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A new approach to modelling the average interannual streamflow in the watersheds of Northern Algeria

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Abstract: The estimation and potential exploitation of water resources in arid and semi-arid regions, especially in the watersheds of Northern Algeria, where climatic variability affects the transformation of precipitation into river flow, needs to be based on effective management of these resources depends on understanding hydrological relationships. This must be grounded in knowledge and probable mastery of the phenomena governing their formation under local physico-geographical conditions, particularly in ungauged watershed areas.

The objective of this approach is to develop a general and regional model for estimating interannual average flow (*IAF*) at the level of ungauged basins. This model is based on the analysing and identifying the influence of local factors such as the surface area of the watershed, relief, geology, soils, and plant cover. Its development relies on statistical and grapho-analytical methods.

The results demonstrate that the watershed area and climatic flow are key parameters, which indicate the dependency of the climatic coefficient k_{obs} on these two factors and give good correlations, which vary from 0.615 to 0.92. Hence, the model was established based on these two parameters and found to perform well in estimating *IAF*, according to the performance criteria.

Keywords: climate, flow, Northern Algeria, precipitation, real evapotranspiration (*ETR*), watershed

INTRODUCTION

In the context of predictable climate change, the estimation of water resources is fundamental question in the surface hydrology of continents – especially under the climatic conditions characterising arid and semi-arid zones (Liu *et al.*, 2020).

The transformation of precipitation into river flow undergoes numerous variations, which, to date, have not been fully characterised quantitatively. However, it is possible to interpret them in a simplified manner over sufficiently long time intervals (monthly, seasonal, annual, and interannual average). Thus, the main challenge in estimating the interannual average flow lies in the search for relationships that accurately translate the elements of the hydrological balance between precipitation, evapotranspiration, and infiltration (Callede *et al.*, 2002; Ladjel *et al.*, 2019).

The glaring lack of hydrometric stations in medium and small watersheds complicates the estimation of interannual average flow (*IAF*). This is because the influence of certain physico-geographical factors is clearer and more tangible than in large watersheds, where this influence is diminished by the presence of other factors (Douvinet, Delahaye and Langlois, 2008, Ladjel and Mezentseva, 2016).

Algeria is dominated by two types of climate: Saharan and Mediterranean, where rainfall can reach over 1,200 mm on the coast and less than 50 mm in the Sahara (Mebarki, 2010). This particular spatio-temporal variability of rainfall has a direct influence on the approach to resource estimation.

Precipitation is the source of surface and groundwater resources. It transforms into runoff that flows into watercourses, or infiltrates to replenish groundwater aquifers. This resource is quantified through the *IAF*. The rational management of water resources is based on the identification of this main hydrological characteristic (Touazi and Laborde, 2004; Touazi, Laborde and Bhiry, 2004; Ladjel and Mezentseva, 2016). On the other, hydrometric data from rivers are typically available at the outlets of certain large and medium-sized watersheds (Blöschl *et al.* (eds.), 2013).

For ungauged watersheds basins, or those with limited available information, estimating flow poses a major challenge despite the abundance of precipitation data. This issue has presented significant scientific difficulties for several hydrologists (Zhang, 2008; Hrachowitz *et al.*, 2013).

In Algeria, early attempts at estimation and methods used, generally relied on empirical approaches based on observation and description of the regimes of the physical environment, along with the proposal of rules for calculation and management. Examples include methods proposed by Medinger (1948), Chaumont (1963), Padoun (1973), and Deri (1977).

These forecasting methods involve seeking correlation between discharge and a previously known or determinable representative factor, based on historical hydroclimatic data, such as surface area, temperature, evapotranspiration, etc.

Since the 1990s, other modelling attempts at the inter-annual average scale of the rainfall–runoff relationship have been initiated through studies conducted by the Ministry of Water Resources, followed by several research projects aimed at improving calculation accuracy by introducing other factors influencing runoff, such as the surface area of the watershed and air humidity. Among these studies are those of Kabouya (1990), Taibi (1993), Beldjoudi and Larbi (1995), Beldjoudi and Ouled-Yahia (1997), Touazi (2003), Touazi, Laborde and Bhiry (2004).

Thanks to this work, good results were obtained at the gauged sites. However, these may not prove entirely effective for ungauged sites, given the non-homogeneity of local physiographic characteristics that control flow generation.

Additionally, the majority of analyses and tests conducted on numerous Algerian watersheds across different geographical areas show that the flow estimation methods used yield different values for the same rainfall amount (Benlarbi *et al.*, 2015). This is due to the many gaps that exist in the hydrological process, particularly with regard to runoff, since both modelling and mapping are dependent on the quality of the available measurement series (Meddi and Meddi 2009; Remini, Leduc and Hallouche, 2009; Touazi *et al.*, 2011). Thus, flows represent a relative response to various factors, including watershed size, topography, geology, soils, and vegetation cover (Kotti *et al.*, 2016).

The objective of this approach is to analyse and identify the influence of these local factors on the interannual average flow and to establish a general and regional model which takes into account the influence of the main factors generating flow. The model should provide estimates consistent with physical reality, particularly at the level of ungauged basins.

MATERIALS AND METHODS

STUDY AREA

Our study focuses on the northern part of Algeria, which covers an area of 13.5% of the country's total area, amounting to 287,900 km^2. This region is characterised by three main relief sets, with very uneven extents stretching from north to south and reflecting a striking climatic contrast. In the north, along a coastal strip of 1,200 km, stretches the narrow plain of the Tell region. Its adjacent valleys contain the vast majority of the country's agricultural land.

On the edge of the Tell, two east-west oriented mountain ranges, the Tellian Atlas to the north and the Saharan Atlas to the south – tend to merge towards the east of Algeria, forming the Aurès massif. The Tell Atlas is formed by a succession of mountain ranges, sometimes adjacent to the Tell plain. These two mountain ranges surround the highlands region, characterised by arid and semi-arid climate.

This zone represents the rainiest part of the territory, receiving annual rainfall between 400 and 1,500 mm. On the High Plateaus and in the Saharan Atlas, annual rainfall does not exceed 200–500 mm. The pre-Saharan and Saharan regions are almost completely rainless, receiving average annual rainfall of between 50 mm and 200 mm. Average temperatures in the region vary between day and night, and between summer and winter. Recorded temperatures are uniform: the average minimum daily temperature is around 10–12°C in December and January, the coldest months of the year, while the average maximum daily temperature varies between 25 and 27°C in July and August, the hottest months of the year. Temperature ranges on the High Plateaus and in the Saharan Atlas are more pronounced than in the coastal regions. This zone also has the densest hydrographic network in the country (Fig. 1).

The vegetation cover is directly linked to the Mediterranean climate that characterises the entire northern part of Algeria. This heterogeneous vegetation cover is unevenly distributed, depending on the distribution of meso-climates, orography, and human activity.

ANALYSIS AND DESCRIPTION OF DATA

The climatic data used in this study were collected from documents provided by the National Agency for Water Resources of Algeria (Fr: Agence Nationale des Ressources Hydrauliques – ANRH). These data come from 93 hydrometric stations and 214 pluviometric stations, covering areas ranging from 19 km^2 to 4,050 km^2. Of these, 70% of the stations were selected for model design (testing), 15% for calibration, and 15% for result validation (see Fig. 2).

These data include the interannual average flow (E_o), interannual average rainfall (P_o), interannual average potential evapotranspiration (ETP_o), watershed area (A), and mean elevation of the watershed (H_o). The morphometric coefficient of the watershed is determined by the ratio of the gross slope to the average slope of the watershed. The ETP_o is obtained directly from the map of Northern Algeria developed by ANRH in 2002 (ANRH, 2002). The hydro-climatic and physical characteristics of the watersheds studied are summarised in Table 1.

Rainfall series lengths range from 18 to 56. To fill in the gaps in some stations, we utilised the concept of continuous spatial

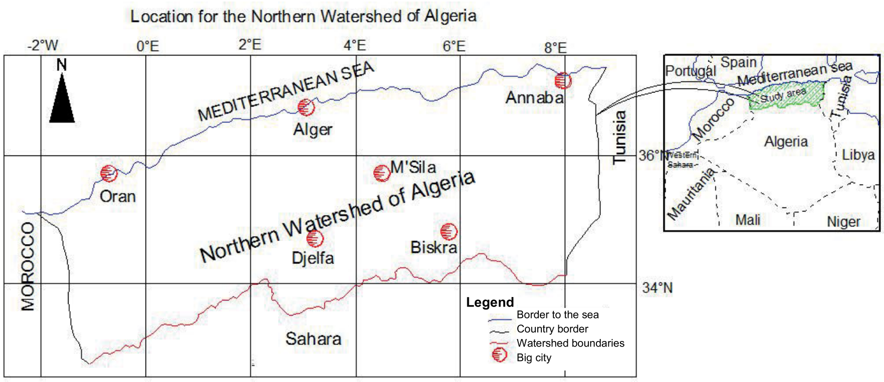

Fig. 1. Location of the study area; source: own elaboration

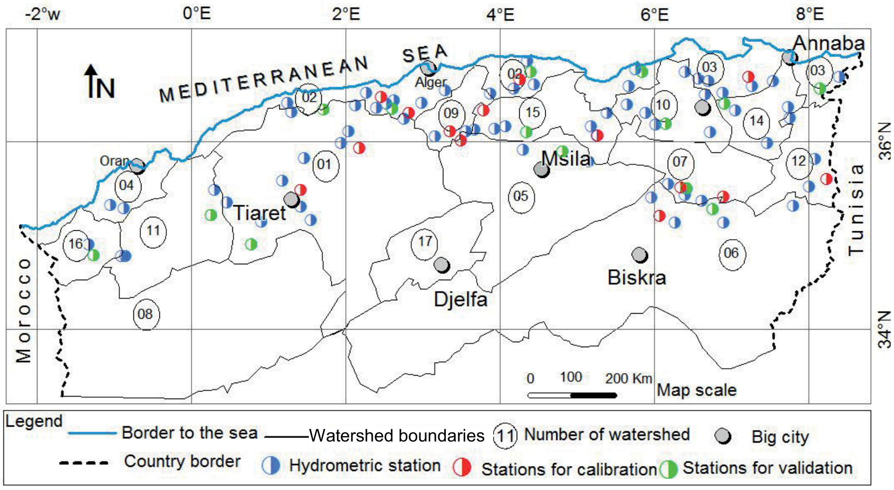

Fig. 2. Spatial distribution of hydrometric stations; source: own elaboration

Table 1. Hydroclimatic and physical characteristics of watersheds

Watershed	River	Code	$X°$	$Y°$	A (km^2)	L (km)	H_o (m)	I (km·km^{-1})	P_o	$E_{o,\text{obs}}$	ETP_o
									mm		
Cheliff	Sousselem	010711	1.55	35.15	490	48.6	1135	10.08	305	15.1	1420
Cotiers Algerois	El Hammam	021905	3.88	36.50	71	14.6	473	4.86	765	192	1337
Cotiers Constantinois	Cotiers Jijel	030310	5.76	36.76	19	7.4	142	2.57	900	349	1225
Cotiers Oranais	El Mallah	040220	–1.04	35.31	697	65.3	317.7	10.67	351	23	1355
Chott el Hodna	El Ham	050101	3.49	35.99	460	77.5	1051	5.94	240	8	1450
Chott Melghir	El Hai	061201	5.97	35.39	1170	76.4	1184	15.31	309	15	1410
Hauts plateaux Constantinois	Ghueiess	070702	6.89	35.39	144	19.4	1317	7.42	460	47	1415
Isser	Malah Ouest	090101	3.16	36.04	662	58.8	956	11.26	385	28.5	1375
Kébir Rhumel	El Kebir	100109	5.65	36.37	960	70.2	955	13.68	590	91	1297
Macta	Mekerra	110201	–0.84	34.77	1890	91.1	1104	20.75	326	19.5	1285
Madjerdah	Medjerda	120101	7.75	36.23	217	39.9	879	5.44	595	100	1303
Seybouse	Cherf	140202	7.46	35.97	1710	57.1	890	29.95	325	21	1225
Soummam	Bousselam	150901	4.07	36.14	4050	189	960	32.15	419	32	1365
Tafna	Sokkak	160704	–1.33	34.89	320	51.9	771	6.17	455	51	1290

Explanations: A = watershed area, H_o = average elevation of the watershed, I = mean slope of watershed, P_o = interannual average rainfall, ETP_o = interannual average potential evapotranspiration, $E_{o,\text{obs}}$ = interannual average flow, L = length of river, $X°$ = longitude, $Y°$ = latitude.
Source: own elaboration.

distribution, which considers the interdependence between stations. Interannual rainfall averages are determined over a period from 1966 to 2022 using the isohyet method for each sub-watershed.

Meanwhile, the lengths of the hydrometric data series range from 16 to 47 observations. The missing monthly data were filled using multiple regression, which allowed for the estimation of the average *IAF* values at the level of each sub-watershed. Only short-term gaps were filled using spatial correlation.

INTERANNUL AVERAGE FLOW

The interannual average flow (*IAF*) is influenced by a number of factors, which can be grouped into two categories: (1) climatic factors (such as rainfall, temperature, evaporation, wind speed, etc.) and (2) intra-zonal factors (such as lithological structure, soil type, vegetation cover, watershed slope, etc.). These categories allow us to decompose the flow into climatic and local components, referred to as climatic flow ($E_{o,\mathrm{clim}}$) and local flow (subsurface flow – $E_{o,\mathrm{loc}}$) respectively (Minea *et al.*, 2018; Ladjel *et al.*, 2019) – Figure 3.

If we consider that the surface of the slopes is impermeable, then we obtain the:

$$IAF = E_{o,\mathrm{clim}} + E_{o,\text{s-flow}} \tag{1a}$$

where: IAF = interannual average flow (mm), $E_{o,\mathrm{clim}}$ = climatic flow (mm), $E_{o,\text{s-flow}}$ = subsurface flow ($E_{o,\mathrm{loc}}$) (mm).

In the contrary case, it is considered that the surface of the slopes is completely permeable, meaning that it is not able to retain a single drop of rainwater. In this case:

$$IAF = E_{o,\mathrm{clim}} + E_{o,\text{s-flow}} \tag{1b}$$

This means that the amount of absorbed rain, must be drained underground and added to the flow of the river.

The climatic component is fundamentally determined by precipitation and actual interannual evapotranspiration (ETR_o), whereas the local component, $E_{o,\mathrm{loc}}$, is influenced by local factors such as relief, exposure of the slopes, vegetation cover, soil layers, and groundwater levels. Several attempts have been made to estimate river flow, but without considering the decomposition of *IAF* (Ladjel *et al.*, 2019). Therefore, we seek an approach to identify and estimate local flow analytically, through the analysis of graphical and grapho-analytical dependencies, expressed as $E_{o,\mathrm{loc}} = f(X_1, X_2, X_3, ..., X_n)$ where X_i is an explanatory variable. It is known that in small watersheds, rainfall is partitioned into overland flow, infiltration, and ETR_o.

In large watershed, rainfall is allocated to runoff – equivalent to the climatic runoff – and to actual interannual evapotranspiration (Fig. 3). In medium watersheds, the flow consists of climatic runoff and an additional component generated by a portion of the infiltrated rainfall upstream, which is called local flow. This demonstrates that the capacity for groundwater drainage determines the volume of this flow ($E_{o,\mathrm{loc}}$).

INTERANNUAL AVERAGE FLOW CALCULATION METHODOLOGY

In small watersheds, where the first drainage horizon is located below the outlet of the watershed, the *IAF* equals climatic runoff. However, when the watershed outlet lies below one or several drainage horizons, the underground contribution increases with the number of drainage horizons, generating a complementary component to the climatic runoff known as local flow (Ducharne *et al.*, 2003).

This local flow component increases with the area of watershed within a range $[S_1, S_2]$, where $S_1 < S_2$. Here, S_1 represents the minimum area below which the E_{loc} flow is zero, and S_2 represents the maximum area below which the local flow reaches its upper limit. For all watersheds with a surface area greater than S_2, the *IAF* can be considered equal to the climatic flow. As for the interannual climatic flow component ($E_{o,\mathrm{clim}}$), its estimation across all catchments poses no difficulty, because it is determined by knowledge of rainfall and potential interannual evapotranspiration (ETP_o).

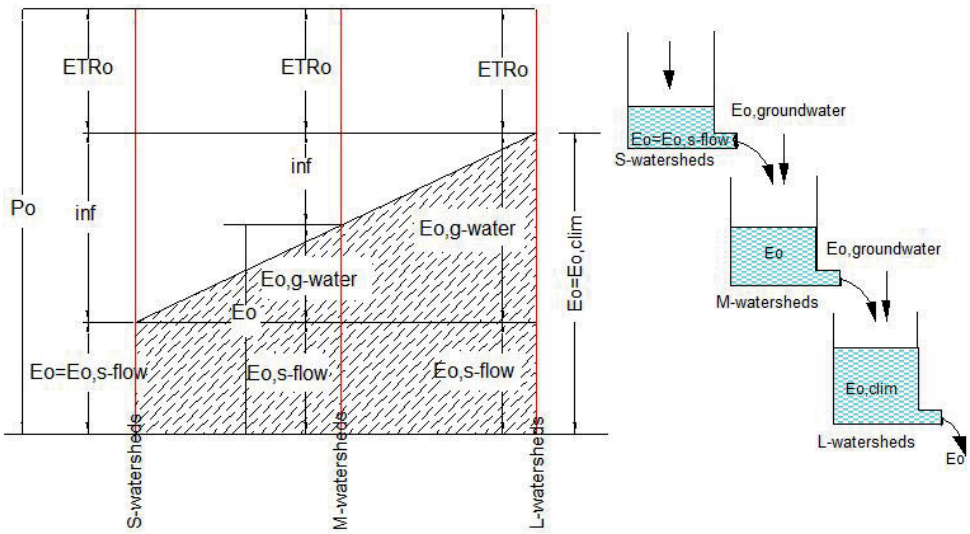

Fig. 3. Explanatory diagram of the hydrological balance; P_o = interannual average rainfall (mm), ETR_o = real interannual evapotranspiration, E_o = interannual average flow, $E_{o,\text{s-flow}}$ = subsurface flow, $E_{o,\text{g-water}}$ = groundwater flow, $E_{o,\mathrm{clim}}$ = climatic flow, S-watershed = small watershed, M-watershed = medium watershed, L-watershed = large watershed, inf = infiltration; source: own elaboration

The climatic flow is expressed by the Equation (2):

$$E_{o,\text{clim}} = P_o - ETR_o \tag{2}$$

where: ETR_o = real interannual evapotranspiration estimated by the Ol'dékop relationship, which gives us the maximum value of this parameter (Ol'dekop, 1911).

The $E_{o,\text{loc}}$ component, generated by temporarily stored water reserves in watersheds, is complex and depends on geological and hydrogeological factors, which are not always evenly distributed across different watersheds, especially in mountainous regions.

The storage or retention capacities of watersheds (in addition to relief, soils, vegetation, aquifers, etc.) depend on their sizes. The larger the watershed, the greater its capacity. Rivers in large watersheds cut through numerous impermeable layers. The succession of these layers leads to a progressive increase in underground contribution, thus increasing the $E_{o,\text{loc}}$ component.

In small watersheds, the amount of rainfall breaks down into overland flow, infiltration, and ETR_o. In medium watersheds, the amount of rainfall breaks down into overland flow, underground flow, infiltration, and ETR_o, whereas in large watersheds, rainfall is partitioned into climatic flow and ETR_o.

In general, the flow of watercourses ($E_{o,\text{obs}}$) is composed of climatic flow ($E_{o,\text{clim}}$), which is governed by the main climatic factors, which include rainfall and actual interannual evapotranspiration, and a complementary flow, called local flow $E_{o,\text{loc}}$, determined by local generating factors (Zannou, 2011; Ladjel *et al.*, 2019). This relationship is expressed by the Equation (3):

$$E_o = E_{o,\text{clim}} + E_{o,\text{loc}} \tag{3}$$

The first component depends solely on climatic elements: rainfall (P_o) and ETR_o. It is specific to large watersheds, where the precipitation drainage capacity is nearly complete (Voskresensky, 1951; Roche 1963), and expressed by Equation (4):

$$E_{o,\text{clim}} = P_o - ETR_o \tag{4}$$

The estimation of average ETR_o can be achieved through various models proposed by Oldékop (1911), Schreiber (1974), Mezntsev (1976), Budyko (Budyko and Miller, 1974) and Turc–Pike (Xing *et al.*, 2018).

RESULTS AND DISCUSSION

ANALYSIS OF THE DEPENDENCY OF CLIMATIC COEFFICIENT

The calculated ETR_o values for all watersheds, applying the formulas of the referenced authors, revealed that for rainfall less than 600 mm, the values of ETR_o are almost identical, whereas beyond this limit, the Ol'dékop formula gives maximum values, while the Schreiber formula shows minimum values (Fig. 4). The Mezentsev, Budyko, and Turc–Pike formulas yield median values.

The average interannual actual evapotranspiration ETR_o is estimated for Algerian conditions by Ol'dékop (1911), which is expressed as:

$$ETR_o = ETP_o \cdot \tanh(P_o/ETP_o) \tag{5}$$

where: $\tanh(P_o/ETP_o)$ = hyperbolic tangent of P_o/ETP_o.

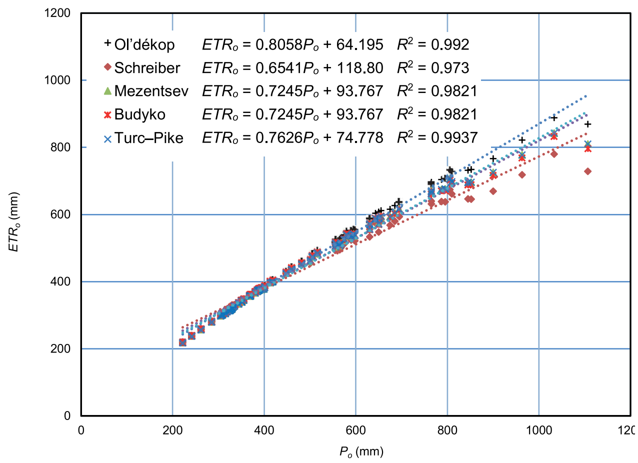

Fig. 4. Curves of real interannual evapotranspiration as a function of average interannual rainfall ($ETR_o = f(P_o)$) by different formulas; source: own study

Under the conditions mentioned above, observations show that local flow consistently exceeds $E_{o,\text{clim}}$, as depicted in Figure 5 (Bouguerra and Bouanani, 2019; Ladjel *et al.*, 2019). With the increase in watershed area, the capacity of groundwater drainage increases. Hence, the value of the total river flow (E_o) approaches the value of the climatic flow (Voskresensky, 1951).

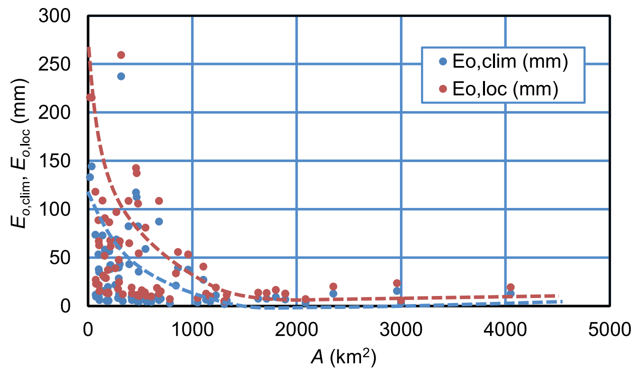

Fig. 5. Variation in local flow ($E_{o,\text{loc}}$) and interannual average climatic flow ($E_{o,\text{clim}}$) as a function of the watershed area (A); source: own study

The $E_{o,\text{loc}}$ also depends on local factors, including the relief. These factors directly influence the volumes of rainfall that generate runoff and the losses of rainwater.

By definition, $E_{o,\text{loc}}$ is the quantity of P_o percolated deeply and discharged at the outlet of the watershed (Roche, 1963; Ladjel, 2020).

$$P_o^{'} = P_o - E_{o,\text{clim}} \tag{6}$$

where: $P_o^{'}$ = quantity of rain percolated (mm).

When we replace $E_{o,\text{clim}}$ from Equation (5) into Equation (6), we find that the value of equals ETR_o.

$$P_o^{'} = ETR_o \tag{7}$$

The dependence of $E_{o,\text{loc}}$ on $P_o^{'}$ has the form of a linear trend, with a coefficient of determination R^2 = 0.9747 (Fig. 6).

When we introduce the logarithmic scale on this trend, we note that it becomes almost linear (Fig. 7).

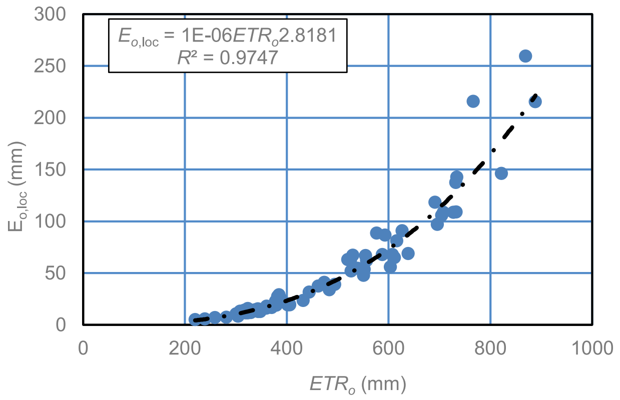

Fig. 6. The dependence of local flow ($E_{o,loc}$) on real interannual evapotranspiration (ETR_o), R^2 = determination coefficient; source: own study

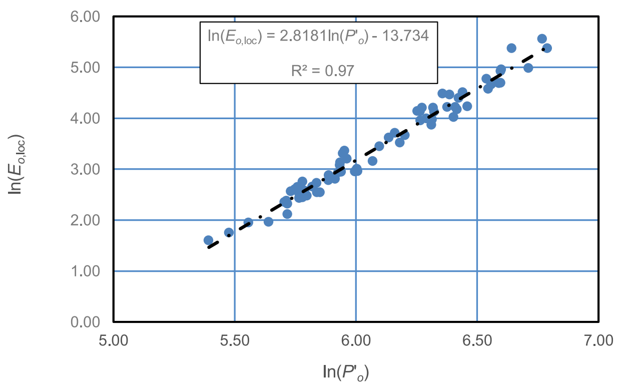

Fig. 7. The dependence of $\ln(E_{o,loc})$ as a function of $\ln(P'_o)$; $E_{o,loc}$ = local flow, P'_o = quantity of rain percolated, R^2 = determination coefficient; source: own study

This trend takes the form $Y = X - X_e^{-kX}$ which can be adapted to the Algerian flow equation (Chaumont, 1963), so $E_{o,loc}$ is written as follows:

$$E_{o,loc} = ETR_o(1 - 10^{-kETRo}) \tag{8}$$

$$E_{o,loc} = ETR_o - ETR_o \cdot 10^{-kETRo} \tag{9}$$

$$ETR_o - E_{o,loc} = ETR_o \cdot 10^{-kETRo} \tag{10}$$

If we consider that, the second part of Equation (10) represents local losses.

$$P'_r = P'_o e^{-kETRo} \tag{11}$$

So:

$$\ln\left(\frac{P'_r}{ETR_o}\right) = -kETR_o \tag{12}$$

$$k_{\text{obs}} = -\frac{1}{ETR_o}\ln\left(\frac{P'_r}{ETR_o}\right) \tag{13}$$

According to the Equations (3), (4), (6) and (13) we therefore have:

$$k_{\text{obs}} = -\frac{1}{ETR_o}\ln\left(\frac{ETR_o - E_{\text{o,loc}}}{ETR_o}\right) \tag{14}$$

where: k_{obs} = climatic coefficient that depends on the value of ETR_o, calculated for each sub-basin.

The graphical and statistical analysis of the dependencies between k_{obs} and physical and geographical parameters showed the existence of dependencies, which can be expressed by the equation: $\ln(k_{obs}) = ax + b$ (x represents the logarithm of the parameter analysed) derived from the linear regression. The graphs shown in Figure 8 represent the most significant trends related to local factors.

To determine the real value of $E_{o,loc}$, we have:

$$E_{o,\text{loc}} = E_o - E_{o,\text{clim}} \tag{15}$$

It is necessary to determine the amount of losses P'_r, and for this, we correct $E_{o,loc}$ by a climatic flow coefficient k_{obs} using the Equation (16):

$$E_{o,\text{loc}} = ETR_o - ETR_o e^{-k_{\text{obs}}ETR_o} \tag{16}$$

To determine k_{obs}, it is necessary to introduce the influencing parameters such as A and $E_{o,clim}$.

The results obtained from the graphical and analytical analysis (Fig. 8) show that there is a good correlation between these parameters and the k_{obs}, with correlation coefficients ranging from 0.65 to 0.92 for both parameters.

The analytical analysis using multiple regression of k_{obs} as a function of A and $E_{o,clim}$ is expressed by the Equation (17):

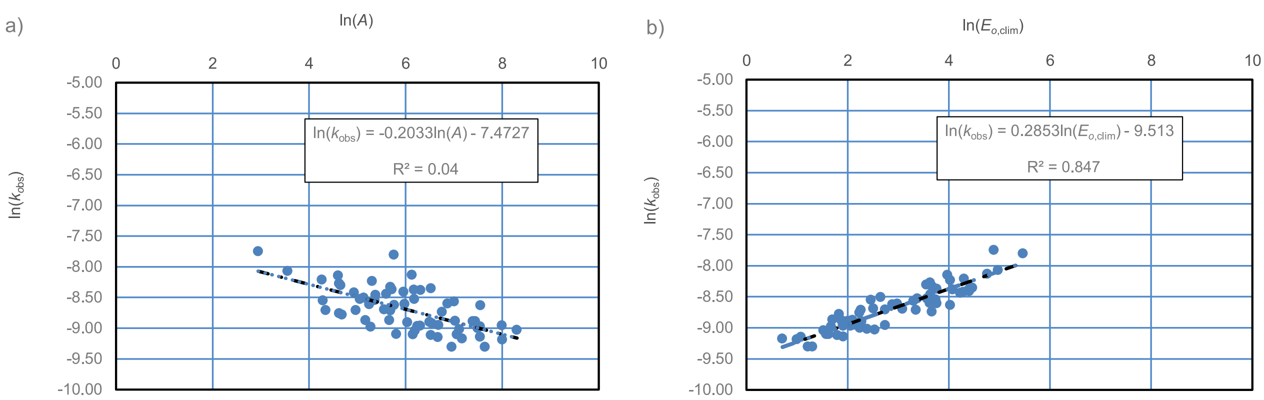

Fig. 8. The dependence of climatic coefficient (k_{obs}) as a function of: a) surface area (A), b) interannual average climatic flow ($E_{o,clim}$); R^2 = determination coefficient; source: own study

$$k_{\text{obs}} = C_k \frac{E_{o,\text{clim}}^{0.25}}{A^{0.1}} \tag{17}$$

This coefficient allows for the determination of the regional climatic coefficient C_k, which reflects the influence of local parameters. This coefficient (C_k) is calculated for each basin and the average C_k is used to adjust the value of the calculated climatic runoff coefficient (k^*) – Figure 9. Both the k^* and k_{obs} follows the same trend with respect to the two parameters A and $E_{\text{o,clim}}$.

PERFORMANCE MEASURES OF THE MODEL

The statistical criteria applied to assess the performance of our model fall into three categories: general criteria (*MAE*, *RMSE*, *MSE*), normalisation criteria (Nash–Sutcliffe and *r*), and finally visual criteria (residual function, observed parameters plotted against calculated parameters). These criteria are detailed in Table 2, where X_o represents the measured (observed) parameter and X_{cal} represents the calculated (simulated) parameter.

The model was calibrated against reference hydrometric stations to test its reliability. The results of the general and normalisation performance criteria across the various stages: training, testing, and validation, are summarised in Table 2.

MAE. The mean absolute error (*MAE*) is a fundamental measure for evaluating the performance of regression models (Brassington, 2017). The *MAE* value indicates the mean absolute difference between predicted and actual values. The smaller the *MAE*, the better the model's predictions align with the actual data. When the *MAE* converges to zero, it signifies a perfect prediction. According to *MAE* values recorded in Table 2, we can see that they converge towards zero in all three phases, which means that our results meet the criteria of the *MAE* index.

***RMSE* and *MSE*.** The values of the *RMSE* and *MSE* are close to zero, confirming a high level of model accuracy (Hodson, 2022).

***NS* and *r*.** When the values of these two criteria are close to 1, it indicates a better fit of the model to the observed values. According to the results recorded in Table 2, these criteria provide values exceeding 70%, affirming that our model is satisfactory and

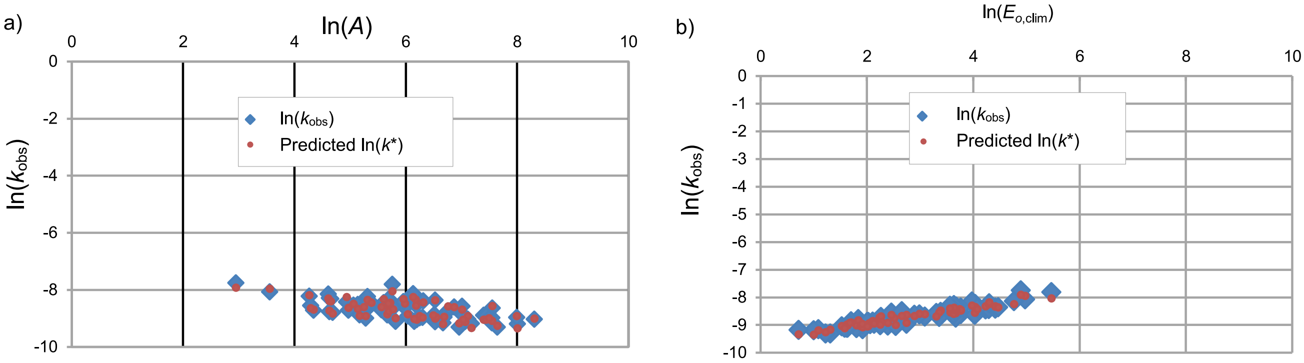

Fig. 9. The dependence of $\ln(k_{\text{obs}})$ and k^* as a function of: a) $\ln(A)$, b) $\ln(E_{o,\text{clim}})$; k_{obs} = climatic coefficient, $E_{o,\text{clim}}$ = interannual average climatic flow; source: own study

Table 2. Performance criteria results

Performance criteria	Relationship	k_{obs}		
		trainings (70%)	test (15%)	validation (15%)
Mean absolute error (*MAE*)	$MAE = \frac{1}{N}\sum_{i=1}^{N}\left|\left(k_{\text{obs},i} - k_{\text{cal},i}\right)\right|$	$1.6 \cdot 10^{-5}$	0.00001	0.00001
Root mean square error (*RMSE*)	$RMSE = \sqrt{\frac{\sum_{i=1}^{N}\left(k_{\text{cal}} - k_{\text{obs}}\right)^2}{N}}$	$2.1 \cdot 10^{-5}$	$1.4 \cdot 10^{-5}$	$2.1 \cdot 10^{-5}$
Mean square error (*MSE*)	$MSE = \frac{1}{N}\sum_{i=1}^{N}\left(k_{\text{cal}} - k_{\text{obs}}\right)^2$	0.0000	0.0000	0.0000
Nash–Sutcliffe (*NS*)	$NS = 1 - \frac{\sum_{i=1}^{N}\left(k_{\text{obs},i} - k_{\text{cal},i}\right)^2}{\sum_{i=1}^{N}\left(k_{\text{obs},i} - \overline{k_{\text{obs}}}\right)^2}$	0.907	0.925	0.986
Correlation coefficient (*r*)	$r = \frac{\sum_{i=1}^{N}\left(k_{\text{obs},i} - \overline{k_{\text{obs}}}\right)\cdot\left(k_{\text{cal},i} - \overline{k_{\text{cal}}}\right)}{\left[\sum_{i=1}^{N}\left(k_{\text{obs},i} - \overline{k_{\text{obs}}}\right)^2\right]^{0.5}\cdot\left[\sum_{i=1}^{N}\left(k_{\text{cal},i} - \overline{k_{\text{cal}}}\right)^2\right]^{0.5}}$	0.952	0.97	0.990

Explanations: N = sample size, i = observation number, k_{obs} = climatic coefficient, k_{cal} = calculated climatic coefficient (k^*).
Source: own study.

that the simulated and observed values are consistent (Nash and Sutcliffe, 1970; Amiar, Bouanani *et al.*, 2015).

Visual criteria. These criteria are represented by: residual function, graph of observed parameters plotted against calculated parameters.

Residual function. According to the residual plots (Fig. 10), it is noticeable that the error deviations vary within a range of 5%. This indicator is valuable for making decisions regarding the performance of our model.

The graph of observed parameters plotted against calculated parameters is presented in Figure 11. A linear trend is observed between k_{obs} and k^* across the three phases: training, testing, and validation, with correlation coefficients of approximately r = 0.952, 0.969, and 0.982, respectively.

The coefficient k^* is introduced to correct the $E_{o,loc}$ resulting in the corrected local flow ($E_{o,loc,cal}$). Subsequently, a linear trend was observed between $E_{o,loc,obs}$ and $E_{o,loc,cal,}$ with correlation coefficients of approximately r = 0.992, 0.995, and 0.996 for training, testing, and validation phases, respectively, as shown in Figure 12.

The comparison of $E_{o,loc,cal}$ to $E_{o,loc,obs}$ initial resulted in an error of approximately 7%. The correction applied to $E_{o,loc}$ led to the correction of the total flow $E_{o,obs}$. An almost collinear trend was obtained between $E_{o,obs}$ and $E_{o,cal}$ for the three phases of the model, with correlation coefficients of 0.995, 0.998 and 0.999, respectively (Fig. 13).

The results obtained by our proposed model are presented in Table 3. The reliability of this model is tested by calculating the

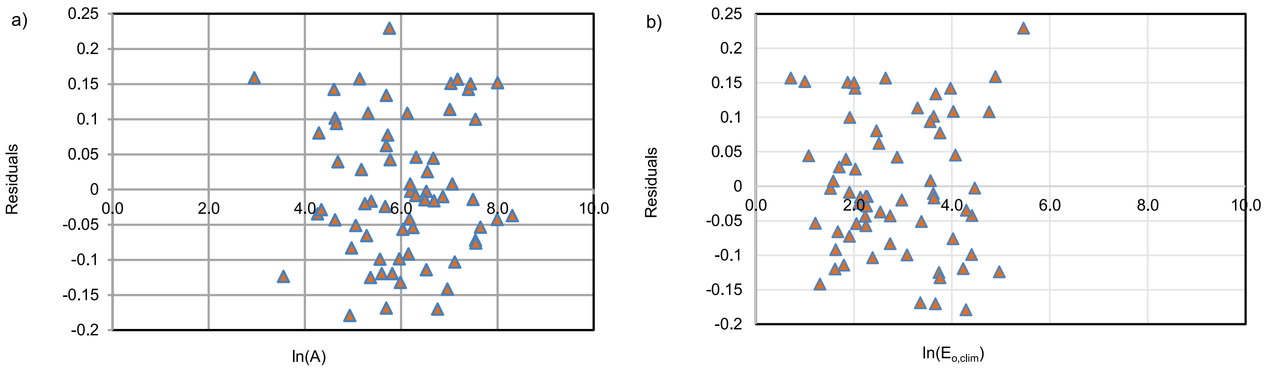

Fig. 10. Graphical representation of residuals as a function of: a) surface area (A), b) interannual average climatic flow ($E_{o,clim}$); source: own study

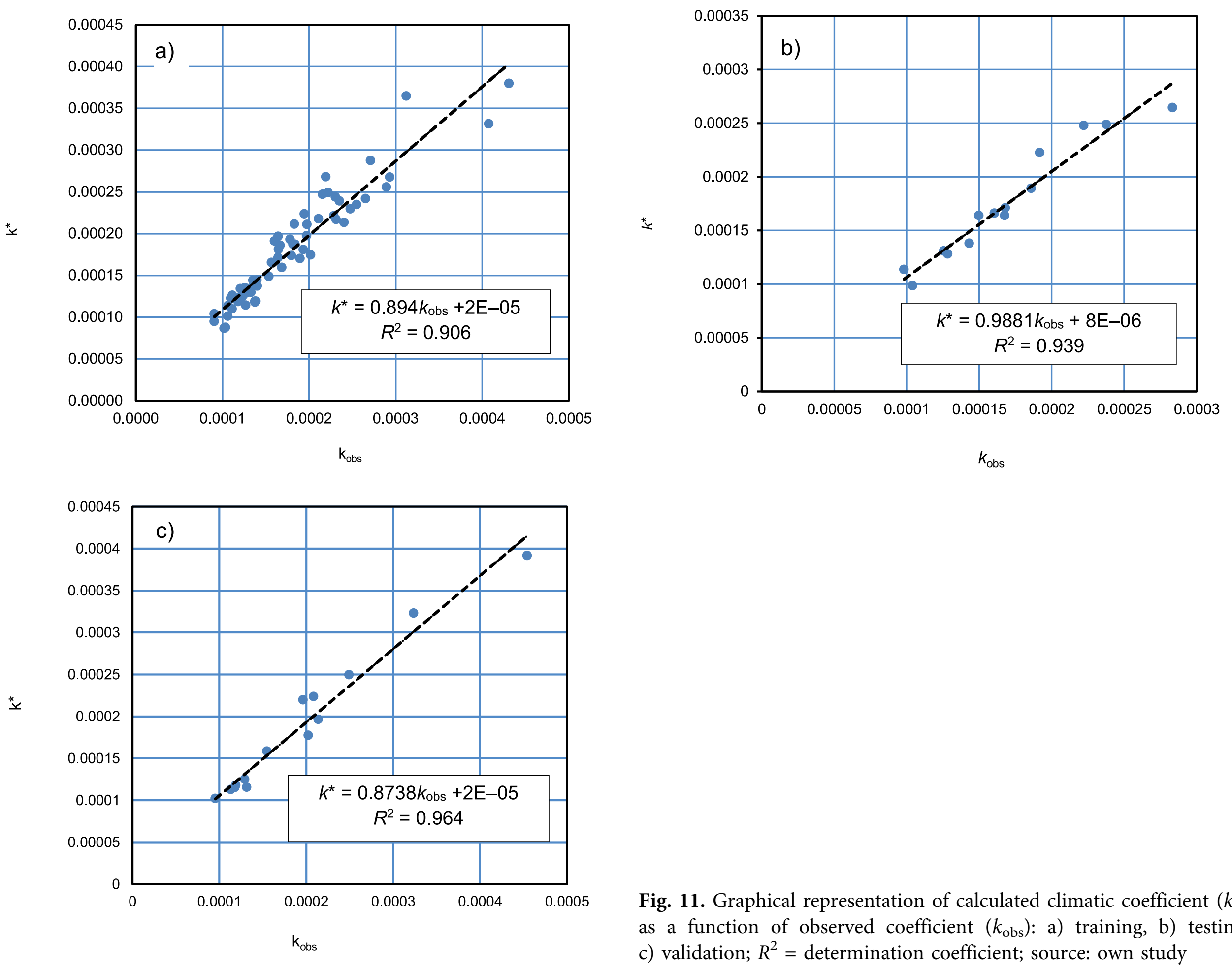

Fig. 11. Graphical representation of calculated climatic coefficient (k^*) as a function of observed coefficient (k_{obs}): a) training, b) testing, c) validation; R^2 = determination coefficient; source: own study

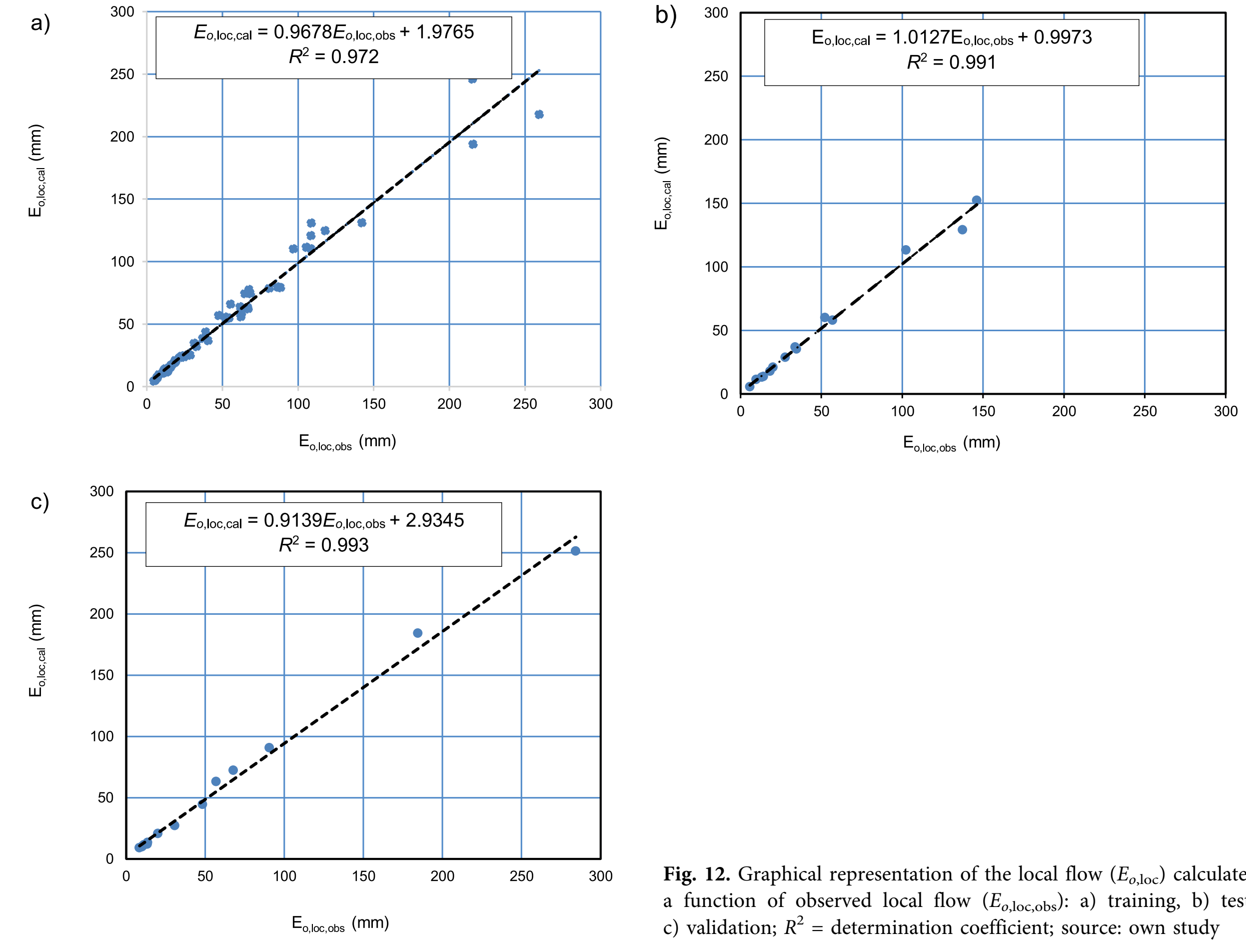

Fig. 12. Graphical representation of the local flow ($E_{o,loc}$) calculated as a function of observed local flow ($E_{o,loc,obs}$): a) training, b) testing, c) validation; R^2 = determination coefficient; source: own study

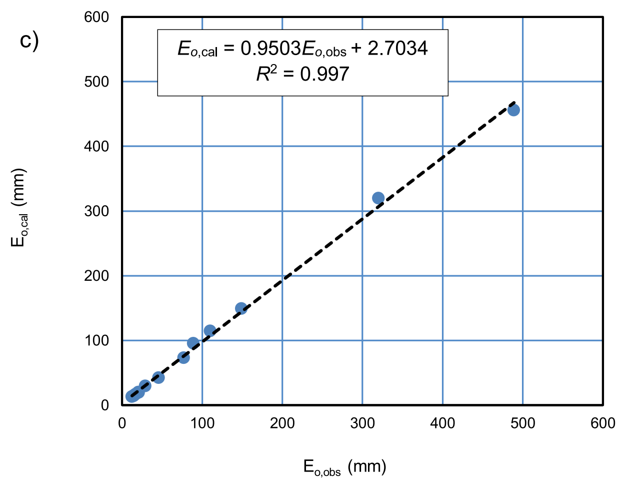

Fig. 13. Graphical representation of the total flow $E_{o,cal}$ calculated as a function of observed flow $E_{o,obs}$: a) training, b) testing, c) validation; R^2 = determination coefficient; source: own study

percentage errors in the estimation of climatic flow and local flow in the North Algerian watersheds studied.

Analysis of these results shows that the maximum average error in local runoff recorded in the Algiers Coastal Watershed (code 02), at 10.87%, followed by the Kébir Rhumel Watershed (code 10), at 10.29%. The minimum error recorded in the Oranais Coastal Watershed, at 2.94%.

For total flow, the maximum average error was recorded in the Kébir Rhumel Watershed, at 6.58%, and the minimum total flow was observed in the Oranais Coastal Basins, at 2.03%.

Table. 3. Percentage error of interannual average flow calculations for watersheds in Northern Algeria

Watershed	$E_{o,loc}$	E_o	MAE ($E_{o,loc}$)	$MAE(E_o)$
	mm		%	
Cheliff	30.74	46.91	6.87	4.71
Cotiers Algerois	112.08	187.26	10.87	6.43
Cotiers Constantinois	119.69	214.84	6.60	3.86
Cotiers Oranais	15.08	22.042	2.94	2.03
Chott el Hodna	10.84	15.43	5.26	3.73
Chott Melghir	9.29	13.22	6.87	4.77
Hauts plateaux Constantinois	21.09	30.52	4.77	3.24
Isser	24.40	36.29	3.66	2.50
Kébir Rhumel	42.67	74.90	10.29	6.58
Macta	12.75	18.67	8.58	5.82
Madjerdah	24.89	38.42	5.30	3.70
Seybouse	46.62	78.66	8.66	5.42
Soummam	26.88	42.38	3.78	2.38
Tafna	29.49	46.08	7.73	5.14

Explanations: $E_{o,loc}$ = local flow or subsurface flow (mm), E_o = interannual average flow (mm), MAE = mean absolute error.
Source: own study.

Finally, our model can be used to estimate the total flow with an error margin of 4.5% compared to the initial flow.

Thus, the majority of the *IAF* results obtained at the watershed level are acceptable when compared to data from reference hydrometric stations. This confirms the reliability of the proposed model, which can be generalised and applied to all arid and semi-arid basins.

The importance of this model lies in its ability to estimate the water supply available at the level of each watershed or sub-watershed, particularly those that do not have hydrometric stations. It also supports the creation of a comprehensive water resources database that brings together all data concerning the quantity of water and its location, to facilitate their rational exploitation of these resources by different sectors. The model contributes to the management and continuous monitoring of changes in water resources within river watersheds. It assists public authorities in making informed decisions on the use, conservation, and protection of water resources, based on accurate, up-to-date data. This is essential for the design and control of hydrotechnical projects such as dams, agricultural developments, as well as to supply drinking and industrial water needs.

LIMITS, RECOMMENDATIONS AND FUTURE PERSPECTIVES

The model developed in this study aims to estimate the *IAF* in the arid and semi-arid watersheds of Northern Algeria, taking into consideration various climatic and local factors.

In our case, we applied the model using two fundamental parameters: the area of the watershed A and $E_{o,\text{clim}}$. These elements are the most significant among the factors considered and have a direct impact on the average interannual flow.

To improve the estimation of the average interannual flow in the watersheds, we recommend the densification and installation of new pluviometric and hydrometric measurement stations. This would ensure a more regular spatial distribution, giving series of complete and reliable measurements in these watersheds.

Looking ahead, we can deal with other factors likely to influence the average interannual flow, such as vegetation cover, soil characteristics, slope, average elevation, temperature, proximity to the sea, and the hydrographic network.

CONCLUSIONS

Our results from the watersheds of Northern Algeria show that, in small watersheds, the quantity of rain is broken down into overland flow, infiltration, and real interannual evapotranspiration (ETR_o). In medium-sized watersheds, the amount of rain is broken down into overland flow, underground flow, infiltration, and ETR_o. In contrast, in large watersheds, rainfall is partitioned into climatic flow and ETR_o.

In general, the flow of watercourses ($E_{o,\text{obs}}$) is composed of a climatic flow ($E_{o,\text{clim}}$), which is determined by the main climatic factors, such as rain and evapotranspiration, and a complement of flow, called local flow ($E_{o,\text{loc}}$), determined by the local generating factors.

The climatic flow is always greater than the total local flow. Moreover, the capacity for groundwater drainage increases proportionally with the size of the watershed.

Graphical and statistical analyses show dependencies between the climatic coefficient k_{obs} and local factors, indicating strong correlations ranging from 0.615 to 0.92. This allowed us to establish a model for calculating the interannual average flow (*IAF*).

The performance of the model was evaluated using statistical criteria, which indicate high performance and provide good results for the values of *Eo*,loc measured and $E_{o,\text{loc}}$ calculated, with an error margin of approximately 7%.

The corrections made to the local flow allowed for the adjustment of the *IAF* resulting in an error of just 4.5% compared to the initial total flow. Most of the total *IAF* results obtained across the watersheds are acceptable when compared to data from the reference hydrometric stations. This supports the reliability of the proposed model.

Finally, this graphical and analytical model can be adopted to estimate the *IAF* in ungauged watersheds.

CONFLICT OF INTERESTS

All authors declare that they have no conflict of interests.

REFERENCES

ANRH (2002) *Carte d'évapotranspiration de l'Algérie du Nord. Une carte au 1/500000e et sa notice explicative [Evapotransperation map of northern Algeria. Scale 1:500000]*. Alger: Agence nationale des ressources hydrauliques.

Amiar, S. *et al.* (2015) "Modélisation pluie-débit: Calage et validation des modèles hydrologiques GR1A, GR2M et GR4J sur le bassin d'Oued Touil (Cheliff amont de Boughzoul, Algerie) [Modeling rainfall – runoff calibration and validation of hydrological models GR1A, GR2M AND GR4J on Oued Touil catchment (Cheliff upstream of Boughzoul, Algeria)]," *Conférence Internationale FRIEND/UNESCO/Programme Hydrologique International sur l'Hydrologie des Grands Bassins Africains*. Hammamet 26–30 October 2015, pp. 1–10.

Beldjoudi, L. and Larbi, T. (1995) *Etude générale des apports. 2e rapport ANRH General study of contributions. 2nd ANRH report]*. Alger, Algérie: Agence nationale des ressources hydrauliques.

Beldjoudi, L. and Ouled-Yahia, S. (1997) *Étude générale des apports. 3e rapport ANRH [General study of contributions, third ANRH report]*. Alger, Algérie: Agence nationale des ressources hydrauliques.

Benlarbi, D., Boutoutaou, D. *et al.* (2015) "Ruissellement, la pluviométrie et l'évaporation des bassins versants de la zone sud de la méditerranée (cas de l'Algérie) [Runoff, rainfall and evaporation from watersheds in the southern Mediterranean region (case of Algeria)]," *Lebanese Science Journal*, 16(1), 3.

Blöschl, G. *et al.* (eds.) (2013) *Runoff prediction in ungauged basins: Synthesis across processes, places and scales*. Cambridge: Cambridge University Press. Available at: https://doi.org/10.1017/CBO9781139235761.

Bouguerra, S.-A. and Bouanani, A. (2019) "Analyse saisonnière et interannuelle de la dynamique des flux en suspension dans le bassin versant de l'oued Boukiou (nord-ouest de l'Algérie) [Seasonal and interannual analysis of the dynamics of suspended flows in the watershed of the Boukiou wadi (north-west Algeria)]," *Géomorphologie: relief, processus, environnement*, 25(2). Available at: https://doi.org/10.4000/geomorphologie.13189.

Brassington, G. (2017) "Mean absolute error and root mean square error: which is the better metric for assessing model performance?," Geophysical Research Abstracts, 19, EGU2017-3574. Available at: https://meetingorganizer.copernicus.org/EGU2017/EGU2017-3574.pdf (Accessed: April 28, 2017).

Budyko, M.I. and Miller, D.H. (1974) *Climate and life*, 508. New York, NY, USA: Academic Press.

Callede, J. *et al.* (2002) "L'Amazone à Obidos (Brésil): étude statistique des débits et bilan hydrologique [The River Amazon at Óbidos (Brazil): Statistical studies of the discharges and water balance]," *Hydrological Sciences Journal*, 47(2), pp. 321–333. Available at: https://doi.org/10.1080/02626660209492933.

Chaumont, M. (1963) "Contribution al'étude des écoulements en Algérie [Contribution to the study of flows in Algeria]," in *Annuaire hydrologique [Hydrological yearbook]*. Alger, Algerie: ANRH.

Deri, J. (1977) *Étude générale de la ressource en eaux en Algérie. Document technique [General study of water resources in Algeria. Technical document]*. Alger Direction d'Etude et d'Aménagement des Ressources Hydrauliques.

Douvinet, J., Delahaye, D. and Langlois, P. (2008) "Modélisation de la dynamique potentielle d'un bassin versant et mesure de son efficacité structurelle [Simulating the dynamic hydrological potential of a catchment and evaluating its structural efficiency]," *Cybergeo: European Journal of Geography*, 412. Available at: https://doi.org/10.4000/cybergeo.16103.

Ducharne, A. *et al.* (2003) "Influence du changement climatique sur l'hydrologie du bassin de la Seine [Influence of climate change on the hydrology of the Seine basin]," *VertigO La revue électronique en sciences de l'environnement*, 4(3). Available at: https://journals.openedition.org/vertigo/3845?lang=pt#citedby (Accessed: December 29, 2003).

Hodson, T.O. (2022) "Root mean square error (RMSE) or mean absolute error (MAE): When to use them or not," *Geoscientific Model Development*, 15(14), pp. 5481–5487. Available at: https://doi.org/10.5194/gmd-15-5481-2022.

Hrachowitz, M. *et al.* (2013) "A decade of predictions in ungauged basins (PUB) – a review," *Hydrological Sciences Journal*, 58(6), pp. 1198–1255. Available at: https://doi.org/10.1080/02626667.2013.803183.

Kabouya, M. (1990) *Modélisation pluie-débit aux pas de temps mensuel et annuel en Algérie septentrionale [Rainfall-runoff modeling at monthly and annual time steps in northern Algeria]*. PhD Thesis. Paris: Université Paris Sud Orsay.

Kotti, F.C. *et al.* (2016) "Etude des pluies et des débits sur le bassin versant de la Medjerda, Tunisie [Study of rainfall and discharges in the Medjerda watershed, Tunisia]," *Bulletin de l'Institut Scientifique, Rabat, Section Sciences de la Terre*, 38, pp. 19–28. Available at: http://www.israbat.ac.ma/wp-content/uploads/2017/04/Kotti%2011Mai%202017%20final.pdf (Accessed: January 30, 2016).

Ladjel, M. (2020) "Genetic determination of the main components of the mean interannual flow wadis in the semi-arid climate of the Maghreb," *Journal of Fundamental and Applied Sciences*, 12(2), pp. 875–894. Available at: https://doi.org/10.4314/jfas.v12i2.24.

Ladjel, M. *et al.* (2019) "Methodical approach for the estimate of flow wadis from the north of Algeria," *Journal of Fundamental and Applied Sciences*, 11(3), pp. 1086–1098. Available at: https://www.ajol.info/index.php/jfas/article/view/247695 (Accessed: September 1, 2019).

Ladjel, M. and Mezentseva, O. (2016) "Method of assessment the annual flow of the Wadi in the north of Algeria," *Journal of Fundamental and Applied Sciences*, 8(2), pp. 313–326. Available at: https://doi.org/10.4314/jfas.v8i2.10.

Liu, J. *et al.* (2020) "Water balance changes in response to climate change in the upper Hailar River Basin, China," *Hydrology Research*, 51(5), pp. 1023–1035. Available at: https://doi.org/10.2166/nh.2020.032.

Mebarki, A. (2010) "La région du Maghreb face à la rareté de l'eau. L'exemple du défi algérien: mobilisation et gestion durable des ressources [The Maghreb region faces water scarcity. The example of the Algerian challenge: mobilization and sustainable management of resources]," in *ICID+ 18 2nd International Conference: Climate, Sustainability and Development in semi-arid regions*, Fortaleza – Ceará, Brazil, 16–20 August 2010. New Delhi: ICID.

Meddi, H. and Meddi, M. (2009) "Variabilité des précipitations annuelles du Nord-Ouest de l'Algérie [Variability of annual precipitation in northwest Algeria]," *Sécheresse*, 20(1), pp. 57–65. Available at: https://doi.org/10.1684/SEC.2009.0169.

Medinger, G. (1948) *Tableau général de l'hydrologie algérienne dans Hydrologie Algérienne, recueil des observations de 1924 à 1946*. Alger, Algérie: SCEGGT.

Mezentsev V.S. (1976). *Raschety vodnogo balansa [Water balance calculations]*. 2nd ed. Omsk: OmSKHI.

Minea, G. *et al.* (2018) "How can the grasslands under rainfall events modify water balance in drought conditions," *Journal of Water and Land Development*, 38, pp. 53–65. Available at: https://doi.org/10.2478/jwld-2018-0042.

Nash, J.E. and Sutcliffe, J.V. (1970) "River flow forecasting through conceptual models part I – A discussion of principles," *Journal of Hydrology*, 10(3), pp. 282–290. Available at: https://doi.org/10.1016/0022-1694(70)90255-6.

Ol'dekop, E.M. (1911) "Ob isparenii s poverkhnosti rechnykh basseynov [On evaporation from the surface of river basins]," *Trudy Yur'yevskoy Meteorologicheskoy observatorii*, 4.

Padoun, N. (1973) *Écoulement interannuel et bilan hydrique de l'Algérie du Nord [Interannual flow and water balance of northern Algeria]*. PhD Thesis. Kyiv: Ukrainskyi hidrometeorolohichnyi instytut.

Remini, B., Leduc, C. and Hallouche, W. (2009) "Evolution des grands barrages en régions arides: quelques exemples algériens [Evolution of large dams in arid regions: some Algerian examples]," *Sécheresse*, 20(1), pp. 96–105. Available at: https://doi.org/10.1684/sec.2009.0172.

Roche, M. (1963) *Hydrologie de surface [Surface hydrology]*. Paris: ORSTOM.

Schreiber, P. (1974) "Über die Beziehungen zwischen dem Niederschlag und der Wasserführung der Flüsse in Mitteleuropa [On the relationship between precipitation and the runoff of rivers in Central Europe]," *Meteorologische Zeitschrift*, 21, pp. 441–452.

Taibi, R. (1993) *Contribution à l'étude de l'écoulement des cours d'eau de l'Algérie septentrionale. Essai de régionalisation [Contribution to the study of the flow of watercourses in northern Algeria. Regionalization test]*. Montpellier: ORSTOM Laboratoire d'hydrologie, USTL laboratoire d'hydrologie et modelisation.

Touazi, M. (2003) *Evaluation des ressources en eau et acquisition de bases de données à références spatiale et temporelle en Algérie du Nord [Assessment of water resources and acquisition of spatially and temporally referenced databases in Northern Algeria]*. PhD Thesis. Nice: Université de Nice.

Touazi, M. *et al.* (2011) "Régionalisation des débits moyens mensuels en Algérie du nord [Regionalization of the mean regimes of the monthly runoff in northern Algeria]," *Revue des sciences de l'eau*, 24(2), pp. 177–191. Available at: https://doi.org/10.7202/1006110ar.

Touazi, M. and J. Laborde (2004) "Modélisation pluie-débit à l'échelle annuelle en Algérie du nord [Contributions from modeling toxic effects at the individual and population levels in aquatic ecotoxicology]," *Revue des sciences de l'eau*, 17(4), pp. 503–516. Available at: https://doi.org/10.7202/705546ar.

Touazi, M., Laborde, J.P. and Bhiry, N. (2004) "Modelling rainfall-discharge at a mean inter-yearly scale in northern Algeria," *Journal of Hydrology*, 296(1–4), pp. 179–191. Available at: https://doi.org/10.1016/j.jhydrol.2004.03.030.

Voskresensky, K.P. (1951) "Stok rek i vremennykh vodotokov na territorii lesostepnoy i stepnoy zony Yevropeyskoy chasti SSSR [Flow of rivers and temporary watercourses in the forest-steppe and steppe zones of the European part of the USSR]," in D.L. Sokolovskiy *Trudy Gosudarstvennogo ordena Trudovogo krasnogo znameni gidrologicheskogo instituta*, 29 (83). Leningrad: Gidrometeoizdat.

Xing, W. *et al.* (2018) "Projection of future runoff change using climate elasticity method derived from Budyko framework in major basins across China," *Global and Planetary Change*, 162, pp. 120–135. Available at: https://doi.org/10.1016/j.gloplacha.2018.01.006.

Zannou, A. (2011) *Analyse et modélisation du cycle hydrologique continental pour la gestion intégrée des ressources en eau au Bénin: cas du bassin de l'Ouémé à Bétérou [Analysis and modeling of the continental hydrological cycle for integrated water resources management in Benin: the case of the Ouémé basin in Bétérou]*. PhD Thesis. Cotonou, Bénin: Université d'Abomey-Calavi.

Zhang, L. *et al.* (2008) "Water balance modeling over variable time scales based on the Budyko framework – Model development and testing," *Journal of Hydrology*, 360(1–4), pp. 117–131. Available at: https://doi.org/10.1016/j.jhydrol.2008.07.021.