ORIGINAL ARTICLE

RATIONALIZATION OF MOROCCAN HYDROLOGICAL NETWORKS: CASE OF THE SEBOU WATERSHED (NORTHERN MOROCCO)

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ABSTRACT

Background: The rainfall records are the base of all hydrological studies (statistical climatic, water planning and resource management, delimitation of the floodplains). However, the precision on the knowledge of precipitations on a given surface requires much network observation and distributed well. The importance of this network often results from a compromise between the desired precision and the constraints of management, budget amongst other things. **Methods**: The methodology of rationalization suggested in the watershed of Sebou, in northern Morocco, is primarily based on the application of the statistical approaches in order to evaluate the relevance of the stations of a network from statistical point of view and to remove the station if this proves to be inevitable. **Results**: The network of observations on the Sebou watershed level is characterized by a density of the pluviometric stations satisfactory. It comprises more than 164 stations for 250 km ². However, the network of observations in the surface of study is denser in plain than in mountain: altitudes higher than 2100 m. For the evaluation of requirements in data, it is important to use the geostatistic techniques such as the clustring and the krigeage and this in order to characterize the distribution of rain and to work out a statistical methodology and to acquire programs of the approaches studied to help in the search of redundancies of hydrological information. **Conclusion**: The results from the 54 studied stations are favorable, with some small exceptions, for a cutting of the Sebou watershed in 4 great homogeneous zones which make it possible to describe in a relevant way the variability of annual precipitations in the basin.
Key words: *Hydrological station, Geostatistic analysis, Krigeage, Sebou watershed, Northern Morocco*

RESUME

Introduction: Les données pluviométriques sont la base de toutes études hydrologiques (statistiques climatiques, planification et gestion des ressources en eau, délimitation des zones inondables). Cependant, la précision sur la connaissance des précipitations sur une surface donnée nécessite un réseau d'observation étendu et bien réparti. L'importance de ce réseau résulte souvent d'un compromis entre la précision désirée et les contraintes de gestion, budgétaire entre autre. **Méthodes** : La méthodologie de rationalisation proposée dans le bassin hydrologique de Sebou est essentiellement basée sur l'application des approches statistiques afin d'évaluer la pertinence des stations d'un réseau de point de vue statistique et supprimer la station dans le cas où ceci s'avère inévitable. **Résultats** : Le réseau d'observations au niveau du bassin de Sebou est caractérisé par une densité des postes pluviométriques satisfaisante. Il comporte plus de 164 stations soit un poste pour 250 km². Cependant, le réseau d'observations dans l'aire d'étude est plus dense en plaine qu'en montagne: les altitudes supérieures à 2100 m ne sont pas documentées. Pour l'évaluation de besoins en données, il est important d'utiliser les techniques géostatistiques telles que le clustring et le krigeage et ce afin de caractériser la distribution de pluie et élaborer une méthodologie statistique et acquérir des programmes des approches étudié pour aider à la recherche de des redondances des informations hydrologiques. **Conclusion**: Les résultats issus des 54 stations étudiées sont favorables, à quelques petites exceptions, pour un découpage du bassin du Sebou en 4 grandes zones homogènes qui permettent de décrire de manière pertinente la variabilité des précipitations annuelles dans le bassin.
Mots clés: *Station hydrologique, Géostatistique, Krigeage, Bassin Sebou, Maroc*

1. INTRODUCTION

The installation of the hydrological network allows the study and the evaluation of several hydrological phenomena; It's an essential element which enables to provide information concerning the flows of rivers and the precipitations received by the catchment area.

The stations constituting the network are distributed in space, from which the readings will be established to acquire a lots of data: as the water level, flow, flood estimates ..., however in several countries the station design is enlarged, it is clear that during these last decades the density varied, but budgetary constraints made that several stations stopped working; thus their number decreased, which imposes a new objective: the development of a reasonable strategy intended to minimize the loss of information. Therefore, the closure of a measurement point leads to the loss of the

collected information, which is necessary for the solution of economic and scientific problems of planning and management of resources, for that the Rationalization is the key.
In this work; whose objective is to develop a reasonable strategy to minimize the loss of information. The study area is the hydrological network of the Sebou watershed, given the importance of its geographical location. It is the keystone of Morocco's hydroelectric and irrigation network.

From the study site, the steps followed are: Identification of the stations representing a redundancy of the hydrological information, grouping together the stations of the same similarity and exploitation of the results to establish precipitation forecast maps.

2. MATERIALS AND METHODS

2.1 Study site

The Sebou basin covers an area of approximately 40,000 km², which represents only 6% of the national territory area, but whose population, estimated at 6.5 million inhabitants in 2003, represents 21% of the whole national. Located in the center of the country, the Sebou basin is marked by a very diverse geographical and climatic context (Figure 1).

The climate prevailing on the Sebou basin is Mediterranean with an oceanic influence and becomes continental inland. It manifests itself by rainy winds from the west and precipitations which decrease away from the sea and in protected valleys like those of Beht or Haut Sebou before increasing rapidly on the slopes of the Rif.

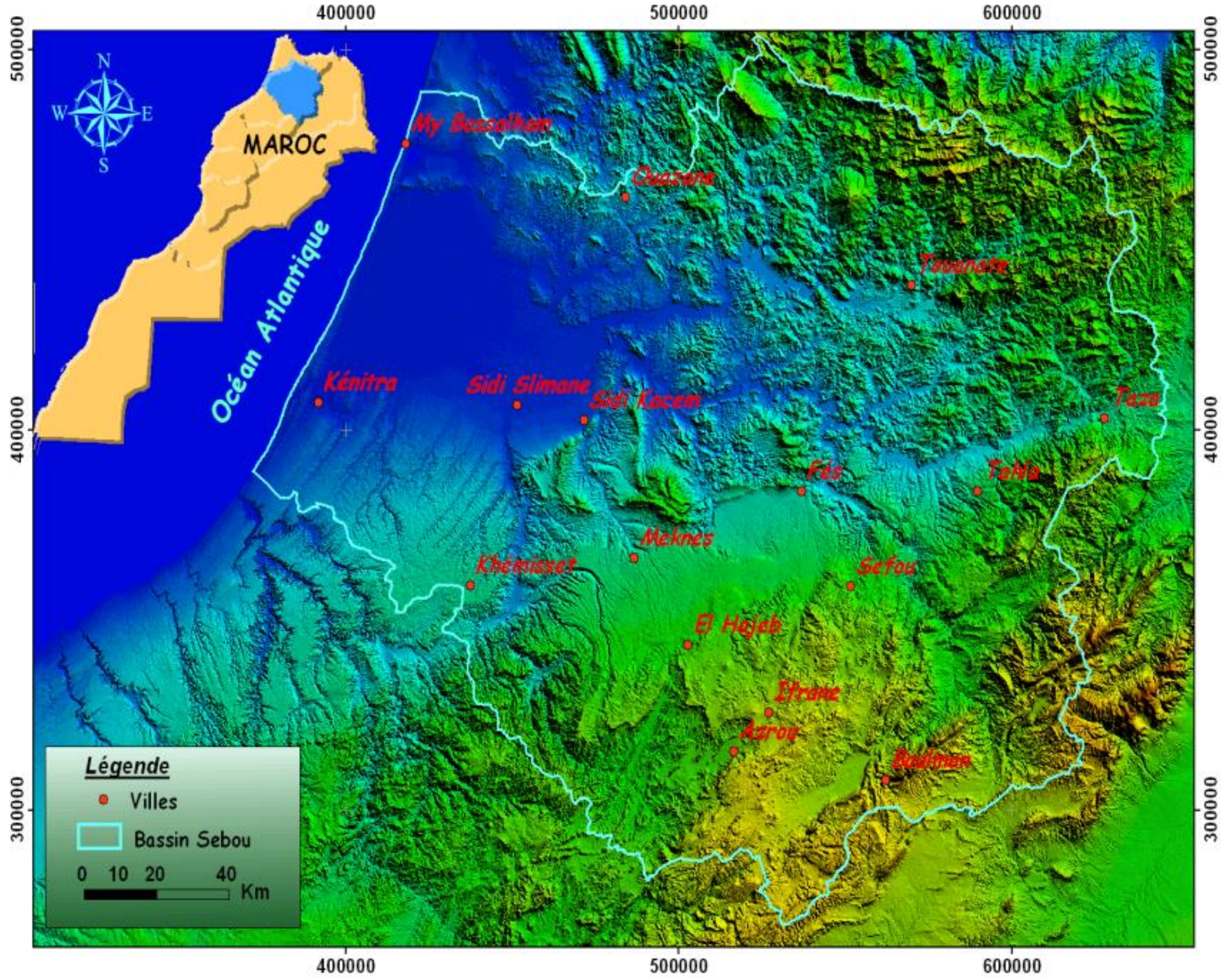

Figure. 1 : Digital elevation map sketch centered on the Sebou basin and geographic location in Morocco.(the resolution of the DEM=30 m).

Oued Sebou has its source under the name oued Guigou in the Middle Atlas at an altitude of 2030 m. It crosses a length of around 500 km before reaching its outlet in the Atlantic Ocean at Mehdia (Province of Kenitra). Along its route, Oued Sebou intercepts several tributaries from contrasting regions. The most important tributaries are Ouergha in the Rif, Inaouene and Lebene in the Taza corridor in contact with the Rif and the Middle Atlas as well as the Beht and Rdom wadis in the central plateau. The Sebou basin produces almost a third of Morocco's surface water. It can be subdivised, from an hydrological point of vue, to four subsets (Figure 2).

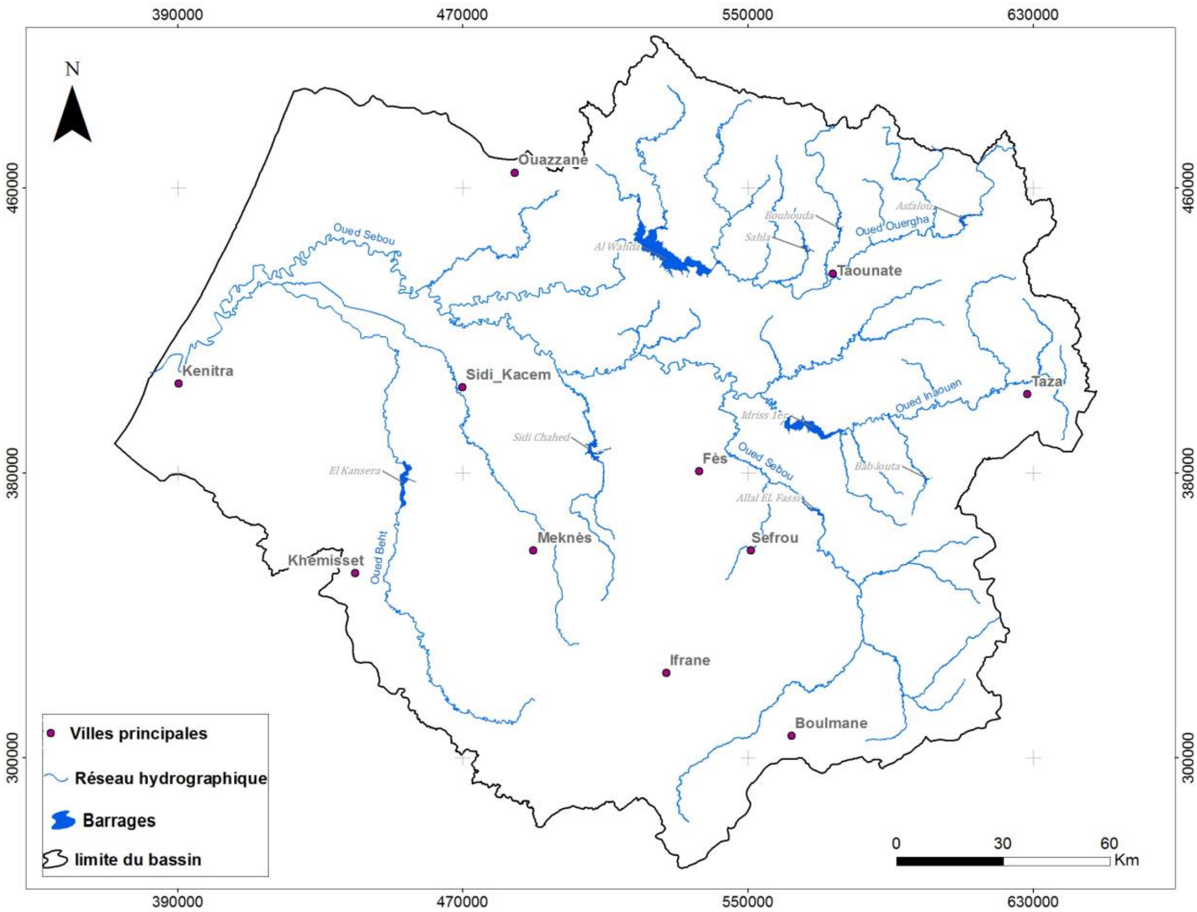

Figure 2 : The figure presents the map of the main drainage of the Sebou basin.

The hydrological network of the Sebou basin is characterized by a density of pluviometric stations satisfactory in the central zone of the basin, on the other hand, in the upper zones of the basin, the density becomes low (Figure3).

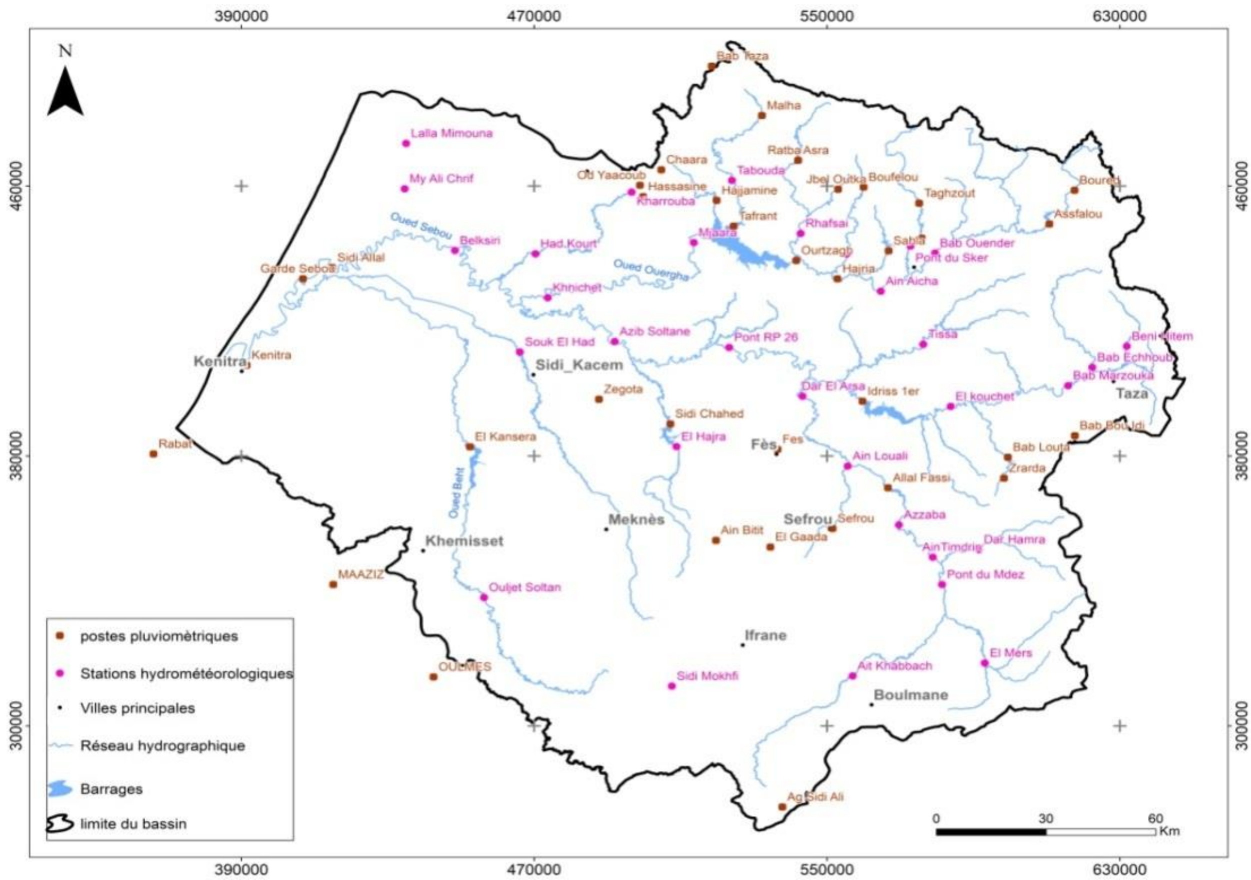

Figure 3 : The figure presents the location of rainfall and hydrometeorological stations in the Sebou basin.

2.2 Equation

In order to rationalize, it's requisite to use geostatistical techniques such as Kriging, which is an interpolation method, of very particular interest for the design of measurement networks and for the estimation of values of hydrometeorological variables in sites where there is no measuring station reconstitution of hydrological data Ouarda et al., (1996) [1].

Clustering analysis:

The classification tree or clustering above is carried out in two main steps**:**

- the first stage consists in choosing the stations to be eliminated and those which will be maintained, based on the stations which have a capacity to reconstitute the data in the lost stations, which will lead to the gain of information ;
- the second step concerns the hierarchical classification to identify the groups of stations for which the correlation coefficient is high. The construction of the classification tree will enable to visualize the neighborhood between stations. For this stage, the correlation is considered as a strong statistical character for the grouping.

2.2.1 Establishment of groups

Given the large size of the hydrometric network, it is desirable to classify network stations in smaller geographic regions. This is why it is necessary to carry out a pre-classification of the stations of the network, by determining subgroups. These will contain the stations which provide the same information about the characteristics of the hydrological variable studied.

A method has been proposed by Burn and Goulter (1991) which is based on the hierarchical classification for the rationalization of networks [2]. To arrive at grouping similar stations we use the correlation coefficient. If we have on several types of variables of interest, we can consider a weighted average of the correlation coefficients. The stages of the procedure consist in the initial phase of recovering the two closest groups by identifying the similarity between two sites **i** and **j** by the similarity index (1).

$$r_{ij} = \sum_{k=1}^{k} w_k r_{k,ij} \quad (1)$$

k: the number of variables considered (minimum, average and maximum annual flows, for example).
wk: the weight associated with the variable **k**
rk, ij: the correlation between sites **i** and **j** for the variable **k**

Then we group their sites together and repeat the procedure until we get a single group. The distance between two groups containing **nx** and **ny** sites is defined by the average distance (Average linkage Clustering algorithm) (2)**.**

$$r_{xy} = \frac{1}{n_x n_y} \sum_{i \in X} \sum_{j \in Y} R_{ij} \quad (2)$$

2.2.2 Dendrogram

This will lead us to build a classification tree which indicates how the different groups have been grouped. In terms of rationalization, the hierarchical classification allows to identify strongly correlated groups, to contain at the end a final network which brings together representative stations of all the identified subgroups, in order to improve the estimation of the mean and the variance**.**

For this, we use Permut Matrix which is software designed to facilitate the graphical analysis of a data table. It implements various approaches to statistical serialization**.**

Firstly, the numerical values of the table of statistical data are transformed to gradations of colors, then, by permutation of the rows or the columns, the research is carried out to bring out a structuring of the data of the table. At the end, the order in which the rows or columns are listed reveals the statistical organization of the initial data**.**

The data must be in the form of a standard text file (ASCII), or a Microsoft Excel file (* .xls). We build the dendrogram which represents the classification tree**.**

On the x-axis, the numbers of the main groups, 30 groups have been identified on the basis of this grouping procedure**.** Later on, the stations with their associated numbers are put on a table for the same group according to the constructed dendrogram.

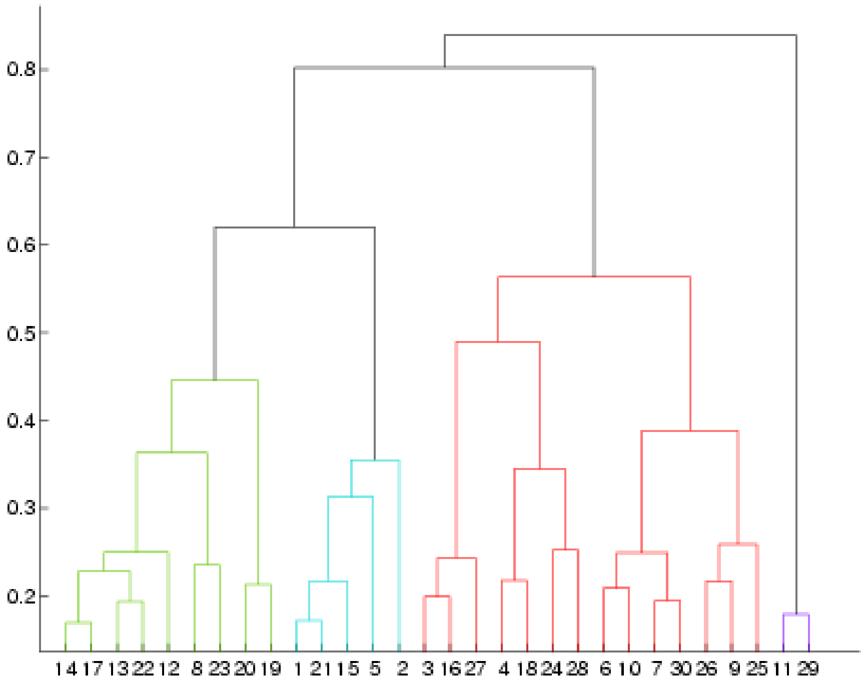

Figure 4: The figure presents the hierarchical classification dendrogram.

2.2.3 Kriging

The Kriging bears its name from its precursor the mining engineer, South African DG Krige who developed in the 1950s, a series of statistical method, in order to determine the spatial distribution of ores. the variance of the kriging constitutes a precision indicator for the optimization of a measurement network [3].

The Chauvet 1992 formalized the approach using correlations between boreholes to estimate the spatial distribution. Krigeage's basic idea is to predict the value of the regionalized variable to be interpolated into an unsampled site s_0 by a linear combination of punctual data 3) [4]:

$$Z^*(s_0) = \sum \lambda_i Z(s_i) \quad (3)$$

$Z^*(s_0)$: The estimated value at point s0

$Z(s_i)$: The value measured at point si = (i: 1,…, n)

λ_i: The weights assigned to the points si for the estimate

The objectives of a hydrological network, budgetary constraints form essential factors for carrying out a rationalization project, the approach ensures the future availability of reliable databases therefore the operation requires a good mastery of statistical methods to maintain the most appropriate measure station for the network and also so that the elimination of the other stations will not cause the loss of the hydrological information, in this case it is essential to emphasize the importance of the validation of the data presented in each site to carry out a high quality study.

The rationalization study is accompanied by the monitoring of observations to carry out a reliable and credible analysis. Also, a global analysis of the stations makes it possible to determine the overall state of the network; it must be examined whether in each zone the available information is sufficient to meet statistical needs.

It was noted that the use of geostatistical techniques such as kriging can be essential to improve the adaptation of the network to better estimates, it is necessary to check if this tool is effective for the network according to the density of its measurement stations by comparing the spatial distribution of points in the networks as well as the relative variance**.**

3. RESULTS AND DISCUSSION

3.1 Results of the clustering analysis

We select 56 stations in the Sebou watershed which will be organized on classes into small geographic areas by groups (clusters) using the classification tree so that similar data are in the same group. We seek to form groups containing stations on the basis of their sim (table 1). Then, we put on a table for the same group, the stations with their associated numbers according to the constructed dendrogram**.**

Table 1: The table presents the grouping of stations in the Sebou watershed with the same similarity.

CLUSTER 1									
	Groupe 1		**Groupe 2**		**Groupe 3**		**Groupe 4**		**Groupe 5**
1 2 3 4 5 6 7 8	AIN AICHA HAJRIA GALEZ BAB OUENDER BGE BOUHOUDA BGE SAHLA TAGHZOUT TISSA BOUKARKOUR	9 10 11 12 13 14	BOURED BGE ASFALOU BENI HAITEM BAB CH HOUB BAB MERZOUKA BAB BOUIDIR	15 16 17 18 19 20 21	AIN KHABBACH EL MERS PONT MDEZ A-TIMEDRINE DAR EL HAMRA ZRARDA BGE B-LOUTA	22 23 24 25 26 27 28 29	AZZABA BGE A-FASSI SEFROU FES ABHS BGE CHAHED DAR ARSA BGR IDRISS 1 AIN BETIT	30 31 32 33 34 35 36 37 38	JBEL OUDKA BOUFFELLOU RATBA EL MALHA TABOUDA BGE EL WAHDA MJAARA OULED YAACOUB KHAROUBA
	Groupe 6		**Groupe 7**		**Groupe 8**		**Groupe 9**		**Groupe 10**
39 40 41 42 43	PONT R.P. 26 AZIB ESSOLTANE KHENICHET HAD KOURT SOUK EL HAD	44 45 46	AGUELMAM SD ALI SK EL HAD O.IFRANE, SIDI MOKHFI	47 48 49	BELKSIRI LALLA MIMOUNA - MY ALI CHERIF	50 51 52	KENITRA DPE BGE GARDE DAR SALEM	53 54	OULJET SOLTANE BGE EL KANSERA

Hierarchical tree or dendrogram: The classification tree allows to arrange the stations which represent the same hydrological information.

Table 1 : The table shows the dendrogram of the hierarchical classification of the Sebou basin**.**

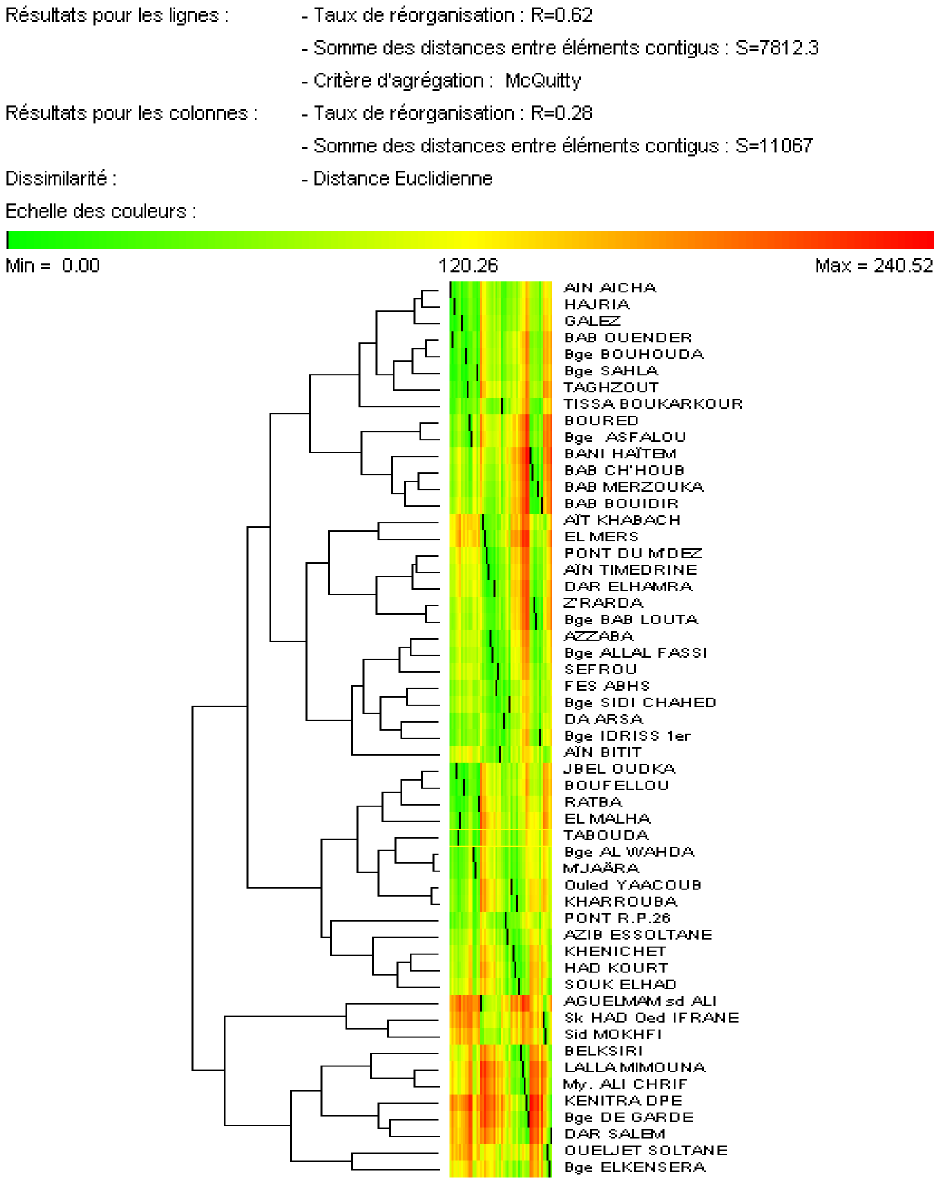

Figure 5: The figure presents the hierarchical classification dendrogram.

It is enough that a station has a similarity with another station then the first group is formed by the most similar pair. The group "station Ain Aicha", "station Hajria" merged, has a similarity of 0.92 to form a group stat (Ain Aicha) ⋅/ stat (Hajria), and this is done for the rest of the station.

Correlation of tree distances: On the hierarchical tree the two stations are possibly linked at a certain level. The link height read on the dendrogram, represents the distance between the two stations, this height is known as the cophenetic height, and we calculate the correlation between the cophenitic distances and the departure distances that generated the classification tree to find out if they are similar. C = 0.28**.**

So the dendrogram reproduces all the information from the distance matrix that was used to generate it. Links that have the same height indicate that there are no divisions between stations at this level of the hierarchy. These links are expected to have a high level of consistency, because the distance between the stations to be assembled is approximately the same as between the distances from the stations they contain. A link whose height differs, indicates the hierarchical classification. shows that only the very close stations favored to regroup, are within the same basin or at the limit of the neighboring sub-basins. The description of the variability of precipitation in space is fundamental for the increase in network density. Geostatistical methods such as kriging consist in predicting realizations of a variable continuously varying over a spatial domain. The stations which are attached to this level of the tree are very far from each other.

3.2 Results of the Kriging:

Whether it is the interpolation by inverse distance method (Figure 6) or by kriging (Figure 7), which reproduce the values at an observation point, the result is the same. The goal is therefore to predict the precipitation value at each point in the watershed. The interpolation is performed on a regular point grid; the variance map by kriging allows finding the configuration of the sample. It is around the measurement sites that the prediction variance is the lowest; as might be expected, the prediction sites far from the measurement sites show a large variance in kriging, which indicates a high uncertainty as to the calculated prediction values**.** The variance of kriging depends only on the distance between the observed point and that not observed, the variance of kriging concerns the density of the information. Neighboring observation points carry more weights than distant ones, the relative weight of a point decreases when the number of neighboring points increases.

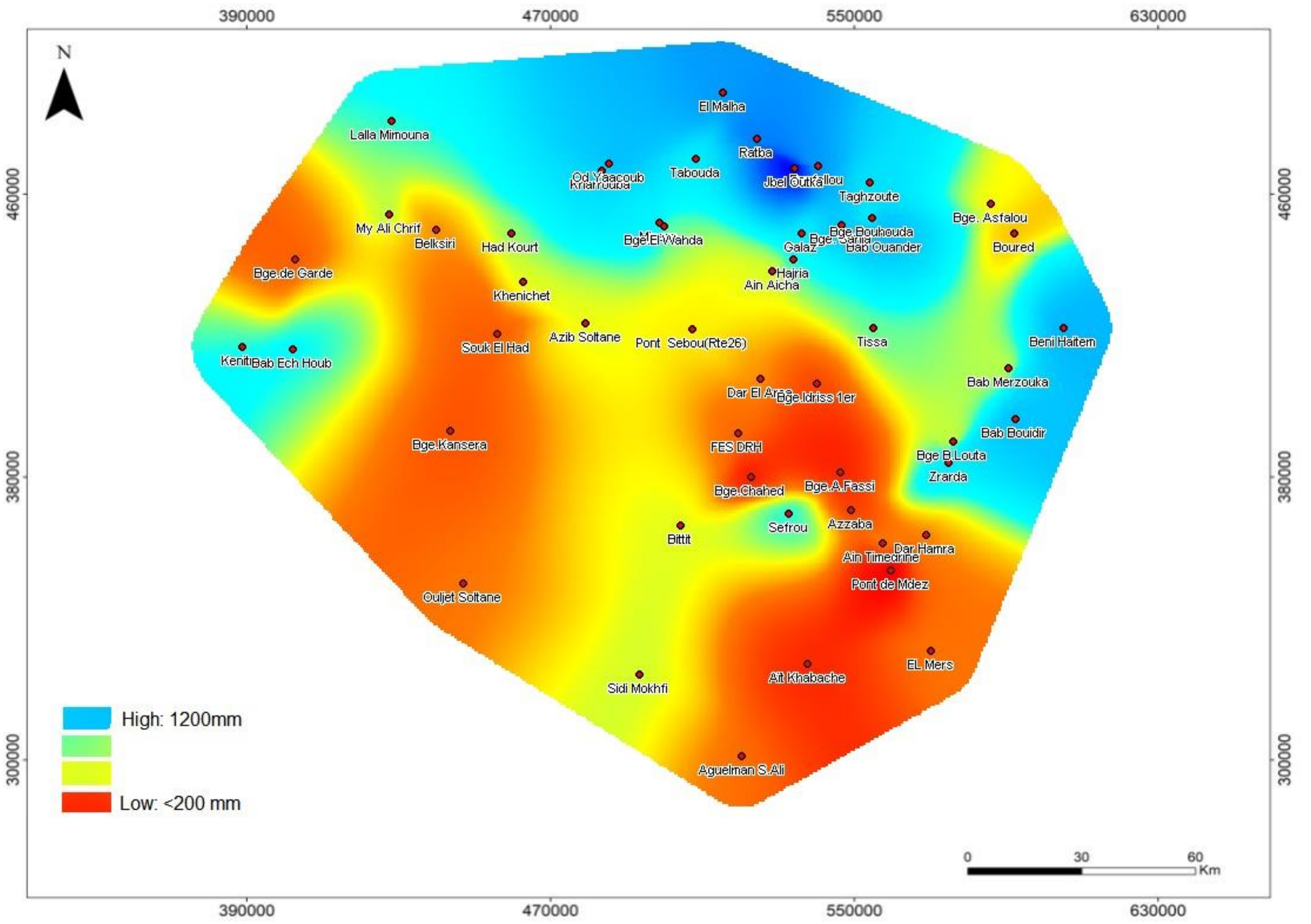

Figure 6: estimates by the inverse of distances method.

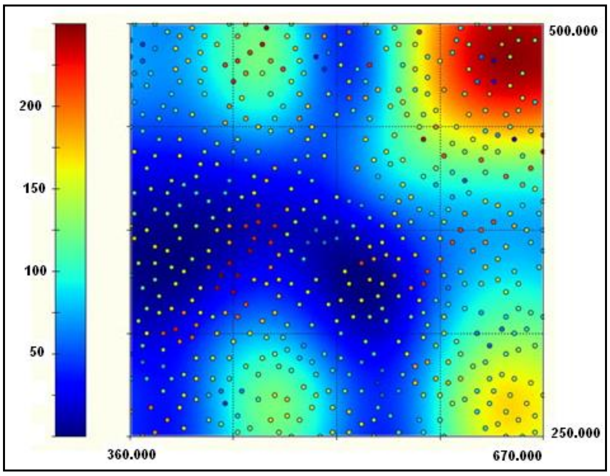

Figure 7: estimates by kriging.

3.3 Isohyets maps

Thanks to the values estimated by kriging, isohyets are plotted from the average annual precipitation of the stations treated in this study; corrected and brought back to the period 1970-2009. (Figure 8,9,10).

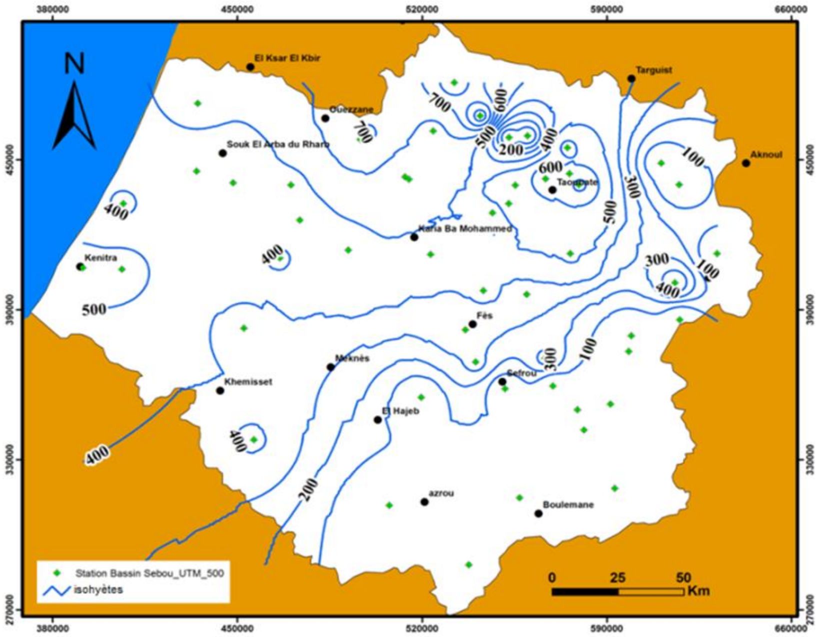

Figure 8: Isohyets map (0-500m) UTM : universal transversal projection Mercator.

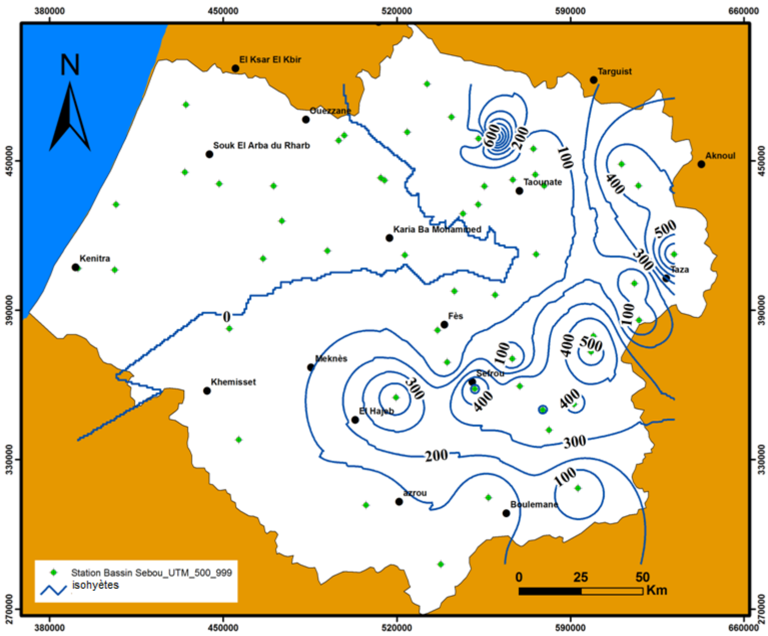

Figure 9: isohyets map (500-1000m).

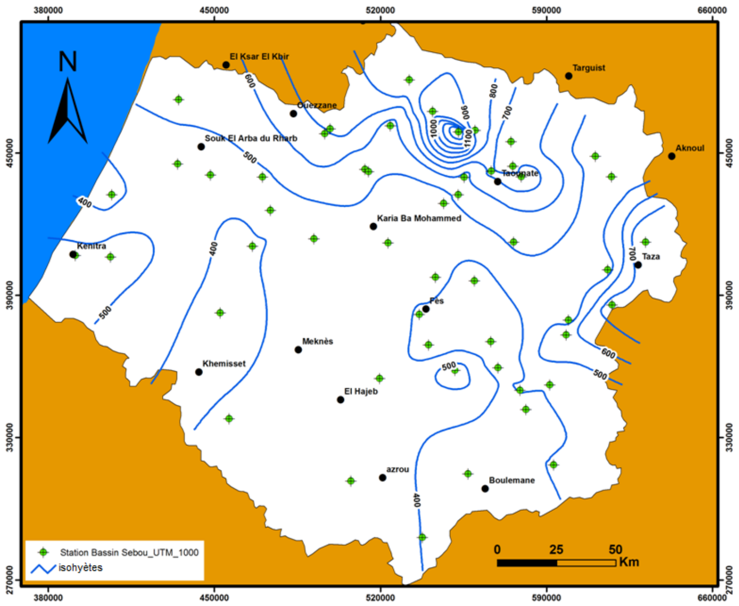

Figure 10: Isohyets map (>1000m).

The kriging of the isohyets of the northern part of the Sebou basin shows a rapid increase in the amount of precipitation and can exceed 1200 mm, on the other hand we note a progressive decrease towards the south. This region is crossed by the mountain ranges of the Middle Atlas. This explains the intensity of the rains due to the orography. The slopes exposed to the wind are very rainy. Hidden slopes are less favorable for large amounts of precipitation. The coastal part shows that the kriging estimates vary between (400-500) while moving away from the sea and in protected valleys like those of Beht or Haut Sebou.

5.CONCLUSION

The rationalization methodology proposed is essentially based on the application of statistical approaches to assess the relevance of the stations in a network from a statistical point of view and to remove the station in the event that this proves to be inevitable in the Sebou basin in northern Morocco**.** in the middle sebou, the sefrou station turns out to be unitile and can be replaced by the Ain Bettit station from a hydrological information point of view, the Dar lhamra station can be replaced by the Ain Timedrine station in Haut Sebou.
The description of the variability of precipitation in space is fundamental for the increase in Density of the Sebou basin network.

These methods are applied for the development of precipitation forecast maps at the various sites of the basin. This study allowed describing the extent of precipitation at the level of the chains of the middle atlas and the parameters which influence the release of precipitation. he stations El Mers, Ait Khabach, Beni haitem, Ratba, which are located at altitudes and on slopes exposed to winds experience heavy precipitation, hence the need to describe the variability of precipitation in space for increasing the density of the hydrological network**.**

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