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# Hydrometric monitoring of sacred fish spring flows in 2020 and 2021 (Rheris watershed-Morocco)

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**Abstract:** Hydrometry is an extremely complex scientific discipline, at the crossroads of the most advanced technologies and theories, a demanding practice of field observation that always reveals many surprises, as rivers are in perpetual remodeling, and an activity that is practiced in conditions, which can be extremely perilous and whose risks must be absolutely mastered. Through this scientific paper, we focus on the hydrometric monitoring of flows from the sacred fish spring. This spring is like a pearl in a semi-arid climate and is part of the Oued Toudgha sub-basin, one of the major tributaries of the Oued Rheris, located in the province of Tinghir. The watershed covers an area of 467 km2 and is characterized by spatiotemporal irregularity of rainfall, which is concentrated in Autumn and Winter. The morph-structure of the study area is characterized by three levels: the Central High Atlas in the north, the Pre-African Sillon in the middle and the Eastern Anti-Atlas in the south, surmounted by the Quaternary cover.

Given the absence of hydrometric data, we carried out hydrometric monitoring of flows from the Sacred Fish spring, with the aim of creating a hydrometric database of water rises, during the study period. Several gauging campaigns were carried out, from 2020 to 2021, with daily monitoring of water levels. After creating the rating curve, we were able to extract instantaneous flows from the Sacred Fish spring during the research period.

## 1. Introduction

In Morocco, water has become a scarce resource in recent years, and one in which investment is urgently needed. While freshwater is becoming increasingly scarce in some regions as a result of climate change, anthropogenic pressure and rising living standards have led to an explosion in demand (Lahlou *et al.,* 2019; Stringer *et al.,* 2021; Priya *et al.,* 2023). South-eastern Morocco is characterized by a semi-arid climate and in this topographical unit, the geology, topography and precipitation regime (snowy precipitation in the upstream part), favor the birth of a series of springs (26 springs in the Rheris watershed) (Benchattou *et al.,* 2021). These springs are pearls in a semi-arid climate, and their existence in this area is an opportunity for life and development for the local population.

In this scientific contribution, we have carried out hydrometric monitoring of flows in the sacred fish spring, which is located in south-east Morocco and forms part of the Oued Toudgha watershed, which covers an area of 467 km². It is an undeveloped watershed, with tourist, economic and environmental issues at stake, especially during the summer period. There are several methods for producing hydrometric data in ungauged watersheds (Akoko *et al.,* 2021; Chen *et al.,* 2022). According to hydrologists, monitoring watercourses during the study period is a genuine methodology for producing hydrometric data (Smith *et al.,* 2023; Moubchir *et al.,* 2024). This scientific study is largely based on fieldwork. We made diagnostic visits to various parts of the study area and found that there was a lack of hydrometric equipment (Garcia *et al.,* 2023). For this reason, we decided to carry out daily monitoring of water level increases in the spring, in relation to a 0 level, with the aim of creating a water level database (Martinez *et al.,* 2022). At the same time, we carried out several gauging campaigns to measure the spring's flow rate at different phases (low water and high water), with the aim of producing hydrometric data on the spring's instantaneous flow rates (Benchattou *et al.,* 2021).

## 2. Methodology

### *2.1 Geographical context of the study area*

The sacred fish spring is located in the Oued Toudgha watershed, a major tributary of the Oued Rheris in south-eastern Morocco. The sacred fish spring watershed has a Mediterranean mountain climate. It is characterized by spatiotemporal irregularity of rainfall, which is concentrated in autumn and winter (Smith *et al*., 2023; Garcia *et al*., 2022). The morpho-structure of the study area is characterized by three levels: the Central High Atlas in the north, the Pre-African Sillon in the middle and the Eastern Anti-Atlas in the south, surmounted by the Quaternary cover, (Ouali *et al,* 2022). For the Oued Toudgha hydrographic network, this structure acts as a collector of water from both the Anti-Atlasic and High-Atlasic watersheds (Brown *et al*., 2023).

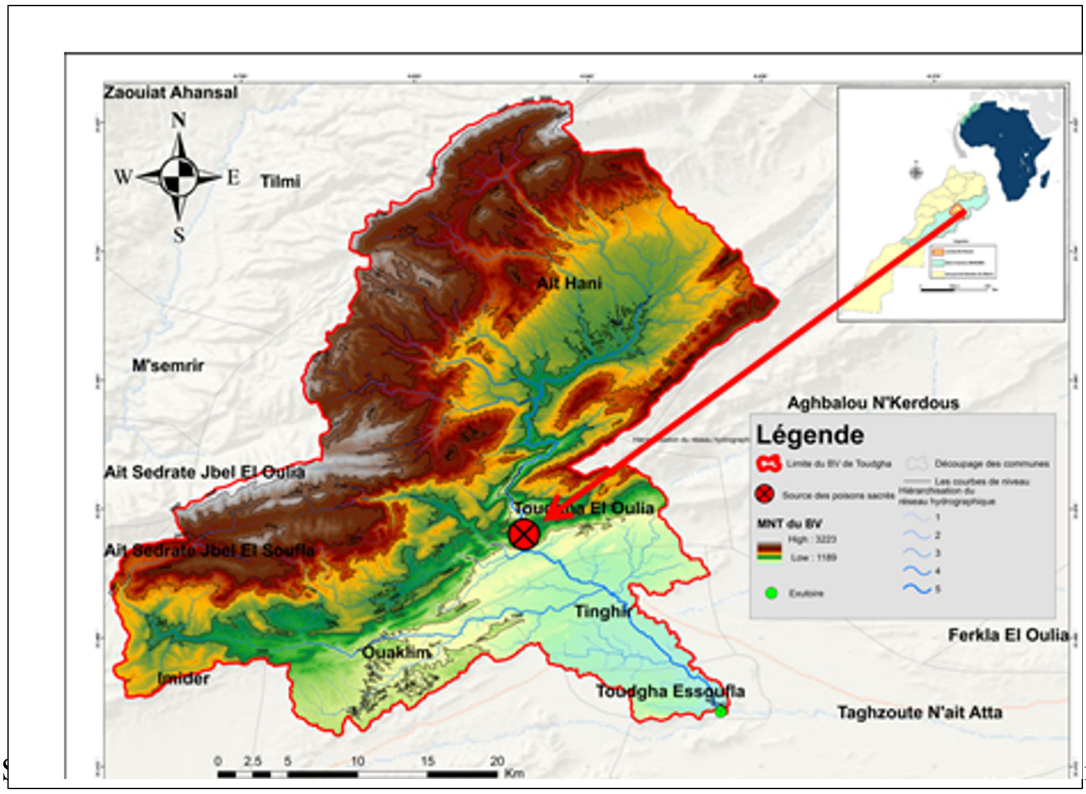


Figure 1: Location of the sacred fish spring

S [illegible] ring, where fish abound. The Toudgha valley is one of the most beautiful oases in south-east Morocco, with its semi-arid climate and famous gorges (the Toudgha gorges) (Brown *et al.,* 2023). The 300-metre-deep Toudgha wadi flows through these gorges, with its cool, clear water drawing from several springs, the most famous of which is the sacred fish spring. (Benchattou *et al.,* 2021) This spring is not only warm, but also teeming with fish that nobody is allowed to catch. And for good reason, these fish are the subject of a legend, according to which, a thirsty man would have seen a spring gushing out of the stone, after having struck a rock with his stick (Garcia *et al.,* 2023). A second blow to the rock caused fish to gush forth. The sacred fish are never caught, as they represent the richness and fecundity of the spring and the natural areas around it, which offer tourists and travelers numerous opportunities for discovery, hiking and climbing (Martinez *et al.,* 2022).

### *2.2. Current hydrological context and the reality of climate change, in the Sacred Fish Spring basin:*

#### *2.2.1 Current climatic and hydrological context of the sacred fish spring:*

Climate change is a reality, now widely recognized by the scientific community (Garcia *et al.,* 2022). This climatic variability favors the disruption of the climate system, which in recent years has been characterized by the dominance of rainfall, concentrated in time and space (Smith *et al.,* 2023). This contributes to the occurrence of floods, so with global climate change we find that there is always a risk in watersheds, which makes them a rich archive for hydrologists to carry out scientific studies (Benchattou *et al.,* 2023). In this context of climate change, this basin is characterized by storm phenomena, which favor the appearance, permanently of floods, which affect the entire watershed, and which negatively influence the socio-economic activities in the study area. A good agreement was observed in the case of Trachurus trachurus, a migratory, semi-pelagic species of the Carangidae family (Nasri *et al.,* 2021). This species has better growth in length than in weight, therefore having a negative or lower allometry. It varies according to sex, length, and season.

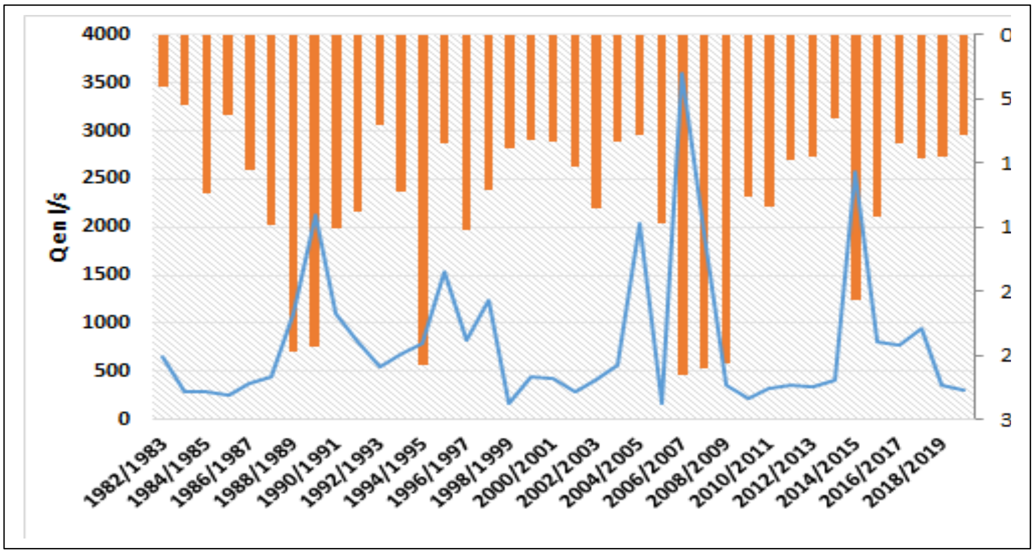


**Figure 2**. Analysis of annual variation in precipitation and flow at the Ait Bouijane station (1975/76 to 2019/20)

The study basin is characterized by high variability in rainfall. This climatic disturbance (rainfall concentrated in time and space) has a negative influence on the hydrological functioning of the sacred fish spring, as it favors the appearance of hydrological extremes in the form of flash floods and inundations, which each time cause material damage and sometimes human losses, as well as a feeling of insecurity among local residents and tourists (Brown *et al.,* 2023).

#### *2.2.2 Hydrological and climate change issues at the sacred fish spring:*

The sacred fish spring provides a sacred point and environmental balance in the area. The hydrological regime of the sacred fish spring is rain-fed, and is characterized by great variability from one season to the next, generally resulting from heavy showers, localized in time and space (Chen *et al.,* 2022). In the context of climate change, the sacred fish spring has tourist, environmental and agricultural implications, especially as local residents used the water from the spring to irrigate their agricultural plots. (Davis & Smith, 2022)

Figure 3: Photo panel of the sacred fish spring

## 2.3 Methodology adopted

### 2.3.1 Selection of the area and section for flow measurement at the sacred fish spring:

The choice of measurement location is a crucial step in the stream flow measurement procedure, and will have a major impact on the quality of the measurements (Patel & Lee, 2023). The cross-section to be gauged is chosen taking into account the flow conditions on the day of gauging (Thompson *et al.,* 2023). The cross-section may differ from one measurement session to the next. When gauging at a hydrometric station, the location can be several hundred meters upstream or downstream of the gauge, provided there is no branch bringing or carrying water into the reach between the measurement site and the hydrometric station (Wang *et al.,* 2022).

Criticisms of the choice of a measuring position are:

- Cross-section regularity (absence of boulders, pits, etc.)
- Regularity of current lines (current line parallel and perpendicular to the cross-section), straight and homogeneous cross-section;
- Sensitivity (sufficient depth >15 cm, sufficient speed>0.2m/s) ;
- The proximity of the gauging station (especially important during low-water periods);
- Stability (possibility of always gauging at the same location, possibly: one low-water site + one high-water site). (Benchattou *et al.,* 2021).

### 1.1.1 Water level monitoring and micro-spinner gauging

Monitoring and observing the water level at the sacred fish spring is a daily and ongoing task, requiring a physical presence to read the water level, while at the same time taking photos of the recorded water level (Smith *et al.,* 2023). To do this, we put an observer in charge of noting rises in the spring, five times a day. Flow measurements are used to determine the volume of water passing through a section per unit of time (Garcia *et al.,* 2023).

### 1.1.2 Creation of a rating curve:

The rating curve is a monotonic, increasing and unambiguous correspondence between flow and head, for a given hydrometric station. It cannot be transposed in space. To establish the setting of a hydrometric station, we need to establish the relationship between the heights measured on a limnimetric scale or recorded by a limnigraphe, and the corresponding flows. (Gharbi *et al.,* 2016) The series of measured heights, or limnimetric chronicle, is characterized by its interval of variation, between the minimum and maximum observed heights.

## 3 Results and interpretation:

### 3.1. Flow measurement (gauging) at the sacred fish spring:

Flow measurements or gauging operations provide information on the volume of water passing through a section per unit of time. The importance of these measurements is now being reinforced by the challenges of hydrological extremes in the context of climate change. In our case, we used the reel method, with source gauging consisting in measuring current velocity. This speed varies laterally, from one bank to the other, and vertically, from the water surface to the bottom of the bed (Lahlou *et al.,* 2019)

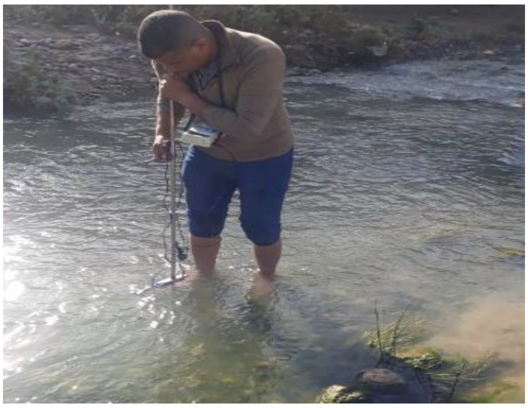

**Photo 1** : Sacred fish spring (A. BENCHATTOU, 2021)

**Photo 2** : Measurement of spring flow (A. BENCHATTOU, 2021)

The following **Table 1** shows the results of the gauging campaigns we carried out, during different periods. (High and low water)

**Table 1**: Results of spring gauging campaigns

| | 29/10/2020 | | 30/01/2021 | | 20/10/2021 | |
|---|---|---|---|---|---|---|
| | H (cm) | Q ($m^3/s$) | H (cm) | Q ($m^3/s$) | H (cm) | Q ($m^3/s$) |
| **Sacred fish spring** | 14 | 53 | 19 | 98 | 22 | 124 |

### 3.2 Creation of a calibration curve for the sacred fish spring

We carried out a series of gauging campaigns to produce a rating curve for the sacred fish spring. This curve enabled us to convert heights into flows. The rating curve, the relationship between head and flow, is the most delicate link. Although this height-discharge relationship is reputed to be stable over a given period of time, it is not necessarily so over time, particularly when the hydraulic control is not provided by an artificial structure (Gharbi *et al.,* 2016). Excel" software was used to construct a rating curve for the sacred poisons spring, and a trend curve was also built to obtain a correlation equation between water levels and flows.

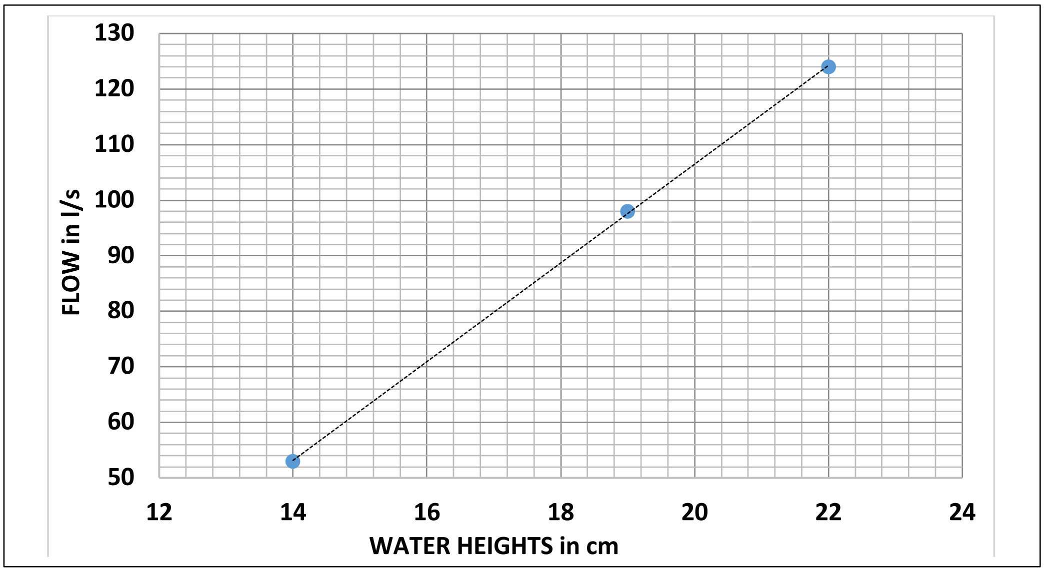


**Figure 5**: Coefficient of determination R2 for the sacred fish source

The coefficient of determination, R=0.97, means that we are virtually perfect. The rating curve is considered to be the best estimate of the height-flow relationship, and point measurements of flow (gauging) enable us to estimate the variance of this relationship. We'll use these data to create the rating curve for the Sacred Fish spring.

### *3.3 Evaluation of the results, with the issue of climate change at the sacred fish spring:*

The sacred fish spring is located in southeastern Morocco. This area is characterized by a semi-arid climate. The spring is a tourist attraction in the area, and also maintains its ecological balance. The water from this spring is used to irrigate agricultural plots.

**Figure 6*:*** Photograph of tourist and agricultural activities in and around the sacred fish spring

In the context of climate change, the hydrological functioning of the sacred fish spring is undergoing remarkable disruption and variation, especially as in recent years the area has received rainfall concentrated in time and space, in the form of stormy precipitation. This favors the occurrence of hydrological extremes (floods), and also influences the supply of water to the spring. So, faced with this climatic variability, the sacred fish spring can be used as a distraction to an ecological space, as in the case of Ain Meski.

## Conclusion

This scientific work focused on a particular problem, namely the production of hydrometric data in the catchment area of the sacred fish spring. Considered one of the most important tourist areas in south-east Morocco, it is like a pearl in a semi-arid climate, containing an exceptional wealth of fauna, flora, water (the Toudgha gorges) and landscapes. It also offers a tourist attraction and an ecological balance to the area. But with climate change, this spring is experiencing a disturbance in its hydrological functioning, and to fully understand this irregularity in the spring's flows, we have carried out a more precise study of the hydrometric monitoring of the Sacred Fish Spring's flows between 2020 and 2021.

We started with zero data and arrived at a hydrometric database for the sacred fish spring. We used a methodology that enabled us to monitor the water level in the spring. We then carried out a series of gauging campaigns to create a rating curve for the spring, and finally extracted the flows from the spring, which enabled us to understand the hydrological functioning of the Sacred Fish Spring in the context of climate change.

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