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USING GIS TOOL FOR PRESENTING SPATIAL DISTRIBUTION OF DROUGHT

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Abstract. *By using GIS tools, it is possible to improve the preview of hydrological processes such as evapotranspiration, precipitation, flood and drought. In order to quantify drought, different type of drought indicators have been developed such as Standardized Precipitation Index (SPI), Reconnaissance Drought Index (RDI), Standardized Precipitation Evapotranspiration Index (SPEI) or Water Surplus Variability Index (WSVI). In this paper the precipitation-based SPI indicator was applied to the monthly precipitation data from Serbia during the period 1948-2012. The data were processed in the QuantumGIS software package. For the purpose of application in the monitoring of drought at the national level, a spatial presentation of meteorological drought was obtained.*

Key words: *Drought, SPI, QGIS, Serbia*

1. INTRODUCTION

Drought is a part of natural climate changes, which occurs in all climatic zones, but without a clear formulation of the phenomenon. The complexity and specificity of drought is explained by the fact that there is no single definition of drought. Regarding the area of impact, droughts can be classified into four groups: meteorological, hydrological, agricultural and socio-economic drought (Wilhite and Glantz, 1985). Meteorological drought occurs because of the reduced precipitation intensity compared to average precipitation in previous years and this is one of the main causes of drought. Hydrological droughts occur when the lack of precipitation over a longer period of time causes deficiencies in surface and ground waters. This type of drought occurs with delay in relation to meteorological and agricultural droughts (from several days to several months), and especially groundwater (in which the delay is measured in months, even years).

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In order to determine the intensity, duration and frequency of drought, there are a large number of quantitative indicators, i.e. drought indices. Studies which analysed drought are particularly important in dry and semi-arid regions, where the data availability is usually limited. Therefore, the main criteria for selecting the indices were: a) to have relatively low data requirements, which allows application of software in many regions; and b) their results can be clearly interpreted for concrete and efficient use.

Based on these criteria, indices for different types of droughts have been developed such as Reconnaissance Drought Index (RDI), Streamflow Drought Index (SDI), Standardized Precipitation Index (SPI), Standardized Precipitation Evapotranspiration Index (SPEI) and Water Surplus Variability Index (WSVI). RDI, SPI, SPEI and WSVI are indicators of meteorological drought, because precipitation is their main indicator. RDI, SPEI and WSVI are also used to analyze agricultural drought, because they can adequately describe the water balance, and are especially useful in selecting a reference period that refers to the development phases of crops (Gocic and Trajkovic, 2014b; Tsakiris et al., 2007; Vicente-Seranno et al., 2010). According to the recommendations of the World Meteorological Organization (WMO), all national meteorological and hydrological services should use the Standardized Precipitation Index - SPI (WMO, 2012). By using the SPI index, it is possible to analyze drought through intervals of 1, 3, 6, 9, 12 and 24 months. In agricultural regions, SPI-3 can be more effective in determining availability of humidity compared to other indices. Therefore, by observing this index in May, it is possible to determine the state of soil moisture during the growing period (WMO, 2012). Detailed analysis of droughts based on SPI for stations in Serbia can be found in Gocic and Trajkovic (2013a, 2013b, 2014a), Tosic and Unkasevic (2014), Trajkovic et al. (2019).

Using GIS tools, in addition to widespread application in geography, it is possible to improve the preview of hydrological processes such as evapotranspiration, water circulation in the atmosphere, and drought, using data obtained from independent Internet services.

The aim of the paper is the development of a methodology for the calculation, input and processing of drought indicators for the purpose of visualisation of drought episodes using GIS software. In the literature, the papers related to the spatial distribution of drought GIS software in Serbia cannot be found.

2. METHODS AND MATERIALS

2.1. Standardized Precipitation Index (SPI)

Standardized Precipitation Index (SPI) was developed at the beginning of the 1990s (McKee et al., 1993). This index quantifies the precipitation deficit for different time scales (1, 3, 6, 12, 24, 48 months) and can be used for different types of droughts. SPI for short time scales (1 or 3 months) is used for meteorological droughts, for time scales of 3 or 6 months for agricultural drought, while SPI for long time scales (12 and 24 months) is used for hydrological droughts (Svoboda et al., 2016). SPI is the amount of precipitation recorded over a period of time represented by the value of a random variable that has a standardized normal probability distribution.

SPI is calculated using:

$$SPI = \begin{cases} -\left(t - \dfrac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3}\right), 0 < H(x) \leq 0.5 \\ +\left(t - \dfrac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3}\right), 0.5 < H(x) \leq 1.0 \end{cases}, \qquad (1)$$

where $H(x)$ is a cumulative distribution of probability, while t is defined as:

$$t = \begin{cases} \sqrt{\ln \dfrac{1}{(H(x))^2}}, 0 < H(x) \leq 0.5 \\ \sqrt{\ln \dfrac{1}{(1 - H(x))^2}}, 0.5 < H(x) \leq 1.0 \end{cases}, \qquad (2)$$

c_0, c_1, c_2, d_1, d_2 and d_3 are coefficients with the following values: c_0 = 2.515517, c_1 = 0.802853, c_2 = 0.010328, d_1 = 1.432788, d_2 = 0.189269, d_3 = 0.001308. The strength of this index lies in the fact that the mutual comparability of precipitation data from uneven lengths of time is possible, as well as data from the season and locations with different precipitation regimes. The most important weakness is the lack of a component of evapotranspiration that is very important for the water balance. Drought classes based on SPI values are shown in Table 1. SPI can be used for drought detection and for determination of wet periods.

Table 1 SPI classification

Class	SPI value
Exceptional drought	SPI ≤ -2.326
Extreme drought	-2.326 < SPI ≤ -1.645
Severe drought	-1.645 < SPI ≤ -1.282
Moderate drought	-1.282 < SPI ≤ -0.935
Minor drought	-0.935 < SPI ≤ -0.524
Near normal	-0.524 < SPI < 0.524
Slightly increased moisture	0.524 ≤ SPI < 0.935
Moderately increased moisture	0.935 ≤ SPI < 1.282
Considerably increased moisture	1.282 ≤ SPI < 1.645
Extremely wet	1.645 ≤ SPI < 2.326
Exceptionally wet	SPI ≥ 2.326

2.2. GIS tools

Geographic Information System (GIS) is a computer information system that collects, stores, analyzes and displays spatial entities and their attributes for solving complex research, design and management problems. GIS is a rapidly growing tool with great potential for hydropower applications. It can be defined as a system for recording, storing, analyzing and managing data and associated attributes that spatially relate to Earth (Longley et al., 2005). The system usually includes hardware, software and geographic information. Through a GIS analysis, users in different disciplines can better consider geographic patterns in their data and explore possible spatial relationships between studied phenomena. GIS is envisioned as an invaluable tool for students for an extended understanding of geography because it provides a visual illustration of data (Bednarz et al., 2006).

GIS software can be commercial and open source software. Quantum GIS (QGIS) is open source software that provides a very good integration with Python, a script language for customizing or automating GIS functions. Python is probably the most popular programming language for GIS, because of that ESRI ArcGIS also adopts Python for its program functions. The software provides useful GIS tools for spatial analysis, geoprocessing, geometry, and data management tasks. Two unique features of QGIS include a link to the GRASS functionality and the support for the DWG file format. QGIS supports basic ESRI formats. GIS software has wide application in geodesy, ecology, tourism, cadastre and urban planning. Also, it can be applied in hydrotechnics as the most efficient tool for processing and managing spatial resources in water management and hydrology. Data integration and their processing result in automation of the procedures for spatial planning in terms of mapping, mapping of floods, analyzes of accumulation basins, integrated river basin management, as well as in terms of spatial distribution of drought, which has been elaborated in detail in this paper.

2.3. Study area

Serbia is located in the Balkans, a region of Southeast Europe. Geographically, and also climatically, it is partly included in the Mediterranean countries. The northern part of Serbia is flat, while the southern parts are dominated by hills and mountains occupying most of the territory and making it the mountainous region.

Serbia's climate can be described as moderately continental with more or less pronounced local characteristics. The spatial distribution of climate parameters is conditioned by the geographical position, relief and local influence, as a result of a combination of relief, the distribution of air pressure of larger proportions, the exposition of the terrain, the presence of river systems, vegetation, urbanization, etc. Among the geographical determinants important for the climate of Serbia should be mentioned the Alps, the Mediterranean Sea and the Genoa Bay, the Pannonian Plain and the Morava valley, the Carpathians and the Rhodope Mountains as well as the hilly mountain part with the valleys and plains.

3. Results and Discussion

Precipitation data from 27 stations were used to determine the SPI index using a calculation program from the National Drought Reduction Center, the University of Nebraska for the reference period 1961-2012 (http://drought.unl.edu). According to Gocic and Trajkovic (2014a), the driest year was 2000, and the SPI values for different time scales (SPI-1, SPI-3, SPI-6, SPI-12) were analysed. The SPI-1 index in most of the stations during that year had negative values in September, and these values were lowest in June and August. According to SPI-3, the negative values begin from March, with the lowest values from June to August. Based on the SPI-6 values, it can be concluded that in Serbia there were no droughts until June from which started severe drought in most of the stations. Similar results are obtained with the SPI-12, with severe drought recorded at most of the stations in November and December.

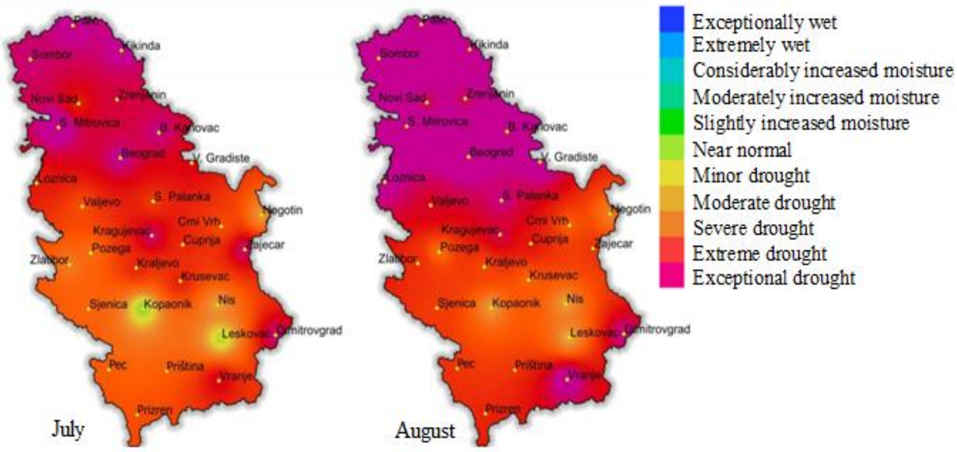

Fig. 1 Drought spatial distribution based on SPI-3 for July and August 2000

For the purpose of spatial distribution of drought in the GIS environment, the "open source" software package Quantum GIS 3.0.1 was used, which is available at qgis.org/en/site. At the very beginning, as the reference coordinate system, EPSG: 4326 - WGS 84 was selected. The procedure consists of two separate parts. In the first part, the map of the Earth was imported and the layer for borders of Serbia was created. In the second part, layers were created for locations of meteorological stations, SPI values loaded and interpolated data for distribution of drought.

As an illustration of the QGIS application, the spatial distribution of drought based on the intensity of SPI-3 and SPI-6 for July and August of the reference - the most severe year (2000) were presented in Fig. 1 and Fig. 2, respectively. The drought according to SPI-3 started in March and reached its highest intensity in August, but was also pronounced in December. Drought was the most intense in the north and southeast parts of Serbia (Fig. 1). The drought according to SPI-6 lasted in the period from June to December and was the most intense in August when extreme drought was recorded throughout the territory of Serbia, except for Kopaonik (Fig. 2).

Since 2007, RHMSS (Republic Hydrometeorological Service of Serbia) has been a member of the DMCSEE (Drought Management Center for South East Europe) and participates in the project of the European Union, which aims to improve the monitoring and preparedness for drought in the countries of South-East Europe. The results of this project are available on the RHMSS website (http://www.hidmet.gov.rs/podaci/agro/SPI.pdf) and are compared with the approach developed in this paper.

Fig. 3 shows the comparison of SPI-6 in the growing season (April-September) for 2007 and 2012 years. Bearing in mind that the method of data processing and display according to RHMSS differs from this paper, the comparison of the results can be concluded that they mostly coincide.

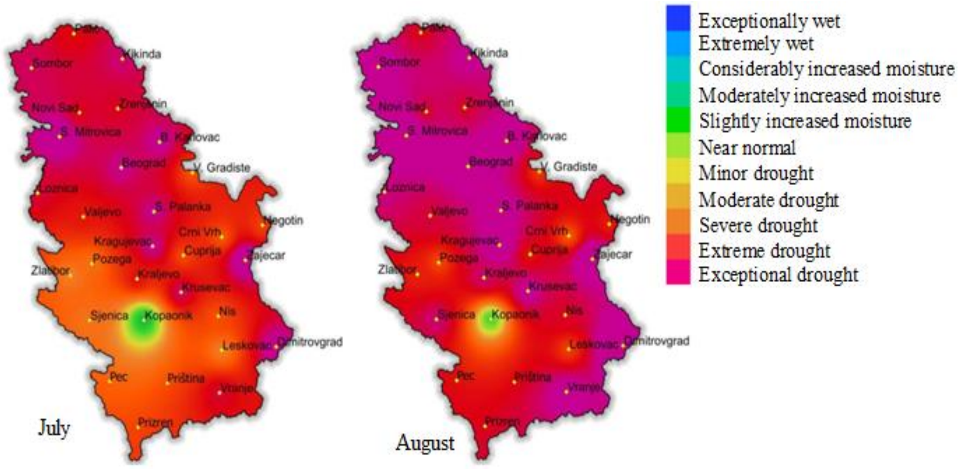

Fig. 2 Drought distribution based on SPI-6 for July and August 2000

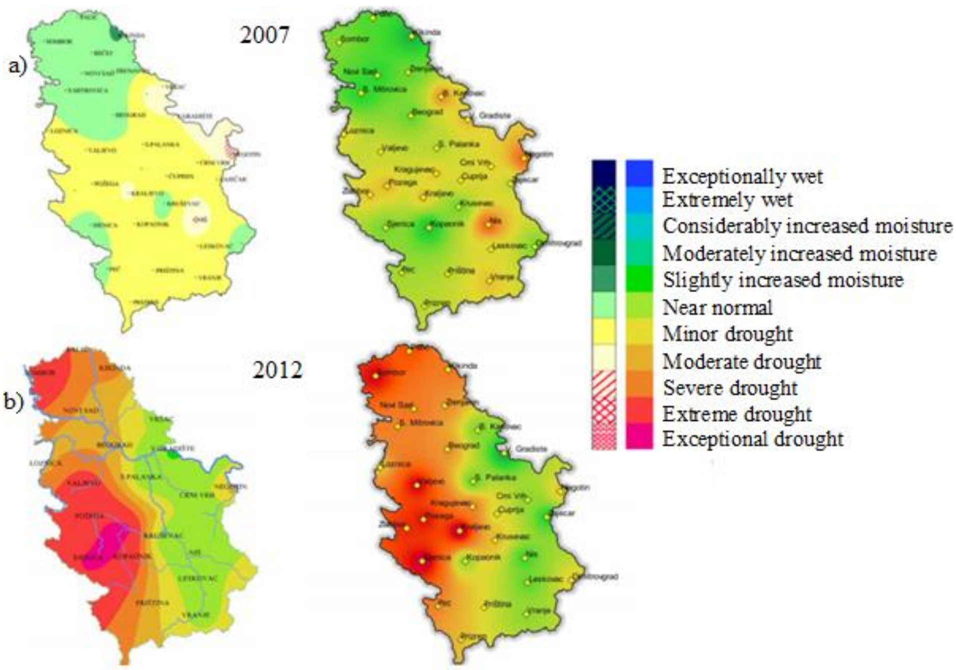

Fig. 3 Comparison results regarding drought in the growing season (SPI-6): a) 2007; b) 2012. Left: RHMSS results, Right: our achieved results

4. CONCLUSIONS

The aim of this research is to look at the possibilities of GIS software as a tool for presenting spatial distribution of drought. The methodology is based on the use of the Standardized Precipitation Index. In the first phase of the work, drought indices were calculated and a database was created. The database itself can have global character since the main feature of the SPI index is that it is neither time- nor location-limited. The second phase of work was concentrated on the development of maps, and locations of measuring stations. The database is imported into the GIS environment and they are processed by an interpolation algorithm. This methodology is limited only by the available historical and measured data. The density and position of the network of measuring stations greatly affect the effectiveness and precision of monitoring as well as the methods of forecasting drought. The analysis of the results showed the most intense drought during the growing season period in 2000 in the north, in Vojvodina, and in the southeast of Serbia.

The achieved results can be applied in ecology, tourism, urban planning, agriculture and water resources management. Our next steps will be to analyse different drought indices in order to better compare them using QGIS.

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KORIŠĆENJE GIS ALATA
ZA PREDSTAVLJANJE PROSTORNE RASPODELE SUŠE

Pomoću GIS alata moguće je poboljšati pregled hidroloških procesa kao što su evapotranspiracija, padavine, poplave i suša. Da bi se kvantifikovala suša, razvijeni su različiti indeksi suše, kao što su Standardizovani indeks padavina (SPI), Reconnaissance Drought Index (RDI), Standardizovani indeks evapotranspiracije padavina (SPEI) ili Water Surplus Variability Index (WSVI). U ovom radu SPI indeks suše zasnovan na padavinama primenjen je na mesečne podatke o padavinama iz Srbije u periodu 1948-2012. Podaci su obrađeni u programskom paketu QuantumGIS. Za potrebe primene u praćenju suša na državnom nivou, dobijena je prostorna raspodela meteorološke suše.

Ključne reči: *suša, SPI, QGIS, Srbija.*