EVOLUTION TRENDENCY IN PLUVIOMETRIC INDEXES USED TO MONITOR GLOBAL CLIMATE CHANGES

Sabău Nicu Cornel*

*University of Oradea, Faculty of Environmental Protection, 26 Gen. Magheru St., 410048 Oradea, Romania, e-mail: nsabau@uoradea.ro

Abstract

Most popular pluviometric indexes used to monitor climate hazards are: Hellman, Criterion, Topor pluviometric index, Rainfall deciles, Angot pluviometric index, Anomaly of standardized precipitation, Bhalme-Mooley drought index, Effective drought index and the Standardized Precipitation Index (SPI).

Analysis of rainfall recorded in Oradea, in the period of agricultural years 1971-2011, with SPI indicates that a series of 4 consecutive years (1995-1999) are rainy and 5 consecutive years (1988-1993) are drought and a trend toward rainy years.

Annual SPI values determined in Oradea during 1971-2011 are correlated linearly with rainfall deciles, the correlation was very significant (R2 = 0.9638) because both pluviometric indexes are based for determining on the cumulative probability of precipitation.

Key words: climate hazards, pluviometric indexes, Rainfall deciles, Standardized Precipitation Index (SPI);

INTRODUCTION

Global climate changes are especially evident in the XX century by increasing global average air temperature; increasing the surface temperature of the globe covered by water (seas and oceans); increasing frequency and intensity of El Niño phenomenon; reducing the thickness of the ice cap; reducing surfaces and thickness of snow cover; rising sea and ocean levels; etc.

These have natural causes (terrestrial population growth, increasing demand for food) or anthropogenic: burning fossil fuels, industrial development, agricultural intensification, changes in the structure of land use, etc., being accompanied by obvious changes in spatial and temporal rainfall regime, manifested by more frequent extreme values, leading to an increased risk of floods and droughts.

In a classification of the most important natural hazards, conducted by Bryant, 1991, taking into account 9 criteria: degree of severity, duration of the event, the total area affected, the total loss of human lives, total economic losses, the social effect, the impact of long term, shutter speed and emergence phenomena associated, puts the drought on first place among the 31 analyzed disasters.

According to the United Nations (UN) Convention "drought is a natural phenomenon that occurs when rainfall amount deposited is less than the annual average amid to high temperatures, which determines intense evaporation from the soil surface and reduce crop productivity". (Potop, 2003)

In contrast, excessive moisture occurs when the amount rainfall exceeds the multiannual average, amid low temperatures; leading for higher extremes precipitation to large flooding, with disastrous social and economic consequences.

Currently, drought management is viewed as management of water resources. Drought effects are manifested on the social side, affecting living conditions and status of environmental factors. Lack of planning and action may exacerbate the impact of droughts, amplifying economic losses, having major consequences on human health and on the environment. (Cismaru et al, 2004)

The main characteristics of droughts are the time or period of manifestation, intensity or severity, frequency of occurrence and their spatial extent (Cheval et al, 2003).

The existence of multiple media (atmosphere, soil, water) and affected sectors (agriculture, industry, fisheries, hydropower, recreation - tourism, salubrity, health, etc.), the particular conditions of geographical order and time variability of these climate hazards leading to difficult defining of the some unitary indexes to characterize the phenomena.

Depending on the factors taken into account in calculating the climate indexes, they can be grouped into: pluviometric indexes, when analyzing precipitation; hydrothermal indexes, calculated using rainfall and temperature; hydroheliothermal indexes, determined on account of rainfall, temperature and duration of brilliance sun; the balance indexes, using evapotranspiration to characterize soil water balance; indices determined using satellite imaging of land.

In the category of pluviometric indexes using over time to monitoring climate hazards belong: Hellman criterion defined by differences in relative precipitation to average, (Marinca et al, 2012); Topor pluviometric index, (Topor, 1964); Deciles, determined by calculation insurance of precipitations, (Gibbs et Maher, 1967); Angot pluviometric index, that represents the ratio between the daily average of a month over a year and the average daily rainfall of the year, (Grecu et al, 2011); Anomaly Standardized of Precipitations, or standard deviation of monthly rainfall, (Şerban, 2010); Bhalme-Mooley drought index, which takes into account rainfall recorded in previous months, (Bhalme et Mooley, 1980); Effective drought index, daily determined on the basis of required precipitation to be returned to the normal situation, (Man et al, 2007) and Standardized Precipitation Index (SPI), based on the cumulative probability precipitation event, in various time periods, (McKee et al, 1993);

The current trend in droughts research is given to the study of drought using intervals of different lengths, defined as sequences with dry days, with precipitation less than or equal to a threshold value chosen. (Anagnostopoulou et al, 2003)

The objectives of this paper are the highlight of new trends emerged relatively recently in the evolution of pluviometric indexes, used to monitor global climate changes, exemplifying by the analysis of situation in Oradea, using the Standardized Precipitation Index, SPI and the comparison of the obtained SPI values with other pluviometric indexes.

MATERIAL AND METHOD

To achieve the proposed objectives were used precipitation records from Oradea Weather Station for a period of 40 agricultural years (1970-2011). In Oradea, normal precipitation, determined as multiannual average of the 1961-1990 period is 605,2 mm, monthly averages ranging from 30,3 mm in February to 90,5 mm in June.

Standardized Precipitation Index (SPI) is one of the most commonly used pluviometric index, to monitor and prognosis global climate changes in recent decades, both in the USA and worldwide. (http://www.ncdc.noaa.gov/oa/climate/research/prelim/drought/spi.html;http://drought.unl.edu/MonitoringTools/ClimateDivisionSPI.aspx;)

From the mathematical point of view SPI is based on the cumulative probability of the event-precipitation, in different time periods, recorded in a certain place, weather station, which is assimilated to a density of probability function. The authors proposed function is the gamma distribution, for which the density of probability function has the form:

$$g(x)=\frac{1}{\beta\cdot\Gamma(\alpha)}x^{\alpha-1}e^{\frac{-x}{\beta}}; \qquad \text{pt. } x > 0; \qquad [1.]$$

where: $\alpha > 0$ is a parameter of the curve shape (slope); $\beta > 0$ is a parameter that takes into account the scale; x > 0 represents the monthly rainfall; $\Gamma(\alpha)$ is the gamma function defined by:

$$\Gamma(\alpha)=\int_0^{\infty} y^{\alpha-1}e^{-y}dy; \qquad [2.]$$

SPI is calculated after adjusting for a probability density function to the real distribution curve of frequency rainfall in the period considered, by estimating the parameters of gamma curve, which varies from one place to another, from one time to another and from month to month.

For monthly rainfall recorded at a some weather station, on long years strings, Edwards et McKee, 1997, suggests using for maximum probability the Thom's approximation, 1958, which the it help can be estimated the values of parameters curve α and β:

$$\alpha = \frac{1}{4A}\left(1 + \sqrt{1 + \frac{4A}{3}}\right); \qquad [3]$$

where:

$$A = \ln\left(\bar{x}\right) - \frac{\sum \ln(x)}{N}; \quad [4.]$$

where: N is the number of observations (or terms) of monthly precipitation string; x is the amount of precipitation of a month; $\bar{x}$ is average rainfall of the represented month;

With these values we can determine the scale parameter of the gamma curve:

$$\beta = \frac{\bar{x}}{\bar{\alpha}}; \qquad [5.]$$

where: $\bar{\alpha}$ is the average slope coefficients;

The cumulative probability of precipitation function G (x) is obtained by integrating the density of probability function in the X axis. (Karavitis et al, 2011):

$$G(x) = \int_0^x g(x)dx = \frac{1}{\beta^{\alpha}\Gamma(\alpha)}\int_0^x x^{\hat{a}} e^{-x/\hat{\beta}} dx; \qquad [6.]$$

If in the above function makes the following substitution:

$$t = -\frac{x}{\beta}; \qquad [7.]$$

incomplete gamma function expression is obtained:

$$G(x) = \frac{1}{\Gamma(\alpha)}\int_0^x t^{\alpha-1} e^{-t} dt; \qquad [8.]$$

Cumulative probability of precipitation, in absolute value, in a certain place for a certain period of time, modeled by the gamma function has maximum value 1.0 and their average value is 0.5. In these circumstances, cumulative precipitation, with absolute probability higher than the arithmetic mean (0.5) indicates rainy intervals (0.5 to 1) and those with values lower than average precipitation, a deficit period indicates.

Due to the fact that the distribution function of cumulative precipitation gamma is not defined for x = 0 (zero precipitation within one month of the analyzed sequence) and their share P (x = 0) which is not zero is defined to be the weight of q = P(x = 0) > 0 which has the meaning of rainfall probability zero. This will produce the following transformation:

$$H(x) = q + (1 - q)\,G(x); \qquad [9.]$$

The next step of the calculation is the probabilistic conversion of the distribution gamma function in normalized, standardized, Gaussian distribution function, of the not exceeding probability of precipitation, the resulting is Z value, which is a measure of the deviation from the average precipitation with a number of standard deviations.

For the arithmetic average of rainfall, the Z value, assimilated Standardized Precipitation Index (SPI) is null. For values greater than zero, rainfall is higher than the arithmetic mean, the periods are wet and when the Z values (SPI) are negative, the periods are dry.

Moisture or drought intensity that characterizes different periods analyzed are appreciated by SPI values calculated based on the frequency of occurrence of precipitation of a certain size. (Table 1.)

Table 1.

Rainfall characterization of a time period relative to the value of the Standardized Precipitation Index (SPI)

SPI	Characterization	Frequency (%)
≥ 2	Extremely wet	2,3
1,99 - 1,5	Severe wet	4,4
1,49 - 1,0	Moderately wet	9,2
0,99 - 0	Slightly wet	34,1
0 - -0,99	Slightly dry	34,1
-1,0 - -1,49	Moderately dry	9,2
-1,5 - -1,99	Severe dry	4,4
≤ -2	Extremely dry	2,3

If SPI is a measure of drought intensity and duration is the time in months from the onset of drought (SPI <0) to the end of the drought, ie month in which SPI> 0, is defined notion of drought magnitude (DM), which is the sum of monthly SPI values during drought period. (Mohseni Saravi et al, 2009)

RESULTS AND DISSCUSIONS

Among the climatic indexes, used for monitoring and prognosis periods of moisture and drought, pluviometric indexes are the most widespread, because they using in the processed data a single climate characteristic, represented by rainfall.

Along the time, pluviometric indexes have evolved from the simple, calculated through various ratios of precipitation and some of their statistical characteristics, into those calculated by means of probabilistic mathematical functions, among which stands SPI.

The main advantages of using SPI are: the possibility of analysis series both calendar years as well as those hydrological or agricultural; the possibility of determining the length of extreme rainfall periods from the point of view of the evolution of rainfall due to the fact that the SPI values can be calculated for different time scales of 1 month, 3 months, 6 months, 12 months, etc.; possibility of monitoring the intensity of extreme precipitation phenomena; their spatial analysis, being possible comparisons between several locations; possibility of processing the spatial analysis using Geographic Information Systems (GIS); prognosis evolution SPI values of a given region.

Between the disadvantages of using this index can be mentioned: necessity of using for the calculations of monthly rainfall recorded for a range of minimum 30-40 years, due to dependence of SPI values on the length and size of analyzed range, lower of 1 month range and higher for 12 or 24 months range, respectively the cumbersome calculation methodology.

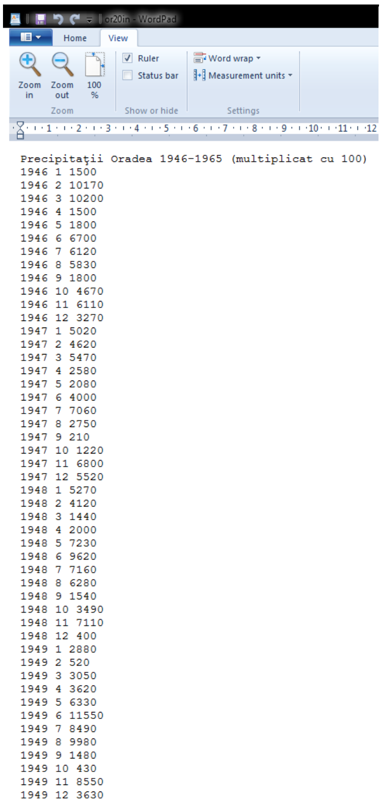
The second disadvantage is overcome through the use of computer programs, which are widespread, among which the most used is "SPI_SL_6.exe" version for Windows provided free on the website National Drought Mitigation Center. (http://drought.unl.edu/MonitoringTools/DownloadableSPIProgram.aspx)

This program, however presents some inconvenience: the presentation of input data in "notepad" where rainfall must be presented in three columns, the first for years, the second for months and the third with the monthly rainfall values multiplied by 100 (or20in); the "dat" file of the output file (or20out.dat) which lists the calculated SPI values, broken down into several columns; because the program does not recognize zero monthly precipitation in input file it must be replaced with the 001; for the graphics processing of calculated SPI values is necessary their transfer from the "dat" format in "xls" format. (Standardized Precipitation Index, User Guide, 2012) (Figure 1.)

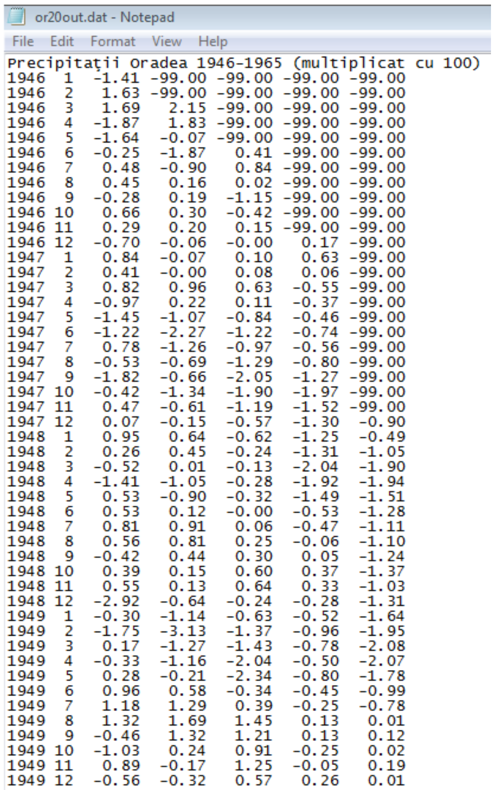
Graphical representation of the annual SPI values, determined by the "SPI_SL_6.exe" program, for the agricultural years 1971-2011 (October-September) allow the identification of rainfall extreme values, the SPI = 2.01 indicating the 2009-2010 year as the wettest, respectively SPI = -1.93 from the 1989-1990 year, shows that it is the driest in the range studied. (Figure 2.)

Graphical representation of the evolution of annual SPI values during the 40 years analyzed (1971-2012) enables prognosis of rainfall regime evolution in Oradea, through the trend line, that suggests evolution toward the positive SPI values, ie the trend toward rainy years.

If we consider the years characterization, according to SPI values is noted that prevails the slightly dry years, with rainfall close to average (SPI = 0 to - 0.99), with the number of 15, their frequency being 37.5 from 100 years (Figure 3)




```
Precipitaţii Oradea 1946-1965 (multiplicat cu 100)
1946 1 1500
1946 2 10170
1946 3 10200
1946 4 1500
1946 5 1800
1946 6 6700
1946 7 6120
1946 8 5830
1946 9 1800
1946 10 4670
1946 11 6110
1946 12 3270
1947 1 5020
1947 2 4620
1947 3 5470
1947 4 2580
1947 5 2080
1947 6 4000
1947 7 7060
1947 8 2750
1947 9 210
1947 10 1220
1947 11 6800
1947 12 5520
1948 1 5270
1948 2 4120
1948 3 1440
1948 4 2000
1948 5 7230
1948 6 9620
1948 7 7160
1948 8 6280
1948 9 1540
1948 10 3490
1948 11 7110
1948 12 400
1949 1 2880
1949 2 520
1949 3 3050
1949 4 3620
1949 5 6330
1949 6 11550
1949 7 8490
1949 8 9980
1949 9 1480
1949 10 430
1949 11 8550
1949 12 3630
```




```
Precipitaţii Oradea 1946-1965 (multiplicat cu 100)
1946  1  -1.41 -99.00 -99.00 -99.00 -99.00
1946  2   1.63 -99.00 -99.00 -99.00 -99.00
1946  3   1.69   2.15 -99.00 -99.00 -99.00
1946  4  -1.87   1.83 -99.00 -99.00 -99.00
1946  5  -1.64  -0.07 -99.00 -99.00 -99.00
1946  6  -0.25  -1.87   0.41 -99.00 -99.00
1946  7   0.48  -0.90   0.84 -99.00 -99.00
1946  8   0.45   0.16   0.02 -99.00 -99.00
1946  9  -0.28   0.19  -1.15 -99.00 -99.00
1946 10   0.66   0.30  -0.42 -99.00 -99.00
1946 11   0.29   0.20   0.15 -99.00 -99.00
1946 12  -0.70  -0.06  -0.00   0.17 -99.00
1947  1   0.84  -0.07   0.10   0.63 -99.00
1947  2   0.41  -0.00   0.08   0.06 -99.00
1947  3   0.82   0.96   0.63  -0.55 -99.00
1947  4  -0.97   0.22   0.11  -0.37 -99.00
1947  5  -1.45  -1.07  -0.84  -0.46 -99.00
1947  6  -1.22  -2.27  -1.22  -0.74 -99.00
1947  7   0.78  -1.26  -0.97  -0.56 -99.00
1947  8  -0.53  -0.69  -1.29  -0.80 -99.00
1947  9  -1.82  -0.66  -2.05  -1.27 -99.00
1947 10  -0.42  -1.34  -1.90  -1.97 -99.00
1947 11   0.47  -0.61  -1.19  -1.52 -99.00
1947 12   0.07  -0.15  -0.57  -1.30  -0.90
1948  1   0.95   0.64  -0.62  -1.25  -0.49
1948  2   0.26   0.45  -0.24  -1.31  -1.05
1948  3  -0.52   0.01  -0.13  -2.04  -1.90
1948  4  -1.41  -1.05  -0.28  -1.92  -1.94
1948  5   0.53  -0.90  -0.32  -1.49  -1.51
1948  6   0.53   0.12  -0.00  -0.53  -1.28
1948  7   0.81   0.91   0.06  -0.47  -1.11
1948  8   0.56   0.81   0.25  -0.06  -1.10
1948  9  -0.42   0.44   0.30   0.05  -1.24
1948 10   0.39   0.15   0.60   0.37  -1.37
1948 11   0.55   0.13   0.64   0.33  -1.03
1948 12  -2.92  -0.64  -0.24  -0.28  -1.31
1949  1  -0.30  -1.14  -0.63  -0.52  -1.64
1949  2  -1.75  -3.13  -1.37  -0.96  -1.95
1949  3   0.17  -1.27  -1.43  -0.78  -2.08
1949  4  -0.33  -1.16  -2.04  -0.50  -2.07
1949  5   0.28  -0.21  -2.34  -0.80  -1.78
1949  6   0.96   0.58  -0.34  -0.45  -0.99
1949  7   1.18   1.29   0.39  -0.25  -0.78
1949  8   1.32   1.69   1.45   0.13   0.01
1949  9  -0.46   1.32   1.21   0.13   0.12
1949 10  -1.03   0.24   0.91  -0.25   0.02
1949 11   0.89  -0.17   1.25  -0.05   0.19
1949 12  -0.56  -0.32   0.57   0.26   0.01
```

Figure 1. Input (or20in) and output (or20out.dat) files used to calculate SPI with SPI_SL_6.exe program, Weather station Oradea, 1946-1965

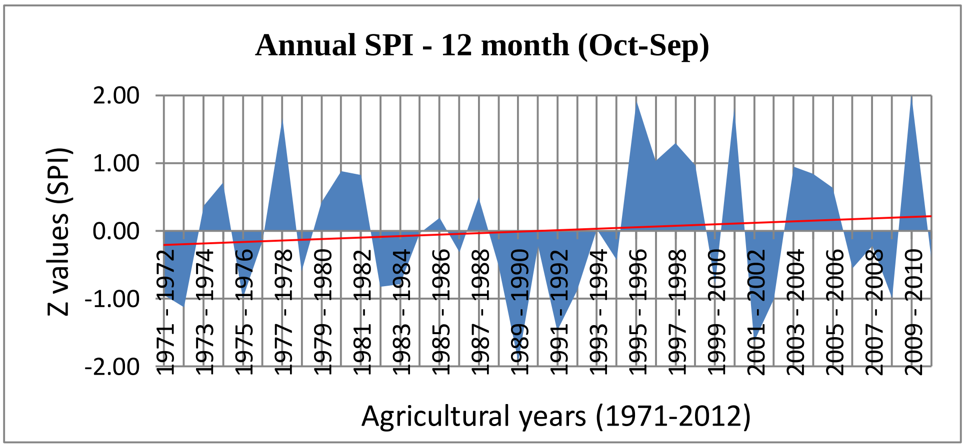


Figure 2. Variation of annual SPI values in Oradea during the agricultural years 1971-2011.

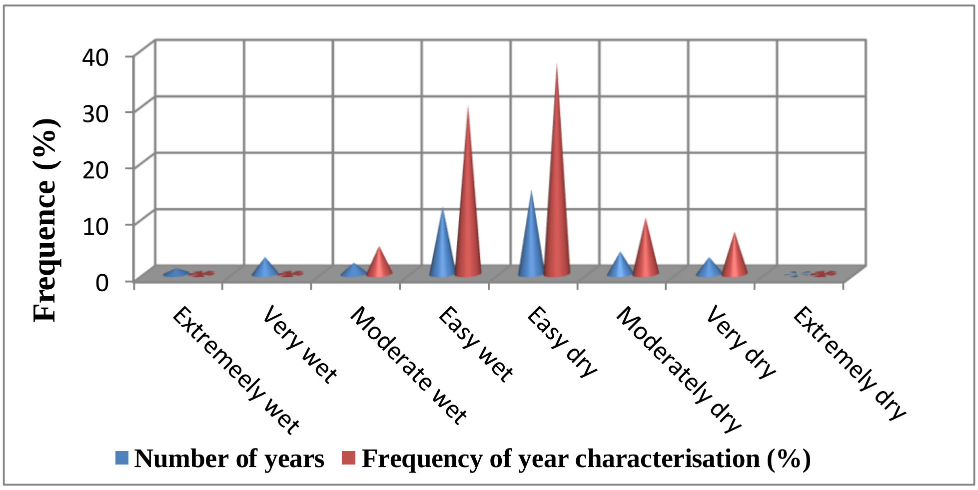


Figure 3. Frequency of drought agricultural years (Oct-Sept) in Oradea, the period 1971-2011

Longest periods, rainy or dry from the analyzed interval are 4 years between 1995 and 1999, and 5 years from 1988 to 1993, when drought magnitude was 5,04. (Table 2.)

Table 2

Consecutive dry years duration and magnitude of drought, Oradea (1971-2011)

Period	Number of consecutive dry years					
	5	3	3	2	2	2
	1988-93	1982-85	2006-09	1971-73	1975-77	2001-03
SPI, year I.	-0,51	-0,83	-0,56	-0,96	-1,00	-1,65
SPI year II.	-1,93	-0,79	-0,23	-1,14	-0,16	-1,01
SPI year III.	-0,23	-0,04	-1,00	-	-	-
SPI year IV	-1,48	-	-	-	-	-
SPI year V.	-0,89	-	-	-	-	-
Duration (months)	60	36	36	24	24	24
Magnitude (DM)	5,04	1,66	1,79	2,10	1,16	2,66

Magnitude continuous series of dry years allow comparisons between periods of the same length or different lengths of time in relation to drought intensity. Thus, if we compare the two dry periods of 3 consecutive years can be said that in 2006-2009, with a magnitude of 1,79 showed more intense drought than during 1982-1985, with a magnitude of 1,66.

SPI being an index that is based on the cumulative probability of precipitation resembles with the rainfall deciles, linear correlation established between the two is very significant statistically. (Figure 4.)

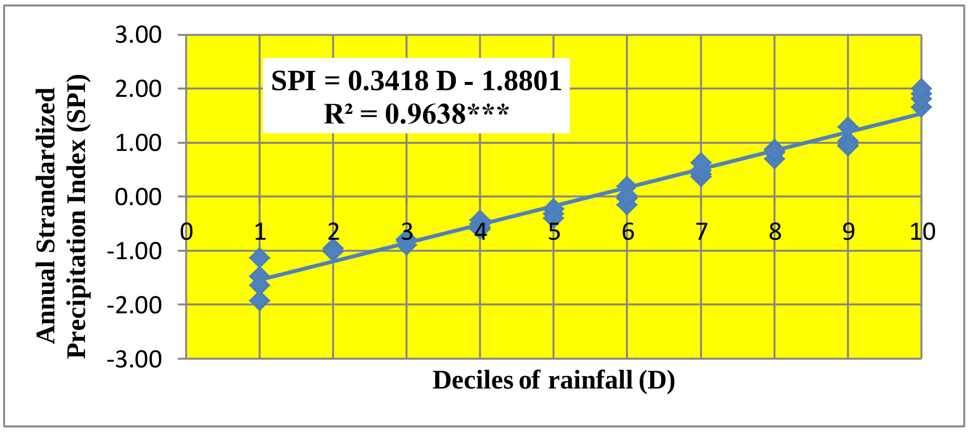


Figure 4. The link between SPI values and Rainfall deciles (1971-2011)

While the calculation methodology of rainfall deciles is simpler than SPI, it is used more increasingly for monitoring of climate hazards due to the higher possibilities of interpretation, analysis and prognosis.

CONCLUSIONS

The best known pluviometric indexes used to monitor rainfall climate hazards are: Hellman Criterion, Topor pluviometric index, Deciles of raifall, Angot pluviometric index, Anomaly Standardized Precipitation Index, Bhalme-Mooley drought index, Effective drought index and the Standardized Precipitation Index.

In the last decades pluviometric indexes have evolved from the simple, calculated by means of various ratios between precipitation and some of their statistical characteristics, into those calculated by means of probabilistic mathematical functions as the Standardized Precipitation Index (SPI).

Analysis of annual SPI values, determined by the "SPI_SL_6.exe" for rainfall recorded in Oradea, in agricultural years 1971-2012 (October-September) show that the SPI = 2,01 characterizes the year 2009-2010 as extremely wet and SPI = -1.93 from the year 1989-1990, shows that it is severely dry.

Annual SPI values determined for the period of agricultural years 1971-2011 in Oradea are linearly correlated, very significant statistically (R^2 = 0.9638) with the values of rainfall deciles, because both indicators as a basis for calculating the cumulative probability of precipitation .

While the calculation methodology of rainfall deciles is simpler than SPI, it is used more increasingly for monitoring of climate hazards due to the higher possibilities of interpretation, analysis and prognosis.

REFERENCES

1. Anagnostopoulou Christina, P. Maheras, T. Karacostas, M. Vafiadis, 2003, Spatial and temporal analysis of dry spells in Greece, Theoretical and Applied Climatology, vol 74, nr. 1-2, Spriger-Verlag, Austria, pp. 77-91;
2. Bhalme H. N., D. A. Mooley, 1980, Large scale droughts/floods and monsoon circulation, Mon. Weath. Rev., 108, pp. 1197–1211;
3. Bryant E.A., 1991, Natural Hazards, Cambrdge University Press, pg. 294;
4. Cheval S., Adina Croitoru, Dana Dragne, Carmen Dragotă, O. Gaceu, Patriche C.V., Popa I., Teodoreanu Elena, Voiculescu M., 2003, Indici şi metode cantitative utilizate în climatologie, Edit. Univ. din Oradea, pg. 119;
5. Cismaru C., I. Bartha, V. Gabor, D. Scripcaru, 2004, Gestiunea secetelor, Ed. Performantica Iaşi;
6. Grecu Florina, Cristina Ghiţă, E. Cîrciumaru, 2011, Land vulnerability to geomorphological hazard induced by pluviometric criteria (Romanian Plain), Revista de Geomorfologie, Vol. 13, pp. 59-66;
7. Karavitis Ch. A., Al. Stavros, D. E. Tsesmelis, G. Athanasopoulos, 2011, Application of the Standardized Precipitation Index (SPI) in Greece, Water, 3, pp. 787-805;
8. Lloyd-Hughes B, M. A. Saunders, 2002, A drought climatology for Europe, Int. J. Climatology, 22, pp. 1571-1592;
9. Man T.E., N. C. Sabău, Gabriela Cîmpan, Marinela Bodog, 2007, Hidroamelioraţii, Vol I şi II, Editura Aprillia Print Timişoara, pg. 498;
10. Marinca I., V. V. Vătămanu, Andrea Florina Marinca, 2012, Agroclimatic conditions in Oltenia during the springof 2011, Forum Geografic, Studii şi cercetări de geografie şi protecţia mediului, Vol. XI, Issue 2, pp.168-181;
11. McKee T. B., N. J. Doesken, J. Kleist, 1993, The relationship of drought frequency and duration to time scales, Preprints, 8th Conference on Applied Climatology, 17-22 January, Anaheim, CA;
12. Mohseni Saravi M., A. A. Safdari, A. Malekian, 2009, Intensity-Duration-Frequency and spatial analysis of droughts using the Standardized Precipitation Index, Hydrol. Earth Syst. Sci. Discuss., 6, pp. 1347–1383;
13. Potop Vera, 2003, Repartiţia spaţială a secetelor cu grad diferit de intensitate pe teritoriul Republicii Moldova, Lucrările Simpozionului "GIS", nr. 9, Analele Universităţii "Al. I. Cuza", Tom XLIX, s.IIc., Geografie, Iaşi, pp. 145-150;
14. Şerban Eugenia, 2010, Hazarde climatice generate de precipitaţii în Câmpia de Vest situată la nord de Mureş, Edit. Universităţii din Oradea, pg.395;
15. Topor N., 1964, Ani ploioşi şi secetoşi în R.P.R., C.S.A, Institutul Meteorologic Bucureşti, pg. 304;
16. * * * Standardized Precipitation Index User Guide, World Meteorological Organization, No. 1090, 2012; http://www.wamis.org/agm/pubs/SPI/WMO_1090_EN.pdf; din 08.07.2014)
17. * * * http://drought.unl.edu/MonitoringTools/ClimateDivisionSPI.aspx; din 05.07.2014;
18. * * * http://www.ncdc.noaa.gov/oa/climate/research/prelim/drought/spi.html; din 05.07.2014;