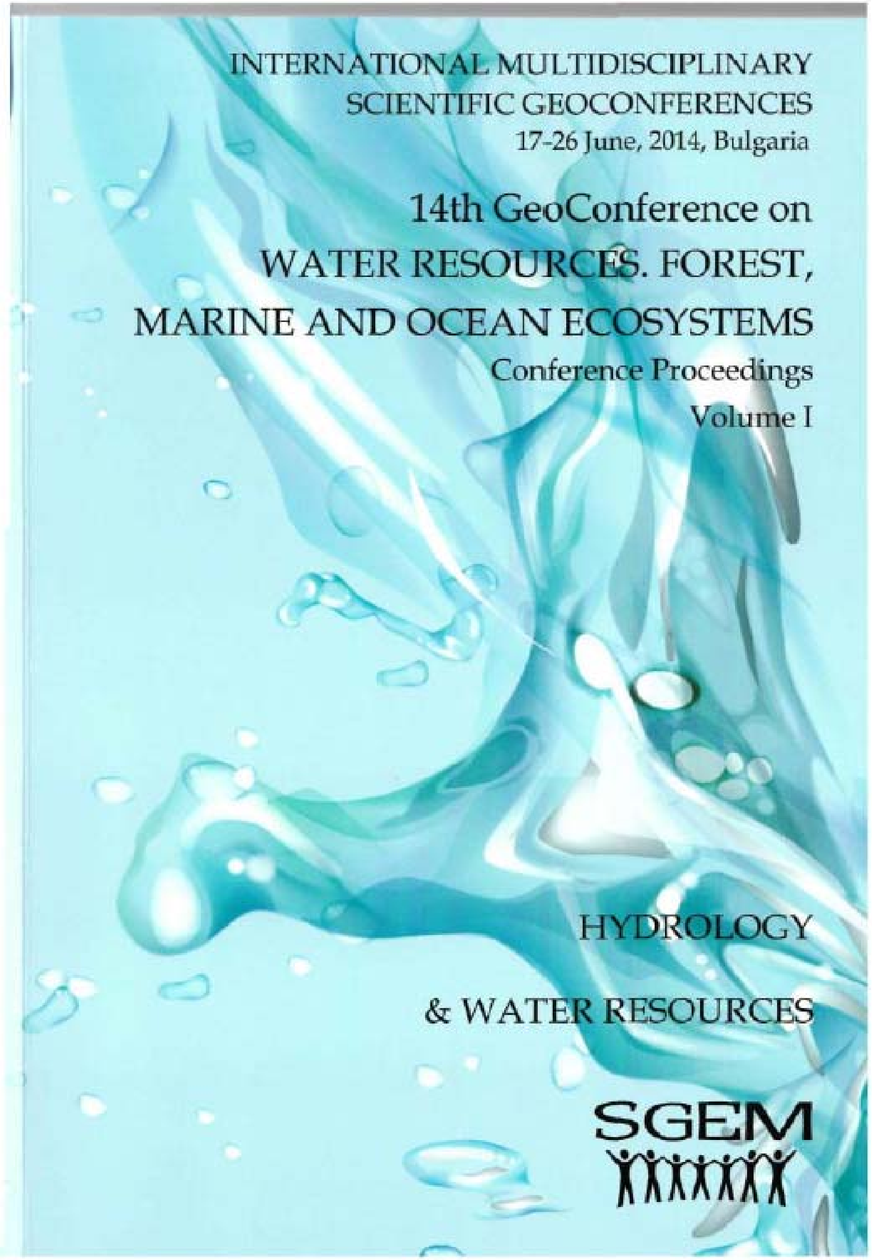
On use of drought indices in modelling hydrological processes

Article · January 2014

Inna G. Semenova
Odessa State Environmental University
8 PUBLICATIONS **4** CITATIONS
SEE PROFILE

V. A. Ovcharuk
Odessa State Environmental University
15 PUBLICATIONS **63** CITATIONS
SEE PROFILE



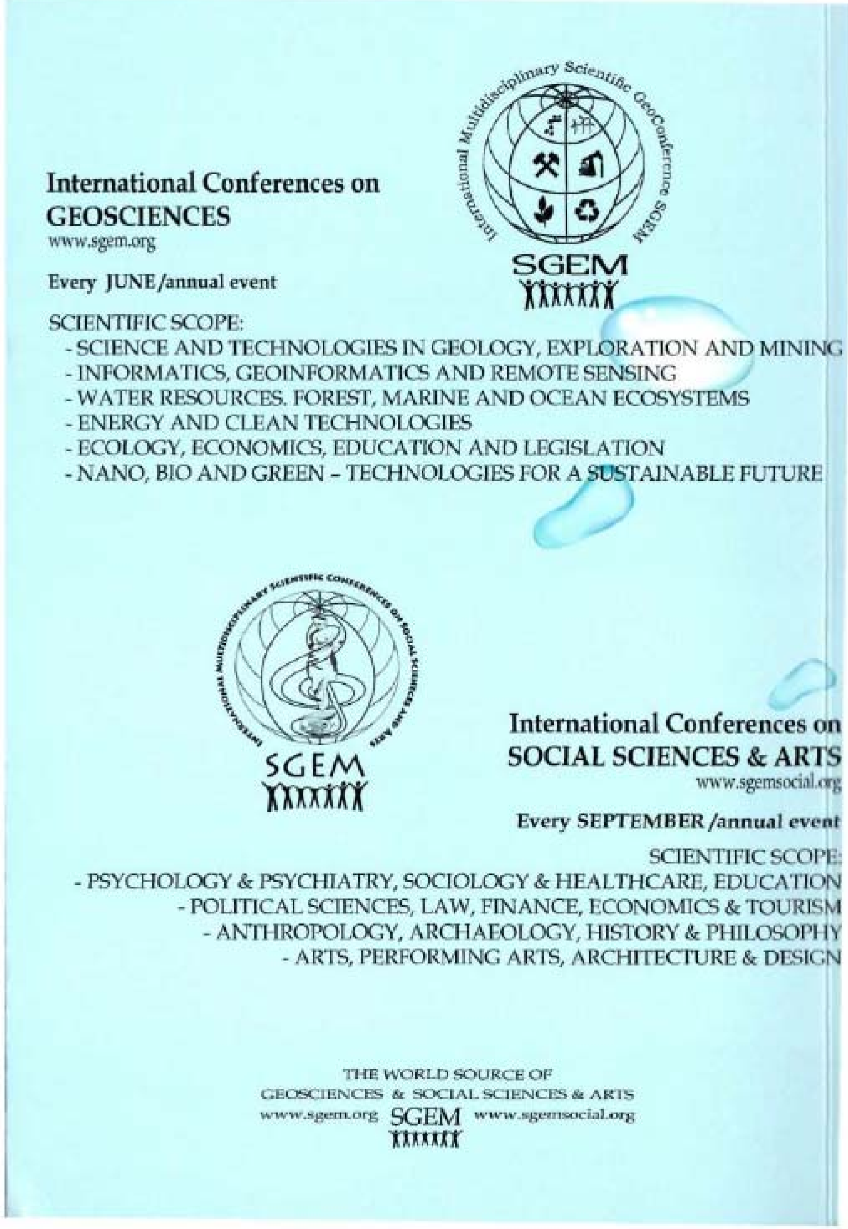
INTERNATIONAL MULTIDISCIPLINARY
SCIENTIFIC GEOCONFERENCES
17-26 June, 2014, Bulgaria

14th GeoConference on WATER RESOURCES. FOREST, MARINE AND OCEAN ECOSYSTEMS

Conference Proceedings
Volume I

HYDROLOGY & WATER RESOURCES

SGEM



International Conferences on
GEOSCIENCES
www.sgem.org

Every JUNE/annual event

SCIENTIFIC SCOPE:
- SCIENCE AND TECHNOLOGIES IN GEOLOGY, EXPLORATION AND MINING
- INFORMATICS, GEOINFORMATICS AND REMOTE SENSING
- WATER RESOURCES. FOREST, MARINE AND OCEAN ECOSYSTEMS
- ENERGY AND CLEAN TECHNOLOGIES
- ECOLOGY, ECONOMICS, EDUCATION AND LEGISLATION
- NANO, BIO AND GREEN – TECHNOLOGIES FOR A SUSTAINABLE FUTURE

International Conferences on
SOCIAL SCIENCES & ARTS
www.sgemsocial.org

Every SEPTEMBER /annual event

SCIENTIFIC SCOPE:
- PSYCHOLOGY & PSYCHIATRY, SOCIOLOGY & HEALTHCARE, EDUCATION
- POLITICAL SCIENCES, LAW, FINANCE, ECONOMICS & TOURISM
- ANTHROPOLOGY, ARCHAEOLOGY, HISTORY & PHILOSOPHY
- ARTS, PERFORMING ARTS, ARCHITECTURE & DESIGN

THE WORLD SOURCE OF
GEOSCIENCES & SOCIAL SCIENCES & ARTS
www.sgem.org SGEM www.sgemsocial.org

14th INTERNATIONAL MULTIDISCIPLINARY
SCIENTIFIC GEOCONFERENCE
SGEM2014

GeoConference on

WATER RESOURCES. FOREST, MARINE AND OCEAN ECOSYSTEMS

CONFERENCE PROCEEDINGS
VOLUME I

HYDROLOGY AND WATER RESOURCES

17-26, June, 2014
Albena, BULGARIA

Published by STEF92 Technology Ltd., 1 "Andrey Lyapchev" Blvd., 1797 Sofia, Bulgaria
Total print: 5000

ISBN 978-619-7105-13-1

ISSN 1314-2704

DOI: 10.5593/sgem2014B31

INTERNATIONAL MULTIDISCIPLINARY SCIENTIFIC GEOCONFERENCE SGEM
Secretariat Bureau

Phone: +359 2 975 3982
Fax: +359 2 874 1088

E-mails: **sgem@sgem.org** | **sgem@stef92.com**
URL: **www.sgem.org**

CONFERENCE ORGANIZERS

- BULGARIAN ACADEMY OF SCIENCES
- ACADEMY OF SCIENCES OF THE CZECH REPUBLIC
- LATVIAN ACADEMY OF SCIENCES
- POLISH ACADEMY OF SCIENCES
- RUSSIAN ACADEMY OF SCIENCES
- SERBIAN ACADEMY OF SCIENCES AND ARTS
- SLOVAK ACADEMY OF SCIENCES
- NATIONAL ACADEMY OF SCIENCES OF UKRAINE
- INSTITUTE OF WATER PROBLEM AND HYDROPOWER OF NAS KR
- NATIONAL ACADEMY OF SCIENCES OF ARMENIA
- SCIENCE COUNCIL OF JAPAN
- THE WORLD ACADEMY OF SCIENCES (TWAS)
- EUROPEAN ACADEMY OF SCIENCES, ARTS AND LETTERS
- ACADEMY OF SCIENCES OF MOLDOVA
- MONTENEGRIN ACADEMY OF SCIENCES AND ARTS
- CROATIAN ACADEMY OF SCIENCES AND ARTS, CROATIA
- GEORGIAN NATIONAL ACADEMY OF SCIENCES
- ACADEMY OF FINE ARTS AND DESIGN IN BRATISLAVA
- TURKISH ACADEMY OF SCIENCES
- BULGARIAN INDUSTRIAL ASSOCIATION
- BULGARIAN MINISTRY OF ENVIRONMENT AND WATER

HONORED ORGANIZER

BULGARIAN ACADEMY OF SCIENCES

EXCLUSIVE SUPPORTING PARTNER

Albena

INTERNATIONAL SCIENTIFIC COMMITTEE
Water Resources. Forest, Marine and Ocean Ecosystems

- PROF. DIPL.-ING. DR.TECHN. GÜNTER BLÖSCHL, AUSTRIA
- PROF. GHISLAIN DE MARSILY, FRANCE
- PROF. MICHAEL BONELL, UK
- PROF. DR PLAMEN NINOV, BULGARIA

CONTENTS

HYDROLOGY AND WATER RESOURCES

ON USE OF DROUGHT INDICES IN MODELLING HYDROLOGICAL PROCESSES

Assoc. Prof. Ph.D. I. Semenova

Assoc. Prof. Ph.D. V.Ovcharuk

Prof. Dr. J. Shakhirzanova

Odessa State Environmental University, **Ukraine**

ABSTRACT

The study considers possibility of use of the drought index SPEI (Standardized Precipitation Evapotranspiration Index) in the analysis and modeling of hydrological processes in the southern Ukraine. The SPEI of various time scale was analyzed for the period of 1950-2010 in the Steppe zone of Ukraine. Time series of the SPEI at scales from 12 to 24 months have an inverse trend in West and East Steppe. In West Steppe the driest period occurred in the two latest decades. On the contrary, in the East Steppe more droughts were observed in the decades of 1950-1970. Statistical relationship between the SPEI of different time scales and some phases of the Southern Bug river flow has been estimated for the period of 1950-2010.

Keywords: Standardized Precipitation Evapotranspiration Index, runoff, drought, high- and low-water phase

INTRODUCTION

A new drought index – the standardized precipitation-evapotranspiration index (SPEI), suggested by Vicente-Serrano et al. [9,10], is similar to the well-known index – *SPI* (the standardized precipitation index), implemented by *McKee* [7] and recommended by the WMO [11] for drought monitoring. Calculation of the *SPEI* is based on monthly precipitation data and potential evapotranspiration data, which depend on temperature. Temperature especially needs to be taken into account in the warm season and under the global warming up process when evapotranspiration increases.

The main feature of the SPEI calculation is the use of difference (D) between monthly precipitation amount (R) and potential evapotranspiration (PET) instead of precipitation amount:

$$D_i = R_i - PET_i, \qquad (1)$$

where i is an index number of an analyzed month.

This expression is a simple scheme of water balance of the vertical soil column, from the surface to the depths, where moisture exchange ceases [9]. Although the expression (1) doesn't account for moisture exchange of the soil with the underlying layers, this expression is satisfactory to take into account impact of temperature conditions on the total moisture.

Since the PET definition is a complicated problem, where it is assumed to use the data on moisture content in the air and the soil, temperature regime of the soil surface, radiation fluxes in the surface air layer etc., therefore authors of the SPEI applied Thornthwaite's (1948) method [8]. It made the new index much the same sensitive to the soil moisture content as the Drought Severity Index [1, 10].

DATA AND METHODOLOGY

The procedure of calculation of the SPEI includes transformation of *D* time series with the use of a three-parameter log-logistic probability distribution. Probabilities obtained are normalized in the SPEI for a possibility of comparison with similar variables in various areas and at different time interval.

Intensity of drought can be defined by the SPEI values given in table 1.

Table 1 – Drought criteria according to the *SPEI*

SPEI value	Category of drought
$-0.99 \le SPEI < 0.00$	Near normal (weakly dry)
$-1.49 \le SPEI < -1.00$	Moderately dry
$-1.99 \le SPEI < -1.50$	Severely dry
$SPEI \le -2.00$	Extremely dry

For calculation of the SPI the time series of precipitation should not be less than 30 years. Since Standardized Precipitation Evapotranspiration Index is associated with the probabilities in the case of each certain site, the probability of occurrence of drought of various severity can be defined. The beginning of a drought can be determined when the value of the SPI turns below -1.0 and the end of a drought occurs as the index gets positive. The drought intensity is calculated as a sum of all the SPI values during a drought period.

The SPEI is defined for various time intervals. One month step (SPEI_1) means that for calculation of the index only one-month precipitation data are used because the SPEI_1 time distribution is similar to month precipitation amount one. For calculation of the SPEI_3 three-month precipitation data for sequential months (current and two previous months) are used. Notably, the SPEI_3 shows short- and medium-range conditions of moisture and provides seasonal assessment of precipitation, therefore time scale is widely used for detecting agrometeorological drought. The time scale of the SPEI_12 and the higher ones describe general conditions of moisture during long-term periods, which are a characteristic feature of hydrological droughts [5], [6].

The correlation relationship between hydrological droughts and water content of the river runoff were studied for the Southern Bug and the Ingulets (the Western Steppe), as well as the Seversky Donets and the Krynka (the Eastern Steppe). Runoff of the main phases of water regime, spring flood, winter and summer-autumn low-water, as well as year runoff are considered. Statistical relationship between the SPEI index and runoff parameters are estemated by means of the Pearson linear correlation coefficient.

The data for analyzing dryness regime by means of the SPEI are obtained from the Global SPEI database (http://sac.csic.es/spei/database.html), which is based on monthly precipitation and potential evapotranspiration CRU (Climatic Research Unit, University of East Anglia) data [10]. The SPEI grid data in a regular grid with a step of 0.5^0 on the scale of 4, 6, 12, 18, 24 months were averaged in the Steppe zone of Ukraine for two areas the Western Steppe ($\varphi = 46\text{-}48^0$ North, $\lambda = 29\text{-}34^0$ East), the Eastern Steppe ($\varphi = 47\text{-}49^0$ North, $\lambda = 34\text{-}40^0$ East).

RESULTS AND DISCUSSION

Analysis of time series of the SPEI for various time scales shows that for a short time interval (6 months) the interchange of dry and moist periods takes place more frequently in accordance with the features of seasonal precipitation process in the Ukrainian Steppe (figure 1, a, e). For the scales of 12 to 24 months the main periods of droughts were singled out in the late 20th century and at the beginning of the 21st century. In the Western Steppe 2-3 drought cases were observed in the 1950s and the 1960s (figure 1, b-d). In the 1970s there registered 1 case of severe drought (1975-1976). It is from 1977 to 1983 that a period of heightened moisture lasted, following which, according to the trend (figure 1, c-d), a long dry period began and has extended till the present time. In the 1990s four drought cases were registered. In the early 21st century, during its first decade, three drought cases were observed, with a four-year one of 2006 to 2010, the longest in the whole series, when the drought reached extreme values. In the Eastern Steppe a period of the 1950s to the mid-1970s was drier, which established an inverse trend in comparison with the Western Steppe (figure 1, g-h). During the 1950s and the 1960s 4 drought cases (2 drought cases per each decade) were observed, with the drought of 1954 being an extreme one. Two dry periods in the early 1970s were followed by a period of heightened moisture of similar length in the Western Steppe. From the mid-1980s to the present time three droughts have been observed in the Eastern Steppe: 1984, 1999 and 2007-2009. In the latter period extreme drought values were observed as well as in the Western Steppe.

In the territory of the Western Steppe in the period from 1950 to 1967, a low-water phase was observed in the chronologic setting of the maximum river runoff. Later, with the periodicity of 4-5 years, it gave place to two high-water and one low-water phases, whereupon, since 1980 to the time present, there has been observed a period of low water level on the rivers.

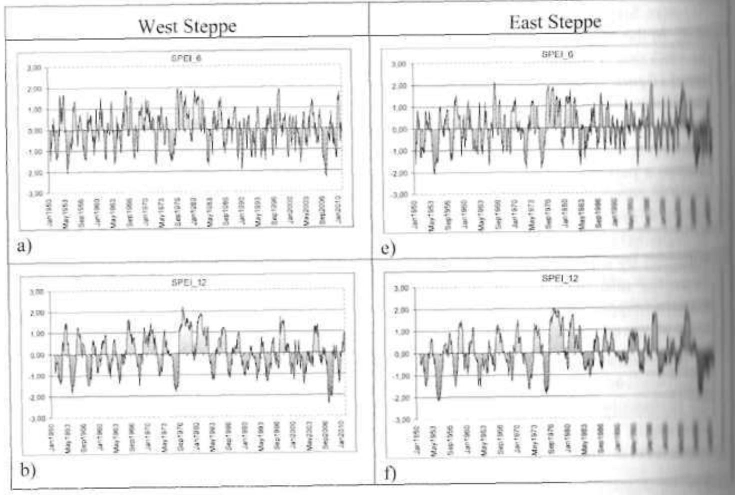
For the minimum runoff, both the summer and the winter ones, from 1950 to 1966, there observed a low-water phase. Then, with the average periodicity of 5-6 years, high- and low-water phases were noticed for a winter minimum runoff. From 1980 to the time present a high-water phase has been observed on the rivers of the studied area.

Variation of the minimum summer runoff is slightly different – after 1967 one prolonged high-water phase of about 30 years can be distinguished, whereupon, with the periodicity of about 5-6 years, there have been registered a consecutive change of 1 low-water and 1 high-water phases.

The rivers flowing through the territory of the Eastern Steppe are characterized by abrupt changes in the water level and a greater number of short-term cycles. However, as well as for the rivers of the first group, it is possible to notice the long-term cycle with a high-water phase, that lasted for the most part till 1971, and a low-water phase from 1972 to 2010.

It should be specified that for the description of the processes, which are complex by their nature and are difficult to measure, e.g. floods and high waters, the indices are quite widely used in Hydrology. As compared to the value characterized by the index, it should be measured in a more simple and easy-to-use way.

In particular, as the indices of hydrological values, varying over the river basin area and the time, one can use the data of specific stations, when they show good correlation with the values generalized for the basin. As an example, it is possible to mention the temperature indices used as predictors for intensity of snowmelt, as well as the indices of the precedent moistening, suggested by Linsley and Koler [4] and later modified by N.F. Befani [2], that are applied to forecasting rainfall runoff.



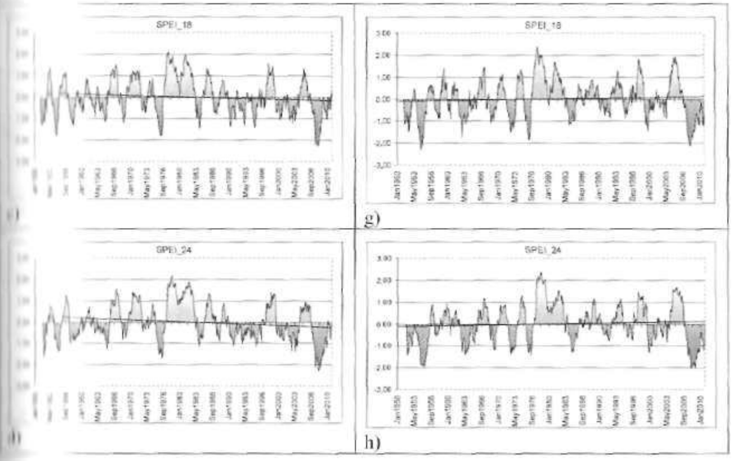


Figure 1. Time series of the SPEI for the scales of 6, 12, 18, 24 months for the Western and the Eastern Steppe

Fig. 2 shows correlation dependences between the *SPEI* index, for various time scales, and the value of a river runoff in diverse periods with the Oleksandrivka station at the Southern Bug River (the water catchment area A=46200 km^2) taken as an example.

The temporal dynamics of the Pearson coefficient for an annual runoff (R) is given in Fig. 2a – the lowest values are observed for the *SPEI_1* and the *SPEI_2*, and the correlation reaches its maximum for the *SPEI_23-24*. Further increase of the time scale leads to a slight decrease in the closeness of links. It is also interesting to notice that the maximum value R = 0.71 is once again observed for the *SPEI_48*. Given that the hidden periodicity of the annual runoff, calculated according to the integral Fourier transformation [3], makes up 3.79 years, this distribution is quite natural.

In analysing Fig. 2.b, it should be noticed that for a spring flood there is a completely different pattern - the highest closeness of links is reached at the time scale of 3-4 months, and a further increase in the calculation period leads to a steady decrease in the correlation coefficient. This situation is quite understandable – the amount of maximum runoff for a spring flood is determined by the snow reserves accumulated over the winter and the rainfall occurring during the flood period, i.e. the total amount of precipitation in the solid and the liquid form for the previous 3-4 months. Within the limits of the studied area, in particular for the Oleksandrivka station at the Southern Bug River, an average long-term date of a maximum spring flood falls on 20 March that explains the greatest value of *R=0.60* for the *SPEI_3* for March.

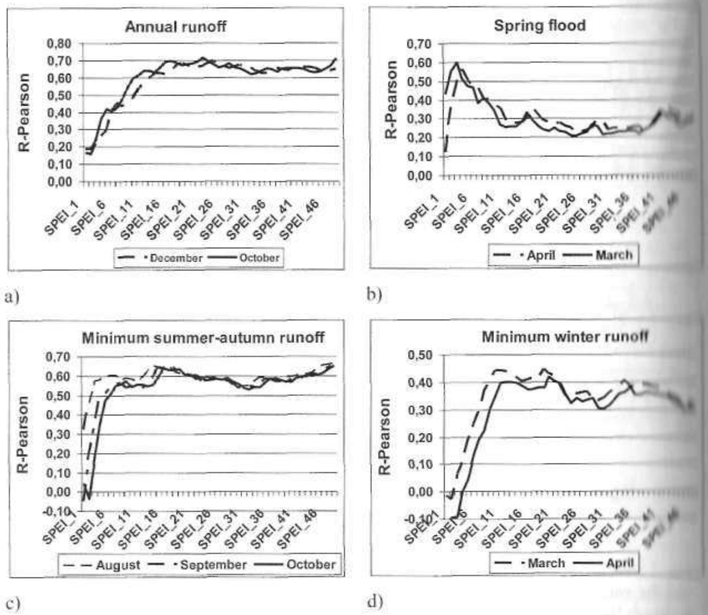


Fig. 2. Correlation between the river runoff and the *SPEI* on the scales of 1-48 months for the Oleksandrivka station at the Southern Bug River

Regularity of these links is well illustrated by Fig. 3, which presents a chronological course of the maximum snow reserves at the beginning of high water period (S_{max}) and the *SPEI_3* for March for the Liubashivka station ($\varphi = 47°50'$ N, $\lambda = 30°15'$ E). On the whole, the coherence of main peaks in the course of the studied values is observed, that is confirmed by the correlation coefficient of $R = 0.54$.

In analyzing the results for a minimum runoff (Fig. 2 c, d), it should be noted that during the summer-autumn low water period the observed distribution of the runoff, as a whole, is similar to the distribution of the annual runoff. Thus, for the *SPEI* at the scales of 1-2 months the correlation coefficient values are insignificant in most cases and are of 3 to 48 months R is significant and varies slightly, ranging from 0.55 to 0.6[illegible]. Apparently, this pattern of links can be explained by the fact that the runoff during the summer-autumn low water is mainly determined by the water level for a year, but this can be disturbed by certain rain floods in a summer period. Therefore the minimum runoff in 3 summer months is characterized by the *SPEI_3* for August with $R = 0.57$. The index values for September and October become significant at the scales from 4-[illegible] months and characterize the summer-autumn period as a whole.

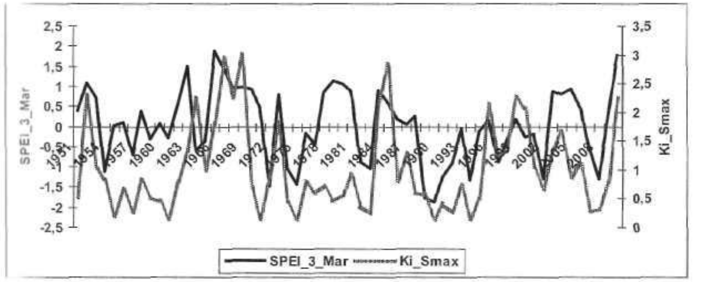


Fig. 3. Time series of the maximum snow reserves at the beginning of spring flood and the *SPEI_3* for March at the Liubashivka station in the period of 1950-2010.

As regards the runoff in the winter low-water, in this case the distribution pattern bears a similarity to a spring flood, but with a shift toward an increase in scale, where the link becomes significant for up to 9-12 months. It is worth noticing that during a winter low water period the runoff regime is determined mainly by a seasonal subsurface feed, supplies of which are formed since autumn, but in warm years, which became prevalent in the latest decade, waters from melted snow and rainfall during winter thaws constitute a part of this feed. It is evident that such combination of factors results in lower coefficients of correlation ($R_{max} = 0.44$-0.45) and they are significant at the scales of 9 to 46 months.

Similar results for all the water level phases are also obtained for the rivers in the territory of the Eastern Steppe.

CONCLUSIONS

- The analysis of the *SPEI* at the scales of 12-24 months showed that in the Ukrainian Steppe in the period of 1950-2010 the inverse trends in distribution of dry and wet periods were observed in western and eastern regions. On the whole area, the period from 1977 to 1983 was notable for heightened moisture, whereupon in the Western Steppe the frequency and duration of droughts increased as compared to the period of 1950-1977, and in the Eastern Steppe the same one, on the contrary decreased..
- The results, stated in this research, proved possibility of the *SPEI* index application for both the low water and the high water periods. In particular, for the period of spring flood the correlation coefficients are obtained at the level of 0.55-0.60, while for the period of low water they comprise 0.55-0.65.
- Rather high coefficients of correlation between the *SPEI* value and the river runoff in its various phases offer the challenge to use the index for modelling hydrological processes.
- Significant correlation between the value of maximum snow reserves by the beginning of high water period and the *SPEI-3* makes it possible to recommend this index for supra long-term forecasting of maximum runoff during a spring flood.

REFERENCES

[1] Abramopoulos F., Rosenzweig C., Choudhury B. (1988). Improved ground hydrology calculations for global climate models (GCMs): Soil water movement and evapotranspiration // J. Climate, V.1, pp. 921–941.

[2] Befani A.N., Befani N.F.and Gopchenko E.D.(1981). Regional models of formation of flood runoff on the territory of the USSR: general information, second ed., Ser. Hydrology of land, Obninsk, VNIIGI MCD, 60p.(in Russian).

[3] Gospodarikov A.P., Kolton G.A., Khachatryan S.A.(2005) Rows of Fur'e. Integral of Fur'e. Operating calculation: Train methodical manual; Saint Petersburg state mountain institute (technical university). SPb, 102 p.(in Russian).

[4] Linsley R., Koler M, Paulyus D.(1962) Applied hydrology. L.:Gidrometeoizdat, 760p.(in Russian).

[5] Lloyd-Hughes B., Saunders M.A. (2002). A drought climatology for Europe // Int. J Climatology, V. 22, No. 13, pp. 1571-1592.

[6] McEvoy, Daniel J., Justin L. Huntington, John T. Abatzoglou, Laura M. Edwards, 2012: An Evaluation of Multiscalar Drought Indices in Nevada and Eastern California // Earth Interact., V. 16, Iss. 18, pp. 1–18.

[7] McKee T.B., Doesken N.J., Kliest J. (1993). The relationship of drought frequency and duration to time scales // Proceedings of the 8th Conference on Applied Climatology, Anaheim, USA, pp. 179-184.

[8] Thornthwaite C.W. (1948). An approach toward a rational classification of climate // Geographical Review, V. 38, Iss. 1, pp. 55–94.

[9] Vicente-Serrano S.M., Beguería S., López-Moreno J.I. (2010a). A multiscalar drought index sensitive to global warming: the standardized precipitation evapotranspiration index // J. Climate, V. 23, Iss. 7, pp. 1696–1718.

[10] Vicente-Serrano S.M., Beguería S., López-Moreno J.I., Angulo M., El Kenawy A (2010b): A new global 0.5° gridded dataset (1901-2006) of a multiscalar drought index: comparison with current drought index datasets based on the Palmer Drought Severity Index // J. Hydrometeorology, V. 11, pp. 1033–1043.

[11] WMO (2009). Experts agree on a universal drought index to cope with climate risk. - WMO Press Release No. 872. Geneva, 15 December 2009.

OPTIMIZING HYDRO POWER RESERVOIR SYSTEM USING HYBRID OPTIMIZATION APPROACH

Ing. Peter Šulek, PhD.

Ing. Martin Orfánus, PhD.

Prof. Ing. Peter Dušička, PhD.

Slovak University of Technology in Bratislava, Faculty of Civil Engineering, Department of Hydraulic Engineering, **Slovakia**

ABSTRACT

This paper describes a hybrid optimization method for finding the optimal operating policy of a reservoir system with water energy utilization. A hydropower plant, in turn, can use its reservoir storage to turbine free water for energy production, thus avoiding fuel expenses with thermal units. The well-timed allocation of hydro energy resource is a complication task, because if water is used in the present period, it will not be available in the future. This hydrothermal coordination problem is solved by peak shaving method using the proposed hybrid optimization method. It combines the genetic algorithms with the traditional numerical optimization method. The proposed hybrid method has been applied on a real hydrothermal system, the Slovak power system.

Keywords: Hydro plant, hydrothermal coordination problem, peak shaving method, genetic algorithms, hybrid optimization

INTRODUCTION

The efficient scheduling of available energy resources for satisfying load demands has become an important task in modern power systems. For hydrothermal systems, the limited energy storage capability of water reservoirs, makes solving load demand problems a more difficult job than for pure systems.

The hydrothermal generation-scheduling problem, which is also called the hydrothermal coordination problem, is a non-linear problem with a high degree of dimensionality, continuous and discrete variables and a non-explicit objective function with many constraints. The solution of the problem has been approached by conventional (traditional) or heuristic optimization techniques. The use of both approaches is often associated with difficulties. The article describes the possibility of solving this problem by a combination of both the numerical and heuristic approaches.

MATERIALS AND METHODS

The objective of hydrothermal coordination (HTC) is to determine the optimal operating schedule of thermal units and hydro plants that minimizes the total system operating