Statistical Analysis of the Precipitation from Constanța (Romania) Meteorological Station

CARMEN MAFTEI
Faculty of Civil Engineering
Ovidius University of Constanta
124, Mamaia Bd., 900527, Constanta
ROMANIA
cmaftei@univ-ovidius.ro

ALINA BĂRBULESCU
Faculty of Mathematics and Computers Science
Ovidius University of Constanta
124, Mamaia Bd., 900527, Constanta
ROMANIA
www.math-modeling.ro alinadumitriu@yahoo.com

PIERRE HUBERT
IAHS/AISH and UMR Sisyphe Université Pierre et Marie Curie, Paris VI
4 Place Jussieu 75252 Paris Cedex 05, France
pjy.hubert@free.fr

CRISTINA SERBAN (GHERGHINA)
Faculty of Civil Engineering
Ovidius University of Constanta
124, Mamaia Bd., 900527, Constanta
serban.cristina@univ-ovidius.ro
ROMANIA

GABRIEL DOBRICA
Student of Faculty of Civil Engineering
Ovidius University of Constanta
124, Mamaia Bd., 900527, Constanta
ROMANIA
gabriel.dobrica@yahoo.com

Abstract: - This study is focused on the analysis of precipitation on the Eastern part of Romania, namely the Dobrudja region, since the water resources in the region are sensitive to climate change. The results of statistical analysis of precipitation data from Constanta meteorological station for the period 1885-2009 are presented. The statistical analysis indicates an increasing trend of the mean annual precipitation and the existence of some break points in the data series. After 1994, the mean annual precipitation increased by 100 mm, a value in agreement with existing estimations for the whole of Europe.

Key-Words: - Annual precipitation, break, statistics, trend, tests

1 Introduction

Annual precipitation is an essential component in the water budget. Most of the water resources projects are designed based on the historical pattern of water availability and demand, assuming constantly climatic behavior [1] [31] So, any change in the climatic behavior has a big influence in the precipitation regimen. The existence of an increasing or decreasing trend in hydrological time series can also be explained by the changes of the factors that influence the precipitation [21] [24] [30] [33].

All the global climate models predict enhanced precipitation in the high latitudes and the Tropics throughout the years [15]. Analysis of observations shows a decreasing tendency of precipitation around the 30°N latitude and an increasing in northern latitudes [18]. A 7–12% increase in annual mean precipitation amounts between 30°N and 85°N was observed in the 20th century [15]. In this context, detecting trends in hydrologic, as well as climatic or other natural time series, has been an active subject for more than three decades. To highlight these changes different methods could be used. Many authors [2] [19] [22] [29] prefer to carry out a linear trend analysis to detect changes in annual precipitation series because the procedure is very simple. But, this method presents thee difficulty of establishing the exact period corresponding to the determined trend.

Typically, the hypothesis of the trend existence is tested by the nonparametric Kendall's test [17]. This test is the most used for this purpose in the environmental sciences, for example in biologic community structure [23], estuarine salinity [32], lake water quality [27], and atmospheric chemistry [8].

Different other tests are available in the literature to identify such change, and have also been successfully applied to hydro-meteorological series: the Pettitt test [25], the Bayesian method of Lee and Heghinian [20], the U test of Buishand [5] [6] and the segmentation procedure of Hubert [13].

In this paper we investigate the change in the precipitation regime on the Romanian littoral between 1885 and 2009, utilizing different statistical tests. These tests are applied of the annual precipitation time series.

The study zone and the data are described in the next section of this paper. The methods to identify a change or trend in the time series are described in section 3 and the conclusions are presented in the last chapter.

2 Data

We analyze the annual time series of total rainfall from Constanta meteorological station, obtained from the archives of the National Agency of Meteorology. It is one of the longest systematic hydro-meteorological records among the Dobrogea region, containing observations starting to 1885.

Constanta meteorological station is located on the Littoral of the Black Sea in a climate unit's I (Fig. 1)

This unit contains the Danube Delta, the lagoons (Razim Lake and Sinoe Lake) and the Littoral (Fig. 1) and is characterized by a mean annual temperature of about 11°C and a precipitation of about 400 mm. Constanta station is currently located at 12.80 m altitude and 120 m from the beach and is one of the oldest stations in Romania. It was founded in July 1885. Between 1891 and 1939, the station operated with some minor interruptions in the Constanta Port (up to 1939, when the war has completely destroyed it), then the dam was reinstalled on an outer perimeter of the Port of Constanta. In 1955, the station was moved on a cliff above the port of Tomis. From 1 May 1969, the weather station was moved to the north of the town, in the southern of Cape Sutghiol, 50 m from the coastline.

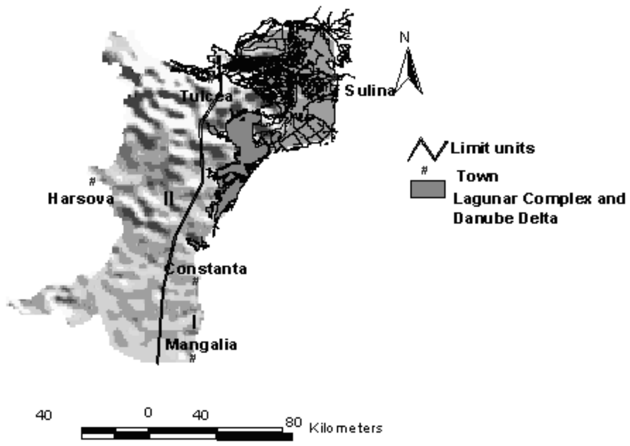

Fig. 1. Dobrogea region

In Fig. 2 we present the evolution of annual precipitation for Constanta station. It reveals the succession of the humid and dry year over the study period. It can be remarked that starting to 1995 the annual precipitation was higher than the multi-annual precipitation – 390mm (excepting 2000 and 2003 which are the driest years).

We have also to specify that there are missing data in the annual series: 1885 is incomplete (it contains only 6 months of records), 1891 (only 8 months' are registered), 1892 (only 11 months are registered). The period 1916 - 1919 is not covered. For this reason, the methods for discontinuities determination will be applied only for the period 1920-2009, that is, 90 years.

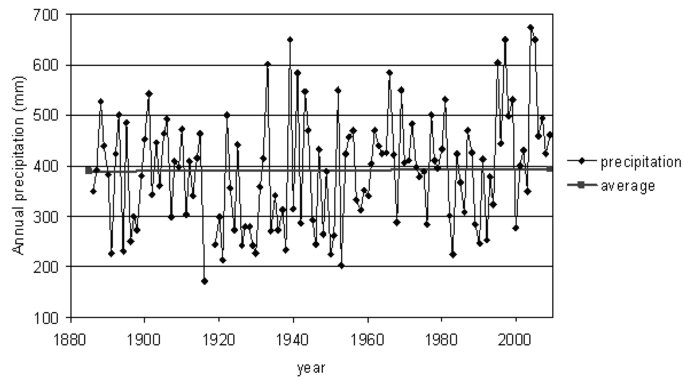

Fig. 2. The annual precipitation at study stations in the period 1985-2009

3 Methods

In order to determine the discontinuities in Constanta precipitation series different tests has been performed. We shortly present them in the following.

The Kendall test [16][17][10] was used to test the independence of the consecutive elements of a equally spaced time series. The null hypothesis is:

H_0: The series is random,

and its alternative is:

H_1: There is a trend in the series.

The break tests of Pettitt [25], *Lee & Heghinian* [20] and *Hubert's segmentation procedure* [13][14] have been performed to detect changes in the mean of the time series.

The *Pettitt test* is a non - parametric one. The null hypothesis that must be tested is that there is no break in the precipitation series $(X_i)_{i\in\overline{1,N}}$.

The basis of this test is the following [4]:

- the studied series is divided into two sub-samples of sizes m and n respectively;
- the values of the two samples are grouped and arranged by increasing order;
- the sum of the ranks of the components of each sub-sample in the total sample is then calculated;
- a statistic, U_t, is defined using the two sums thus obtained in order to assess whether the two samples belong to the same population.

Defining:

$$\operatorname{sgn}(x)=\begin{cases}1\,,\ x>0\\ 0\,,\ x=0\\ -1,\ x<0\end{cases},$$

$$D_{i,j}=\operatorname{sgn}(x_i-x_j),$$

$$U_{t,N}=\sum_{i=1}^{t}\sum_{j=t+1}^{N}D_{i,j},$$

$$K_N=\max_{t=\overline{1,N-1}}\left|U_{t,N}\right|,$$

if k is the value of K_N taken on the studied series, under the null hypothesis, then:

$$\mathrm{Pr}ob\left(K_N>k\right)\approx 2\exp(-6\cdot k^2/(N^3+N^2)).$$

For a significance level α, if $\mathrm{Pr}ob\left(K_N>k\right)<\alpha$, then the null hypothesis is rejected.

Lee & Heghinian test is a Bayesian procedure applied under the assumption that the studied series is normally distributed. The test is based on the following model, which supposes a change in the series mean:

$$X_i=\begin{cases}\mu+\varepsilon_i\quad, & i=1,.....,m\\ \mu+\varepsilon_i+\delta, & i=m+1,.....N\end{cases},$$

where ε_i are random variables, independent and normally distributed, with null expectance and a constant variance.

The break point m and the parameters μ and δ are unknown. This test performs well to determine a break at the middle of the series, but it doesn't furnish the break point.

This test has been applied after the normalization of the data series, applying a logarithm transformation.

Hubert's segmentation procedure [12][14] detects the multiple breaks in time series. The principle is to cut the series into m segments (m>1) such that the calculated means of the neighbouring sub-series significantly differ. To limit the segmentation, the means of two contiguous segments must be different to the point of satisfying Scheffé's test [28]. The procedure gives the timing of the breaks.

Giving a m-th order segmentation of the time series, $i_k, k=\overline{1,\ m}$, the rank in the initial series of extreme end of the k – th segment (with i_0 = 0), the following are defined:

$$\overline{x_k}=\frac{\sum_{j=i_{k-1}+1}^{i_k}x_j}{n_k},$$

with

$$n_k=i_k-i_{k-1},$$

$$d_k=\sum_{i=i_{k-1}+1}^{i_k}(x_i-\overline{x_k})^2.$$

$$D_m=\sum_{k=1}^{m}d_k.$$

D_m is the quadratic deviation between the series and the segmentation.

For a given segmentation order, the algorithm determine the optimal segmentation of a series that is such that the deviation D_m is minimal.

The authors affirm [14] that this procedure can also be interpreted as a stationarity test, the null hypothesis being *the studied series is non-stationary.* If the

ISBN: 978-1-61804-084-8

procedure doesn't produce acceptable segmentations of order bigger or equal to two, the null hypothesis is accepted.

4 Results

The result of Kendall test for Constanta series denotes that for all the significance levels (0.01, 0.05, 0.1), the null hypothesis is rejected, so the series has a trend. The residuals (Fig. 3) seem to be from a random distribution indicating that a linear trend may be present.

To estimate the true slope of an existing trend the Sen's nonparametric method is used.

The results of the Pettitt test at the significance levels $\alpha = 0.05$ and $\alpha = 0.01$ lead us to accept the hypothesis that there is a break point in 1953.

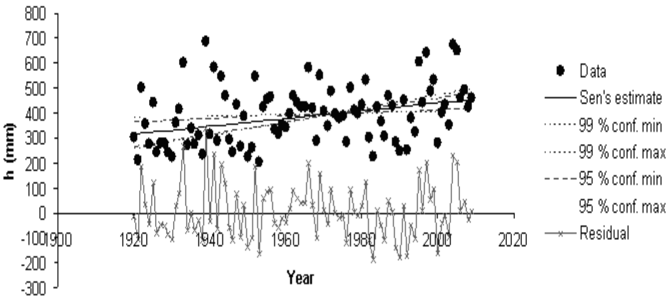

Fig. 3. The results of Kendall test and Sen's slope estimation

The *Lee & Heghinian* test gives the following result: a posteriori probability density function mode of the break point position is equal of 0.1165 (in 1994).

The objective of the Hubert's segmentation procedure is to divide up a time series into stationary sub series (segments), the difference of the means of two contiguous segments being significant.

To have a better view of the time series internal structure, we have applied the procedure not only to the whole time series but to all sub series beginning in 1920 or ending in 2009 as it has been done in a study of the Senegal river annual discharge time series [14]. For any year *n* (*n* = 1920, 2009) the segmentation procedure has been applied for the time series (*n* - 1920) and (2009 - *n*). The results of these segmentations are reported in Fig. 4 (*n* in abscissa) where a thin dash appears where a decrease of the mean was found and a thick dash appears where an increase of the mean is detected. Therefore, it was found that the general trend of the annual rainfall in Constanta along the XXth century is increasing.

Two dates seem to be especially significant: the transition 1938 - 1939, with an increase of the mean of 20 %, and the transition 1994 - 1995, with and increase of the mean of 26 %. From earlier short time series (1886 - 1890; 1893 - 1915) it appears that a negative jump of the mean of -14% should exist between 1915 and 1920 (Fig. 5).

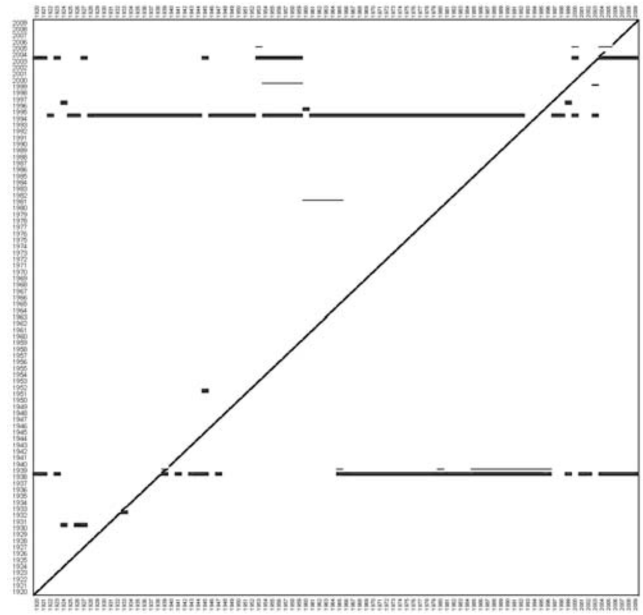

Fig. 4. Results of segmentation procedure

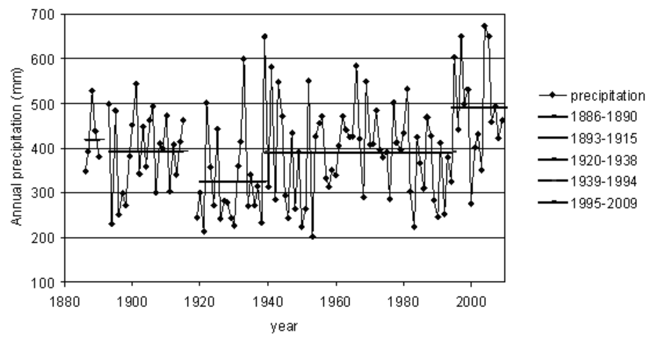

Fig. 5. Sub-periods with constant mean (determined by the segmentation procedure)

In another study (done by a part of the authors of this article) on other series in the Dobrudja area it was proved that in the climatic unit I, the mean annual precipitation increased with 98 mm in the same period. Unfortunately, the precipitation distribution in time is not uniform. For example, at the Constanta station, a precipitation value of 259 mm was recorded (in August 2004), representing one third of the annual mean precipitation at this station.

4 Conclusion

The results of this study are based on annual precipitation records on Constanta station. After the application of different methods of change point's detection, it was found that 1939, 1994 are the break points years for the series 1920 - 2009. The existence of the break point in 1939 is due to the destruction of the meteorological station as a result of war damage.

The mean annual precipitation increased with approximately 100 mm over the period 1994 - 2009 with respect to 1939 - 1994 and 97 mm with respect to the multi- annual mean of the period 1886 - 2009.

This result is consistent with results identified in Romania and over Europe. For example, in the Dobrudja region Busuioc's study shows [7] an increase in precipitation (+82 mm) at Constanta station over the 1891- 2007 period (Fig. 6).

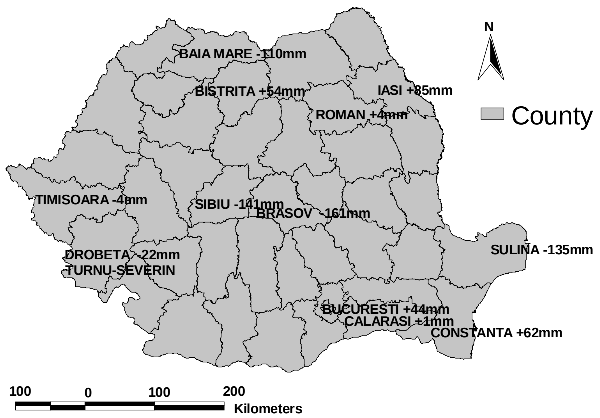

Fig. 6. General evolution of precipitation (adapted from Busuioc et al. (1995)

Annual precipitation totals also show upward trend in many regions others than Bulgaria [9]. Positive trends in precipitation amounts are reported for many mid- and high-latitude regions of the world [3] [18]. Estimated evolution of annual precipitation for the period 2071-2100 based on the data of DMI/PRUDENCE [26], processed by the Joint Research Centre (JRC) during the PESETA study prove a considerable increase of the quantities of precipitations in northern Europe (+20-+80 % of the total annual quantity of precipitations). In the south-eastern part of Romania, this model predicts an increase between 5 and 10% of the total annual quantity of precipitation.

ACKNOWLEDGMENT

The authors thank A.N.M. (National Meteorological Agency) for the data provided.

References:

[1] O.I. Abdul Aziz, D.H. Burn, Trends and variability in the hydrological regime of the Mackenzie River Basin, *J. Hydrol.*, 319, 2006, pp. 282–294.

[2] V.B. Aizen, E.M. Aizen, J.M. Melack, J. Dozier, Climatic and hydrologic changes in the Tien Shan, Central Asia, *J. Climate*, 10, 1997, pp. 1393–1404.

[3] L. Bocheva, T. Marinova, P. Simeonov, I. Gospodinov, Variability and trends of extreme precipitation events over Bulgaria (1961–2005), *Atmospheric Research*, 93, 2009, pp. 490–497

[4] J.F. Boyer, Logiciel Khronostat d'analyse statistique de séries chronologique, IRD UR2, Programme 21 FRIEND AOC, Equipe Hydrologie UMRGBE, Université de Montpellier II, Ecole des Mines de Paris, (2002), available:
http://www.hydrosciences.org/mytech/khronostat.html

[5] T. A. Buishand, Some methods for testing the homogeneity of rainfall records, *Journal of Hydrology*, 58, 1982, pp. 11-27.

[6] T. A. Buishand, Tests for detecting a shift in the mean of hydrological time series, *Journal of Hydrology*, 58, 1984, pp. 51-69.

[7] A. Busuioc, R. Bojariu, Synthetic analysis of Romanian regional precipitations variability. In: Precipitations variability and climate change, Proc. of Symp. on Precipitation and Evapotranspiration, vol. 2, Sevruc B. and Lapin editors. Bratislava, 1993

[8] D.R. Cortes, R.A. Hites, Detection of statistically significant trends in atmospheric concentrations of semivolatile compounds, *Environmental Science and Technology*, 34, 2000, pp. 2826–2829.

[9] A. Dai, I.Y. Fung, A.D. Del Genio, Surface observed global land precipitation variations during 1900–1988,. *J. Climate*, 10, 1997, pp. 2943–2962.

[10] D. R. Helsel, M. Hirsch, Statistical methods in water resources, *U.S. Geological Survey Techniques of Water-Resources Investigations*, book 4, chap. A3, 2002. Available
http://water.usgs.gov/pubs/twri/twri4a3/

[11] P. Hubert, J.C. Bader, H. Bendjoudi, Un siècle de débits annuels du fleuve Sénégal, *Hydrological Sciences Journal*, 52(1), 2007, pp. 68-73.

[12] P. Hubert, The segmentation Procedure as a tool for Discrete Modeling of Hydrometeorological Regimes, *Stochastic Environmental Research and Risk Assessment*, 14 (4-5), 2000, pp. 297-304.

[13] P. Hubert, J. P. Carbonnel, Segmentation des séries annuelles de débits de grands fleuves africains, *Bulletin de liaison du CIEH* 92 (3), 1993

[14] Hubert P., J.P. Carbonnel, A. Chaouche, Segmentation des séries hydrométéorologiques. Application à des séries de précipitations et de débits de l'Afrique de l'Ouest, *Journal of Hydrology*, 110, 1989, pp. 349-367.

[15] IPCC Climate Change—The IPCC Scientific Assessment, Intergovernmental Panel on Climate Change, WMO, 2001

[16] M. Kendall, A New Measure of Rank Correlation, *Biometrika*, 30, 1938, pp. 81 – 89.

[17] M. Kendall, *Rank Correlation Methods*, Charles Griffin & Company Limited, 1948.

[18] V.Ch. Khon, I.I. Mokhov, E. Roeckner, V.A. Semenov, Regional changes of precipitation characteristics in Northern Eurasia from simulations with global climate model, *Global and Planetary Change*, 57, 2007, pp. 118–123.

[19] B.D. Keim, J.F. Cruise, A technique to measure trends in the frequency of discrete random events, *J. Climate*, 11, 1998, pp. 848– 855.

[20] A. F. S. Lee and M. S., Heghinian, A Shift of the Mean Level in a Sequence of Independent Normal Random Variables - A Bayesian Approach, *Technometrics*, 19(4), 1977, pp. 503-506.

[21] D.P. Lettenmaier, E.F. Wood, J.R. Wallis, Hydro-climatological trends in the continental United States (1948–88), *Journal of Climate*, 7, 1994, pp. 586–607.

[22] J. R. Metcalfe, B. Routledge, K. Devine, Rainfall measurement in Canada: changing observational methods and archive adjustment procedures, *J. Climate*,10, 1997, pp. 92– 101.

[23] C.R. Moore, Determination of benthic-invertebrate indices and water-quality trends of selected streams in Chester County, Pennsylvania, 1969–80: *U.S. Geological Survey Water-Resources Investigations Report* 85–4177, 1987

[24] T. Partal, E. Kahya, Trend analysis in Turkey precipitation data, *Hydrologic Processes*, 20, 2006, pp. 2011–2026.

[25] A. N. Pettitt, A non - parametric approach to the change-point problem, *Applied Statistics*, 28(2), 1979, pp.126 - 135.

[26] PRUDENCE project, available: http://prudence.dmi.dk

[27] K.H. Reckhow, K. Kepford, Hicks, W. Warren, Methods for the analysis of lake water quality trends: *U.S. Environmental Protection Agency report* 841–R—93–003, 1993.

[89] M. Scheffe, *The analysis of variance*, Wiley, New York, 1959.

[29] E. H. Steinberger, N. Gazit-Yaari, Recent Changes in the Spatial Distribution of Annual Precipitation, *Israel J. Climate* 9, 1996, pp. 3328-3336.

[30] M. Türkes, Spatial and temporal analysis of annual rainfall variations in Turkey, *International Journal of* Climatology, 16, 1996, pp. 1057– 1076.

[31] J.R. Westmacott, D.H. Burn, Climate change effects on the hydrologic regime within the Churchill–Nelson River Basin, *J. Hydrol.*, 202, 1997, pp. 263–279.

[32] W.J. Wiseman, E.M. Swenson, J. Power, Salinity trends in Louisiana estuaries, *Estuariesi,* 13 1990, pp. 265–271.

[33] X. Zhang, L.A. Vincent, W.D. Hogg, A. Niitsoo, Temperature and precipitation trends in Canada during the 20th century, *Atmospheric Ocean*, 38 2000, pp. 395–429.