process mechanisms occurred in the studied periods

Erosion processes (%)	2016	2017	2018	2022
Fluvial erosion	25.30	25.10	23.40	18.90
Deposition area	62.20	55.80	48.10	68.00
Transport process	12.50	19.10	28.50	13.10
Max	62.20	55.80	48.10	68.00
Min	12.50	19.10	23.40	13.10
SD	25.81	19.69	13.04	30.16

Deposition area, referring to the accumulation of sediment, displays variations, starting at 62.20% in 2016 and declining over the years to 48.10% in 2018, but after registered a substantial increase to 68.00% in 2022.

The transport process, the movement of sediments along the river, exhibits variability, with an initial value of 12.50% in 2016, increasing to 28.50% in 2018, and then decreasing to 13.10% in 2022. The maximum and minimum values for each erosion process are also highlighted, showcasing the range of variation.

Standard deviation (SD) values suggest the degree of variability around the mean, with higher SD indicating greater fluctuations in the data.

Fluvial erosion and deposition area seem to be inversely correlated, with changes in one corresponding to changes in the other. This data implies the dynamic nature of the river's morphology and emphasizes the importance of ongoing monitoring to understand and manage erosion and sedimentation patterns in the El Abid river meander.

Discussion on the factors controlling the morphology change

The box plot (Figure 3) visually represents the process of erosion in the downstream of the El Abid River and its relation to the factors of fluvial erosion, deposition area, and transport process. The data points provide insights into the variability of these parameters. The box plot highlights the central tendencies and dispersion of the dataset. In terms of fluvial erosion, the median value appears to be around 24, indicating a relatively consistent erosion rate. The deposition area shows a wider spread, with the median approximately at 55, revealing variability in the areas where sediment settles. The transport process values, concentrated in the lower quartile, suggest that the majority of the data points experience a lower rate of transport processes. Overall, the box plot visually captures the distribution of erosion, deposition, and transport values, aiding in the understanding of their relationships and the variability within the downstream of the El Abid River.

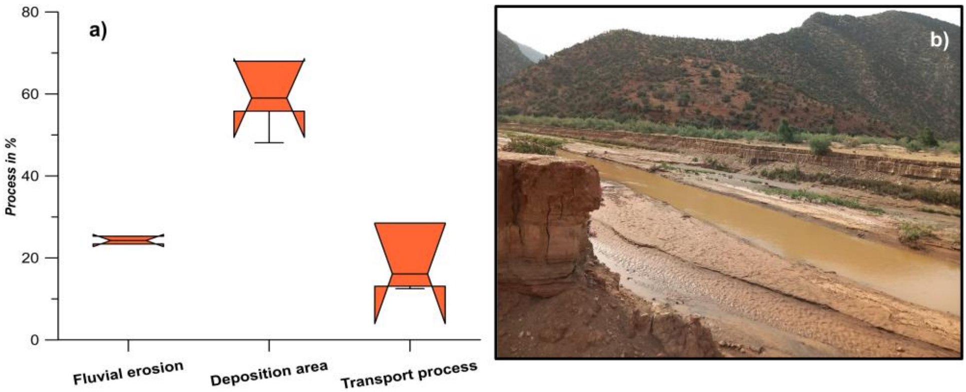

Figure 3. a) Box plot for the importance of erosion processes during the studied period, and b) photos from the field indicating the high significance of deposits and transport dynamics of the studied section

The study of the dynamic changes occurring within El Abid river meanders provides crucial insights into the complex geomorphological processes shaping fluvial landscapes.

The current studied section is subject to continuous alterations driven by various factors such as sediment transport, bank erosion, and flow dynamics what was witness in similar studied regions and comparable researches (Chalise *et al.*, 2019; Tavares *et al*., 2019; Ayt Ougougdal *et al.*, 2020). Such changes impact both the physical characteristics of the channel, including width, depth, and curvature, as well as the ecological and hydrological responses of the surrounding areas (Estrany *et al.*, 2010; Estrany *et al.*, 2011; Estrany and Grimalt, 2014; López-Tarazón and Estrany, 2017).

Studies by authors like Rosgen (1996) and Schumm (1968) underscore the significance of understanding meander dynamics for effective river management and environmental conservation.

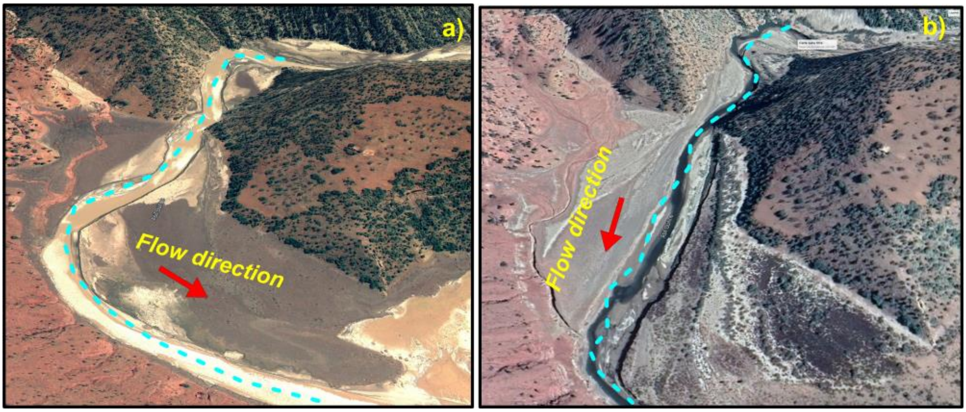

Figure 4. a) Dynamic of erosion process in the studied meander during 2017 and b) 2022. (Google imagery)

By employing techniques such as remote sensing, hydraulic modeling, and geomorphic analysis, researchers can quantify the extent of channel adjustments over time, providing valuable information for sustainable river basin management and mitigation strategies against potential hazards like erosion and flooding. In essence, the study of dynamic changes in river meanders contributes to a deeper comprehension of the intricate interplay between geomorphological processes and the evolving nature of river systems (Figure 4).

Widespread occurrences of meandering channel systems are found in contemporary arid and semi-arid basins, even when vegetation is absent or limited in its ability to stabilize banks and control runoff. Additionally, many of these rivers' traverse regions with varying degrees of vegetation cover, encompassing vegetated and non-vegetated areas (Santos *et al.*, 2019). Surprisingly, these variations in vegetation do not visibly impact the overall arrangement of the channel network, as evidenced by rivers like the Senegal River. The analysis of the El Abid River's meandering behavior demonstrates that the existence of vegetation is not obligatory for the formation of meandering patterns. This stands in contrast to conventional models of rivers before the presence of vegetation, which wrongly assumed that meandering channels rarely developed (Konsoer *et al.*, 2016).

CONCLUSIONS

This research emphasis the erosion dynamics of a meandering section within the downstream part of oued El Abid River and its implications for the morphology change of landscape. The studied section, positioned in the Central High Atlas of Morocco, holds significance as the primary tributary of the Oum-Err-Bia basin. Through extensive field monitoring, the utilization of Geographic Information Systems (GIS), and Google Earth imagery, the investigation started from 2016 to 2022, revealing substantial metamorphosis and ongoing dynamism within the targeted meandering section near the Bin El Ouidane dam. The obtained findings indicate a fluctuating interplay between fluvial erosion, deposition area, and transport processes. However, the erosion mechanisms exhibit changes over time, with fluvial erosion and deposition area demonstrating an inverse correlation. The study underscores the non-linear nature of river systems' responses to modifications in external conditions and highlights the importance of ongoing monitoring for understanding and managing erosion and sedimentation patterns. The research contributes to the broader understanding of meander dynamics, providing insights into geomorphological processes and river system evolution. The findings have implications for effective river management strategies and environmental conservation efforts in regions with similar meandering channel systems.

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