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Approach and an Indicator system for prolonged drought identification in Bulgaria

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Abstract: Drought indicator systems help decision-makers to understand *how* and *where* the drought occurred. The main goal in the Water Framework Directive (WFD) is the achievement "good ecological status", but the Article 4.6 allows temporary deterioration of the status, occurred as a result of so called "prolonged drought". The severity of the "prolonged drought" is related to its duration, specificities of the river basin, reservoir management and impacts. The research is related to the system of drought indicators developed at the National Institute of Meteorology and Hydrology-NIMH (http://hydro.bg: Standardized Runoff Index, SRI; Standardized Precipitation Index, SPI; Soil Moisture Index, SMI) and its improvement at River Basin level. A new approach for integrated analysis of the indices of the NIMH system, and of the indicators used by the Ministry of Environment and Water (MoEW) - inflow and levels of reservoirs, groundwater, etc., has been developed. Thus the so-called *hot spots* and *critical areas* are identified - reservoirs, watersheds and river basins for which indicators identify drought and/or whose regulatory capabilities have declining potential and are at risk in the prolonged drought. Systems of criteria and drought indicators to identify "prolonged droughts" have been experimentally applied. A joint analysis of the SRI, SPI, SMI maps, the maps for inflow and volume of complex and significant reservoirs from Annex 1 of the Water Act and the groundwater storage trends was performed. The Standartised State Index is applied for Drought Risk Assessment in reservoir systems and river basins. The correlation and phase lag between the SRI and SPI indices was estimated. Drought periods in Bulgaria are analyzed, especially prolonged drought 2019 – 2020. The approach supports the operational application of the NIMH drought indicator system in the practice of the MoEW.

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Keywords: prolonged drought, Drought indicator systems, Standartised State Index, Drought Risk Assessment, (Water Framework Directive)

1. INTRODUCTION

Drought indicator systems help decision-makers to understand how and where the drought occurred and to take measures according to the Drought Management Plans. The main goal in the Water Framework Directive (WFD) is the achievement of "good ecological status", but the Article 4.6 allows temporary deterioration of the status, occurred as a result of so called "prolonged drought".

Reduction of natural resources is associated with a decrease of available water resources for water supply, including runoff regulation (so-called "operational" and "socio- economic" drought). It is recommended that Basin directorates establish an appropriate indicator system allowing to identify the different extreme phenomenon phases, to predict possible impacts and establish associated measures to apply. The indicator systems for "prolonged drought" assessing include rainfall, river runoff, inflows and reservoir levels, groundwater levels, etc. (Monzonís et al, 2015; Prolonged drought…, 2007).

2. MATERIALS AND METHODS

The research is related to the system of drought indicators developed at NIMH (http://hydro.bg, Standardized Runoff Index, SRI; Standardized Precipitation Index, SPI; Soil Moisture Index, SMI), its development at River Basin level. A new approach for integrated analysis of the indices of the NIMH system, the indicators used by the Ministry of Environment and Water (MoEW) - inflow and levels of reservoirs, groundwater storage trends, etc., has been developed (Guidelines for the use…, 2021; Ilcheva et al., 2022). Systems of criteria and drought indicators to identify "prolonged droughts" have been experimentally applied – Table 1 (Ilcheva et al., 2019; Dimitrov and Ilcheva, 2021).

Thus, from the first months, the so-called *hot spots* and *critical areas* are identified – reservoirs, watersheds and river basins for which indicators identify drought and/or whose regulatory capabilities have declining potential and are at risk in the prolonged drought.

Table 1. Experimentally applied Drought Indicator System

Drought type	Indicators and Indices
1.Meteorological Drought	**Standardized Precipitation Index**, SPI
2.Agrometeorological Drought	**Soil Moisture Index**, SMI
3.Hydrological Drought	**Standardized Runoff Index**, SRI

4.Hydrogeological Drought	Groundwater, **trend analysis**
5. Hydrological Drought 6. Operational and Socio -economic Drought	**Reservoir inflow**, RI – monthly reservoir inflows with certain probability of exceedance (PE) – 50%, 75%, 95% **Total reservoir inflow**, TRI with certain PE. **Reservoir volume**, (RV) – percent of the volume or effective capacity, **Standardised State Index**, SSI (for reservoir and river basins), etc. **Impact indicators** (socio-economic and environmental)

For assessing the indicators for the Reservoir inflow, a scale used by the MoEW is adapted – Total reservoir inflow (TRI) with certain exceedance probability: yellow (*average year,* with certain PE – 50 %), orange (*medium dry year* – 75 %), red (*dry year* – 95 %) (Guidelines for the use …, 2021). The developed by NIMH monthly inflows with certain probability of exceedance (An update.., 2015), uploaded to the (https://www.moew.government.bg) are experimentally applied – Table 2 (fragment).

Table 2. Reservoir inflow indicator – inflows with certain probability of exceedance

Reservoir	PE %	Monthly reservoir inflow with certain probability of exceedance, 10^6 m^3												
		I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	S
Ogosta	50%	16,71	20,31	35,35	49,62	45,96	26,42	11,74	7,35	6,68	7,86	10,68	17,22	255,91
	75%	11,21	11,91	15,04	28,87	23,31	11,57	7,24	5,08	3,42	4,74	6,4	9,19	137,97
	95%	0,76	0,13	0,29	0,83	2,42	0,08	0,97	0,34	0,01	0,26	0,18	0,05	6,29
Srechenska Bara	50%	2,01	5,68	3,08	8,02	9,27	7,44	4,09	2,06	1,14	1,84	2,46	2,35	49,43
	75%	1,7	2,53	2,26	6,27	6,89	4,66	2,61	1,23	0,7	1,28	1,47	1,51	33,11
	95%	0,66	0,71	1,26	2,85	2,84	2,09	1,15	0,72	0,41	0,5	0,44	0,47	14,09

The Standardised State Index (SSI) is applied for Drought Risk Assessment in reservoir systems and river basins (Ortega-Gomes et al., 2018; Ilcheva et al., 2019; Dimitrov and Ilcheva, 2021):

$$V_{i,t} \geq V_{med,t} \rightarrow SSI_{i,t} = 1/2 * (\ 1+ ((V_{i,t} - V_{med,t})/(V_{max,t} - V_{med,t})) \qquad (1)$$

$$V_{i,t} < V_{med,t} \rightarrow SSI_{i,t} = 1/2 *(V_{i,t} - V_{min,t})/(V_{med,t} - V_{min,t})$$

where:

$SSI_{i,t}$ – the Standartised State Index for year i and month t;

$V_{i,t}$ – the value of the indicator for year i and month t;

$V_{med,t}$, $V_{max,t}$ and $V_{min,t}$ – monthly statistics (mean, maximum, minimum).

Once the river basin reaches the emergency status, the phenomenon could be considered as “prolonged drought”. The derived SSI at river basin level is calculated as a weighted sum. For this purpose, the criteria developed at NIMH are applied (Criteria for ..., 2015). At National level, based on the Portuguese indicator system, a scale for assessment of the % of the volume has been adapted: 81-100% blue; 61-80% green; 51-60% yellow; 41-50% orange; 21-40% red; 0-20% dark red.

The possibilities of parameters for assessment of the hydrogeological drought have been experimentally investigated (Guidelines for the use…, 2021).

The regularities of the drought process are studied, identifying both the correlation and the transition from meteorological to hydrological drought, as well as the expected phase shift of the hydrological drought over time (Yordanova et al., 2022).

3. RESULTS AND DISCUSSION

This research is part of a project (Guidelines for the use…, 2021, agreement with the MoEW). The approach and the indicator system are applied to the complex and significant reservoirs of Annex № 1 of the Water Act, for integrated space-time analysis and the prolonged drought identification in Northwestern Bulgaria, Struma River Basin, etc. (Ilcheva et al., 2019; Dimitrov and Ilcheva, 2021).

Up-to-date information from NIMH was used.

The results of the experimental application of the Standardized Status Index for the “Studena“ reservoir, “Srechenska Bara” reservoir and Ogosta River Basin are presented in Figures 1 to 3.

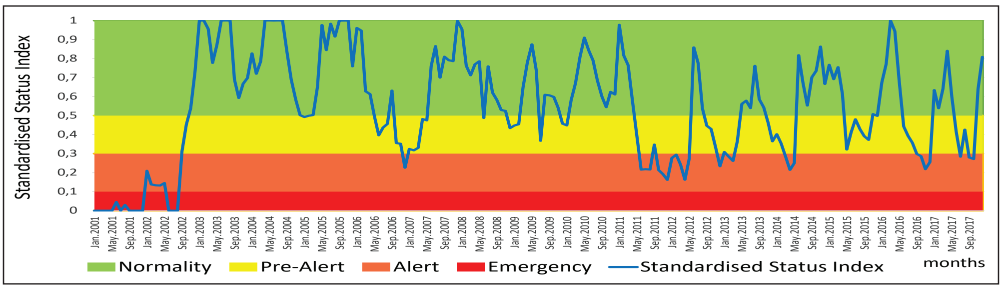

Fig. 1. Standardised Status Index – “Studena” Reservoir

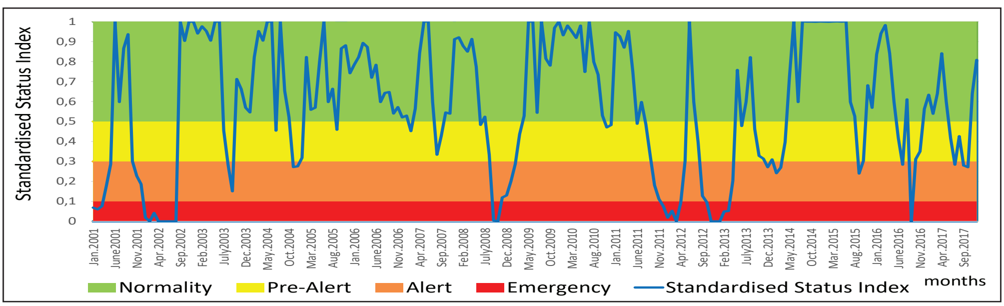

Fig. 2. Standardised Status Index – “Srechenska bara” Reservoir

The weight of the reservoirs takes into account their significance for the water supply, river basins and the impacts to society, ecology and economy. For this purpose, the developed at NIMH criteria for MOEW (Criteria for …., 2015), are applied. The weights of the reservoirs are respectively 0.6 for "Srechenska Bara" reservoir and 0.4 for "Ogosta" reservoir – Figure 3.

Periods of meteorological and hydrological drought in Northwestern Bulgaria have been identified by SPI and SRI - 1963, 1965; prolonged drought 1983-1995 and 2000-2002; 2007, etc. (Dimitrov and Ilcheva, 2021). The same has been done for Struma River Basin, Iskar River Basin, etc. (Ilcheva et al., 2019; Yordanova et al. 2022).

A correlation was found between the proposed indicators of reservoir inflow and hydrological drought. For prolonged droughts, we have a good match of reservoir state indices with SRI. The SRI24 index better identifies long-term drought - there is a coincidence with the SSI. There is a displacement, which is explained by the gradual depletion of the volumes of reservoirs and ground water.

The new SSI is more suitable for assessing the operational drought and condition of reservoirs with seasonal flow regulation (Ortega-Gomes et al., 2018).

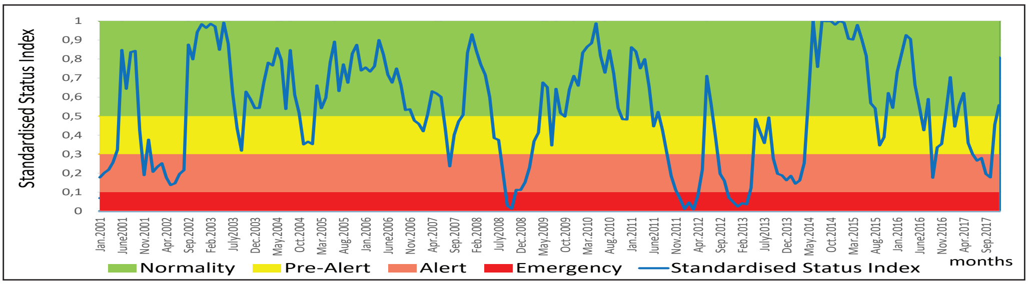

Fig. 3. The composite Standardised Status Index - Ogosta River Basin

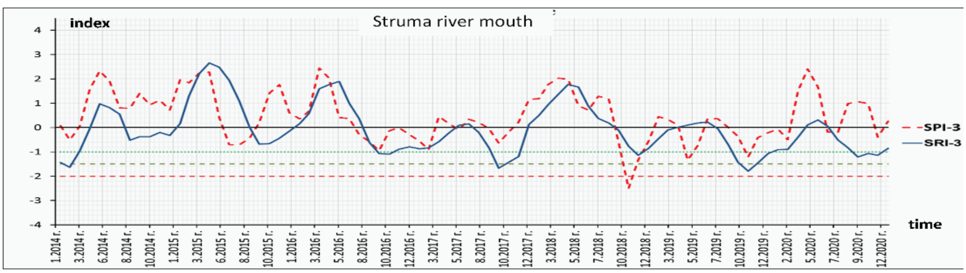

Fig. 4. Comparison of SRI3 and SPI3 indices for Struma River, 2014 - 2020

The influence of climatic factors on the hydrological cycle components and the role of the characteristics of river basins has been studied (Yordanova et al., 2022). The correlation analysis is made across the time scales to evaluate the relationship between meteorological (SPI) and hydrological drought (SRI) – Figure 4, Table 2.

Table 3. Correlation between SPI and SRI in different time steps, 2014-2020

	Iskar river	Struma river	Ogosta river
Correlation between SPI6 and SRI6	0,54	0,61	0,53
Correlation between SPI3 and SRI3	0,45	0,53	0,46

The result of the correlation between the SRI and SPI indices confirms the development regularities for the drought process in space and time – both: correlation and the transition from meteorological to hydrological drought are clearly identified, as well as the expected hydrological drought phase lag over time.

The correlation between indices increased with a transition from 3-month time step to 6-month step (Yordanova et al, 2022). The effects of a meteorological drought greatly vary depending on the river basin specificities: basins with regulating infrastructures (e.g. reservoirs) or storing aquifers could be less vulnerable to impacts, while basins without storing capacity could be more rapidly affected.

At national and river basin level, a joint analysis of the SRI, SPI, SMI maps (http://hydro.bg), the developed maps for inflow and volume of complex and significant reservoirs from Annex № 1 of the Water Act, groundwater, etc., was performed (Guidelines for the use…, 2021; Ilcheva et al., 2022). Drought periods in Bulgaria are analyzed, especially prolonged drought 2019 – 2020.

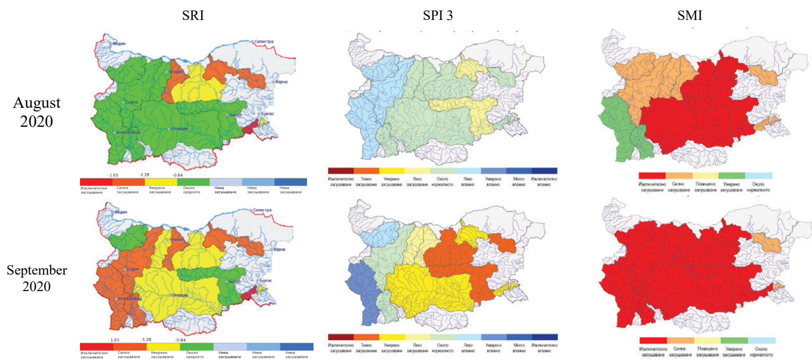

Fig. 5. A joint analysis of the SRI, SPI, SMI maps – improvement at River Basin level

The analysis should be performed by the decision-makers from the MoEW together with the expertise and information from the NIMH. It must be done at least: at the beginning of the year (identified drought in the previous year is reported; first and second quarter - identified drought before summer low flow; autumn; end of the year, etc. (Ilcheva et al. 2022). Thus, from the first months, the hot spots, critical areas and river basins at risk in the event of prolonged drought are identified.

The severity of drought is related to its duration, climatic conditions, specificities of the river basin and measures applied throughout the previous phases. The analysis should be more careful in the identified critical areas, especially if the precipitation deficit (identified with SPI3) is in the watersheds of the reservoirs.

The analysis should also take into account the critical thresholds of SPI3 and SMI established by NIMH experts, where hydrological drought most often occurs (SRI), correlation dependencies and the estimated phase lag of hydrological drought (Guidelines for the use …, 2021).

The characteristic intra-annual distribution of river flow in Bulgaria should be taken into account also. The hydrological drought risk can be assessed by the integrated analysis and timely measures should be taken before summer low water. The *hot spots* and *rivers at risk* were identified even before July 2019: these being related to the reservoirs “Studena”, “Dyakovo”, “Asenovec”, “Ticha”, etc. – Figure 6, Figure 8, Figure 10.

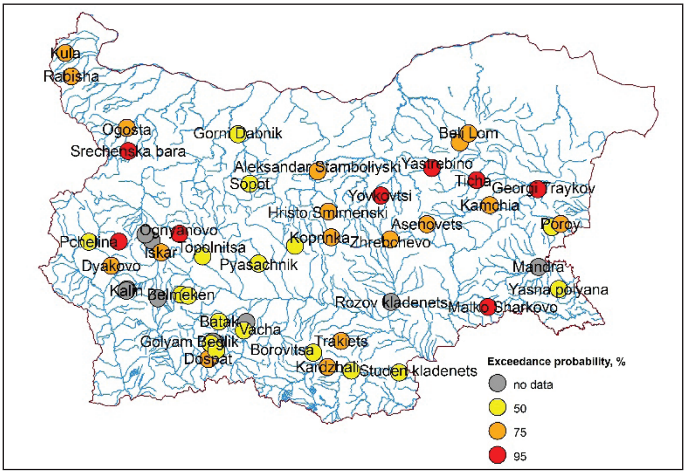

Fig.6. Total inflow to complex and significant reservoirs, July 2019

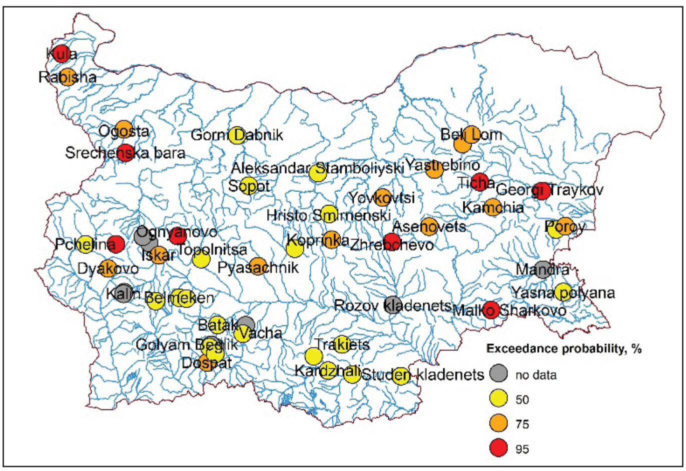

Fig.7. Total inflow to complex and significant reservoirs, December 2019

If the analysis finds reduced inflow and volumes in the reservoirs by July, it is unlikely that the reservoirs will be fill up in the coming months (Ilcheva et al., 2022; Guidelines for the use…, 2021; Santurdjian et al, 2019-2022).

Although 2019 and 2020 are not the driest years, during the period there is a prolonged drought, manifested in all components of the hydrological cycle: run-off in rivers, reduced inflow and available volume in reservoirs, reduced groundwater, water scarcity. Two consecutive dry years and the autumn/winter drought are critical.

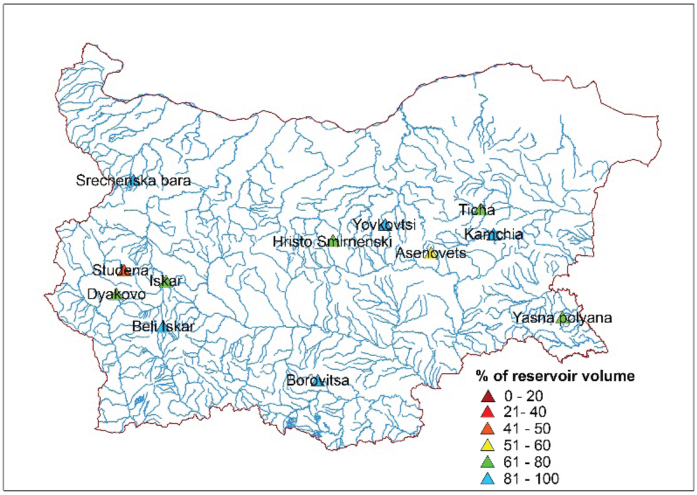

Fig.8. Percent of the volume of reservoirs for drinking water supply, July 2019

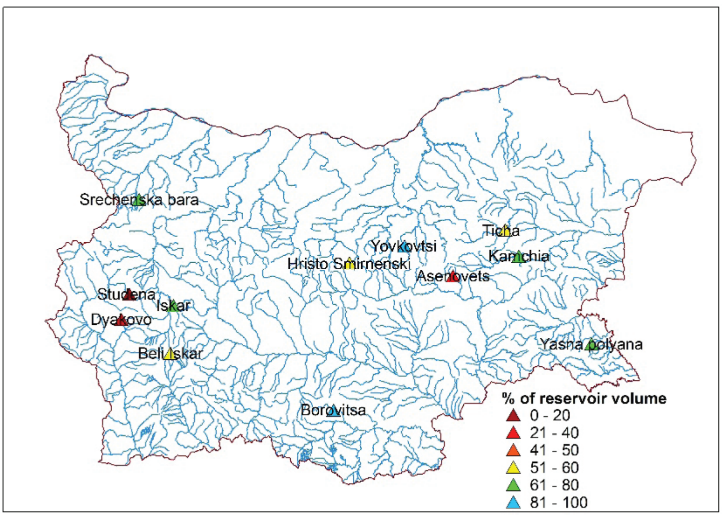

Fig.9. Percent of the volume of reservoirs for drinking water supply, January 2020

Hydrological drought is a complex result of meteorological conditions, accumulation of rainfall deficits, subsequent soil drought, and in addition high temperatures, increased evapotranspiration, reduced infiltration, etc. All hydrometeorological information, plus assessment of water resources, trends, etc., must be taken into account (Guidelines for the use …, 2021; Georgieva and Kazandzhiev, 2015; Ninov et al., 2017).

It is very important to identify the autumn-winter drought, because it leads to a decrease in: 1) snow reserves, 2) the available resource in the reservoirs, 3) the groundwater nourishment. Prolonged drought affects the regulatory systems – reservoirs and groundwater Figures 10 and 11.

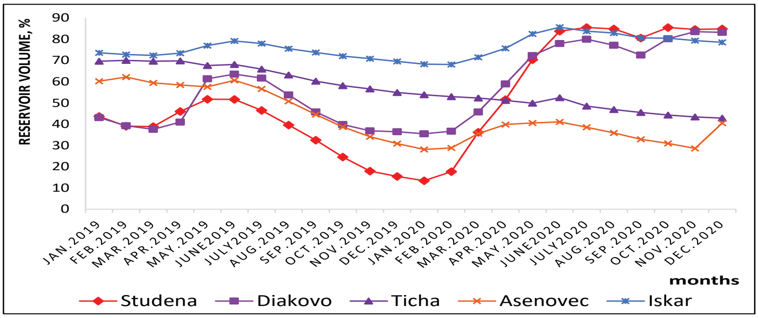

Fig. 10. The degree of filling of the dams for drinking water supply (2019 – 2020)

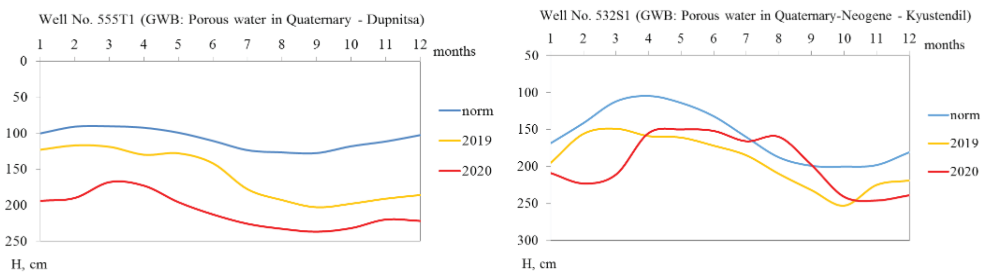

Fig. 11. Groundwater levels (H) changes of the porous waters in Struma River basin for the period 2019 – 2020

The surface water release formed on the territory of Bulgaria in 2019 is 11-12 million m³ and about 50% lower than for 2018. The volume of weed for 2020 is the smallest for the last 5 years. Compared to the driest years in the period 1961-2019 (1968, 1985-1990, 1992-1995, 2001, 2011 and 2019), which have annual run-off volumes in the range of 6312-12924 million m³, the volume in 2020 is closest to 1989 and 1992, with annual volumes of 9700.5 and 11063.1 million m³ respectively.

As part of the overall assessment of drought periods, a trend analysis of the monthly reduction of the groundwater storage in Bulgaria according to operational monitoring data has been performed by three-point scale applied – Table 3.

The results show that during both years 2019 and 2020, groundwater storage has decreased with a very well-marked monthly tendency in most cases. This means that for more than 70% of the observed cases of different types of groundwater throughout the country, a decrease in levels and spring flows has been registered according to their norms for the considered month. In addition, in both years there is a predominant tendency to reduce (over 80% of the observed cases) the groundwater storage during the autumn-winter period.

Table 4. Monthly trends of groundwater storage reduction in Bulgaria, according to operational information for the period 2019-2020

Months	2019 year	2020 year
January	well-marked trend	predominant trend
February	very well-marked trend	predominant trend
March	very well-marked trend	very well-marked trend
April	very well-marked trend	very well-marked trend
May	very well-marked trend	very well-marked trend
June	well-marked trend	very well-marked trend
July	very well-marked trend	very well-marked trend
August	very well-marked trend	very well-marked trend
September	predominant trend	predominant trend
October	predominant trend	very well-marked trend
November	predominant trend	predominant trend
December	predominant trend	predominant trend

The Minister of Environment and Water convenes the Supreme Advisory Council on Water (SCCS) and the MoEW takes measures to ensure the drinking water supply for the reservoirs with a reservoir volume below 50%. As of December 2019, these are: res.”Studena”, “Dyakov”, “Asenovec”, “Ticha”. The measures of the MoEW after November 2019 are adequate but, as apparent from Figure 10, do not immediately produce a result. It takes time for rainfall and snow melting to form an influx, fill the dams and nourish groundwater.

In September 2020, the critical areas are also a number of reservoirs for irrigation and water supply – “Koprinka”, “Zrebchevo”, “Yastrebino”, “Tcha”, “Asenovec”, “Kamchia”. This imposed a re-meeting of the SCCS and urgent measures.

4. CONCLUSIONS

Hydrological drought depends on the meteorological conditions, but the severity of drought’s impact depends on the river basin specifics - the size of the catchment, regulating volumes, reservoirs, aquifers, vulnerability of water supply systems and measures applied throughout the previous phases. The Article 4.6 of the Water Act allows temporary deterioration of the status, occurred as a result of so called "prolonged drought".

The research is related to the system of drought indicators developed at NIMH (http://hydro.bg, SPI, SRI, SMI) and its improvement at River Basin level. A new approach for integrated analysis of the indices of the NIMH system, the indicators used by the Ministry of Environment and Water - inflow and levels of reservoirs, groundwater storage trends, etc., has been developed. Thus, from the first months, the so-called hot spots and critical areas are identified - reservoirs, watersheds and river basins for which indicators identify drought and/or whose regulatory capabilities have declining potential and are at risk in the event of prolonged drought.

The proposed indicator system has been successfully applied. The results of the experimental application of the integrated analysis confirm that the reservoirs and groundwater can be considered as an important part of the Indicator systems for prolonged drought identification.

The result of the correlation between the SRI and SPI indices confirms the development regularities for the drought process in space and time – both: correlation and the transition from meteorological to hydrological drought are clearly identified, as well as the expected hydrological drought phase lag over time. The analysis of the correlation between the indices is a long process and the time scale should be chosen depending on the characteristics of the basin.

Although 2019 and 2020 are not the driest years, during the period, we have a prolonged drought, manifested in all components of the hydrological cycle: river runoff, reduced inflow and available volume in dams, reduced groundwater storage, water scarcity. The measures taken in the period 2019 - 2020 by the MoEW correspond to the good practices in developing the Drought Management Plans (DMP). If they are taken in time they will give faster results.

The results of the experimental application of the integrated analysis and the indicator system, show that the approach helps decision-makers to implement timely measures. The analysis should also take into account the critical thresholds of SPI3 and SMI established by NIMH experts, where hydrological drought most often occurs (SRI). The approach supports the operational application of the NIMH drought indicator system in the practice of the MoEW and the DMP realization.

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