STUDY OF LOW FLOWS AND BASE FLOWS IN NORTHWESTERN ALGERIA*

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Abstract

The hydrological regimes of minimum annual flows are crucial for an efficient development of water resource management tools, especially in those areas stressed by the combination of a dry climate and excessive water demand, such as the Mediterranean basins. Many efforts have been made by the worldwide scientific community to predict the characteristics of minimum annual flows in ungauged basins.

The main objective of our study is to find models and tools that help us to predict low flows in Mediterranean and semi arid climate, for this we have tried to present the main factors that condition the minimum annual flows in northwestern Algeria.

The objectives of this study are:

- Presentation of the study area and the different methods used for the extraction of the morpho-metric and hydrographic characteristics of basins using digital terrain models.
- Examine the main climate and hydrological conditions by the study of the behavior of the various parameters that control the change of the extreme flow regime before tackling the study of low flows using direct and indirect methods that are made available to us by our predecessors.
- We will focus on the description of surficial formations and their spatial organizations. We will also focus on the properties of soils and subsoils (geological and hydrogeological factors) to identify the issues related to infiltration and aquifer recharge.
- The application of a method of hydrograph decomposition to separate baseflow from total streamflow, quantify the BFI values for each station of the examined database.
- The delineation of homogeneous regions is made using the Principal Component Analysis (PCA) and k-means cluster analysis.
- The evaluation of independent regional and global relations between the BFI and the climatic, morphometric and geological characteristics of watershed.

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Introduction

In northern Algeria, the socio-economic, hydroclimatological, lithological and geomorphological conditions are the main parameters that determine the phenomenon of low flows.

- The lithological nature of formations having a predominance of sandy soils in the major wadis bed, as soon as we moves away from that, the soil has a fine texture of clay type.
- The Mediterranean climate, characterized by a sharp contrast between wet and dry seasons, where a period of intense and abundant rainfall is followed by a long period of heat and drought.
- The vegetation cover, virtually non-existent on mal areas, generally sparse on reliefs (many degraded stands play only very imperfectly their protective role); and socio-economic factors that significantly contribute to speed up the process of land colonization which accelerate flows.
- The weakness of the Chellif wadi slope between the Touil Wadi up to low Chellif is the area where all tributaries flow;
- Another cause is the change in rainfall regime since the 70s, the impacts on the hydrological regime of rivers are therefore inevitable.
- The increase of the seasonal and interannual irregularity of flows for most of the year.

All these phenomena will be detailed in our thesis before tackling the study of low flows using direct and indirect methods by:

- The application of a method of hydrograph decomposition to separate baseflow from total streamflow, quantify the BFI values for each station of the examined database.

- The delineation of homogeneous regions is made using the Principal Component Analysis (PCA) and k-means cluster analysis.

- The evaluation of independent regional and global relations between the BFI and the climatic, morphometric and geological characteristics of watershed.

General presentation of the study area

I.1.Natural division:

The study areas covers a total area of 133 500 Km^2, it is located between 32°65' and 36°65' north latitude and between -2°30' and 3°92' east longitude. It covers two major basins of northwestern Algeria, the Chellif basin and that of Oran. It affects roughly the shape of the axe-head of North-South axis (figure 01).

This region corresponds approximately to the centre of what geographers call the Maghreb and the traditional divisions of this country are particularly clear. This region extends from the Mediterranean Sea in the north and cover successively from north to south the Inter Tellian depression, the southern boundary coincides with the crest of the Saharan Atlas.

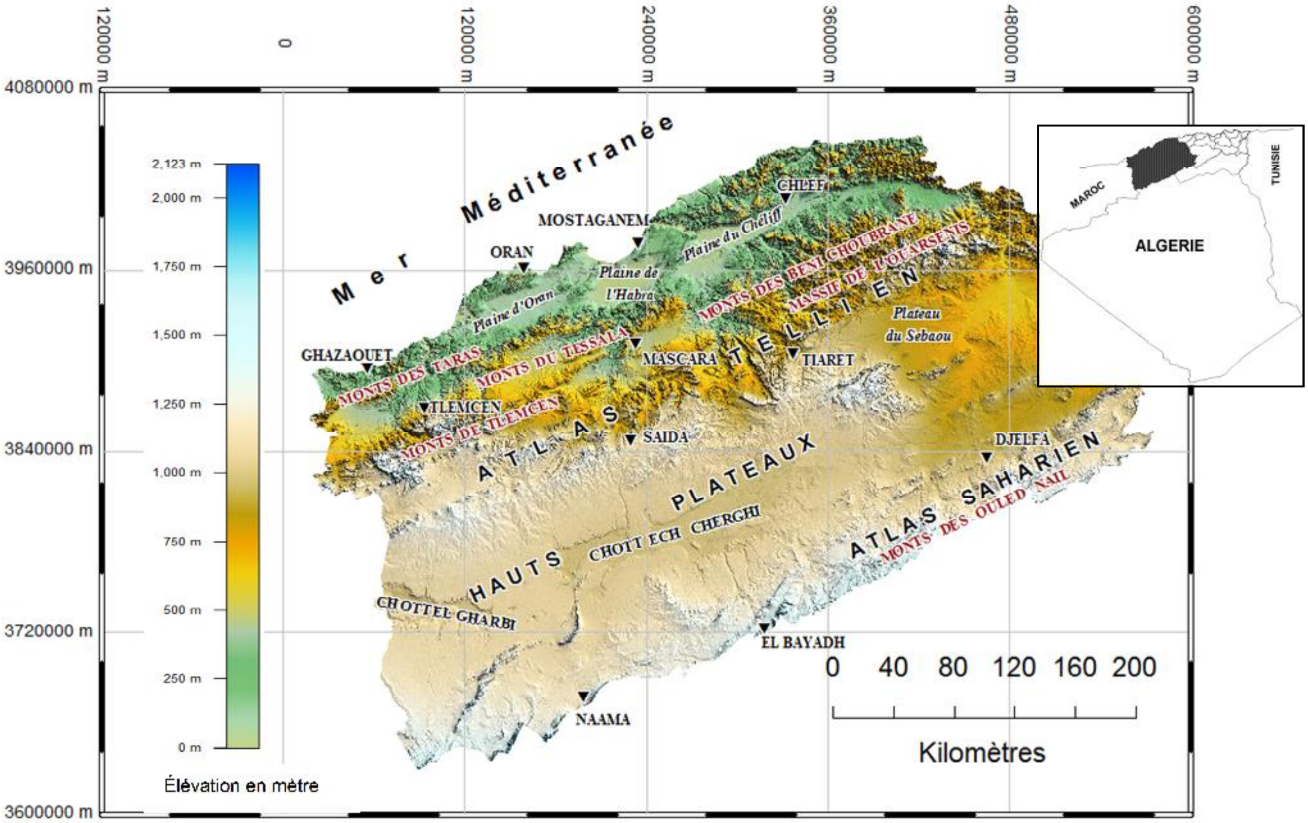

Figure 1: location map of the study area and distribution of sub watersheds.

I.2. Morphological characteristics of sub basins

The morphological characteristics of a region or more specifically a watershed, basic unit in a hydrological study, play a crucial role in determining the different behaviors of the hydrological regime.

Thus, two neighboring basins with similar climatic and geological conditions and different morphological characteristics react differently in terms of flow regime.

The computer tool whose use is more common these days is a very powerful tool in terms of execution speed and calculation accuracy. The delineation of sub basins (drainage divide) and hydrography are drawn from a digital terrain model, using a watershed modeling tool (WMS, Watershed Modeling System) (figure 2). This tool can also calculate the morphometric characteristics of basins.

Table 1: details of watersheds of the study area: reference map number and station name, area (km2), the Gravelius compactness index, the average altitude of the topographic watershed (H_{moy}), the average slope of the topographic watershed (I), drainage density, mean annual precipitation (P_{moy}), annual flow (Qmoy), baseflow index (BFI), aridity index (IR), percentage of vegetation cover(PCV), hydrogeological classes (CHG).

Nbr Station	code Station	Name Station	wadi	area (Km^2)	K_G	Hmoy (m)	Imoy (%)	Dd	Pmoy (mm)	Qmoy (m3/s)	IEB (%)	IR	PCV (%)	CHG
1	010711	FERME FARHAT	SOUSSELEM	483.64	1.94	1139.4	5	0.45	302.9	0.0667	21.2	3.87	15	1
2	011210	SIDI BOUABDELAH	TOUIL	282.32	2.11	792.9	1	0.48	325.5	1.0615	45.6	1.83	12	9
3	011501	TAMEZGHIDA	HARBIL	238.84	1.59	817.6	15	0.35	465.6	2.5558	42.2	3.05	45	1
4	011715	EL ABBABSA	HARREZA	109.36	1.73	511.4	9	0.38	433.6	0.1761	28.8	3.19	20	5
5	011801	ARIB EBDA	EBDA	289.84	1.79	753	26	0.39	570.8	2.5649	53.9	3.87	72	1
6	011905	BIR OUELD TAHAR	ZEDDINE	582.16	2.07	697.9	13	0.39	423.9	0.5228	33.5	2.88	25	5

7	012004	TIKAZAL	TIKAZAL	124.16	1.78	474.6	12	0.4	429	0.6372	16.5	2.88	35	5
8	012201	OULED FARES	OUAHRANE	259.12	1.83	361	10	0.37	396.3	0.146	29.9	2.92	18	5
9	012501	OUED LILLI	RIOU	333.52	1.78	782.1	11	0.41	365.7	0.479	46.6	2.84	35	1
10	012601	AMMI MOUSSA	RIOU	1923.2	1.91	673.6	12	0.39	375.8	1.998	27.5	2.88	30	1
11	012701	DJEDIOUIA RN4	DJEDIOUIA	835.36	2.04	468.2	8	0.39	369.1	0.634	30.7	2.34	10	1
12	013001	KEF MAHBOULA	TAHT	677.08	1.76	862.1	8	0.41	336.6	0.3496	34.3	2.96	22	1
13	013301	TAKHMART	EL ABD	1546.6	1.85	1006.2	4	0.42	256.9	0.6013	43.0	2.02	10	1
14	013302	AIN AMARA	EL ABD	2526.1	2.04	887.3	5	0.42	294.6	1.1257	47.5	1.96	10	3
15	020114	KRAMIS	KRAMIS	375.28	1.73	378.8	11	0.37	441	0.7765	41.6	3.2	20	1
16	020207	SIDI AKACHA	ALLALAH	297.8	1.78	321.6	11	0.39	555.2	0.4583	15.7	4.29	23	5
17	040101	GHAZAOUET	EL MARSA	264.68	1.9	409.6	12	0.44	391.45	0.111	35.3	3.25	40	3
18	040220	TURGO NORD	EL MELAH	548.08	1.73	366	7	0.35	462.99	0.5681	58.6	3.82	25	5
19	110301	SIDI BEL ABBES	EL MEBTOUH	2987.7	2.44	920.6	4	0.43	323.20	0.9561	67.0	2.39	38	9
20	111101	SAIDA PARCHAL	SAIDA	95.08	1.79	1074.2	4	0.45	266.40	0.1125	85.7	1.96	15	3
21	111129	SIDI BOUBEKEUR	SAIDA	621.76	1.9	854.1	8	0.43	329.58	0.4201	36.0	2.46	28	3
22	111208	SIDI MIMOUN	SI MIMOUN	762.44	1.72	1089.8	5	0.43	302.60	0.3365	67.7	2.5	35	3
23	160402	BENI BEHDEL	TAFNA	509.44	2.07	1118.3	10	0.42	432.57	0.9092	68.7	2.9	27	3
24	160	SIDI	ISSER	815.	1.	977.	13	0.	342.	0.39	48	2.	38	1

	614	AISSA		56	83	1		41	76	41	.4	45		

These characteristics result in significant differences between watersheds in the study area. Table 1

The vegetation is sparse and has a low density across the study area. It has been widely degraded and eliminated by fires in mountains and by extensive and continuous agricultural practices.

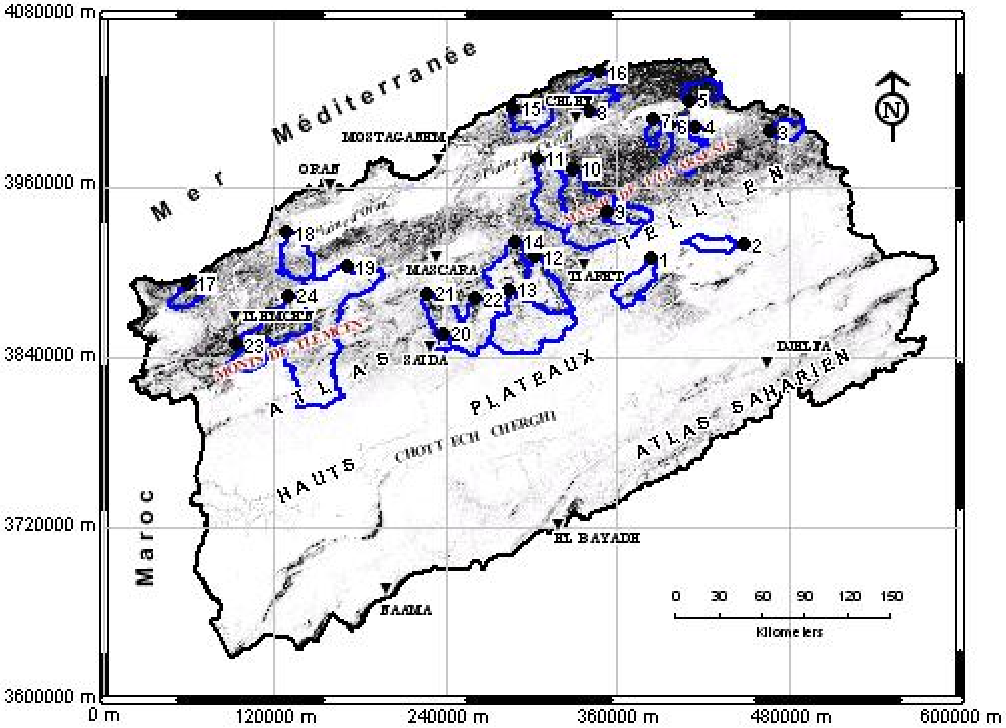

Fig. 02: Sub watersheds controlled by the hydrometric stations selected in the study.

V Estimation and variation of baseflow

V.1 Description of the UKIH method

In this study, the modified separation hydrograph is obtained through the use of the method proposed by the UK Institute of hydrology, now the Center for Ecology and Hydrology in Wallingford (Institute of Hydrology, 1980). This empirical filtering technique was proposed as the most reliable method for hydrograph separation in an area of similar context of climatic and geological parameters of the area (Longobardi et Villani, 2008).

The UKIH method is based on the identification and interpolation of turning points within an input time series of streamflows. The method is applied to daily average data. The turning points indicate the days and corresponding values of streamflow where the observed flow is assumed to be entirely baseflow. To calculate the points, the streamflow data are partitioned into a sequence of five-day segments and the minimum values of streamflow within each segment, an *x* and *y* pair where *xi* is the day on which the minimum value of flow of *yi* occurred, are selected and defined as candidate turning points. Each candidate is then compared to the minima for the previous and subsequent segments. Turning points are defined where the condition

$$09.y_i<\min(y_{i-1}\,;y_{i+1})$$

is satisfied, where : *yi* is the minimum value of mean daily flow in a five-day segment, that occur the day 1, and the value 0,9 is the value of the inflection factor. The method was revised by Piggott et al. (2005), to resolve two aspects of the initial method that lead to less than optimal results: the calculation of values of baseflow that exceed the corresponding values of streamflow and the dependence of the calculated values on the origin of the five-day segmentation of the streamflow data. The implementation of the UKIH method resolves this aspect by constraining the calculated values of baseflow: if the value of baseflow determined by the interpolation is greater than the corresponding observed flow, the observed value is used in place of the interpolated value.

Figure 8 illustrates the result of the application to the data of average daily flows observed during two months of 1982 for the PIERE DE CHAT station (N=5). The dashed lines indicate that the order of the five-day segments of data and the large black dots indicate the minimum for each segment. A point of minimums occurring during the period satisfying the equation « $f.y_i < \min(y_{i-1}\,;\ y_{i+1})$ » is defined as the turning point and represented by an open circle. The linear interpolation connecting the turning points indicates the variation of baseflow.

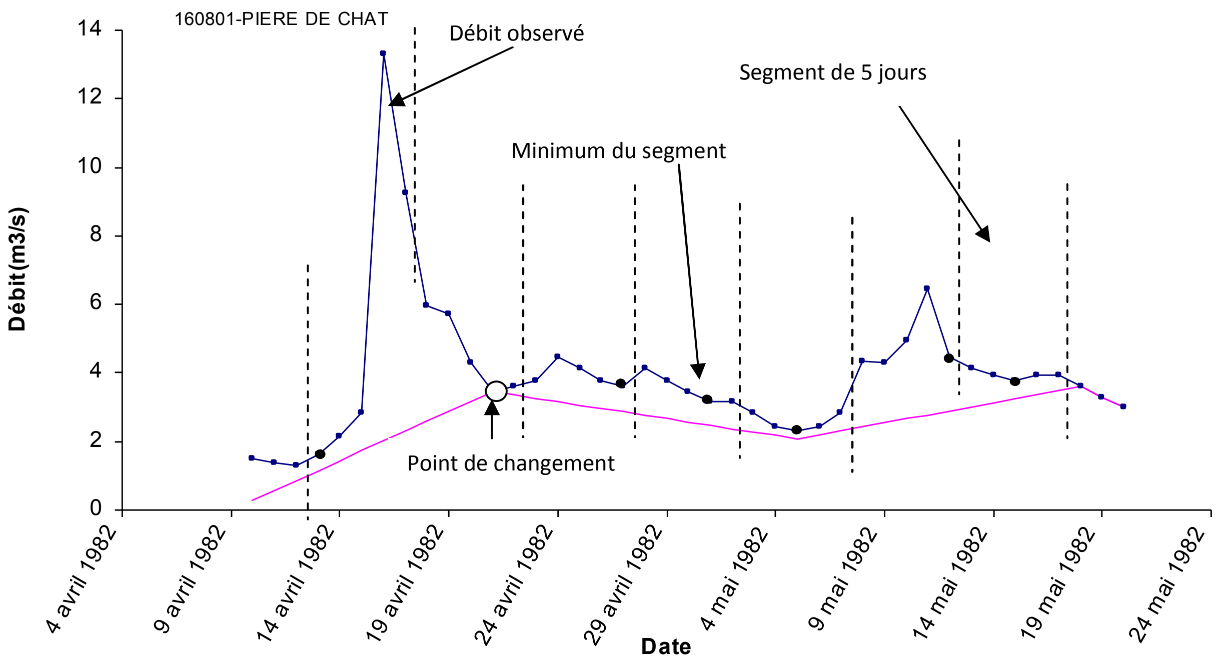

Figure 8: separation of the BFI of April and May 1982 in the PIERE DE CHAT station

The UKIH technique was applied, to each station, both on all time series of flows, to calculate the BFI for periods of time and on an annual basis, to derive a series of annual BFI and the corresponding statistics. Data are reported in Table 5.

A comparison between the BFI of the period and the BFI average, the average of the series of annual BFI highlight that the differences are not systematic, but depend on the variance of the series of annual BFI, with the largest differences related to the highest value of the BFI variation coefficient. In what follows, the average BFI was considered the target index.

Table 5: Comparison between the statistics of the time series of annual BFI and the estimations of the entire period of BFI.

code Station	BFI of the period	BFI annual average	standard deviation	Coefficient of variation
10711	0.211	0.431	0.280	1.321
11210	0.456	0.482	0.218	0.478
11501	0.421	0.412	0.115	0.271

11715	0.287	0.424	0.207	0.718
11801	0.539	0.554	0.105	0.194
11905	0.335	0.378	0.116	0.346
12004	0.165	0.268	0.189	1.143
12201	0.299	0.233	0.174	0.580
12501	0.466	0.500	0.124	0.266
12601	0.275	0.328	0.161	0.586
12701	0.306	0.307	0.132	0.430
13001	0.343	0.315	0.394	1.148
13301	0.430	0.485	0.221	0.518
13302	0.475	0.436	0.208	0.438
20114	0.416	0.513	0.467	1.120
20207	0.157	0.177	0.121	0.766
40101	0.352	0.392	0.185	0.526
40220	0.586	0.573	0.197	0.336
110301	0.670	0.655	0.199	0.297
111101	0.857	0.860	0.039	0.044
111129	0.360	0.324	0.157	0.435
111208	0.677	0.672	0.243	0.358
160402	0.687	0.691	0.137	0.198
160614	0.484	0.427	0.199	0.412

VI. Baseflow index regionalization

VI.1. Delineation of homogeneous regions of low flows: watershed clustering

The baseflow is conceptually related to many climatic, physiographic and geological parameters, a significant variability can be observed in the behavior of low flows. For this reason, before attempting to identify a procedure to predict the baseflow index in ungauged basins, the delineation of homogeneous areas was necessary, with a uniform behavior of low flows. In most cases, the choice of the technique of clustering into homogeneous regions is far from evident, and it can also affect the goodness of fit of the corresponding regional regression models, validated for each particular region. For this reason, both the Principle Component Analysis (PCA) and k-means cluster analysis were applied and the establishment of the comparison between the corresponding independents regression.

The watershed characteristics must be selected for the application of clustering techniques. The following elements were taken into consideration in this study, to represent topography, land use, geology and climate.

VI.2. Application of the Principle Component Analysis (PCA) and k-means cluster analysis

The Principle Component Analysis (PCA) is a statistical technique largely used for a large number of water resources related to the analyzed issues, and of these, for baseflow index estimations (Eslamian et al., 2010). It reduces the number of variables to those that are the most significant among a set of variables and it is used to find a link between the stations and group them into homogeneous regions in terms of low rates. One of the objectives of the PCA is to obtain useful information from a data matrix, and provide a graphical representation of data to facilitate the analysis.

The mathematical procedure of the principle component analysis is in fact a multivariate statistical method to process data. As part of this work, a correlation matrix was used and the components were determined with and without "Varimax" rotation type of orthogonal axes. The reconstruction of the sub basins clustering, allowed the definition of the factorial axes (vectors), they are factors responsible for linking the spatial distribution and thus highlight the affinities and differences between groups and deduce from it the parameters that best characterize each group. Geological, hydrogeological and climatic (mainly precipitation and evapotranspiration), drainage density, watershed slope and vegetation cover could affect the BFI value, and for this reason, they are taken into consideration in the PCA, which leads to the realization on the mentioned physiographic parameters, the climatic and geological variables are presented in Table 7 and 8.

Table 7: Percentage of variance after Varimax rotation.

Vectors	F1	F2	F3
Variance (%)	32.42	29.83	22.63
Cumulative (%)	32.42	62.25	84.88

Table 8: Contribution of variables (%) after Varimax rotation.

Vectors	F1	F2	F3
Drainage density Dd	0.22	49.01	5.90
Average slope Ig	38.15	4.31	13.76
Aridity index IR	4.92	44.99	0.63

percentage of vegetation cover PCV	55.80	1.17	0.06
Hydrogeological classification CHG	0.89	0.49	79.62

According to the variance criterion, the cumulative contributions of each variable to the orthogonal components are presented for the first three ones of them: the first three axes explain 84.88'% of the total variance for the study area (Table 4), and the influence of geological parameters on baseflow gave rise as dominant. The circle F1-F2 (62,33% of the cumulative inertia) is illustrated in Figure 4 the upper part: the F1 axis is determined by the conditions of topography and soil, while the F2 axis is determined by the drainage density and aridity index.

The circle F1-F3 (54,89% of the cumulative inertia) is illustrated in Figure 9 the lower part: the F1 axis has the same meaning and the F3 axis is strongly determined by the permeability (Table 5). The circle F1-F3 can also distinguish five groups of watersheds, with homogeneous climatic and physiographic characteristics. The boundaries of these five areas are illustrated in Fig.9.

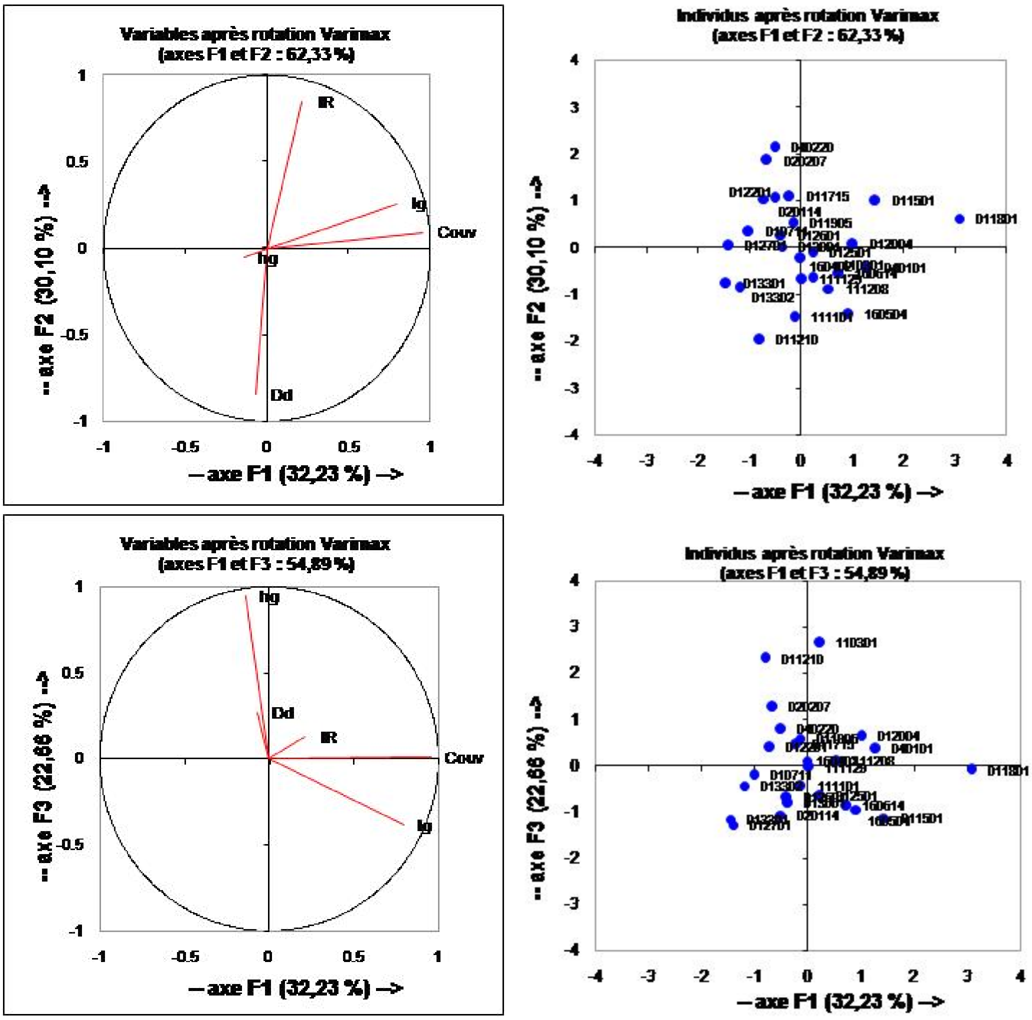

Figure 8: Results of the PCA after Varimax rotation

Region	Numéro	Code station	Nom station
A	4	011715	EL ABABSA
	6	011905	BIR OUELD TAHAR
	7	012004	TIKAZAL
	8	012201	OULED FARES
	16	020207	SIDI AKACHA
	17	040101	GHAZAOUET
	18	040220	TURGO NORD
B	1	010711	FERME FARHAT
	9	012501	OUED LILLI
	10	012601	AMI MOUSSA
	11	012701	DJIDIOUIA RN4
	12	013001	KEF MAHBOULA
C	15	020114	KRAMIS
	13	013301	TAKHMART
	14	013302	AIN AMARA
	20	111101	SAIDA PARCHALL
	21	111129	SIDI BOUBEKEUR
	22	111208	SIDI MIMOUN
	23	160402	BENI BEHDEL
	24	160614	SIDI AISSA
D	3	011501	TAMEZGHIDA
	5	011801	ARIB ABDA
E	2	011210	SIDI BOUABDELAH
	19	110301	SIDI BEL ABBES

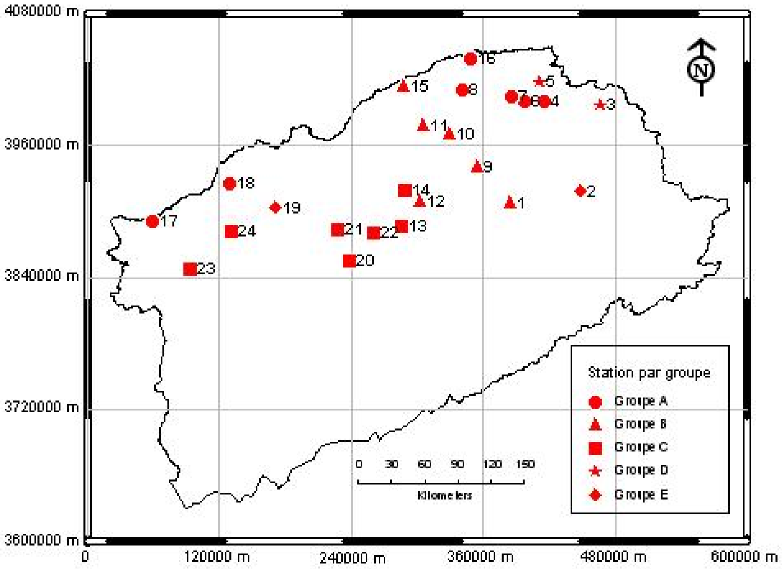

Figure 9: watersheds clustering by the PCA in the study area.

The results in Table 8 show that all the above-mentioned climatic and physiographic factors have the potential to affect minimum annual flows, but it is clear that, in the study area, the geological and hydrogeological parameters have the greatest influence on the conditions of minimum annual flows: regional hydrogeological parameters can completely change hydrogeological regime during periods of drought, especially for basins with abundant sources of calcite areas (karst) that could increase several times the component baseflow of total streamflow (Dzubak et Dub, 1961).

As mentioned earlier, in order to prevent the quantitative study from being affected by the choice of a particular clustering technique, an alternative method of group delineation, the k-means cluster analysis was applied. The relative importance of the number of groups to be reproduced in the analytical results could have been explored, but, for comparison, it was set at 5, as the result of the PCA. For the same reason, the same descriptive variable used in the PCA was used to delineate groups. The results of clustering are shown in table 9.

Table 9: Results of K-means clustering of stations

Region	A	B	C	D	E
Objects	6	7	7	3	1
Sum of weights	6	7	7	3	1
Intra-class variance	26.10	46.83	15.21	5.07	0.00
Centroid minimum distance	2.04	2.40	2.88	0.97	0.00
Centroid average distance	4.27	5.49	3.58	1.72	0.00
Centroid maximum distance	7.15	10.38	4.07	2.51	0.00

Even if the number of groups is the same, there is no strong apparent correspondence between clustering methods: the groups have different numerical consistency and a particular station belongs to different regions for different methods. The two methods indicate, moreover, that the five regions, the numerical consistency of two of them is not enough to apply the prediction model in the ungauged basins. None of these techniques reproduces geographically adjacent regions; this is not an unexpected characteristic since the conditions of minimum annual flow are not primarily related to variables, which have a high spatial coherence, such as climatic factors that, on the other hand, strongly influence the flood conditions, in this case, the geographical contiguity is much more likely to be reproduced. The PCA technique is however able to indicate the extent of the dependence of BFI on the clustering variables: as mentioned above, the geological parameters are the most important conditions of the study area. Another comparison of clustering techniques is given, on a quantitative basis, through the calibration and validation of multiple linear regression models of the independents of each region.

VI.3. BFI regionalization: multiple linear regression models

VI.3.1. Linear models of multiple regression

The great extension of the study area required the delineation of homogeneous regions of minimum annual flows. The effectiveness of the clustering approach and the clustering technique in particular is explored through a comparison of the regional regression models of independents, calibrated on each region for each method, and a global model of regression, calibrated over the entire region. For the two analyses; the PCA and k-means cluster analysis, the regions D and E do not have the numerical consistency for the validation of an empirical model, they are abandoned in this analysis. Further study would be needed to explain the big differences exposed from watersheds falling within these groups, the hydrological regime that could be strongly affected by anthropogenic factors, which are outside the class of independent variables taken in this study. The model equations are presented in Table 10 and 11. The five independent variables appear in each of the model equations, except for Region B clustering by the PCA and region A clustering by the k-means cluster analysis, where the CHG parameter is not included because watersheds in these regions are all characterized by the same hydrogeological class. The validation of multiple linear regression models is discussed in the following paragraph.

Table 10: regional models and a global model of multiple linear regression and the relative goodness of fit (of PCA clustering).

Region	Model equation	R^2	R^2_{cor}	d
A	BFI = -2.26 – 8.15*log Dd – 0.23*log Ig – 0.60*log IR + 0.81*log PCV -2.05* log CHG	0.92	0.91	1.42
B	BFI = -0.054+ 0.757*log Dd + 0.743*log Ig - 0.320*log IR + 0.097*log PCV	0.84	0.80	2.64
C	BFI = 3.916+ 11.190*log Dd + 1.027*log Ig + 2.233*log IR -0.708*log PCV -0.263* log CHG	0.82	0.79	2.63
global model	BFI = 0.494 + 0.314*log Dd + 0.093*log Ig -0.862*log IR + 0.238*log PCV + 0.049* log CHG	0.32	0.18	1.83

Table 11: regional models and a global model of multiple linear regression and the relative goodness of fit (of k-means clustering).

Region	Model equation	R^2	R^2_{cor}	d
A	FBI = 1.142 + 3.479*log Dd + 0.914*log Ig - 1.158*log IR + 0.205*log PCV	0.99	0.99	2.97
B	FBI = -1.116 + 1.049*log Dd -0.452*log Ig - 1.765*log IR + 2.107*log PCV -0.186* log CHG	0.70	0.64	2.76
C	FBI = -2.142 – 4.964*log Dd -0.520*log Ig + 0.282*log IR + 0.723*log PCV -0.286* log CHG	0.97	0.96	2.42
Global model	FBI = 0.494 + 0.314*log Dd + 0.093*log Ig -0.862*log IR + 0.238*log PCV + 0.049* log CHG	0.32	0.18	1.83

VI.3.2. validation of regression models

The average values of the observed BFI and the estimates of global and regional models are shown in Table 12. The illustrated data show that the average error associated with the global model (validated through the study area) is about 35%, while the two clustering techniques can reduce the average error to about 10%.

The two regional and global models (regardless of the clustering technique) predict a significant underestimation (19 to 46%) for some watersheds: this could be an indicator of the effects caused by man.

The main statistical data are listed in Table 10 and 11 for each validated model.

Table 9: comparison between the observed and estimated BFI

Code station	Observed average BFI	Estimated BFI Global model	estimated BFI regional model (PCA clustering)	estimated BFI regional model (K-means clustering)
10711	0.212	0.230	0.199	0.209
11210	0.456	0.539	0.456	0.467
11501	0.306	0.456	0.294	0.327
11715	0.430	0.375	0.453	0.391
11801	0.480	0.398	0.428	0.491
11905	0.857	0.443	0.877	0.855
12004	0.500	0.460	0.500	0.443
12201	0.165	0.411	0.201	0.242
12501	0.466	0.448	0.414	0.463
12601	0.352	0.442	0.352	0.368

12701	0.670	0.390	0.670	0.696
13001	0.677	0.373	0.630	0.496
13301	0.484	0.443	0.502	0.606
13302	0.288	0.467	0.256	0.270
20114	0.335	0.297	0.271	0.304
20207	0.299	0.404	0.355	0.337
40101	0.343	0.404	0.398	0.338
40220	0.416	0.361	0.407	0.413
110301	0.157	0.596	0.167	0.173
111101	0.586	0.478	0.581	0.589
111129	0.275	0.492	0.305	0.280
111208	0.360	0.505	0.526	0.525
160402	0.687	0.424	0.600	0.517
160614	0.539	0.504	0.539	0.539

The need for homogeneous delineation is evident from the comparison of the coefficients of determination (R^2 and R^2 cor) of the global model validated over the entire area and all data, and regional models calibrated on the regions A, B and C.

The global model explains only 18% (R^2 cor) of the variance, while regional models explained the variance from 64% (R^2 cor of region B by the k-means cluster analysis) to 99% (R^2 cor of region A by the k-means cluster analysis). The effectiveness of the clustering technique in particular, either the principle component analysis or the k-mean cluster analysis, is not really obvious, at least for this case study. the coefficients of determination (R^2 and R^2cor), calculated for the regions A, B and C, for each clustering method are comparable, with a strong trend for large consistent values of R^2 cor for all regions, in the case of the PCA method. The same remark can be given on the test of residual autocorrelation, where the Durbin-Watson index shows similar consistent values close to $d = 2$, which indicates that there is no evidence of a significant autocorrelation in the residuals of the model.

Conclusion

We presented in this study (1) the quantification of low flows and (2) the application of a simple regional approach to predict the BFI on ungauged sites, for a northwestern region of Algeria, with a large surface area of about 130.000 km2, and a low density of hydrometric network.

To prevent this quantitative study from being affected by the choice of a particular watershed clustering technique, alternative methods of group delineation have been applied; the principle component analysis and k-means cluster analysis.

The principle component analysis is however able to indicate the degree of dependence of baseflow conditions on the clustering variables, which would be a favourable feature. The importance of the delineation of homogeneous regions and the effectiveness of the specific clustering technique was tested by comparing the global model and regional models of the multiple regression of independents. For the study area, the PCA highlighted the main dependence of BFI on geological parameters, but to develop approaches of multiple regression, independent variables were selected in order to improve the performance of the model, such as drainage density, the average slope of watershed, the aridity index, geological characteristics and the percentage of vegetation cover.

The need for the delineation of homogenous areas results from the comparison of the main fittings of global and regional models: the global model explains only 18% of the variance, while regional models explain up to 99% of the variance.

The effectiveness of the specific clustering method is not very obvious, with a strong trend for large consistent values of the variances explained for all regions in the case of the PCA method.

In the end, the analyses are also a preparatory step towards an overall framework for the estimation of baseflow indices and a study of the dependence of several independent variables, such as weather conditions, with a possible impact that depends on the spatial and temporal variability.

Application perspectives

Besides these research perspectives, this work should help to start more confidently the development of hydrological tools based on models and also to be used in the operational area. Indeed, there is a strong demand for these tools in Algeria and abroad from engineers, structure designers, resource managers and decision-makers, as water becomes an increasingly important issue. Propose applications of the models could help make progress in comparison with current methods, still too rudimentary. If our modeling approach can not address now all the problems of quantitative hydrology, it is, in our opinion, among the most reliable and easier to use for a wide range of issues.

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