Patterns of runoff change in Bulgaria

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Abstract Variations in temperature, precipitation and runoff complex over the territory of Bulgaria are considered. The analysis is made on the basis of a sufficiently large number of stations broadly distributed across the country. Basic structures such as phases, cycles and long-term tendencies of the variations are found. A positive phase in temperature variations, as well as a negative phase in precipitation and runoff, are estimated after 1981. The degree of the changes in the different years is determined by their percentage deviation towards the norm for the period 1961–1990. The numbers of years of appearance in the temperature, precipitation and runoff variations are also determined.

Key words Bulgaria; cycles; phases; precipitation and runoff variations; probabilistic processes; temperature

SHORT CLIMATIC CHARACTERISTIC

The past literature describes the climate of Bulgaria as wetter than it is now and some of the bigger rivers—the Strimon and Mestos—were navigable almost to their middle reaches. More recently, gradual variations describe the state of the river systems as different from the present.

Bulgaria is situated in the eastern part of the Balkan Peninsula and occupies 22% of the whole area: 111 000 km^2. The geographic coordinates are between 41°14′ and 44°12′30″N, and between 22°21′30″ and 28°36′30″E.

The diversity in the transfer of air masses over Bulgaria is influenced by both the weather and climate of the country. The weather circulation depends mainly on: (a) the geographic situation of the country in southeastern Europe, and (b) the role of the active atmospheric systems, particularly over eastern Europe.

The remoteness of Bulgaria from the Atlantic Ocean and the Arctic Basin are the reason for the significant transformation of the air masses passing over the country. The Mediterranean air masses pushing into Bulgaria are transformed mainly under the influence of the local orography and the underlying surface. During the year, the air masses passing over the country come from the middle latitudes (oceanic and continental), from the tropic regions and from the Arctic region.

In most cases ocean air masses from the middle latitudes come to Bulgaria from the northwest and southwest, but the continental air masses come from the northeast and southeast. The Mediterranean cyclones have a seasonal character and are especially significant for the Bulgarian climate in the cold half of the year. Normally these cyclones are moving in northeasterly, easterly and southeasterly directions. They determine the variable and non-stable rainy weather during the cold part of the year in the southern parts of the Balkan Peninsula and Bulgaria.

On the basis of modern conceptions of climate as a complex system, the country is divided into the following basic climatic regions: moderate continental, transitional and continental-Mediterranean (Bulgarian Academy of Sciences, 1991).

RUNOFF VARIATIONS—HYPOTHESIS

Runoff is an integral characteristic of the interaction of the different geophysical processes over different surface territories. In this respect, the monthly and annual values of the runoff show the existence of cycles. These cycles are developed from phases of increased and decreased wetness. Normally their manifestation is connected with the local climate and the transformation ability of the river catchments.

In the last 50 years in hydrology the hypothesis that the influence of the external causality is coded into the development of the runoff processes has been accepted (e.g. Box & Jenkins, 1974; Drujinin, 1987; Kartvelishvily, 1985; Ratcovitch, 1976; Rojdestvensky & Chebotarev, 1974; Shelitko, 1983; Gerassimov, 2002; Genev, 2002). Because of this, each monthly or annual value can be regarded as an integral indicator of the external causality impact determining the internal causality development of these processes.

Taking into account the above thesis, the following working hypothesis can be used in the investigation of runoff variations:

(a) The runoff $X(t)$ is considered as a random quasi-stationary process:

$$\{X(t): t \in T\}, \{\bar{x}(t), R(t_1, t_2), \sigma^2(t)\} \tag{1}$$

(b) The runoff is an integral characteristic of the interaction of the different geophysical factors over different surface areas. Its future development cannot be simply estimated but usually can be determined with a given probability:

$$P_i(x_i - \delta) < \xi_i < (x_i + \delta) \tag{2}$$

where ξ_i is a continuous probability process.

(c) The influence of all external impacts is coded into the presented historical information. In general the development of hydrological processes in time is determined under the influence of external and internal causality translated by the probability causality–evidence connections:

$$G_t = \sum_{s=1}^{u} f_s(A_{s,t}) + \sum_{s=1}^{v} f_s(B_{s,t}) + \eta(t) \tag{3}$$

where the first addenda are the external causality, the second are the internal ones, and the third, the remaining elements of chance.

(d) The development of the geophysical processes (the runoff) occurs in accordance with the statistical and dynamical regularities and shows cyclic recurrence, which is their specific characteristic:

$$R(\tau) = \sum_{\mu}^{n} b_\mu \cos \lambda t \tag{4}$$

i.e. each process which consists of a great number of probabilistic elements has to be cyclic and, moreover, has an internal correlation.

METHODS OF INVESTIGATION

The general interaction of the processes developed in the catchment areas can be typified as corresponding complexes. In the frames of one catchment the temperature regime $T \equiv \beta(t)$, is presented as a great number of point characteristics (sections of the process in given space coordinates). Usually, when investigating the development of similar processes over a given territory in which several catchment areas are placed, a generalized characteristic of the process for this territory is used, given as:

$$T^{\circ} \Leftrightarrow \overline{\beta}(t) \equiv \left\{ \overline{\beta_k^1(t), \beta_k^2(t), \ldots, \beta_k^n(t)} \right\} \tag{5}$$

Following the logical scheme for the precipitation we obtain:

$$P \Leftrightarrow \overline{\gamma}(t) \equiv \left\{ \overline{\gamma_k^1(t), \gamma_k^2(t), \ldots, \gamma_k^n(t)} \right\} \tag{6}$$

and for the process of evapotranspiration:

$$E \Leftrightarrow \overline{\eta}(t) \equiv \left\{ \overline{\eta_k^1(t), \eta_k^2(t), \ldots, \eta_k^n(t)} \right\} \tag{7}$$

The combined influence of several factors including the soil surface structures, geological texture, afforestation, etc., may be accounted for by the degree of the reduction of the precipitation. Landscape factors, hydro-geographical conditions and anthropogenic changes have to be taken into account also. All these elements formed the structure of the *transforming basin system*.

The spatial characteristics of the natural river flow process account for the integrated flow from the different small river basins of the catchment reported at the outlet, expressed as:

$$Q \Leftrightarrow \xi(t) \equiv \left\{ \xi_v^1(t) + \xi_v^2(t) + \ldots\ldots + \xi_v^n(t) \right\} \tag{8}$$

The mutual manifestation of the processes that form the catchment runoff can be presented as the relation:

$$\overline{\beta}(t) \leftrightarrow \overline{\gamma}(t) \leftrightarrow \overline{\eta}(t) \Rightarrow \xi(t) \tag{9}$$

The basic component of the impact over the catchment is precipitation. Because of this, runoff can be regarded as being a result of the direct impact of the meteorological complex on the transforming river basin system.

Investigation of the variations in hydro-meteorological processes is possible by different approaches and methods using probability theory and mathematical statistics. Using these methods the basic time series are analysed and their internal row structure is determined, as well as their parameters and functions, which describe their state. In addition, descriptive and correlation analyses are carried out for the determination of periods of different duration.

The main methods applied are: regression analysis, system analysis, autocorrelation analysis, cluster analysis, spectral analysis (e.g. Jenkins & Watts, 1972; Draper & Smith, 1986; Kendall, 1981; Mosteller & Tukey, 1982).

The processes describing the variations in temperature, precipitation and runoff complex are presented by their random numerical realizations—time series row. The investigations of their chronological annual time variations can be differentiated into two basic approaches applied for establishment of hidden cyclic recurrence and external manifested fluctuation.

In the analysis of the time series connected with the determination of the presence of phases, series and periods, integral curves are used (Genev, 1992). These integral curves are calculated using the following formula:

$$K_{\text{int}} = \left[\sum_{i=1}^{n} (k_i - 1) \right] / C_v \qquad (10)$$

where $k_i = x_i/\bar{x}$ are the characteristic coefficients; C_v is coefficient of variation of the row, $C_v = \sigma / \bar{x}$, where σ is the standard deviation of the row.

ESTIMATION OF RUNOFF VARIATION OVER BULGARIA

For the investigation of runoff over Bulgaria, a large number of stations, 140, was used; for temperature, 150, and for precipitation, 300 stations were used. The large number of stations enables use of a regular net superimposed over the country with a step length of 25.6 km for the temperatures, 19.2 km for precipitation, and 27.3 km for the runoff, using Class I and II meteorological stations.

Analysis of the variations in temperature, precipitation and runoff complex allowed determination of the phases and cycles in the annual chronological time changes.

A summary of the variations is made on the basis of ensembles of point characteristics of these complexes for the Danube (north Bulgaria, NB), Black Sea (east Bulgaria, EB) and Aegean (south Bulgaria, SB) flow basins. The form of the generalized time series is developed using equations (5), (6) and (8).

The variation in the numerical characteristics of the complexes investigated are given in Fig. 1(a)–(c). From analysis of the integral curves describing the variations in temperature, precipitation and runoff, the following important characteristics for the flow basins can be determined:

Basic phases and cycles

Danube flow basin (NB)

- temperature complex: [(–) 24, (+) 53], (1892–1968); [(–) 12, (+) 10], (1976–1997);
- precipitation complex: [(–) 20, (+) 9], (1916–1944); [(–) 9, (+) 28], (1945–1981);
- runoff complex: [(–) 9, (+) 28], (1945–1981).

Black Sea flow basin (EB)

- temperature complex: [(–) 23, (+) 58], (1892–1972); [(–) 12, (+) 9], (1977–1997);
- precipitation complex: [(–) 28, (+) 10], (1907–1944); [(–) 7, (+) 31], (1945–1982);
- runoff complex: [(–) 17, (+) 30], (1935–1981).

Aegean flow basin (SB)

- temperature complex: [(–) 23, (+) 54], (1892–1968); [(+) 16, (–) 9], (1973–1997);
- precipitation complex: [(–) 33, (+) 10], (1902–1944); [(–) 6, (+) 30], (1945–1980);
- runoff complex: [(–) 9, (+) 31], (1942–1981).

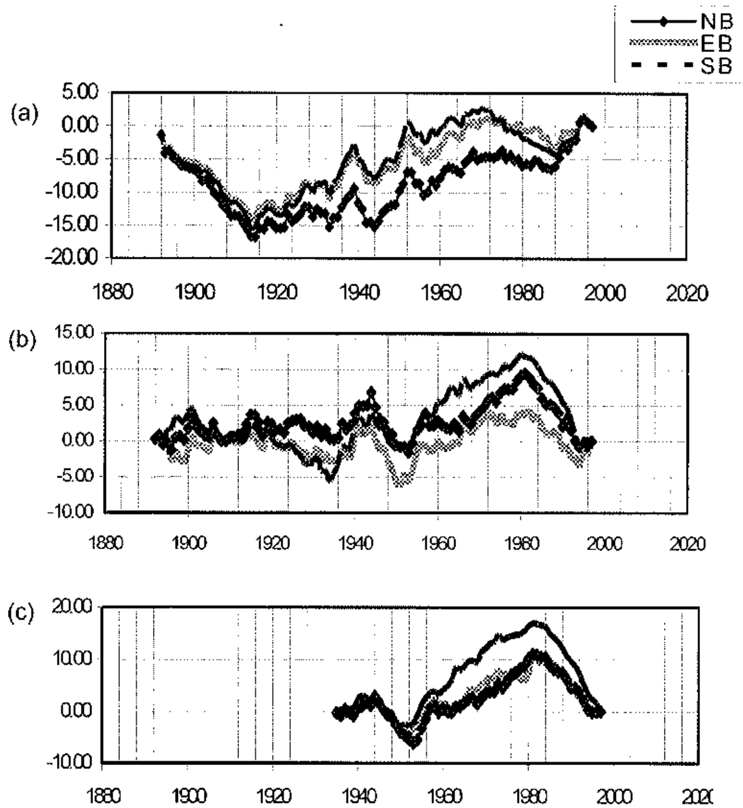

Fig. 1 Integral curves of variations in (a) temperature, (b) precipitation and (c) runoff over Bulgaria.

The long-term tendencies of the variations in temperature, precipitation (1982–1967) and runoff (1935–1967) over Bulgaria were analysed on the basis of their generalized annual rows. The time variations of these rows through their gradients show tendencies of a slight increase in temperatures and a notable decrease in precipitation and runoff. The annual variations determined are based on their integral curves as shown from equation (10) and plotted in Fig. 1(a)–(c). In the same figure, the different phases, which structurally build the different cycles, are clearly manifested. The trends in their changes are well demonstrated especially after 1981, when the last well-defined positive phase of temperature, and negative phases in precipitation and runoff are clear. From all the regular net information over Bulgaria we can conclude that the duration of these well-defined phases is 17 years (Fig. 1), a result not previously observed in the regime of the precipitation and runoff of the country.

To establish the degree of these annual chronological changes, their deviations from the average (in %) were calculated according to the recommended WMO standard value for the period 1961–1990 (Table 1). It is evident that in the different regions of Bulgaria, the deviations from the standard value (irregularities) for temperature, precipitation and runoff are different. We can see that the increase in temperature during this phase is slight, but the changes (decrease) in precipitation and runoff are well demonstrated.

Table 1 Percentage deviations in temperature, precipitation and runoff.

Year	Temperature:			Precipitation:			Runoff:		
	NB	EB	SB	NB	EB	SB	NB	EB	SB
1981	0.8	0.3	0.2	5.0	5.6	–4.6	24.8	110.9	22.4
1982	–2.6	–1.3	–2.4	–8.4	1.9	0.5	–4.7	–1.8	–1.6
1983	3.0	1.9	–1.9	–13.5	–17.7	–2.9	–12.9	–46.7	–4.0
1984	–2.4	–1.7	–1.3	–7.2	3.9	–10.0	–1.8	46.5	–4.9
1985	–5.3	–5.8	–2.0	–22.9	–22.8	–15.5	–50.8	–43.5	–34.6
1986	–1.9	–1.5	–0.9	–13.0	–14.9	–10.8	–25.8	–25.1	–21.6
1987	–2.5	–8.1	–2.5	1.7	–4.7	0.2	–10.5	–41.5	–20.8
1988	1.2	–1.6	–1.2	–4.7	6.9	–8.9	–9.8	–26.1	–29.9
1989	6.2	4.2	1.5	–12.2	–10.5	–12.0	–37.4	–54.8	–39.7
1990	7.6	7.9	7.1	–28.5	–29.2	–15.5	–53.3	–67.2	–29.2
1991	–3.0	–0.1	1.4	18.0	3.0	–9.5	–1.7	49.3	–22.6
1992	5.4	0.8	1.3	–24.6	–21.1	–23.3	–22.7	–54.5	–40.9
1993	1.0	–4.1	0.2	–22.8	–7.8	–29.9	–56.4	–61.3	–52.9
1994	13.8	11.8	13.5	–13.2	–12.1	–15.1	–59.1	–58.1	–50.3
1995	1.2	3.1	1.2	11.7	26.4	9.4	–14.2	–2.9	–31.1
1996	–4.4	–4.8	–1.4	–5.6	0.2	5.7	–37.3	–30.0	–22.9
1997	–4.0	4.4	–3.3	11.1	28.5	–2.8	–19.1	16.9	–38.2
Average	**0.8**	**–0.2**	**0.6**	**–7.6**	**–3.8**	**–8.5**	**–23.1**	**–22.9**	**–24.9**

From Table 1 we can see the balance of the sign of the anomalies in the different annual series. Especially important are those with a positive sign for temperatures and negative signs for precipitation and runoff. The series for the investigated complexes are as follows (the number before the parentheses shows the length of the time series in years):

Temperature complex:

T (NB): (+) 1 [1981, 1983], (+) 3 [1988–1990], (+) 4 [1992–1995]
T (EB): (+) 1 [1981, 1983, 1992, 1995], (+) 2 [1989–1990]
T (SB): (+) 1 [1981], (+) 7 [1989–1995]

Precipitation complex:

Pr (NB): (–) 1 [1996], (–) 3 [1988-1990, 1992–1994], (–) 5 [1982–1986]
Pr (EB): (–) 1 [1983], (–) 2 [1989-1990], (–) 3 [1985–1987, 1992–1994]
Pr (SB): (–) 1 [1981, 1997], (–) 4 [1983–1986], (–) 7 [1988–1994]

Runoff complex:

Q (NB): (–) 16 [1982–1997]
Q (EB): (–) 2 [1982–1983], (–) 12 [1985–1996]
Q (SB): (–) 16 [1982–1997]

From Table 1 the specific features in the time variations of the investigated complexes are determined by the atmospheric circulation prevailing over the different regions of the country, as well as by the local climate.

CONCLUSION

In the last 50 years climate change problems have become of great interest not only at a regional scale but also from a global point of view. That is why investigation of the changes in the main climate elements—temperature and precipitation—and also in runoff are of great importance for the central region of the Balkan Peninsula.

The analysis of the annual time variations of the complexes of temperature, precipitation and runoff show that, during the period investigated, a temperature increase is observed in the different flow basins after 1987–1988. There is a clear decreasing trend in the precipitation after 1981–1982, and also in the runoff.

For the temperatures after 1981, a gradual long-term positive phase of slight increase is observed, with averages of between 0.6 and 0.8%.

It is clearly demonstrated that, during the negative phase in precipitation after 1981, the decrease trend averages between 3.8 and 8.5%, leading to the runoff decrease of between 22.9 and 24.9%.

From preliminary estimates we note that the most recent negative phase of precipitation and runoff lasts until 2000.

REFERENCES

Anderson, T. W. (1971) *The Statistical Analysis of Time Series*. John Wiley & Sons, New York, USA.

Box, G. & Jenkins, G. (1970) *Time Series Analysis*. Holden-Dey, San Francisco, California, USA.

Bulgarian Academy of Sciences (1991) *The Climate of Bulgaria*. Bulgarian Academy of Sciences, Sofia, Bulgaria.

Draper, N. & Smith, H. (1972) *Applied Regression Analysis*. John Wiley & Sons, New York, USA.

Drujinin, I. P. (1987) *Long Term Forecast and Information*. Nauka, Novosibirsk, Russia (in Russian).

Genev, M. (1992) Analysis of internal structure for forecasting. In: *Hydrological Forecasting and Hydrological Bases of Water Management* (Proc. XVI Conf. of The Danube Countries, Kelheime, May 1992), vol 1 & 2, 311–318 (in Russian).

Genev, M. (1998) Probabilistic character of natural phenomena of river discharge. *J. Bulgarian Acad. Sci.* **3–4**, 43–48.

Gerassimov, S., Genev, M., Bojilova, E. & Orehova, T. (2002) Water resources of Bulgaria during the drought period. In: *Drought Period 1982–1994 in Bulgaria as a Model of the Future Global Changes* (in press). Bulgarian Academy of Sciences, Sofia, Bulgaria (in Bulgarian).

Houghton, J. (1996) *Global Warming: The Complete Briefing*. Lion Publishing, Oxford, UK.

Jenkins, G. & Watts, D. (1969) *Spectral Analysis*. Holden-Dey, San Francisco, USA.

Kartvelishvily, N. A. (1985) *Theory of Probability Processes in Hydrology and Regulation River Discharge*. Gidromet, Leningrad, Russia.

Kendal, M. (1969) *Time Series*. Charles Griffin & Co., London, UK.

Ratkovich, D. J. (1976) *Long-term Variations of the Runoff*. Gidromet, Leningrad, Russia.

Rojdestvensky, A. V. & Chebotarev, A. I. (1974) *Statistical Methods in Hydrology*. Gidromet, Leningrad, Russia.

Shelitko, V. A. (1984) *Statistical Models and methodology for Investigation of Long-Term Variations of Runoff*. Gidromet, Leningrad, Russia.