INTERNATIONAL JOURNAL OF SCIENTIFIC RESEARCH AND INNOVATIVE STUDIES
ISSN: 2820-7157
www.ijsrisjournal.com

December 2024 Volume 3 Number 6 181-187

Received Date: 05 November 2024 Accepted Date: 26 November 2024 Published Date: 01 December 2024

Hydrological Regime Alteration in the Lower Ouerrha River Basin Following the Construction of Al Wahda Dam

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Abstract

The Al Wahda Dam is a major hydraulic structure in the integrated management of water resources in Morocco. Its commissioning has significantly improved flow regulation, secured the water supply for irrigation and human consumption, and guaranteed minimum flows during periods of drought. It also plays a key role in mitigating flood risks and supporting agricultural and socio-economic development in the affected areas.

Through this study, we analyse the extent of the Al Wahda Dam's hydrological impact on its environment, highlighting the changes it has brought about in the hydrological functioning of the Ouergha catchment and, more broadly, the Sebou catchment. The results show that this structure contributes to better mobilisation and utilisation of water resources, whilst strengthening the region's resilience to climate variability and extreme hydrological events. This research thus highlights the strategic role of the Al Wahda Dam in promoting sustainable water resource management and in strengthening water and food security at regional and national levels.

Introduction

For a long time, most geographical studies have focused on analysing the natural environment separately from human behaviour, driven by the trend towards specialisation that characterised the various sciences at the time. In light of the increasing changes affecting natural environments across the globe—changes largely driven by human interventions and natural forces—new trends have emerged in geography that seek to examine the tripartite relationship between climatic factors, human behaviour and the natural environment.

Recognising the paramount importance of this subject, and wishing to keep pace with developments in the national and international scientific arena—both to raise and address its issues and to find appropriate solutions— We have therefore decided to study one of the most fundamental components of the natural environment, namely the river systems of Morocco, given that they represent active geomorphological and hydrological systems.

The Lower Ourgha Basin serves as a representative example of a range of temporal and spatial developments, having long benefited from development projects and undergone significant interventions in its ecosystem which, in some locations, have had major hydrological impacts, such as the construction of the Al-Wahda Dam.

Studying the hydrological impact of the Al-Wahda Dam on the dynamics of the Lower Ourgha Valley is of great importance, as it helps to explain the changes experienced by the hydrological system during the period between 1983 and 1996. Therefore, in this article, we shall attempt to assess the hydrological impact of the Unity Dam on the activity of the Lower Ouergha Basin using a comparative approach. The hydrological evolution of the river during this extended period is divided into two phases: the pre-dam construction phase and the post-dam construction phase, based on data from two different weather stations: the Majara station upstream of the study area and the Al-Khnishat station downstream of the river.

1. Physical characteristics of the Lower Warqa Basin

1.1. Location of the study area

The Lower Ourgha Basin is situated in northern Morocco, between longitudes 4°5' and 5°46' west, and latitudes 34°23' and 34°44' north. To the north, it is bordered by rural areas passing through the Katama, Bab Berd and Bab Taza regions. It lies 30 km from the Mediterranean Sea; to the south, it is bordered by the tributaries of the Middle Oued Sebou; to the west, by the Lakous watershed, approximately 60 km from the Atlantic Ocean; and to the east, by the Moulouya basin.

The study covers the Lower Ourgha Basin, extending from the foot of the Al-Wahda Dam (Al-Majara area) in the south of the Central Rif to Wadi Sebou (Map 1). The watercourse in this area stretches for an estimated distance of 105.8 km and falls within the administrative boundaries of the Sidi Qasim province.

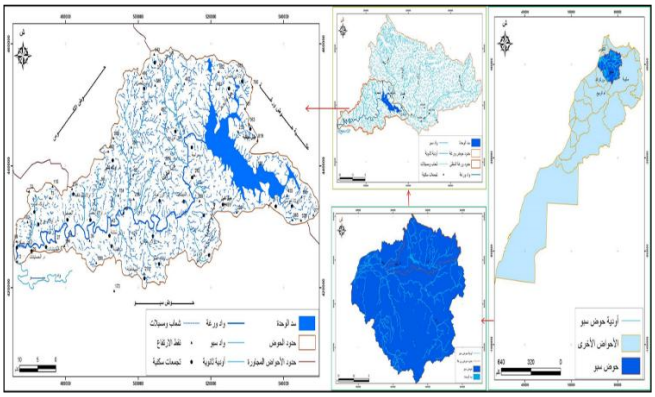
The course of Wadi Warqa, from the foot of the Al-Wahda Dam to Wadi Sebou, forms the main drainage axis into which all branches of the hydrographic network flow, in a north - south and south-north directions. Beyond the Majara area, the course of the wadi changes radically, abandoning its meandering flow to take on a linear form towards the Debishat area in the south, before meandering once more in a general east-to-west direction until it meets Wadi Sebou.

1.2. Topographical context

The Lower Warqa Basin belongs to the foothills of the Rif and is characterised by a predominance of low, rugged hilly terrain, marked by a high degree of fragmentation and a wealth of detailed and varied topographical features, including both rounded and elongated hills. Within this area, several topographical units can be distinguished, including: **Block-like hills** to the north of the study area, between Wadi Jamoua and Wadi Hamdallah; **isolated hills** separated by narrow, elongated depressions that occupy the right bank of the river basin and are particularly prominent to the north of 'Jebel Aouf'; **and rounded and elongated hills** such as Tel Klia (324 m) and Jebel Tadla (282 m).

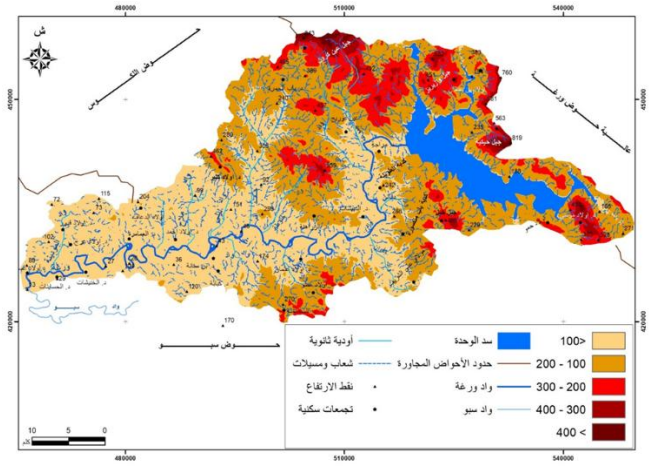
The distribution and elevation of the hills within the study area also vary. The hills at the edge of the countryside extend along the banks of Wadi Warqa al-Asfal, with elevations ranging from <100 to >400 metres; they are characterised by diversity in their composition and the orientation of their slopes, moderately dissected and interspersed with a network of wadis and gullies, the majority of which are subject to severe erosion due to the prevalence of brittle, low-permeability clayey rocks, compounded by the sparse vegetation cover on these hills.

The hills at the edge of the countryside also appear relatively gradual in terms of elevation and relief between the two banks of the lower Oued Warqa, with the height of the hills decreasing as one move from the Majara area towards the confluence of Oued Warqa and Oued Sebou. In addition, there are hill-like elevations that overlook Wadi Warqa directly, such as 'Jebel Boukhalfon' and 'Jebel al-Kalakh' on the left bank of the wadi in the al-Dabishat area, and 'Jebel Bou Slimane' on the right bank. The area is dominated by a group of block hills that are lower in elevation than the aforementioned hill ranges and, in turn, slope gradually downwards from east to west; the most significant of these are: Kaddiya Qadida (443 m), Kaddiya Bin Yusuf (343 m), Kaddiya Masnawa (297 m). (Map 2)



Map No. 1. Location of the Lower Warqa Basin

Source: Based on topographic maps of Khénichat, Troal, Oulad Issa, Sidi Slimane, Tafrant, Ghafsay, the Belkaciri Project, Had Kourth and the village of Bamohamed Salim¹ /50000 + 30-metre digital elevation model, adapted.



Map No. 2. Elevation distribution in the Lower Oued Warqa basin

In the same context, on the left bank of the Lower Oued Warqa, there is a clear absence of a dense, perennial hydrographic network, with the exception of a few observed watercourses (Oued Ifrane, Oued Al-Bariya, etc.), which remain seasonal and have low flow rates.

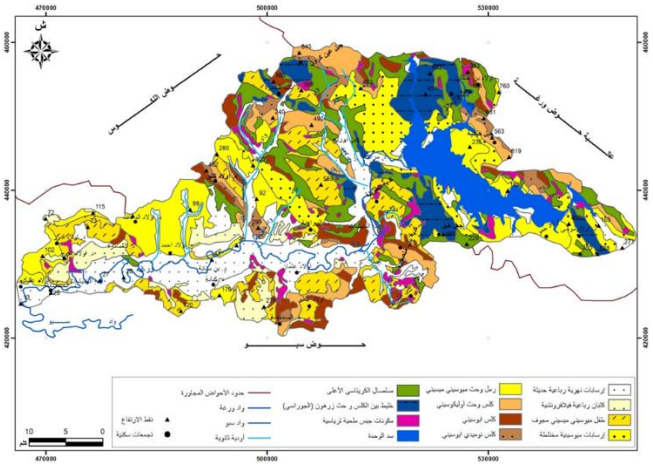
In contrast, during the rainy season, water from the hills on the right bank of Wadi Warqa flows through a series of small, semi-permanent watercourses (Wadi al-Dardar, Wadi Ifran, Wadi Damasin, Wadi Jamoua, Wadi Hamdallah, etc.). In addition, there are seasonal wadis characterised by low flow and complete dryness during the summer, which contribute to the flow of Wadi Warqa from the northern side.

1.3. Geological characteristics

Geological and geomorphological characteristics have a direct or indirect influence on determining the general morphological course of the river basin, for whilst the basin's bedrock plays important roles in the morphology and hydraulics of the watercourse, tectonic movements have also played a significant role in shaping many of the geomorphological units within the Lower Wergha Basin.

The Lower Ouergha Basin is characterised by lithological and stratigraphic diversity (Map 3), reflecting the variation in sedimentation and deposition conditions. Thus, Cretaceous and Jurassic strata are the most widespread in the area, whilst older elements, represented by the Triassic, are also present. Overlying these strata, and unusually so, is a Tertiary cover characterised by its great thickness and diversity of facies (Suter, 1966).

Consequently, the study area is dominated by brittle clayey-loamy rocks, generally characterised by low permeability. This leads to increased surface runoff, which continuously feeds the Wadi Warqa al-Asfal stream; its hydrological effects remain evident in determining the hydrological behaviour of the basin and the movement of water within it.



Map No. 3. Geology of the Lower Wargha Basin

2. The impact of the Al-Wahda Dam on the hydrological behaviour of the Lower Wargha Wadi

2.1. Reduction in the severity of floods

The Ouergha basin covers an area of approximately $7{,}200$ km^2; prior to the construction of the Al-Wahda Dam, it was considered one of the most dynamic basins in Morocco in terms of runoff and flooding, contributing approximately 55 per cent of the surface water resources of the Sebou basin, with average annual inflows reaching approximately 3.3 billion m^3, which explains the severity of the floods that used to affect the Western Plain, where discharge rates during major floods exceeded^{3,000}m³/s (Erraji I., 2024).

The Al-Wahda Dam project forms part of the dam policy pursued by the Moroccan government for several years. Its reservoir covers an area of approximately 12,300 hectares and holds an estimated 3.8 billion m^3 of water, making it the most important dam in the Ourgha basin (Table 1) and the largest dam in occupied Morocco, ranking second in Africa. The construction of this dam was long overdue, given the significant disruption and losses caused by the flooding of Wadi Sebou—and particularly its main tributary, Wadi Ourgha— as it threatens an area of approximately 15,000 hectares and causes heavy material losses (1969 flood: 50 million dirhams; 1970 flood: 190 million dirhams) (Al-Majara Project Report, 1991).

Table 1. The importance of the Al-Wahda Dam amongst the dams of the Warqa Basin

The dam	Wadi	Location	Year of construction	Dam capacity (million m^3)	Purpose
Asfalou	Asfalo	Located 70 km west of Taounate	1999	317	Irrigation
Bouhuda	Sra	Located 10 km north of Taounate	1998	55.5	Irrigation – mud control
Easy	Easy	Located in the north-west of Taounate, 70 km away	1994	62	Irrigation – Mud Control
Unit	Warga	Located 5 km west of Al-Majara	1996	3714	Irrigation, flood protection and hydroelectric power generation

Source: Sebou Water Basin Agency, 2020

It is natural that the construction of dams should be planned to meet the demand for surface water suitable for irrigation, domestic and industrial use, particularly as Morocco's situation regarding water resources is set to become a cause for concern in the coming years . For this reason, one of the objectives of the Majara Dam (Al-Wahda) dam, alongside its primary objective of reducing the risk of flooding—the first signs of which became apparent in the periods following the construction of the Al-Wahda dam (December 1996)—was to bring about immediate spatial changes, which serve as an indicator of the extent to which the frequency, intensity and severity of floods had declined prior to the dam's construction (January 1996), particularly in the Western Plain (Figure 1),

Photo 1. The Western Plain in January 1996, prior to the construction of the Unity Dam, with a flood volume of ^{3,}700 m^3/s

Photo 2. The Western Plain in December 1996 after the construction of the Unity Dam, with a flood volume of $5^{,000}$ m^3/s

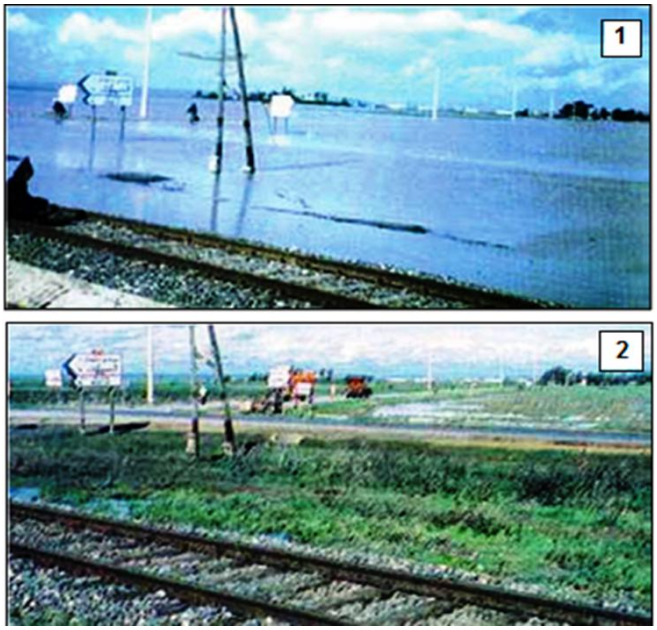


Figure 1. The importance of the Unity Dam in reducing the severity of flooding in the Western Plain

Source: Sebou Water Basin Agency

Thanks to the construction of the Unity Dam in 1996, the severity of the floods has decreased and they have become relatively manageable; consequently, the Western Plain has been protected from the floods of the Wadi Warqa, which has had regional implications: the area of agricultural land affected has decreased, losses to infrastructure, roads and facilities have been reduced, and settlements along the Sebou river course have been protected, whilst the stability of agricultural activities in the Western Plain has improved (Essoussi I., 2018).

It should also be noted that, despite the importance of the Al-Wahda Dam, it does not completely eliminate the risk of flooding due to the presence of tributaries flowing into the Ouergha or Sebou downstream of the dam, over which it has no control; water inflows have exceeded the dam's storage capacity during exceptional rainy periods (Figure 2), in addition to a reduction in the dam's storage capacity due to siltation. For this reason, the Sebou River Basin Authority relies on pre-emptive emergency releases prior to heavy rainfall to maintain a reserve volume within the reservoir that allows for the reception of new inflows.

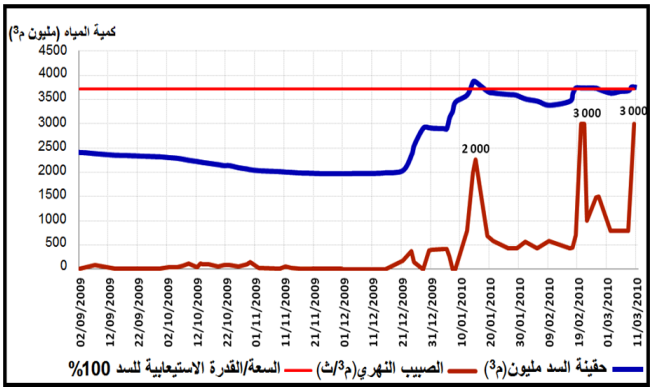


Figure 2. Water inflows exceeded the dam's storage capacity during the 2009–2010 floods

Source: Report by the Regional Office for Agricultural Investment in the Western Region on the 2009–2010 floods

Furthermore, the importance of the Al-Wahda Dam also lies in its provision of water suitable for domestic consumption and irrigation; it currently supplies a significant irrigation network, providing water to approximately 103,000 hectares of the Western Plain (Regional Office for Agricultural Investment in the West), and approximately 11,000 hectares of agricultural land within the study area. This has contributed to a transformation in the nature of the prevailing agricultural system, particularly in the lower reaches of the Ourgha Basin, where crop types have evolved and can now be cultivated continuously throughout the months and seasons of the year. In addition to all this, the Majara Dam is set to become the main water supplier for the coastal strip stretching between El Bayada and Rabat in the future. Not to mention its current role in generating 390 gigawatt-hours per annum of hydroelectric power.

Consequently, the Al-Wahda Dam can be regarded as a pivotal facility in Morocco's flood control policy, as it has transformed the flood management system of the Oued Ourgha from a natural system into a controlled hydrological management system, thereby reducing the risk of flooding in the Western Plain and improving food security. However, its continued effectiveness depends on maintaining the capacity of its reservoir, effective sediment management and adaptation to climate change.

2.2. Water management and utilisation in the Oued Warqa

2.2.1. Annual Runoff

The hydrodynamics of the Lower Ouergha basin have undergone a marked change since the Al-Wahda Dam came into operation, with the wadi's natural flow now subject to human management aimed at storing water in the dam's reservoir and regulating its release throughout the year. To assess the impact of the construction of the Al-Wahda Dam on the flow of the Ouergha Wadi, we will compare the average annual and monthly flows at the Majara and Khnishat stations between two distinct periods: before and after the construction of the Al-Wahda Dam (Figure 3).

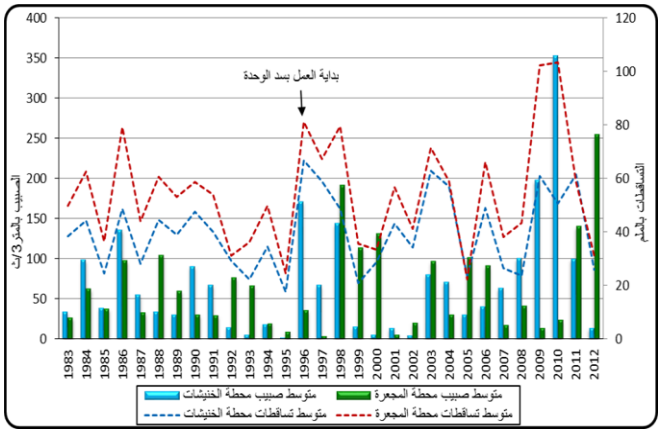


Figure 3. Trends in average flow and its relationship to average annual rainfall at the Majara and Khnishat stations between 1983 and 2012

Source: Based on data from the Sebou Water Basin Agency, adapted

A. Pre-1996 period: spanning 1983 to 1995, the discharge showed average values ranging from the minimum recorded in 1997 at both stations to a maximum of 136 m^3 /s in 1986 at the Al-Khnishat station and 104 m^3 /s at the Al-Majara station in 1988; for approximately seven years at both stations, discharge values did not exceed 50 m^3 /s. When comparing the two stations, the annual average discharge shows a discrepancy between them, with Al-Maj'ara station recording lower values than Al-Khnishat station. This is due to the latter's location at the confluence of Wadi Warqa and Wadi Sabou on the one hand, and the abundance of tributaries supplying the main channel on the other, which enhances the hydrological behaviour of the Warqa.

Thus, prior to the construction of the Unity Dam in 1996, the Oued Warqa was characterised by a natural hydrological regime, and its flow was directly influenced by the heavy rainfall typical of the Rif Mountains; it was therefore considered the most abundant of the Sebou River's tributaries. The natural flow of the Ouergha Valley also played a prominent role at both the hydrological and geomorphological levels, as it fed the Sebou River with a significant water load, contributing approximately 70 per cent of the water resources of the Sebou basin (Essoussi I., 2018). The water yield of the basin amounted to approximately 3.3 billion m^3, equivalent to

an average annual discharge of around 105 m^3 per second in the outer catchment's discharge area (Al-Khnishat station), with significant variation between wet and dry years. In addition to feeding neighbouring aquifers and transporting vast quantities of sediment towards the Western Plain, it contributed to the formation of new morphological units, foremost among which are the alluvial plains.

B. The post-1996 period: Spanning from 1996 to 2012, over a 16-year reference period, the annual flow regime of the Wadi Warqa became subject to various disturbances resulting from direct human intervention, with the water yield recorded at the Al-Khnishat station during the study period showing significant values, albeit with some exceptional years characterised by low flow, either due to low rainfall—as was the case in 2000, 2001 and 2002, or due to human control of the flow through the construction of the dam, which created significant variations in annual flow values. Consequently, in 2010, the Khnishat station recorded the highest flow value during the study period, amounting to 352 m^3 /th, which exceeded the level of rainfall. This is primarily attributable to the direct effects of exceptional releases from the dam and the importance of tributaries in feeding the main channel, whilst bearing in mind that this station is situated at the foot of the basin where the Oued Warqa meets the Oued Sebou, which increases the strength of the flow and accelerates fluvial dynamics.

2.2.2. Monthly discharge

In light of the above, we will compare the monthly discharge over two periods:

A. The 1983–1995 period: This period was characterised by a lack of correlation between discharge and rainfall at the Majara and Khnishat stations between March and May, whilst the opposite was true between September and December. During this statistical series, both stations recorded varying values across the different months; thus, the highest values were recorded in the early months (January and February) and the last months of the year (November and December). The Al-Majara and Al-Khnishat stations recorded their maximum discharge in November at approximately 159 m^3 /th 83 m^3 /th respectively, when flooding occurred, reflecting the Mediterranean rainfall pattern of the Lower Ouergha Basin's hydrological system (Figure 4).

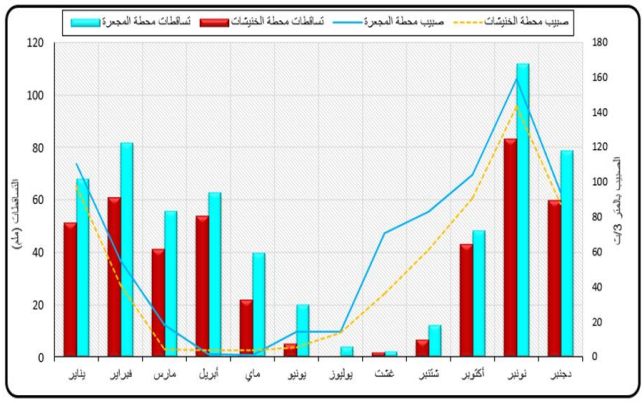


Figure 4. Relationship between discharge and precipitation at the Majara and Khnishat stations, 1983–1995

Source: Sebou Water Basin Agency, adapted

Thus, prior to the construction of the Al-Wahda Dam, the Lower Ouergha Valley was characterised by a natural flow regime directly dependent on rainfall, with discharge peaking during the winter and falling sharply in the summer; seasonal floods were a key factor in shaping the valley's channel, transporting sediment and renewing the floodplains.

B. The 1996–2012 period: The river basin underwent hydrological changes following the construction of the Al-Wahda Dam in 1996, with discharge levels recorded in various months at the Al-Majara and Al-Khnishat stations exceeding those recorded during the first phase, this was due to increased rainfall and the exceptional effects of inflows into the Al-Wahda Dam. The period from April to May was characterised by a lack of response in discharge to rainfall (Figure 5), with discharge levels reaching their lowest due to the impact of the Al-Wahda Dam, which prevented water resources from the Lower Ouergha Basin from reaching the river. Consequently, the flow in Wadi Warqa during the summer has come to be controlled by exceptional dam releases, and in some dry years the flow drops to its lowest levels when these releases are reduced.

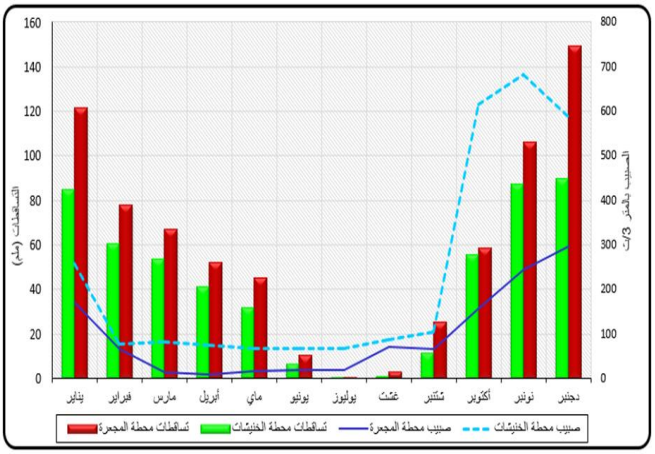


Figure 5. Relationship between discharge and rainfall at the Majara and Khnishat stations between 1996 and 2012

Source: Sebou Water Basin Agency, adapted

The construction of the Unity Dam brought about a fundamental transformation in the hydrological regime of the Lower Ouergha Valley during the period from 1983 to 2012. This study therefore sought to divide this development into two main phases: **the 1983–1996 phase**, which was characterised by a predominantly natural hydrological regime, characterised by fluctuations in annual discharge in response to changes in rainfall, with frequent flooding, particularly during wet periods; sediment load was also high, feeding the floodplain of the Ouergha Valley, thereby maintaining the morphological balance of the river channel. **The period 1997–2012,** however, saw a marked shift in the hydrological regime of the Ouergha Valley following the construction of the Al-Wahda Dam, as river discharge became regulated, flooding events decreased and annual flow fluctuations diminished; Furthermore, the amount of sediment transported towards the Lower Ouergha decreased, leading to a reduction in sedimentation within the floodplain and increased erosion in some sections.

Conclusion

The results of this study highlight that the Al-Wahda Dam has brought about a structural transformation in the hydrological system of the Lower Ouergha basin, by reorganising the flow regime both temporally and spatially, reducing fluctuations in discharge, and enhancing control over water resources during both wet and dry periods. Conversely, this intervention has resulted in hydromorphological and ecological changes to the river environment, necessitating an integrated approach to dam management that strikes a balance between the requirements of water development and the preservation of the natural functions of river systems. These findings underscore the importance of utilising hydrological indicators and long-term temporal analyses to assess the impacts of dams and guide policies for the sustainable management of water resources in the face of increasing climatic pressures and growing demand for water.

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