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PREDICTING MAXIMUM DISCHARGE IN ALGERIA WADIS USING DIMENSIONAL ANALYSIS AND STATISTICAL MODELING
A CASE STUDY OF SEMI-ARID WATERSHEDS

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ABSTRACT

Accurate estimation of maximum discharge (Q_{max}) is essential for hydraulic infrastructure design and flood management in semi-arid regions, particularly where hydrometric data are scarce. This study presents a physically meaningful and regionally calibrated empirical model to estimate Q_{max} in Algerian wadis, combining approach of dimensional analysis and statistical modeling. Based on data from 60 watersheds provided by the Algerian National Agency for Hydraulic Resources (NAHR), the model integrates three key watershed descriptors: catchment area (A), rainfall intensity (P_{tc}), and average slope (S). The proposed model demonstrates strong predictive accuracy, with a correlation coefficient of R = 0.97 and a mean normalized error of 15% in the validation phase. Comparative tests against widely used formulas (Giandotti, Mallet-Gauthier, Sokolovsky, Turazza) reveals that the proposed model yields significantly lower errors and better prediction stability. Additionally, 66.6% of the estimates fall within ±10% of observed values, compared to just 3-13% for conventional methods. These results underscore the model's utility as a reliable, simple, and transferable tool for peak discharge estimation in data-scarce, semi-arid environments such as Algeria.

Keywords: Maximum discharge, Statistical modeling, Dimensional analysis, Algerian wadis, Flood management.

INTRODUCTION

Accurately estimating the maximum discharge (Q_{max}) of wadis and rivers remains a major challenge, particularly in arid and semi-arid regions such as Algeria. This parameter is essential for designing effective flood protection structures (Boulghobra, 2013; Aroua, 2020; Baudhanwala et al., 2023; Zegait and Pizzo, 2023; Ben Said et al., 2024; Ezz, 2025), including bridges, culverts, spillways (Mezenner et al., 2022; Shaikh et al., 2024; Achour and Houichi, 2019; 2025), and levees (Hamlat et al., 2021). The task is further complicated by the limited availability of field measurements, which often forces engineers to rely on empirical or semi-empirical formulas (Abdeddaim and Benkhaled, 2016; Hachemi and Benkhaled, 2016; Faregh and Benkhaled, 2016). However, many of these methods are poorly adapted to the hydrological conditions of Algerian basins, leading to significant inaccuracies and uncertainty in flood predictions (Ayari et al., 2016; Cherki, 2019; Bekhira et al., 2019; Benslimane et al., 2020; Hafnaoui et al., 2023; Athmani et al., 2025).

The inconsistent and often arbitrary application of Q_{max} estimation methods in wadi hydrology has created a lack of clear criteria for selecting appropriate models. Most existing equations are derived from watershed outside the local context, resulting in considerable variability in outputs (Kouadio et al., 2018). This undermines their reliability and hinders the effective design of flood protection infrastructure. As Beven (2012) emphasized, practical experience, hydrological expertise, and engineering judgment continue to play a central role in decision-making processes.

Infrastructure planning must balance two key considerations: the financial cost of designing for a specific discharge and the potential damage resulting from design underestimations (Zhou et al., 2004; Pappenberger et al., 2012; Mehta et al., 2023; Verma et al., 2024). In Algeria, climate change, urban expansion, and land encroachment into natural floodplains have amplified flood risks (Falter et al., 2014), reinforcing the need for reliable predictive models.

Several studies have demonstrated that catchment surface area strongly influences both flood volume and peak discharge (Benkhaled et al., 2013; Abdeddaim and Benkhaled, 2016; Natarajan and Radhakrishnan, 2019; Zhang et al., 2014). Additionally, the slope of the natural terrain is a key driver of flow dynamics in open-channel conditions (Riahi et al., 2020; Oberauer and Lehmann, 2023), with numerous investigations (Ferro, 2018; Recking, 2006) showing a positive correlation between terrain slope and discharge rates. Other researchers (Golubstov, 1969; Bjerklie et al., 2003, 2005) have formulated discharge equations using parameters such as flow velocity (U), slope (S), and hydraulic radius (R_h), often employing the Chezy equation or multiple regression methods (Riggs, 1976; Dingman and Sharma, 1997). The physical properties of water, such as viscosity and density, also play a role in determining maximum flow (Mavis et al., 1937).

In the absence of field data, rainfall-runoff models and empirical formulas are commonly used to estimate flood discharges (Abdi and Meddi, 2015; Mehta and Yadav, 2024; Atallah et al., 2024). These models often rely on climatic or rainfall information, which is typically more accessible but may be incomplete or inconsistent (Mehta et al., 2023;

McMillan et al., 2011). Empirical methods for estimating Q_{max} can be broadly categorized into three main groups (Morlat, 1951):

1. Historical flood-based methods, which rely on past flood records and apply safety factors. These methods are effective in regions with long hydrological records, sometimes spanning centuries (Neal et al., 2012; Diederen et al., 2019).

2. Empirical formulas based on watershed characteristics, such as area, rainfall, and return period. These formulas are widely used in data-scarce regions (Sahli et al., 2024) and are often calibrated on specific regional datasets (Sari Ahmed, 2002; Keef et al., 2012). Subcategories within this group include formulas that: rely solely on catchment area (Feyera et al., 2010), incorporate rainfall intensity or mean annual rainfall (Kherde et al., 2024; Aqnouy et al., 2018; Jin et al., 2015) and account for flood frequency, expressed as $1/T_r$, where T_r is the return period (Raiford et al., 2007).

3. Envelope curve methods, which use graphical analysis of historical peak discharges from multiple basins to establish upper bounds on flow magnitudes (Castellarin, 2007; Pramanik et al., 2010).

One of the earliest statistical methods was introduced by Fuller (1913), who related Q_{max} to return period T_r, laying the foundation for modern frequency analysis (Réméniéras, 1986).

While each of these approaches offers valuable insights, most require careful regional calibration and are not easily transferable to areas with different topographic or climatic conditions (McCuen, 1998; Addor et al., 2020).

This study introduces a new model for estimating peak discharge Q_{max} in Algerian wadis, combining dimensional analysis with statistical modeling. By integrating key physical variables catchment area, rainfall intensity, and slope. The model offers a simple yet robust tool tailored to semi-arid and data-scarce environments. It improves local flood prediction accuracy and supports hydraulic infrastructure planning through a regionally calibrated and physically consistent approach.

MATERIAL AND METHODS

Study area

Algeria, located in North Africa, covers a vast area of approximately 2,380,000 km^2, with more than 80% of its territory classified as desert. The country stretches over 2,000 km from north to south and nearly 1,800 km from east to west, encompassing a wide range of climatic conditions from Mediterranean in the north to arid and hyper-arid in the south.

Algeria is considered one of the most vulnerable regions to climate change in the mediterranean basin (Mrad et al., 2018). Understanding the spatial distribution of precipitation (Fig. 1) over the past four decades is crucial for planning and managing infrastructure, assessing flood and drought risks, supporting agriculture, and ensuring sustainable water resource management. Studies indicate a consistent spatial pattern of extreme rainfall across Algeria: the northern regions receive the highest rainfall, followed by gradually decreasing intensities in the northeast, northwest, and central areas. In contrast, the southern part of the country typically experiences lower levels of extreme rainfall, with a few exceptions in regions such as Adrar (Salhi et al., 2024). This distribution is influenced by a combination of topography, hydrological networks, prevailing winds, and ongoing climatic shifts.

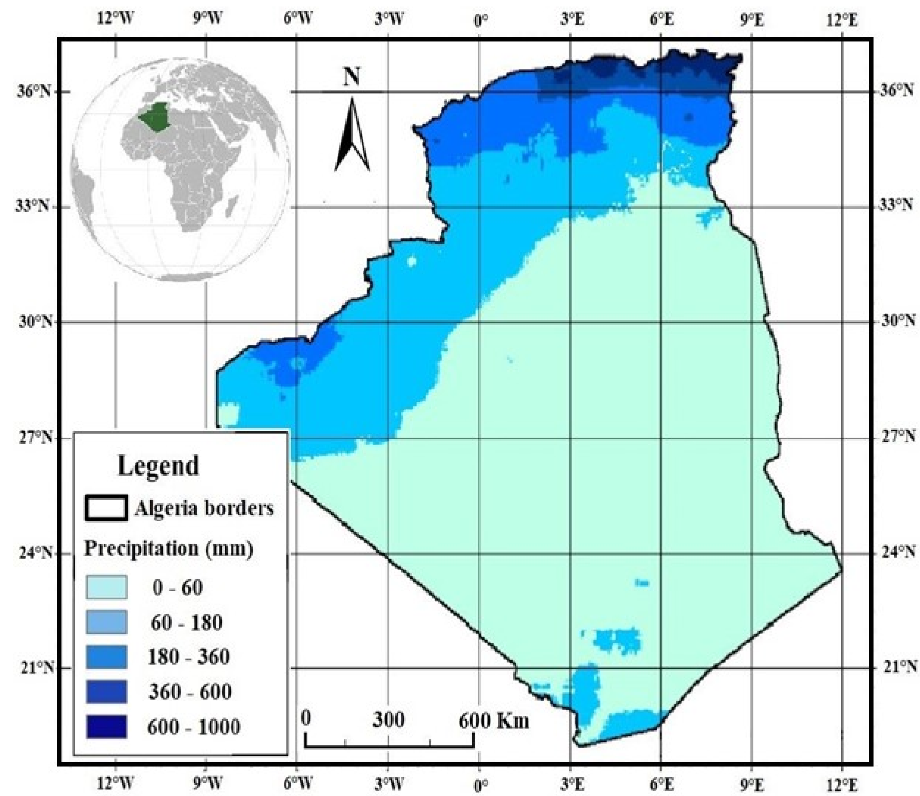


Figure 1: Precipitation distribution across Algeria

Dimensional analysis for maximum discharge modeling

Dimensional analysis was employed to formulate a model for predicting maximum discharge Q_{max} in Algerian wadis, following the methodology proposed by Barenblatt (1987). The selection of variables is guided by a qualitative understanding of hydrological processes and prior research (Fox et al., 2003). For open-channel flow, especially under flood conditions, Q_{max} is influenced by several key parameters, including:

ρ: fluid density (kg/m^3);

A: catchment area (km^2);

L: length of the main wadi (km);

S: average slope of the main wadi (m/m);

T_r: return period (years);

$P_{tc\ (P\%)}$: rainfall intensity corresponding to a specified return period (mm).

Thus, the general functional form of the model can be expressed as follows:

$$Q_{max} = f(\rho, A, L, S, T_r, P_{tc,(P\%)}) \tag{1}$$

Applying the Buckingham theorem and simplifying the dimensional relationship yields the following reduced empirical form:

$$Q_{\max P\%} = f(A, S, P_{tc,(P\%)}) \tag{2}$$

This formulation forms the basis for statistical modeling in the next step.

Estimation of rainfall intensity (P_{tc})

Rainfall intensity P_{tc}, is a key parameter in estimating the maximum discharge Q_{max}. It is calculated based on the daily maximum precipitation corresponding to a specific non-exceedance probability ($P_{j\ max\ (P\%)}$) and the concentration time (T_c), using the empirical formula proposed by Montana [Eq. (3)], which is widely adopted in the Algerian context (Raiford et al., 2007):

$$P_{tc} = P_{j\ \max\ p\,(\%)} \left(\frac{T_c}{24} \right)^b \tag{3}$$

where:

$P_{j\ max\ (P\%)}$: daily maximum precipitation (in mm) for a given non-exceedance frequency;

T_c: concentration time (in hours);

b: climatic coefficient, typically set to 0.32 in Algeria (Houichi, 2017).

In this study, a return period of 100 years is adopted, in accordance with standard practices for flood protection infrastructure design (McCuen, 1998). The extreme precipitation values ($P_{j\ max}$) are estimated using the Gumbel distribution, which is particularly well suited for modeling hydrological extremes (Heffernan and Tawn, 2004).

The concentration time T_c, represents the time required for runoff from the most distant point of the watershed to reach the outlet. Various methods have been proposed in the literature to estimate it. In this study, the Giandotti formula, Eq. (4), is used due to its simplicity and reliability in Mediterranean environments (Sari Ahmed, 2002):

$$T_c = \frac{4\sqrt{A} + 1.5\,L}{0.8\sqrt{\Delta h}} \tag{4}$$

Where A is the catchment area (km^2), L is the main channel length (km), and Δh is the elevation difference (m).

This approach provides a consistent evaluation of rainfall intensity, considering both extreme precipitation conditions and the morphological characteristics of the basin, thus supporting a more accurate estimation of Q_{max} in the modeling framework.

Data and statistical modeling approach

When analytical models are unavailable or too complex, statistical modeling offers a practical means to estimate values based on observed data (Yamazaki et al., 2011). The modeling process involves the following key stages: data collection, model selection, parameter estimation, predictive equation derivation, and performance evaluation using statistical metrics (Winsemius et al., 2013).

In hydrology, statistical modeling is commonly used to explore relationships between variables such as catchment area, rainfall intensity, slope, and discharge. Correlation analyses and scatter plots such as (Q_{max}, A), (Q_{max}, P_{tc}) and (Q_{max}, S) are used to reveal dependencies. The correlation coefficient (R) is calculated to assess the strength of these relationships. In this study, Q_{max} is treated as the dependent variable, while A, P_{tc}, and S are independent predictors.

Data used in this research were obtained from the Algeria's National Agency for Hydraulic Resources (NAHR) and include 60 gauged wadis (N) distributed across various Algerian regions. Table 1 presents the statistical properties of the dataset, including the range, average, standard deviation (σ), and coefficient of variation (C_V) for each parameter.

Table 1: Statistical summary of variables used in modeling

Variable	N	Average	σ	C_V	Range
Q_{max} (m^3/s)	60	1827	2829	1.55	10-12700
A (km^2)	60	1101	1865	1.69	1.02-8735
L (km)	60	51	55	1.09	0.85-236
H_{max} (m)	60	1469	441	0.30	520-2350
H_{min} (m)	60	897	336	0.37	167-1980
P_{tc} (mm)	60	60	20.1	0.33	25-116
S (m/m)	60	0.021	0.015	0.74	0.001-0.068

Discharge data was obtained from hydrometric stations installed along the wadis, which measured water levels and discharge over a period ranging from 1976 to 2018. Each Q_{max} value corresponds to the peak discharge recorded at a given station during the observation period. Fig. 2 illustrates the spatial distribution of these stations across the study area.

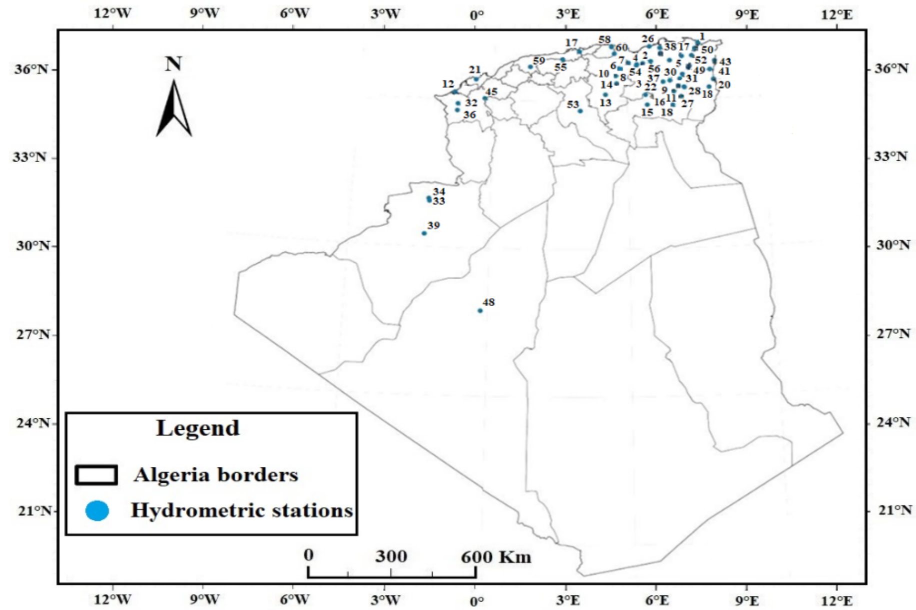


Figure 2: Spatial distribution of hydrometric stations

RESULTATS AND DISCUSSION

The purpose of this study is to investigate how physical watershed characteristics influence the maximum discharge Q_{max} in Algerian wadis. The results reveal strong statistical correlations between Q_{max} and three key variables: catchment area A, rainfall intensity P_{tc}, and average slope S.

Influence of catchment area on maximum discharge

Fig. 3 highlights the relationship between catchment area A and maximum discharge Q_{max}, with a segmentation between small (1-300 km^2) and large basins (301-9,000 km^2). In both cases, a clear positive trend is observed: Q_{max} increases with A, with high correlation coefficients ($R = 0.87$ for small basins and $R = 0.97$ for large ones), confirming the well-established relationship between drainage area and flood magnitude (Diederen et al., 2019; Harman et al., 2009; Feyera et al., 2010).

This high correlation, particularly pronounced in large basins, underscores the relevance of integrating A as a primary predictor in peak discharge models. The methodological choice to distinguish between basin size classes enhances the clarity of results and highlights distinct hydrological behaviors.

However, for smaller basins, the slightly greater dispersion suggests a stronger influence of local factors such as land use, slope, or geology, which make these systems more sensitive to the spatial variability of rainfall (Blöschl et al., 2013; Norbiato et al., 2009).

Furthermore, although the relationship between A and Q_{max} is robust, it may become nonlinear in semi-arid environments, where precipitation irregularity and specific hydrogeological conditions can significantly affect hydrological response (Merz and Blöschl, 2009). Therefore, while catchment area is a reliable predictor of maximum discharge particularly in large basins its use alone in small basins may require the integration of additional variables to improve prediction accuracy.

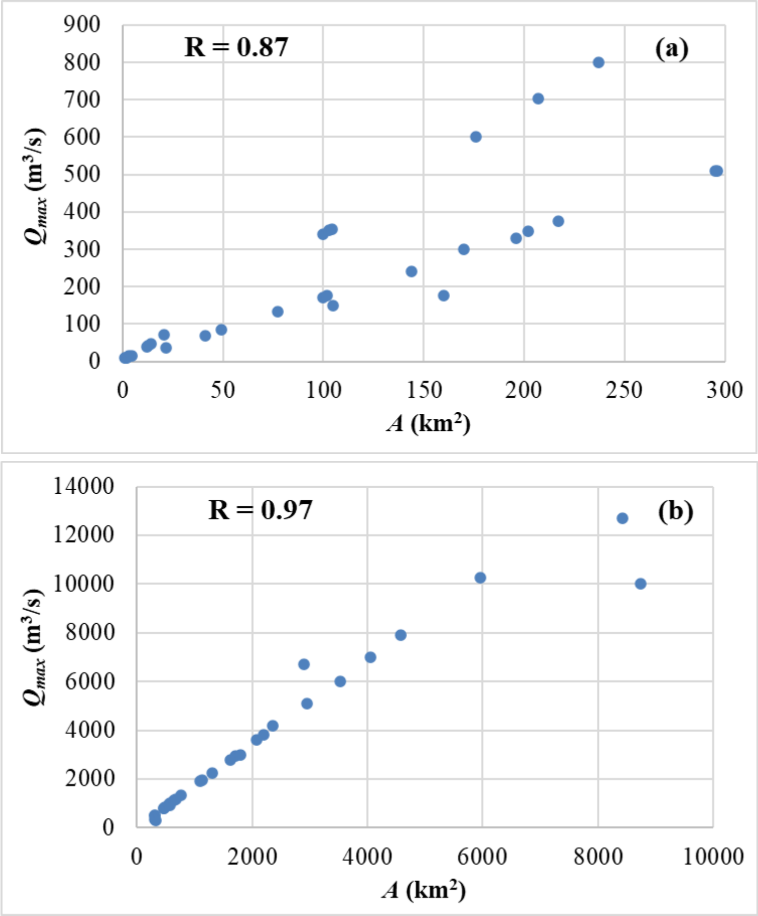


Figure 3: Relationship between catchment area (A) and maximum discharge (Q_{max}). (a) small basins (1-300 km^2), (b) large basins (301-9,000 km^2)

Rainfall intensity as a predictor of Q_{max}

Rainfall intensity P_{tc}, calculated from daily maximum precipitation values $P_{j\ max\ (P\%)}$ and concentration time T_c using the Montana formula recognized for its suitability in Algerian climatic conditions (Raiford et al., 2007) represents a key hydrological factor in flood estimation.

Numerous studies have confirmed the relevance of this variable for modeling peak discharge, including those by Heffernan and Tawn (2004), Falcone et al. (2010), and McMillan et al. (2011), and Baudhanwala et al. (2024), all of which incorporate rainfall intensity in empirical or semi-distributed hydrological models. In this context, the present study follows a scientifically established approach by using P_{tc} as one of the main explanatory variables.

Fig. 4 illustrates the relationship between P_{tc} and Q_{max} for the 60 analyzed catchments. Although the data exhibit more dispersion than the area Q_{max} relationship, the correlation remains high (R = 0.85), indicating a clear positive trend. This variability may be attributed to local factors such as land cover, surface roughness, slope, or soil saturation, all of which influence runoff response even under similar rainfall intensities (Blöschl et al., 2013; Norbiato et al., 2009).

Therefore, while P_{tc} is generally a reliable predictor, its explanatory capacity may be partially limited in heterogeneous environments due to its sensitivity to local hydrological conditions. Nonetheless, its integration into empirical Q_{max} models is justified, particularly in semi-arid regions where rainfall data are more readily available than discharge measurements.

These findings are consistent with those of Aziz et al., (2020) and Sampath et al., (2015), who demonstrated that models incorporating rainfall intensity as a central input significantly enhance flood prediction accuracy, especially for extreme events.

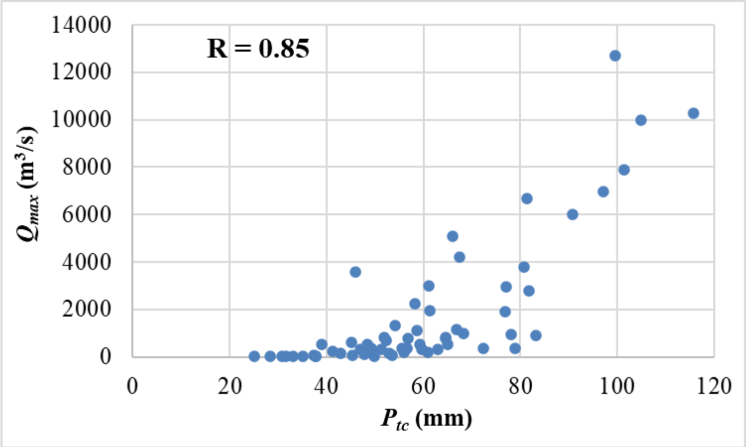


Figure 4: Relationship between rainfall intensity (P_{tc}) and maximum discharge (Q_{max})

Role of slope in flow dynamics

The average slope S of the main channel plays a fundamental role in the analysis of flood dynamics under open-channel flow conditions, as it represents the primary driving force behind gravitational runoff (Recking et al., 2008).

Fig. 5 illustrates the relationship between the slope of the main wadi and Q_{max}, showing a correlation coefficient of R = 0.71. This indicates a significant and physically consistent link between increasing slope and intensified flood peaks. Steeper slopes promote faster surface runoff, reduce concentration time, and enhance sediment mobilization, leading to a more rapid and pronounced hydrological response.

These findings are consistent with previous studies by Ferro (2018), Ferro and Porto (2018, 2019), and Recking et al., (2008), who highlighted the crucial role of slope in flood generation and sediment transport in small watersheds. However, the observed relationship between S and Q_{max} also exhibits a certain degree of dispersion, which may be attributed to the variability of local conditions such as land use, infiltration capacity, and temporary water storage. Moreover, relying on a single average slope value for the entire basin may oversimplify the complex internal morphology, neglecting the impact of secondary slopes or sub-catchment heterogeneity on flow response.

In anthropized or regulated environments, the influence of slope may be diminished or masked by other factors such as hydraulic infrastructure or soil sealing (Fletcher et al., 2013; Brath et al., 2006). Therefore, while slope may not be the dominant factor in all contexts, its inclusion alongside other variables such as A and P_{tc} provides a more comprehensive understanding of flood generation mechanisms, particularly in steep or topographically complex basins.

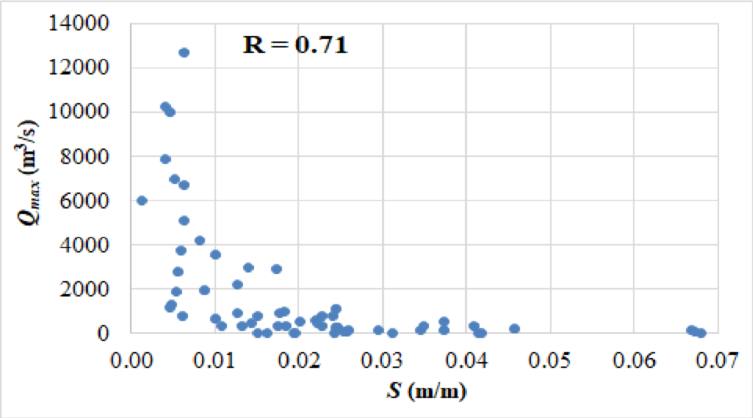


Figure 5: Relationship between channel slope (S) and maximum discharge (Q_{max})

The joint analysis of the three variables A, P_{tc}, and S confirms their key role in estimating the maximum discharge Q_{max} of Algerian wadis.

Catchment area emerges as the most influential factor, reflecting the watershed's water collection capacity, followed by rainfall intensity, which captures the magnitude of precipitation events, and finally slope, which governs runoff velocity. While each variable has limitations P_{tc} being sensitive to local variability and S affected by morphological complexity their combined use offers a more accurate and physically meaningful representation of runoff dynamics in semi-arid regions. Integrating these three parameters into a dimensionally derived empirical model strengthens both the robustness and transferability of the approach for application in similar hydrological settings.

Model calibration and equation development

The dataset from Table 1 was randomly divided into two equal parts: one for model calibration (Table 2) and the other for validation (Table 3). Using watershed parameters derived through dimensional analysis (Appendix 2) and statistical modeling of the calibration data, we developed an empirical model tailored to Algerian wadis, it is expressed by the following relationship:

$$Q_{\max p(\%)} = 1.6\,A - 1.6\,P_{tc\;p(\%)} - 4590\,S + 263 \tag{5}$$

The resulting Eq. (5) demonstrates that Q_{max} is most sensitive to catchment area A, moderately influenced by rainfall intensity P_{tc}, and less affected by average slope S, although the latter becomes more significant in steep basins. This sensitivity ranking aligns with established hydrological understanding and supports findings from previous studies (Harman et al., 2009; McMillan et al., 2011).

Table 2: Statistical summary of variables used in model calibration

Variable	N	Average	σ	C_V	Range
Q_{max} (m^3/s)	30	538	733.4	1.36	10-3589
A (km^2)	30	291	429.2	1.47	1.02-2080
L (km)	30	24.7	24.8	1.00	0.85-112
H_{max} (m)	30	1298	470	0.36	520-2326
H_{min} (m)	30	862	367	0.43	167-1980
P_{tc} (mm)	30	50.3	15.2	0.30	25-83.30
S (m/m)	30	0.025	0.016	0.65	0.004-0.068

A key strength of the model lies in its calibration based on data specific to Algerian hydrological and climatic conditions, unlike many existing empirical formulas developed in non-arid contexts. The model is also dimensionally consistent and grounded in physically interpretable variables, enhancing its robustness and transferability within the region. However, it does not account for anthropogenic factors or land cover variability, which may affect runoff in certain basins. Furthermore, the use of average slope may overlook intra-basin morphological complexity. Despite these limitations, the model offers a reliable and regionally adapted tool for estimating maximum discharge in semi-arid north African environments.

Model validation and error analysis

The validation dataset (Table 3), comprising 30 watersheds not used during calibration, was employed to assess the predictive performance of Eq. (5) for estimating maximum discharge Q_{max} in Algerian wadis.

Table 3: Statistical summary of variables used in model validation

Variable	N	Average	σ	C_V	Range
Q_{max} (m^3/s)	30	3119	3483.5	1.36	10-3589
A (km^2)	30	1911	2337	1.47	1.02-2080
L (km)	30	76.4	63.9	1.00	0.85-112
H_{max} (m)	30	1639	331	0.36	520-2326
H_{min} (m)	30	932	298	0.43	167-1980
P_{tc} (mm)	30	69.9	19.9	0.30	25-83.30
S (m/m)	30	0.014	0.82	0.65	0.004-0.068

As illustrated in Fig. 6, the comparison between observed discharges Q_m and model estimates Q_c reveals a strong agreement, with a high correlation coefficient (R = 0.97), indicating excellent model performance and consistency with real measurements.

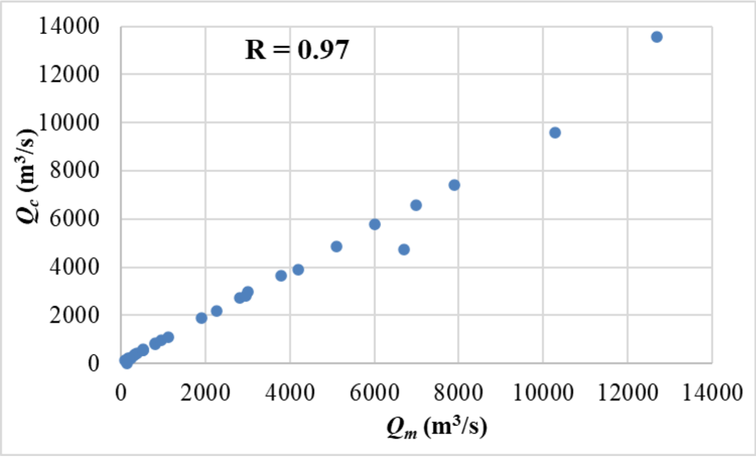
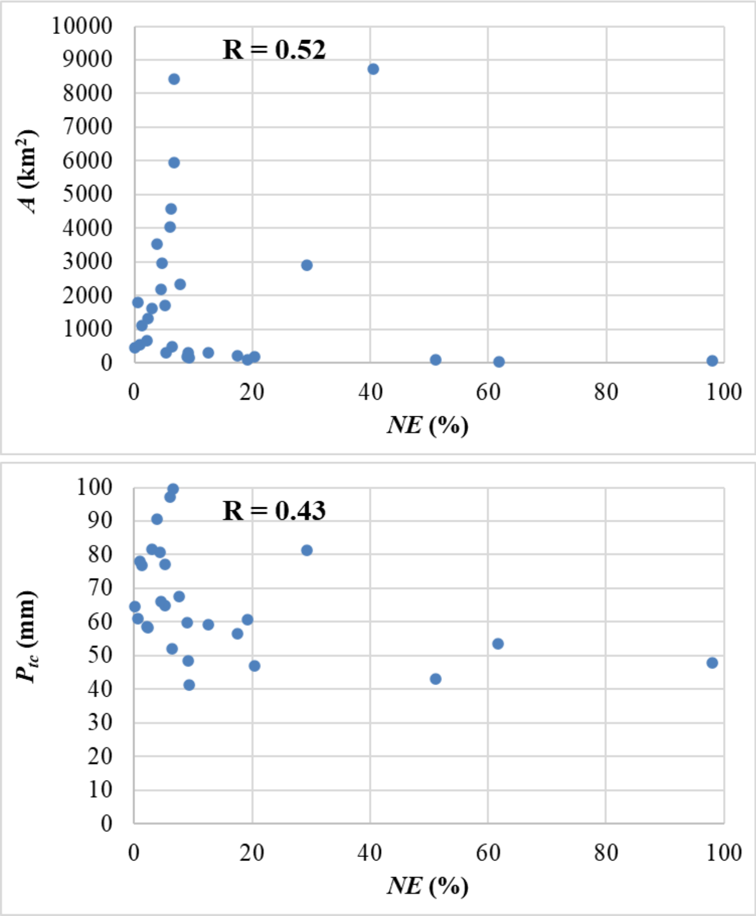


Figure 6: Comparison of observed (Q_m) and calculated (Q_c) maximum discharge values

To quantify relative discrepancies, the normalized error (*NE*) was calculated for each watershed using the following relationship:

$$NE = 100 \times \frac{\left| Q_c - Q_m \right|}{Q_m} \tag{6}$$

The analysis shows that catchment area significantly influences both Q_{max} and *NE* values (Figs. 3 and 7), with larger basins showing lower errors and more accurate predictions supporting previous findings by Natarajan and Radhakrishnan (2019) and Zhang et al., (2014), who demonstrated the dominant role of watershed size in flood volume generation.



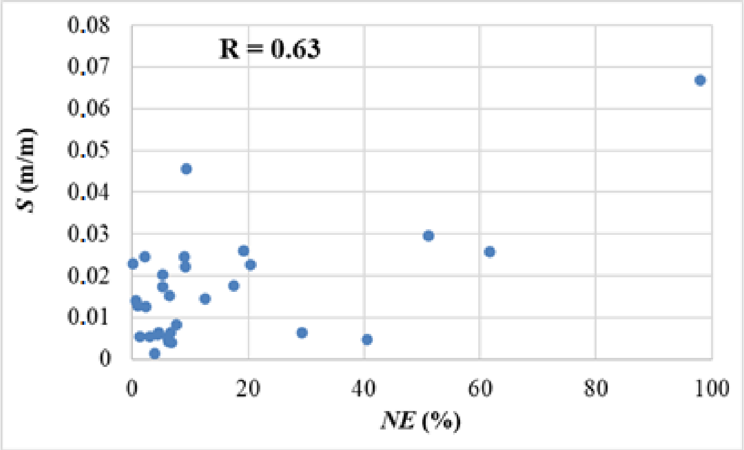


Figure 7: Normalized error (*NE*) in relation to *A*, P_{tc} and *S*

In contrast, rainfall intensity P_{tc} appears to have a lesser impact on prediction errors (Fig. 7), possibly due to its variable influence under semi-arid conditions. Meanwhile, the average slope *S* of the main channel (Fig. 7) emerges as a critical parameter, especially in steep catchments, where it strongly affects runoff dynamics consistent with studies by Di Stefano et al., (2019) and Recking et al., (2008). The use of a simple average slope value, however, may limit precision in morphologically complex basins, and the model does not explicitly incorporate land use or soil infiltration effects, which can be influential in smaller or anthropized catchments. Nevertheless, the high correlation, reduced prediction errors, and alignment with established hydrological behavior confirm the validity and relevance of the proposed model for estimating Q_{max} in semi-arid Algerian environments.

Model comparison with existing formulas

To assess the predictive performance of the proposed model, a comparative analysis was conducted using four widely applied empirical formulas in Algeria: Giandotti, Mallet-Gauthier, Sokolovsky, and Turazza. Using the validation dataset from Table 3, the mean normalized error (*MNE*) was computed for each model, as summarized in Table 4.

Table 4: Comparison of mean normalized error (*MNE*) between Models

Model	Formula	σ	*MNE* (%)
Proposed model	$Q_{\max p(\%)} = 1.6A - 1.6P_{tc\,p(\%)} - 4590S + 263$	0.22	**15.0**
Giandotti	$Q_{\max} = 170A\dfrac{(H_{mean} - H_{min})^{0.5}}{4A^{0.5} + 1.5L}P_{tc}$	0.56	57.7
Mallet-Gauthier	$Q_{\max} = 2k\log(1+\beta P_A)\dfrac{A}{\sqrt{L}}\sqrt{1+4\log T - \log A}$	0.68	70.9
Sokolovsky	$Q_{\max} = 0.28\dfrac{(P_{tc} - H_0)}{T_c}\alpha f A$	0.24	61.4
Turazza	$Q_{\max} = \dfrac{\alpha A P_{tc}}{3.6T_c}$	0.24	60.5

Where:

K: a constant that depends on the characteristics of the watershed and is set to 1.2;

β: a regional coefficient set to 20;

P_A: represents the average annual rainfall of the watershed (m);

T: is a period of no return (year);

H_0: is the initial loss of water, which is 7 mm in Algeria;

α: the runoff coefficient for a major flood, set to 0.9;

f: is the flood shape coefficient, set to 1.04;

σ: the standard deviation for the thirty errors.

The results demonstrate the superior accuracy and stability of the proposed model, which achieved an *MNE* of 15%, significantly lower than those obtained with the traditional formulas Giandotti (57.7%), Mallet-Gauthier (70.9%), Sokolovsky (61.4%), and Turazza (60.5%). In addition, the proposed model also showed the lowest standard deviation of error ($\sigma = 0.22$), indicating more consistent predictive behavior across a wide variety of watershed conditions.

In contrast, formulas such as Mallet-Gauthier exhibited not only the highest error (*MNE* = 70.9%) but also a tendency to systematically overestimate peak discharge, which could pose significant design and safety concerns for flood protection infrastructure.

The Sokolovsky and Turazza models, although slightly more stable ($\sigma = 0.24$), still underperformed in terms of overall accuracy. These results reinforce the importance of using region-specific models tailored to local hydrological behavior rather than relying on generalized equations developed under different climatic and geomorphological conditions (McCuen, 1998; Bouchard et al., 2004).

The consistent performance of the proposed model confirms its reliability, reduced uncertainty, and improved suitability for practical flood forecasting and infrastructure planning in Algerian wadis.

To further highlight the superiority of the proposed model, the percentage of predictions falling within specific error margins (±10%, ±20%, and ±30%) was calculated for each model, as shown in Table 5.

Table 5: Percentage of predictions within error margins

Model	±10%	±20%	±30%
Proposed model	66.6 %	76.6 %	83.3 %
Giandotti	13.3 %	40 %	40 %
Mallet-Gauthier	6.7 %	13.3 %	26.7 %
Sokolovsky	3.3 %	10 %	13.3 %
Turazza	3.3 %	6.7 %	16.7 %

The results reveal that the proposed model achieved exceptionally high accuracy, with 66.6% of the predictions falling within ±10% of the observed values, and up to 83.3% within ±30%. In stark contrast, the performance of the traditional models was significantly lower, with the Giandotti and Mallet-Gauthier formulas showing only 13.3% and 6.67% of predictions within ±10%, respectively, and the Sokolovsky and Turazza models performing even worse each with only 3.3% of predictions within this narrow range.

Notably, the Sokolovsky model showed poor precision overall, with more than 80% of its predictions exceeding the ±30% error threshold, indicating a lack of robustness and calibration for Algerian hydrological conditions. These results underscore not only the accuracy but also the consistency of the proposed equation across diverse catchment types. Such stability is critical for operational hydrology, particularly in semi-arid regions where flood events are often abrupt and highly variable. Compared to generalist formulas developed in temperate climates, the performance of the proposed model reflects the benefit of regional calibration and the inclusion of physically relevant parameters (A, P_{tc} and S) tailored to the Algerian context. As emphasized in previous studies (McMillan et al., 2011; Beven, 1984), model reliability and predictive precision are essential for supporting effective water resource planning and flood mitigation.

The study could be extended by incorporating remote sensing data, land use classifications, and soil properties into the model. Future work may also integrate climate change projections and perform seasonal analysis to improve temporal applicability. Limitations include the reliance on daily rainfall data and the assumption of spatial uniformity in precipitation and slope.

CONCLUSION

This study presents a robust and regionally calibrated model for estimating the maximum discharge Q_{max} in Algerian wadis, addressing the critical challenge of flood prediction in data-scarce environments. By applying dimensional analysis, we identified the most influential watershed parameters catchment area, rainfall intensity, and main channel slope and integrated them into a compact empirical formulation.

The resulting model, expressed in Eq. (5), demonstrated excellent predictive capability, achieving a correlation coefficient of R = 0.97 and a mean normalized error of 15% on the validation data set. Compared to widely used empirical formulas (Giandotti, Mallet-Gauthier, Sokolovsky, Turazza), the proposed model showed superior accuracy, particularly for medium to large catchments, where over 66.6% of predictions fell within a ±10% error margin.

This performance highlights the strength of combining physically meaningful variables through dimensional analysis with statistical calibration using local data. The model's simplicity and effectiveness make it a practical tool for hydrologists and engineers involved in flood risk management and infrastructure design in Algeria and other semi-arid regions with similar physiographic conditions.

Future work could involve: (a) incorporating additional variables such as land use, soil type, and rainfall duration; (b) applying the model to other North African basins; (c) testing its adaptability under climate change scenarios.

Ultimately, the proposed approach contributes to bridging the gap between theoretical hydrology and practical flood estimation in regions where conventional methods fall short due to data limitations.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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