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ASSESSMENT OF WATER RESERVOIR IMPACT ON CHANGING OF DROUGHT INDICATORS OF THE RIVER RUNOFF OF CHIRCHIK BASIN

Annotation: *In the article, first time, river streams flowing into the Chravak reservoir was studied by the standardized stream index (SSI). Initially, the drought indexes of the natural stream of the Chatkal and Pskem rivers flowing into the Charvak reservoir and anthropogenic outflow from the reservoir were estimated separately for the period of 1977-2020 years and their drought characteristics were determined. As a result, the reservoir effect on the river runoff and drought characteristics was estimated. These results can be helpful to assess the state of water resources management.*

Key words: *river, river basin, river stream, drought, meteorological drought, hydrological drought, standardized stream index, reservoir, drought characteristics, drought duration, drought peak value, drought magnitude, drought intensity.*

Introduction. Nowadays, as a result of climate change, human demand for water resources is gradually increasing. Every summer month, people in many places of the world suffer from seasonal drought. In addition, there is an increase in the number of regions where drought frequency and severity is increasing. From hot deserts to cold poles, drought is affecting plants, animals, and people around the world. Studying this phenomena trends in the future and finding ways to prevent them remains relevant.

Drought is a complex phenomenon that can be considered as a manifestation of climate change. There are mainly meteorological, hydrological and agricultural types of drought.

The main sign of **meteorological drought** is a relatively low amount of atmospheric precipitation in a certain period of time. This is combined with other phenomena such as the decrease of surface runoff, seepage, and ground water reserves, as well as high temperature, low relative humidity, and increased flow of solar radiation. All of them, together, lead to an increase in evaporation and transpiration of moisture through plants.

Hydrological drought is characterized by a decrease in water flowing into rivers and lakes, a decrease in their level, and a decrease in groundwater reserves. It is formed in the rivers of Uzbekistan under the influence of low water content, high seasonal air temperatures and low amount of autumn-winter precipitation.

Meteorological and hydrological droughts is assessed by internationally accepted standardized precipitation and stream indices. Standardized precipitation index (SPI) is an indicator of atmospheric precipitation in a certain period of time compared to the long-term norm. Similarly, the Standardized Stream Index (SSI) is understood as the value of the river flow in a certain period of time compared to the long-term flow norm. Indicators revealing its characteristics are determined by drought indices. These drought indicators include the duration of drought, maximum depth of drought, magnitude of drought, intensity of drought etc. The duration of the drought is understood as the drought observed in a certain period of time. The maximum depth of drought indicates the minimum value of SPI or SSI in a certain period, and the magnitude of drought is the sum of SPI or SSI indices of observed drought. The intensity of the drought is understood as the ratio of the magnitude of the drought to its duration.

Taking into account the above, the main goal of this research is to evaluate the changes in river flow, drought index and indicators of the water reservoir.

In order to achieve the goal, the following objectives were defined and solved in the study:

a) Determining the flow of the Chatkal and Pskem rivers flowing into the Charvak reservoir as a natural flow with a drought index;

b) Estimation of drought index of the flow of the Chirchik River, which outflows from Charvak reservoir, considering as an anthropogenic flow;

c) Assessment of anthropogenic drought indicators caused by the effect of the reservoir, compared to the naturally formed drought index, which is flows into Chrarvak reservoir.

Chirchik river and its tributaries - Chatkal and Pskem rivers were selected as research objects. The subject of the study is the assessment of the flow of rivers flowing into and out of the reservoir using standardized drought indeces.

Results and discussion. Based on the objectives of the research, firstly, stream index of the Chatkal and Pskem rivers flowing into the Charvak reservoir for the natural years 1977-2020 (SSI1 to SSI12, SSI18, SSI24, SSI36, SSI48, SSI60, SSI72 , SSI84, SSI96) were estimated. Drought indices of natural and anthropogenic flow for 6-month and 12-month conditions were shown on Figures 1 and 2, respectively.

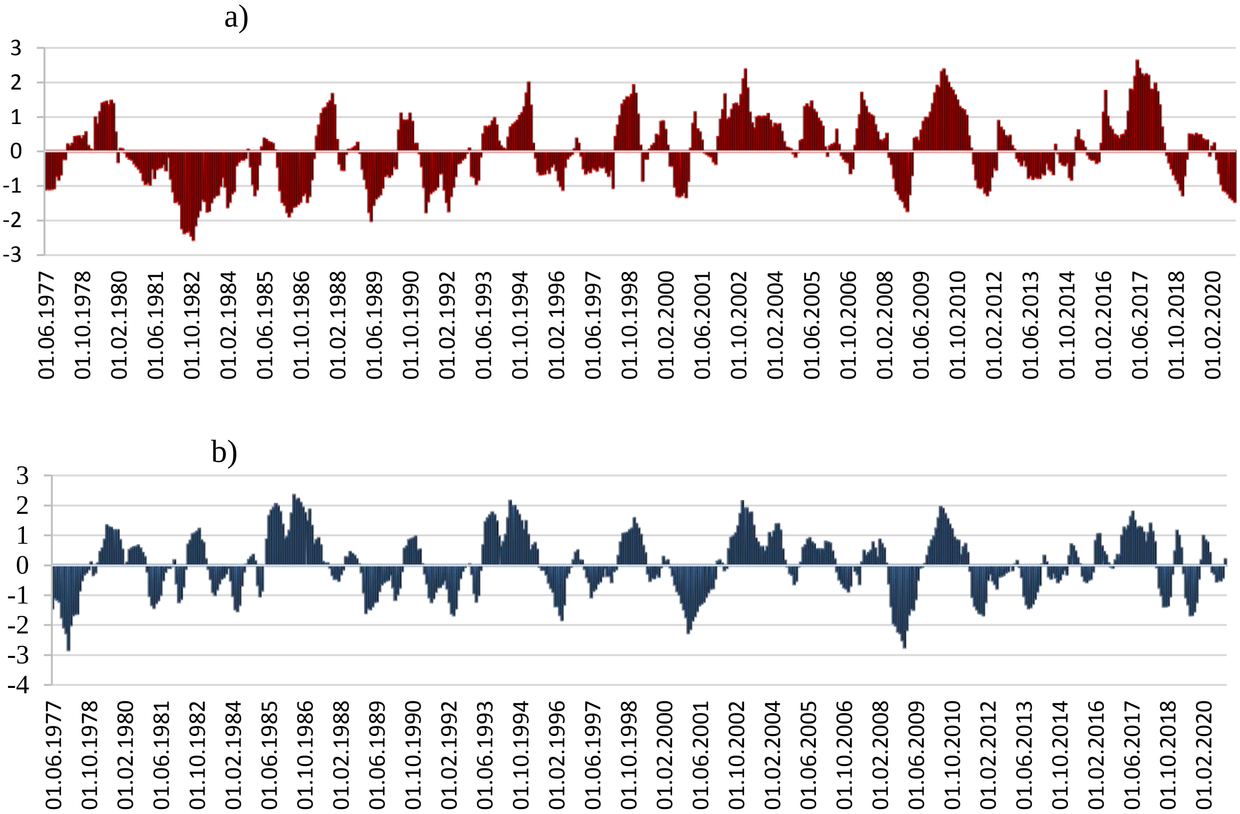


Figure 1. Interannual variation of drought indices of inflow (a) and outflow (b) runoff to Charvak reservoir (SSI6)

In Figure 1a, duration of 6-month drought index of the rivers Chatkal and Pskem flowing into the Charvak reservoir was 33 months in 1982-1984, and it lasted 3 months by 1985 (Table 1). In the last years, 2018-2019, the duration of the drought index was equal to 4 months. It was found that the duration of drought was 130 months during the period when natural flow was observed on SSI6 during the observing years.

In this research 6-month drought indices of the river flow from the reservoir with anthropogenic influence were analyzed. During the observing period, the longest drought was 19 months in 2011-2013 (Figure 1b), and the shortest was 2 months in 1985 (Table 2). The total drought duration was 169 months due to the influence of flow management in the reservoir.

Table 1

Drought indicators of the natural flow of Pskem and Chatkal rivers
for the period 1977-2020 (SSI6)

Drought index indicators						
Start time	End time	Duration, month	Maximum	Magnitude	Intersity	Median
01.06.1977	01.04.1978	10	-1,1	-8,04	-0,8	-0,94
01.02.1982	01.11.1984	33	-2,56	-46,64	-1,41	-1,44
01.02.1985	01.05.1985	3	-1,27	-2,74	-0,91	-1,09
01.01.1986	01.05.1987	16	-1,88	-21,88	-1,37	-1,46
01.03.1989	01.05.1990	14	-2,01	-14,99	-1,07	-1,05
01.04.1991	01.12.1992	20	-1,76	-18,4	-0,92	-1,03
01.05.1996	01.10.1996	5	-1,11	-1,94	-0,39	-0,2
01.03.1998	01.04.1998	1	-1,05	-1,05	-1,05	-1,05
01.06.2000	01.01.2001	7	-1,32	-8,22	-1,17	-1,27
01.07.2008	01.03.2009	8	-1,72	-10,41	-1,3	-1,31
01.07.2011	01.04.2012	9	-1,27	-8,43	-0,94	-1,03
01.12.2018	01.04.2019	4	-1,27	-3,28	-0,82	-0,9
Sum/Mean		**130**	**-2,56**	**-146**	**-1,01**	

Table 2.

Drought indicators of anthropogenic flow from Charvak reservoir
for the period 1977-2020 (SSI6)

Drought index indicators						
Start time	End time	Duration, month	Maximum	Magnitude	Intensity	Median
01.06.1977	01.11.1978	17	-2,82	-22,68	-1,33	-1,44
01.01.1981	01.12.1981	11	-1,42	-8,11	-0,74	-0,99
01.02.1982	01.06.1982	4	-1,23	-3,19	-0,8	-0,92
01.02.1984	01.08.1984	6	-1,53	-6,21	-1,03	-1,17
01.02.1985	01.04.1985	2	-1,03	-1,88	-0,94	-0,94
01.01.1989	01.06.1990	17	-1,59	-15,44	-0,91	-0,86
01.05.1991	01.11.1992	18	-1,66	-15,07	-0,84	-0,8
01.02.1993	01.05.1993	3	-1,21	-2,36	-0,79	-0,99
01.01.1996	01.09.1996	8	-1,83	-8,2	-1,03	-1,33
01.05.1997	01.05.1998	12	-1,07	-5,95	-0,5	-0,46
01.09.2000	01.01.2002	16	-2,25	-21,68	-1,36	-1,3
01.06.2008	01.09.2009	15	-2,74	-23,49	-1,57	-1,64
01.06.2011	01.01.2013	19	-1,67	-14,36	-0,76	-0,51
01.05.2013	01.01.2014	8	-1,43	-9,09	-1,14	-1,2
01.07.2018	01.01.2019	6	-1,38	-6,39	-1,07	-1,19
01.06.2019	01.01.2020	7	-1,66	-8,88	-1,27	-1,3
Sum/Mean		**169**	**-2,82**	**-173**	**-1,01**	

Drought duration indicators of rivers flowing into and out of the reservoir was also analyzed based on the results of SSI12 (Figure 2a). It can be seen from the graph that the highest values of the duration of the drought index in the natural flow flowing into the reservoir corresponded to 47 months, and this value was observed between 1981 and 1985. The drought index in these rivers lasted from January to June 2012, that is, for 6 months. In the subsequent period, there was no high level of drought (Table 3).

The duration of the drought index of the river flowing from the reservoir (Figure 2b) has been changing in different values over the years under the influence of the human factor. For example, in 1977-1979, the duration of drought was 16 months, but by 1989-1990, it was reduced to 12 months. As a result of the effect of the reservoir, a drought duration of 59 months was observed in 2011-2016 (Table 4). This value is considered to be the longest drought month during the operation period of the reservoir. In general, when the drought index with SSI12 was estimated for natural and anthropogenic flow, its duration was equal to 156 months.

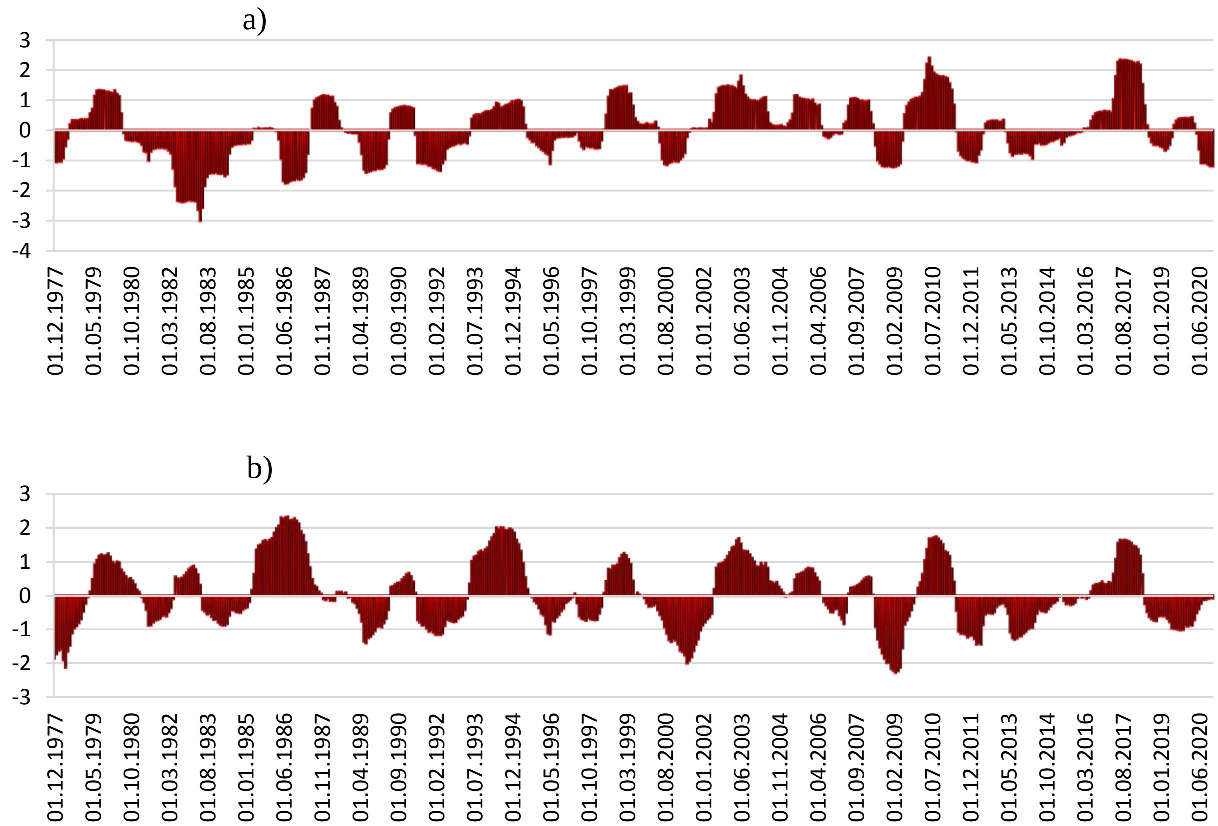


Figure 2. Interannual variation of drought indices of inflow (a) and outflow the Charvak reservoir (SSI12)

The next part of the research was focused on the change of the duration of the drought index of inflow and outflow of the Charvak reservoir under the influence of natural and anthropogenic condition (Figure 3). Drought indices of the Pskem and Chatkal rivers, which flow into the reservoir, and the Chirchik river, which outflows from the reservoir were analysed by the categories of moderate (-1), severe (-1.5) and extreme (-2) values from drought for the time interval from 3 months to 12 months (Figure 3).

Table 3

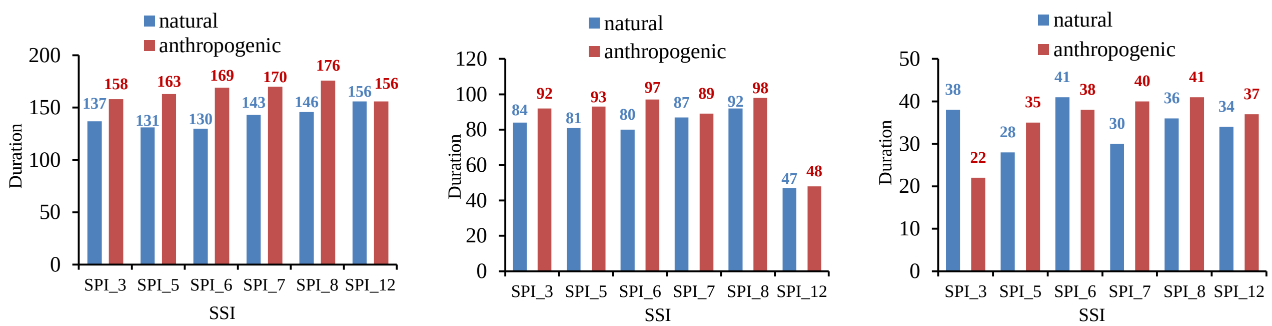
Drought indicators of the natural flow of Pskem and Chatkal rivers
for the period 1977-2020 (SSI12)

Drought index indicators						
Start time	End time	Duration, month	Maximum	Magnitude	Intensity	Median
01.12.1977	01.07.1978	7	-1,06	-5,96	-0,85	-1,04
01.06.1981	01.05.1985	47	-3,01	-61,76	-1,31	-1,4
01.06.1986	01.06.1987	12	-1,78	-18,9	-1,58	-1,66
01.06.1989	01.06.1990	12	-1,41	-14,61	-1,22	-1,3
01.06.1991	01.06.1993	24	-1,35	-20,18	-0,84	-1,03
01.05.1996	01.05.1998	24	-1,13	-9,91	-0,41	-0,34
01.08.2000	01.08.2001	12	-1,16	-10,43	-0,87	-1,03
01.07.2008	01.07.2009	12	-1,23	-13,22	-1,1	-1,19
01.01.2012	01.07.2012	6	-1,06	-4,68	-0,78	-0,92
Sum/Mean		**156**	**-3,01**	**-160**	**-1,00**	

Table 4

Drought indicators of the anthropgenic flow of Charvak reservoir
for the period 1977-2020 (SSI12)

Drought index indicators						
Start time	End time	Duration, month	Maximum	Magnitude	Intensity	Median
01.12.1977	01.04.1979	16	-2,13	-19,26	-1,20	-1,3
01.06.1989	01.06.1990	12	-1,41	-12,16	-1,01	-0,99
01.11.1991	01.05.1993	18	-1,17	-14,97	-0,83	-0,79
01.04.1996	01.04.1997	12	-1,15	-6,44	-0,54	-0,53
01.09.2000	01.06.2002	21	-2,01	-27,75	-1,32	-1,34
01.07.2008	01.01.2010	18	-2,28	-25,91	-1,44	-1,64
01.07.2011	01.06.2016	59	-1,45	-38	-0,64	-0,51
Sum/Mean		**156**	**-2,28**	**-144**	**-1,00**	



Moderate drought, -1 Severe drought, -1.5 Extremely drought, -2

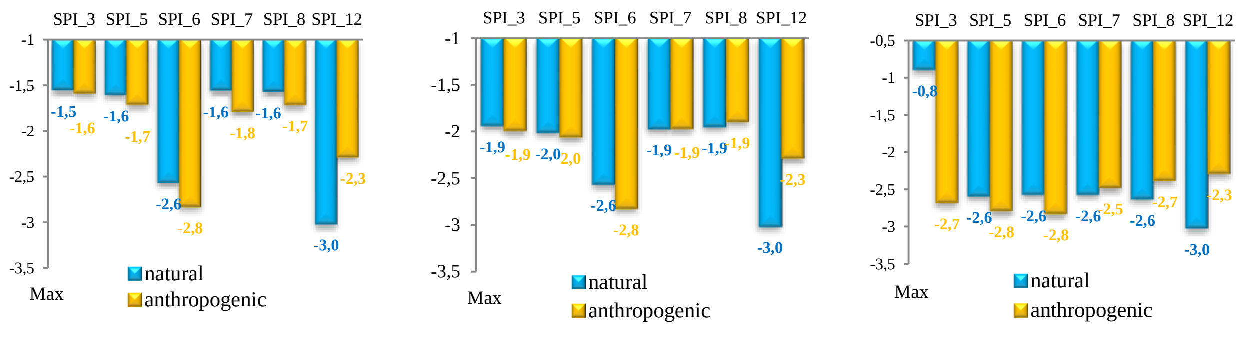
Figure 3. Changes in the duration of the drought index in natural
and anthropogenic conditions at different drought thresholds

The duration of the drought of the Pskem and Chatkal rivers, which flow into the reservoir, was initially studied according to the -1 degree of the drough severity of

SSI. Duration of drought in the natural flow of SSI3 was observed 137 months, and in the anthropogenic flow it was 158 months. On SSI6 duration of drought was observed 130 months in natural flow and in anthropogenic flow its value increased up to 169 months. It should be noted that at moderate severety (-1) boundary of SSI, duration of drought was longer compared to the natural flow due to the influence of the human factor (Figure 3). It was found that the duration of drought increased under the influence of anthropogenic flow even at the extreme drought limit (-1.5) (Figure 3).

We continue the research work by analyzing the duration of drought according to the extreme drought threshold (-2). In that case, duration of drought in the natural flow of SSI3 was observed 38 months in total, while 22 months under the influence of anthropogenic condition. Moreover, in total drought lasted 41 months in the natural flow of SSI6, and 38 months in the anthropogenic condition. Except for the 3-month and 6-month drought indices, it was found that the duration of drought was longer in the anthropogenic flow than in the natural flow in all other months (Figure 3). From these results, it can be stated that the drought caused by anthropogenic factors, i.e. as a result of the reservoir effect, lasted longer than the naturally formed drought. Therefore, it can be concluded that due to the (mis)management of the Charvak reservoir the duration of the drought was observed more frequently then natural condition.

In the study, the change of the maximum deepening of drought indices of the river flow under natural and anthropogenic conditions was also studied (Figure 4). The greatest value of the drought index of the Pskem and Chatkal rivers flowing into the reservoir was -3.01 in SSI12, and the smallest value was -1.5 in SSI3. The largest value of the maximum deepening of the drought index of the river leaving the reservoir was -2.8 (SSI6), and the smallest was -1.6 (SSI7-8). The maximum deepening of the drought index was recorded in the range of -3.0 ÷ -1.5 in almost all cases (Figure 4).



Moderate drought -1 Severe drought -1.5 Extreme drought -2

Figure 4. Changes in peak of drought the of the river flow
under natural and anthropogenic conditions

Estimation on determining the magnitude of the drought index for the natural and the anthropogenic flow was performed (Figure 5). According to the Figure 5, the value of the drought index magnitude in SSI5 was -145 at the moderate drought threshold (-1) in natural flow, while it was -173 in anthropogenic flow due to the influence of the reservoir. The sum of the magnitude of the drought index of the natural stream flowing into the reservoir during the studied accounting period was -146. The magnitudes of the drought index on SSI12 were 159 and 144 in the natural and anthropogenic condition, respectively (Figure 5a).

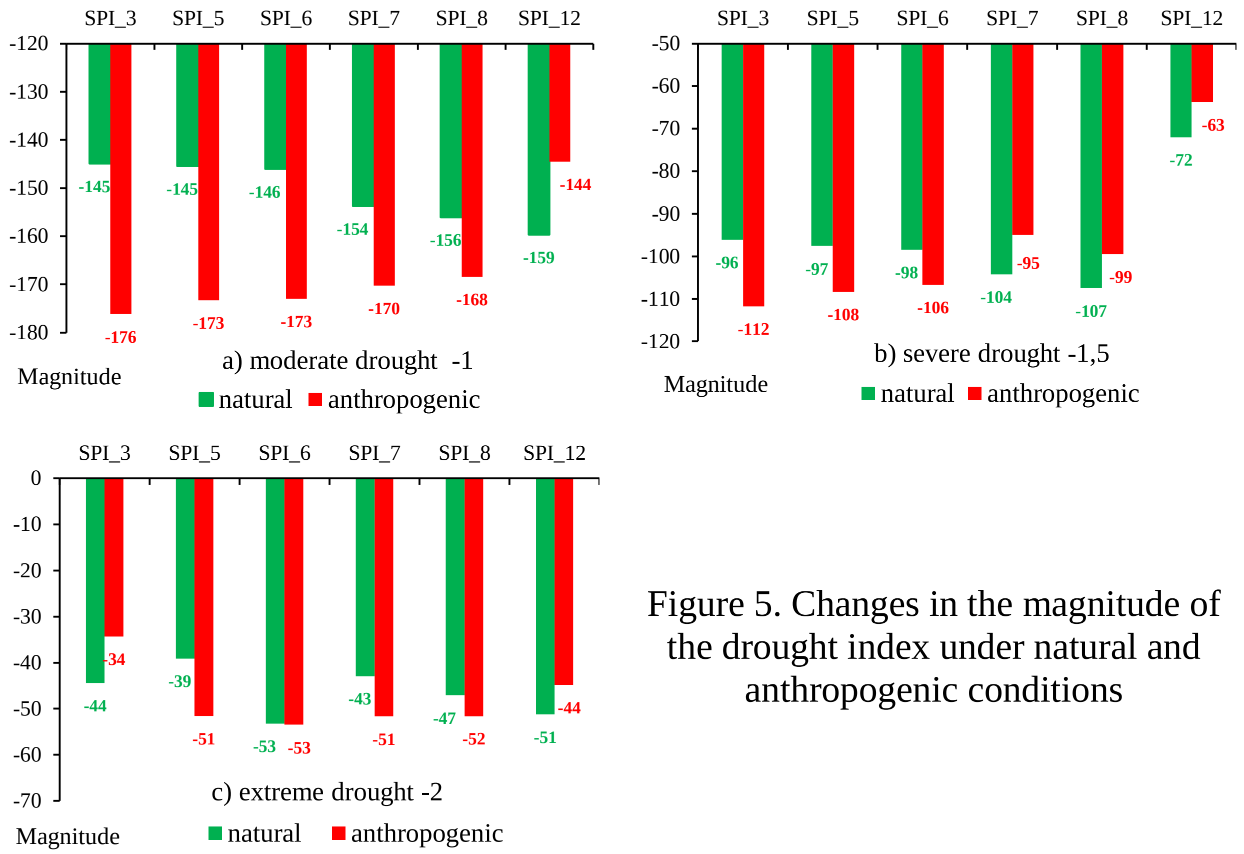


Figure 5. Changes in the magnitude of the drought index under natural and anthropogenic conditions

The change in the magnitude of the drought index under natural and anthropogenic conditions was also confirmed for the severe drought limit (-1.5). The drought magnitude of SSI5 was recorded as -97 in the natural flow, and -108 in the anthropogenic flow. The highest indicator of drought magnitude on SSI12 in the border (-1) was observed -72 in the natural flow and -63 in the anthropogenic flow (Figure 5b).

In the case of extreme drought (-2), the magnitude of drought in 3 months and 12 months was smaller in the anthropogenic flow compared to the natural flow. The value of the magnitude of the 6-month drought index has not changed in natural and anthropogenic flows (-53). During periods of extreme drought, it was found that the magnitude of drought did not differ significantly in natural and anthropogenic flows (Figure 5c).

Based on the results of the research conducted to assess the impact of water reservoirs on changes in the drought index and indicators of river flow, the following main conclusions can be noted:

1. First time the impact of water reservoirs on river flow was evaluated by drought index and indicators. The flow of the Chatkal and Pskem rivers flowing into the Charvak reservoir was defined as a natural condition its longest drough duration was observed 33 months in the period 1982-1984. It was found that the duration of drought on SSI6 was 130 months for natural flow;

2. The highest values of the duration of drought in the natural stream flowing into the reservoir corresponded to 47 months, and it was found that this value was observed between 1981 and 1985. It was noted that the drought index in these rivers lasted from January to June 2012, that is, for 6 months, and in the subsequent period, no high level of drought was observed;

3. Peak values of drought index of Pskem and Chatkal rivers was observed maximum -3.01 on SSI12, and minimum-1.5 on SSI3. The maximum depth of the drought index was recorded in the range of -3.0÷-1.5 in almost all cases. The value of drought index magnitude in SSI5 was -145 at moderate drought threshold (-1) in natural flow, while it was -173 in anthropogenic flow. The sum of the magnitude of the drought index of the natural stream flowing into the reservoir during the observed period was -146. The magnitude of the drought index on SSI12 was -159 in natural and -144 in anthropogenic condition.

4. Drought caused by anthropogenic factors by (mis)management of the water reservoir lasted longer than the naturally occurring drought. The main focus for future research should be considered on studying drought indices before and after construction of Charvak reservoir, and ultimately on determining the main factor causing drought phenomena.

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