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XIX WORLD WATER CONGRESS
International Water Resources Association (IWRA)
Marrakech, Morocco | 1-5 December 2025

Kingdom of Morocco



Ministry of
Equipment and Water

Run-of-River: a Powerful solution for harnessing hydropower potential of the Bouregreg watershed in Morocco

Imane El Kasimi, Moulay Driss Hasnaoui, Driss Khomsi, Ahmed Bouziane, and Amal Aboulhassane

Mohammadia School of Engineers, Mohammed V University

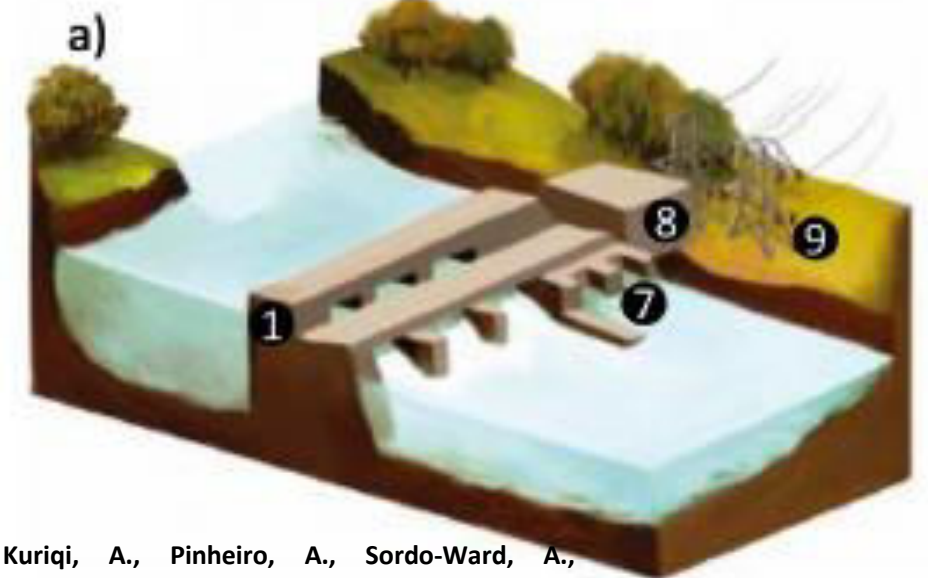
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Introduction

- The global energy transition requires expanding low-carbon and cost-effective renewable sources. Hydropower remains one of the most reliable and mature renewable technologies.
- In recent years, run-of-river hydropower has gained attention due to its lower environmental footprint, reduced social impacts, and lower construction costs compared to large dams.
- Morocco has not yet integrated run-of-river schemes into its national energy strategy; the hydropower system remains dominated by large storage dams and pumped storage hydropower.
- Run-of-river hydropower generates electricity by harnessing the natural flow of the river with minimal storage. It provides environmentally friendly electricity generation that follows seasonal flow variations.

Dam-toe run-of-river scheme



Kuriqi, A., Pinheiro, A., Sordo-Ward, A., Bejarano, M. & Garrote, L. (2021).

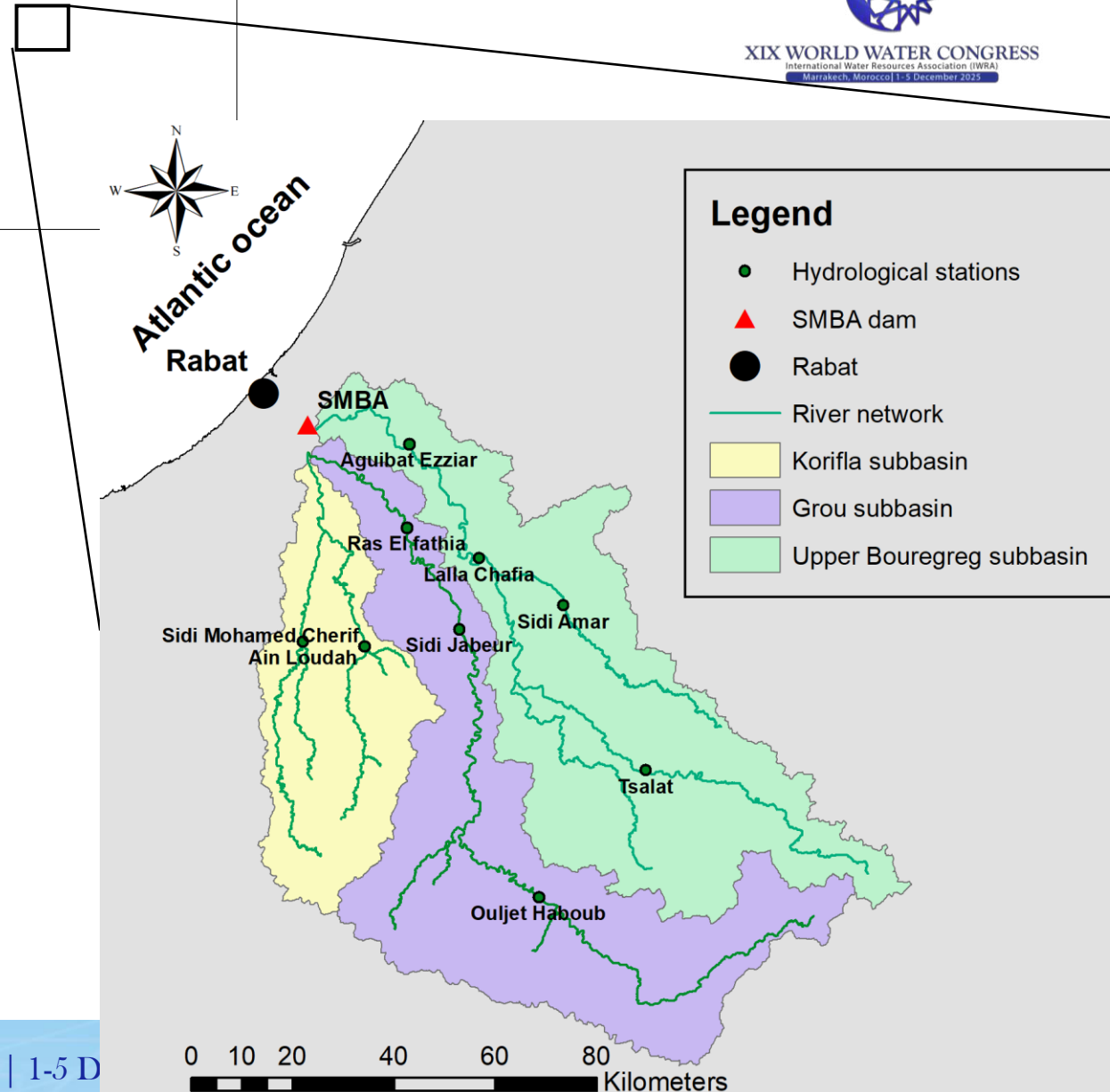


Study area

- The watershed covers an area of 9545 km².
- It has a semi-arid climate, with wet winters and dry summers.
- Annual rainfall ranges from approximately 400 mm in the downstream areas to about 760 mm in the upstream regions.
- The outlet is controlled by the Sidi Mohamed Ben Abdellah (SMBA) dam, which has a storage capacity of 974 Mm³.
- The dam is supplied by three main sub-basins: Upper Bouregreg, Grou, and Korifla.
- A network of nine hydrological stations is distributed across the watershed.



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Methodology

1. Hydrological modeling using the SWAT model

- Daily runoff simulations were performed for the period 1978–2020.
- Model calibration and validation were conducted in SWAT-CUP using the SUFI-2 algorithm, with the Nash–Sutcliffe Efficiency (NSE) as the objective function.
- A 5-year warm-up period was applied (1978–1982).
- Calibration covered 28 years (1982–2010).
- Validation covered 10 years (2011–2020).

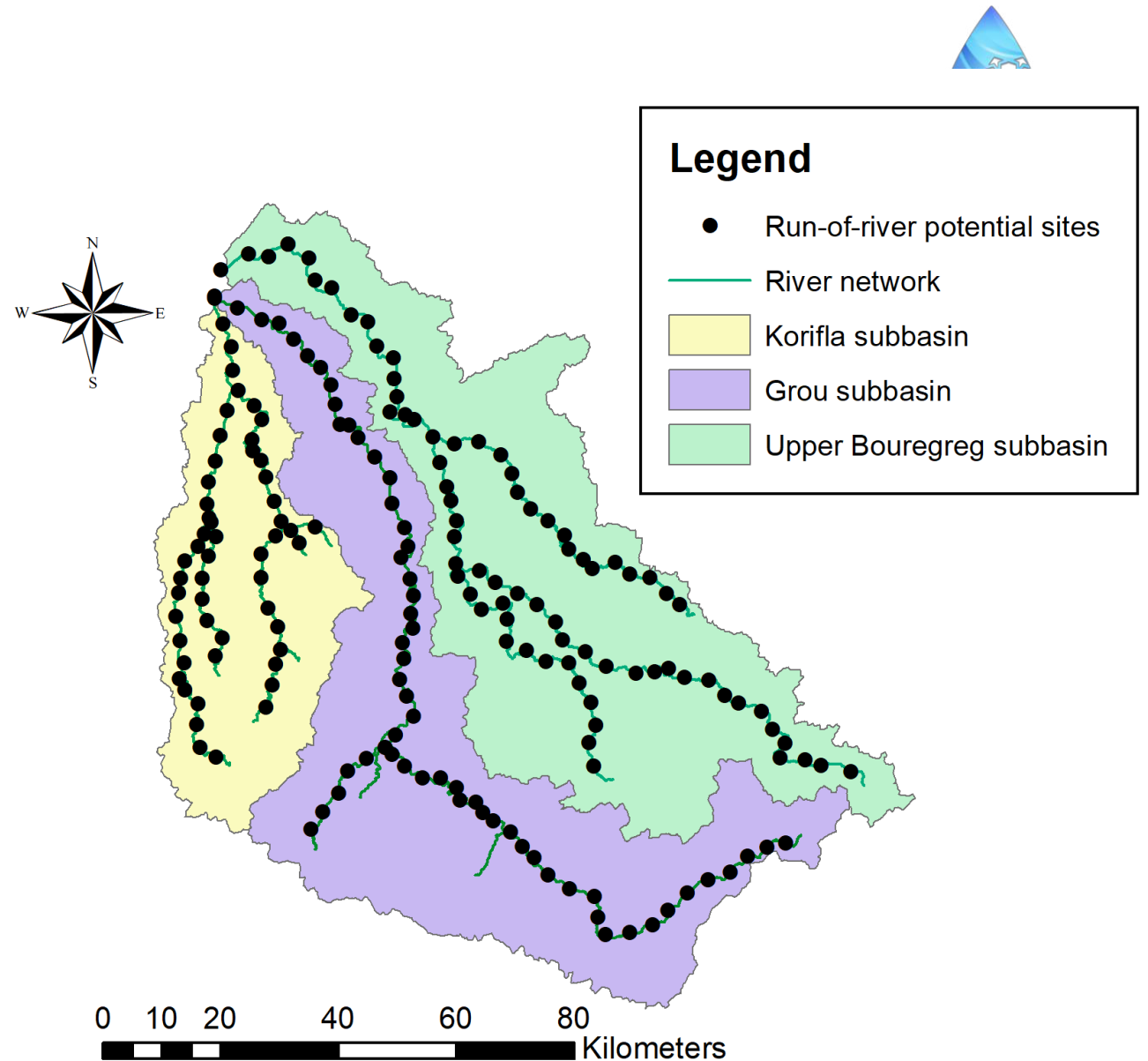
Data sets	Source	Details
Rainfall and streamflow	The Moroccan Ministry of Equipment and Water	1978 – 2020 period
Temperature – Wind speed – Solar radiation – Relative humidity	ERA5-Land	1978 – 2020 period
DEM	ALOS PALSAR	12.5 m resolution
Soil map	FAO-UNESCO Soil Map of the World.	50 km resolution
LULC map	Sentinel-2 10m Land Use/Land Cover (2020)	10 m resolution



Methodology

2. Select run-of-river potential sites :

- The main river network of each sub-basin was discretized using a 5-km spacing criterion.
- A total of 175 potential sites were identified for analysis



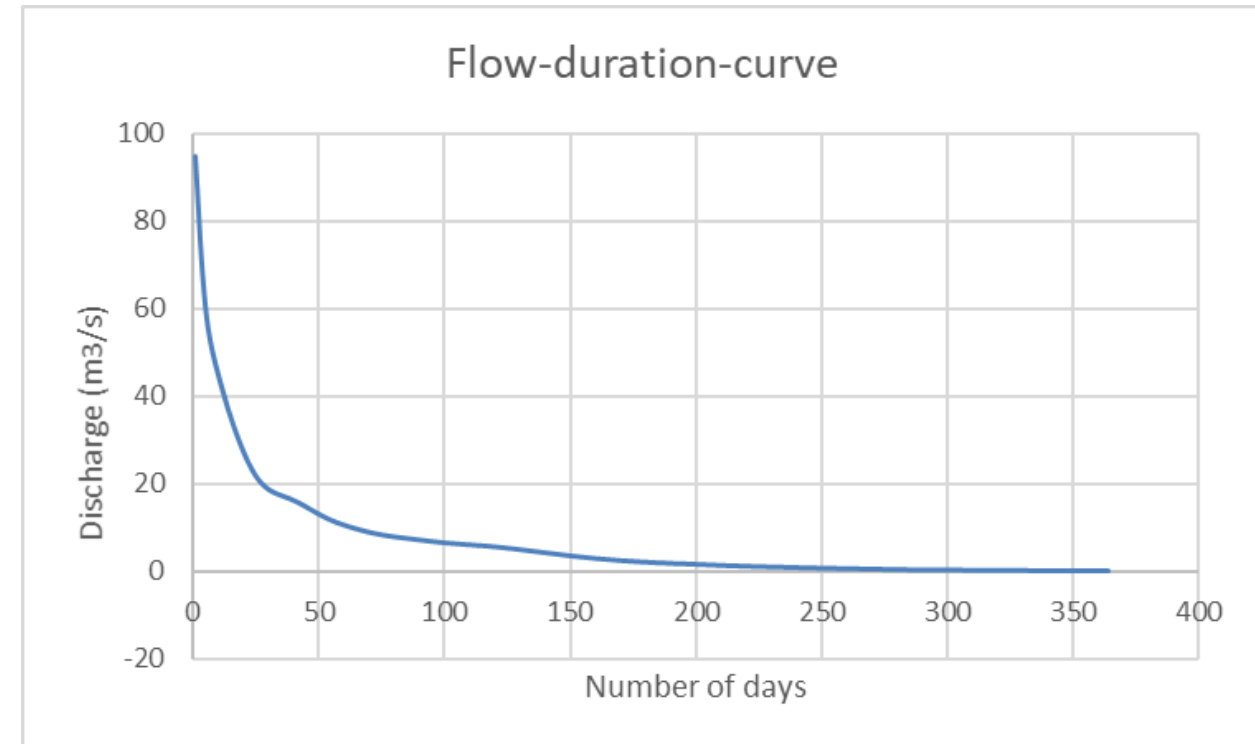
Methodology



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3. Construction of the Flow-Duration-Curve (FDC):

- For each site, daily simulated flows for every year were used to construct yearly Flow Duration Curves (FDCs).
- By computing the yearly flow at the outlet (SMBA dam), the median hydrological year is identified.
- The median FDC for each site was then selected for subsequent calculations.





Methodology

4. Construction of the Energy-Duration-Curve (EDC) :

For each site, the EDC is constructed using the formula :

$$E = 24 * \rho * g * H * Q * d$$

- E is the energy produced during d days (*Wh*)
- Q is flow available during d days, derived from the FDC (m^3/s)
- ρ is the water density (kg/m^3)
- g is the gravitational acceleration (m/s^2)
- H is the hydraulic head created by the RoR plant (*m*), assumed to be 5 m





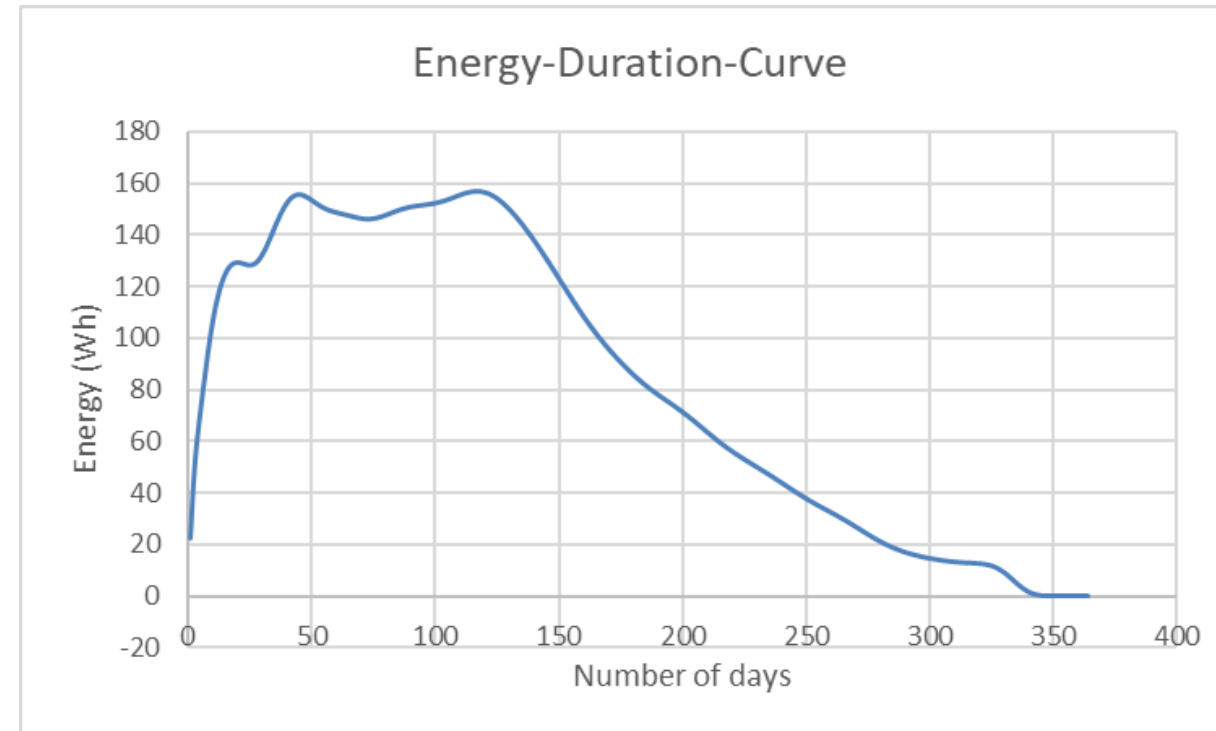
Methodology

5. Identification of the design discharges:

The peaks of the EDC are used to identify the corresponding design discharge. This discharge is then used to estimate the theoretical hydropower potential using the formula:

$$P = \rho * g * H * Q_d$$

- P is the theoretical hydropower potential of the RoR plant (W)
- Q_d is the design discharge (m^3/s)
- ρ the water density (kg/m^3)
- g is the gravitational acceleration (m/s^2)
- H is the hydraulic head created by the RoR plant (m), assumed to be 5 m

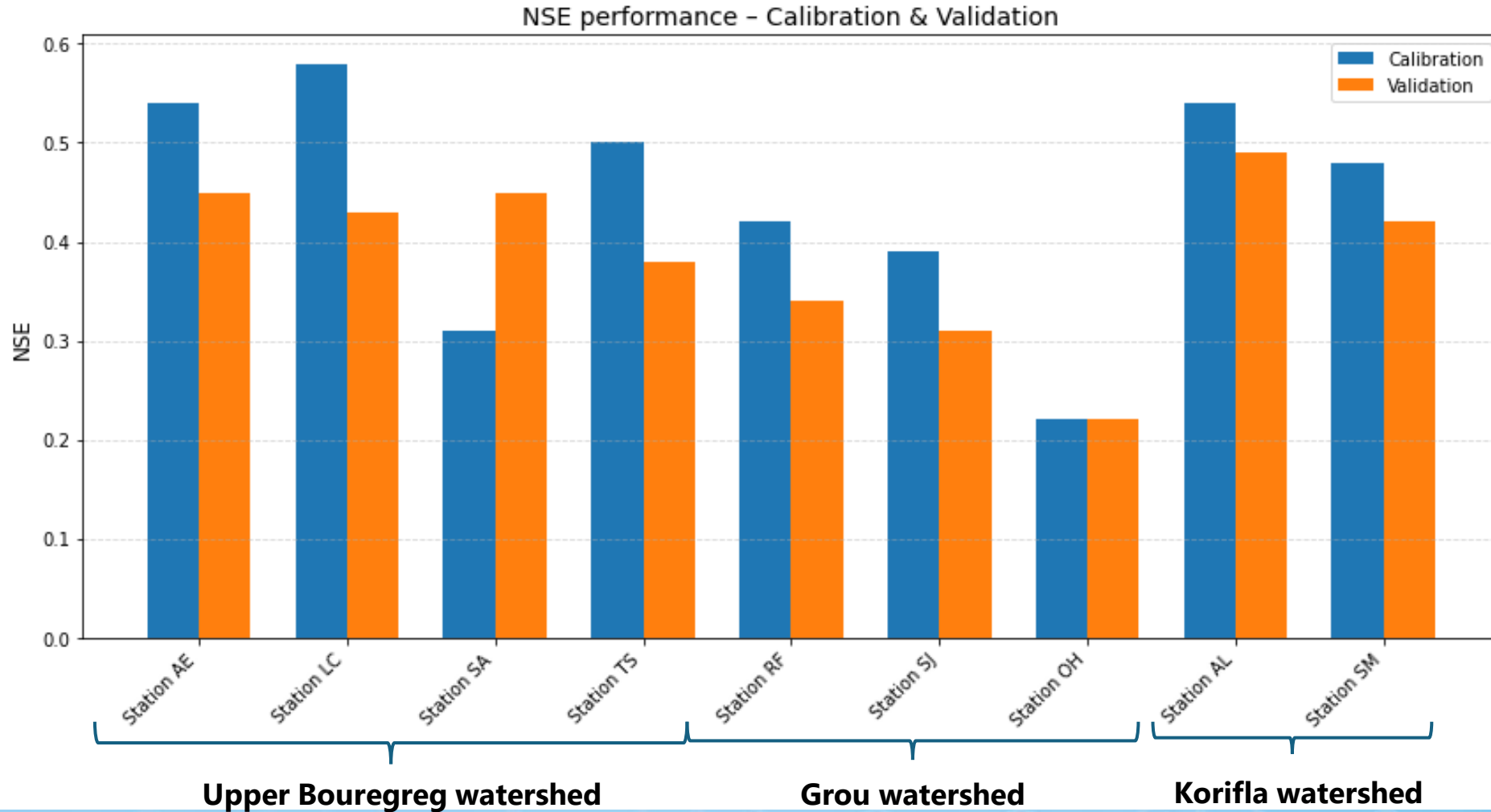


Results

SWAT performance metrics for daily runoff (Kalin *et al.*, 2010)

Performance	NSE	PBIAS
Very Good	$NSE \geq 0.7$	$ PBIAS \leq 0.25$
Good	$0.5 \leq NSE < 0.7$	$0.25 < PBIAS \leq 0.5$
Satisfactory	$0.3 \leq NSE < 0.5$	$0.5 < PBIAS \leq 0.7$
Unsatisfactory	$NSE < 0.3$	$ PBIAS > 0.7$

Hydrological modeling results : NSE and PBIAS values

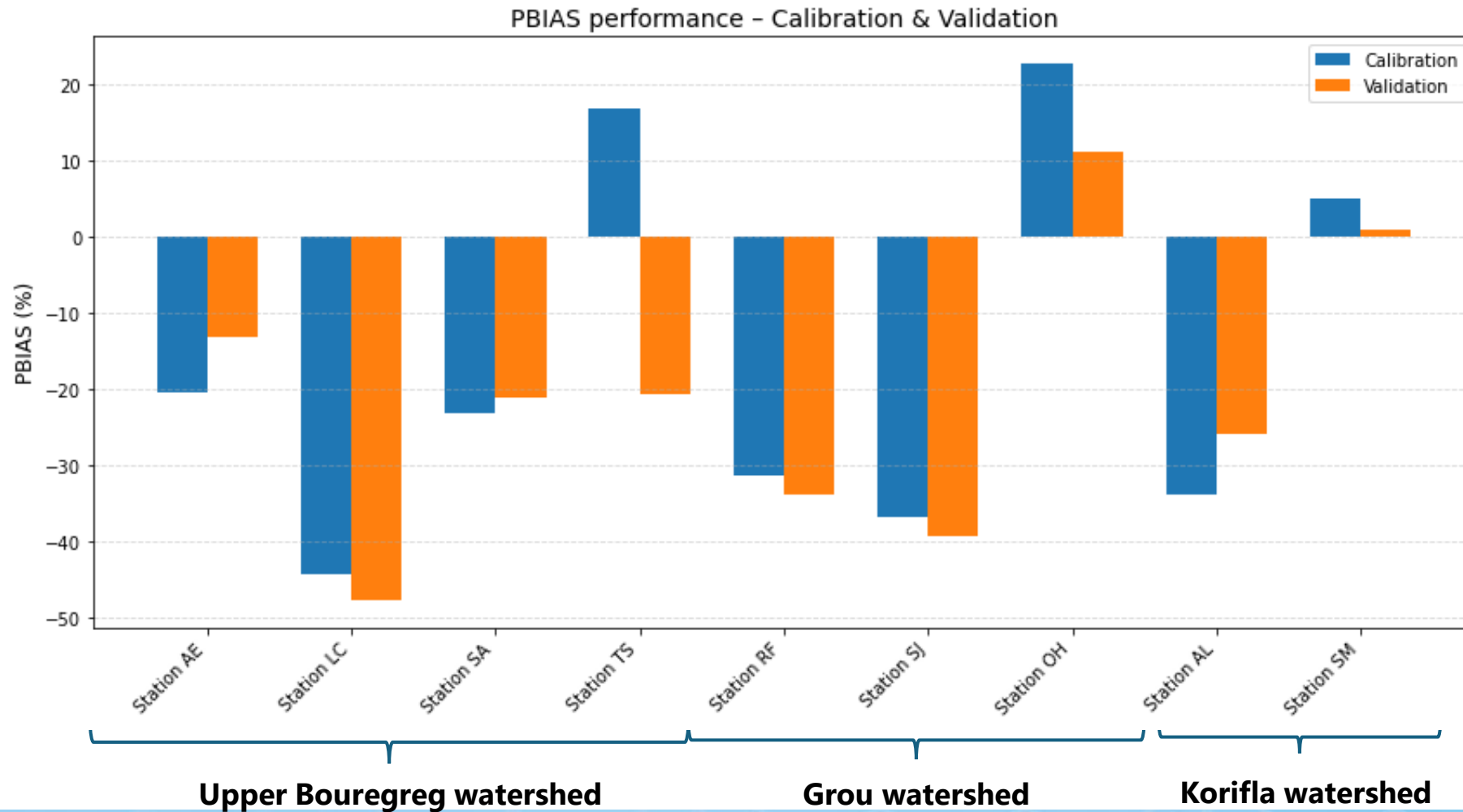


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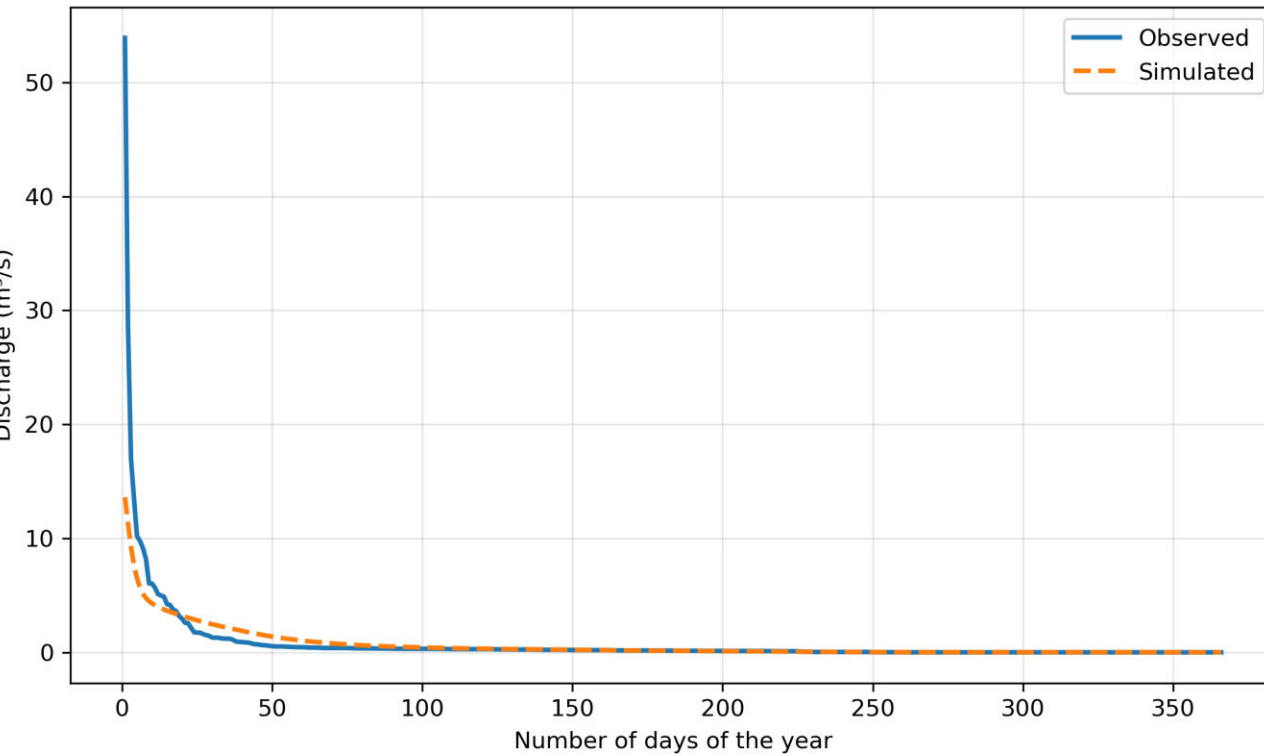


Results

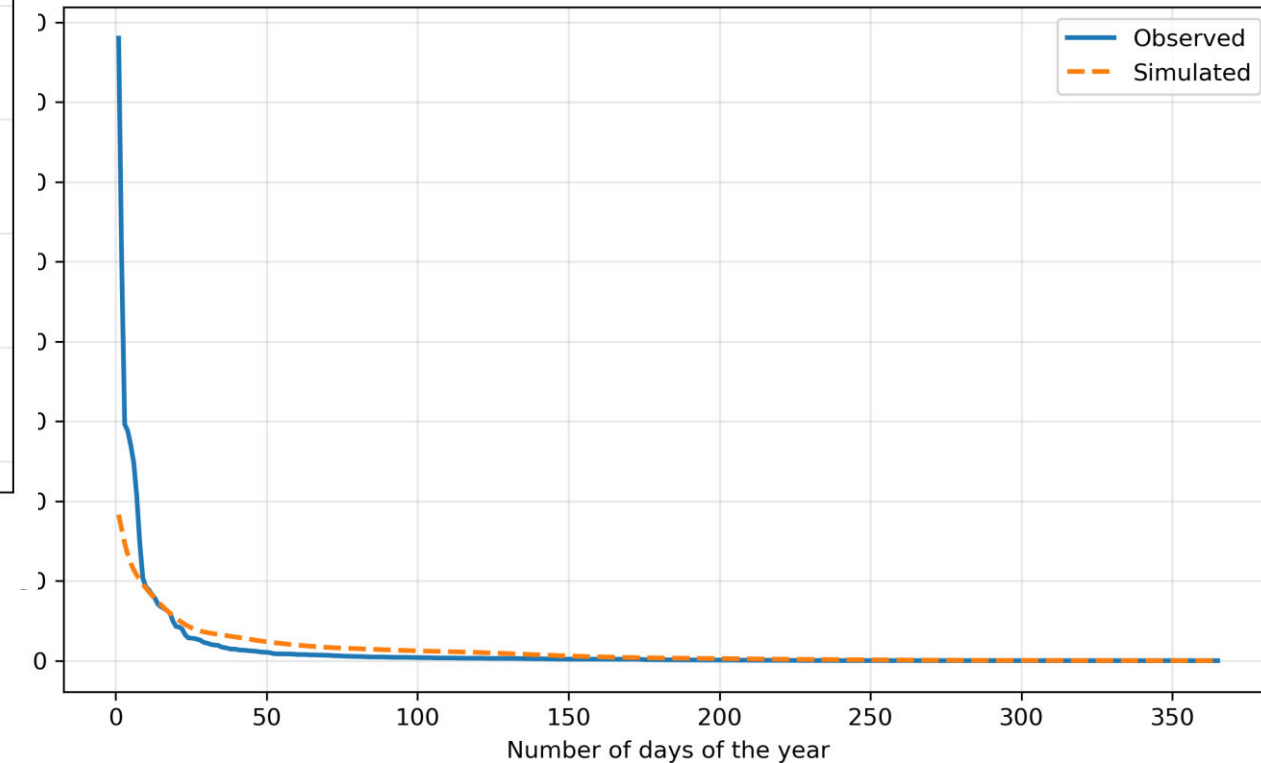


Construction of the median FDC at each potential RoR site : The 1988/1989 FDC

Station SM (Korifla) — FDC (Median Year)



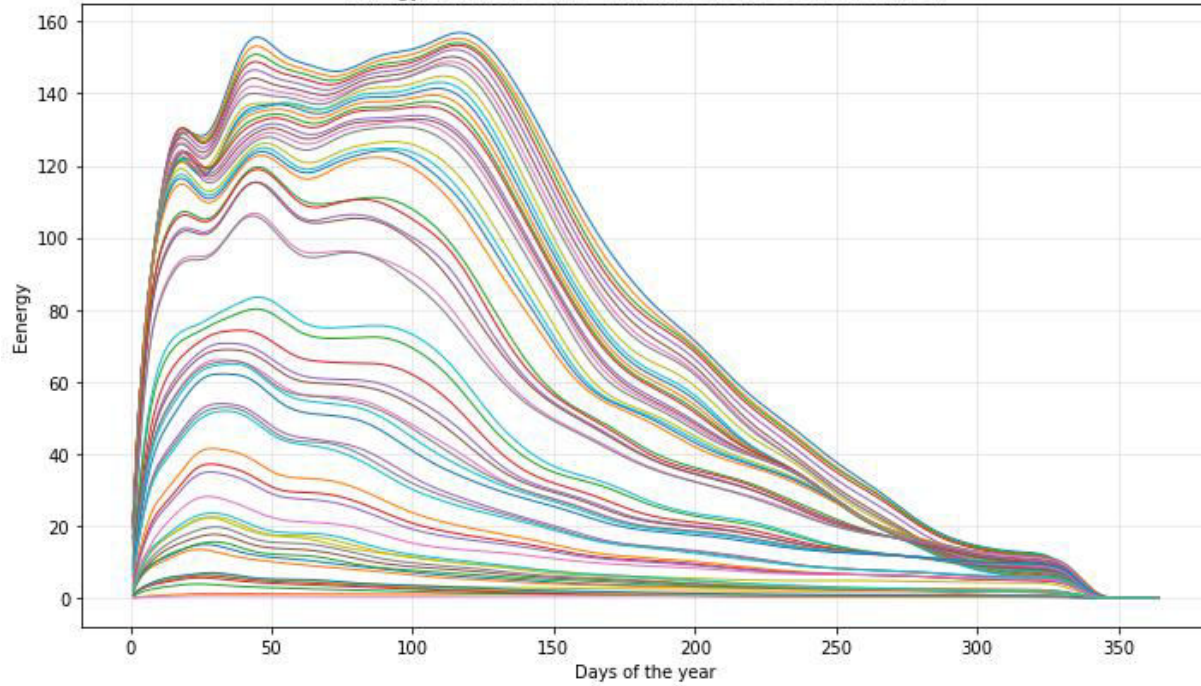
Station RF (Grou) — FDC (Median Year)



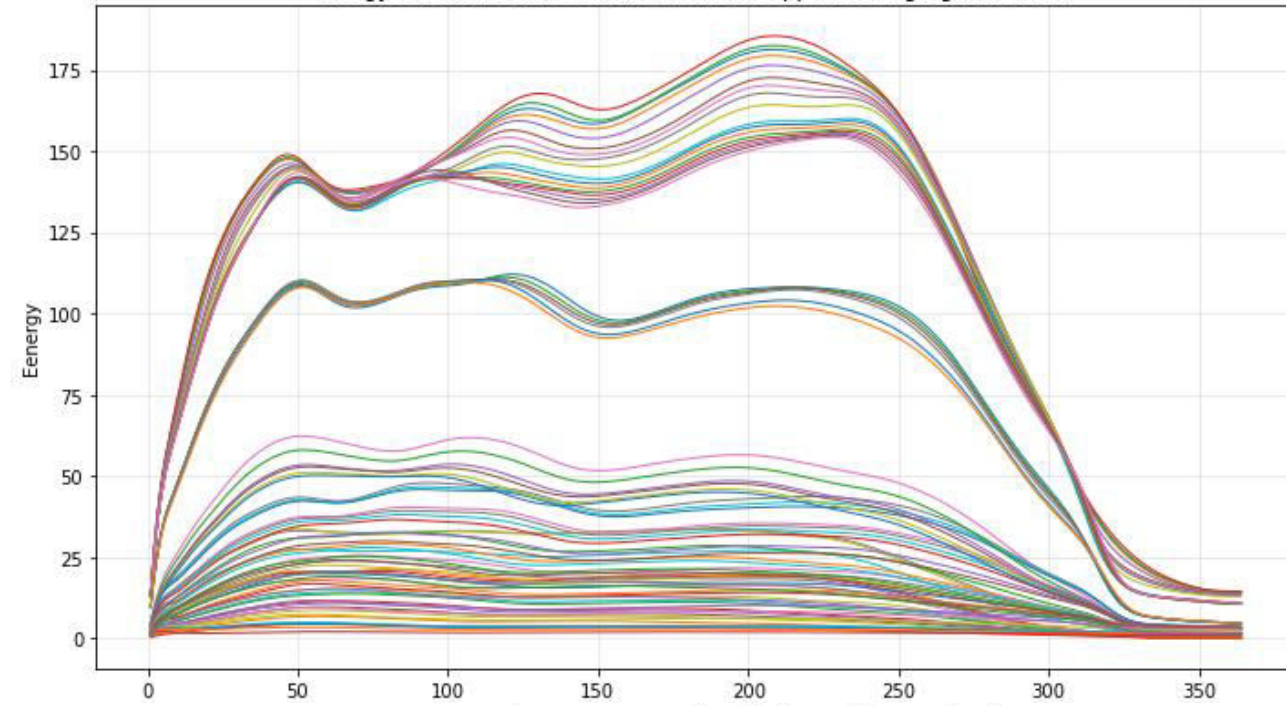
Results

Construction of the median EDC at each potential RoR site :

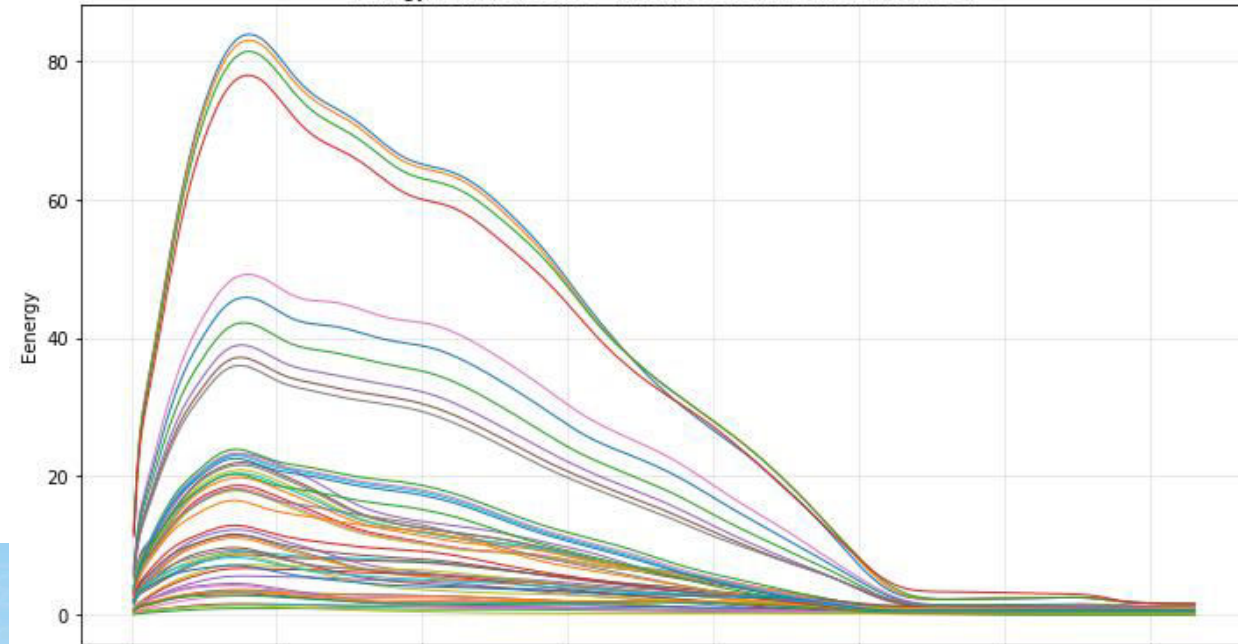
Energy-Duration-Curve - RoR sites in the Grou watershed



Energy-Duration-Curve - RoR sites in the Upper Bouregreg watershed



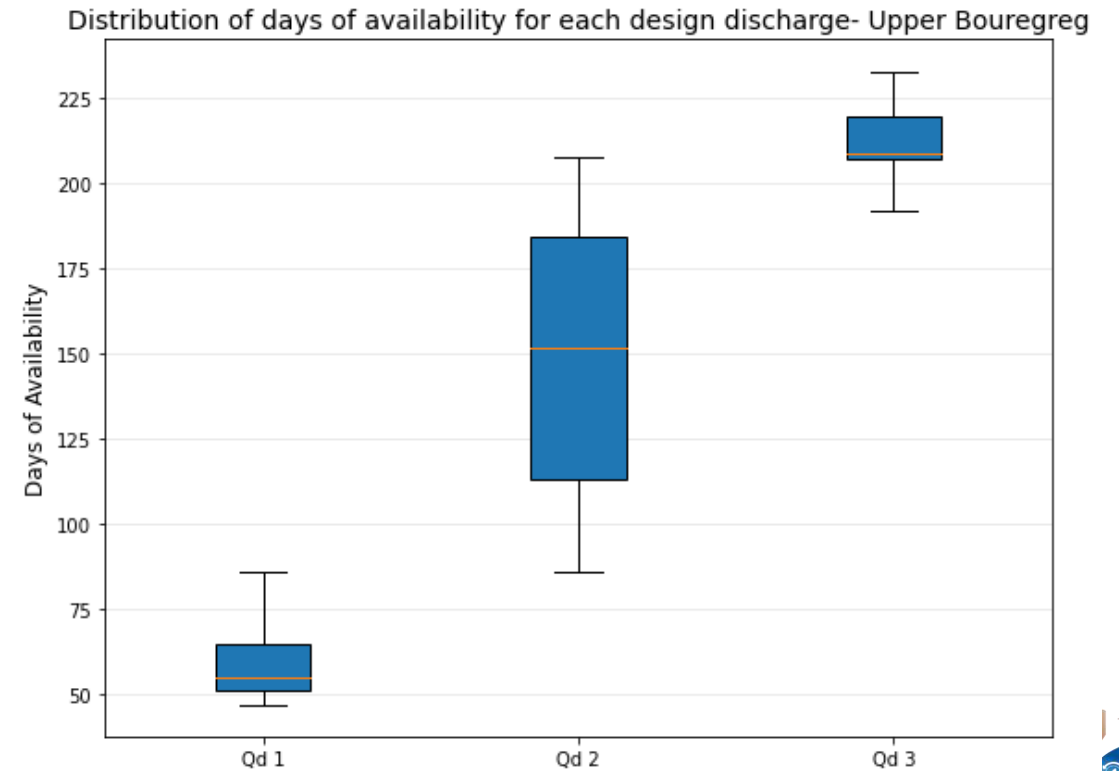
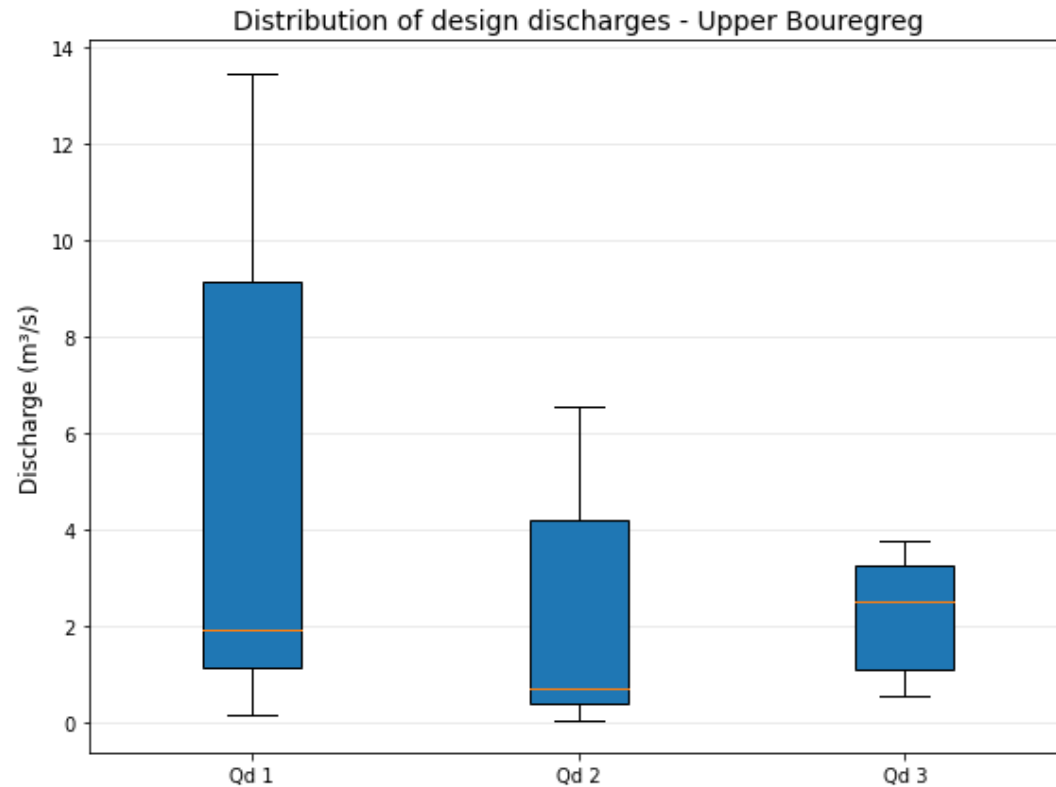
Energy-Duration-Curve - RoR sites in the Korifla watershed



Results



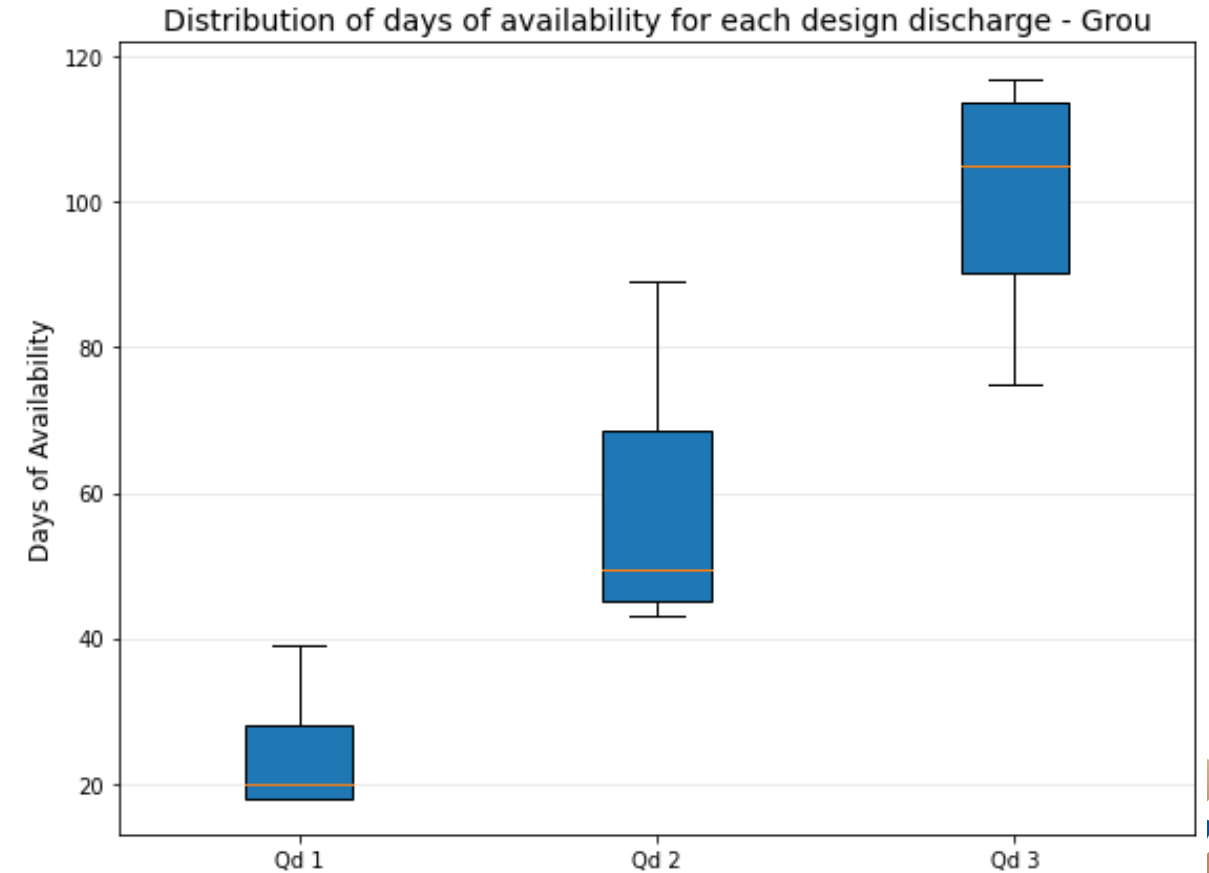
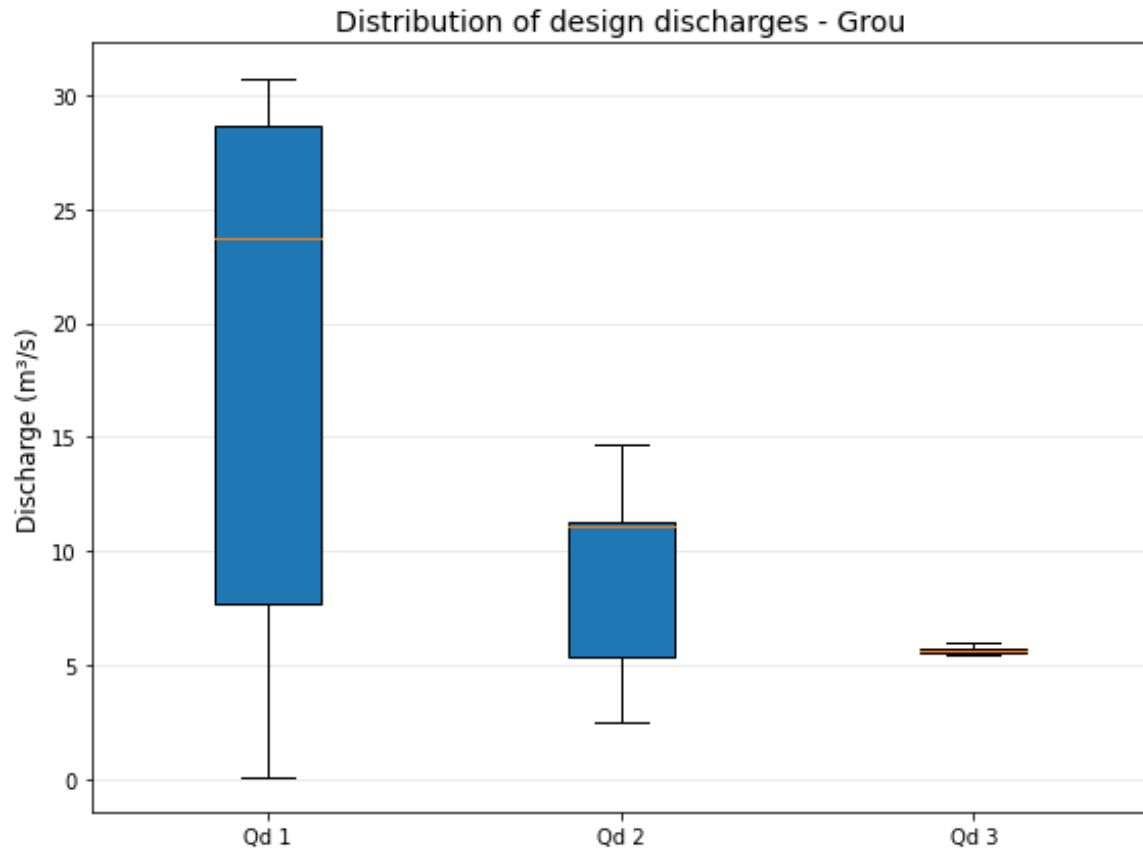
Distribution of the design discharges and their days of availability in each watershed



Results



Distribution of the design discharges and their days of availability in each watershed

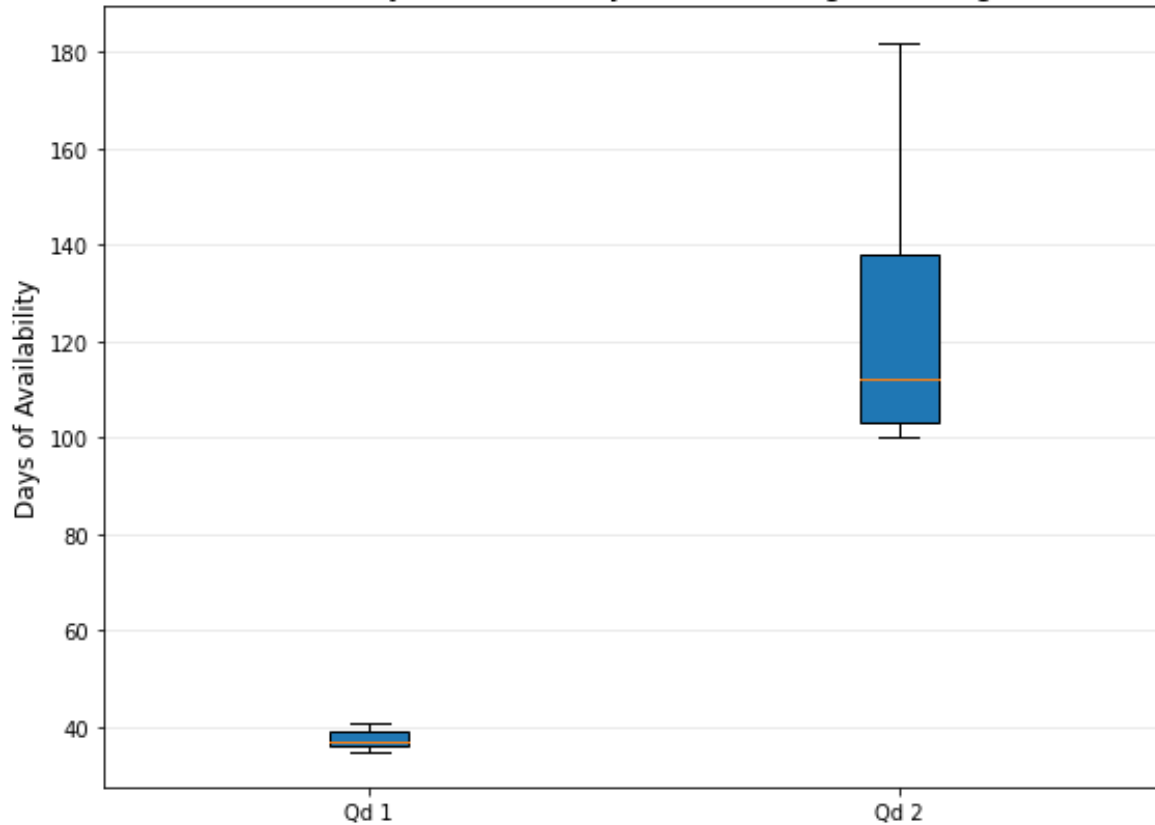


Results

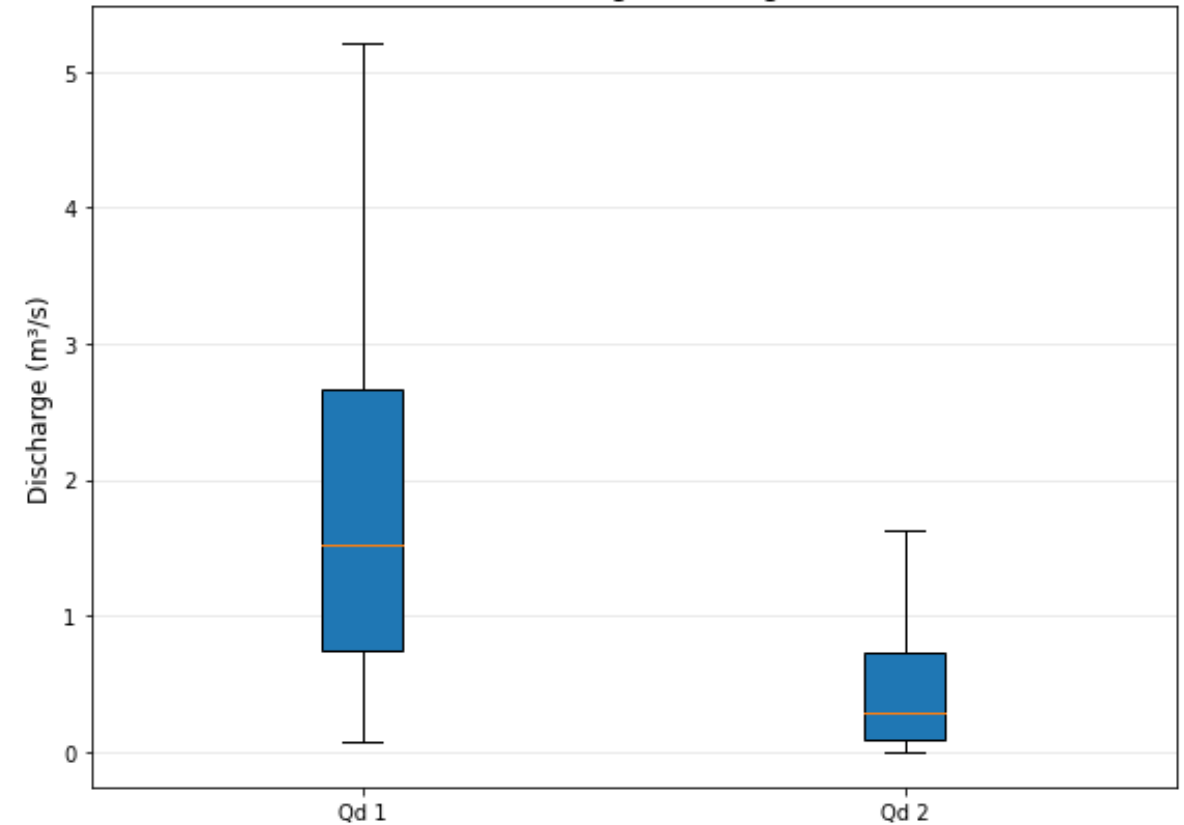


Distribution of the design discharges and their days of availability in each watershed

Distribution of days of availability for each design discharge - Korifla



Distribution of design discharges - Korifla



Results



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Total hydropower potential capacity of the watershed

Subwatersheds	Total potential	First level	Second level	Third level
Upper Bouregreg	29.1	17.5	7.8	3.8
Grou	67.4	41.8	17.8	7.7
Korifla	7.3	5.9	1.4	

Watershed	Total potential	First level	Second level	Third level
Bouregreg	103.8	65.2	27.0	11.6





Conclusion

- By considering a cascade scheme of run-of-river plants, the Bouregreg watershed is theoretically capable of producing up to 100 MW under typical hydrological conditions.
- Hydropower estimates would be higher for sites where the available hydraulic head is greater than the assumed 5 m.
- Even under semi-arid conditions, run-of-river technology can remain a cost-effective and clean source of energy.
- The framework developed in this study provides a method for selecting optimal design discharges, offering multiple options ranging from less-frequent high flows to more regular, year-round lower flows.
- By using modular turbines, run-of-river plants can harness a wide range of discharges throughout the year, improving both flexibility and energy yield.



Conclusion

- The hydropower estimates presented here are based on theoretical calculations. A more realistic assessment would require integrating technical, environmental, and economic constraints.
- The analysis was conducted using the median hydrological year. Therefore, evaluating the potential for each individual year would provide insight into the interannual variability of hydropower production.
- Future work should incorporate climate change scenarios to assess long-term impacts on runoff and hydropower availability.
- Publication: Findings related to the Grou sub-watershed have been published recently in the *International Journal of Renewable Energy Development*, in the article titled: "Optimal hydropower potential assessment in semi-arid regions," by Imane El Kasimi, Moulay Driss Hasnaoui, Driss Khomsi, Ahmed Bouziane, and Amal Aboulhassane.



Optimal hydropower potential assessment in semi-arid regions

Imane El Kasimi[✉], Moulay Driss Hasnaoui[✉], Driss Khomsi[✉], Ahmed Bouziane[✉], Amal Aboulhassane[✉]

Hydraulic System Analysis Team (HSAT) Laboratory, Mohammed V University, Rabat, Morocco

Abstract While hydropower is a cornerstone of global renewable energy strategies, its development in semi-arid regions remains insufficiently explored. Limited and highly variable water availability often discourages comprehensive assessments of its potential. In particular, run-of-river hydropower, despite its environmental and economic advantages, remains largely underexplored in these contexts due to its sensitivity to flow variability. This study evaluates the theoretical hydropower potential of run-of-river schemes within the semi-arid Grou watershed, a major tributary of the Bouregreg river in Morocco, with a focus on optimizing energy production under dry hydrological conditions. Hydrological modeling was applied using the Soil and Water Assessment Tool (SWAT), enabling the generation of flow-duration curves across the river network. These curves were then used to develop energy-duration curves, allowing for the identification of multiple optimal design flows. Consequently, instead of relying on a single turbine, the study explores the deployment of modular turbines per plant, each tailored to specific flow regimes, thereby expanding the range of exploitable run-of-river hydropower. Results indicate an untapped hydropower potential of approximately 32.4 MW per meter of head, with outputs of 31.5 MW, 783.3 kW, and 98.9 kW for high, moderate, and low flows, respectively. These findings highlight the feasibility of run-of-river hydropower in semi-arid regions and underscore the importance of adaptive turbine systems in enhancing sustainable energy production, specifically in water-scarce environments such as Morocco.

Keywords: Run-of-river, Hydrological modeling, SWAT, Flow-duration curve, Modular turbines.



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1. Introduction

Adopting renewable energy is crucial in combating greenhouse gas emissions; therefore, it is considered an essential pillar in the mitigation strategies defined by the United Nations Framework Convention on Climate Change. While all renewable energy sources contribute to reducing fossil fuel dependence, hydropower is particularly reliable and can be adjusted to meet demand throughout the day and across seasons (Killingtveit, 2020). Conversely, other sources are mostly intermittent and may fall during periods of extreme need (IRENA, 2023a). From a technical standpoint, hydropower technology is mature, as it is one of the oldest and most efficient energy sources (Killingtveit, 2020). This underscores its role as the most prominent renewable energy globally, contributing to nearly 53% of renewable electricity production and approximately 15% to the total electricity production in 2022 (IRENA, 2024). It is also considered one of the most economically efficient sources of electricity, with a lower levelized cost of electricity compared to fossil-fueled energies during the 2010-2021 period (IRENA, 2023b). In Morocco's case hydropower is the leading renewable energy source, (Vedie, 2020). By 2015, during COP21, the country raised its ambition to increase the share of hydropower in the national energy mix by 12%, to be achieved through the development of 1,330 MW of additional capacity by 2030 (El Hafdaoui, Khallaayoun, & Al-Majeed, 2025).

Given the significance of hydropower, the question arises as to whether the potential of watersheds has been fully exploited. In fact, the International Energy Agency highlights that nearly 50% of the economic hydropower potential remains untapped, with a significant portion located in Africa (IEA, 2021; IRENA, 2023b). Hence, substantial opportunities for hydropower production have yet to be efficiently harnessed to meet the objectives of the climate change policies (IRENA, 2023b).

In this context, run-of-river (RoR) hydropower plants have emerged as a key contributor to the renewable energy mix, particularly in supporting rural electrification in developing countries (Malhan & Mittal, 2021). The RoR scheme typically includes a small intake weir constructed in a section of the river, creating a small impoundment. Water is then directed toward a forebay, which regulates elevation for stable power generation. A channel called the penstock then guides the water under pressure to the powerhouse, where a turbine transforms the hydraulic energy of the flow into electricity. Finally, the water is discharged at the plant's outlet. Power is generated using the water flow and the hydraulic head H , which is defined as the difference in altitude between the surface of the water level behind the weir and the placement of the turbine. Typically, RoR systems exploit heads ranging from a few meters to over 15 m and can produce up to 10 MW (Skoulikaris, 2021).

Recently, there has been a growing interest in these hydropower systems largely due to their numerous socioeconomic advantages (Nedaei & Walsh, 2022). They

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elkasimi@emi.ac.ma

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