The evolution of precipitation on the Romanian Black Sea coast during 1965-2016, from the perspective of regional and global climate changes

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Abstract: Atmospheric precipitation and air humidity are the most important meteorological parameters in characterizing the climate of a region. Global warming, among its many effects, can also lead to changes in types of precipitation, which could produce a chain reaction, reducing rainfall in already dry areas. Also, the reverse effect of increasing the amounts of precipitation following the intensification of extreme phenomena is analyzed. The present study is an analysis of the precipitations on the Romanian seaside in the period 1965-2019, in order to foresee the evolution of these, compared to the multiannual averages and to make a prediction of evolution, necessary for sustainable development in this region.

Keywords: Black Sea, Dobrogea, atmospheric precipitation, climate changes

1. INTRODUCERE

The present work represents a continuation of the studies regarding the evolution of the meteorological parameters - the atmospheric precipitation, as a part of the project The influence of the global and regional geo-climatic changes on sustainable development in Dobrogea - GLOBE, 2007 - 2011. The general objective of the project was to highlight the impact suffered by the Dobrogean territory during its evolution under the influence of global and regional geo-climatic changes, with an impact on the sustainable development of Dobrogea today, under the pressure of global/regional changes. Each coastal area has unique interrelations of physical, biological and human components and processes and therefore the extension and nature of the impacts in a given place will be different from those in any other coastal area. Atmospheric precipitation is a main component of the water circuit in nature, and together with the air temperature, one of the most important meteorological parameters in the characterization of the climate of a region. The study of the evolution of this climatic element with the greatest instability in time and space, over a long period of time (1965-2016) is of particular interest, not only from theoretical point of view, but also practical, for agriculture, industry, hydrotechnical and social-urban constructions, etc. The regime of precipitation over time is given by the recorded quantities that differ from one year to another and from one area to another. Local
factors contribute to their formation: the sources of moisture and the intensity of vertical movements of the air. There are periods when due to thermal convection in the warm season, clouds develop that give rains with relatively large quantities, having the character of averse accompanied of hail, electrical discharges and short-term intensifications of wind speed, causing the phenomenon of thunderstorms.

Studies on global warming have shown that among its many effects is the modification of the types of precipitation, which could produce a chain reaction, reducing precipitation in already dry areas. Also, the reverse effect of increasing the amounts of precipitation following the intensification of extreme phenomena is analyzed. The present study is an analysis of the precipitations in Dobrogea from 1965-2016, to see the evolution of them compared to the multiannual averages, and to make a prediction of their evolution, necessary for a sustainable development in this region.

Dobrogea, located in the south-eastern part of Romania, is characterized by a temperate climate – semi-arid continental, of a low altitude plateau, which, in the context of the national territory, presents the highest degree of continentalism, influenced by its position in the immediate vicinity of the Black Sea, the Danube corridor (to the west and to the north), the complexity of the surface rock active, as well as its position on the periphery of the barrier centers generating precipitation or drought.

2. DATA AND METHODS

The comparative analysis of the multiannual average precipitation quantities recorded on the territory of Dobrogea shows the obvious influence of the Black Sea waters, in the sense that the stations located on the coast they recorded, usually over time, smaller quantities compared to the stations located in the continental part of Dobrogea.

Compared to the scale of the entire country, it can be said that on the coast and in the Danube Delta are produced annually the lowest quantities of precipitation, due to the influence of large areas of water that favors the development of the descending currents, temperature inversions and breezes, which leads to the homogenization of the temperature, to the prevention of thermal convection and to the breakup of cloudy systems. Atmospheric precipitation is the totality of the products resulting from the condensation of water vapor that reaches the surface of the earth either in liquid state (rain, drizzle) or in the state solid (snow, hail) or combined (sleet-snow and rain). Together with air temperature, solar radiation, moisture and wind, atmospheric precipitation is an important and useful parameter to define the climate of a regions.

The rainfall regime is of importance for the design and development of different sectors of the national economy. The amount of precipitation is of great importance especially for agriculture, in the construction of irrigation systems, of water retention basins, in the design of hydro-technical constructions (dams, sewerage networks, etc.).

In order to analyze the amount of precipitation recorded on the coast, the amount of precipitation from four meteorological stations over a period of more than 25 years was taken into account in order to highlight the amount of precipitation the individuality of each station by the values it records from the low values to the very high ones.

3. RESULTS

a. From the undertaken study it resulted that on the Romanian Black Sea coast are recorded the lowest amounts of precipitation, an important role having the processes of descent of the cloudy systems in the summer months that lead to the ancestor of cloud formations with precipitation.
Rainfall amounts have sufficient variability over time. In their formation, an important role is played by local factors: moisture sources (lakes), the intensity of vertical movements of the air (thermal convection).

b. There are periods in the warm season when due to thermal convection, cloud formations with heights of 10,000-14,000 m high are developed, from which relatively large quantities with averse character fall, accompanied by hail, electric discharges, and short-term intensification of the wind speed, causing the phenomenon of thunderstorms and dust transport on the beaches.

c. Another cause of the occurrence of heavy rainfall is the cold atmospheric fronts. One such case was in the period 29.09-03.10.2013, when high rainfall amounts were recorded on the coast, differentiated if we take into account the multiannual monthly average for that month; 5 times more in Constanta, almost 2 times in Mangalia and 3 times in Gura Portiței (Table 1 and Table 2).

| No. crt. | Meteorological Station | Cant.de precipitații (l/mp) |
|---------|------------------------|-----------------------------|
| 1       |Constanța               | 175,8                       |
| 2       | Mangalia               | 64,5                        |
| 3       | Gura Portiței          | 101,0                       |
| 4       | Sfântu Gheorghe         | 35,8                        |

| No.crt. | Meteorological Station | Cant.de precipitații (l/mp) |
|---------|------------------------|-----------------------------|
| 1       | Constanta              | 31,81                       |
| 2       | Mangalia               | 35,8                        |
| 3       | Gura Portiței          | 28,3                        |
| 4       | Sfântu Gheorghe         | 23,0                        |

d. The amounts of monthly average, and annual rainfall are differentiated from one month to another. This is due to the general circulation of the atmosphere on the one hand, and on the other hand to the interaction with local physical-geographical factors.

e. In the distribution of the monthly rainfall quantities, a first maximum is found in May-June of over 35 mm and a second maximum in September-October (Table 3). The minimum monthly rainfall amounts shall be recorded in February. In the summer season, although the rainfall occurs less often, a rain is enough that gives a very large amount. This is due to the baric formations that generate humid air masses of Mediterranean origin rich in precipitation. In the period 1965-2016 there was in Constanta, years rich in precipitation: 1970, 1971, 1991 and 1997 (may), when there were recorded monthly quantities exceeding 100 mm. The year 1970, in May, in Constanta were registered 115.4 mm; Mangalia 105.9 mm; and in June of the years 1972, 1978, 1983, 1992, 1997 were recorded monthly precipitation amounts of up to 140.3 mm in Mangalia (Table 4 and Figure 1).

Table 1 The amount of precipitation recorded between 29.09. – 03.10.2016 at the Constanta, Mangalia, Gura Portiței, Sfântu Gheorghe meteorological stations

Table 2 Multiannual averages (1961–2012) monthly precipitation values for October 2013 at Constanta, Mangalia, Gura Portiței, Sfântu Gheorghe meteorological stations
Table 3 Multiannual average precipitation (1965-2016) at Constanta, Mangalia, Gura Portiței, Sfântu Gheorghe meteorological stations

| No.crt. | Meteorological Station     | Precipitation (l/sqm) |
|---------|----------------------------|-----------------------|
| 1.      | Constanța                  | 396.7                 |
| 2.      | Mangalia                   | 459.6                 |
| 3.      | Gura Portiței              | 345.9                 |
| 4.      | Sfântu Gheorghe            | 333.4                 |

Table 4 Monthly and annual average precipitations (mm) recorded at Constanta, Mangalia, Gura Portiței, Sfântu Gheorghe stations (1965-2016)

| Stația     | I   | II  | III | IV  | V   | VI  | VII | VIII | IX  | X   | XI  | XII | Annual |
|------------|-----|-----|-----|-----|-----|-----|-----|------|-----|-----|-----|------|--------|
| Mangalia   | 43.6| 23.6| 43.5| 29.0| 41.9| 40.7| 63.8| 25.6 | 39.3| 65.5| 28.7| 43.4| 459.6  |
| Constanța  | 31.0| 26.0| 28.7| 39.5| 36.1| 41.9| 35.7| 31.2 | 31.8| 35.9| 37.9| 35.3| 396.7  |
| Gura Portiței | 21.0| 17.5| 24.4| 25.0| 42.0| 35.4| 23.1| 27.2 | 23.5| 34.8| 32.5| 33.8| 345.9  |
| Sfântu Gheorghe | 25.8| 21.5| 24.4| 21.4| 26.5| 18.7| 32.3| 35.0 | 38.3| 28.2| 29.3| 32.0| 333.4  |

Figure 1 Monthly average precipitation recorded at Constanta, Mangalia, Gura Portiței, Sfântu Gheorghe, (diagram method: \( p_I + p_{II} + p_{III} + \ldots + p_{XII} / 12 = \Sigma an \); after A.M.M. Bucharest, 2016)

f. Average annual amounts of atmospheric precipitation

The Romanian Black Sea coast between Murighiol-Sfântu Gheorghe and Vama Veche records annual precipitation amounts sometimes less than 300 mm, as they were in the years: 1983 in Constanta (225.2 mm), 1990 in Mangalia (245.9 mm), 1990 in Gura Portiței (163.7 mm), 1983 in Sf. Gheorghe (165.4 mm). In January, as in the other winter months the precipitation amounts are reduced. The smallest monthly average quantities recorded on the Black Sea coast being between 0 and 10 mm. In July, the territorial distribution of precipitation quantities can be characterized by high values exceeding 60 mm, this being mainly due to convective processes. Thus, at Sfântu Gheorghe were registered 91.6 mm in 1964, 83.2 mm in 1973, 73.6 mm in 2008, 70.8 mm in 2016; at Gura Portiței in the middle sector: 62.8 mm in 2008 and 63.6 mm in 2016; and, in the southern sector over 100 mm, in Constanta: 106.6 mm in 2009; 124.5 mm in 1997; 129.7 mm in 1892,
and 181.2 mm in 1931, and in Mangalia: 101.3 mm in 2016; 101.4 in 1983 and 130.9 mm in 1997.

g. Maximum precipitation amounts in 24 hours

The maximum daily precipitation amounts recorded in 24 hours can sometimes equal the average seasonal amount. For example, for the studied period (1965-2016), at Mangalia was recorded a very large amount of precipitation of 127.7 mm in 18.09.1995, 111.7 mm on 17.09.2011; 84.6 mm on 27.04.2003; 146.6 mm on 22.09 2005; at Gura Portișei 60.8 mm on 01.10.2013; 65.8 mm in 24.08.1994 and 69.0 mm on 24.09.2005, and at Sfântu Gheorghe 65.6 mm on 02.09.1999; 74.1 mm on 23.08.1994; 76.6 mm on 19.09.1971 and 80.2 mm on 3.07.1964. Rain showers are those that sometimes record large amounts of fallen in short intervals of time that cause flooding (Figure 2). Example: in Constanta, 205.8 mm on 24.08.2004 in a time frame of 15 hours.

These substantial amounts of precipitation are due to invasions of the humid air masses of Mediterranean origin and the Icelandic cyclone series that have been active in some years since the period under review (1965-2016), on the coast being recorded annual quantities of precipitation exceeding 600 mm, for example: 2004 in Constanta (674.6 mm); 1995 in Mangalia (671.1 mm) and (615.0 mm) in 1997; year 1966 at Sf. Gheorghe (606.9 mm) (Table 5 and Figure 3).

Table 5 The maximum quantities of precipitation (mm) fallen in 24 hours on the Romanian Black Sea coast, between Murighiol – Sf. Gheorghe and Vama Veche (1961-2016)

| Station     | May | June | July | August | September | October | November | December |
|-------------|-----|------|------|--------|-----------|---------|----------|----------|
| Constanta   | a   | 46.7 | 28.3 | 44.7   | 50.1      | 49.8    | 69.9     | 44.4     | 205.8    | 58.4    | 75.7    | 36.8    | 28.0    |
|             | b   | 5/66 | 25/70| 31/95  | 37/73     | 28/97   | 27/99    | 11/65    | 32/90    | 03/99   | 18/81   | 26/02   | 30/89   |
| Mangalia    | a   | 54.1 | 29.4 | 31.4   | 84.6      | 66.7    | 69.1     | 59.4     | 86.6     | 127.7   | 111.7   | 68.8    | 31.6    |
|             | b   | 10/10| 37/99| 31/95  | 27/03     | 38/2    | 22/83    | 25/97    | 20/84    | 18/95   | 17/11   | 23/15   | 30/89   |
| Gura Portișe | a   | 46.6 | 22.8 | 40.1   | 38.9      | 51.1    | 58.2     | 31.0     | 36.7     | 48.9    | 50.8    | 33.3    | 29.2    |
|             | b   | 7/12 | 15/10| 24/02  | 17/88     | 28/97   | 13/86    | 30/10    | 29/1     | 60/9    | 17/13   | 27/85   | 16/09   |
| Sfântu Gheorghe | a   | 36.3 | 34.3 | 28.3   | 37.7      | 29.1    | 31.5     | 80.2     | 74.1     | 51.2    | 52.0    | 35.4    | 33.7    |
|             | b   | 8/16 | 11/82| 29/02  | 19/74     | 12/78   | 13/80    | 36/1     | 25/94    | 14/00   | 17/13   | 27/77   | 12/69   |

Source: (Romanian Meteorological Yearbook, 1961-2016)
From the analysis of the above data, the following: in the warm season of the year, on the coast, the descending movements produce the breakup of the Cumulonimbus type clouds; however, due to the existence of highly developed atmospheric fronts located in the coastal area, these maximum precipitation values occur.

g. The lowest and highest amounts of monthly rainfall in the period (1965-2016) at the meteorological stations on the Romanian seaside.

The minimum monthly amount of precipitation occurs towards the end of summer when the values are between 2 mm and 20 mm, and the maximum occurs in May and June. A second high is in November with an average of 39.2 mm, and another second low in January, with an average of 25.8 mm, and February with 26.3 mm, this being due to certain contrasts related to local circulations. Example: in the coastal area, the sea breezes have a very large role in stabilizing the baric structures or of appearance on the Black Sea of local baric formations.

The highest monthly amounts of precipitation were recorded in August and September as follows: in Mangalia in 1995 in September (188.1 mm), in Constanta in 2004 in August (205.8 mm), in Gura Portitei September (177.0 mm), and at Sfantu Gheorghe in 1972 August (126.2 mm). These quantities were recorded from heavy rain showers (Table 6 and Table 7).

Table 6 The smallest and highest monthly precipitation amounts (mm) - 1965-2016

| Meteo Station   | min. | Month | Year  | Max.  | Month | Year  | Amplitude |
|-----------------|------|-------|-------|-------|-------|-------|-----------|
| Mangalia        | 0.0  | August| 1989  | 188.1 | September | 1995 | 188.1     |
| Constanta       | 0.0  | August| 2004  | 205.8 | August | 2004 | 205.8     |
| Gura Portitei   | 0.0  | August| 1989  | 177.0 | September | 2005 | 177.0     |
| Sfantu Gheorghe | 0.0  | July  | 2001  | 126.2 | August | 1972 | 126.2     |
The largest amounts of precipitation occur in the warm season of the year when the local processes of thermal and dynamic convection intensify, generating Cumulonimbus clouds from which rain showers fall.

In Table 8, the signs (+) and (-), the deviations of the precipitation quantities from the multiannual average at the meteorological stations under study are highlighted. It is found that the positive deviations marked in red (which exceeded 200 mm) were recorded in the years: 1995 (211.8 mm) and 2005 (298.2 mm) in Mangalia; year 2004 (210.3 mm) in Constanta; over 100 mm at Mangalia and 108.9 mm at Sf. Gheorghe. Negative deviations were recorded in the years: 1991, 1996, 1997, 2000, 2001, 2002, 2003, and 2005, but the most significant were in 2000 at all stations. Their value was more than 100 mm: Mangalia 206.0 mm, Constanta 171.7 mm, Gura Portitei 146.1 mm, and at Sfantu Gheorghe, the minimum deviation occurred in 2002 and was 120.7 mm.

Table 8 Deviations of the average annual amounts of precipitation in 20 years compared to the multiannual average (1994-2013), (method statistical-mathematical; \( \Sigma \text{p1994} + \Sigma \text{p1995} + \Sigma \text{p1996} + \ldots \Sigma \text{p2013}/20 = \text{mean multiann.} \) after A.N.M. Bucharest, (2008)

| Meteo Station    | Mangalia Mean 499.3 | Constanța Mean 464.3 | Gura Portitei Mean 369.4 | Sfântu Gheorghe Mean 328.0 |
|------------------|---------------------|----------------------|--------------------------|---------------------------|
| Years            | Mean sum - Amplitude Mean sum - Amplitude Mean sum - Amplitude Mean sum - Amplitude |
| 1994             | 325.1 -134.2        | 324.1 -140.2         | 520.4 -151.0             | 393.9 -65.9              |
| 1995             | 671.1 211.8         | 604.3 140.0         | 520.4 151.0             | 393.9 65.9             |
| 1996             | 386.5 -72.8         | 443.4 20.9          | 405.9 36.5             | 369.4 41.4             |
| 1997             | 615.0 155.7         | 642.2 77.9          | 496.3 126.9             | 404.2 76.2             |
| 1998             | 470.5 11.2          | 488.7 24.4          | 331.0 -38.4             | 266.4 -61.6             |
| 1999             | 459.1 -0.2          | 511.1 66.8          | 326.7 -42.7             | 417.1 89.1             |
| 2000             | 253.3 -206.0        | 292.5 -171.8        | 223.3 -146.1             | 231.3 -96.7             |
| 2001             | 411.8 -47.5         | 400.4 -63.9         | 236.7 -137.7             | 243.6 -84.4             |
| 2002             | 584.9 125.6         | 431.6 -32.7         | 329.4 -40.0             | 207.3 -120.7             |
| 2003             | 454.8 -4.5          | 350.2 -114.1        | 325.4 -44.0             | 348.4 20.4             |
| 2004             | 362.8 -96.5         | 674.6 280.3         | 434.9 65.5             | 330.6 2.6             |
| 2005             | 757.5 298.2         | 649.9 185.6         | 564.8 195.4             | 427.5 99.5             |
| 2006             | 425.7 -33.6         | 458.4 -5.9          | 322.2 -47.2             | 301.7 -26.3             |
| 2007             | 480.3 21.0          | 493.7 29.4          | 374.5 51.0             | 353.2 25.2             |
| 2008             | 467.9 8.6           | 423.9 -40.4         | 351.5 -17.9             | 320.1 -7.9             |
| 2009             | 475.5 16.2          | 461.7 -2.6          | 368.3 -1.1             | 343.1 15.1             |
| 2010             | 644.4 185.1         | 583.8 119.5         | 502.0 132.6             | 436.9 108.9             |
| 2011             | 462.3 3.0           | 307.0 -157.3        | 293.9 -75.5             | 240.5 -87.5             |
| 2012             | 408.6 -50.7         | 487.9 23.6          | 309.2 -60.2             | 281.7 -46.3             |
| 2013             | 448.7 -10.6         | 528.3 64.0          | 407.6 -38.2             | 384.6 -56.6             |
| Media            | 459.3              | 464.3              | 369.4                   | 328.0                   |
4. CONCLUSIONS

The present study proves once again that precipitation manifests the highest degree of variability in time and space, compared to all other meteorological phenomena (Figures 4, 5, 6).

The type of precipitation that occurs at the Romanian seaside is in the form of simple oscillations, with a maximum at night or towards dawn (since the development of clouds is favored by convection, as a result of the heating of the air in the vicinity of the water warmer than the atmospheric air above) and a minimum in the afternoon (when the atmospheric air above the water has a higher temperature, favoring the appearance of thermal inversions in altitude, which prevents convection).

The occurrence of these precipitation amounts must be taken into account in the design of the transport lines aimed at the development of traffic, crop protection, management of rivers, and sewerage system in localities, in order to reduce or avoid the negative effects of floods.

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