Improvement of Interpolation Using Information From Rainfall Stations and Comparison of Hydroclimate Changes (1913-1938)/(1986-2016)

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Abstract. The primary objective of this study is to use a better method for rainfall mapping in areas with low density rain gauge networks. Secondly, to identify and study hydro-climatic change in the semi-arid high plains of eastern Algeria on the basis of a comparative mapping approach. The latter concerns the annual rainfall map produced by the authors of this paper for the period studied (1986/2016) and the annual rainfall map for the period 1913/1938, prepared by Chaumont and Paquin (1971). The results of this analysis show that isohyets between 300 mm and 350 mm cover a large part of the study area, they occupy an area of 14444 Km², followed by isohyets between 200 mm and 300 mm with an area of 5298 Km². In addition, the comparative analysis between the periods showed that hydro-climatic change was clear for the 200 mm, 300 mm and 400 mm isohyets, whereas there are no major changes for the 500 mm and above isohyets. Data processing based on a combination of statistical and geostatistical analysis (multiple linear regression and kriging) has once again shown the value of taking into account other parameters in the design of rainfall maps, such as geomorphological and geographical parameters.

Keywords. Hydroclimate change, Digital mapping, Statistical modeling, Geostatistics, decision-making tools, Algeria.

I. INTRODUCTION

Climatic random parameters constitute constraints that may affect directly or indirectly the performance of the economy. They limit by their natures the interventions of the decision-makers at the macroeconomic or microeconomic level [1]. In this context, it is important to study the climate, statistically, while considering it as an intrinsic factor with defined and uniform characteristics [2]. The rains fluctuate in space and time its among and distribution are affected by many factors, including geographical, seasonal variations, temperature, atmospheric pressure and topography [3]. Many studies have been conducted to correlate these variables with the mentioned factors based on mathematical modeling. Multiple regression, interpolations, etc. as an alternative to improve estimation using data provided by available meteorological measurement stations [4-10]. The necessity to take into account the temporal and spatial variability of the data, the possible errors and limitations of the samples (Rain gauging stations) contributed to choos a rainfall modeling approach in its spatio-temporal dimension. Indeed, it is not so much the average annual rainfall that matters as its spatial and temporal distribution [11]. Precipitation could be estimated incorrectly if topographic variables influencing precipitation are not taken into account [12]. rainfall can be spatially estimated using interpolation methods with simple mathematics models (inverse of distance, surface trend analysis, splines, etc.). and Thiessen polygons, etc.). In addition, precipitation can be estimated by a a more complex method based on kriging. Actually, geostatistical interpolation has become an important tool in climatology because it takes into account spatial variability and quantifies the uncertainty in the estimate [13-15]. The Geographic Information Systems (GIS), geostatistics provide explanations spatial rationality of the phenomenon under study. Multiple linear regression (MLR) is a well-known method of mathematics modelling the direct linear relationship between a dependent variable and one or more independent variables [16]. It has been widely used for the estimation of climate variables [17]. Independent variables generally include station location and elevation in areas where climate is significantly correlated to topography. Independent variables generally include station location and elevation in areas where climate is significantly correlated to topography [18] and have been applied with a number of topographic variables in order to analyse orographic rainfall.

In this study, we focused on reproducing the observed properties of rain fields, through the numerical tools of simulation (multiple regression and geostatistics). This approach considers the rainy field as a realization of a random process for the modeling of rain fields and tries to reproduce this phenomenon, respecting the statistical and geometric properties observed. Also, it is important to note that this study is a continuation of a work already started and published [19]. Consecutively with the first results, the objective is to present a tool which will increase the accuracy of precipitation estimation in the space and to realize a comparative analysis of the annual rains between two different periods (1986-2016) and (1913-1939) applied to the Eastern High Plateaus region of Algeria.

II. MATERIAL AND METHODS

- **Study area description**

With a total area of 2.381.741 square kilometres, Algeria is situated in the transition zone between the Mediterranean sub-humid and humid climate in the north, and arid Saharan climate in South [20,21]. The northern part is characterized by a cold-rainy winter and a hot-dry summer. Moreover, the climate presents a clear East-West and North-South apparent hydro-climatic gradients [22]. The distribution of precipitation is very heterogeneous and varies generally according to the relief and the distance from the sea [23]. In addition, the yearly rains in the north part of Algeria were distributed according to a normal root distribution [24]. However, North East of Algeria is subjected to very irregular spatio-temporal variations [25].

With an area of 33,610 Km^2 and a perimeter of 1,872 kilometers the study area is located in semi-arid Eastern high plateaus region of Algeria, geographically situated between 4.2 ° and 8.3 ° North latitude and between 35.00 ° and 36.6 ° East longitude. It is part of the alpine orogen, which is the backbone of the reliefs of all northern Algeria. The relief offers much more open horizons, the sedimentary cover, less thick and more discontinuous [26]. Several chains of Mountains naturally limit the study area between a north and the south. The main plains are those of Bordj Bou Arreridj, Setif, Oued El Othmania and El Khroub at Constantine. Furthermore, other plains occupy the area, plains of Mila in north and plains of Touffana and Batna in South [27]. Moreover, by bachir et al. 2016, the study area is dominated by plains with very low slopes (0-5%). The choice and delimitation of the region is based mainly on the particular importance of cereales crops, particularly durum wheat in terms of area and yeild.

- **Prospecting and data collection**

In order to highlight the characteristics of the region, prospecting and investigation work in the agropedoclimatic context was necessary for the identification and selection of the most reliable informations. Investigations were carried out to highlight previous work carried out in the study area. This research mainly concerned work related to natural data and the physical environment, in particular for any variable data over time, such as climate data (Tab.1). These latter are collected, for the most part, from the professional and auxiliary weather stations belonging to the National Office of Meteorology, also from some rainfall stations belonging to the National Agency for Water Resources (NAWR).

TABLE 1. Inventory of data collected from the study area.

Thematic	Supplier organizations	Years	Periode	Ladders
Rainfall accumulation at a few stations.	N.A.W.R	2018	1986-2016	-
Yearly Rainfall map of Chaumont and Paquin	National Superior School of Agriculture (E.N.S.A)	1971	1913-1938	-
Slope map.	(Bachir et al, 2016)	2001		1/200 000
Hydrographic network map.	National Institute of Cartography and Remote Sensing	2001		1/200 000
Digitized map of the administrative division.	//	2001		1/200 000
Crop cover overview map.	National institute of sol, irrigation and drainage	//		1/200 000
Differents studies	Studies and Bibliography provided from different Institutions			

The observation allowed identifying some stations whose periods of observation or operation are very heterogeneous and contain data gaps in their time series. Thus, this situation poses problems to constitute a climate dataset, which makes it possible to study the evolution of climatic parameters at the scale of the region. Given that the objective is to produce thematic maps based on complete reference data, we have selected the most reliable ones, which are 65 rainfall stations (Tab.2).

TABLE 2. Geographical information of rainfall stations.

Wilaya (province)	Station name	Latitude (degree)	Longitude (degree)	Altitude (m)
Bordj Bou Arreridj	El Mehir	36,13	4,37	550
Bordj Bou Arreridj	B.B.A	36,00	4,66	928
Bordj Bou Arreridj	Bouaziz	36,27	4,82	850
Bordj Bou Arreridj	El Hamadia	35,97	4,75	850
Bordj Bou Arreridj	Ghafsitiane	35,93	4,67	900

Bordj Bou Arreridj	Ras El Oued	35,97	5,03	1000
Bordj Bou Arreridj	Bordj Ghdir ANRH	35,91	4,90	1054
Bordj Bou Arreridj	Bordj Ghdir ONM	35,88	4,90	1050
Batna	Barika	36,33	5,35	460
Batna	O.S.Slimane	35,47	5,45	622
Batna	Bitam	35,32	5,37	474
Batna	Ras El Ayoun	35,68	5,65	880
Batna	Seggana	35,37	5,63	673
Batna	Merouana	35,63	5,91	1000
Batna	Batna A	35,71	6,03	468
Batna	Tifelfel	35,62	6,23	800
Batna	Attouta	35,55	6,18	471
Batna	Bouzina	35,28	6,12	1350
Batna	Menaa	35,17	6,02	1000
Batna	El Madher	35,62	6,37	913
Batna	Boulhilet	35,73	6,67	985
Batna	Toufana	35,48	6,60	1040
Constantine	Ain Smara	36,27	6,50	680
Constantine	Constantine	36,28	6,63	419
Khenchela	Khenchela	35,47	7,08	983
Mila	Ferdjioua	36,40	5,93	580
Mila	Beni Guecha	36,38	6,00	550
Mila	Ain Trik	36,28	5,97	1100
Mila	Chelghoum Laid	36,16	6,16	768
Oum el Bouaghi	Bir Chouhada	35,90	6,30	800
Oum el Bouaghi	Sigus	36,13	6,78	820
Oum el Bouaghi	Ain Kercha	35,90	6,70	780
Oum el Bouaghi	A. El bordj	36,03	6,89	780
Oum el Bouaghi	O.E.B	35,87	7,11	889

Oum el Bouaghi	Ksar Sbahi	36,08	7,27	850
Oum el Bouaghi	Ain Babouche	35,93	7,18	893
Oum el Bouaghi	Medfoun	35,86	7,23	900
Oum el Bouaghi	Ain El Beida ANRH	35,80	7,40	1004
Oum el Bouaghi	Ain El Beida ONM	35,78	7,40	1000
Oum el Bouaghi	Meskiana	35,63	7,67	970
Setif	Ourtilen	36,45	4,86	1020
Setif	Guenzet	36,32	4,83	1100
Setif	Maoklane	36,40	5,07	950
Setif	Bougaa	36,32	5,10	886
Setif	Setif	36,18	5,25	1030
Setif	Tizi Nbechar	36,43	5,33	900
Setif	Guellal	36,03	5,33	908
Setif	A.Oulmane	35,92	5,28	960
Setif	Saleh Bey	35,85	5,28	978
Setif	A.El Kebira	36,37	5,50	1020
Setif	Ras El Ma	36,10	5,52	980
Setif	Beni Aziz	36,47	5,65	750
Setif	El Eulma	36,13	5,68	964
Setif	Beida Bordj	35,88	5,67	895
Setif	Bouandas	36,50	5,90	580
Setif	Bir El Arch	36,13	5,83	950
Setif	Rasfa	35,75	5,23	1100
Setif	O.Teben	35,82	5,38	1030
Setif	Boutaleb	35,70	5,32	960
Setif	Meghres	35,33	5,35	450
Setif	Ain Azel	35,82	5,52	960
Tebessa	El Aouinet	35,86	7,89	654
Tebessa	Tebessa	35,41	8,01	820

Tebessa	Tabessa ANRH	35,41	8,12	850
Tebessa	Tebessa pciv	35,42	8,31	853

- **Approch adopted for rainfall mapping**

Currently, in the study area, the density of the climate network remains low. Only professional stations in aerodromes measure all climate parameters. Faced with such a situation of lack of rainfall data and a poor spatial representation of climate stations (Fig. 1), which can lead to errors or even aberrations in data interpolation, mapping becomes difficult to achieve consistency.

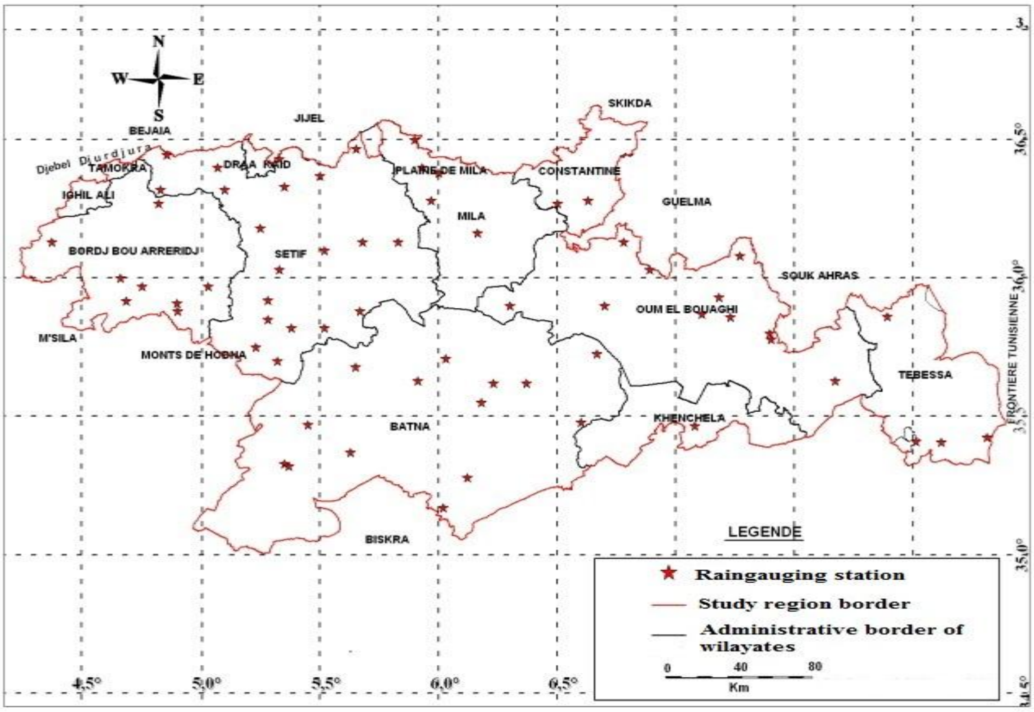

FIGURE 1. Spatial location of selected rain gauging stations in the study area.

To overcome this problematic, the authors have put in place a reflection on the methodology and the tools that must be used to estimate the precipitation parameter in the region of study following a very specific framing (Fig.2). To this end, we have adopted a methodology wich consists in expressing the rainfall variable (P) from a multiple regression equation to three (03) simple type factors.

$$P = \beta_1.X + \beta_2.Y + \beta_3.Z + \beta_0 + \varepsilon \quad (1)$$

With:

P: represents rain and is considered as a dependent variable.

β1, β2 and β3 are the coefficients of the multiple linear regression respectively of the independent variables X, Y and Z.

We also note, that X, represents the longitude, Y the latitude and Z the Altitude. The parameter 'β0' represents intercepts and errors. However, this step required the establishment of a reflection on the methodology and tools that must be used to determine the parameters of the equation (Figure 2). To do this, we found it useful to make some basic information materials (D.E.M, the fictitious point grid) for the production of precipitation maps.

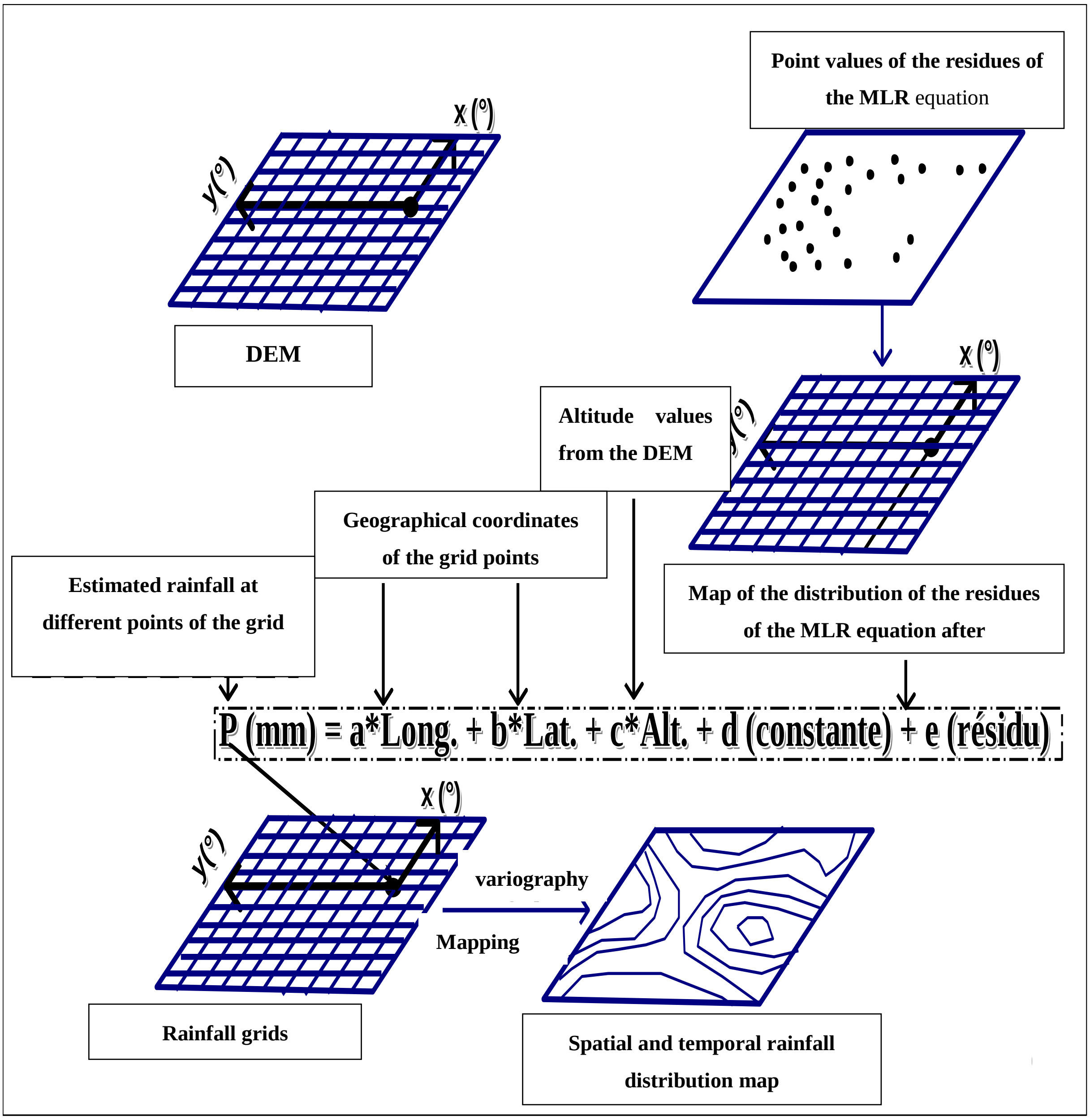

FIGURE 2. Stapes implemented for rainfall mapping according to 1986/2016 perriod.

- **Grid of fictitious points**

In order to perform kriging mapping and to be able to use robust variographic models, necessary for a better representation of the precipitation phenomenon in the study area, we have set up a grid with nodes representing fictitious stations (figure .3). These represent the estimated points based on the regression equation (1).

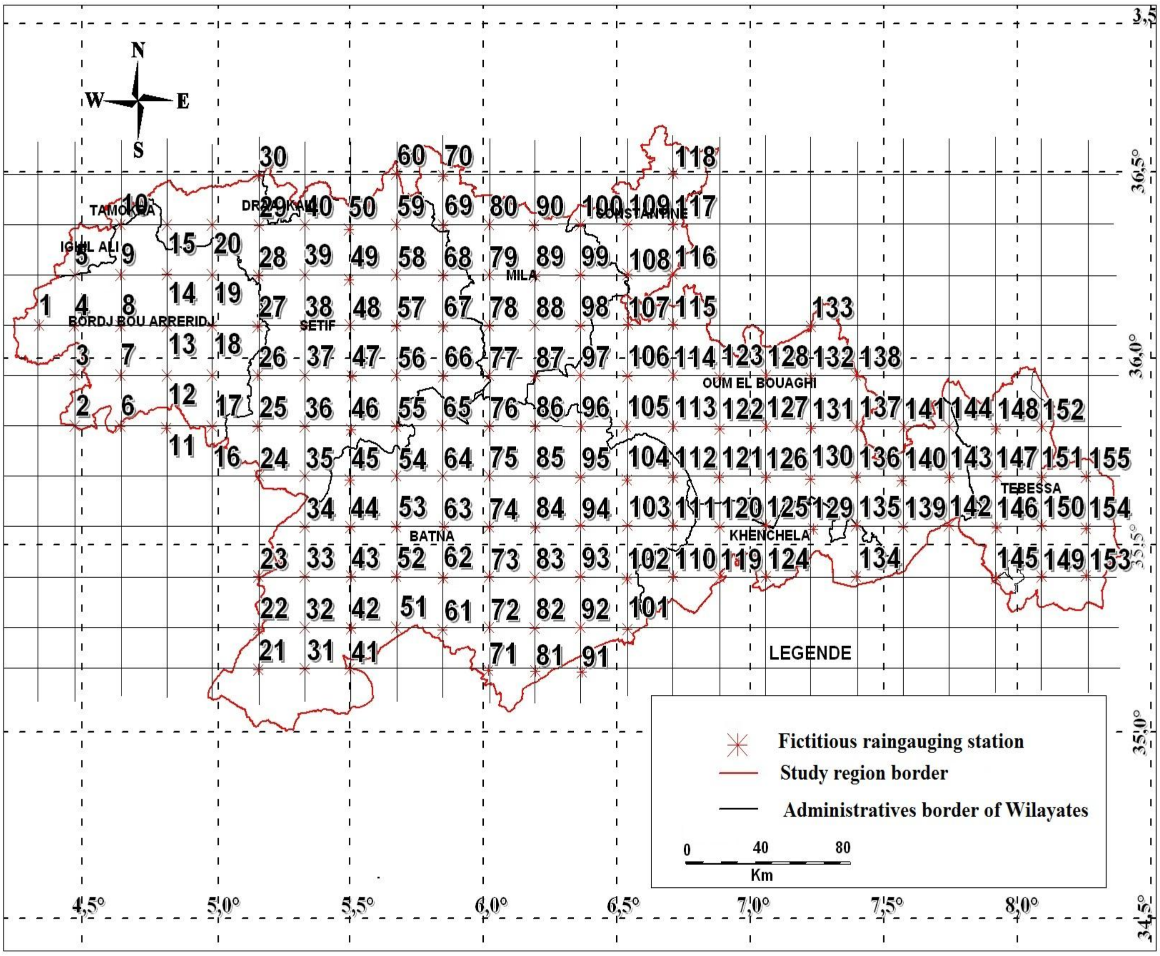

FIGURE 3. Presentation of the sampling grid of fictitious rain gauging stations

It is useful to indicate that this procedure was not done randomly, but according to a regular sampling, following a square mesh of 15 km x 15 km; meteorological station installation standards in a mid-mountain region. This sampling allowed us to bring out 155 points. The construction of D.E.M is based on digitized topographic maps (I.N.C.T., 2001). The principle was to transform the contours of the base map of the study area into a set of georeferenced points, from which we could realize a ground model by interpolating their altitude values.

- **Geostatistical analysis**

Using the Variowin 2.2 tool [28], this step consists in determining the types of variograms that best fit the experimental variograms, and determining the parameters of the variograms. Thus, the I.G.F (indicative Goodness of Fit) which is a basic criterion in the variographic choice will be determined. Furthermore, the type of variogram, the nugget effect, scope, the bearing and the anisotropy ratio will be determined. These adjusted model elements, are used in the procedure of interpolation by "kriging", in order to arrive at the iso-value maps

In its general design, the krigated or predicted value $Z(x_0)$ is a linear combination of observations at N_{nb} neighboring stations [28]. Kriging is applied to estimate the values of non-sampled rainfall locations using the points around it. The kriging estimator is written as follows:

$$Z(x_0) = \sum_{i=1}^{N_{nb}} \lambda_i Z(x_i) \quad (2)$$

With $Z(x_0)$ the estimator of the mean Z on x_0. Z (x_i), the known value Z at the point x_i. N_{nb} are a number of data points used for estimation and λ_i **,** are kriging weights which are estimated as solution of the kriging system. The weightings involved in the linear combination are obtained by solving the minimization problem whose equations depend on the theoretical variogram and the geometric configuration of rainfall data point's knowledge [29]. The equation of Semi-variogram is expressed as:

$$\gamma(h) = \frac{1}{2m} \sum_{i}^{m} \{Z(Xi) - Z(Xi+h)\}^2 \quad (3)$$

Where h is the distance between X_i and X_j , m is the number of pairs which are separated by the distance h. The obtained variogram is characterized by the nugget effect, the range and the Sill. The experimental variogram is adjusted on theoretical models based on the value of the Indicative Goodness of Fit (IGF) which is a basic criterion for the selection of the adjusted variogram model. An IGF value close to zero indicates a good fit of the model.

III. RESULTS AND DISCUSSIONS

- **Multiple regression analysis**

It was discussed to adjust the explanatory model for precipitation (P) by multiple regression. A rain-specific MLR model is developed from all 65 rain gauging stations and, using cumulated yearly rainfall variables of each station. From the interactive model regression analysis, the coefficient values found were as follow: β_1 = 17.93, β_2 =256.54, β_3 = 0.051 and the intercept β_0= -9001. By inputting the obtained results in Eq. (1), the equation of annual rainfall obtained from regression analysis becomes:

$$P(mm) = 17.923\ X + 256.546\ Y + 0.0513\ Z - 9001.727 + e \quad (3)$$

With X, Y and Z are respectively longitude, latitude and altitude ε Represents error.

With X, Y and Z are respectively latitude, longitude and altitude. ε Represents error of estimation 53.2. Table 3 displays the regression coefficients values and the validation tests of the MLR model. According to Table 3 the goodness-of-fit of rainfall MLR model has relatively low multiple R, R^2 and adjusted R^2 (R^2 = 0.623, multiple-R = 0.721 and the adjusted R^2 = 0.545). F-test was used to check the overall significance of the developed MLR model. The advantage of the *F- test* over R^2 is that the *F-test* takes into account the degrees of freedom, which depend on the sample size and the number of predictors in the model (F (3.61) =19.05, p-value p=0.00000). In addition, t-test, RMSE and MSE were used to evaluate the performance of the MLR equation (t= -7.399, p-level= 0.00000, RMSE = 0.14, MSE = 0.026) indicating that indeed the MLR model is significant at the 0.05 confidence level. Moreover, X (t=7.399, p= 0.000000) and intercept β_0 (t= -7.0, p= 0.000000) are highly significant explanatory variables, indicating higher t values and very low p-value at the 95 % significance level. However, Y (t=1.296, p= 0.190) and Z (t= 0.762, p= 0.454) are statistically insignificant in the MLR estimation.

From this equation it can be seen that the constant in the multiple regression equation always has the largest (negative) effect on annual precipitation (-9001,727). Second, we have latitude with a coefficient of 256.54 and to a lesser degree longitude with a coefficient of 17.92. While elevation appears to have the smallest contribution to the annual precipitation estimate with a coefficient of 0.0513.

TABLE 3. Coefficients of the MLR application and validation test.

	Coefficient synthesis		
	β	**t-test**	**p-level**
origin	-9001.72	-7.00	0.000000
Longitude	17.92	1.296	0.190
Latitude	256.54	7.399	0.000000
Altitude	0.0513	0.762	0.454
	Cross validation of MLR		
Multiple -R	0.721	ε	53.2
R^2	0.623	t-test	-7.122
$R^2_{adjusted}$	0.545	p-level	0.00000
MSE	0.026	df	3.61
RMSE	0.14	F-test	19.05

- **Geostatistical study and numerical precipitation mapping**

According to [30], the adjustment step is the most delicate step of spatial interpolation. Indeed, the choice of a function serving as a model is the most important, because the results of this modelization are used by kriging. The surface variogram average annual rainfall (fig.4) indicates an east-west direction (0°) of continuity of annual precipitation

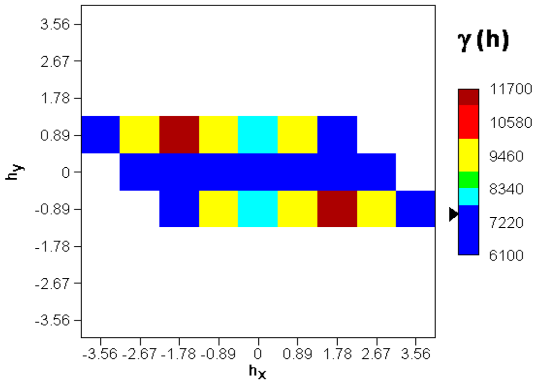

FIGURE 4. Surface variogram of annual rainfall.

The directional variogram obtained at the annual scale is presented in Figure 5.

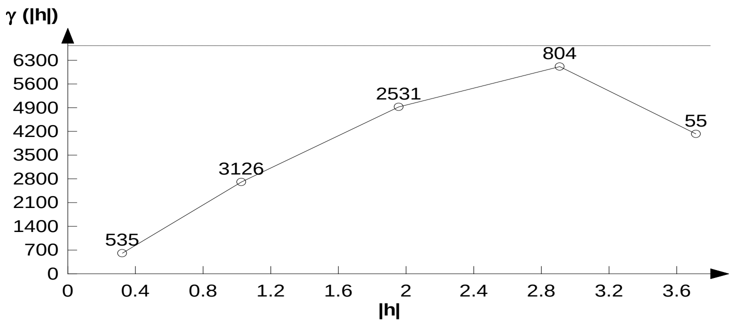

FIGURE 5. Directional variogram of annual precipitation in 0° direction

Table 4 lists the variogram parameters and the cross-variogram test

TABLE 4. Theoretical variogram Parameters.

Variogram	**Theoretical variogram (Model)**				
Parameters	Model	Nugget effect	Sill/ Power	Range/Slope (Km)	IGF (Best fit found)
Annual rainfall according to the East/West direction (90°).	Gaussian	535	5660	295	2.75 e^{-3}

Figure 5 and 4, illustrate the structure of variograms which fit a Gaussian model with Best Fit Found (IGF) equal to 2.75 e^{-3}. The results show the existence of increasing range of fluctuations limited to the distances of 295 km, (Tab.4). The low value nuggets effect show existence of low fluctuations undetectable by the climate network set in place. The Gaussian variogram with small nugget effect indicates non-existence of a microclimate in the region (Slimani et al., 2007) contrarely with results published in Bachir et all 2016 where results of geostatistical analysis of annual rainfall shows a existence of rapid fluctuations undetectable by the climate network set in place and higher nugget effect indicating the existence of a microclimate in the region, this result is due to the updating of the data (30 years) and also to the correction given by the method proposed in this paper based on the consideration of the information by the fictitious rainfall stations.

The mapping approach is based on the simple kriging interpolation method to perform isohyets from 220 study points representing reel raingauging station (65 stations) and estimated values from (155 fictional stations).

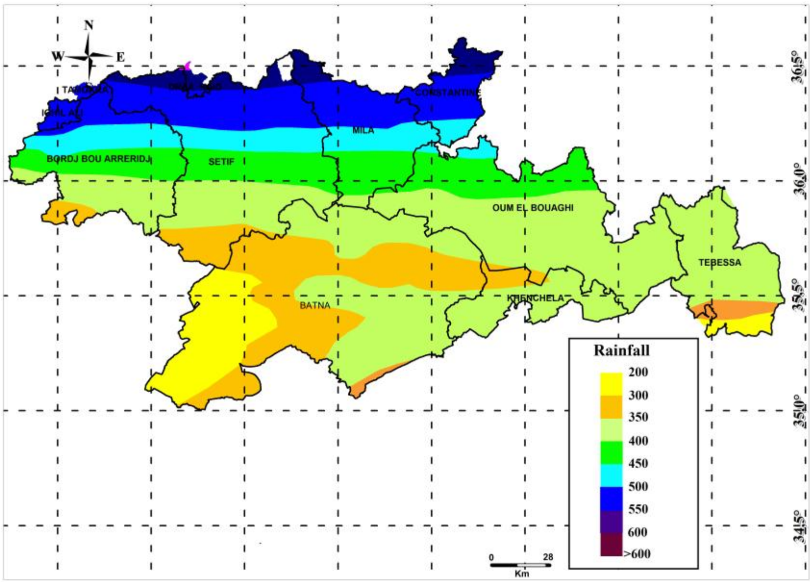

FIGURE 6. Map of the Spatial and temporal rainfall distribution in Eastern Hight plateau region of Algeria for period (1986-2016).

From Figure 6, we can say that the effect of the latitude has well marked the behavior of the precipitations. It is clear that the isohyets 300 mm to 350 mm dominate the study area, it occupies an area of 14444 km^2. The second important range is between 200 mm and 300 mm with an area of 5298 km^2, it occupies a significant part of the wilaya of Batna, it crosses the south wilayas of Setif, Bordj Bou Arréridj and Tebessa Moreover, isohyets between 350 mm to 400 mm cover an area of 4304 km². Isohyets greater than 400 mm occupy the northern part of the study area with a total area of 7582 km² of which an area of 404 9 km² represented by isohyets between 450 mm and 550 mm. To try to better characterize the study area in terms of climate, the question arises: Does the study area seen hydro-climatic changes during the last 80 years? To answer to this question, we made a comparison map between the map of isohyets for the period (1986-2016) and the map of isohyets made by Chaumont and Paquin 1971 for the period 1913 to 1938 (fig.6).

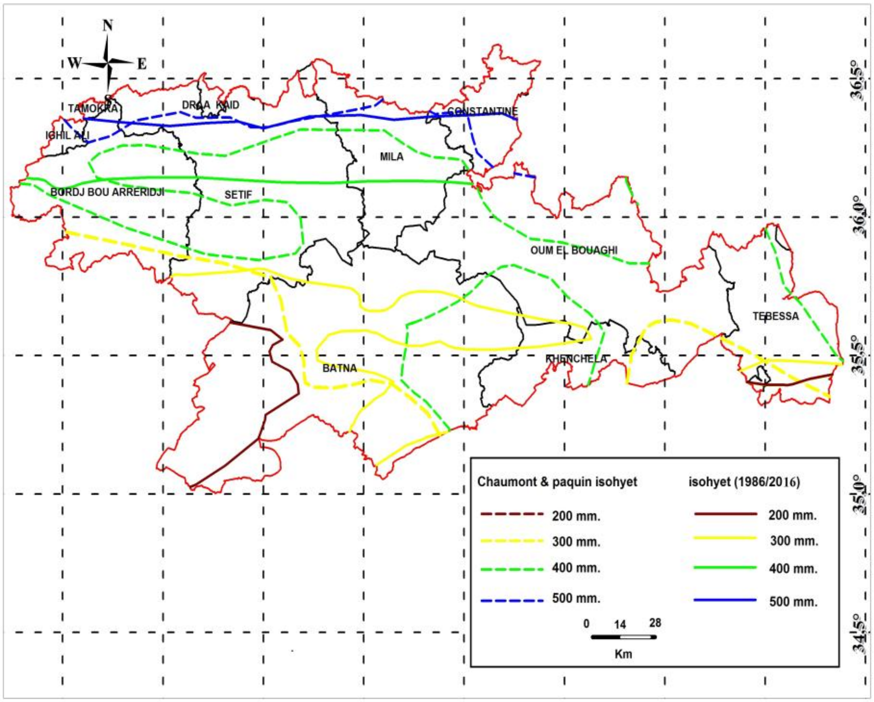

FIGURE 7. Comparison map of the isohyet curves of the two periods.

The examination of this map shows the following:

– There is no big change in the time for the 500 mm isohyet;

– The change is clear at the isohyets 200mm, 300mm and 400mm:

❖ For the 400mm isohyet, which previously affected a larger area (between the wilayas of Sétif Bordj Bou Arreridj, Mila, Oum El Bouagui, Batna and Tébessa), it currently covers only a small part of the northern highlands of eastern Algeria (between the wilayas of Sétif, Bordj Bou Arreridj and Mila);

❖ For the 300mm isohyet, we notice, firstly, a slight shift of the curve towards the South-East for the wilayas of Sétif and Bordj Bou Arreridj, secondly, the curve is more accentuated towards the East of the region. Indeed, it covers a larger area for the wilaya of Batna and it is again observed for the wilayas of Khanchela, Oum el Bouagui and Tebessa;

❖ For the isohyet 200 mm, it is presently observed only in the west of the wilaya of Batna and south of Tébessa. This situation shows that these two wilayas have become, over time, more arid.

IV. CONCLUSION

The measurements of the rainfall heights of the 1986-2016 period, recorded in the selected rainfall network, showed that the average annual rainfall varies from one station to another. We can say that rain mapping, based on MLR model and geostatistics, allows to optimize rainfall estimation at any point of a considered area and has given good results.

This method provides a much better interpolation than that made from the usual interpolation methods. Furthermore, the comparative analysis between the map of yearly rainfall for the period (1986-2016) and the map of isohyets produced by Chaumont and Paquin (1971) showed that there is no great change over time for the 500 mm isohyet and that the change is clear for the 200 mm, 300 mm and 400 mm isohyets. Given the extent of the study area which is characterized by a geomorphological and even pedological diversity, the results obtained lead to reflect on the importance of strengthening and extending the current climate network by adopting statistical methods and GIS tools.

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