Dimitrov, I., Ljubenova, K., Vuchkov, B., Rankova M. (2025), Hydrological drought monitoring and characterisation, application for drought early warning system in yantra river basin in Bulgaria, pp. 65-72. In Gastescu, P., Bretcan, P. (edit., 2025), Water resources and wetlands, *7th International Hybrid Conference Water resources and wetlands, 10-14 September 2025, Tulcea (Romania)*.
Available online at http://www.limnology.ro/wrw2025/proceedings.html

7th International Hybrid Conference Water resources and wetlands, 10-14 September 2025, Tulcea (Romania)

HYDROLOGICAL DROUGHT MONITORING AND CHARACTERISATION, APPLICATION FOR DROUGHT EARLY WARNING SYSTEM IN YANTRA RIVER BASIN IN BULGARIA

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Abstract. Hydrological Drought propagation has a different direction in scarcity and spatial attitude. Drought monitoring and drought characterisation helps us to find the tendency in development of that process more precise. This is important in the field of water management and agriculture in drought conditions. The better understanding and earlier disclosure, the better results for hydrological drought mitigation and adaptation are provided. The goal of the study is to propose risk assessment hydrological indices and complex indices modular system to find when/if and where drought development conditions probability occur, by daily variable threshold method, statistical methods and maps used. This system includes deficit volume toward the adopted threshold levels, magnitude, drought duration and temporal statistics, for the river main course and its tributaries, presented with colour codes scales schemes, graphs, tables and maps, that gives us an objective estimates and appraisals for drought declaration process and water resources restoration required after episode of prolonged drought. The results of the investigation and proposals made in Yantra river pilot watershed, should be part of more comprehensive Drought Early Warning System (DEWS) in Bulgaria. The annual minimum runoff varies widely - below 4 m^3/s and above 20 m^3/s. The occurrence of minimum runoff is possible at almost any time of the year, with most cases between 240th and 300th day of the year. Actual hydrological droughts duration reach over 350 days and deficit volume below -28 m^3/s per day. Finally, maps and tables are used to visually present the synchronicity of drought development in a watershed, which can be used for drought forecasting, adaptation and mitigation purposes.
Keywords: indices, variable threshold, deficit, duration, probability, early warning

1. INTRODUCTION

Monitoring the processes related to river droughts is of paramount importance for adaptation and mitigation of the consequences and faster recovery after a prolonged period of drought. Monitoring allows the detection of conditions for the formation of a hydrological drought and the categorization of the risk of severe drought. It includes a system of indicators and indices that assess changes in the hydrological cycle of the region. The characterization and typification of a given event is necessary in connection with the optimal use of water resources in conditions of deficit, to balance the interests of competitors in a tense atmosphere and conflict of interests.

Droughts are a natural process, but they can also be caused by human activity. When studying hydrological drought, this requires first establishing the genesis of the phenomenon and its beginning. In addition, the presence of low (minimum) runoff may be part of the drought period, but the occurrence of minimum runoff does not always mean "drought". This runoff is a complex system of cause-and-effect phenomena that vary indefinitely in space and time. The direct impact of man on the river regime is carried out in two directions: the creation of reservoirs to regulate the river runoff and the withdrawal of part of the river's water for irrigation, water supply, industrial and other needs or vice versa - the release of water to the river from neighboring catchment areas. Reservoirs redistribute the runoff and influence the maximum and minimum water quantities. Before making a decision on a design drought, the parameters of which are to be evaluated, under the adopted criteria, it is necessary to conduct a preliminary study of all periods of drought during the available period of the hydrological series and establish the local natural and geographical features that determine the redistribution of precipitation. Droughts of river systems are a regional or local phenomenon that develops at different speeds. "Drought" and "Hydrological drought" are concepts describing a phenomenon that does not have a precise starting date and time of occurrence and does not have a precisely defined territorial scope, which is why it is necessary to adopt criteria to establish whether/since when a given territory has experienced this phenomenon and to what extent. Hydrological droughts occur in both traditionally wet and dry periods of the year and can have different impacts in strength and direction. Low waters are usually observed during drought, but they include only one element of drought, i.e. the magnitude of the drought.

A prerequisite for good hydrological water management is a thorough understanding of the drought. Hydrological drought (below normal runoff) is more heterogeneous in space and time than meteorological drought. This is due to significant connections with preconditions, which are crucial for understanding and assessing the development of drought, spreading from meteorological through hydro-meteorological to hydrological drought.

Several researchers, including Mishra and Singh (2010), Cloke and Hannah (2011), and Pozzi et al. (2013), emphasize that hydrological drought has not received sufficient attention despite its strong connection to the societal and environmental impacts of drought events.

Pozzi et al. (2013) highlight the importance of developing a global drought early warning system. They identify several key obstacles that currently limit progress, including inadequate in situ monitoring networks, limited seasonal forecasting capabilities in many regions, and insufficient infrastructure for converting data into actionable information. The authors also stress that hydrological drought is a complex phenomenon that requires the monitoring of multiple variables in order to accurately assess its evolution and its effects across different water-dependent sectors.

Some large-scale investigations into the influence of climate variability and change on hydrological drought include the work of Van Lanen (2006) and Van Loon et al. (2012). Distinguishing between different types of hydrological drought is essential for robust statistical analysis, reliable attribution of observed changes, and improved prediction of drought development and recovery processes. However, the proposed classifications and approaches require further validation across a broader range of catchments, particularly to assess their applicability in operational and decision-making contexts.

Recent research by Bozhilova (2024) highlights the relevance of water problems in the Yantra River catchment. It reveals the spatio-temporal dynamics of the river outflow whithin the boundariesof the river catchment through various approaches and methods.

In modern science of resource management in drought conditions, the so-called "Three Pillars of Drought Management" have been identified: 1. Monitoring 2. Risk Impact Assessment 3. Preparedness and Response to Reduce Risk. The aim of the article is to show the practical use of hydrological droughts characterization methods at local level to modular drought indices system creation to fulfill these three tasks. The results will serve for the creation and justified implementation of an operational Early Warning System for hydrological drought on the NIMH website.

2. METHODS

The "threshold" method is the most commonly used quantitative method for hydrological drought, where it is essential to determine the beginning and end of the drought. The threshold can be fixed or vary (variable) during the year (Tallaksen L., H.A.J. van Lanen, 2004). A variable threshold is a threshold that changes during the year, for example by using a seasonal, monthly or daily variable threshold level. The variable threshold approach is adapted to detect water flow deviations during both high and low runoff seasons. Periods of lower than normal water flow during high runoff seasons can be important for later drought development. The values for Q_{dvp70} (daily variable threshold for 70% quantile) were selected and difference between the threshold and measured river water quantity represent the deficit volume in real time. The vulnerability of rivers to hydrological drought is determined by the period T_d, which takes the flow to fall from the starting level Q_{ms} to below the drought threshold, Q_d. The shorter the time, the greater the risk that the area will be affected by drought if the dry meteorological signal prevails for a long period of time.

The natural groundwater reservoir is not filled to its highest level when an extended atmospheric dry signal occurs over the entire catchment. In addition to Q_{ms} and Q_d, it is necessary to be indexed and determined from the measured water quantities and the characteristic average recession behavior in order to assess the vulnerability to drought of unstudied catchments.

During a prolonged dry spell, it is often observed that the flow exceeds the threshold level for a short period of time, and thus a large drought is divided into several small droughts, which are, however, interdependent. To avoid these problems, which could distort the modeling of extreme values, a consistent definition of drought events should include some kind of pooling to define an independent sequence of droughts (e.g., a moving average procedure; a moving average window of ten days is recommended). To reduce the problem of insignificant droughts, a minimum drought duration may be required that eliminates droughts with a duration of less than a specified number of days (here, d_{min} is set to 5 days). The time between events criterion is used to pool dependent droughts that are separated by a short period of runoff above the threshold. If the time between two droughts is less than a critical duration, t_{min}, the two events are pooled. In this work, t_{min} is equal to two days. In this way, a variable threshold can be used to define periods of deficit, as deviations or anomalies from the normal seasonal or daily range of the river. A daily varying threshold level can be defined as the probability of exceeding the 365-day supply curve.

Since there is no universal indicator for assessing the vulnerability and magnitude of drought periods and their consequences, the method with a system of indices (Rossi, 2011; Ilcheva, I. et al. 2022), adapted with a set of excel calculated hydrological indices. The need to homogenize the indicators into a dimensionless numerical value that can quantify the current situation in relation to historical series and allow for quantitative comparison between the selected indicators and river systems.

3.RESULTS

The source of the Yantra River is located in the Shipka section of the Central Stara Planina above the town of Gabrovo. The length of the river is 285.5 km with a catchment area of 7861.6 km^2. Its main tributaries are the Lefedzha River from the east and the Rositsa River from the west. They flow into the Yantra River north of the Veliko Tarnovo Heights. About 20 km further on is Hydrometric Station (HMS) No. 23850 Yantra River – Karantsi Village, southwest of the town of Byala (Fig. 1). The average river flow (1974-2019) at this point is 45,284 m^3/s with a minimum average annual flow of 9,911 m^3/s for 1994 and a maximum average annual flow of 128 m^3/s for 2005. The absolute minimum flow is 1,299 m^3/s as of September 30, 1985. The absolute maximum flow is 1,890 m^3/s as of July 5, 2005.

The years with the largest drop in water levels, 1985-86, 1994 and 2001, had annual minimum quantities (AM1) below 5 m3/s and the largest daily deficits of runoff were recorded compared to the accepted variation threshold, and with a probability of 10%, below -25 m^3/s (2.16 million m3). The exception is 2007, which did not have an extremely low runoff, but at the same time was one of the driest years, with one of the largest deficits of runoff (-22.005 m^3/s) and a number of dry days (214 days) below the established daily norms. In 2002, the deficits were also large, but for a short period, before the end of winter.

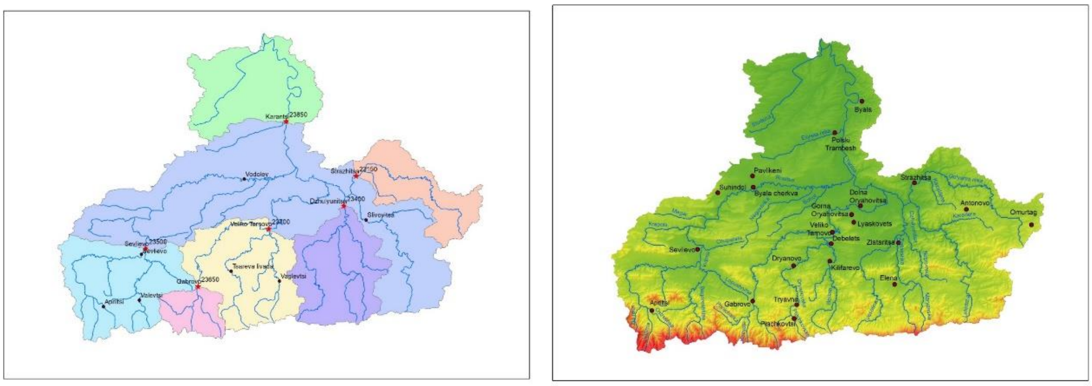

Figure 1. Map of the Yantra River catchment area with the main tributaries and location of the 6 HMS (Hydrometric station) used

The annual minimum runoff varies widely with cases of values both below 4 m^3/s and above 20 m^3/s (Fig. 2). Its study is related to periods of hydrological drought, but not every manifestation of the annual minimum water quantity can be qualified as a drought phenomenon. Half of the cases have a measured runoff below 12 m^3/s, and in 20% it is below 6 m^3/s (Fig. 3). Depending on the objectives of the study and the season of occurrence, a given value can be interpreted as a drought, but depending on the accepted criteria, the same value can also be accepted only as a manifestation of low runoff.

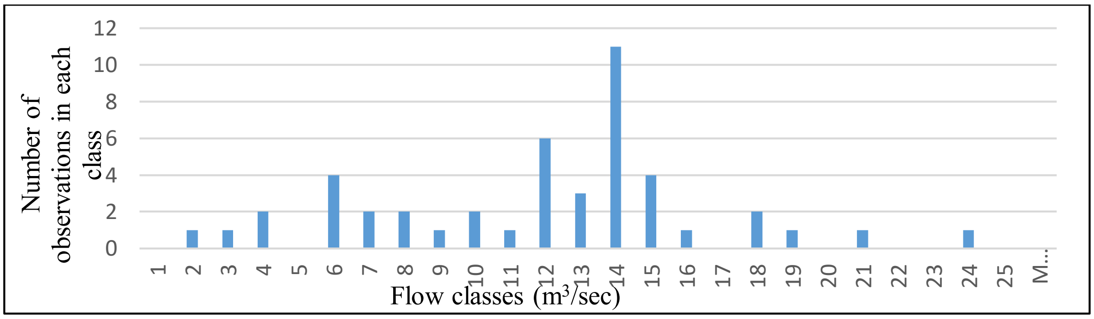

Figure 2. Histogram of the annual minimum runoff

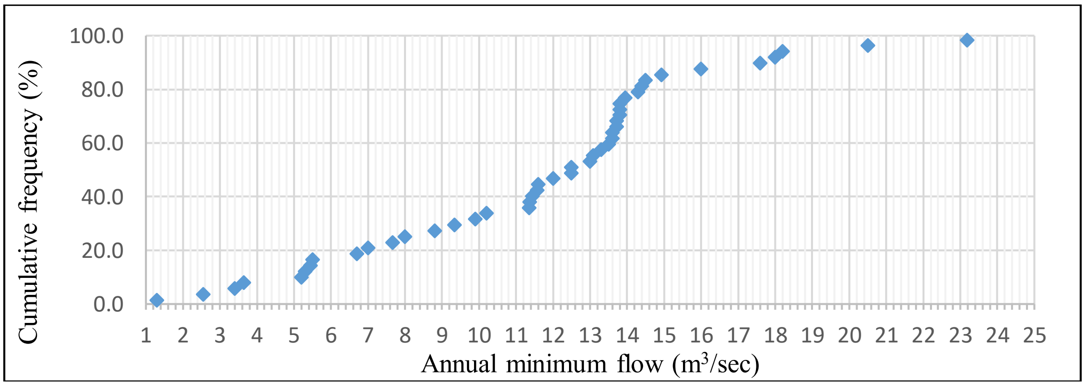

Figure 3. Probability of occurrence of minimum runoff

The occurrence of minimum runoff is possible at almost any time of the year (Fig. 4), with the highest number of cases observed after the 210th calendar day of the year and before the 60th day. By quarter, the number of registered annual minimums is as follows: 0-60 days – 9 cases; 60-120 – (1); 120-180 – (2); 180-240 – (4); 240-300 – (16); 300-365 – (14).

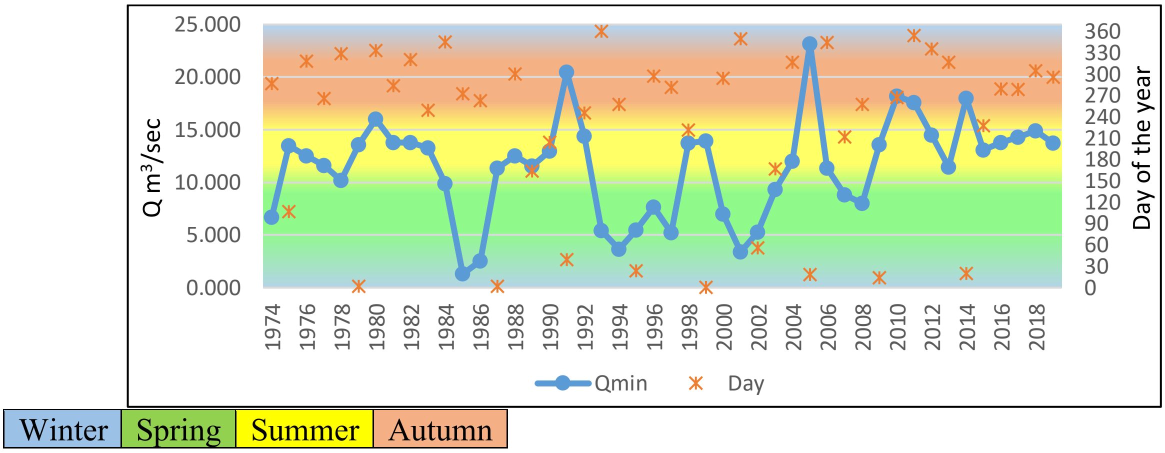

Figure 4. Minimum water quantities - season and calendar day of the year

The entire spectrum of drought duration is observed in the Yantra River catchment area towards Q_{dvt70} (daily variable threshold), (from single dry days; through minor; rapidly developing droughts lasting less than a month; longer multi-seasonal droughts and interconnected individual droughts forming the so-called "prolonged drought") (Fig. 5). The largest number of individual droughts are in the range between 10 and 20 days - a total of 49. In 83% of cases, droughts are shorter than two months and 10% end by the sixth day (Fig. 6).

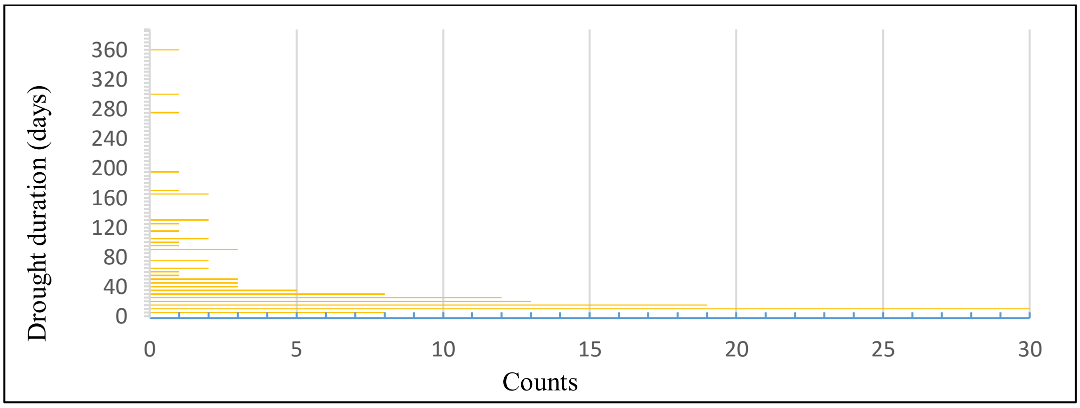

Figure 5. Histogram of hydrological drought duration periods in days, compared to the adopted threshold Q_{dvt70}, criterion for at least 5 consecutive days with deficit and interruptions (separation) between dry periods of high waves up to 2 days. Single dry days and periods shorter than 5 consecutive days are not considered

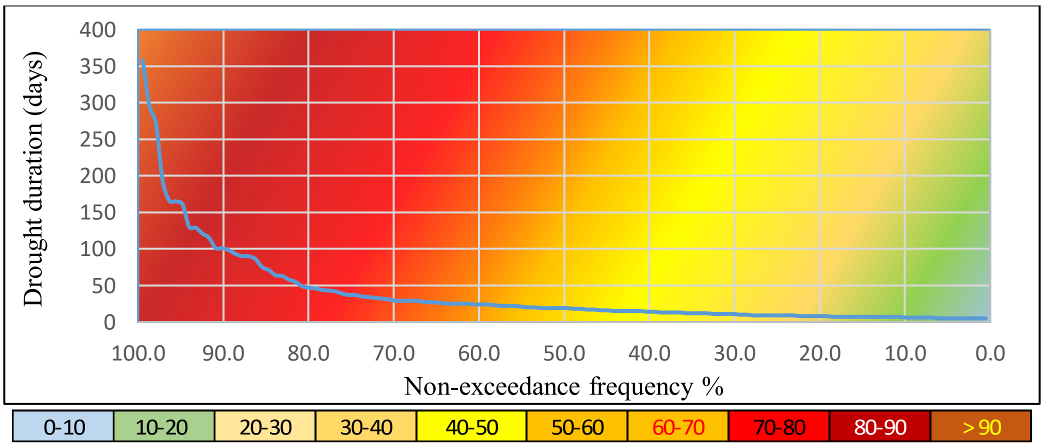

Figure 6. Actual hydrological droughts duration

One of the main characteristics – the deficit water volume, relative to the threshold, characterizing the intensity of a given event shows that in half of the cases it is possible to have one below -10 m^3/s, and in 10% of the years no days below Q_{dvt70} are observed (Fig. 7). In addition, the methodology also assumes the presence of two main types of hydrological drought – by minimum runoff and by deficit relative to the selected threshold of Q_{dvt70}. They can pass from one type to another depending on the duration of the drought and in turn are divided into other types depending on the manifestation of individual factors, characteristics, accepted criteria and the presence or absence of short-term high waves.

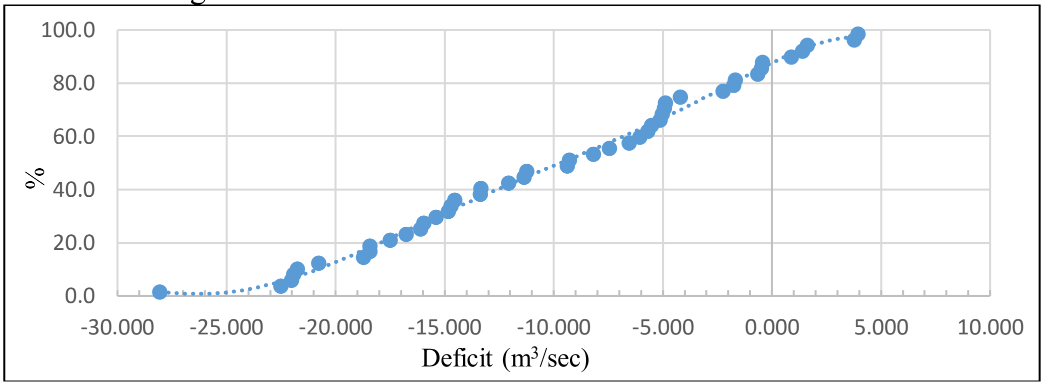

Figure 7. Annual maximum volume of average daily deficit

4. DISCUSSION

The Drought Early Warning System (DEWS) consists of Modules for the individual characteristics and hydrological indices inherent to each HMS, as well as for the joint consideration of the calculated values of practical interest. During the formation of a drought, the so-called "dry signal" is sometimes observed with a gradual deterioration of hydrological conditions in one or several river basins, as well as a regional manifestation of the drought with similar characteristics (Tables 1 and 2).

The results, in addition to graphical and tabular form, can also be presented in the form of maps (Fig. 8), and other statistical parameters can be extracted, such as: cumulative percentage of affected area; percentage of area by drought categories; cumulative area; area by categories; affected population - cumulative; categories of population in drought areas, etc.

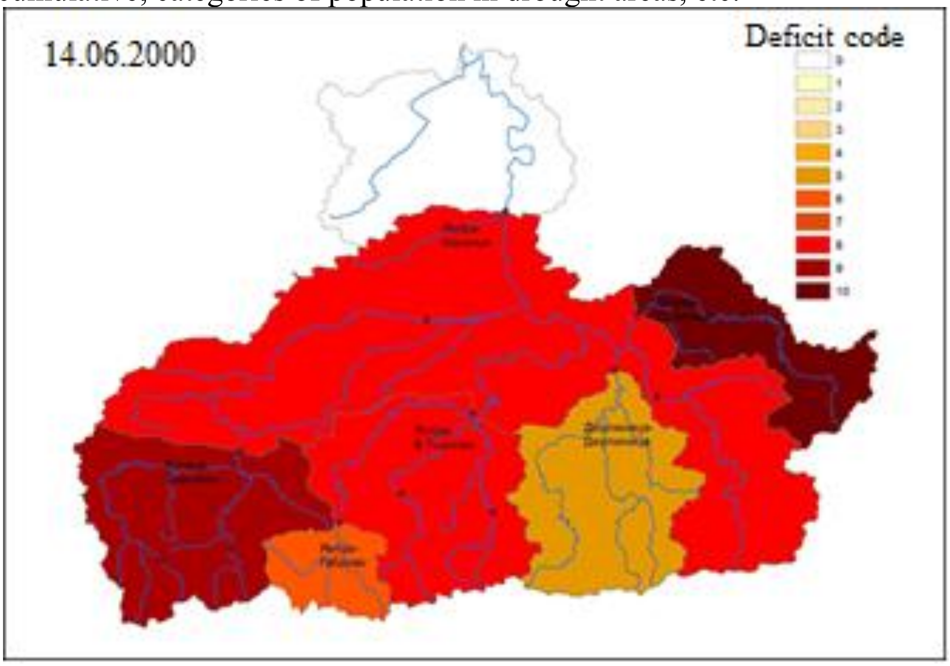

Figure 8. Hydrological situation for one day (14.06.2000) with the degree of drought, for a rapidly developing hydrological drought with a start date of 03.06.2000 and an end of the drought after 92 days with Q_{min} 8.328 m^3/sec on day 89 (no data for the catchment before the inflow, but regionalization is possible)

Table 1. Example segment (February – March. 2007) for dry signal and onset of hydrological drought, with coding scheme for Q relative to minimum runoff; Deficit; Duration of the phenomenon and Amount of the deficit volume for HMS No. 23400 - Dzhuliunitsa River

Year	Date	Day	Threshold	Flow	Deficit	Duration	Deficit sum
2007	15.Feb	46	4.488	26.243	21.755	0	
2007	16.Feb	47	4.526	14.290	9.764	0	
2007	17.Feb	48	4.596	10.235	5.639	0	
2007	18.Feb	49	4.676	7.836	3.160	0	
2007	19.Feb	50	4.761	6.462	1.701	0	
2007	20.Feb	51	4.808	6.194	1.386	0	
2007	21.Feb	52	4.855	5.400	0.545	0	
2007	22.Feb	53	4.898	4.844	-0.054	1	-0.054
2007	23.Feb	54	4.902	4.570	-0.332	2	-0.385
2007	24.Feb	55	4.913	4.844	-0.069	3	-0.455
2007	25.Feb	56	4.931	4.034	-0.897	4	-1.351
2007	26.Feb	57	4.919	3.277	-1.642	5	-2.994
2007	27.Feb	58	4.914	3.040	-1.874	6	-4.867
2007	28.Feb	59	4.916	3.040	-1.876	7	-6.743
2007	1.March	60	4.979	3.040	-1.939	8	-8.681
2007	2.March	61	5.025	2.830	-2.195	9	-10.876
2007	3.March	62	5.058	3.040	-2.018	10	-12.894
2007	4.March	63	5.085	3.040	-2.045	11	-14.939
2007	5.March	64	5.153	2.830	-2.323	12	-17.263
2007	6.March	65	5.239	2.630	-2.609	13	-19.872
2007	7.March	66	5.342	2.630	-2.712	14	-22.584
2007	8.March	67	5.449	2.630	-2.819	15	-25.403
2007	9.March	68	5.534	2.630	-2.904	16	-28.306
2007	10.March	69	5.579	2.439	-3.140	17	-31.447

Probability
1.0
5.0
10.0
25.0
30.0
50.0
70.0
75.0
90.0
95.0
99.0

Table 2. Example segment of the beginning phase of the hydrological drought in June 2000 in the Yantra River catchment with a color-coded scheme with characteristic quantiles determined by the frequency characteristics for each river basin

Year	Day of the year	Date	23500 Rositsa - Sevlievo	23650 Yantra - Gabrovo	23700 Yantra - V. Turnovo	23850 Yantra - Karantsi	23400 Dzhulunitsa - Dzhulunitsa	23150 Golyama - Strazhitsa
2000	153	2.June	8.388	3.008	2.212	6.687	5.564	0.696
2000	154	3.June	1.947	0.709	-1.955	3.734	2.712	0.680
2000	155	4.June	-1.498	0.127	-3.438	1.309	1.494	0.475
2000	156	5.June	-1.922	-0.083	-3.626	0.056	1.143	0.671
2000	157	6.June	-3.022	-0.451	-3.621	-3.390	0.962	0.471
2000	158	7.June	-3.284	-0.418	-3.576	-4.560	0.582	0.047
2000	159	8.June	-3.235	-0.539	-3.516	-5.462	0.391	-0.213
2000	160	9.June	-3.451	-0.639	-3.702	-5.740	0.005	-0.367
2000	161	10.June	-3.604	-0.618	-3.626	-7.144	-0.169	-0.496
2000	162	11.June	-3.483	-0.587	-3.493	-7.922	-0.411	-0.528
2000	163	12.June	-3.546	-0.565	-3.562	-8.655	-0.343	-0.582
2000	164	13.June	-3.431	-0.646	-3.659	-9.350	-0.434	-0.571
2000	165	14.June	-3.382	-0.615	-3.760	-9.604	-0.518	-0.565

Probability
1.0
5.0
10.0
25.0
30.0
50.0
70.0
75.0
90.0
95.0
99.0

5. CONCLUSIONS

The complex interplay of different processes and their effects create a complex hydrological situation when a drought occurs. Identifying, defining and assessing the impacts of different types of drought ("prolonged drought", "flash" hydrological droughts or short-term deficits, shorter than a month), supports more effective recovery of the economy and water resources. Ensuring frequent analysis of the manifested characteristics of droughts is crucial for ensuring an early warning system that monitors, assesses and provides appropriate information on hydrological conditions and trends at the relevant stage of the drought cycle and whether and how much the phenomenon is progressing.

The hydrological indices system is sensitive to the slightest changes in one direction or another of the intra-annual regime of the rivers in the region. Short-term droughts, less than 10 days, occurring in a certain vegetation or biotic period, can be dangerous, due to the possible mass extinction of river fauna, which without a daily early warning system cannot be predicted fast enough and mitigated the consequences, according to preliminary adopted and approved measures from drought management plans, corresponding to the warning code and the significance of the drought. Not all dry periods are droughts; there must be a justification for the process of declaring a hydrological drought. It should be taken into account whether the phenomenon is due to negative effects acting simultaneously (low rainfall, high temperature, etc.) or is part of a cascade type of extreme events (heat wave leading to soil drying, forest fires, crop failure, food shortages, poor health, etc.), and also whether it occurs due to illegal water abstractions or losses in the water supply system.

The drought monitoring system with its different modules collects applicable operational and model data, aiming to provide information to water users on the current status of the drought. The evolution of the indicator system allows monitoring the variations of hydrological droughts over time. In this context, ordinary water users tend to prefer short-term information (for the next few weeks), while authorities are interested in longer-term information (from one season to the next).

Proactive activities and improved drought monitoring and forecasting, as well as public participation, are key elements for addressing future episodes of prolonged hydrological drought.

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