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Impact of hydro-morphometric characteristics on the hydrological response of the Adoudou river watershed (Western Anti-Atlas, Morocco)

Hassan Nait-Si
hassan.nait-si@edu.uiz.ac.ma 0000-0003-3299-5447
Equipe de recherche: Géographie, Aménagement, Démographie et Développement (GEAMDD), Département de Géographie, FLSH Agadir, Université Ibn Zohr. Cité Dakhla, BP 29/8, Agadir, Maroc.

M'hamed Nmiss
mhamed.nmiss@usmba.ac.ma 0009-0001-4107-3690
Equipe de recherche: Milieux naturels, Aménagement et Dynamiques Socio-Spatiales (MNADSS). FLSH Fès-Sais, Université Sidi Mohamed Ben Abdellah-Fès. BP 59, Route Immouzer. 30000 Fès, Maroc.

Mahjoub Benbih
benbihelmahjoub@gmail.com 0009-0008-5759-8097
Abdourrahmane Boukdoun
abdourrahman.boukdoun@edu.uiz.ac.ma 0009-0000-2703-1622
Abderrahmane Ouammou
a.ouammou@uiz.ac.ma 0009-0000-3579-1947

Equipe de recherche: Géographie, Aménagement, Démographie et Développement (GEAMDD), Département de Géographie, FLSH Agadir, Université Ibn Zohr. Cité Dakhla, BP 29/8, Agadir, Maroc.

KEYWORDS

Hydrological response
Hydro-morphometric characteristics
Ungauged watershed
Hydrological risk
GIS

INTRODUCTION

The Oued Adoudou catchment area is part of the Western Anti-Atlas, located in central-west Morocco. It is bounded to the north and north-west by coastal dune complexes and the Atlantic Ocean, to the south by the Ifni massif and the Lakhssas plateau and to the east by the Kerdous massif. The Oued Adoudou rises from the Kerdous tributaries in the south-east of the basin. It then flows downstream, where it receives several tributaries from the anti-atlasic mountain massifs and the Tiznit plain, before emptying into the Atlantic Ocean to the north-west after a journey of 97.3 km. In the plain, two major tributaries join the Oued Adoudou: the Oued Bounaâmane, which originates in the Lakhssas plateau, and the Oued Tamdroust, which comes from Kerdous.

Climatically, the basin is subject to an arid climate, characterised by low annual rainfall that is often irregular in time and space, with low annual averages downstream (Tiznit station = 168 mm; Youssef Ibn Tachfin station = 146 mm) compared with upstream (Amaghouz station = 289 mm). The arid climatic conditions of the region have a strong influence on the plant cover, which is degraded.

This study aims to evaluate and analyze the hydro-morphometric characteristics that influence the hydrological response to intense rainfall events in an arid, ungauged basin context.

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Correspondencia autores: hassan.nait-si@edu.uiz.ac.ma (Hassan Nait-Si)

METHODOLOGY

The present study aims to analyze the impact of hydro-morphometric characteristics of the Adoudou watershed on the hydrological response. The absence of sufficient hydrometric data, typical of ungauged basins, justifies this approach, based a quantitative analysis focused on the calculation and interpretation of key hydro-morphometric parameters such as the basin's geometry, topography, and hydrography. Geometric parameters provide insights into the watershed's shape and drainage area; topographic parameters address elevation and slope characteristics; and hydrographic parameters quantify and describe the drainage network's structure. Together, these elements offer a comprehensive understanding of the watershed's physical evolution and the interaction of its attributes on hydrological behavior and flash flood generation.

To ensure the reliability and accuracy of the results, the study utilized Geographic Information Systems (GIS) tools, incorporating a 30-meter resolution Shuttle Radar Topography Mission Digital Elevation Model (SRTM-DEM) and 1:50,000 scale topographic maps. The watershed boundary and hydrographic network were extracted from the topographic maps. To correct inherent errors in the raw DEM, a hydrological correction was applied based on the hydrographic network using spatial analysis tools in ArcGIS. The hydro-morphometric parameters were then calculated using GIS analysis and Microsoft Excel, following established mathematical equations introduced by experts in hydrology and hydraulics.

RESULTS

Geometric parameters analysis:

The surface and the perimeter of a watershed give an initial idea of its shape and the quantity of water it can receive, and can influence the hydrological response and hence the amplitude of flood hydrographs. Several parameters were calculated to determine the influence of size and shape on the hydrological response of the Adoudou watershed. Our study basin has a surface area of 834.7 Km^2 and a perimeter of 183.3 Km. The Gravelius compactness index, the aspect ratio and the circularity ratio results indicate that our watershed has an elongated shape marked by a strong relief. The equivalent rectangle results reveals that the contours are fairly tight upstream of the basin (Elevation between 1304 m and 500 m), testifying to a steep slope and strong relief. In the downstream part (Elevation between 500 m and 100 m), the contours become progressively more widely spaced towards the basin outlet, reflecting the decrease in slope.

Topographic parameters analysis:

The hypsometric curve is slightly concave with a steep slope. The straight line intersects the diagonal between 23% and 35% elevation, indicating that the Adoudou watershed is in a mature state, meaning that the basin is in equilibrium with regard to erosion and transport processes within the fluvial system. The characteristic altitudes reveal that the mean altitude is higher than the median altitude, with a standard deviation of 56 m. This means that the basin has an irregular relief. Altitudes are high in the upstream, where mountains predominate, and become gentler in downstream. The average slope of the whole basin is high, reaching 16 m/km, indicating that our basin has steep slopes. The overall slope index Ig is equal to 13.22 m/km, and the specific gradient Ds of the basin is 382 m.

According to the ORSTOM relief classification, our basin has a strong relief character. The slope map reveals a very particular distribution from upstream to downstream, controlled by both lithology and tectonics. The southern and western parts of the basin are characterized by the predominance of very steep and steep slopes (occupying 11% and 9% of the basin surface respectively), which are typical of the western Anti-Atlas range, made up of ancient Precambrian and Cambrian geological outcrops. Medium slopes (occupying 27%) are predominant at the foothills, at the contact of the Anti-Atlas range with the Tiznit plain, and are formed

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by Quaternary-age alluvial fans nested against the bordering slope. As for the lower slopes (54% surface area), they occupy the Quaternary formations of the Tiznit plain.

Hydrographic parameters analysis:

From a hydrographic point of view, BVOA is designated as a Seventh Order basin, with a total of 2876 streams covering a total length of 1944.13 Km. The 1st order streams make up the majority of the area's drains at around 78%, with a total length of 1025.05 Km; 17.3% for the 2nd order with a length of 425.47 Km; 3.7% for the 3rd order with a length of 205. 39 Km; 1% for the 4th order with a length of 161.42 Km; 0.17% for the 5th order with a length of 63.23 Km; 0.07% for the 6th order with a length of 41.18 Km and 0.03% for the 7th order with a length of 22.39 Km. the hydrographic network shows a typical disorganization, which can be explained by several geological, structural, topographical and climatic factors. Two geographical zones can be distinguished according to the density and typology of the hydrographic network:

- Upstream: characterized by a dense dendritic network with a tree-like morphology due to the steep slope and geological nature of the outcrops. The flow regime has a torrential character and the presence of a large number of streams means that the surface is undergoing erosion;
- Downstream: the drainage network is less developed of the parallel type, as well as the presence of endoreic systems (the locals call them 'TALAT'), which can communicate exceptionally during major floods and induce sheet flow. The network is controlled by Plio-Quaternary geological soils of high permeability associated with low and medium slopes in mountain-piedmont contact zones.

The confluence ratio (RC) and stream length ratio (RL) indicate a strongly hierarchical drainage network, heavily influenced by slope and bedrock characteristics. In low-slope, permeable regions, stream numbers are limited but individual lengths are greater. Conversely, steep and impermeable zones support a higher number of shorter streams. The drainage density (Dd) is 2.33 km/km^2, signifying an efficient drainage system. The hydrographic density (Fs) is 3.45 km^{-2}, indicating a strong surface flow response to rainfall. The infiltration index is 8.03, highlighting a low capacity for water retention and infiltration, hence high surface runoff. The drainage density map reveals that the upstream part of the basin is characterized by very high drainage density, which can be explained by the steep slope and semi-permeable substrate. In contrast, in the downstream region where the substrate ranges from permeable to semi-permeable and the slope is gentle, the drainage density is generally moderate in areas drained by the Oued Adoudou. However, it tends to be high near confluences and low in other parts of the plain.

Main stream gradients show that Oued Adoudou has an average slope of 1.3%, while its tributaries, Oued Bounaâmane and Oued Tamdroust, have steeper slopes of 1.8% and 2%, respectively. Longitudinal profiles exhibit generally concave shapes with slope breaks. Oued Tamdroust has a smooth, concave profile, while Oued Adoudou and Oued Bounaâmane display irregularities and abrupt slope changes. These features are controlled by contrasting geological settings between the Western Anti-Atlas (upstream) and the Tiznit plain (downstream). Upstream slopes average 4.2% (Tamdroust), 2.6% (Bounaâmane), and 1.6% (Adoudou), compared to 1.1% downstream, underscoring the geological and topographic influence on flow behavior and confirming the watershed's susceptibility to flash floods.

Based on the above findings, we can assume that the Adoudou watershed characterized by a contrasting geomorphology between upstream and downstream areas, which controls the typology and density of the drainage network. The basin's hydrological response to a rainfall event is strongly influenced by several factors: geology, topography and hydrography. The mountainous upstream area, with its steep slopes and high drainage density, favors rapid runoff. In contrast, the flatter downstream zone shows a delayed response, resulting in spatial disparities in flood risk. This geomorphological complexity, which characterizes the Adoudou watershed, highlights an increased vulnerability to hydrological hazards, particularly in the downstream. The extreme hydro-meteorological event of November 2014, which impacted the study

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area, highlights the significant influence of the basin's characteristic hydro-morphometric features on the generation, intensity, and propagation of flash floods. This event caused extensive downstream damage, with the most severely affected areas located in the commune of Tnine d'Aglou, particularly within the alluvial plains of the Oued Adoudou, between El Aouina upstream and Zaouiya Sidi Ouaggag downstream.

CONCLUSION

This study highlights the key role of spatial analysis using GIS tools in the mapping and assessment of hydro-morphometric characteristics. Precise delimitation of the Adoudou watershed, digitization of the hydrographic network from 1:50,000 topographic maps and hydrological correction of the raw DEM have enabled us to build a reliable database for calculating hydro-morphometric indices. This latter approach helps to improve the accuracy of the results, thus ensuring the accuracy of interpretations aimed at understanding hydrological response and identifying the major factors influencing hydrological risks in our basin.

For an ungauged basin, hydro-morphometric analysis is a key method for understanding the influence of morphometric and hydrographic parameters on hydrological behavior. This approach represents a major challenge, because of the extent of the basin studied and the diversity of its geomorphological features. Indices calculated on the scale of the entire basin provide a global view of its hydrological dynamics, making it possible to identify the relevant geomorphological factors influencing the genesis of flash floods.

The Adoudou wadi watershed exhibits highly diverse topography, characterized by a stepped plateau structure in the downstream area and rugged mountainous relief upstream. The upstream region benefits from both orographic effects and more intense rainfall compared to the downstream area. Despite its elongated configuration, the Adoudou watershed is marked by torrential flows, primarily driven by geological, topographical, and hydrographic factors that exacerbate hydrological risks during heavy rainfall events. Two distinct zones can be identified based on topographical and hydrological variations: the upstream zone, dominated by mountainous relief, steep slopes, exposed hard rock outcrops, and a high drainage density, which collectively favor abundant torrential runoff heavily laden with solid materials. These torrential inflows are conveyed downstream, where the lower part of the watershed acts as a receiver of these floodwaters, thereby intensifying soil erosion in arable lands and causing floods in urbanized alluvial plains. This presents a significant risk to urban areas and infrastructure. The findings obtained contribute to a better understanding of the drainage patterns and hydrological functioning of the Adoudou wadi watershed. Furthermore, they can support the anticipation and management of hydrological risks associated with torrential floods in the basin.

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