International Journal of Advanced Research in Biological Sciences
ISSN: 2348-8069
www.ijarbs.com
DOI: 10.22192/ijarbs Coden: IJARQG(USA) Volume 7, Issue 2 -2020

Research Article

DOI: http://dx.doi.org/10.22192/ijarbs.2020.07.02.010

Climatic factors of mobile dune stations populated by beetle fauna of the Northern fringe and the Eastern region of Morocco

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Abstract

The present study concerns the analysis of abiotic factors and more precisely the climatic conditions of the dune environment is distributed over a 4000 km route from the dunes of Guercif (North) to the large dunes of Merzouga (Sahara), all the way through the dunes of the following stations: North East of Missour, Midelt, Ain Beni Methar, Tendrara, Rich, Boulmane, Bouârfa, Boudnib and Erfoud taken as part of a faunistic syunthesis of the settlement of the beetles of these dunes. The temperature allowed us to note the stations of Guercif and in the stations of Erfoud, Merzouga and Figuig present less cold winters while the middle stations of the West (Midelt, Missour, Rich) and the East (Tendrara) which are influenced by altitude have colder winters. However, the summers are the hottest in the southernmost resorts and in Missour and the coolest in Midelt, Guercif and on the Eastern Highlands (especially in the North). The stations of Erfoud and Merzouga are in a strict desert environment, while the stations of Bouânane and Figuig are just there. The rainfall shows two geographic gradients of increasing aridity. The first North-South and the second East-West.
In terms of climatology, we were able to establish three main types of climate along a North-South geographic gradient, the first has a moderate, relatively arid and humid semi-continental climate (Guercif, Midelt and Aïn Beni Methar), the second presents in moderate continental climate, arid and dry (Tendrara, Boudnib, Bouânane, Rich and North East of Missour) and the third presents a Saharan climate (Figuig, Merzouga and Erfoud). The climate of the region studied is Mediterranean towards the North (characterized by a large period of drought and a regular rainy season from October to May), while towards the South, it becomes Saharan.

Keywords: Climatic factors, mobile dunes, northern fringe, eastern region, Morocco, Sahara.

I- Introduction

Knowledge of the climatology of the North-Western Sahara region is of prime priority for studying the flora and fauna of this region. Thus, the construction of continental sandy formations follows a very specific process, the sands of these regions are the products of successive erosions, the process of which was described in broad outline by PIERRE (1958). He contains :

- River erosion, in a closed basin, of sandstones of various origins, which results, at the mouth of the rivers, from alluvial aquifers composed for the most part of sandy materials.

- A wind erosion which, in an arid climate and between each pulsation of the river, performs, on the alluvial aquifers, the selection of sands, ensures its sorting and dispersion and, finally, builds the dune and maintains its life by constant changes. Followed by a limited wind erosion of inconsistent sandstone reliefs and, sometimes, an in situ peeling of the substrate.

The formation of these dunes is a consequence of the desertification of the environment. This is above all linked to an irreversible reduction of the plant cover, leading to the denudation of the soil. Bare soil is prey to wind erosion. This desertification ultimately manifests itself in a new distribution of the soil. The loose part is carried away by deflation and accumulated elsewhere in the form of dunes for the sandy fractions, and in the form of loess for the silty and clayy fraction. On the ground thus stripped comes then accumulates, under the combined action of the relief, the wind,…., Sandy deposits of exogenous origin which, gradually, constitute mobile dunes. The best sandy fixers of exogenous origin which gradually form mobile dunes. The best fixers seem to be local grasses like the drinn (*Aristida pungens*) and very locally, the alfa (*Stipa tenacissima*) as well as various shrubs or bushes (Alluaude, 1924; Bruneau de mire¸ 1958; Cassola, 1973, Chessel and *al*., 1975; Joly and *al*., 1951; Bouraada, 1996; Bouraada and *al*., 2015; Bouraada and *al*., 2016; Brun, 1968; Kocher and Raymond, 1951; Soudi and *al*., 1990… .etc.

Unevenly distributed, the sand of the desert constitutes buildings of various shapes and sizes, comprising not only the immense massifs of dunes so characteristic of the ergs of the North, but, the dunes of the Sahara are only the result of the accumulation of sands torn away by river and wind erosion, the trampling of herds and excessive clearing.

As the most interesting training that can be encountered in the desert environment (Pierre 1958), we can cite:

- The ergs : To the ergs can be attached all the quick sands of the desert.

- Hamadas sands: These are immense limestone, lacustrine or marine plateaus, fairly compact and where the sand is scarce. It sprinkles the surface by place and in a few cases accumulates at the foot of the plants, under the stones or, more rarely, forms small dunes on the wadis.

- The regs : These are rounded or angular gravel plains mixed with sand, silt or clay. These materials usually plug large depressions and gullies at the foot of the mountains.

- The Nebkhas : These are formations where the sand is retained in mounds of variable size at the foot of isolated plants (Bouraada, 1996).

This study covering various stations in the East and South East of Morocco (Guercif, Aïn Beni Methar, N-E Missour, Tendrara, Boudnib, Bouârfa, Rich, Figuig, Erfoud, Merzouga).

In the present work, we will limit ourselves to dealing with and deepening the points which seem interesting and on which general data are necessary.

II) The stations studied

Distributed over a trajectory of almost 4000km, for the choice of our 12 stations we took into account various criteria. The first is the fact that all of these sandy formations are at least partially mobile. We also chose these stations according to geographic, climatic and accessibility parameters (Figure 1).

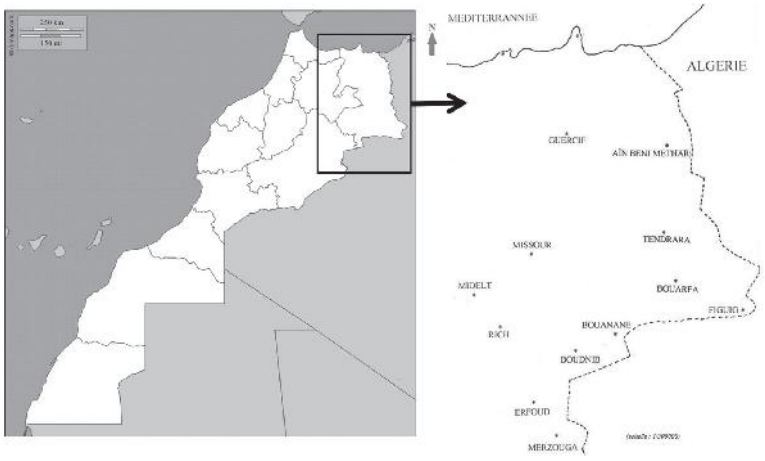

Figure 1 - Location of study stations (Bouraada and *al.*, 2016)
(Scale : 1⁄500000)

We have chosen 12 stations roughly distributed along a North-South axis, from the northern zone to the Saharan borders. The twelve stations therefore have in common the presence of mobile sandy formations.

Thus, we are led to group the stations studied according to the climate and according to the following north-south geographic gradient:

1) The northern and central west stations: Guercif, Midelt and Aïn Beni Methar, characterized by a moderate or warm semi-continental climate;

2) The stations in the center-east : northeast of Missour, Rich, Bouârfa and Tendrara, characterized by a moderate or hot continental climate;

3) The central and southern stations : Boudnib, Bouânane, Figuig, Merzouga and Erfoud, characterized by a warm continental climate.

III) Climate data

The different climatic factors including temperature, precipitation, evaporation and wind allowed us to define the general trends of regional climates and, therefore, the atmosphere prevailing at each of our stations.

Our data were taken from the analysis of the climatic indices of Sauvage (1963).

III-1) The temperature

For all stations, the average annual temperature is fairly constant from one year to the next. In the S_1 station at Guercif, the annual thermal average of this station is around 17 ° C (Table I). It is the lowest of all the stations studied with an average of the coldest month minimums of 3.8°C and an average of the hottest month highs of 37.3°C. It is therefore the station with the least harsh winter temperatures of all the stations studied.

Table I, Climatic index characteristics of study stations (Sauvage, 1963)

[Guercif (S_1), NE Missour (S_2), Midelt, (S_3), Aïn Beni Mathar (S_4), Tendrara (S_5), Bouârfa (S_6), Rich (S_7), Bouânane (S_8), Figuig (S_9), Boudnib (S_{10}), Erfoud (S_{11}), Merzouga (S_{12})].

Station	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	S_{10}	S_{11}	S_{12}
Prec.	192	159	226	256	209	160	245	100	100	102	88	59
M(°C)	373	41	341	32,6	37,5	37,8	37,5	40,9	42,5	40,8	41,6	41,8
m(°C)	38	0,1	-0,3	1,5	0,3	19	0,3	1,8	3,5	1,8	2,7	3,4
(M-m)	335	40,9	34,4	31	37,2	36,9	37,2	39,1	39	39,3	36,9	38,4
(M+m)/	20,	20,5	16,9	16,9	18,75	18,75	18,7	21,3	23	22,1	22	22,8
Q2	19,	13,2	22,6	22,6	17,6	18,75	23,4	8,68	9,2	8,8	5,9	5,2
Cl. Emb.	Arid	Saharan	Dry arid	Dry arid	Medium	Arid belo	Dry arid	Medium	Medium	Medium	Medium	Medium

Prec.	:	Precipitation in mm
M(°C)	:	Average of the lime's maximums
m(°C)	:	Average of coldest ego minimums
Q2	:	Rainfall quotient of Emberger
Cl. Emb.	:	Bioclimatic classification of Emberger

The average annual temperature of Station S_2: Northeast of Missour is 19°C. The difference between the extreme temperatures is the highest of all the stations (40.9°C) and highlights the frankly continental character of the climate of this locality with a very hot summer (M = 4°C) and a winter very severe (average of minimums for the coldest month of around 0.1°C) with frequent frost periods during this season. The S_3: Midelt station has an average annual temperature of 19°C. With an average of the minimums of the coldest month of -0.3°C and an average of the maximums of the warmest month of 34.1°C. It's the coldest station. Winter in particular is very harsh there as the average of the coldest month's minimum shows. During this season, frost periods are very frequent. The fairly high altitude also contributes to these low winter thermal values. Aïn Beni Methar (S_4) Station has an average annual temperature of 19°C. The average for the hottest month's minimum is around 32.5°C, while the average for the coldest month is around 1.5°C. This station has the lowest average of the hottest month's maximums. The difference between extreme temperatures is the smallest of all the stations. The S5 station of Tendrara has an average temperature of this station is 18°C. The difference between the extreme temperatures is high (37.7°C) and highlights the frankly continental character of the climate of this locality. Winter, in particular, is very harsh there as shown by the average of the minimums of the coldest month which is very harsh as shown by the average of the minimums of the coldest month which is 0°C and which translates that, during this season, frost periods are quite frequent. The fairly high altitude also contributes to these low winter thermal values. The Bouârfa S_6 station has an average annual temperature of 19°C. Although the temperature in summer can reach 45°C, the average maximum for the hottest month is practically identical to that of the Tendrara and Rich stations. On the other hand, minimums for the coldest month are significantly higher, perhaps due to more frequent inflows of relatively warm air from the South, during the winter season. As a result, the thermal differences between winter and summer are slightly smaller than those of the Tendrara and Rich stations. The Rich (S_7) Station an average annual temperature of this station is 19,5°C. The extreme thermal values (M and m) are almost identical to those of Tendrara with a winter however slightly less cold. Bouânane (S_8) Station has an average annual temperature of this station is 19°C. The extreme thermal values of this station are relatively identical to those of Boudnib station (average of the maximums of the hottest month of around 40,9°C. Station (S_9) in Figuig in turn has an average annual temperature of this station is 20,5°C. This station is the warmest of all the other stations studied, especially in summer when the average of the maximums of the hottest month reaches 42,5°C. It is even warmer than the more Saharan stations of Erfoud and Merzouga. The average for the most Saharan month's minimums is also high. The very high summer thermal values give the climate of this locality a difference between extreme temperatures among the highest. Station S_{10} (Boudnib) has an annual thermal average of this station is around 19,6°C.

The average high of the hottest month is around 40,8°C while the average of the minimums of the coldest month is around 1,5°C. The difference between the extreme temperatures is therefore 39,9°C. The Erfoud (S_{11}) Station has an average annual temperature of around 20°C. With an average of the hottest month highs of 41,6°C and an average of the coldest month highs of around 2,7°C. It ranks in the group of hottest stations. Finally, the (S_{12}) station (Merzouga) has an annual average temperature of around 20,5°C. The Figuig station is the hottest. Although during summer the temperature can exceed 50°C, the average of the hottest month's highs is almost identical to that of the previous station (41,8°C). However, the average for minimums in the coldest month and is significantly higher in the order of 3,4°C, possibly due to more frequent inflows of relatively warm southern air during the winter season.

III-2) Precipitation

All the stations studied are located in regions receiving less than 4000mm of water per year. In general, the precipitation for all the stations is very irregular from one year to the next. In Station S_1 of Guercif, precipitation is spread from the end of September to May. The dry period covers the months of June, July and August. The average annual precipitation is around 192mm. In the locality of S_2 station northeast of Missour, the rains spread between November and May. The dry season runs from April to November. The average annual precipitation is 159 mm, therefore very close to that of Bouârfa located a little further south and especially more east. The majority of the rains that can water this station are indeed retained by the Middle Atlas. Midelt (S_3) station, the rains in this station are spread between the month of November and the month of May. The dry period runs from April to August and is particularly accentuated in late July and August. The average annual precipitation is 226mm with generally heavy rains in autumn. The low winter temperatures of this station and its high altitude make snow fall there almost every winter. The S4 station (Aïn Beni Methar), Located in the northern part of the Highlands with an altitude of 1200m, this station is marked by the highest value of the average annual precipitation (246 mm/year). The rains are spread out between November and May. The dry period runs from April to November and is particularly severe in July and August. Snow falls almost every winter. In the S_5 station of Tendrara, the rains, in the southern part of the Highlands, spread between November and May. The dry period runs from April to November. Average annual precipitation is 209mm, with fall rains generally being more abundant than spring rains. Due to the low winter temperatures it snows almost every winter in Tendrara.

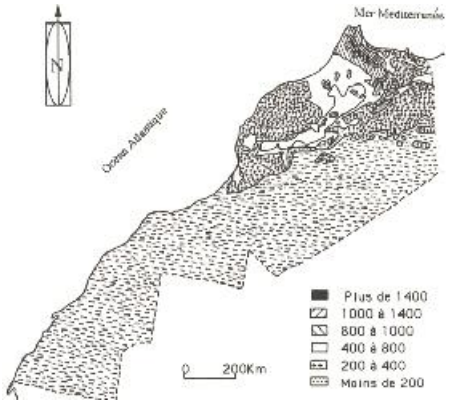

Figure 2, Distribution map of annual precipitation averages in Morocco (*in* Maachi, 1995)

In station S_6 of Bouârfa, the rains of this station occur mainly in autumn and spring. They are rare or absent during the winter. The dry period runs from April to November and is particularly severe in July and August. The average annual precipitation is 160mm. In Rich's S_7 Station, the distribution of rains in this station is spread between November and May. The dry season covers the same period as in the previous station. The average annual precipitation is 245mm (Figure 2). The fairly high altitude also contributes to snowfall in winter. Bouânane (S_8) Station looks very similar to the previous station in these climatic conditions. The average annual precipitation is 100mm with fall rains generally more frequent than spring rains. The dry period is very long and lasts from March to November and the rains are mainly in the form of thunderstorms. Precipitation at the S_9 station in Figuig is still very irregular, relatively infrequent and of very random occurrence. The very long dry season runs from March to November. Rainfall is

mainly in the form of thunderstorms, sometimes violent. This station is characterized by an average annual rainfall of 100mm. In Boudnib (S_{10}), the rains occur mainly from the end of autumn to the beginning of spring. The dry period lasts from April to November and is most pronounced in July and August. Average precipitation is around 102mm. This rainfall is therefore relatively low. At Station S_{11} (Erfoud), rainfall is very low (68mm/year on average) and is mainly in the form of thunderstorms, sometimes violent, the rainy period is very short and goes from the end of November to the beginning of March. The dry season is however very long, it goes from March to November. And in the S_{12} station in Merzouga, is characterized by the lowest annual average rainfall of all the stations studied (59 mm/year). Relatively infrequent and of very random occurrence, mainly in the form of thunderstorms. The dry period is very long.

III-3) Potential evapotranspiration

In all the stations studied, this parameter follows two gradients of increasing values. The first North-South and passes from the Nordic and central stations (Table II) : Guercif (890mm/year), Aïn Beni Mathar (790mm/year), Rich (798mm/year), Tendrara (877mm/year), Midelt (880mm/year); Intermediate stations: North-East of Missour (940mm/year) and Bouârfa (932mm/year); South station: Merzouga (1450mm/year), Erfoud (1309mm/year); Boudnib (1120mm/year), Bouânane (1130mm/year) and Figuig (1127mm/year). A second gradient is not very obvious and is of the East-West type and passes from Boudnib, Bouânane, Bouârfa, Figuig, Tendrara and Aïn Beni Methar towards Guercif, North-East of Missour, Midelt and Rich. As a result, the increase in potential evapotranspiration from East to West, and from North to South associated with the decrease in precipitation along these two axes contributes strongly to the increase in aridity respectively from Midelt to Aïn Beni Mathar and from Guercif to Merzouga.

Table II, Potential evapotranspiration in mm/year

Station		Potential evapotranspiration
S_1	Guercif	890 mm/year
S_2	Nord-Est of Missour	940 mm/year
S_3	Midelt	880 mm/year
S_4	Aïn Beni Methar	790 mm/year
S_5	Tendrara	877 mm/year
S_6	Bouârfa	932 mm/year
S_7	Rich	798 mm/year
S_8	Bouânane	1130 mm/year
S_9	Figuig	1127 mm/year
S_{10}	Boudnib	1120 mm/year
S_{11}	Erfoud	1309 mm/year
S_{12}	Merzouga	1450 mm/year

III-4) The wind

Regardless of its action on temperature and on increasing the rate of evaporation, wind plays an important role in seed dispersal. It also acts in the transport of materials (sand, silt, etc.) which are then fixed by the vegetation, making it possible to constitute secondary soils of wind origin.

The Nordic stations (Midelt, North East of Missour, Guercif and Aïn Beni Mathar) are marked during winter by a relatively humid and cold north wind characterized by a low speed; However, in these stations, during the summer, the warm south wind prevails.

In the other stations, Rich, Tendrara, Bouârfa, Bouânane, Boudnib, Erfoud, Figuig and Merzouga there are dry and hot winds from the South which dominate with Tendrara also a dominance from the North wind, cold in winter.

IV) Climate synthesis

For the global characterization of the different climates we used the classification of DEBRACH (1953) and that of EMBERGER (Sauvage, 1963(*in* Haloui, 1991)).

IV-1) Calssification of DEBRACH

Based on the thermal difference between the average of the maximum temperatures of the hottest month (M) and the average of the minimum temperatures of the coldest month (m) (Table III), DEBRACH (*in* Haloui, 1991) defines four types of climatic domains :

Island climate: M-m <15 ° C
Coastal climate: 15 <M-m <25 ° C
Semi-continental climate: 25 <M-m <35 ° C
Continental climate: M-m> 35 ° C

Table III, Climatic classification of stations according to thermal difference (M + m)
(Climagram of DEBRACH (1953)

STATION	Climatic domain	Climatic nuance
S_1 : Guercif	Semi-continental	hot
S_2 : Nord-Est of Missour	continental	hot
S_3 : Midelt	semi-continental	moderate
S_4 : Aïn Beni Methar	semi-continental	moderate
S_5 : Tendrara	continental	moderate
S_6 : Bouârfa	continental	moderate
S_7 : Rich	continental	moderate
S_8 : Bouânane	continental	hot
S_9 : Figuig	continental	hot
S_{10} : Boudnib	continental	hot
S_{11} : Erfoud	continental	hot
S_{12} : Merzouga	continental	hot

Examination of the thermal data shows that the thermal difference (M and m) is between 31°C and 40.9°C respectively at Aïn Beni Methar which has a semi-continental climate with moderate shade and North East of Missour which has a moderate shade continental climate which tends to be warm.

Thus, we are led to regroup the stations studied according to the climate and according to the following North-South geographical evolution :

1-) The North and Center-West stations: includes the stations of Guercif, Midelt and Aïn Beni Methar and are characterized by a moderate or hot semi-continental climate.
2-) The stations in the Center-East: includes the stations in the North-East of Missour, Rich, Bouârfa and Tendrara and are characterized by a moderate or relatively hot continental climate.
3-) The stations of the Center and the South: regroups the stations of Boudnib, Bouânane, Figuig, Merzouga and Erfoud and are characterized by a hot continental climate.

IV-2) Classification of EMERGING (Sauvage, 1963)

In addition to the difference between M and m, EMBERGER also integrates the annual average precipitation (P) into its rain-heat quotient Q2 which it expresses according to the formula:

$$Q2 = (1000P) / \{[M + m) / 2] (M + m)\}$$

P is the annual average precipitation in mm
M is the average of the maximums of the hottest month
m is the average of the minimums of the coldest month
(M and m are expressed in absolute degrees (t ° K = t ° C + 273.2))

In general, a climate is all the more humid as this quotient is high. In summer, aridity is the primary limiting factor for vegetation development (Figure 3). In winter, however, this factor is replaced by temperature (at its minimum values) which, during this season is the main factor limiting plant growth (Haloui, 1991). According to OZENDA (*in* Haloui, 1991), geographer and botanist agrees to consider as desert regions which can be characterized, as a first approximation, as having an average annual rainfall less than 200 mm / year. According to this criterion, only the Midelt, Rich (Figure 3), Tendrara and Aïn Beni Methar stations would not be in a desert climate. But, according to Y. and M. VIAL (1974(*in* Haloui, 1991)), other authors consider the desert in a narrower sense with the Sahara of isohete 100 mm for the northern limit and the isohete 150 mm for the southern limit (Figure 4).

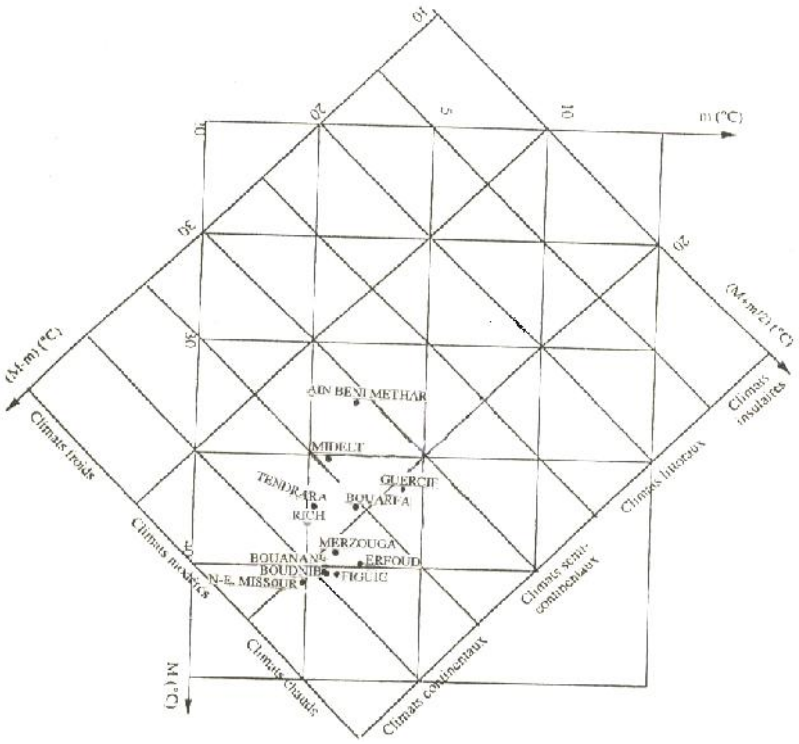

Figure 3, position of stations in the DEBRACH climmagram (1953)

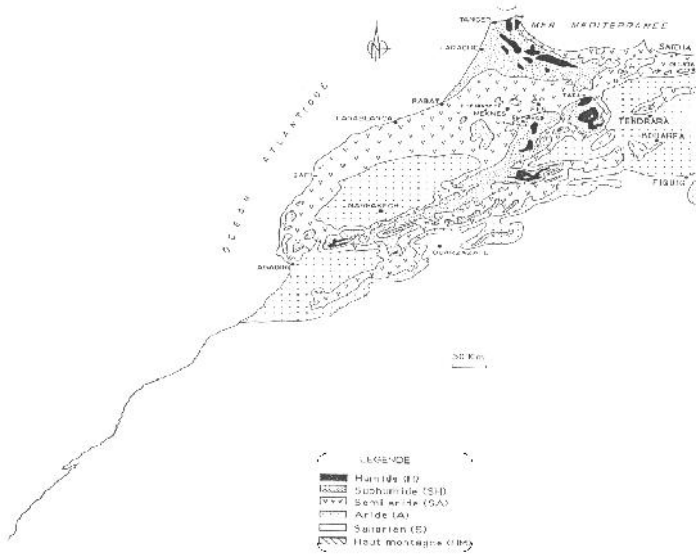

Figure 4, Bioclimatic stage of EMBERGER (1932) - (*in* Maachi, 1995) -

Analysis of the Climagram established for our 12 stations according to Sauvage (1963) (Figure 4) shows that Aïn Beni Methar and Rich are at the upper limit of the arid stage in cool winter while Midelt presents a winter rather cold. In addition, Guercif and Tendrara are located at the lower limit of the arid stage with a temperate winter in Guercif and cold in Tendrara. Bouârfa is between the arid and Saharan floor in cool winter. The Boudnib, Bouârfa and Erfoud stations are on the Saharan floor in cool winter. While Figuig and Merzouga are upstairs in the temperate winter.

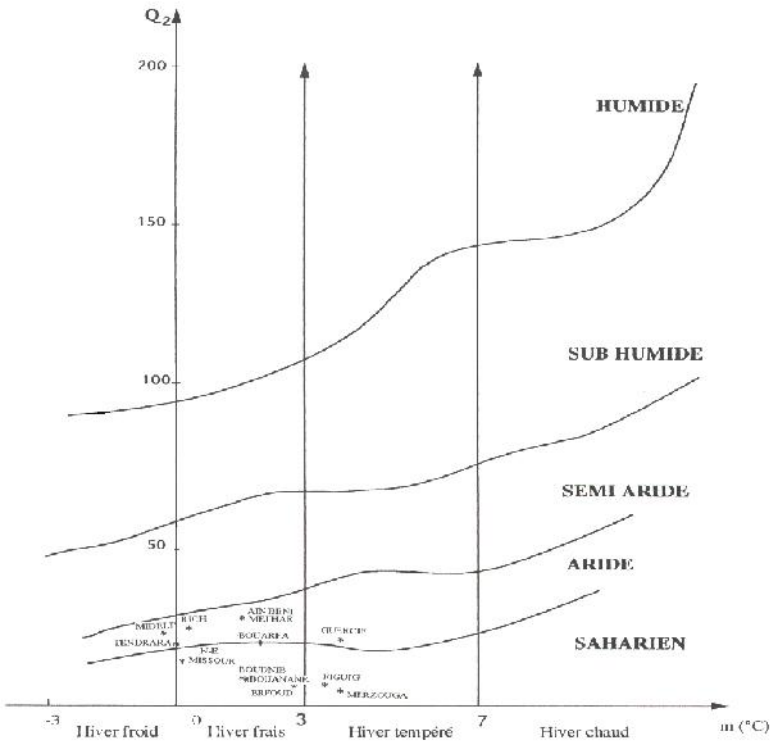

Figure 11, EMBERGER's climagram (SAUVAGE, 1963)

V- Conclusion

The temperature factor analysis allowed us to note the stations studied with the following characteristics:

➢ Winters are the least cold in Guercif and in the stations of Erfoud, Merzouga and Figuig and the coldest in the middle stations of the West (Midelt, Missour, Rich) and the East (Tendrara) partly less under the effect of altitude.

➢ The summers are the hottest in the southernmost resorts and in Missour and the coolest in Midelt, Guercif and on the Eastern Highlands (especially in the North).

From these two remarks follow that the station of Missour has the most contrasted climate during the year and that of Aïn Beni Methar the least contrast. The southernmost stations generally have higher extreme temperature differences than the others.

Taken within these limits, only the stations of Erfoud and Merzouga are in a strict desert environment, while the stations of Bouânane and Figuig are just there at the limit.

In all the stations studied, the rainfall shows two geographic gradients of increasing aridity.

The first North-South and the second East-West. Along these two gradients, the average annual precipitation decreases sharply while the dry period becomes longer and longer. There is also an increasing irregularity in the rain regime.

By climatological analysis of the study stations, we were able to establish three main types of climate:

- A moderate, relatively arid and fairly humid semi-continental climate: Guercif, Midelt and Aïn Beni Methar.
- A continental, moderate, arid and dry climate: Tendrara, Bouârfa, Boudnib, Bouânane, Rich and North East of Missour.
- A Saharan climate: Figuig, Merzouga and Erfoud.

The rainfall and the rainfall quotient also show a clear decreasing gradient from North to South. On the contrary, evapotranspiration increases gradually from North to South and from East to West.

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DOI:10.22192/ijarbs.2020.07.02.010	

How to cite this article:
Khalid BOURAADA, Mariam ESSAFI, Guy CHAVANON and Lahcen EL GHADRAOUI. (2020). Climatic factors of mobile dune stations populated by beetle fauna of the Northern fringe and the Eastern region of Morocco. Int. J. Adv. Res. Biol. Sci. 7(2): 111-120.
DOI: http://dx.doi.org/10.22192/ijarbs.2020.07.02.010