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ESTIMATES OF THE DURATION OF DEPLETION IN TIME OF THE LIQUID FLOW OF A RIVER IN THE ABSENCE OF PRECIPITATION BY ANALYZING THE DECAY CURVE OF THE FLOW HYDROGRAPH

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ABSTRACT: *Under the current climate change and due to the fact that water resources are limited and under increasing pressure, it is necessary to analyze the problems encountered during periods of scarcity. An analysis of the downward curve of the hydrog,*
raph of streamflow through the behavior of a watershed in the absence of precipitation will determine a forecast of the runoff through rivers. The decline in the flow of a river during periods of low or no precipitation is reflected as a downward curve and defines the drainage or rate of decline. For the planning and management of water resources, as the main source of water supply for Vaslui municipality and adjacent areas is the Solesti reservoir, it is necessary to analyze the downward curve of the hydrograph of the river upstream of the reservoir, the way in which certain processes and groundwater resources re-draw the runoff in the riverbed during dry periods.
Keywords: *liquid flow; hydrograph downslope curve; climate chang; water resources management;*

1. Introduction

Ongoing climate change introduces a number of current and future challenges for human society, where the need to protect water is absolutely necessary, due to its indispensability for life. Climate change superimposed on the domestic demand for socio-economic activities and urban development will put water resources under continuous increasing pressures, making it a finite resource.

Nearly all regions of the world are expected to experience negative impacts on water resources and freshwater ecosystems due to climate change (Intergovernmental Panel on Climate Change (IPCC), 2007). However, the intensity and characteristics of the impacts may vary significantly from region to region. Some regions are likely to face water scarcity and together with increasing demand, this is likely to lead to a significant increase in the number of people at risk of water scarcity [1].

The increasing frequency and intensity of droughts and extreme floods induce in the coming years a risk of shrinking volumes of renewable freshwater resources with negative impacts felt in both economic and social areas.

In the context of continuous climate change, with droughts becoming more frequent and intense, the water cycle in nature (rainfall, surface runoff, groundwater movement and soil moisture) is fully affected.

Delivering water requirements to users with the volume of water stored in a reservoir or directly from the river as a source of supply requires the approach of optimal operating rules taking into account the water resources available at the time as well as the short or medium term forecast of the hydrological regime at the catchment level.

The sustainability of water supply services to water regions during dry periods requires a recognition of the vulnerable areas of a river, especially those with increased variability due to the magnitude and duration of low-water intervals.

An understanding of the groundwater or water table discharge process is also essential in water assessment and basin response studies [2].

The assessment of minimum runoff and drought on rivers characterizing the surface water runoff regime is proposed to be carried out by determining minimum runoff indices according to the methodology described in the "Manual for Minimum Runoff Estimation and Forecasting" (WMO-No. 1029, 2008).

2. Materials and Methods

The determination of the minimum runoff indices will consist in the use of the LFSTAT application package, developed in the RStudio program, based on the procedures documented in the "Manual of Low - flow Estimation and Prediction".

The "Manual of Low - flow Estimation and Prediction" published by the World Meteorological Organization, provides a comprehensive summary of how to analyze river flow data, focusing on minimum flows[2].

The realization of the downward curve of the hydrograph of river flows involves the choice of analytical expressions, derivation and optimization of the parameters of the downward curve of the hydrograph of river flows. The segments of the curve represent certain steps in the downscaling process and depend on the adopted calculation methodology. A reduced length of the segment or a seasonal element occurring on the rate of decline will quantify the accuracy of the decline curve of a river flow hydrograph.

During dry periods, water stored in the basin is removed by ground and subsurface water drainage and evapotranspiration. These processes proceed differently in time and space and are not easy to quantify. The gradual depletion of runoff during periods with little or no precipitation constitutes the drainage or recession rate, shown graphically as a recession curve[3] Figure 1.

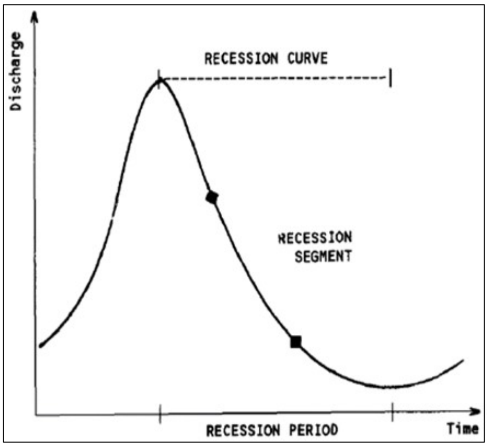

Fig. 1. Decline curve (after L.M. Tallaksen)

Climatic regime, topography and hydrogeology describe the hydrograph descent curves of a river. An elongated curve characterizes a good subsurface supply, whereas a steep curve characterizes fast-flowing rivers with impervious headwaters and limited water storage.

The analysis of the downward curve of the flow hydrograph starts from the identification of an analytical expression that defines the corresponding liquid flow rate at the given time Qt

The equations used to calculate the downward curve of the flow hydrograph are generally given by the following equations:

$$Q_t = Q_{t=0}\exp\left(-\frac{t}{c}\right) \quad (1)$$

$$Q_t = Q_{t=0}\exp(-\alpha t) \quad (2)$$

$$Q_t = Q_{t=0}k^t \quad (3)$$

where: -Qt - the flow at time t

-Qt=0- the flow in the initial phase of the modeled decay curve

-C, α, k - coefficients describing the slope of the decay curve of the liquid flow hydrograph.

Constant C represents the duration of the flow to meicosecrate by half and is given by Eq:

$$C = t_{0.5}/\ln\left(\frac{1}{2}\right) \quad (4)$$

The lack of suitability of this simple equation for a wide range of runoff has led to the separation of the hydrograph decay curve into separate components of runoff, namely, surface, hypodermic and subsurface runoff[4].

In the guide (WMO-No. 1029, 2008) on minimum runoff on rivers, two computational procedures have been described to characterize the hydrograph decay curve of liquid streamflow, as follows:

- Master Recession Recession Curve(MRC), based on the construction of the main hydrograph recession curve.
- Individual Recession Segments (IRS), based on an individual calculation of the segments of the hydrograph recession curve.

3. Case study

The presented case study is given by the numerical estimation of the indices of the decay curve of the hydrograph of the liquid flow in the rivers upstream of the Solesti reservoir, which is the main source of water supply for the municipality of Vaslui and adjacent areas, Fig. 2.

The natural regime of water resources in the vast majority of cases is not in accordance with the requirements of the uses[5]. This aspect is specified in countless studies, which conclude that the south-eastern part of Romania is deficient or presents a high water risk.

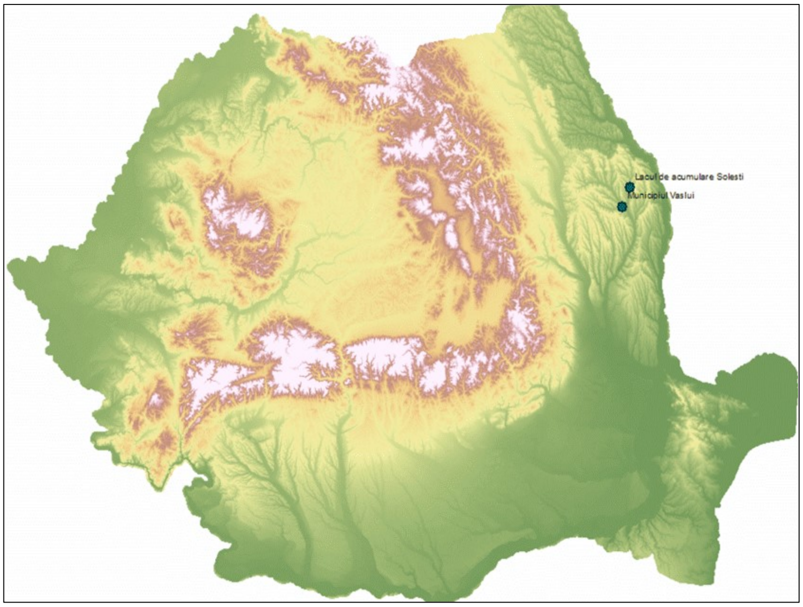

Fig. 2. Study area localization

The numerical estimation of the indices of the hydrograph of the hydrograph of the liquid flows decreasing curve consists in using the series of the mean daily flows over a 19-year period (2005-2023) from 3 hydrometric stations (Table 1), located upstream of the Solesti reservoir, in the Vaslui catchment (Figure 3).

The hydrological year taken into account in the calculation is identified between the two moments of maximum depletion of groundwater stocks, from October 1 to September 30. After October 1, liquid precipitation is considered to replenish groundwater stocks until April 1, followed by their gradual depletion when evaporation begins.

The behavior of a watershed will be represented by the quantification of the decay curve of the hydrograph of the liquid discharge by the 2 procedures (MRC and IRS), developed in the RStudio program, according to the working methodology of the LFSTAT application package, taking into account the following: the threshold Q80 (80th percentile of the duration curve of the mean daily discharge) and a length of the segment of the decay curve, according to the histogram of the decay curve at the given calculation point.

4. Results

Following the loading of the hydrometric data for the period October 1, 2005 - September 30, 2023, from the 3 hydrometric stations in the upper catchment of the Vaslui river, in the RStudio application and the application of the "seglenplot" function, the histogram of the decrease curve shown in figure 4 will result (Figure 4).

Considering that the hydrometric station Codaesti on the Vaslui river represents the control point that defines the liquid flow entering the reservoir Solesti, for the estimation of the indices of the decay curve of the liquid flow (constant C and parameter k), figure no. 5, it is proposed in the first phase, to analyze them according to the

Table 1. Hydrometric stations in the upper Vaslui river basin

Nr. crt.	River	Cadastral code	Hydrometric station	Altitude (m)	Catchment area (km^2)	Specific multiannual average flow (l/s/km^2)
1	Vaslui	12.1.78.16	Satu Nou	270	105	256
2	Vaslui	12.1.78.16	Codaești	252	362	688
3	Dobrovat	12.1.78.16.5	Codaești	245	184	388

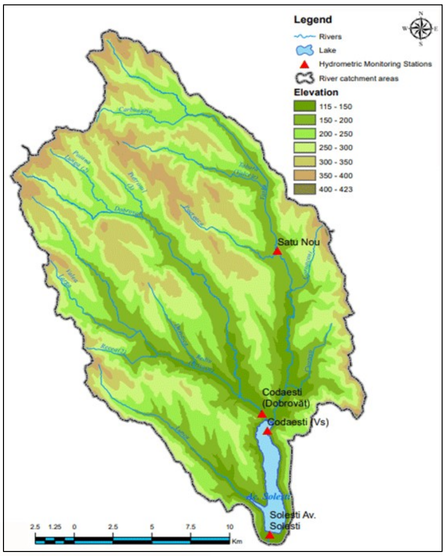

Fig. 3. Hydrometric stations in the Vaslui river basin

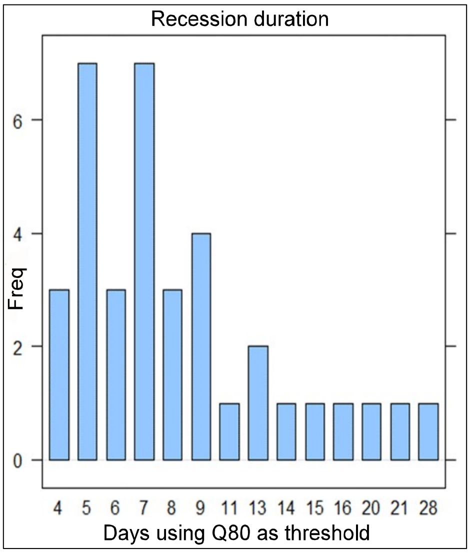

Fig. 4 Histogram of the decay curve at the hydrometric station Codaeşti r. Vaslui

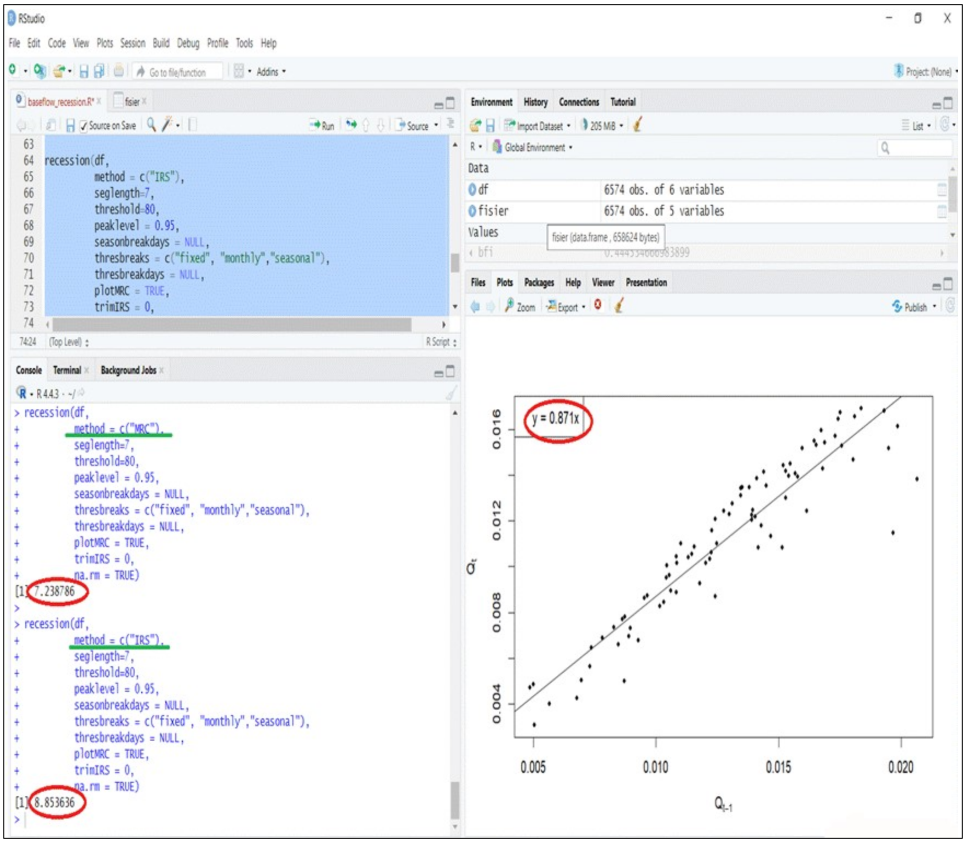

Fig. 5. Determination of constant C and parameter k - s.h. Codaeşti r. Dobrovat

length of the segment of the recession curve on 5, 7 and 9 days respectively by the 2 procedures Master Recession Curve (MRC) and Individual Recession Segments (IRS) Table 2.

Graphical analysis of these correlations is often performed by means of the lower and upper points on the graph, respectively by plotting the minimum and maximum values of the observed

Table 2. Value of constant C

Nr. crt.	River	Hydrometric station	Constant C (days)					
			MRC segment length			IRS segment length		
			5	7	9	5	7	9
1	Vaslui	Codaești	2.5039	5.2724	6.6774	9.5287	9.6363	9.4989
2	Dobrovat	Codaești	6.4355	7.2388	7.9014	8.9284	8.8536	10.3010
3	Vaslui	Satu Nou	7.0990	8.4246	13.0590	54.7420	68.8430	61.6870
Sum			5.3461	6.9786	9.2126	24.3400	29.1110	27.1623

recession rates [6].

The constant C (the duration of the decay curve of the liquid flow hydrograph) represents the potential of a river to maintain its flow. A high value of this constant characterizes a catchment whose river is less influenced by the lack of precipitation and has a substantial groundwater inflow, whereas a low value of the C constant describes a catchment with a low groundwater inflow in the absence of precipitation.

The deviation of the constant C of the hydrometric station from the average determined over the entire catchment is given in Table 3.

the value of the constant C expressed by the 2 procedures, parameter k (slope of the curve) obtained after applying the MRC procedure. The values of the parameter k are in the range [0;1], but the time unit of interest will normally imply a value of k in the upper range, usually k>0.7 (after Tallaksen, 1994).

The values of the parameter k at the 3 hydrometric stations under analysis are higher than 0.8, which proves a very good correlation on the graph of the point pairs (Qt-1,Qt)as well as the appropriate choice of the method of calculation of the hydrograph descent curve of the liquid flow.

Table 3. Deviation of C

Nr. crt.	River	Hydrometric station	Deviation Constanta C (%)					
			MRC			IRS		
			5	7	9	5	7	9
1	Vaslui	Codaesti	53.2	24.4	27.5	7.0	4.4	2.8
2	Dobrovat	Codaesti	20.4	3.7	14.2	2.4	1.6	2.4
3	Vaslui	Satu Nou	32.8	20.7	41.8	47.6	60.4	48.6

Table 4. Hydrograph decay curve indices of liquid flow rate

Nr. crt.	River	Hydrometric station	Altitude (m)	Catchment area (km²)	MRC		IRS
					C(days)	k	C(days)
1	Vaslui	Satu Nou	270	105	8.4246	0.8881	68.843
2	Vaslui	Codaesti	252	362	5.2724	0.8272	9.6363
3	Dobrovat	Codaesti	245	184	7.2389	0.8710	8.8536

Based on these results obtained, Table no. 2, it can be deduced that the smallest deviation from the basin average is the length of the segment of the downward curve of the hydrograph of the liquid flow of 7 days which will be representative for the upper catchment of the Vaslui river.

Table 4. shows the indexes of the decrease curve of the hydrograph of the liquid flow curve,

5. Conclusions

The elaboration of hydrological analyses using historical data from hydrometric stations in the upper catchment of the Vaslui river provides a solid basis for its response to the impact of significant ongoing climate change, in the context that the eastern part of Romania is characterized by a deficit river runoff.

Through the series of daily mean streamflows from the 3 hydrometric stations located in the upper catchment of the Vaslui river, period 2005-2023, with the help of the LFSTAT application, developed in the RStudio program, it was possible to determine the duration of the hydrograph decay curve of the liquid flow hydrograph by the constant C(days) and the slope of the curve by the parameter k.

By analyzing the spatial distribution of the value of the constant C, of the decrease curve of the hydrograph of the liquid flow in the upper catchment of the Vaslui river we can conclude that the rivers are vulnerable to drought in the context of lack of precipitation for a longer period of time due to the low water supply from the underground layer. The correlation obtained by inserting pairs of (Qt-1,Qt)values, so that the flow at one point in time Qt-1is correlated with the flow at a later point in time Qt, has a very high degree of confidence.

We can conclude that the use of modern research programs to characterize the water runoff in a watershed is opportune in view of the rapidity of data provision and their visualization as explicit as possible in different work scenarios.

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