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SYSTEMIC APPROACH OF THE IMPACT INDUCED BY CLIMATE CHANGES ON HYDROTHERMIC FACTORS AT THE ROMANIAN BLACK SEA COAST

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Abstract. Systemic global environmental changes are manifested in the whole Earth system and represent the global effects of anthropogenic activity on the environment. Global climate changes are included in these global environmental changes. The combined effects of climate change, extreme weather and human alterations of the environment are especially pronounced in the coastal zone where people and ecosystem goods and services are most concentrated and inputs of energy and matter from land, sea and air converge. These realities call for a more systemic and adaptive approach to resource management, environmental protection, coastal zone management, coastal engineering, an approach that considers the effects both of human activities and natural variability change in an ecosystem context. Implementing such an approach requires the capability to routinely and rapidly detect and predict changes in the state of the coastal environment. Identifying variations in hydrothermal Romanian Black Sea coastal area will be based on data about temperature, rainfall and potential evapotranspiration. Period considered is 1999–2008, and coastal stations Sulina, Constanta and Mangalia are analysed. Data used have hydrothermal character and provide information on water demand of the atmosphere, depending on the size of the temperature factor. Temporal variability of hydrothermal factors is presented with some statistical parameters. They are linked as indicators of central tendency and dispersion measurement. A model for estimating the distribution of intra-annual values for hydrothermal factors is proposed for the period analysed.

Keywords: hydrothermic factors, the Black Sea, climate changes, annual variability, statistical parameters.

AIMS AND BACKGROUND

Coastal environment is distinguished as an integrated system at the contact of 2 completely different systems: the deep continental terrestrial and marine system. This interface consists of 6 subsystems: coastal landscape, lithologic coastal system,

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coastal atmosphere system, system aquatory coastal, biome coastal system and coastal socio-economic system. Between all these subsystems there are interconnectors which ensure a certain structure and functioning of coastal environment in accordance with all general features of systems[1]. There are also similar subsystems interconnections with adjacent 2 areas: continental land and deep sea[2]. These subsystems of the coastal system through many relationships that exist between them generate some peculiarities of the Romanian coastal environment factors impact on hydrothermal features along the coastline[3–5]. In the context of climate variations existing studies point out that over the past 100 years, climate has warmed about 0.6°C and that are identified during the two periods 1910–1945 and 1976 to present[6].

The purpose of this article is to identify variations in hydrothermal factors, compounded by climate changes in recent years, in the Romanian Black Sea coastal region. Under natural conditions, evapotranspiration flows continuously throughout the year, representing a main link in the water cycle and an important factor affecting heat exchange ecosystems[7,8]. Potential evapotranspiration is the maximum amount of water likely to be obtained by evaporation of soil and transpiration of plants in an environment. Thermal factor has a significant influence on evapotranspiration as temperature, on the one hand, direct conversion of water vapour increases and, on the other, increased air capacity to maintain water vapour saturation, reducing the evaporating power of the atmosphere[9,10]. For the analysed space, the presence of Black Sea and the position somewhat lateral from the center of influence of anticyclone north-Uralian, which acts mainly on the eastern part of the country, it is determined that the number of days with temperatures ≥0°C to be the largest in the country.

For example, at the Mangalia station the number of days with temperatures ≥ 0°C is 339 days (Ref. 11). There is a difference from north to south coastal area analysed in the continental stronger at Sulina than in Constanta (number of frost days over possible higher number of summer days and tropical). This can be explained by the influence of general circulation, stronger at Sulina in winter, i. e. the Siberian anticyclone. The same thing happens in summer, i. e. increased circulation of the same anticyclone, but much lower, with the center of action in the south of Ukraine, affecting both first and then the rest of Sulina, for which baseline characteristics are lost. Rainfall recorded on the Romanian Black Sea coast are influenced by air masses from west and north-west. In their submission to the east, gradually they lose moisture, so that on the eastern edge of the coast they have small amounts of precipitation[12]. To these are added the presence of sea surface air descent which favours in summer months and thus reducing cumuliform clouds formation process, dispelling of the clouds and the quantity of rainfall.

For the Danube delta area, where water surfaces are the predominant, the land is water-logged and there are reeds and where the conditions of convective ascending air is not favourable, the average annual precipitation is lower than on the south coast.

Distribution of rainfall by months and seasons reveals the influence of barometric centers in the Mediterranean. Maximum amounts of rainfall in 24 h are generally lower in winter, when they come mainly from clouds that are stratus type due to advection of cold masses. They grow in warm period of the year, when the absolute humidity is higher and the front and convection thermal processes contribute to the development of clouds and their intensification. Because of the predominance of traffic western Black Sea influence felt only a 15–30 km wide zone along the coast to the interior of Dobrogea. Above the Danube delta, due to reduced temperatures of active surface, in the warm period of year, it is not developed a vertical movement of air and therefore they are characteristic in sunlit summer days, spreading clouds and a general reduction of precipitation.

EXPERIMENTAL

Quantifying and predicting climate change frequencies for certain events is difficult to follow. Generally two methods are used to study certain specific weather and climate events – general circulation models and the method based on statistical modelling[13–15].

In this article, to make a systematic approach related to the variability of immersion in the Romanian Black Sea coastal area, data from 3 meteorological stations located along the Romanian coast, from north to south, were analysed. These stations are Sulina, Constanta and Mangalia (Fig. 1). The period analysed was 1999–2008.

Systemic approach to this problem was based on a statistical analysis and inter-annual variability of rainfall, air temperature and potential evapotranspiration[16]. To determine how climate changes affect the coastal area and inter-annual potential evapotranspiration was started, primarily from the fact that potential evapotranspiration (PET) shows strong fluctuations in time and space as a direct consequence of changes in the factors determining it. Intra-annual values and annual potential evapotranspiration were determined by the method of Thornthwaite[17]. Specific statistical indicators were implemented. Thus, indicators calculated were: central tendency (arithmetic mean, median), average position indicators, indicators for the scattering string values (standard deviation, coefficient of variation, standard error, coefficient of asymmetry)[18–20]. On the basis of the analysed data for the 3 sites were constructed box plot charts in order to identify the degree of scattering of the observed values. There are identified outliers and extreme values for analysed strings[13,21,22].

Fig. 1. Study area

This graphical comparison supports rapid inter-group values. Also, we propose a distribution model, best for monthly rainfall amounts, temperature and potential evapotranspiration. For each type of distribution diagrams were constructed *Q–Q* plot. This type of chart shows observed values of the variable on the O*x* axis relative to the corresponding values of the O*y* axis projected.

RESULTS AND DISCUSSION

The analysis of climatic data from 3 meteorological stations for the period from 1999 to 2008 has resulted in some observations of variability strings and their homogeneity. Thus, for the data used, the conclusion that can be drawn is that, in recent years, the annual amounts of rainfall exist as an increasing trend for stations Constanta and Mangalia and drops for Sulina station.

The data related to air temperature and potential evapotranspiration show that there is a slight increase for all three coastal stations in the last 10 years. Capturing variability data string is presented in Tables 1–3. In these tables are presented the main statistical indicators that perform multiple functions, namely measurement, comparison, analysis, estimation and checking or testing the significance of parameters used for each state.

For strings of data, standard deviation was determined to show how far the data are analysed by their arithmetic mean and coefficient of variation as a measure of relative dispersion. It was also to highlight determinant skewness and asymmetry distribution. This test refers to the degree of curvature of plotting variable values.

For strings of data was calculated an intermediate trend indicator, interquartile. It highlights the dispersion of values analysed. Often data to evaluate the dispersion around central data string amplitude are determined. This is a measure of the spills and information on the length of the variation and not on how the data are scattered between the extremes. If the air temperature amplitude varies at the three stations in the range within 28.2–28.9°C, the magnitude rainfall varies between 78.4 and 329.6 mm and potential evapotranspiration variation is in the range 164–172 mm. The analysis of data related to air temperature at the three stations Sulina, Constanta and Mangalia, for the period 1999–2008, showed that datasets are heterogeneous, as the distribution is left asymmetry. Calculation of these indicators shows that the arithmetic mean of the three rows of temperature data has a level of low significance.

Applying statistical indicators for analysis of rainfall for the three sites revealed that the datasets have heterogeneous values obtained from the statistical indicators that data strings have a skewed distribution. Right asymmetry and distribution curves are sharp with leptocurtik form. Coefficients of variation values indicate that the rows of data for monthly average change between 1999–2008 do not properly characterise the central tendency of the data string. To obtain statistical parameters it was used a statistical program (STATISTICA). After applying statistical description function the values were obtained based on tables.

Table 1. Descriptive statistics for air temperature in 1999–2008

No	Statistic	value	No	Statistic	Value
		Sulina			
1	mean	12.20	5	skewness	–0.05
2	std. deviation	8.24	6	25% (Q1)	5.25
3	coefficient of variation	0.66	7	50% (median)	12.10
4	std. error	0.75	8	75% (Q3)	19.9
		Constanta			
1	mean	12.64	5	skewness	–0.04
2	std deviation	8.10	6	25% (Q1)	5.70
3	coefficient of variation	0.64	7	50% (median)	12.3
4	std. error	0.73	8	75% (Q3)	19.75
		Mangalia			
1	mean	12.20	5	skewness	–0.04
2	std deviation	7.82	6	25% (Q1)	5.70
3	coefficient of variation	0.63	7	50% (median)	11.85
4	std. error	0.71	8	75% (Q3)	19.50

Table 2. Descriptive statistics for rainfall in 1999–2008

No Crt.	Statistic	Value	No Crt.	Statistic	Value
		Sulina			
1	mean	12.17	5	skewness	2.07
2	std. deviation	12.03	6	25% (Q1)	3.05
3	coefficient of variation	1.05	7	50% (median)	7.87
4	std. error	12.83	8	75% (Q3)	17.27
		Mangalia			
1	mean	12.64	5	skewness	–0.04
2	std. deviation	8.10	6	25% (Q1)	5.70
3	coefficient of variation	0.64	7	50% (median)	12.3
4	std. error	0.73	8	75% (Q3)	19.75
		Constanța			
1	mean	12.20	5	skewness	–0.04
2	std. deviation	7.82	6	25% (Q1)	5.70
3	coefficient of variation	0.63	7	50% (median)	11.85
4	std. error	0.71	8	75% (Q3)	19.50

By applying statistical indicators the rows of data on the potential evapotranspiration have resulted in the following. Term trend indicator and coefficient of variation show that PET is a heterogeneous string. The form of distribution of values is right asymmetry and distribution curves are sharp, with a leptokurtik form. The arithmetic mean for strings of data on potential evapotranspiration has a low significance level.

Table 3. Descriptive statistics for potential evapotranspiration in 1999-2008

No Crt.	Statistic	Value	No Crt.	Statistic	Value
		Sulina			
1	mean	63.82	5	skewness	0.39
2	std. deviation	53.49	6	25% (Q1)	13
3	coefficient of variation	0.83	7	50% (median)	50.5
4	std. error	4.88	8	75% (Q3)	113.5
		Mangalia			
1	mean	65	5	skewness	0.42
2	std. deviation	53.65	6	25% (Q1)	15.25
3	coefficient of variation	0.82	7	50% (median)	52
4	std. error	4.89	8	75% (Q3)	114.75
		Constanta			
1	mean	62.36	5	skewness	0.41
2	std. deviation	51.86	6	25% (Q1)	13.75
3	coefficient of variation	0.83	7	50% (median)	49.5
4	std. error	51.86	8	75% (Q3)	111.75

The analysis of monthly mean values of PET obtained for the three sites shows that there is a functional correlation of these values with the mean monthly air temperature *T*. For the both periods analysed, the correlations are straightforward, the type is linear regression. For calculation of the correlation coefficient *r* between potential evapotranspiration and air temperature for 1999–2008 period under study, the result value of this coefficient is $r = 0.97$. Analysis of hydrothermal values at stations Sulina, Constanta and Mangalia for the period 1998–2008 is used for making a special type of diagram-and-whisker plot box (Box Plot). This diagram shows how the distributions made strings of values analysed, balanced or unbalanced. Each box shows the median (horizontal line), quartiles (upper and low extend of box) and range (vertical lines) for each binned range within the predictor variables. The width of the boxes is proportional to sample size.

For the mean monthly temperature and PET box plot graphs were constructed (Fig. 2).

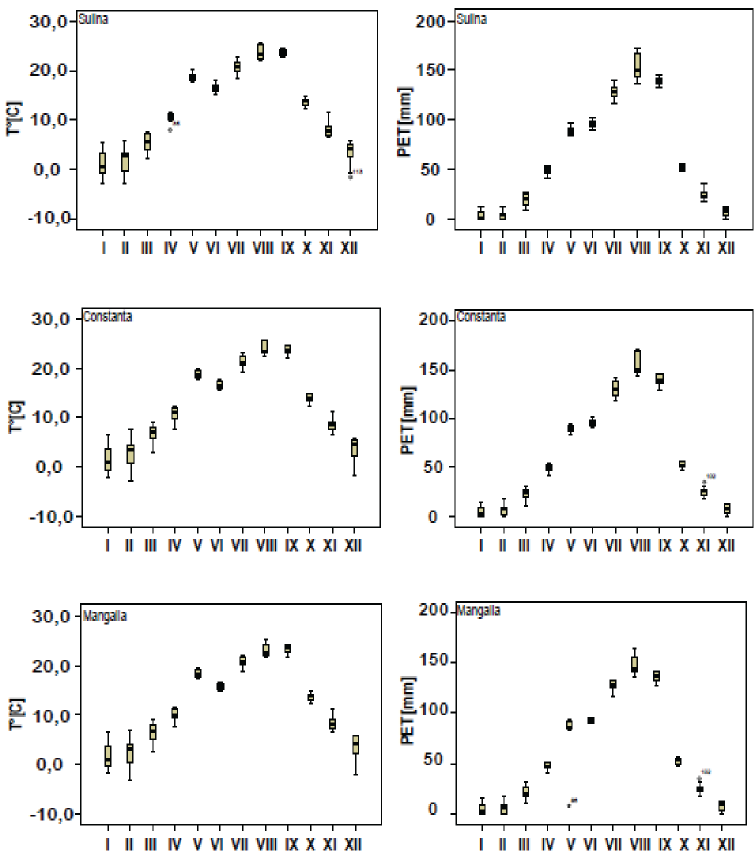

Fig. 2. Box plots for inter-annual change of air temperature and potential evapotranspiration

The graph shows that temperature at stations Mangalia and Constanta in a row does not have outliers. Values are closer than 1.5 *IQ* (interquartile range) below the first quartile or above the third quartile. For the Sulina station are identified two outliers.

In the cases of potential evapotranspiration (Fig. 2) is identified an aberrant and extreme value at Mangalia station. The extreme is located less than 3 *IQ* than the interquartile range. This means that the identified values are excessively high or excessively low. At steady state is identified one aberrant value (Fig. 2).

In the rainfall analysed using box plot are identified a large number of extreme outliers at the three sites. Most outliers are identified at steady state, and most extreme values are identified for the Mangalia station (Fig. 3).

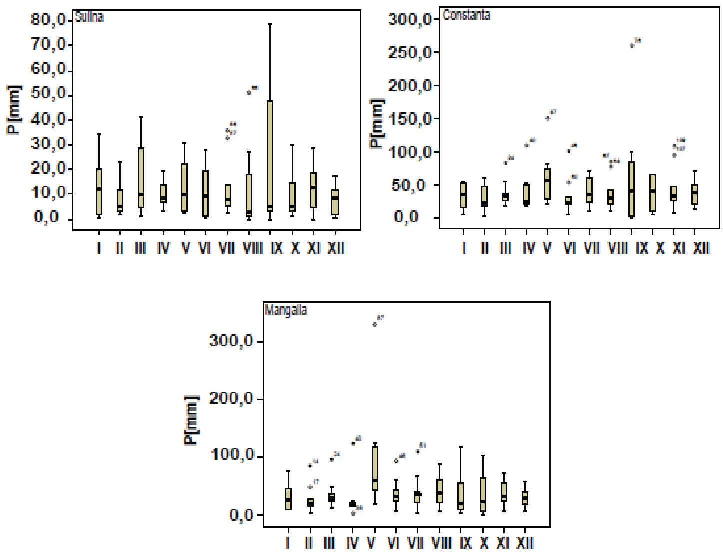

Fig. 3. Box plots for inter-annual variation in rainfall

For each factor is suggested a hydrothermal type of distribution. Checking the distribution as proposed is appropriate to approximate the distribution of strings of values analysed from the three meteorological stations, using the graphical representation of type-quintile–quintile (*Q–Q* plot).

Using *Q–Q* plots is useful to see if a string of data analysis follows a specific distribution found after applying specific test. Thus, if the distribution model proposed appropriate values should have an approximately linear distribution. They deviate shortly or not at all from the type of pattern distribution found. The testing of different types of distribution was performed by representation of *Q–Q* plots. Thus, if climate values analysed are from a series Generalised Pareto, Johnson SB, Gamma or Dagum, then between series quantile of empirical and series quantiles of theoretical there will be a linear relationship.

Types of distributions to find the best estimate of the factors for the hydrothermic station Sulina, Constanta and Mangalia for the period 1998–2008 are: air temperature generalised *Pareto distribution* is used for potential evapotranspiration; *Johnson SB distribution* is used for rainfall, and *Gamma distribution* – for station to station *Dagum distribution* Sulina and Constanta and Mangalia.

In Figs 4 and 5 are presented the plots of probability *Q–Q* plots – the observed values of the variables appear on the O*x* axis relative to the corresponding values on the axis O*y*, expected.

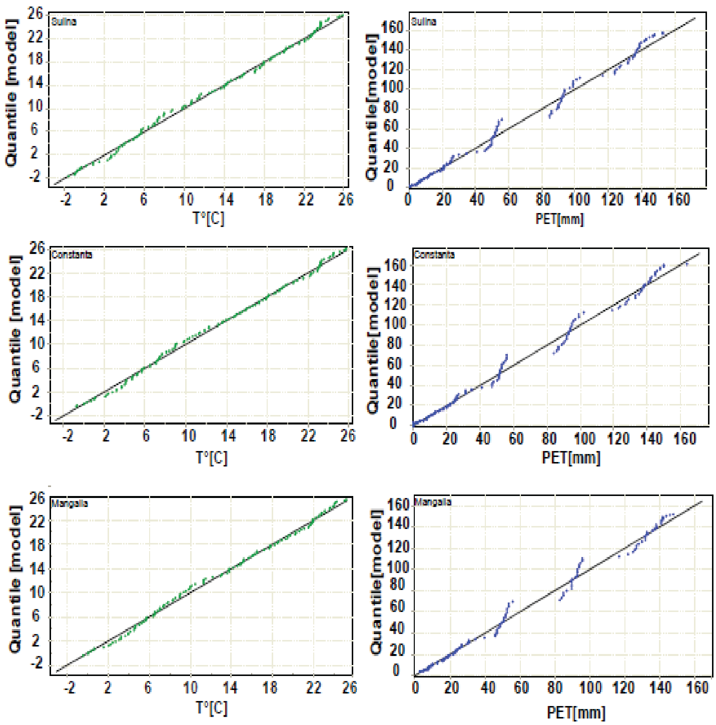

Fig. 4. Diagnostic plots for *Q–Q* model distribution of values of temperature and potential evapotranspiration

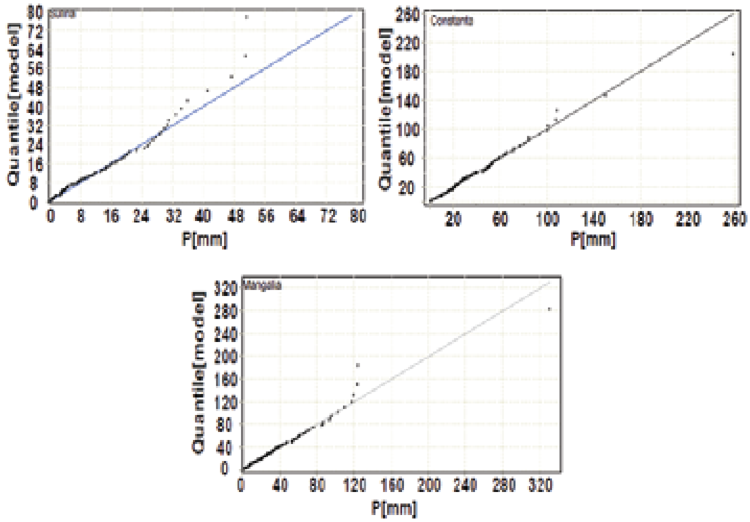

Fig. 5. Diagnostic plots for *Q–Q* model rainfall distribution values

For air temperature distribution at the three stations was proposed and tested a model to suggest the best type of distribution. In this case it is the *generalised Pareto distribution*.

$$f(T)=\begin{cases}\dfrac{1}{\sigma}\left(1+k\,\dfrac{(x-\mu)}{\sigma}\right)^{-1-1/k}, k\neq 0\\[2ex] \dfrac{1}{\sigma}\exp\left(-\dfrac{(x-\mu)}{\sigma}\right), k=0\end{cases} \tag{1}$$

where k is continuous shape parameter; σ – continuous scale parameter; μ – continuous location parameter. The domain $\mu \le x \le \infty$ for $k \ge 0$ and $\mu \le x \le \mu - \sigma/k$ for $k < 0$.

Values for α, β and γ are as follows: for $k = -1.0607$ for Sulina, $\sigma = 30.069$, $\mu = -2.284$ for the constant $k = -1.0522$, $\sigma = 29.36$, $\mu = -1.6692$, for Mangalia $k = -1.0432$, $\sigma = 28.139$ and $\mu = -1.4713$.

If evaporation potential distribution model for data sets from the three stations analysed is determined and *SB Johnson*.

$$f(\mathrm{PET}) = \frac{\delta}{\chi\sqrt{2\pi z}\,(1-z)}\exp\left(-\frac{1}{2}\left(\gamma+\ln\left(\frac{z}{1-z}\right)\right)^2\right) \tag{2}$$

where γ is continuous shape parameter; δ – continuous scale parameter ($\delta > 0$); λ – continuous scale parameter; ζ – continuous location parameter ($\zeta \le x \le \zeta + \lambda$); $z = (x - \zeta)/x$.

Values for γ, δ, λ and ζ are: $\gamma = 0.3119$ for Sulina, $\delta = 0.4237$, $\lambda = 162.65$ and $\zeta = -1.3283$ for $\gamma = 0.3320$ for Constanta, $\delta = 0.4358$, $\lambda = 165.49$ and $\zeta = -1.3283$ and $\gamma = 0.3117$ for Mangalia, $\delta = 0.3927$, $\lambda = 153.23$ and $\zeta = -1.3118$.

For distribution of monthly average atmospheric precipitates between 1999–2008 was proposed and tested in this study, a model considered most suitable: *Gamma distribution* namely for Sulina station and a *Dagum distribution* for stations Constanta and Mangalia (Fig. 4).

Gamma distribution is characterised by the following distribution function:

$$f(\mathrm{P}) = \frac{(x-\gamma)^{\alpha-1}}{\beta^{\alpha}\,\Gamma(\alpha)} \exp\left(-(x-\gamma)/\beta\right), \tag{3}$$

where α is continuous shape parameter ($\alpha > 0$); β – continuous scale parameter ($\beta > 0$); γ – continuous location parameter (yields the two parameter gamma distribution), and Γ – the Gamma function.

Values determined for the distribution station are the following: $\alpha = 0.8996$ for Sulina, $\beta = 13.535$ and $\gamma = 0$.

Dagum distribution is characterised by the following distribution function:

$$f(P) = \frac{\alpha k \left(\dfrac{x-\gamma}{\beta}\right)^{\alpha k-1}}{\beta\left(1+\left(\dfrac{x-\gamma}{\beta}\right)^{\alpha}\right)^{k+1}}, \tag{4}$$

where k is continuous shape parameter ($k > 0$); α – continuous shape parameter ($\alpha > 0$); β – continuous scale parameter ($\beta > 0$), and γ – continuous location parameter (yields the three parameter *Dagum distribution*).

Values for this type of distribution for stations Constanta and Mangalia are: $k = 0.3564$, $\alpha = 3.412$, $\beta = 55.43$ at station Constanta and for Mangalia the values are $k = 0.5049$, $\alpha = 2.6148$, $\beta = 45.15$. At both stations the value of $\gamma = 0$.

After testing a good dependence is observed and almost linear dependence between empirical and theoretical quantiles. This indicates that the analysed series indicating that temperature, rainfall and PET at the three stations respect of specified distributions.

CONCLUSIONS

The results on the variability of hydro-thermal factors for the time frame analysed for the three stations confirm, to a certain extent, the overall situation in Romania. As such, an increase of multiannual average temperatures througout the study period in all stations was registered. PET values result in a significant increase of the evapotranspiration amounts in the three study locations.

There is no clear and homogenous trend for rainfall. Thus, while in Sulina the annual value dropped compared to the multiannual average, in Constanta and Mangalia an increase of annual rainfall amounts was reported. Applying the Box-whisker plot method resulted in marking out the average multiannual variability of hydrothermal factors. The interquartile range for temperature is wider for cold season months and narrower for warm season months. The median is not located in the middle of the interquartile range, thus the values are not normally distributed. It was also found that no outliers occurred in any of the analysed stations. However, two extreme values were recorded in Sulina in April and December. The interquartile range is much wider for rainfall. The median is not located in the middle of the interquartile range and outliers were recorded in Constanta and Mangalia during the late cold semester and early warm semester. In addition, extreme values were recorded in all stations, which suggests that the rainfall parameter is more variable than temperature and PET. The situation of PET is similar to temperature, as follows: two extreme values were recorded in Constanta and Mangalia; the interquartile ranges are narrow and the median is not located in the middle of the interquartile range. To conclude with, the analysed hydrothermal data are not normally distributed. The *Q–Q* plot analysis shows that the selected theoretical distribution types concur with the data recorded in the 3 stations during 1999–2008.

The results obtained confirm that there are changes in the global climate regime and, consequently, Romania is also affected. Several driving factors were identified, for example, during the cold season there is a significant link between the North Atlantic oscillation index and the atmospheric rainfall/snowfall system. The variability of rainfall/snowfall in winter is linked to sea surface temperature to a small extent. Changes in average temperature regime are due to natural physical causes, which are overlaid on global anthropogenic causes.

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