MODELING FLOOD HYDROGRAPHS FOR UNGAUGED RIVERS: APPLICATION TO THE ALGERIAN CONTEXT

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Flood forecasting in ungauged basins remains a major challenge in Mediterranean regions, particularly in Algeria, where short and intense rainfall events frequently generate flash floods. This study presents the development and validation of an analytical synthetic unit hydrograph model specifically adapted to ungauged watersheds.

The proposed approach is based on a modified lognormal function (Galton's law), calibrated using data from 53 hydrometric stations and 83-unit flood hydrographs distributed across Algeria.

Three key parameters govern the model: peak discharge (Qp), time to peak (tp), and an adjustable shape coefficient (k), all empirically related to the physiographic characteristics of the basins.

Validation results show a strong agreement between simulated and observed hydrographs, with correlation coefficients ranging from 0.65 to 0.85, and low relative errors in peak flow.

The proposed model provides a simple, flexible, and operational tool for estimating flood hydrographs in data-scarce Mediterranean catchments, offering valuable support for flood management, hydraulic structure design, and water resources planning in Algeria.

Keywords: Flood hydrograph, model, analytical formulation, ungauged River, Algeria.

1. Introduction

Flood forecasting and management are critical challenges in Mediterranean regions, particularly in Algeria, where episodes of intense and short-duration rainfall often cause sudden and devastating floods.

Understanding and modeling these hydrological responses are essential for the design of flood protection infrastructure, including levees, culverts, bridges, and

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dam spillways, as well as for risk mitigation and real-time flood management [1, 2].

In gauged catchments, flood hydrographs can be directly derived from measured discharge data. However, most Algerian rivers remain ungauged, due to the limited spatial coverage of hydrometric stations and the scarcity of long-term datasets. Under these conditions, the Unit Hydrograph (UH) approach proposed by Sherman (1932) remains a valuable conceptual tool, linking rainfall inputs to runoff outputs under the assumptions of linearity and time invariance.

Over the decades, several synthetic unit hydrograph (SUH) models have been developed to overcome data limitations: empirical methods [3,4,5], standardized approaches [6, 7], and analytical formulations [8,9,10,11].

More recent developments, such as physically-based distributed models [12, 13,14], have improved hydrological representation but remain difficult to apply in data-scarce regions.

Despite these advances, few models are specifically adapted to the Mediterranean semi-arid context, where rainfall events are highly variable in space and time, and hydrological responses are rapid and asymmetric [15]. This highlights the need for a simple and flexible analytical model that can reproduce the shape of observed flood hydrographs using a minimal set of parameters.

The present study addresses this gap by developing a synthetic unit hydrograph model based on a modified lognormal distribution (Galton's law).

The model is calibrated using historical data from 53 hydrometric stations across Algeria and validated on multiple basins representing different climatic and geomorphological conditions. Its objective is to provide a reliable and operational method for simulating flood hydrographs in ungauged Mediterranean basins, while ensuring simplicity, adaptability, and physical consistency.

2. Material and Methods

2.1 Data and selection criteria

The methodological approach adopted in this study is based on the analysis of hydrometric data collected at 53 measurement stations, evenly distributed across the entire Algerian territory (Fig. 1).

The observation period varies between 3 and 10 years depending on data availability. The selected hydrological events are flood hydrographs generated by unitary rainfalls meeting several criteria: sufficient rainfall intensity, homogeneous spatial distribution over the basin, and an isolated rainfall sequence to avoid cumulative influences.

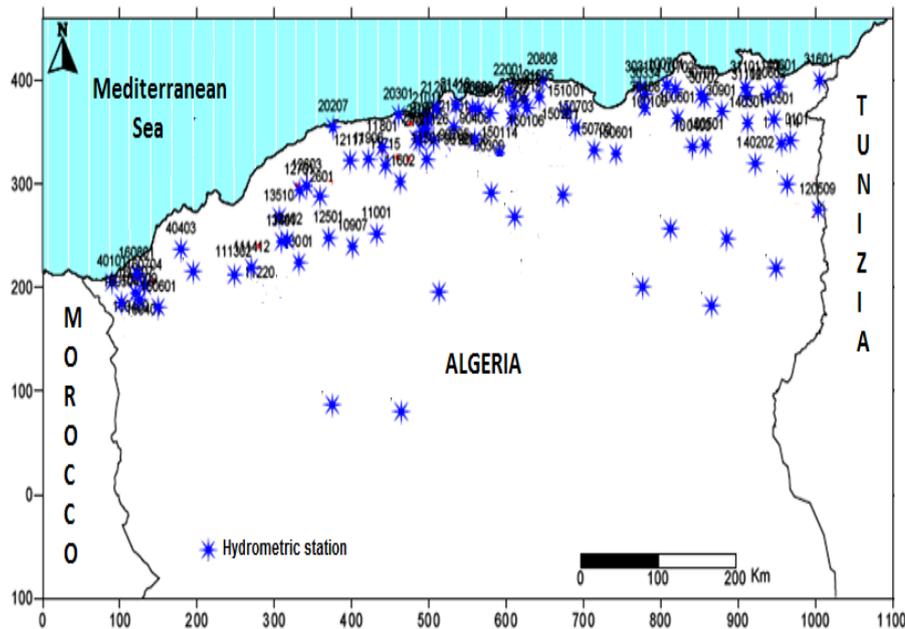The distorted or complex flood hydrograms that do not meet these criteria have not been retained.

Fig. 1. Location of hydrometric stations

2.2 Unit hydrograph theory

The establishment of a unit hydrograph is based on the classical theory of the unit hydrograph (UH), introduced by Sherman [16, 17]. This theory is based on the following assumptions: a) the net rainfall is assumed to be uniform in space and constant in time; (b) the characteristics of the (UH) are stationary over time; (c) the response of the basin is linear: for the same duration of rain, the runoff is proportional to the volume; (d) the unit hydrogram HU reflects the physical properties of the watershed.

Thus, the theory of the unit hydrograph proposed by Sherman allows for the construction of a hydrograph or an average distribution graph of surface runoff for a given basin and the application of this hydrogram to the same basin for other rainfalls of different intensities from that of the unit rainfall. Figure 2 illustrates, as an example, the unit hydrograph of the flood that occurred on March 3, 1975, on the Oued Allalah (Sidi Akkacha hydrometric station).
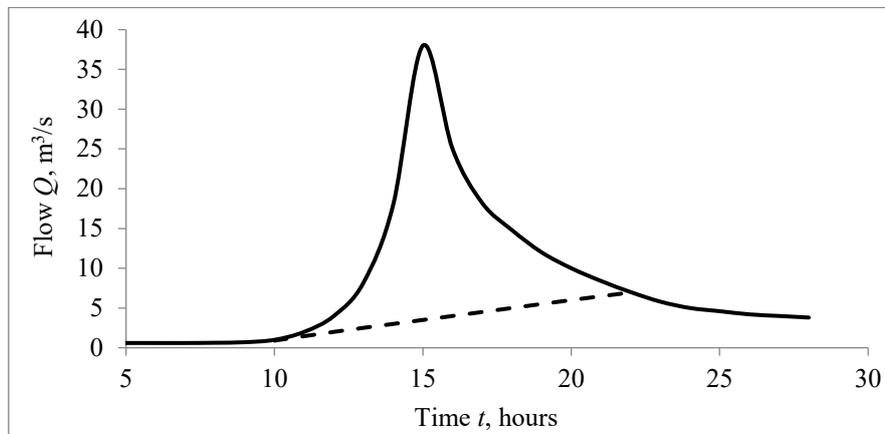
Fig. 2. Unit hydrograph of the flood of March 3, 1975 from Oued Allalah to Sidi Akkacha. The intersected line separates the surface flow from the underground flow

The ordinates of the runoff hydrograph, expressed as a percentage of the total runoff volume during the flood on March 3, 1975, are presented in Table 1.

Table 1

The ordinates (in % of the total runoff volume) of the distribution diagram of the unit hydrogram of the flood on 03/03/1975 at the Sidi Akkacha station (river Allalah).

Duration of the flood (hours)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
% of the total runoff volume	0	0.6	0.9	1.2	1.5	27.3	24.3	15.2	9.5	7.0	5.3	3.2	2.1	1.2	0.5	0

By superimposing the reduced unit hydrographs (UH) (Table. 2) and calculating the average or median of their ordinates, one can obtain a typical hydrogram, or standardized hydrograph, specific to the watershed of the Wadi Allala at Sidi Akkacha.

The dimensionless representation (the typical hydrograph) of the discharges of the Ahllalah wadi as a function of time, i.e. $Q(t)/Q_p$ as a function of t/t_p.

(Q(t)= flood discharge at time t, Q_p= peak flood discharge and t_p= flood rise time) are illustrated in Figure 3. This typical hydrograph can be used as a basis for generating specific desired hydrographs (project hydrographs, rare hydrographs etc.) for this same watercourse.

Table 2

Ordinate values (as a % of the total runoff volume) of the unit hydrographs of Oued Allalah observed at the Sidi Akkacha station.

| Date of flood	Duration (hour)																
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
20/01/78	0.0	0.0	0.0	0.1	0.5	3.4	28.0	21.3	19.0	10.3	6.7	4.1	3.0	1.8	1.3	0.0	0.0
08/01/77	0.0	0.0	0.6	1.2	5.1	12.3	27.5	16.7	11.9	9.3	6.2	3.1	2.7	1.9	1.5	0.0	0.0
19/12/78	0.0	0.0	0.6	0.8	5.1	14.7	22.4	20.1	17.6	6.8	4.2	3.1	1.7	1.4	1.1	0.3	0.0
16/04/74	0.0	0.0	0.3	0.3	0.5	1.0	26.0	25.0	19.4	8.7	6.7	5.0	3.3	2.0	0.9	0.4	0.1
03/03/75	0.0	0.0	0.6	0.9	1.2	1.5	27.3	24.3	15.2	9.5	7.0	5.3	3.2	2.1	1.2	0.5	0.0
26/12/78	0.0	0.0	0.0	0.9	0.9	8.0	22.1	19.2	19.2	9.2	7.0	4.7	3.5	2.6	2.1	0.5	0.0
24/01/77	0.0	0.0	0.0	4.2	4.8	14.1	22.0	17.2	12.1	10.9	5.9	3.7	2.3	1.7	0.8	0.7	0.0
Average	0.0	0.0	0.3	1.2	2.6	7.9	25.0	20.6	16.4	9.2	6.3	4.1	2.8	1.9	1.3	0.3	0.0
Médian	0.0	0.0	0.3	0.9	1.9	7.9	25.5	20.3	17.0	9.2	6.5	4.1	2.9	1.9	1.2	0.4	0.0
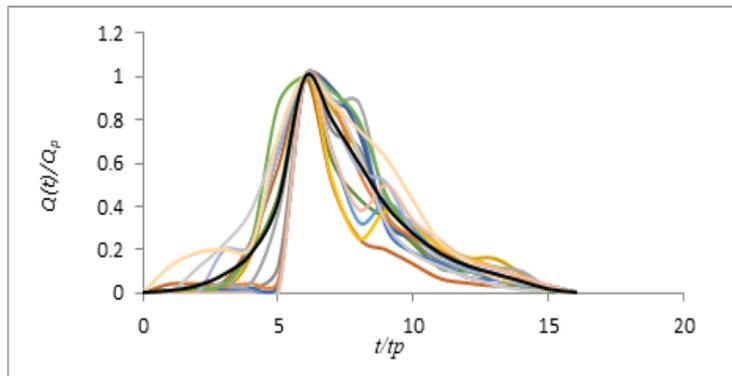
Fig. 3. Typical unit hydrograph (in bold) of Wadi Allalah at the Sidi Akkacha hydrometric station

In practice, the distribution diagrams differ slightly from one event to another, particularly at the beginning and end of the flood. The median diagram obtained then constitutes a typical representation of the hydrological behavior of the basin.

2.3 Construction of dimensionless typical hydrographs

Type hydrographs have been constructed for several watercourses using the dimensionless representation of flows [18]. This method allows for direct comparison of basins of different sizes and responses, and for the attenuation of

weakly distorted flood hydrographs from the same watershed. The typical hydrographs of the rivers in the West, East, and Central regions of Algeria were obtained using this approach (Figs. 4, 5, and 6).

Each flood hydrograph obtained for a watercourse is unique and reflects the physical characteristics of its watershed. This allows for the modeling of flood hydrographs for ungauged basins, for which no gauge data is available.
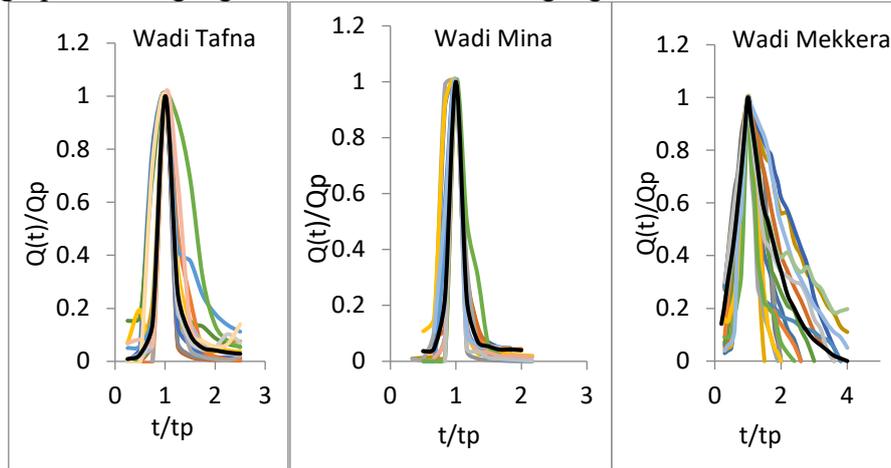

Fig. 4. Typical flood hydrographs of some wadis in eastern Algeria. The black curve represents the median hydrogram, $\frac{Q(t)}{Q_p}$ dimensionless flow, $\frac{t}{t_p}$ dimensionless time
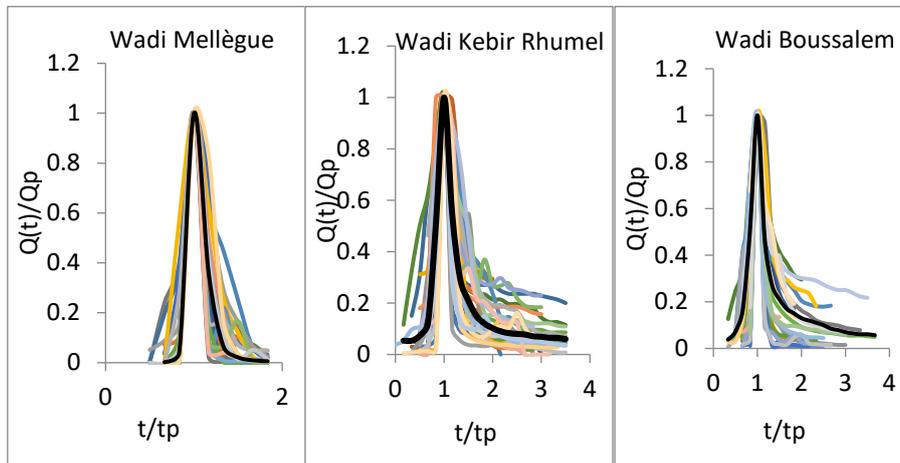

Fig. 5. Typical flood hydrographs of some wadis in eastern Algeria. The black curve represents the median hydrogram, $\frac{Q(t)}{Q_p}$ dimensionless flow, $\frac{t}{t_p}$ dimensionless time
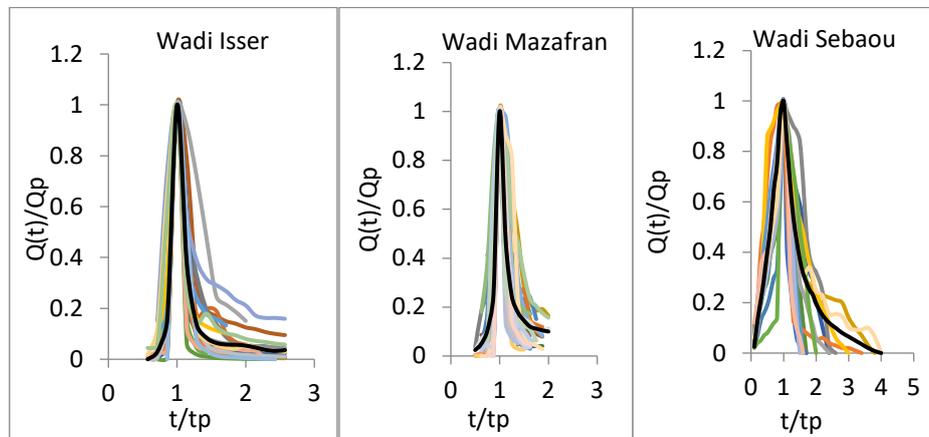
Fig. 6. Typical flood hydrographs of some wadis in central Algeria. The black curve represents the median hydrogram, $\frac{Q(t)}{Q_p}$ dimensionless flow, $\frac{t}{t_p}$ dimensionless time

2.4 Analytical form of the flood hydrograph

The analysis of obtained typical hydrographs reveals an asymmetric shape, with a rapid rise in water levels (ascending part) followed by a slower decline (descending part). This shape is characteristic of the hydrological response of a watershed to a rainfall event. Figures 3, 4, and 5 illustrate this asymmetric shape with the rising part rising quickly and the falling part spreading over a longer duration of time.

This behavior can be faithfully reproduced by a mathematical function representing the response of a watershed to effective rainfall. It is often a parametric function that simulates the rise, peak, and recession of the flow.

Among these functions, there is Nash's, which is established based on the Gamma statistical distribution law [19], and Alekseev's, based on the Goodrich statistical distribution law [20]. Other similar analytical formulations using different statistical laws have also been developed.

To simulate the flood hydrographs of Algeria's rivers, the Log-normal density function (or Galton's law) was chosen in accordance with the following properties: (a) asymmetric shape (bell-shaped curve stretched to the right), (b) taking only positive values, and (c) a very small number of parameters included in this law.

The density function of the Galton distribution is expressed by the relation (1) [21]:

$$f(x) = \frac{1}{u\sqrt{2\pi}\sigma} Exp\left[-\frac{1}{2}\left(\frac{Lnu}{\sigma}\right)^2\right]$$ (1)

Where:

$$u = \frac{(x - x_0)}{s} \; ;$$

x_0 - Position parameter;
s - Positive non-zero scale parameter;
σ - Positive non-zero shape parameter.

If we set $x_0 = 0$ and $s = 1$, we obtain $u = x$, expression (1) becomes:

$$f(x) = \begin{cases} 0 \, pour \, x \leq 0 \\ \dfrac{1}{x\sqrt{2\pi}\sigma} Exp\left[-\dfrac{1}{2}\left(\dfrac{Lnx}{\sigma}\right)^2\right] pour \, x > 0 \end{cases}$$ (2)

If we set:
$y = \dfrac{Q_p}{Q_t}, x = \dfrac{t}{t_p}$, and assign the values (0.25; 0.4 and 1) to the parameter σ,
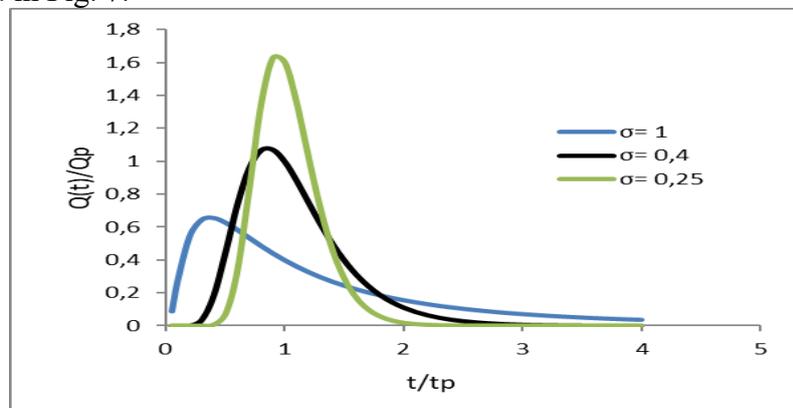we obtain the fictitious curves of dimensionless distribution of reduced flow rates, illustrated in Fig. 7.

Fig. 7. Fictitious distribution curves of reduced flow rates for different values of the shape parameter σ. $\frac{Q(t)}{Q_p}$ dimensionless flow, $\frac{t}{t_p}$ dimensionless time

The dimensionless distribution corresponding to σ = 0.4 was chosen as the model for a normalized dimensionless hydrograph. This theoretical basis will be used to develop a hydrograph with an analytical formulation, described further in the study.

3. Results and Discussions

3.1 Modeling of flood hydrographs of Algerian wadis

The analysis of hydrographs from various Algerian watersheds reveals a typical shape: a rapid rise in flow followed by a slower decline. This asymmetry is particularly characteristic of Mediterranean areas, where intense showers cause an almost immediate hydrological response.

This behavior is well reproduced by the density function of the Log-normal distribution, which presents an asymmetric curve, stretched to the right, and defined only for positive values.

However, the direct application of this standard law presents two major limitations:(a) the flood peak does not correspond to the required moment $t = t_p$; (b) the shape parameter $\sigma = 0.4$ is fixed, which limits the adaptability of the curve to the varied conditions of the studied basins.

To overcome these limitations, a modified formulation of the Log = normal law density was proposed, incorporating an adjustable parameter k.

This parameter allows for fixing the position of the peak flow at the defined moment t = tp and adapting the shape of the flow decay curve for different sizes of watersheds.

The proposed flood hydrograph model with an analytical formulation, which describes the evolution of the flow over time, is therefore as follows:

$$Q(t) = \begin{cases} 0 & pour \quad t \leq 0 \\[2em] Q_p \left(\dfrac{t}{t_p} \right)^{-0.1} Exp\left[-\dfrac{1}{2}\left(\dfrac{Ln\left(\dfrac{t}{t_p}\right)}{k} \right)^2 \right] & pour \quad t > 0 \end{cases} \tag{3}$$

Where:

$Q(t)$ = Instantaneous flood discharge (m^3/s); Q_p = Peak flood discharge (m^3/s); t_p = time of flood rise (hours or days);

t = time (hours or days);

k = coefficient characterizing the shape of the flood hydrogram, it is adjusted based on the physical characteristics of the watershed.

The adjustment coefficient (0.1) integrated into Eq. (3) was established based on a comparative analysis between the calculated and measured flood hydrographs.

Eq. (3) significantly improves the model's flexibility and its ability to represent different types of floods hydrographs of Algeria's rivers.

4. Determination of flood hydrograph parameters

4.1 Peak flood discharge

The peak flood discharge Qp is calculated using a formula derived from the isochrone method, which is considered an extension of the rational method:

$$Q_p(T) = u\, i(t,T)\, \alpha(T)\, A \qquad (4)$$

Where:
$Q_p\ (T)$ - peak flood discharge with a return period of T;
$i\ (T,\ t)$ - rainfall intensity for a duration equal to t and a return period of T;
$\alpha\ (T)$ - runoff coefficient with a return period of T;
A - watershed area;
u - unit conversion coefficient.

The values of the parameters in expression (4) are determined according to the geomorphological and climatic characteristics of the Algerian basins [22].

4.2 Flood rise time

The rise time of the flood tp varies depending on the size of the basin, from 4 to 24 hours for small basins (< 600 km²), from 12 hours to 5 days for intermediate basins (600 to 6000 km²), and up to 10 days for large basins (> 6000 km²).

The time of flood rise tp is generally related to the duration of the rain t and the time tlag, corresponding to the response delay of the watershed. According to the unit hydrograph theory, tp can be considered constant and equivalent to a lower limit value, often equated to the concentration time tc [23].

Moreover, when the return period of the flood increases, the response time of the basin tends to decrease, also approaching this limiting value. It is therefore accepted that for floods with a return period between 5 and 10 years, the following equality can be applied:

$$t_p \approx t_{lag} \approx t_c \qquad (5)$$

The concentration time tc is calculated using the empirical relationship adapted to the Algerian contexts [22]:

$$t_c = 1.7\left(\frac{A L}{\sqrt{I}}\right)^{0.19} \qquad (6)$$

Where: A- Watershed area (km^2);
L- length of the main watercourse (km);
I- average slope of the watercourse (%).
Eq. (6) allows for a robust estimation of the concentration time based on the physiographic characteristics of the watershed.

4.3 Shape coefficient of the flood hydrograph

The shape parameter k in expression (3) determines the appearance of the recession curve of the hydrograms. The extreme values of this parameter are 0.1 and 0.7. In the majority of cases, it is primarily between 0.2 and 0.6. Its significant variation, due to numerous factors (characteristics of the watershed, soil conditions, permeability, etc.), makes it difficult to model with a precise mathematical equation that includes all these factors.

The meticulous analysis of 83 standardized flood hydrographs generated in areas ranging from 50 to 7000 km² allowed for the identification of the limits of the coefficient k within several categories of basins (Table 3).

Table 3
Limit values of parameter k depending on the category of watersheds

Category of watersheds, A, km²	Parameter: k_{min} - k_{max}
Less than 600	0.20 - 0.35
600 - 3000	0.35 - 0.45
3000 - 6000	0.45 - 0.55
Upper than 6000	0.55 - 0.65

Taking into account the variations of the parameter k within each category of basins and its tendency to increase with basin area, a simple empirical relationship was developed for an approximate estimation of k as a function of area:

$$k = 0.0102(A+1)^{0.4} + 0.20 \tag{7}$$

Depending on the importance of the project, it seems that the best solution would be to adopt the lower limit (k_{min}) for small-scale projects (protection of agricultural perimeters, secondary roads against floods, etc.), the upper limit (k_{max}) for medium and large-scale projects (flood spillways of dams, bridges, culverts in highways, etc.).

4.4 Model validation and comparison with observed data

Model validation (3) was carried out by comparing the simulated hydrographs with those observed, the majority of which are independent of those used for calibration. Figs (8) and (9) illustrate these comparisons for hourly and daily floods respectively, in different climatic contexts.

The comparison between simulated and observed hydrographs demonstrates the robustness and reliability of the Galton-type synthetic model. The correlation coefficients obtained (0.65–0.85) indicate a strong agreement with observed data, consistent with the performance range of established synthetic

models such as the SCS unit hydrograph and Snyder's method (1938). In Snyder's formulation, deviations in peak discharge often reach up to 30%, whereas the proposed model maintains much lower relative errors. Similarly, studies by Pilgrim and Cordery (1993) [24] report correlation values between 0.65 and 0.80 under semi-arid conditions, which aligns closely with our results.
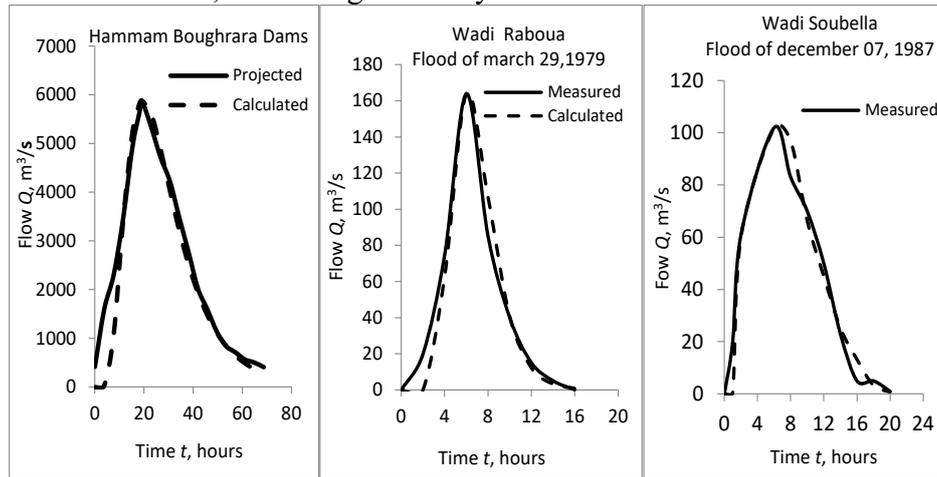

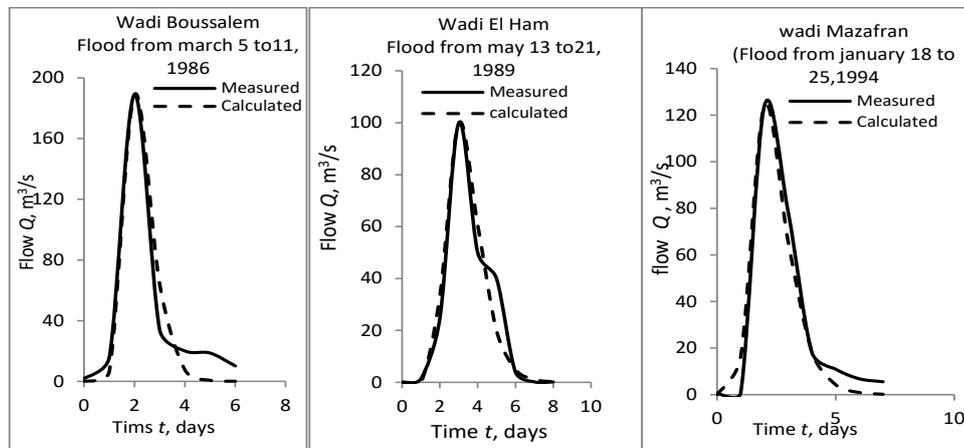Fig. 8. Comparison of measured and calculated hourly flood hydrographs.

Fig. 9. Comparison of measured and calculated daily flood hydrographs

More recent studies conducted in Mediterranean environments confirm these findings. Abida and Ellouze [25] reported comparable correlation levels when applying regional synthetic hydrographs to ungauged basins. In North African contexts, Boutoutaou et al. [26] showed that empirical hydrograph shapes provide acceptable results but often lack flexibility when applied to basins with contrasting morphologies.

The advantage of the Galton-type model lies in its analytical formulation and its adaptability to various basin morphologies through the shape coefficient (k). Unlike classical triangular or parabolic representations, the asymmetric lognormal form captures both the rapid rise and extended recession typical of Mediterranean floods [27,28]. This makes it particularly suitable for small and medium basins characterized by short concentration times and steep slopes.

Furthermore, the model's ability to maintain performance across a wide range of basin areas (50–7000 km²) and climatic regions (eastern, central, and western Algeria) confirms its regional transferability. Such robustness is rarely achieved by empirical approaches, which tend to be highly site-specific [14, 28].

The findings also confirm that the three parameters used—peak discharge (Qp), time to peak (tp), and shape coefficient (k)—are sufficiently discriminative to represent flood dynamics even in the absence of direct gauging. This parameterization offers a balance between physical interpretability and computational simplicity, a key requirement for operational hydrology in developing and semi-arid regions.

Overall, the proposed method provides a methodological bridge between empirical and physically-based models: it retains the simplicity of traditional approaches while improving the hydrological realism of flood hydrograph shapes.

5. Conclusions

This study developed and validated a Galton-type synthetic unit hydrograph model based on a modified lognormal distribution, tailored to the Mediterranean and semi-arid hydrological context of Algeria. Using data from 53 hydrometric stations and 83 flood hydrographs, the model incorporates three physically interpretable parameters peak discharge, time to peak, and an adjustable shape coefficient that effectively describe flood dynamics across a wide range of watershed conditions.

The model demonstrates strong predictive capability, with correlation coefficients ranging from 0.65 to 0.85 between observed and simulated hydrographs, and maintains robustness across diverse basin morphologies and climatic settings. Its simplicity, flexibility, and analytical structure make it an effective tool for hydrological analysis in ungauged basins, particularly where data scarcity limits the use of complex numerical models.

Beyond its methodological contribution, the proposed model has practical applications in flood forecasting, hydraulic structure design, and water resources management. Future work will focus on integrating updated hydrometric and remote-sensing data, as well as exploring machine learning calibration to further refine parameter estimation and enhance model transferability across Mediterranean and African regions.

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Appendix

1. Practical application: Case of the Taksebt dam basin

As an illustration of the method developed, the calculation of the project hydrograph of the millennial flood (T=1000 years) of the Taksebt Dam watershed is presented. The physiographic data and the millennial flood hydrograph of the basin are borrowed from the hydrological study of the Taksebt Dam [19], they are as follows:

Basin area A = 448 km^2;
Length of the main watercourse L = 39 km;
Average slope of the wadi I = 0.23%;
Estimated peak flow of the millennial flood (T=1000 years) Qp = 2407 m^3/s;
Rise time: tp = 13 hours.

2. Solution

2.1 Calculation of the rise time tp

The concentration time of the basin is determined by the empirical formula (5):

$$t_c = 1.7 \times \left(\frac{A \times L}{\sqrt{I}} \right) = 1.7 \times \left(\frac{448 \times 39}{\sqrt{0.23}} \right) = 12.5 \, hours \tag{A1}$$

Assuming that $tp = tc$, we adopt: $t_p = 13 \, hours$.

2.2 Calculation of the shape coefficient k

$$k = 0.0102 \times (A+1)^{0.40} + 0.20 = 0.0102 \times (448+1)^{0.40} + 0.20 \approx 0.32 \tag{A2}$$

Final formula of the flood hydrograph.
The flood hydrograph at the Taksebt dam site is calculated by modul (3), it is expressed as follows:

$$Q(t) = Q_p \left(\frac{t}{t_p} \right)^{-0.1} \times Exp \left[-\frac{1}{2} \left(\frac{\ln\left(\frac{t}{t_p}\right)}{k} \right)^2 \right] = 2407 \left(\frac{t}{13} \right)^{-0.1} \times Exp \left[-\frac{1}{2} \left(\frac{\ln\left(\frac{t}{13}\right)}{0.32} \right)^2 \right] \qquad (A3)$$

The calculation of $Q(t)$ is performed for a series of times t (Example: 4 h, 8 h, 13 h, 16 h, etc.).

Noticed: for $t = o \Rightarrow Q(0) = 0$ (condition).

The calculation of flood hydrograph is presented in Table 4. The comparison between projected and modelled flood hydrographs of Taksebt Dam is illustrated in Figure (10).

Table 4

Calculation of the flood hydrograph of the Taksebt dam by formula (2).

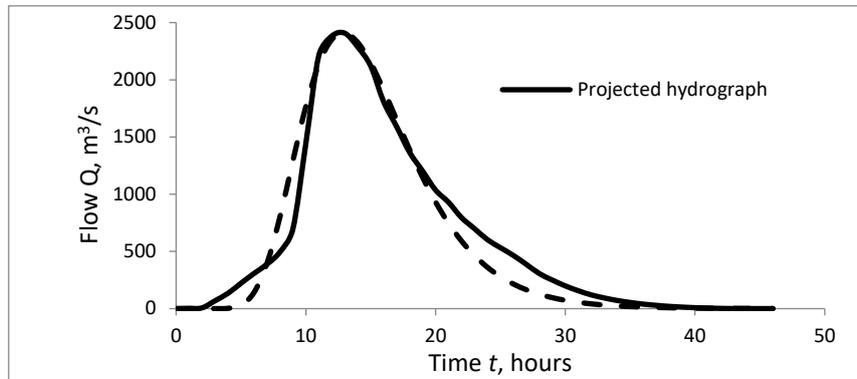| Times, t (hours)	0	4	8	t_p= 13	…	…	40	44
Flow rate $Q(T)$, m3/s	0	1.2	682	**2407**	…	…	1.93	≈ 0

Fig. 10. Comparison of projected and modeled flood hydrographs
at the Taksebt dam location