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Analysis of droughts due to the operation of water structures: Gidra river case study

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Pollack Periodica • An International Journal for Engineering and Information Sciences

17 (2022) 1, 111–116

DOI:
10.1556/606.2021.00463

ORIGINAL RESEARCH PAPER

Received: June 9, 2021 • Revised manuscript received: August 4, 2021 • Accepted: August 6, 2021

ABSTRACT

The paper deals with an analysis of a drought in the small basin of the Gidra River in Slovakia due to problems with the abstraction of water from small reservoirs and ponds. A detailed hydrological assessment of the M-daily discharges for a long-term period was based on a dataset from the only gauging station on the upper part of the river. Because of the existing water structures with prescribed operations during the year, hydrometric and geodetic measurements were taken by the authors. The solution to this problem represents the conditions for the minimum required Q_{355} discharge in the river anytime and anywhere. This can only be solved with a master operational manual for the whole river to be able to flexibly react to the current hydrological situation.

KEYWORDS

drought, small catchment, M-daily discharges, hydrology, prediction

1. INTRODUCTION

In the context of climate change, the drought balance is coming to the forefront not only of water managers, but especially of people who use water and live close to water. Drought was defined by many authors as e.g., [1] a period of abnormally dry weather long enough to cause a serious hydrological imbalance or [2] a natural phenomenon caused by a lack of rainfall which consequently leads to a decrease in the amount of water in various parts of the hydrological cycle. Drought also means [3] a lack of water in the soil, plants and atmosphere and has consequences for the life of human society.

Drought can be classified [4] as a meteorological drought, a soil moisture (agricultural) drought and a hydrological drought. As a result of the lack of precipitation, there is a decrease in water levels and discharges in surface streams, a decrease in groundwater levels, in lakes, wetlands and in water reservoirs - a hydrological drought begins. This drought represents a decrease in the water yields and a significant deviation [5] from the average status of the natural variability of the water regime of the stream. Hydrological drought is a phase that follows a meteorological drought. Delay between the meteorological and hydrological phases of a drought is different for the surface and ground water. Another major factor that influences the creation of drought, except the climate, is the human activity [6], i.e., water abstraction and operation via reservoirs, what can have a significant effect on the stream-flow in surface water courses, especially in low flow periods.

If the amount of available water resources is not sufficient to meet the requirements of society, we speak about water shortages. Drought and water deficit can cause economic losses in key water-using industries and at the same time can have environmental impacts on biodiversity, water quality, deterioration of water bodies, loss of wetlands, soil erosion, soil degradation and desertification.

Many scientific works have been undertaken concerning droughts, e.g., Yevjevich [7] formulated droughts in mathematical terms as a stochastic process, and Laaha et al. [8], who studied droughts in 2015, where the territory of the Slovak Republic was also included.

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Fig. 1. Gidra River with ponds, reservoirs and the most significant tributaries

A hydrological drought can become a global problem and can include areas that have not encountered this phenomenon before. On rivers subject to water management, this problem then becomes more significant in the modification of the operating manuals of individual water structures.

The drying up of the Gidra River in Slovakia was observed by the inhabitants of the villages around the river. Therefore, the Slovak Water Management Enterprise (SWME), as its administrator, tried to find out where the water was had disappeared, because, despite the measures introduced into the operating manuals of the water structures, they did not bring about the desired effects. Research was therefore undertaken, and measurements were performed on the Gidra River to achieve the same level of the regime as in the past.

2. MATERIALS AND METHODS

In Slovakia, the areas most endangered by droughts are considered to be the lowlands of the Pannonian Basin, which are the most economically used and also the warmest. The Gidra River also belongs to this basin; it springs in the Little Carpathians below Badurka at an altitude of 470 m above sea level [9] and joins the Dolný Dudváh River. Although the Gidra is only 38.5 km long, it feeds several ponds, which are located in the villages of Častá, Cífer and Voderady. The water reservoirs of Budmerice, Hájiček and Ronava are also supplied with water from the Gidra (Fig. 1). The most important tributaries of the Gidra River are the Štefanovský River and Ronava River (the Ronava is dry most of the year).

The only water gauging station on the Gidra River is located above the village of Píla. Despite, and possibly due to several reservoirs, the lower part of the river (the area of the village of Malá Mača, near its junction with the Dolný Dudváh River) is affected by drought [10].

2.1. Field survey and measurements

Based on the previous information obtained from SWME and the inhabitants of the surrounding villages, the first step was a reconnaissance along the whole river (10.10,2019); the Slovak HydroMeteorological Institute (SHMI) (who has the only water gauging station in the village of Píla at km 33.3) provided the following hydrological data: the average M-daily discharges for the reference period of 1961–2000 (Table 1); the long-term average annual discharge for the reference period of 1961–2000: $Q_{a\ 1961\text{-}2000} = 0.298\ \mathrm{m^3 \cdot s^{-1}}$; the daily discharges for the period of 2004–2018, and SWME provided us the operating manuals of all the water structures along the river that affect the water balance in the river.

Other data, like precipitation, soil moisture [11], or the size of the snow cover were not provided.

Afterwards in situ measurements were performed at different periods of the year (10.24-10.25,2019, 11.30,2019, 12.14,2019, 2.12,2020, 11.5,2020) to determine whether the abstractions of the single water structures correspond to the prescribed values of the discharges. The parameters, which were measured by the water structures, i.e., the discharges upstream and downstream (hydrometric measurements of the vertical velocities in single cross sections using the Marsh-McBirney Flo-Mate 2000 flow meter, by which the discharges were evaluated) to determine the quantity of the abstraction and the altitudes of the constructions or sills in the river that ensure the water abstraction for the ponds and reservoirs to verify if they are set up in an appropriate way.

Tables 3 and 4 contain the data processed from the operating manuals and measurements (one example: 11.30,2019).

Explanations of single abstractions:

- Častá fishery – system of ponds – water is diverted by a side abstraction; the water level is increased by a low sill built across the river bed;
- Budmerice water structure and Hájiček pond - a water diversion structure upstream of the Budmerice, which diverts water into the Budmerice reservoir and into the Gidra River; water from the Budmerice reservoir overflows into the Hájiček pond and then back to the Gidra (according to the operating manual);
- Cífer pond - flow-through pond (volume of water, which inflows into the pond and outflows back to the Gidra River on the other side of the pond);

Table 1. Average M-daily discharges for the reference period of 1961–2000, Gidra River, Píla gauging station, provided by SHMI for purposes of this study

Days in year	30	90	180	270	330	355	364
$\mathrm{m^3 \cdot s^{-1}}$	0.698	0.340	0.180	0.106	0.070	0.050	0.030

Table 2. Discharges for single abstractions along the Gidra River prescribed in the operating manuals of each structure, provided by SWME for purposes of this study

		abstraction [$\mathrm{l\cdot s^{-1}}$] in single months of the year												residual discharge in Gidra downstream	
km	water structure	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.	XI.	XII.	Q	$\mathrm{l.s^{-1}}$
30.700	Častá	40	44	76	80	76	72	68	68	68	56	68	68	Q_{270}	122
29.015	Budmerice													Q_{364}	38
	Hájiček	64	64	128	128	128	128	128	128	128	64	64	64		65
16.870	Cífer	8	8	42	42	8	8	8	8	8	8	8	8	Q_{355}	88
15.400	upper Ronava	150	150	150	filling up to the operating level	filling up to the operating level	0	0	0	0	0	150	150	Q_{355}	92
13.800	lower Ronava	300	0	0	0	0	0	0	0	0	0	300	300	Q_{355}	92
11.04010.967	side abstraction Voderady	59–83 (according to the hydrological situation)												Q_{355}	92

Table 3. Measured discharges for single abstractions along the Gidra River (11.30, 2019)

km	water structure	Q ($\mathrm{l\cdot s^{-1}}$)	note	prescribed Q_{bio}
33.300	Píla - gauging station	139		
30.700	Častá upstream side abstraction	131	side abstraction $29\,\mathrm{l\cdot s^{-1}}$	
	Častá downstream side abstraction	102		$Q_{270} = 122\,\mathrm{l\cdot s^{-1}}$
29.015	Budmerice	122	zero abstraction	
	Hájiček	–	it was empty	
16.870	Cífer upstream pond	205	flow-through pond	
	Cífer downstream pond	196		$Q_{355} = 88\,\mathrm{l\cdot s^{-1}}$
15.400	upper Ronava	204	zero abstraction	$Q_{355} = 92\,\mathrm{l\cdot s^{-1}}$
13.800	lower Ronava upstream	143	side abstraction $70\,\mathrm{l\cdot s^{-1}}$	$Q_{355} = 92\,\mathrm{l\cdot s^{-1}}$
	lower Ronava downstream	61		
11.040	side abstraction	5		
10.967	Voderady	68		$Q_{355} = 92\,\mathrm{l\cdot s^{-1}}$
0.000	Malá Mača	36	water was lost	

- upper Ronava - this abstraction serves to fill the Ronava reservoir in the neighboring catchment (built from 1965–1967);
- lower Ronava - this abstraction serves to fill the Ronava reservoir in the neighboring catchment (built from 1988–1992);
- side abstraction upstream of the Voderady weir - this abstraction supplies a small pond in the park of the Voderady manor house;
- Voderady weir - located at rkm 10.967 to increase the water level for the side abstraction at rkm 11.040.

2.2. Analysis of the hydrological data and assessment of the hydrological drought

A minimum residual discharge has to be ensured under a water structure to allow for the general use of the surface waters and to secure the functions of the river and the preservation of the aquatic ecosystems. If it is a question of maintaining the biological balance in the river under the water structure, a minimum (guaranteed, sanitary, biological) discharge is specified downstream of the structure. The permits for the intakes from surface waters are related to the selected values of the M-daily discharges, specifically to $Q_{355\mathrm{d}}$ [12].

An M-day discharge is the average daily discharge reached or exceeded after M days in a selected period (currently, the hydrological representative period of 1961–2000 (according to the SHMI) is approved). The period chosen is usually for one year. If another period is used, this must be stated; for example, the M-day discharges in the growing season. For M-day discharges over a multi-annual period, the symbol M indicates the average time of reaching or exceeding the relevant discharge in the year. Discharges of 330, 355 and 364-days are discharges that occur with a high degree of probability, and, in Slovakia, they are among the most used flow characteristics for low water stages in terms of their utility in the water management practice and in environmental assessments [5].

Hydrological droughts or periods of low flows are a natural part of the hydrological regime of surface water. The surface runoff regime in Slovakia is typically characterized by increased spring runoff, which occurs at a later time in mountainous areas at higher altitudes than in lowland watercourses because of the later melting of snow and reserves of snow, which are also usually larger and are significant factors affecting the spring runoff. Most Slovak watercourses have a period of low flows in the summer and autumn (usually from August to October), and there are significant periods of low flows in mountainous areas in the winter (usually from December to February). A winter low-flow period is primarily caused by precipitation in the form of snow, which does not contribute immediately to runoff in periods of low temperatures (below freezing), and also by the partial or complete freezing of watercourses. This fact has led to the use in drought studies of the concept of the hydrological year, which ensures that precipitation that falls as snow at the end of the calendar year but runs off mainly in the spring is counted towards runoff in a closed time period/year. Different countries use a different definition of the hydrological year; the Slovak hydrological year runs from November 1 to October 31 of the following year. The increased spring runoff is also an important factor for runoff conditions for the rest of the year. Analyses of droughts have shown that in many cases, dry periods in the summer and autumn are preceded by the absence of the usual periodic runoff, especially by a quantitative reduction in runoff in the usually high-flow spring months [6].

Assessments were made of the daily discharges for the period 2004–2018 to see whether the Gidra River also fulfills the conditions above. If so, it would then be possible to predict hydrological droughts according to the flow conditions of the spring months of the current year in the river, which would be a useful tool in the hands of the SWME as the administrator of the river.

A drought assessment was performed according to the SHMI methodology, where in order to ensure the comparability of the discharge data between watercourses with different size characteristics, the computation of the annual average discharges for the hydrological years uses relative values, i.e., the percentage ratio of the average annual discharge (Q_r) and the long-term average discharge for the reference period 1961–2000 (Q_a) for the individual discharge gauging stations to assess dry (Q_r/Q_a in % $\leq$ 89), normal (Q_r/Q_a in % = 90–110), and wet (Q_r/Q_a in % $\geq$ 111) years [6].

3. RESULTS AND DISCUSSION

3.1. Findings resulting from the field measurements

Upon comparing the results from Tables 2 and 3 (as well as verifications by other field measurements), it can be stated that the water content of the Gidra, especially in the lower third of the course, is not sufficient to cover the necessary biological discharges prescribed in the operating manuals of each water structure to be provided under the water structure. It must be ensured that water from the Gidra is taken in permitted quantities and not arbitrarily according to the needs of private pond owners.

Another problem involves the emptying and filling of the Hájiček and Ronava reservoirs/ponds due to fish pond harvesting, which requires a considerable volume of water. Additionally, the Ronava River, which should supply the Ronava reservoir, does not flow downstream of the structure; during all of our measurements, it was totally dry (at the confluence of the Ronava and Gidra rivers). The water content of the Ronava River was also weak in the past; therefore, 2 abstractions (designated in Tables 2 and 3 as the upper Ronava and lower Ronava) on the Gidra were built to supply the Ronava reservoir. According to Table 2, these two abstractions are allowed to take the highest discharge values from the Gidra River.

Previous modifications of nearly all the operating manuals of the water structures along the Gidra River, i.e., reductions of the abstraction discharges and increasing of the minimum discharge (Q_{bio}) downstream of the structure, did not bring about the expected improvement of the water level regime, especially in the lower part of the river. It will therefore be necessary to make predictions about the hydrological situation and, in the case of a low water period or drought, to significantly reduce or even forbid abstractions from the Gidra.

3.2. Findings resulting from the assessment of the hydrological data

The data evaluated shows higher average monthly discharges during the months of January - April (Fig. 2) for the assessed period of 2004–2018, than the rest of the year. It could be stated that if the assessed year does not replicate the trend showed in Fig. 2, there will be a wet (above the trend) or dry year (below the trend). The first four months of the year have the most significant effect on the amount of water in the river for the rest of the year.

Then also assessment of all years for the given period 2004-2018 according to the SHMI methodology were performed (Table 4) to visualized variety of drought and wet to make analysis of impact of hydrology on the drying out of the Gidra River. And also average monthly discharges for drought and wet years were processed (Fig. 3) to confirm presumption about above/below trend from average evaluated data (Fig. 2). Data homogeneity for the long-term average annual discharge for the reference period of 1961–2000: $Q_{a\ 1961\text{-}2000} = 0.298\ \mathrm{m}^3\ \mathrm{s}^{-1}$ is guaranteed by the SHMI, where this Institution takes into account also built up of the water structures on the Gidra River in different time periods.

Table 4 demonstrates that the years 2016, 2017, and 2018 were assessed as dry. This lack of water in the Gidra's catchment could have contributed to the drying out in the lower part of the Gidra River in 2019. The river probably

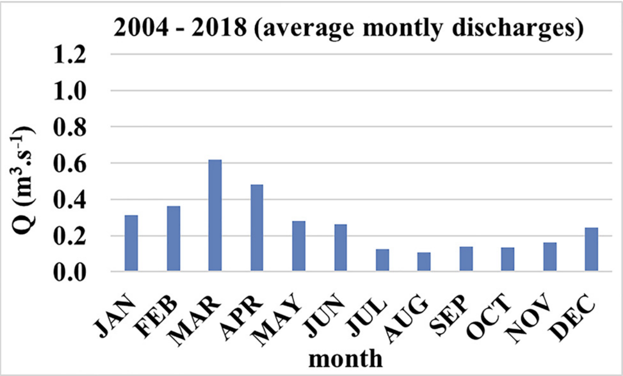

Fig. 2. Graph of the average monthly discharges for the period 2004–2018

Table 4. Assessment of the droughts in the single years for the period 2004–2018 on the Gidra River

year	Q_r ($m^3.s^{-1}$)	$Q_{a\ 1961\text{-}2000}$ ($m^3.s^{-1}$)	$Q_r/Q_{a\ 1961\text{-}2000}$ (%)	assessment
2004	0.265	0.298	89	dry
2005	0.195	0.298	66	dry
2006	0.462	0.298	155	wet
2007	0.187	0.298	63	dry
2008	0.110	0.298	37	dry
2009	0.372	0.298	125	wet
2010	0.554	0.298	186	wet
2011	0.379	0.298	127	wet
2012	0.151	0.298	51	dry
2013	0.348	0.298	117	wet
2014	0.239	0.298	80	dry
2015	0.303	0.298	102	normal
2016	0.220	0.298	74	dry
2017	0.105	0.298	35	dry
2018	0.149	0.298	50	dry

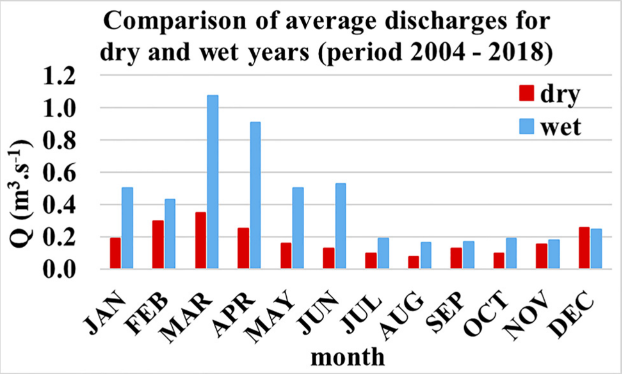

Fig. 3. Graph of the average monthly discharges for the dry and wet years for the period 2004–2018

subsidized ground-waters [13], the level of which was reduced, due to the previous three years of droughts. This statement should be confirmed by the data from ground water monitoring in the future, but in this time the network of the observation bore holes is very poor along the Gidra River and there were no data available for the research parallel to open channel measurements and hydrological assessment. Achieved results are in compliance with research on flood in 2011 on Gidra River, detailed described in [14].

4. CONCLUSION

The operation of water structures includes various procedures based on past experience (when to retain water and when to release it); however, they all depend on the purpose of the water structure. At the moment, there are extremes in the climate, where there is little time to prepare for disasters. Therefore, a predictive hydrological model will have to be increasingly designed, which could be helpful in deciding how to manage water in a given river basin.

In the future, it will therefore be necessary to re-evaluate the operating manuals of water structures for a specific river and harmonize them with an emphasis on hydrological forecasting. Of course, there is often a lack of historical data, or only discharge records, so neural networks could be used to predict whether the coming year will be dry, normal or wet. Based on the evaluated data of the river below the mountains, which was presented in this article, as well as the hydrology of Slovakia (assessed by SHMI), it is clear that the first four months of the year (January - April) are of significant importance for the water content of a river in the foothills. This finding will contribute to the creation of a model for predicting the status of the year (dry/wet), which will help the river manager (SWME) to manipulate the water or reconsider downstream abstractions that are in the hands of freeholders.

ACKNOWLEDGEMENTS

The contribution was developed within the frame of and based on the financial support of the APVV-19-0383 project “Natural and technical measures oriented to water retention in sub-mountain watersheds of Slovakia” and of the APVV-15-0489 project “Analysis of droughts by multi-criterial statistical methods and data mining from the viewpoint of preventive structures in a landscape”.

REFERENCES

[1] C. B. Field, V. Barros, T. F. Stocker, D. Qin, D. J. Dokken, K. L. Ebi, M. D. Mastrandrea, K. J. Mach, G. K. Plattner, S. K. Allen, M. Tignor, and P. M. Midgley, Eds. *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation*, Cambridge, UK: The Intergovernmental Panel on Climate Change, Cambridge University Press, 2012.

[2] Concept for protection against the consequences of drought for the territory of the Czech Republic, Database of strategies, Portal of strategic documents in the Czech Republic (in Czech), 2017. [Online]. Available: https://www.databaze-strategie.cz/cz/mze/strategie/koncepce-na-ochranu-pred-nasledky-sucha-pro-uzemi-ceske-republiky?typ=struktura#sid2402467. Accessed: Jun. 18, 2021.

[3] L. Blaškovičová, K. Melová, J. Poórová, and P. Škoda, “Assessment of the hydrological regime of Slovakia with a focus on the hydrological drought assessment in surface waters” (in Slovak), in *Effective Utilization of Water Resources in the Conditions of Climate Change (Drought and Water Scarcity)*, Slovakia: Bratislava, May 17–18, 2016, oral presentation.

[4] J. V. Vogt, G. Naumann, D. Masante, J. Spinoni, C. Cammalleri, W. Erian, F. Pischke, R. Pulwarty, and P. Barbosa, *Drought Risk Assessment and Management*. Luxembourg: EUR 29464 EN, Publications Office of the European Union, 2018.

[5] Z. Danáčová, L. Blaškovičová, Ľ. Lovásová, J. Poórová, V. Šimor, and P. Škoda, “Hydrological extremes: Modeling and forecasting” (in Slovak), *Acta Hydrologica Slovaca*, vol. 16, Thematic issue, pp. 13–22, 2015.

[6] M. Fendeková and L. Blaškovičová, *Prognosis of Hydrological Drought Development in Slovakia*. Bratislava, Slovakia: Comenius University in Bratislava, Faculty of Natural Sciences, Publishing house of Comenius University, 2018.

[7] V. Yevjevich, "An objective approach to definition and investigation of continental hydrologic droughts," *Hydrological Papers*, no. 23. Fort Collins, CO: Colorado State University, USA, 1967, pp. 1–8.

[8] G. Laaha, T. Gauster, L. M. Tallaksen, J. P. Vidal, K. Stahl, Ch. Prudhomme, B. Heudorfer, R. Vlnas, M. Ionita, H. A. J. Van Lanen, M.-J. Adler, L. Caillouet, C. Delus, M. Fendeková, S. Gailliez, J. Hannaford, D. Kingston, A. F. Van Loon, L. Mediero, M. Osuch, R. Romanowicz, E. Sauquet, J. H. Stagge, and W. K. Wong, "The European 2015 drought from a hydrological perspective," *Hydrol. Earth Syst. Sci.*, vol. 21, no. 6, pp. 3001–3024, 2017.

[9] A. Janík and A. Šoltész, "Flash flood mitigation modeling - case study small Carpathians," *Pollack Periodica*, vol. 12, no. 2, pp. 103–116, 2017.

[10] A. Šoltész, L. Čubanová, and J. Mydla, "Gidra - Water management solution of runoff conditions in terms of minimum discharges" (in Slovak), Research report, Slovak University of Technology in Bratislava, Faculty of Civil Engineering, 2019.

[11] A. Kandra and M. Gomboš, "The importance of volume changes in the determination of soil water retention curves on the East Slovakian Lowland," *J. Water Land Development*, no. 45, (IV–VI), pp. 54–60, 2020.

[12] L. Blaškovičová, K. Melová, Z. Danáčová, Ľ. Lovásová, V. Šimor, and J. Poórová, "Minimum balance discharge in relation to ecological flows" (in Slovak), *Acta Hydrologica Slovaca*, vol. 16, Thematic issue, pp. 23–30, 2015.

[13] B. M. Koczka, Y. Velísková, R. Dulovičová, and R. Schügerl, "Influence of surface water level fluctuation and riverbed sediment deposits on groundwater regime," *J. Hydrol. Hydromechanics*, vol. 62, no. 3, pp. 177–185, 2014.

[14] T. Pindajková, S. Kelčík, and A. Šoltész, "Simulation of flood progress on the River Gidra," *Pollack Periodica*, vol. 11, no. 1, pp. 25–34, 2016.