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Approach to simulation of annual runoff process for estimation of main water reservoir characteristics

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Abstract Today, demand for water is on the rise everywhere in the world, particularly in arid and semiarid countries including Iran. About 70 % area of Iran suffer somehow from the lack of precipitation. The research is dedicated to estimation of main probabilistic characteristics of river flow regulation by perspective water reservoirs with help of annual runoff process simulation by Monte-Carlo method. Results of the research allows do conclusion about possibility of application Monte-Carlo method for simulation of annual runoff and about necessary of runoff regulation by water reservoirs on the rivers of Iran – Gharasu and Hablirud. Their annual runoff regime is differing significantly. From the estimated 1000-year hydrological series were formed sequences of 2-years, 3-years, 4-years and 5-years periods. Preliminary analysis of the runoff difference integral curve and planned water loss showed that under the current situation, several consecutive deficit years are likely to exist in a row.

Keywords: Monte-Carlo method; Simulation; Annual runoff; Iran

1. Introduction

Iran being located in the world dry belt is faced with scanty rainfall, drying up of its underground water resources and wetlands and the new unwelcomed phenomenon of dust storms. Frequent droughts coupled with over-abstraction of surface and groundwater through a large network of hydraulic infrastructure and deep wells have escalated the nation's water situation to a critical level. This is evidenced by drying lakes, rivers and wetlands, declining groundwater levels, land subsidence, water quality degradation, soil erosion, desertification and more frequent dust storms. Statistics indicate that Iran ranks 13th among the most water-stressed countries in 2040. Due to unconditional agricultural activities and extraction of too much of its aquifers, today Iran

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has lost much of its underground water resources causing large holes in almost 50% of its plains (Alizadeh, 2017).

Iran enjoys a diverse topography and climate variability. Temperature can vary between −20 and +50 °C while precipitation varies from less than 50 mm to more than 1,000 mm per year. Iran's average annual precipitation is 250 mm (less than one-third of the global average) with most of the country receiving less than 100 mm of rain per year (Mahdadi, 2013).

The research is dedicated to estimation of main probabilistic characteristics of river flow regulation by perspective water reservoirs with help of annual runoff process simulation by Monte-Carlo method (Robert and Casella, 2010, Smith, and Marshall, 2008). Results of the research allows do conclusion about possibility of application Monte-Carlo method for simulation annual runoff and about necessary of runoff regulation by water reservoirs on the rivers of Iran – Gharasu and Hablirud.

2. Materials and methods

Objects of research were rivers of Iran – Gharasu and Hablirud. These rivers are located in the north of Iran. Gharasu River on the northern slopes and Hablirud River on the southern slopes of the Alborz Mountains are located. The Hablerud River with the length of 117.3 km is located in the north of Iran and the east of Tehran and Gharasu River with the length of 100.15 km is located in the north of Iran and the east of the Caspian Sea. Their annual runoff regime is differing significantly and data series observation content 30 years only, they contain a small number of combinations of low-water and high-water years, but we need a much greater combination of different runoff scenarios for an objective assessment of long-term water use and flow regulation by water reservoirs. Therefore, artificial row of annual runoff was simulated by Monte-Carlo method on the base statistical parameters (Ilinich, 2004).

Three-variable gamma distribution (Blokhinov, 1974) for random values of river annual runoff was adopted on the basis of an analysis of its adequacy to the observed data, this law makes it possible to take into account the asymmetry of distribution quite accurately (Ilinich, 2014). Artificial series of annual runoff were modelled in accordance with the traditional procedure [Ilinich and Gmorshuk, 2001, Svanidse and Khomeriki, 1970, Smith and Marshall, 2008, Vrugt and et al., 2008). Next main statistical parameters. Were compared between the observed hydrological row and AGR: averages $(\overline{W})$, variation coefficients (C_V), coefficients of skew (C_S), correlation coefficients between adjacent annual runoff volumes (Ra).

To assess adequacy of the artificial modelled hydrological series with respect to the initial observations series were analysed the degree of difference in their statistical parameters (Blokhinov, 1974). The differences between them were compared with their relative average quadratic errors of original series of observations, which were calculated by the following formulas (Jandaghi, 2014):

For average: $\varepsilon_1 = {C_V}/{\sqrt{n}} * 100\%$; Eq.(1)

$Cv - \varepsilon_2 = \frac{1}{n+4Cv^2}\sqrt{\frac{n(1+Cv^2)}{2}} * 100$ Eq. (2)

Ra- $\varepsilon_3 = \frac{1-r^2}{\sqrt{n-1}} * 100\%$; Eq. (3)

Cs - $\varepsilon_4 = \frac{1}{C_S}\sqrt{\frac{6}{n}(1+Cv^2)} * 100$; Eq. (4)

3. Results

The results are in tables (1) and (2). Based on the data in tables, it can be seen that the differences in the statistical parameters are less than their relative mean-square errors calculated by the formulas. So, modeled and observed series are series from general set of random variables.

Table 1. Comparison of the statistical parameters of annual flow between observed and modeled data (Hablirud River)

$\bar{Q}$(Observed)	$\bar{Q}$(Modeled)	$Error\ \varepsilon_1(\bar{Q}), \%$	($\Delta\bar{Q}/\bar{Q}_{Modeled}$)*100%
7.30	7.42	7.37	1.63
Cv(Observed)	Cv(Modeled)	$Error\varepsilon_2(Cv), \%$	($\Delta Cv/Cv_{Modeled}$)*100
0.4	0.4	13.63	0.39
r(Observed)	r(Modeled)	$Error\ \varepsilon_3(r), \%$	($\Delta r/r_{Modeled}$)*100
0.41	0.43	15.48	4.67
Cs(Observed)	Cs(Modeled)	$Error\varepsilon_4(Cs), \%$	($\Delta Cs/Cs_{Modeled}$)*100
0.8	0.58	29.07	38.65

Table 2. Comparison of the statistical parameters of annual flow between observed and modeled data (Gharasu River)

$\bar{Q}$(Observed)	$\bar{Q}$(Modeled)	$Error\ \varepsilon_1(\bar{Q}), \%$	($\Delta\bar{Q}/\bar{Q}_{Modeled}$)*100
1.93	1.97	9.86	2.03
Cv(Observed)	Cv(Modeled)	$Error\varepsilon_2(Cv), \%$	($\Delta Cv/Cv_{Modeled}$)*100
0.54	0.53	14.12	1.69
r(Observed)	r(Modeled)	$Error\ \varepsilon_3(r), \%$	($\Delta r/r_{Modeled}$)*100
0.42	0.44	15.29	4.55
Cs(Observed)	Cs(Modeled)	$Error\varepsilon_4(Cs), \%$	($\Delta Cs/Cs_{Modeled}$)*100
1.08	0.78	47.06	38.46

From the estimated 1000-year hydrological series were formed sequences of 2-years, 3-years, 4-years and 5-years periods (sequences of 500, 333, 250 and 200 series members).

On the artificial hydrological series was estimated the occurrence frequency of deficit years, which was taken as the probability of this event (P_d). Also were estimated the average annual deficits (for 10 years) - Vd10, and the maximum annual volume V_{dmax}.

For river Gharasu: P_d=0.3; V_{d10}=37.8 mil.м^3; V_{dmax}=29.1 mil.м^3;

For river Hablirud: P_d=0.05; V_{d10}=11.9 mil.м^3; V_{dmax}=79.5 mil.м^3;.

Preliminary analysis of the runoff difference integral curve and planned water loss showed that under the current situation, several consecutive deficit years are likely to exist in a row (Fig. 1, 2).

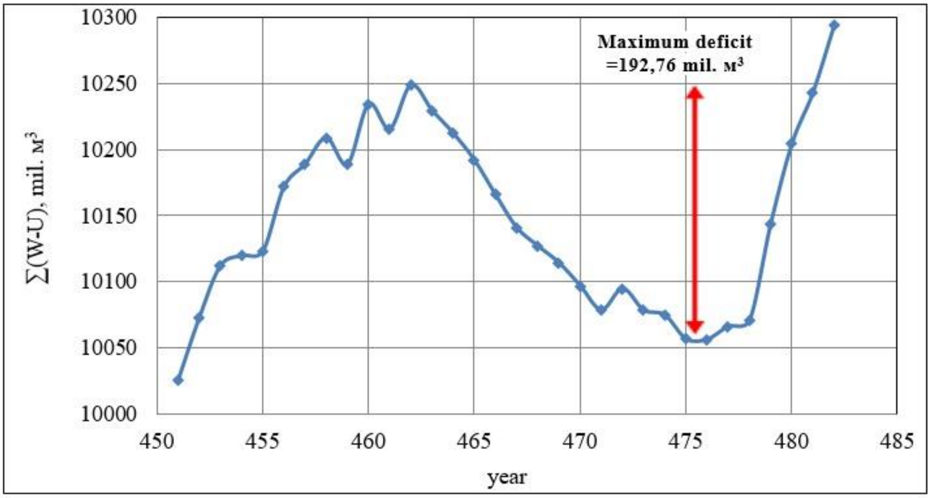

Figure 1. Difference integral flow curve (W) and water loss (U) –Gharasu River basin

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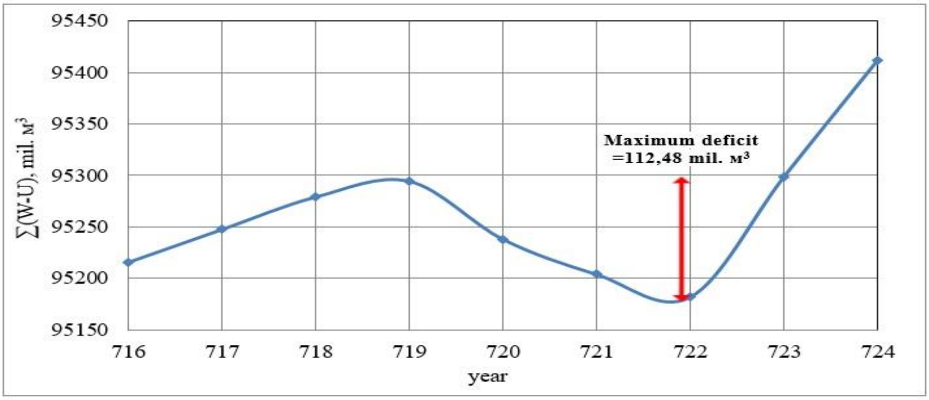

Figure 2. Difference integral flow curve (W) and water loss (U)–Hablirud River basin

Probabilistic assessment of appearance of deficit n-years and the corresponding maximum deficits were made. With helping simulated series were formed flow rows: 2-years, 3-years, 4-years and 5-years intervals. Total deficits were calculated and occurrence probability of deficits was determined for these intervals, and also maximum total deficit (V_d) was recorded (table 3).

Based on the data in Table (3) it can be said that total deficit is rising steadily with increasing in duration of continuous deficit period for Gharasu River, in comparison to Hablirud River.

Accordingly, it can be concluded that the Gharasu River requires a long-term flow regulation by water reservoir, while on the Hablirud River is sufficient only seasonal flow regulation.

Table 3. Probabilistic characteristics of water use in natural flow

River basin	Deficient n-years	$P_д$	Pα,%	V_d, mil.$м^3$
Gharasu	2-years	0.236	76.4	56.4
	3-years	0.207	79.3	75.5
	4-years	0.188	81.2	78.0
	5-years	0.160	84.0	93.3
Hablirud	2-years	0.028	97.2	56.1
	3-years	0.030	97.0	65.0
	4-years	0.004	99.6	26.9
	5-years	0.005	99.5	7.4

4. Conclusions

Thus, the conducted studies allow us to state that applied technology of modelling artificial hydrological series is quite adequate relative to initial series of observations for functioning conditions of the Iranian rivers considered. In the Hablirud River, the provision of planned annual water loss in the natural conditions is high enough that does not require flow regulation by water reservoir, or only seasonal regulation is sufficient. But for the Gharasu River, it is necessary to provide for long-term flow regulation.

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