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Fluvial Dynamics of the Ouergha River between Al Wahda Dam and its confluence with the Sebou River

Ilham ESSOUSSI [1], Taieb BOUMEAZA [1]

1. Hassan II University, Casablanca, Faculty of Arts and Humanities, Mohammedia

Abstract

Natural environments in general, and wadis in particular, are characterised by constant and regular dynamics, linked on the one hand to morphosedimentary processes (water erosion, morphological legacy and climatic factors) and on the other hand to human activities. Successive tectonic factors and regular fluvial dynamics in the areas surrounding Oued Ouergha, between the Al Wahda Dam and the junction with Oued Sebou, are responsible for the emergence of recent morphosedimentary formations comprising mountainous elevations and fluvial terraces. However, human intervention in this natural environment within the study area, through the construction of the Al Wahda Dam, has altered the character of the natural environment in general and disrupted the natural fluvial dynamics of the Oued Ouergha in particular; indeed, it has halted the development of certain morphosedimentary features and the formation of fluvial terraces. This change has led to the degradation of the natural environment.

In terms of morphological changes, the period following the dam's commissioning has been characterised by an increase in human activities encroaching upon the Oued Ouergha alluvial plain: the expansion of agricultural land, the proliferation of quarries extracting alluvial material, and the excessive exploitation of water resources, etc. In addition to the impact of exceptional releases from the dam, these activities are further exacerbating the degradation and imbalance of the current riverine dynamics of the Ouergha.

Finally, taking into account all the findings of this work, this study puts forward practical proposals, based primarily on the concepts of mobility and freedom of watercourses. These proposals could serve as a basis for a more thorough study of this riverine environment.

Keywords: river dynamics, Morocco, Oued Ouergha, dam, human interventions.

1. The natural parameters of the study area and the factors influencing river formation

1.1. The natural parameters of the study area

1.1.1. The geographical context

The Ouergha catchment area is situated in North Atlantic Morocco, between latitudes 34°15' and 34°36'N and longitudes 4° and 5°45'W. It extends across most of the Rif Mountains and occupies the bulk of the southern Atlantic slope of the Rif arc.

It is bounded to the north by the Rif ridge running through Ketama, Bab Berred and Bab Taza, some 30 km from the

Mediterranean. To the south, it is bounded by the catchment areas of the pre-Rif tributaries of the Sebou; to the west, by the catchment area of the Loukkous, some 100 km from the Atlantic; and to the east, by the tributaries of the Moulouya and the Sebou in the Eastern Pre-Rif.

The Ouergha catchment area covers an area of 6,190 km² with a runoff coefficient of 104.6 m³/s. The study area is situated downstream of the Al Wahda dam, extending 65 km to the confluence of the Ouergha and the Sebou rivers. (Fig. 1)

The cartographic mosaic at a scale of 1:50,000 comprises five topographic maps: Tafrant, Oulad Aissa, Khnichète sur Ouergha and Sidi Slimane.

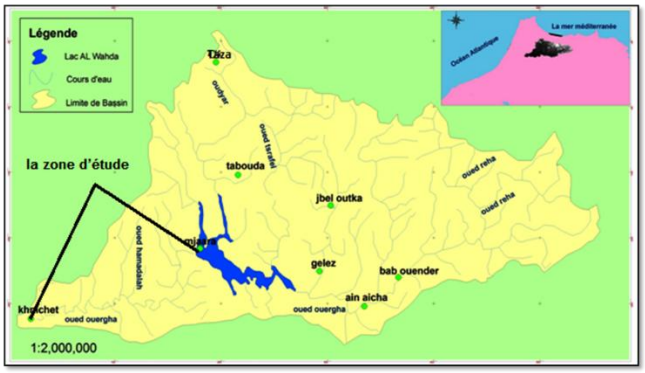

Fig. 1. Geographical location of the study area

1.1.2. Geological context

The Rif is one of Morocco's three structural zones: the intra-Rif zone (the Kétama and Tangier units), the meso-Rif zone and the pre-Rif zone. Together with the Atlas and Anti-Atlas regions, it forms the northernmost part of Morocco, which is distinctly separate from the rest of the country.

It has undergone recent tectonic movements during the Tertiary period. It is also characterised by the presence of superimposed thrust sheets. It was within this context that the Ouergha Valley was formed. The structure, tectonics and lithology of these pre-Quaternary terrains were influenced by morphology and sedimentation during the Quaternary period.

The structure of the Central Rif, to which the Ouergha Valley and its catchment area belong, is highly complex. Given the upheaval in this region, the thrusting of its nappes and their tectonic throughout its heterogeneous geological and morphological history are characterised by a rugged structure. This, in fact, defines the morphostructure of the Ouergha.

1.1.3. Topography

The topography of the Ouergha catchment area comprises homogeneous yet highly diverse morphological and morphostructural units.

Mountain ranges, isolated ridges, aligned peaks, ridges, basins and valleys are the main topographical features that make up the Ouergha catchment area.

Table 1. Distribution of the surface area of the Ouergha river basin

Altitude (m)	Area (km²)	Percentage of area	Cumulative area %
<400	1,368.97	22.55	22.55
400–800	2015.75	33.2	55.75
800–1,200	1,300.5	21.42	77.17
1200–1600	1,109.67	18.28	95.45
1600–2000	254.42	4.19	99.64
>2000	21.7	0.36	100

Elevations rarely exceed 100 m, but the deep valleys and steep slopes are responsible for the contrast and fragmentation of the terrain. (Table 1)

Most climatic and hydrological factors vary with altitude; it is therefore important to divide the catchment area into altitude bands and identify the various topographical parameters.

1.1.4. Hydrology of the Ouergha

The Ouergha is the main tributary of the Sebou; its estuary covers an area of 7,300 km². The map of the hydrographic network of the Ouergha catchment area shows an asymmetry in the density of the network between the two banks. Indeed, the main tributaries are found on the right bank (northern slope); they are situated upstream of the M'jara bend. These main tributaries, from east to west, are: Asfalou; Ras Ouergha; Guezzar; Sra; Amzez; Sahela; Agoulai; Audour; Aoudiar and Hamadallah. (Fig. 2)

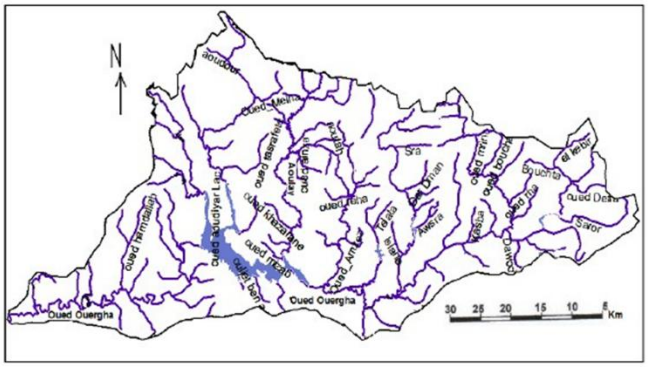

Fig. 2. Map of the water network of the Ouergha river basin

1.2. Factors influencing river formation

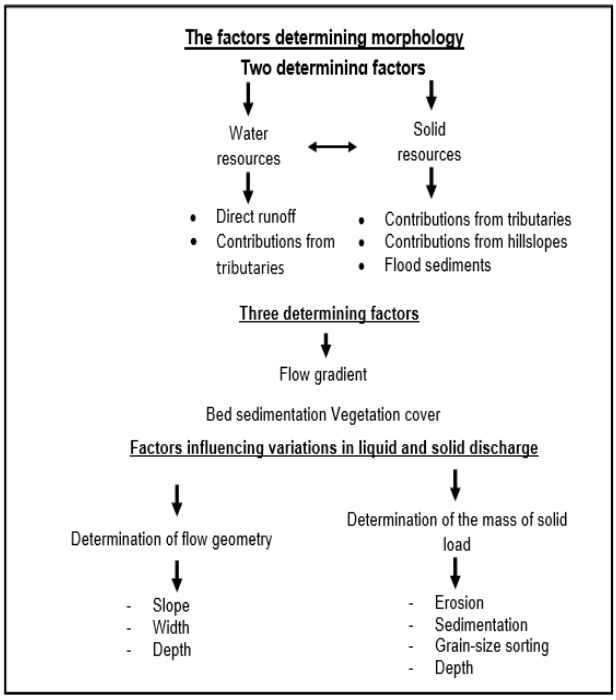

Fig. 3. The main factors determining flow morphology

1.2.1. Bioclimatic factors

The climatic factor is present in all studies concerning the river's geomorphogenetic zones, particularly when seeking to understand the hydrodynamic behaviour of watercourses that carry water through river basins. This factor enables us to understand the mechanisms of the hydrological supply system, as well as the spatio-temporal dimensions of surface and groundwater dynamics. Our objective, therefore, is to integrate the various components of the climate and to examine the impact of various climatic elements on the hydrological characteristics of the Ouergha Valley, particularly on the river's bed. (Fig. 4)

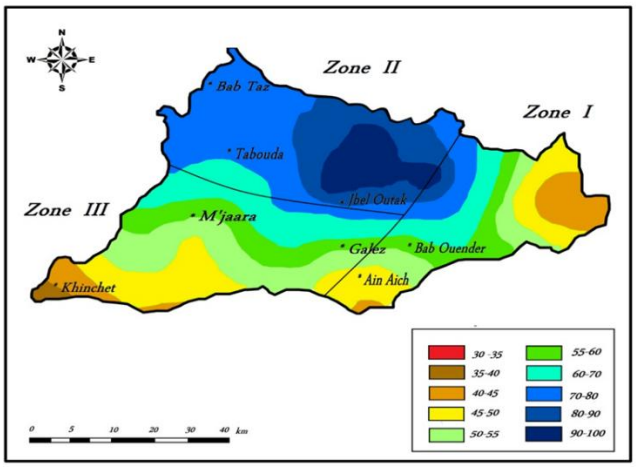

Fig. 4. Map of rainfall indices and boundaries between homogeneous areas

The area under study is characterised by the prevailing influence of the Mediterranean climate and by the presence of two distinct seasons: the first is dry, running from June to September, and the second is wet, beginning in winter and ending in early spring.

- **Wind:** the wind distribution pattern in the Ouergha catchment area is not unusual, as it falls within **the** known **categories of wind types**. The two types of wind characteristic of the area are as follows:

moist westerly wind: blows during the winter season. It is often laden with rain, which generates runoff in the Ouergha catchment area. This has a positive influence on the hydrological and geomorphological dynamics of the main flow axis of the Ouergha Valley.

Dry easterly wind: blows during the summer season. Also known as the easterly wind, it is often characterised by dry conditions. This results in a reduction in flow rate.

- **Temperature:** The importance of studying this factor is reflected in its major role in controlling certain aspects of the hydrological cycle, particularly evaporation and evapotranspiration. Annual average temperatures are generally fairly constant, except in certain areas subject to continental influences or elevation. These averages increase towards the arid zones – that is to say, towards the south-east of the basin.

- **Precipitation:** precipitation plays a key role in governing the hydrological behaviour of the Oued Ouergha catchment, as do geology and geomorphology. These factors are at work during the winter.

1.2.2. Vegetation

Vegetation plays an important role in the soil's resistance to erosion on the one hand: it reduces the intensity of the impact of various erosion factors. It therefore protects surface formations and soils against erosion on slopes. On the other hand, it plays an essential role in determining the patterns of runoff, although this importance varies depending on the quality and density of the vegetation cover in the river basins under study.

1.2.3. Hydrological factors and flow regime

The river network, flow patterns and dynamics are the main determinants of river morphodynamics. In this context, upstream hydrological characteristics are considered a factor determining the water balance received downstream. Accordingly, the hydrological regime and its abundance have been regarded as factors influencing fluvial dynamics and hydromorphodynamic evolution.

1.2.4. Impact of the Al Wahda Dam on the hydrological regime

As part of the hydro-agricultural policy and the construction of dams in Morocco, hydrological development works on the Ouergha river basin were launched following the construction of the Al Wahda Dam downstream of the Oued at the M'jaara site in 1997.

The hydrodynamics of the Ouergha Valley were completely altered following the dam's construction: the flow rate decreased, as did the sediment load, particularly coarse material. This change is primarily due to the filtration mechanism employed by the dam: coarse material settles at the dam's intake, whilst fine sediments settle at the bottom or downstream of the dam. It can therefore be concluded that human intervention is the factor responsible for the complete alteration of the normal flow regime of the Oued Ouergha throughout the year. (Fig. 5)

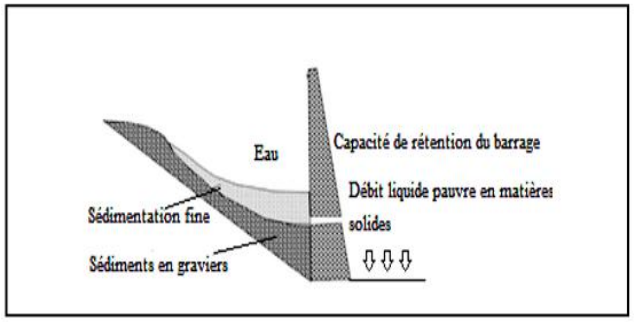

Fig. 5. Example of sediment sorting

1.2.5. Human factors

The impact of human factors on the morphology of the Oued can be direct (changes to the shape of the valley) or indirect (changes to water currents and sediment transport, and effects that may occur beyond the boundaries of the local river area). In conjunction with natural factors, human factors also come into play at various levels, either to slow down, accelerate or intensify natural dynamics—particularly climatic ones. In fact, these factors play a leading role in the process of the evolution of the natural landscape in general and in determining the various characteristics of the river zone in particular (Akdim et al., 2000) through practices in the floodplains – which represent available natural potential subject to demographic pressure and a concomitant acceleration of intensive land-use practices, such as agricultural activities and the unjust encroachment on areas of natural vegetation.

1.3. The morphological features of the Oued Ouergha

1.3.1. Spatial dynamics of the Oued Ouergha's course

The nature of the substrate through which the Oued Ouergha flows is characterised by constant change. In the Rif, the Oued forms sinuous meanders with a very broad morphology, flowing through small hills and low mountains; whilst at the Ouazzane aquifer level, where sandstone and flysch predominate, the Oued narrows and occasionally alters its course, particularly at El Mjaara and Debichéte.

Among the effects of this dynamic are floods, which are particularly evident along the banks. Three possible scenarios can therefore be distinguished:

- When the wadi flows through a foothill composed of soft rock, erosion first occurs at the base, subsequently causing the upper section to collapse under the force of gravity. The result is an anticline, as is the case in the Jorf region.

- During floods, the water can reach a maximum level (in the El Hart region), causing cracks and fractures which worsen over time, leading to massive rockfalls.

- Relatively stable areas, equivalent to sedimentation zones, also release fine particles and gravel. Thanks to this dynamic process, the wadi flows in a network of channels and leaves behind its former course. (Fig. 1.)

Fig. 6. Example of network flow (M'jaara area)

1.3.2. Morphological features formed by the Oued Ouergha

1.3.2.1. A very wide alluvial plain

Regarded as the largest in the Central Rif, the Oued Ouergha is characterised by a wide alluvial plain in its lower reaches and a very high flow rate. Along its course, the Oued forms meanders of various shapes. Its basin widens progressively from the east (3 km) towards the west (5.5 km) in its lower reaches; this widening is due to the following factors:

The nature of the rock: where there are friable rocks (marl, sandstone), the wadi widens laterally, whilst it cuts deeper into the central axis where resistant rocks are present.

Slope factor: The very steep gradient from east to west favours the wadi's deepening in the direction of its flow, whereas where the slope becomes gentler – particularly at the junction of the Oued Hamadallah and the Ouergha in the Gharb plain – the widening becomes very pronounced.

The two banks are asymmetrical; indeed, the bank on which the wadi is eroding more is characterised by a very steep gradient (0.35 per cent).

1.3.2.2. Fluvial terraces

These vary according to the distribution of alluvial deposits, the extent and the nature of the substrate. Most of these terraces are stratified into two distinct layers: a lower sandstone layer overlain by a very thin upper layer. This is due to the settling of sediments as the flow slows down.

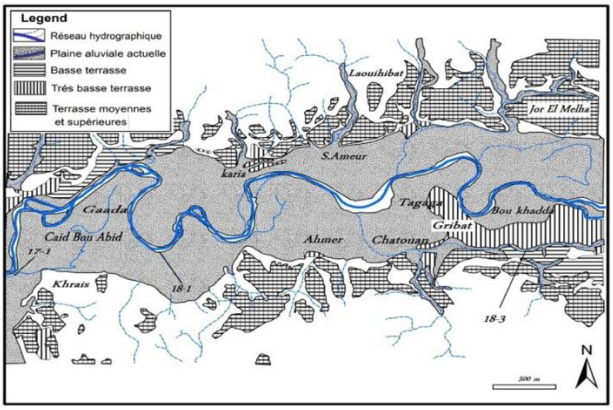

Fig. 7. Sketch showing the location of sections in the Khenichet sector

2. Human utilisation of the Oued Ouergha and the constraints of draining the Al Wahda dam

2.1. Human use of the Oued Ouergha

2.1.1. Agricultural Use

Over recent decades, agricultural practices have expanded significantly within the Ouergha catchment area. Specifically, during the 1970s, when the alluvial plain was morphologically dynamic (the development of various geomorphological units is evident), it has now stabilised into several large-scale agricultural holdings on good-quality soil. (Fig. 2)

2.1.2. Quarrying

Alongside agricultural activity, which has led to the depletion of water resources, another form of exploitation dominates the area: the operation of quarries. The extraction of sediments (gravel, sand, rock) is carried out by digging numerous pits along the riverbed of the Oued.

This phenomenon is very long-standing. Its duration is heavily dependent on the strength of the water flow. However, with the current decline in flow rates and the widespread construction of dykes, the phenomenon is undergoing a remarkable expansion in terms of its scale, nature and spatial distribution.

During a field trip, we observed the distribution of several quarries along the banks of the 'Ouergha' valley. These have often been extracted using technologically advanced machinery, which explains their intensive exploitation.

img.2. Agricultural areas along the riverbanks

img.3. Quarries

2.2. The impact of human activities on the morphodynamics of the Oued Ouergha

2.2.1. The impact of canals

Concrete canals have a clear impact on the landscape. They are divided into two types:

- **Concrete** channels **that drain water from certain tributaries into the main wadi (Ouergha):** based on a number of interviews conducted with the people of M'jaara, it can be deduced that the main objective of constructing these concrete canals (the Oued Foum Al Jomaa canals) is to protect the agricultural land at the mouth of the main wadi from flooding (photo no. 4). This type of intervention has a negative impact on the dynamics of the Oued Ouergha: more aggressive currents accompanied by an accelerated rate of erosion and the deepening of the wadi bed.
- **Concrete channels draining wastewater into the watercourse (Ouergha):** according to fieldwork (field trip in December 2012), concrete channels were clearly observed on the right bank of the Ouergha river near the Al Wahda dam, the purpose of which is to drain wastewater from the olive mills in M'jaara; this has a negative impact on water quality: pollution of surface and groundwater and detriment to the beauty of the landscape.

2.2.2. Impact of concrete embankments

Currently, the construction of sedimentation weirs has evolved dramatically. Their role is to protect agricultural land near the wadi during flood seasons by regulating the flow rate.

An assessment of these human interventions reveals that they have profound negative effects on the current dynamics of the riverine ecosystem as a whole, particularly downstream of the weir, where alarming soil degradation is evident.

However, this is the case with exceptional releases from the dam reservoir. Sedimentation thresholds increase the intensity and extent of the overflow and supply the watercourse with coarse material that breaks down due to the force of the flow; in other words, the force of the water current increases and the impact between the particles intensifies at the banks.

Generally speaking, sedimentation weirs influence the dynamic behaviour of the wadi. Indeed, they act as small hillside dams, which limits the extent of the alluvial plain. In fact, the water table level drops due to its reduced contact with the watercourse.

2.2.3. Impact of the discharge from the Al Wahda Dam on fluvial dynamics

Since the Al Wahda Dam came into operation, the Sebou River Basin Authority has carried out several exceptional releases during sudden floods. The scale of these releases varies from year to year depending on climatic conditions.

These releases accelerate the rate of: flow, erosion, sediment transport and sediment deposition, accompanied by successive shifts in the direction of flow, widening of the river channel in particular, and marked changes to the river ecosystem in general.

Among the most direct consequences of exceptional discharges are: siltation, erosion and the transport of solids downstream.

In addition to fieldwork, topographical maps (Oulad Aissa, Khenichet) at a scale of 1:50,000 and the LANDSAT 1987 and LANDSAT TM+ 2009 images (fig.) **show that:**

- The direction of flow is linear, characterised by minor diversions (Khenichet, Sidi Slimane);
- Density of the river network (low flow downstream of the Ain Dorrije bridge);
- The dynamics of fluvial terrace deposition are weakening;
- A shift in sediment distribution.

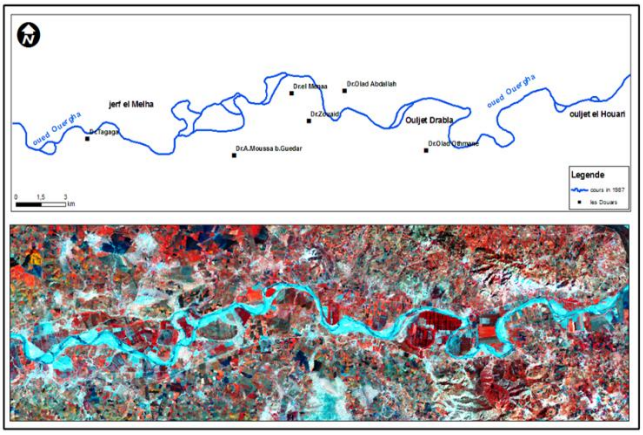

Fig. 8. Fluvial morphodynamics of the Ouergha River in 1987

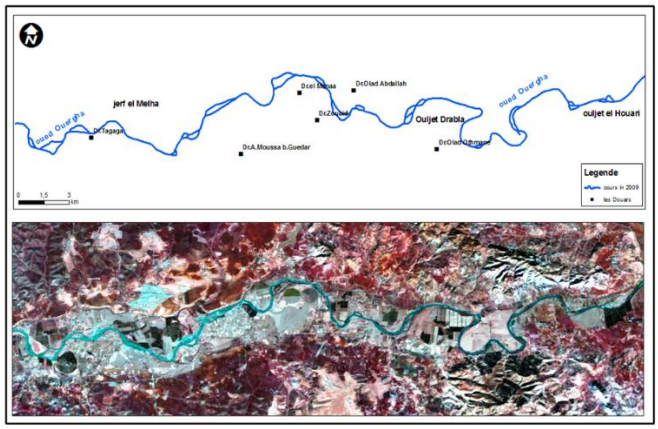

Fig. 9. Fluvial morphodynamics of the Ouergha River in 2009

3. Practical proposals for delineating zones of hydrodynamic mobility

Based on what has been presented above, it is evident that illegal exploitation is taking place, leading to morphodynamic and ecological imbalance within the river ecosystem. To prevent this type of exploitation, it is necessary to have a thorough understanding of the zones of morphodynamic mobility within the Oued, so that they can be delineated as part of a comprehensive and effective management of the river environment, enabling scientists to identify the factors responsible for these current dynamics.

3.1. Delimitation of the zones of morphodynamic mobility of the Oued Ouergha

Morphodynamic equilibrium is established through the interplay of several zones that determine mobility and are distributed spatially between the limits of maximum and minimum functional mobility. The Oued 'Ouergha' was taken as an example, where these zones were delineated and located from the Al Wahda dam to the confluence of the Ouergha with the Sebou.

3.1.1. Delimitation of the zone of maximum mobility

This zone corresponds to the extent of the wadi bed; it is currently partially submerged by water. Field observations revealed that these zones correspond to the maximum limits of sedimentation. As the watercourse becomes increasingly linear, the zone of maximum mobility narrows, which gradually reinforces the dynamics of minimum mobility.

3.1.2. Delimitation of the functional mobility zone

It is very difficult to delineate this area. In this context, several methods have been used to delineate this zone, but the method described by Malavoi et al. (1998) remains the most widely used; it consists of six stages:

- Understanding the geomorphological equilibrium of the area
- Identifying the sediment transport capacity
- Delimiting dynamic geomorphological zones
- Simulation and identification of erosion zones
- Delimiting the minimum functional zone
- Implementation of a socio-economic approach to delineate the functional mobility zone.

3.1.3. Delimitation of the minimum mobility zone

This area corresponds to the semi-permanent dynamics of the current course of the Ouergha river, despite variations in instantaneous liquid and solid flow. Field observations have

shown that this zone is frequently crossed by roads and quarries.

This area varies depending on the diversion of the current flow direction, which is constantly seeking its path, whether due to natural mobility or human intervention.

3.1.4. Delimitation of the Ouergha's free zone

Given the various impacts on the river zone, the delineation of the free zone remains a scientific contribution; its objective is to adopt a modern approach to managing the river ecosystem based on the preservation of the zone.

Several scientists regard the free zone as the functional zone in the case of watercourses unaffected by human intervention; however, in our case, this principle varies according to the type of watercourse and the degree of intervention. Consequently, the methods used to delineate the free zone remain highly diverse.

Based on the recent morphodynamic characteristics of the watercourses studied—linked primarily to the construction of the Al Wahda dam at the M'jara site—the extent of the free zone differs entirely from that of the functional mobility zone, as the latter is linked to inherited morphodynamic processes and, furthermore, overlaps with other types of mobility.

The extensions of the mobility zones at Ouergha, linked to variables observed in the field, are primarily driven by demographic pressure on the river's dynamic space. Each riparian sector subject to human pressure varies according to its specific characteristics and degree of resilience.

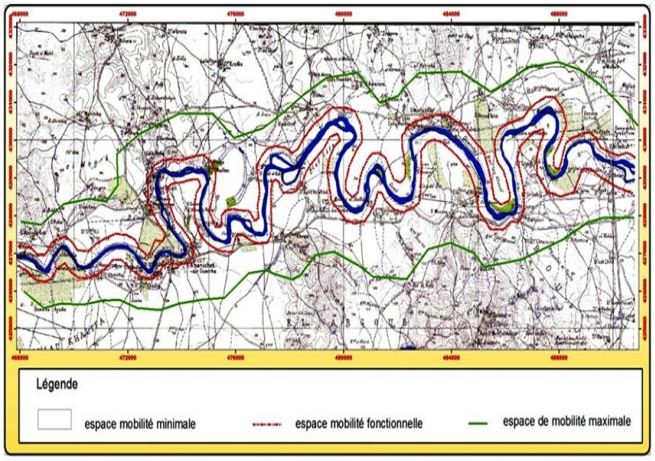

Fig. 10. Approximate limits of the morphodynamic mobility space (Ouergha-Khenichet)

Conclusion

The morphodynamics of the Oued Ouergha have been completely altered:

Natural changes: due to declining rainfall, leading to a reduction in the number of floods, the current definition of the river's extent, and the low degree of channel diversion.

Changes due to human intervention: these determine the patterns and processes of hydromorphodynamic evolution resulting from the effects of development works, intensive quarrying and agricultural intensification; consequently, the extent of morphological variables is limited, particularly the maximum extent of the watercourse.

Field observations have shown that the nature of land use along the banks of the Oued Ouergha is illegal. Consequently, it is evident that there are various forms of spatial intervention: the principle of exploitation, which creates a conflict between natural fluvial dynamics and the benefits to the population on the one hand, and the logic of conservation on the other.

In light of all that has been said, we have recognised the importance of fluvial geomorphology through the delineation of the various zones of mobility along the watercourse, which have been highlighted by the scenarios for riverside land-use planning and by their spatial location, in order to define the free-flowing zone of the watercourse—which is the area most conducive to quasi-natural morphodynamics.

These suggestions may be regarded as a scientific contribution that helps to strengthen the legislation governing the demarcation of river water rights.

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