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Région Marrakech Safi

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Faculté des Lettres et Sciences Humaines - Marrakech

أعمال الملتقى الجهوي للبحث والابتكار بجهة مراكش أسفي

الجغرافية التطبيقية في خدمة التنمية الترابية بجهة مراكش أسفي: التحديات والفرص

متنوعات مهداة إلى الأستاذ

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2025

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La géographie appliquée au service du développement territorial dans la région de Marrakech-Safi : défis et opportunités

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Mélanges en l'honneur du professeur

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Sommair

Axe 1 :
Hydrologie, Changement Climatique et Risques Naturels

Integration of QMNA Analysis into Climate Resilience Planning for Semi-Arid Watersheds: Lessons from Oued Reghaya in the Context of Climate Change

Intégration de l'analyse des QMNA dans la planification de la résilience climatique pour les bassins versants semi-arides: Leçons tirées de l'Oued Reghaya dans le contexte du changement climatique

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Abstract: The Oued Reghaya sub-watershed, a vital tributary of Oued Tensift in central Morocco, is highly vulnerable to climate change due to its high-altitude location in the Jbel Toubkal region (4165 m). Increasing temperatures, erratic precipitation, and prolonged droughts have intensified water stress, particularly during low-flow periods. The growing demand for agricultural and domestic water use further strains available resources, exacerbating scarcity.

This study examines long-term hydrological trends using a 55-year dataset (1963–2018) from the Tensift Hydraulic Basin Agency (ABHT), focusing on the QMNa (Monthly Average Low Flow Rate of the year) to assess climate variability's impact. Statistical analysis reveals significant declines in low-flow water levels, underscoring the region's heightened exposure to droughts and water shortages. The findings highlight the urgent need for adaptive water management strategies to mitigate climate-induced risks and ensure sustainable resource allocation. Given the critical role of Oued Reghaya in regional water supply, proactive measures such as improved groundwater regulation, efficient irrigation practices, and climate-resilient infrastructure are essential to safeguard water security in the face of ongoing climatic and anthropogenic pressures.

Keywords: Low flow analysis; QMNa; Climate change; Water resource management; Oued Reghaya.

Introduction

The Oued Reghaya watershed, located in the High Atlas of Morocco, receives precipitation throughout the year due to snow accumulation at high altitudes (Boudhar, 2009). However, the region experiences fragile and vulnerable hydro-climatic conditions that negatively impact natural and human resources. This situation results in an uneven distribution of water resources between upstream and downstream areas. The surface and groundwater resources are increasingly overexploited due to socio-economic development and climate change. The focus of this study is the extreme hydrological regime (low flows) of the Oued Reghaya watershed, where climatic and anthropogenic influences are varied. Observing the decrease in low flows in a river that operates under both natural and anthropogenic regimes is crucial.

To study low flows, various statistical, mathematical, and geographical analysis techniques are necessary to adequately characterize the hydrological data collected periodically in the regions of interest (Mehaiguene, 2017). This study focuses on the lowest monthly mean flows of each year based on the statistical analysis of hydrological data.

1. Presentation of the Oued Reghaya watershed

Reghaya watershed, covering an area of 306 km², is located in the High Atlas of Marrakech and is classified among the most important sub-basins of the Oued Tensift. It is about forty kilometers south of Marrakech, in the Toubkal massif, between latitudes 30°10' and 30°20' and longitudes 7°40' and 8° West. It encompasses a large part of the highest peaks in North Africa, including Jbel Toubkal (4165 m). Its main outlet is located a few kilometers south of the town of Tahanaout, at the confluence of two streams, Assif Imnene and Assif n'Ait Mizaine. The administrative boundaries are defined as follows:

To the north: the Haouz plain

To the south: the Assif Tifnout basin (High Souss)

To the east: the Ourika basin

To the west: the N'fis basin

The watershed is predominantly covered by impermeable formations (metamorphic and eruptive rocks), accounting for 60% of its area. Vegetation cover is sparse on the slopes, with irrigated crops located near the valley bottoms. The slopes are steeper in the upstream part. Average precipitation at the Tahanaout station (at an altitude of 1064 m) is 356 mm per year, while the average flow at this station is approximately 1.57 m³/s (Hajhouji, 2018).

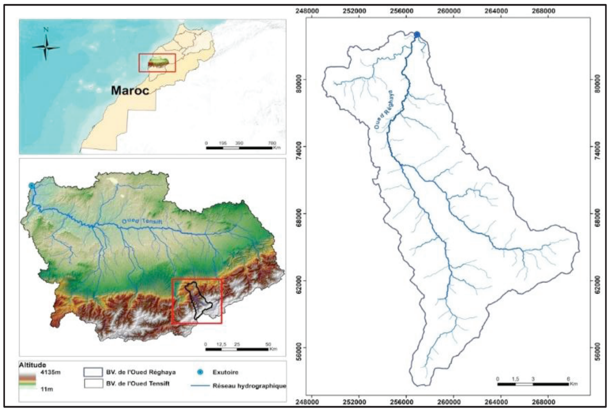

Figure 1: The geographical location of the watershed of Oued Reghaya (Personal work using the ArcGIS program)

2. Problem statement and stakes

Although the Oued Reghaya watershed receives precipitation throughout the year due to snow reserves accumulated at high altitudes (Boudhar, 2009), the region is subject to frequent hydrological disturbances due to poor water resource management. Climate change, socio-economic development, and increased withdrawals during low-flow periods exacerbate water scarcity. The issue lies in the extreme hydrological functioning (low flows) of the Oued Reghaya watershed, where climatic and anthropogenic influences are multiple. Therefore, it is interesting to observe the decrease in low flows in a river subjected to both natural and anthropogenic regimes.

Figure 2(a,b): Impacts of low flow in the upstream of the Oued Reghaya watershed, photos taken on 27/08/2018

a

b

3. Data and Methods

3.1. Methods

The phenomenon of low flows presents complexity due to its slow dynamics and variation over long periods. According to the French Dictionary of Surface Hydrology, low flow refers to the lowest annual level reached by a river at a given point (Roche, 1986). This work aims to characterize the severity of low flows using statistical analysis of hydrometric data, primarily flow rates. This analysis generally involves tests to verify the homogeneity and reliability of the data, notably the method of simple and double accumulations for the studied stations (Tahanaout station, Armed station). Several authors have proposed various statistical tools to characterize low flow rates, among which (Chakir, 2022):

- The QMNa represents the lowest monthly mean flow reached by a river in a given year. This hydrological measure allows for the statistical evaluation of the lowest flow over a determined period. In France, QMNa5 is defined as having a probability of being exceeded once every five years, while QMNa should not be exceeded more than one year over the given period. This method will be applied to the Oued Reghaya sub-watershed, considering its distinct climatic characteristics (El Ghachi, 2010).
- A frequency approach was adopted to examine data variability. This method is used to analyze the occurrence of extreme events and estimating them probabilistically for future events (Meylan et al., 2008). Low flows are calculated and associated with a certain return period (Abi-Zeid & Bobée, 1999).

In general, a frequency study begins by ranking flows in ascending order and assigning each value its rank in the series. The experimental frequency of the values is calculated using the following formula:

$F = (r - 0.3) / (N + 0.4)$

Where:

- r: rank of each value
- N: sample size

The data from the Tahanaout (downstream) and Armed (upstream) hydrometric stations were adjusted to all laws described by Abi-Zeid and Bobée (1999), concluding that the Frechet law is the most suitable for our study area.

3.2. Data

According to Qadem et al. (2019), the statistical study is based on the selection of stations according to three criteria:

1. Having a long series of observed data at the recording stations.
2. The geographical position of the stations relative to the studied watershed.
3. The absence or rarity of data gaps to ensure their quality.

Flow data recorded on a monthly scale over a period of 55 years (1969-2018) at the Tahanaout station (considered the reference station) located downstream of the Oued Reghaya was analyzed. This station has the longest data series. A shorter series of 14 years (2000-2014) at Armed station, located upstream, was also examined to confirm the results obtained with the main chronicle.

Table 1: Characteristics of the measurement station

Station	***Stream***	***In-service date***	***Data used***	***Surface of the bassin (Km^2)***	***Altitude at outlet (m)***	***X (m)***	***Y (m)***
Armed	Reghaya	1998	Q (m^3/s)	306	1050	259300	621000
Tahanaout		1962	Q (m^3/s)			255900	804000

4. Results

4.1. QMNa Variability

According to the French Dictionary of Surface Hydrology, low flow is defined as the "exceptionally low flow of a river, not to be confused with usual seasonal low waters, even if it is their exacerbation" (Lang, 2007), (Ghadbane et al., 2024).

The statistical analysis of low flows in the Oued Reghaya sub-watershed is based on the extraction of the lowest monthly mean flow of the year. The QMNa obtained for Armed station during the period 2000-2014 is consistent with those of the Tahanaout station. For the Tahanaout station, the years 2001, 2002, and 2014 stand out with increasingly lower QMNa values, with a minimum value not exceeding 0.01 m^3/s. Although Armed station's chronicle is short, it confirms the values of the Tahanaout station, with the year 2001 showing the lowest QMNa at 0.01 m^3/s.

The analysis of the average QMNa values at the two stations also identifies wet and dry years in the watershed. For the Tahanaout station, over a period of 55 years, 20 years exceed the annual average QMNa (0.23 m^3/s), while 35 years are considered dry. For Armed station, 4 years are wet and 10 years are dry.

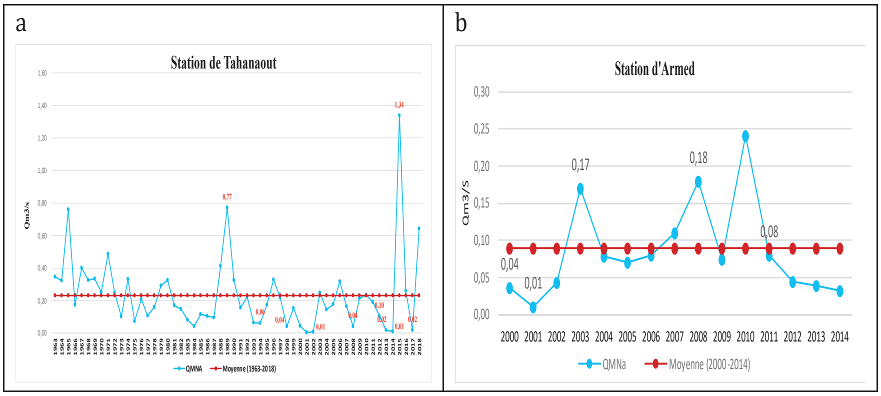

Figure 3(a,b): The variability of QMNa (streamflow characteristics) of Oued Reghaya, Tahanaout station (1963-2018), Armed station (2000-2014)

4.2. Frequency Analysis of QMNa

The frequency study requires processing a long series of data to observe the impacts of low flow values on significant phenomena occurring a few days later (Loganathan et al., 1985). The analysis reveals a good distribution of points around the line, even for extreme years such as 2001, 2002, and 2014, which are at the left end of the histogram. However, there is a significant difference in the regression line slope between Armed and Tahanaout stations. The return period was calculated according to QMNa5 and QMNa10, where the first value corresponds to a 5-year return period and the second to a 10-year return period. It was observed that a QMNa of 0.01 m^3/s occurs approximately every 5 years, while a QMNa of 0.1 m^3/s occurs every 10 years.

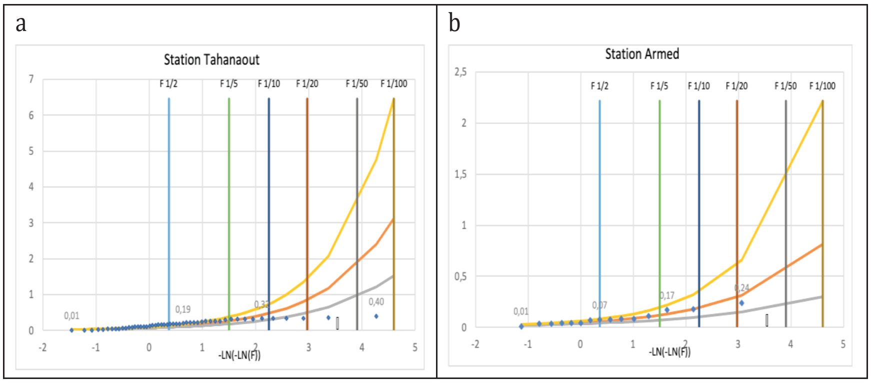

Figure 4(a,b): The fitting of QMNa (streamflow characteristics) using the Frechet distribution

4.3. Return Periods of QMNa

From a hydrological perspective, most regulatory thresholds used for water management are based on characteristic low flows during dry periods. The most commonly used frequencies in the analysis of these flows are as follows:

- Frequency 1/2: characteristic low flow with a recurrence interval of one year out of two.
- Frequency 1/5: characteristic low flow with a recurrence interval of one year out of five.
- Frequency 1/10: characteristic low flow with a recurrence interval of one year out of ten.

- Frequency 1/20: characteristic low flow with a recurrence interval of one year out of twenty.

It should be noted that these frequencies are directly related to the severity of the low flow. For instance, low flows with a frequency of 1/2 can be considered common, whereas a frequency of 1/10 represents an exceptional and more severe situation (Lang, 2011).

Table 2: Return periods of QMNa (streamflow characteristics) of Oued Reghaya, Tahanaout station (1963-2018), Armed station (2000-2014)

Frequency	**1/2**	**1/5**	**1/10**	**1/20**	**1/50**
Return time	2 ans	5 ans	10 ans	20 ans	50 ans
Armed station	0,10	0,05	0,03	0,02	0,01
Tahanaout station	0,10	0,07	0,05	0,02	0,01

4.4. Months of Low Flow Occurrences

The main objective is to analyze low flow discharges occurring during the groundwater recharge period in the Oued Reghaya watershed. According to Figure 5, low flows observed during the period 1963-2018 most frequently occur in September, followed by August, with a significant number also in October. This trend is expected as it corresponds to the summer season characterized by a rainfall deficit and active evaporation. Additionally, Figure 5 indicates that the months of March, April, May, and June represent the period when most groundwater recharge occurs.

Over the 55-year period, low flows in Oued Reghaya are generally rare events, except for the year 2016 when the lowest monthly average flow (QMNA) was recorded in April during the high flow period. This suggests that the low flow observed that year was unusual and could be attributed to a random phenomenon.

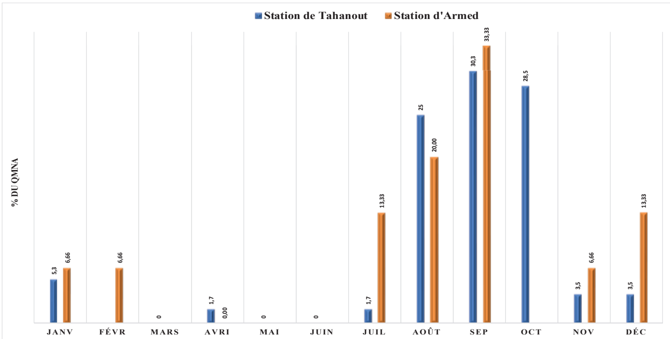

Figure 5: The monthly occurrence of QMNa (streamflow characteristics) for the reference station (Tahanaout), using Excel worksheet

5. Discussion

The Oued Reghaya basin experiences a semi-arid climate with significant interannual rainfall variability. The decrease in water resources in this area is closely linked to climatic fluctuations and anthropogenic actions. The low-flow periods are particularly critical, especially for local populations relying on agriculture and tourism (Boukhari et al., 2015).

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A closer examination of the QMNa values shows a steady decline, indicating an increasing severity of low-flow events over the years. The 2000-2014 period, in particular, highlights the intensification of low-flow events, with frequent occurrences of extremely low QMNa values. These observations align with global trends indicating a general decrease in water availability due to climate change and increased human consumption (IPCC, 2022).

To mitigate the impacts of these extreme low-flow events, it is essential to implement integrated water resource management strategies that take into account both natural variability and human needs (Brown & Lall, 2006). This approach would help ensure the sustainability of water resources in the Oued Reghaya basin and maintain the livelihoods of the local communities.

Conclusion

This study demonstrates a significant intensification of low-flow periods in the Oued Reghaya watershed, with hydrological analysis of minimum monthly flows (QMNA) over 55 years revealing a marked declining trend. Record-low values reaching 0.01 m^3/s were observed during critical years, particularly in dry summer months, reflecting the combined impacts of climate change and anthropogenic pressures on this semi-arid mountainous hydrologic system.

The findings underscore the urgent need for adaptive water resource management strategies that improve water use efficiency while implementing early drought warning systems. They also highlight the necessity for further research integrating detailed hydrological modeling with prospective climate scenarios.

This scientific contribution establishes a robust foundation for developing sustainable water policies that balance ecosystem preservation with socioeconomic needs amid increasing climate variability. Future studies should particularly focus on quantifying the complex interactions between natural processes and human factors in this vulnerable region.

References

- Abi-Zeid, I., & Bobée, B. (1999). Methodology for the use of probability distributions in hydrology. *Water Resources Research*, 35(4), 1307-1318.
- Boudhar, A. (2009). Snow hydrology in the High Atlas of Morocco: Snow cover modeling and snowmelt runoff prediction. *Ph.D. Thesis*, University of Strasbourg.
- Boukhari, K., Boudhar, A., & Oulehri, R. (2015). Impact of climate change on water resources in the Oued Tensift watershed. *Journal of Hydrology*, 531(3), 687-694.
- Brown, C., & Lall, U. (2006). Water and economic development: The role of variability and a framework for resilience. *Natural Resources Forum*, 30(4), 306-317.
- Chakir, M. (2022). Étude statistique des étiages et des tarissements dans le bassin versant de l'oued de Tassaout (Amont du Barrage de Moulay Youssef): Détermination, extraction, modélisation et problématique de la gestion (1978-2020)(Haut Atlas-Maroc) (Doctoral dissertation, Thèse de doctorat de 3ème cycle, Université Sultan Moulay Sliman, FLSHBM. Maroc).

- El Ghachi, M. (2010). Hydrology of the High Atlas: Analysis and modeling of hydrological regimes. *Journal of Hydrology*, 390(1), 1-11.
- Hajhouji, Y. (2018). Characterization of flood risks in the Oued Tensift basin. *Hydrological Sciences Journal*, 63(1), 37-52.
- IPCC. (2022). Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.
- Lang, M. (2007). Hydrological Dictionary of Surface Water Hydrology. *Hydro-météorologie*, 12(2), 45-53.
- Loganathan, G. V., et al. (1985). Stochastic modeling of streamflow series. *Journal of Hydrology*, 77(1-2), 55-70.
- Mehaiguene, A. (2017). Statistical Methods in Hydrology: Low Flow Analysis. *Hydrological Processes*, 31(3), 543-560.
- Meylan, A., et al. (2008). Frequency analysis of extreme low flows in a mountainous watershed. *Water Resources Research*, 44(3), W03416.
- Omar, G., Mohamed, C., & Hasan, O. (2024, October). The effect of climate change on the variation of low flow rates within mountainous basins: Case study of the Srou basin-Middle Atlas-Morocco (1976-2016). In IOP Conference Series: Earth and Environmental Science (Vol. 1398, No. 1, p. 012025). IOP Publishing.
- Qadem, M., et al. (2019). Methodology for choosing hydrometric stations for statistical studies. *Hydrology Research*, 50(2), 400-412.
- Roche, M. (1986). The low flow of rivers. *Geography Review*, 65(3), 21-29. Soler, M., et al. (2012). Variability of precipitation in the High Atlas of Morocco. *Climate Dynamics*, 39(5), 1281-1292.