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Spatiotemporal characterization of the annual rainfall in Setif region - Algeria

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ABSTRACT

The annual rainfall in Sétif during 1970-2011 series reveals a spatial pattern oriented north-east/south-west, with annual average of 458 mm. A positive trend of rainfall is noted between 1970-1990 and 1991-2011 sub periods, with annual records of 442 mm and 456 mm respectively. Based on 5 rainfall classes of 150 and 250mm for each, precipitation maps best illustrate the rainfall pattern. However, rainfall probability maps are performed on the basis of exceeding annual threshold of 400 mm. The variability is increasingly observed during the period 1991-2011 for the central zone of the study area. There is also a shift of the barycenters of the rainfall classes and shrinkage of the humid zone in the north between the two sub periods 1970-1990 and 1991-2011.

1. Introduction

According to the World Meteorological Organization, the climate corresponds to the distribution of atmospheric conditions in a given region over a period of at least 30 years. Lamb (1972) describes climate as the predominant weather experienced at a place during the year and over the years. Its characterization is carried out using calculations based on annual and monthly measurements of the local climatic parameters, such as temperature, precipitation, sunshine, humidity, wind speed. Rainfall plays an important role in maintaining and distributing vegetation cover (Berrayah 2009). It also represents the most important climate factor. For these reasons, studies and analyzes focus much more on rainfall than other parameters. Characterizing the impact of climate variability on seasonal rainfall regimes becomes essential to propose solutions to development projects (Kouassi et al., 2010) and local food availability management (Dore 2005). The amplitude of spatiotemporal variation of rainfall series is even more pronounced than temperature (Skouri 1994). This parameter is often associated with inter-annual precipitation deficits, causing droughts responsible for an estimated 30% reduction in gross primary production of terrestrial ecosystems in some areas (Ciais et al., 2005). Because of the deficit of the annual rainfall, the major part of Algerian land is classified in the semi-arid and the arid bioclimatic stages. According to Halitim (1988), the arid zone covers almost 95% of the national territory, of which 89.5% are part of the hyper-arid domain (Sahara) (Nedjraoui 2003). Semi-arid and arid climate are very restrictive and unpredictable from year to year. Areas receiving more than 400 mm in one year are considered semi-arid, sub-humid or humid (Emberger 1930). However, areas receiving less than 100 mm of precipitation are classified as desert or Saharan (Emberger 1930; Le Houérou 1959). At the national level, Sétif region is a potential leader in agricultural production, it is characterized by a typical semi-arid climate, where the majority of agricultural lands are conducted under rainfed systems. Therefore, climate studies should be of particular interest. The purpose of this study is to perform a spatiotemporal characterization of the local rainfall, by analyzing the annual rainfall of the period 1970-2011, taking into account an observational network of 50 rainfall stations spread over Sétif region.

2. Material and methods

2.1 Source of data and methodological approaches

The observation network included 50 rainfall stations, belonging to the National Meteorological Office (ONM) and the National Water Resources Agency (ANRH) (Table A1). The observation network covered the territory of Sétif province and its immediate vicinity (Fig 1). Rainfall dataset include annual precipitation for 1970-2011 time series .The study focused initially on the spatial pattern of the annual precipitation. Thereafter, rainfall and occurrence maps will be developed at different time scales in order to illustrate rainfall change and thus the most affected regions. The whole time series was divided into two sub-periods: 1970-1990 and 1991-2011, ie duration of 20 years for each series.

2.2 Geographic location

Sétif province is situated between 35.5° and 36.5° north latitude and between 4.7° and 6° east longitude. According to the executive Law (84/09) of February 4th 1984, relating to the territorial organization of the country, Sétif province is limited to the north by Béjaïa and Jijel provinces, in the east by the province of Mila, to the south by the provinces of Batna and Msila and in the west by Bordj bou arreridj province. It covers an area of 6.549 km², corresponding to 0.27% of the national territory. The relief is relatively rugged in the northern part and dominated by forested mountains. However, it is rather flat in the center and the south. Located in the semi-arid region of Algeria, Sétif region has long been a favorable region for cereals cultivation and livestock farming. Given to the communication network woven by the national roads and the East-West motorway, Sétif is a compulsory passage of flows coming from South to the ports of Jijel and Béjaia and the movements between East and West. Composed of 60 municipalities, Sétif province is ranked second after Algiers in terms of demographic potential (MATE, 2008).

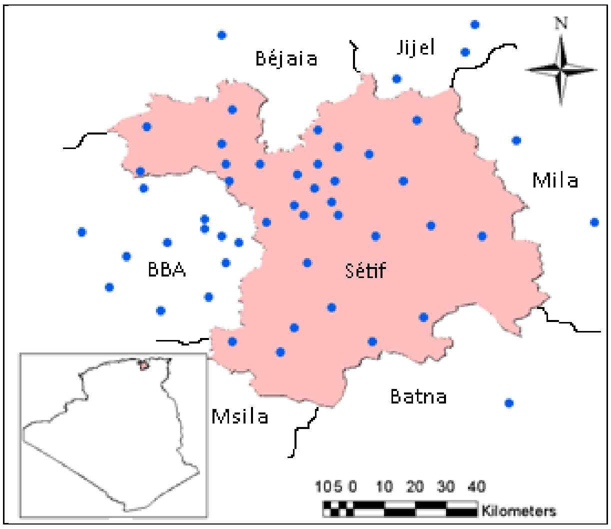

Figure 1. Situation of the study areas and the geographic distribution of the weather rainfall gauges

2.3 Statistical and cartographic processing

The observation network includes 50 rain gauges, homogeneously distributed over the study area. Indeed, observation stations should have geographic coherence and statistical reliability. Statistical applications are initially implemented on 56 rainfall gauges in order to detect unreliable ones; afterwards, 6 stations are rejected because they have several outliers and more than 25% of missing data. The Two-Step statistical classification is conducted in order to classify the observation stations. For this purpose, the variables used are latitude, longitude and annual rainfall. The Two-Step classification aims at forming two groups on the basis of rainfall rates, one group with high annual rainfall and a second one with less rainfall. This technique could illustrate the rainfall gradient that characterized the region throughout the entire period 1970-2011.

Geographic Information System (GIS) software is a mapping tool, that is used in many meteorological and climatic applications, where the task is to interpolate precipitation (Tsanis and Gad, 2001; Akinyemi and Adejuwon, 2008). The implementation of rainfall maps over different sub-periods (1970-1990), (1991-2011) and the entire period (1970-2011) will illustrate the pattern of the rainfall gradient and the estimation of the climatic variation between the different sub-periods. The rainfall maps as well as the spatial probability maps are carried out using the geostatistical interpolation method of the "universal kriging", using "ArcGis10.0"software. Universal Kriging is a powerful statistical interpolation method used for diverse applications such as meteorology (Sluiter, 2009). The rainfall maps are drawn up on the basis to have 5 rainfall classes, where the stretches of classes are 150 mm and 250 mm. Whereas, probability maps are developed under the condition that annual precipitation exceed threshold of 400 mm, this rainfall level is the minimum threshold received in semi-arid climate according to Tassin (2010).

3. RESULTS AND DISCUSSION

3.1 Rainfall gradient and precipitation pattern during the period (1970-2011)

During the entire period (1970-2011), the annual rainfall records an average of 458 mm for all observation stations. While (1970-1990) and (1991-2011) periods record averages of 442 mm and 456 mm respectively. The Two-Step classification during the period (1970-2011) show two different clusters: the first one is situated at the north with an average of 672 mm and a southern cluster with an average of 337 mm. The northern cluster includes 18 stations, while the southern one has 32 stations (Fig 2).

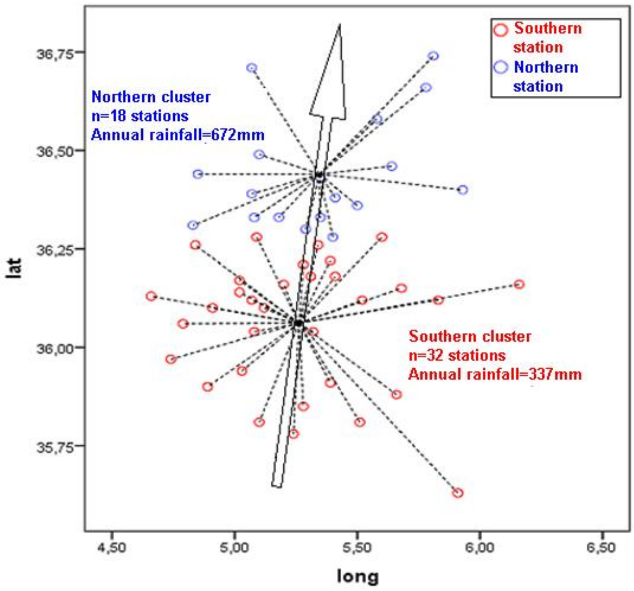

Figure 2. Rainfall clustering and direction of precipitation gradient for (1970 -2011) period

The Two-step classification demonstrates two clusters during the first period (1970-1990); one cluster located north, composed by 5 stations, with an annual rainfall of 1030 mm. While the southern cluster, contains 45 stations with an annual rainfall of 377mm. Indeed, the Euclidean distance between the two barycenters was 0.579°, equivalent to 63km. Gsell (1913) pointed out that the ancient climate of the northern zone of Sétif was of a very important rainfall exceeding 1000 mm, especially behind *Babor* mountain chain. Unfortunately, this level of rainfall tends to decline in recent decades.

However, the Two-step classification during the second period (1991-2001) points out 2 clusters; the northern cluster records an annual rainfall of 665mm, including 17 stations. The southern cluster includes 33 stations with an annual rainfall of 349mm and the 2 barycenters become closer (0.395°) corresponding to 43km.

During the period (1970-1990) the difference between the rainfall averages of the two clusters is 653 mm. while a smaller difference (316 mm) occurred during the second period (1991-2011), with a geographical proximity ranging from 0.579° to 0.395°. This proximity is probably due to the decrease in the average precipitation of the northern zone followed by the displacement of its barycenter towards the south. Also, the south cluster barycenter shows a small southward shift with a decline in annual rainfall ranging from 377mm to 349mm (Table 1).

Table 1 Evolution of the rainfall barycenters during (1970-1990) and (1991-2011) periods

Period	barycenter	Longitude	Latitude	Annual rainfall	Rainfall difference	Euclidean distance
1970-1990	Southern	5.27°	36.15°	377 mm	**653 mm**	**0579°**
	Northern	5.58°	36.64°	1030 mm		
1991-2011	Southern	5.26°	36.07°	349 mm	**316mm**	**0395°**
	Northern	5.37°	36.45°	665 mm		

3.2 Mapping local rainfall

The rainfall mapping of the entire period 1970-2011 shows a north-east/south-west gradient, with a northward rainfall increase. The maximum rainfall range (900-1261mm) is located at the extreme north, where the maximal altitude is about 2004m in Babor Mountain (Ahmim and Moali 2011). This zone is directly exposed to the sea streams coming from the north, for which purpose the annual rainfall recorded the highest rates (Fig 3).

The pluviometric range (750-900 mm) characterizes the part of the southern foothills of *Babor* and *Beni Aziz* Mountain chain, this zone is often deprived of the maritime flows coming from the north. The rainfall range (500-750 mm) crosses the region from west to east, through the mountains of the small Kabylie up to *Maaouia* and *Djemila* municipalities. Meanwhile, the Mountains of *Bouandas* and *Beni Ourthilane* do not record the same rainfall level as the mountains of *Babor*, even they have the same latitude. This is probably due to altitude and sea proximity factors. Indeed, the three first rainfall fringes (900-1260 mm), (750-900 mm) and (500-750 mm) represent the sub-humid bioclimatic stages. The rainfall abacus (350-500 mm) favorable for the cultivation of cereals was spread over the majority of the center and a small part of the extreme south, where the occurrence of rainfall is mainly favored by *Boutaleb* and *El hodna* Mountain chains from the south and the west respectively. The last rainfall range (237-350 mm) covers the most part of the southern zone, often characterized by large plains spanning between 700m to 900m altitude. Given this annual rainfall deficit, the farming system in the south is based mainly on agro-pastoral activities. Recently, farming system becomes less dependent on rainfed crops, it articulates on intensive irrigated crops and greenhouse crops conducted by the drip irrigation system.

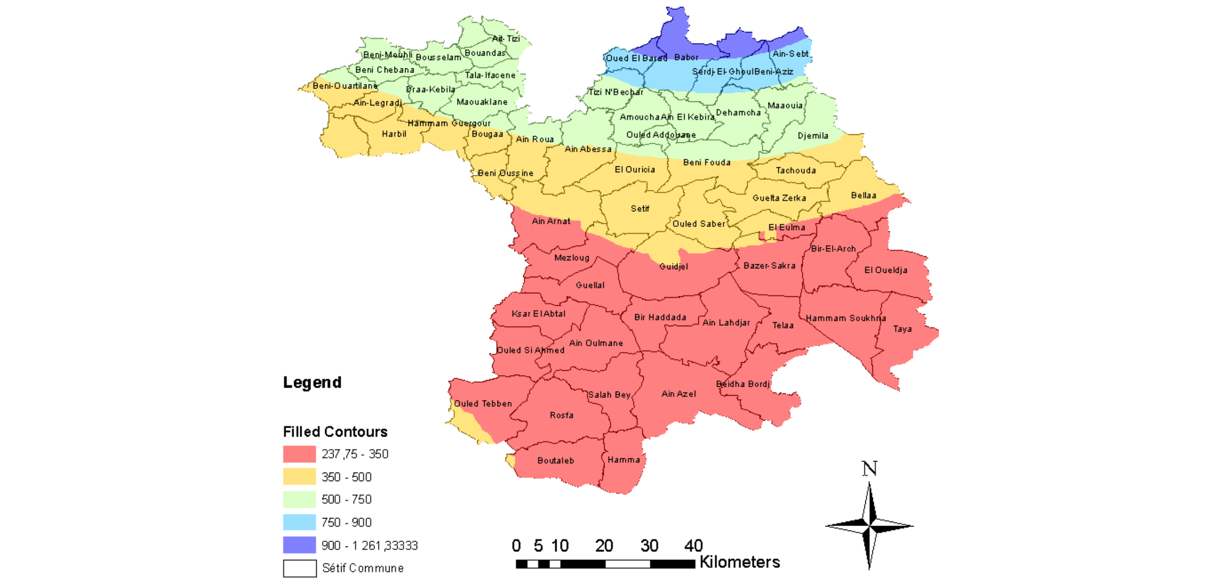

Figure 3. Rainfall map of Setif province during (1970-2011) period

In order to examine the temporal evolution of the rainfall, each sub-period is mapped separately and compared together. The wetter area that exceeds 750 mm located in the north becomes narrower during (1991-2011) period compared to (1970-1990) period (Fig 4). On the other hand, the fringe (500-750 mm) becomes wider during (1991-2011) period and regains more extent especially in the northwest zone. Whilst, during the period (1991-2011), the rainfall range (350-500 mm) is getting more heterogeneous and wider, leading to the appearance of some foci of (350-500 mm) range in both high latitude and extreme south. During the period (1991-2011), the rainfall inferior to 350 mm is reduced in particular on the east side of Sétif province. In general, the rainfall pattern of the period (1991-2011) shows more disturbances compared to (1970-1990) period. It should be noted that the northern zone is more affected by the decline in rainfall between the two periods. However, the appearance of foci (350-500 mm) in the north supports the previous results, saying that the clusters become closer and therefore reinforces the hypothesis of Le Houérou (1959) postulating that the process of climate change must globally lead to a displacement of the Mediterranean bioclimatic stages towards the North. Whereas, the central and southern zones of the province do not show clear variations, actually they maintained annual rainfall rates between 240 and 500 mm. At variance, Meddi et al (2007) consider that rainfall variability increases towards the arid regions. Indeed, rainfall variations can affect areas and cereal yields by 50% and 58% respectively (Smadhi et al, 2009).

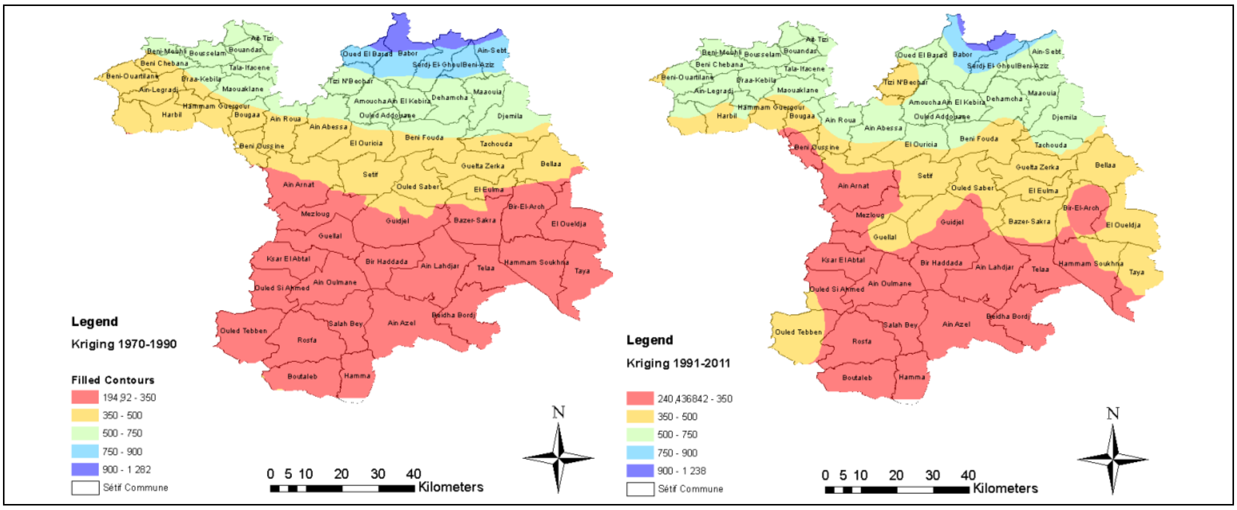

Figure 4. Temporal rainfall maps: (Left) 1970-1990 period. (Right) (1991-2011) period

The implementation of occurrence maps aimed to compare the two periods (1970-1990) and (1991-2011) with respect to the stability of the rainfall level compared to the 400mm threshold.

During (1970-1990) period, the south/north rainfall gradient was so clear; much of the northern zone had an occurrence superior to 75% exceeding the 400 mm threshold (Fig 5). Whereas, in the southern part, annual precipitation have a low occurrence (25%) exceeding this threshold. Both probability fractions (25-50%) and (50-75%) are compressed in the center of the study area, thus characterized by a high inter-annual variability around 400 mm of annual rainfall. During (1991-2011) period, probability range (75-100%) tends to decrease in the northern zone, but the probability ranges (0-25%) and (25-50%) becomes irregular, indicating a high inter-annual variability during the recent period. According to Lazri et al (2015) the Algerian north will experience more dry periods and the occurrence of extreme events will increase from 0.2650 in 2005 to 0.5756 in 2041.

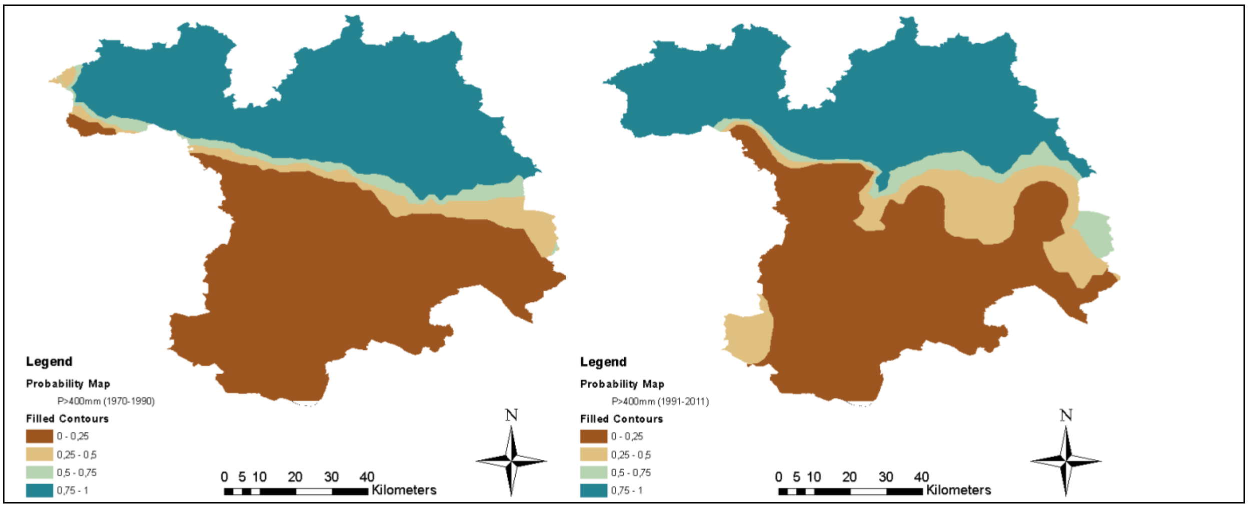

Figure 5 Probability Maps of annual rainfall exceeding a threshold of 400mm: (Left) 1970-1990 period. (Right) (1991-2011) period.

4. Conclusion

This work aimed at developing rainfall maps and to study the spatiotemporal evolution of precipitation in the Sétif region. Indeed, the objectives of work were achieved, although the results obtained were a function of external factors. In this work we were forced to administer several obstacles related to the failure of the information source, such as the availability, reliability of the data and the quality of the observation network. The results showed that the precipitation during the last period (1991-2011) became slightly different and spatially more heterogeneous. Indeed, the northern zone was more concerned by this variability. The utility of climate studies is essential in the agricultural and environmental field in Sétif region. For this purpose, it is time to rely on finer climatic analyzes, highlighting other climatic parameters and conquer fields of climate modeling in order to predict the future climate in our region.

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Appendix

Table A1 Rainfall gauges implemented in the study

Station	longitude (°)	latitude (°)	Rainfall (mm) (1970-2011)	Station affiliation
Ain Abessa	5.30	36.30	556.55	ONM+ANRH
Ain Arnat	5.32	36.18	338.57	ONM+ANRH
Ain Azel	5.51	35.82	283.75	ONM
Ain el Kebira	5.50	36.36	629.93	ONM
Ain Oulmène	5.39	35.91	270.07	ONM
Ain Roua	5.18	36.33	546.50	ONM
Ain Taghrout	5.08	36.13	327.80	ONM
Ain Zada	5.20	36.17	326.27	ONM
Amoucha	5.42	36.38	613.23	ONM
Beida Bordj	5.67	35.88	287.95	ONM
Beni Aziz	5.65	36.46	815.30	ONM
Beni Fouda	5.61	36.29	425.57	ONM
Béni Ourthilane	4.85	36.44	462.00	ONM
Bir el Arch	5.83	36.13	312.43	ONM+ANRH
Birkasdali	5.03	36.14	391.23	ONM+ANRH
Bordj Ghdir	4.90	35.90	383.33	ONM+ANRH
Bordj Zemoura	4.85	36.27	443.23	ONM
Bouandas	5.10	36.49	718.43	ONM
Bougaa	5.08	36.33	405.67	ONM
Bouhira	5.28	36.22	391.67	ONM
El Eulma	5.68	36.15	403.67	ONM
El Hamadia	4.75	35.98	287.80	ONM
El Ouricia	5.41	36.28	486.70	ONM
Fermatou	5.40	36.23	404.73	ONM+ANRH
Guellal	5.33	36.05	346.00	ONM
Guenzet	4.84	36.32	462.33	ONM
Khelil	5.03	36.18	302.57	ONM
Maghraoua	5.09	36.28	382.35	ONM
Mahouane	5.34	36.26	369.33	ONM
Maoklene	5.07	36.40	502.03	ONM
Medjana	4.67	36.13	263.95	ONM
Megress	5.35	36.33	520.75	ONM
Ouled Mosli	5.13	36.11	241.05	ONM
Ouled Tebbène	5.10	35.81	373.53	ONM
Ras el ma	5.53	36.12	356.93	ONM
Ras el oued	5.03	35.94	310.93	ONM
Rasfa	5.24	35.79	280.03	ONM
Salah bey	5.29	35.86	272.13	ONM
Sétif	5.41	36.19	400.85	ONM
Sidi Embarek	4.91	36.10	315.10	ONM
Tixter	5.08	36.05	237.75	ONM
Tizi N'bechar	5.36	36.43	622.55	ONM
Cheddia	5.82	36.75	1129.67	ANRH
Chelghoum Laid	6.17	36.16	363.57	ANRH
Erraguene	5.58	36.59	1261.33	ANRH
Fedj Mzala	5.94	36.40	470.00	ANRH
Merouana	5.91	35.63	344.00	ANRH
Texena	5.79	36.66	1132.67	ANRH
BBA	4.79	36.07	355.59	ONM
Bejaia	5.08	36.72	765.27	ONM
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