Environ Monit Assess (2007) 127:383–388
DOI 10.1007/s10661-006-9287-5

ORIGINAL ARTICLE

Integral assessment of climate impact on the transboundary Mesta River flow formation in Bulgaria

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Received: 3 October 2005 / Accepted: 8 May 2006 / Published online: 21 October 2006

Abstract The present work considers the section of the Mesta River on Bulgarian territory using the integral method for evaluation of climate and anthropogenic impact on the river flow.

The level of this impact is determined by the index K_i (flow module), the coefficient C_i for the deviation of the average annual water volume Q_i from the flow norm Q_o and the index h_i for the deviation of the average annual rainfall volume H_i from the average multi-annual rainfall volume H_o.

The dynamics of the average annual flow Q_i at two typical hydrometric stations – Yakoruda and Khadzhidimovo, as well as the dynamics of the average annual rainfall for the Yakoruda station was examined for the period 1955–2003.

The data for the considered period 1955–2003 exhibit a decreasing trend of the average annual water volumes dynamics for both stations due to the impact of climate changes in the Mesta River catchment.

Keywords River flow · Climate · Trends · Catchment

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Introduction

The transboundary Mesta River is located in Western Bulgaria, with catchment area of 2768 km^2, at altitude of 1318 m and length of 125.9 km in the Bulgarian part of the river. The catchment of the river follows a mountainous pattern and is characterized by relatively low forestation level and 693 settlements with 13 500 inhabitants in total. Forests cover 50% of the catchment area.

The river rises from the alpine parts of Rila and Pirin mountains and from the lower parts of Rhodopes. The Mesta River flows through Bulgaria and Greece to the Aegean.

The Mesta River Catchment Area is a part of the region that experiences the influence of the European continental climate over the flow. The southern-most part of the river valley serves as a corridor for the Mediterranean climate.

Two typical periods for the river flow formation are determined: a period of winter-spring (high water) and a period of summer-autumn (low water).

The Mesta River is used for tap water, industrial water supply and for irrigation.

The water quantity of the Mesta River is controlled at 22 hydrometric stations: five of them along the Mesta River and the rest 17 stations along the river feeders (Ivanov *et al.,* 2004).

The characteristics of the Mesta River natural flow are basically assessed according to the information coming from two typical hydrometric stations – the

Fig. 1 Catchment area of Mesta River in Bulgarian section

Yakoruda one in the upper river course and the Khadzhidimovo station in the lower course at a distance of 23 km from the Greek border.

The relief of the investigated area is diverse: the difference between the highest point (2204 m) and the lowest point at the Greek border (388 m) is significant. Preliminary studies have shown that the natural state of the river flow formation depends on the altitude (Ivanov *et al.*, 2004).

The natural conditions of the Mesta River flow formation are due to the climatic impact, while the effect of economic activity is negligible.

In the recent years many researchers focused their attention on the climate changes due to anthropogenic activity (McGuen *et al.,* 1989; Bilger 1992; Silver *et al.*, 1990). Many authors believe that a period of warming will characterise the coming decades. Others are more reserved on the issue (Tardy 1986; Anderson *et al.,* 1985; Frecaut *et al.*, 1983). What can be pointed out is that the natural climate dependencies are disturbed by the anthropogenic impacts. Therefore, in our opinion, difficult for prediction climate changes at regional and global level, are possible. The present work considers a particular regional problem and the goal is to manage the waters in a transboundary river basin.

The basic goals of this research are:

- To clarify the tendencies of the annual average values dynamics of the Mesta River water flow along the Bulgarian Mesta River section during the period 1955–2003.
- To clarify the tendencies of the annual average atmospheric precipitation in the Bulgarian Mesta River basin.

- To clarify the characteristics of the climate impact on the river flow formation in natural conditions.

Materials and methods

The retrospective analysis of the river water flow dynamics is carried out on the basis of the information coming from two hydrometric stations – Yakoruda and Khadzhidimovo (TRANSKAT, 2005).

The main trend is defined by a linear function with the *Statistica 5.5* software.

The trend reflects the main tendencies in the dynamics of the studied indices. In hydrology, statistical and water balance methods for assessment of climatic and anthropogenic impact on the annual river flow formation are used in specific cross sections of the river basin (Mandadjiev, 1998; Hershy *et al.*, 1998; Meybeck *et al.*, 1978; Sing, 1995). The impact on the river flow is determined as a difference (ΔQ) between the natural river flow (Q_e) and the actual measured river water flow (Q_i) for a time period *t* (season, year) for a given point along the river course:

$$\Delta Q = Q_e(t) - Q_i(t) \tag{1}$$

The analogy method is widely applied for determining river flow under natural condition (Q_e).

In this work, an integral approach is used for evaluating the level of climate impact on the river flow formation. The anthropogenic impact in the catchment area is negligible (Ivanov *et al.*, 2004) and therefore it has not been considered here.

The climate and economic activities including land- and water-use in the catchment area influence the river flow formation. The rate of this impact is determined by the change of the surface run-off from agricultural and forest areas. The index of the run-off variation is determined by the ratio M/M_o, where M is the module of the actual surface run-off in agricultural and forest areas estimated as l/s.km^2.

The M module is the ration ($M = Q_i/F$) between the annual average water flow per year i (Q_i) at a control point of the river flow and catchment area (F) at this point. M_o module is the ratio ($M_o = Q_o/F$) between the multiyear (>30 years) average water flow Q_o at control point i of the river flow and the catchment area (F) at this point.

The flow norm Q_o, the K_i index for the module of run-off in the catchment area and the coefficient C_i for the degree of deviation of Q_i from Q_o are a basis for determination of the rate of climate and anthropogenic impact on the river flow formation (Diadovski *et al.*, 2000; 2001; 2004a and 2005).

The climate and human activity including the land- and water-use substantially affect the surface run off within the catchment.

The index K_i for the module run-off change can be presented as the ratio between the annual water quantity per year i (Q_i) at a control point of the river flow and the multi-year average water quantity (Q_o) for a period of time of more than 30 years.

The coefficient C_i represents the degree of deviation of Q_i (annual average water volume) from Q_o (multi-annual average water volume) for a many-year period (exceeding 30 years).

The K_i index and C_i coefficient are determined by the equations:

$$K_i = Q_i/Q_o \tag{2}$$

$$C_i = (Q_i - Q_o)/Q_o \tag{3}$$

The fluctuations of the K_i index and the C_i coefficient for a given period provide the possibility of making an integral assessment of the climate impact on river flow formation at river basin scale (Diadovski *et al.*, 2004). The positive values of C_i the values of K_i higher than unity indicate increased water resources in comparison with the flow norm Q_o. In contrast, the negative values of C_i and the values of K_i lower than unity indicate decreased water resources compared to the flow norm Q_o.

The climate influences the river water volume formation by atmospheric precipitation and air temperature. The climate impact on the Mesta River flow formation is determined on the basis of the average multi-annual atmospheric precipitation H_o (mm), the annual average atmospheric precipitation H_i (mm) by means of the index h_i for the atmospheric precipitation dynamics. The index h_i can be presented as the ratio between the annual average atmospheric precipitation per year i (H_i) at a control point in the river basin and the average multi-annual atmospheric precipitation for a period longer than 30 years.

The index is determined by the equation:

$$h_i = H_i/H_o \tag{4}$$

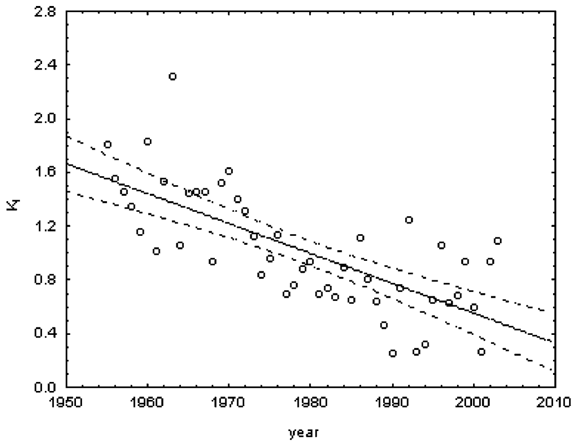

Fig. 2 Dynamics of the K_i index for the Mesta River at Yakoruda point

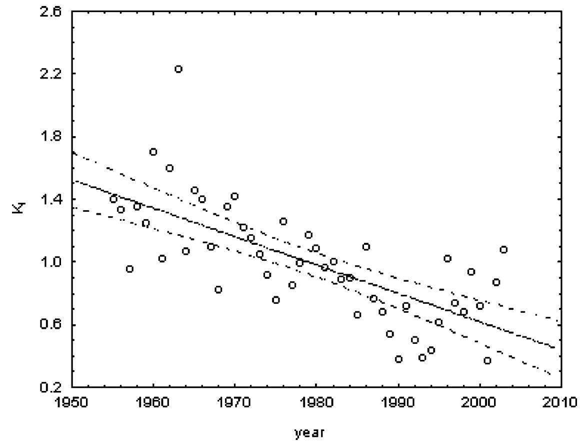

Fig. 3 Dynamics of the K_i index for the Mesta River at Khadzhidimovo point

The integral assessment of climate impact on river flow formation on a river basin scale exhibits a very precise regularity in the fluctuation of the *hi* and K_i indices and the C_i coefficient. The dynamics of the h_i index at the Yakoruda, Razlog and Gotze Delchev stations is analyzed.

Results and discussion

In the river system studied, the changes of the river flow detected are considered to be natural and due to the environmental condition, i.e. fluctuation of the climate and physical characteristics. According to Amoros (1993) and Sing (1995), these changes are assigned as trend, insertion or leap-like (catastrophic) events.

In our study the trends of the basic characteristic of the river flow (K_i index, C_i coefficient) and the atmospheric precipitation (h_i index) are observed.

The multi-annual average river water flow for a period of 49 years (Q_o) at Yakoruda point is 5.35 m^3/s. The variation coefficient (C_v) is 0.41, the probability for errors is 5.52%. The module of the surface run-off is 12.75 l/s km^2, determined for Q_o.

The multi-annual average river water flow for a period of 49 years (Q_o) at Khadzhidimovo point is 25.56 m^3/s. The variation coefficient (C_v) is 0.33 and the probability for errors is 4.72%. The module of run-off is 11.33 l/s km^2, determined for Q_o.

The analyses of the dynamics of the h_i index and C_i coefficient at Yakoruda and Khadzhidimovo points during the period (1955–2003) are presented at Fig. 2–4.

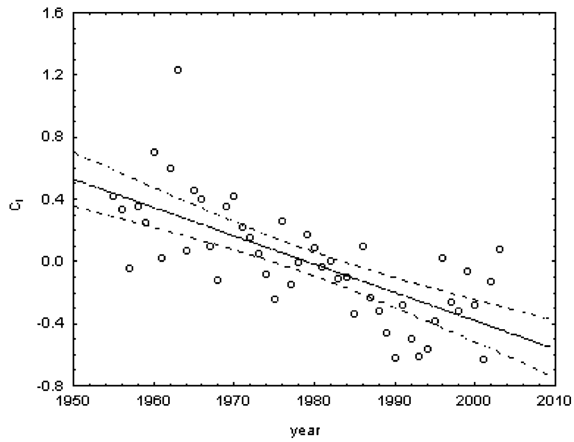

Fig. 4 Dynamics of the C_i coefficient for the Mesta River at Khadzhidimovo point

The main trend in the dynamics of the K_i index tends to decrease of the annual values at both points for the considered period. The trend is given by a linear function with a value of the correlation coefficient $R = 0.71$ for Yakoruda and $R = 0.70$ for Khadzhidimovo. The theoretical correlation coefficient R_t at degrees of freedom $n = 48$ and a probability error of 0.5% is 0.283. The linear function describing the tendency in the fluctuations of the K_i index has turned to be an adequate model for the K_i dynamics during the considered period.

The influence of climatic and physical characteristics (Yakoruda, Khadzhidimovo) is determined by the obtained results. The fluctuations of the K_i index at Yakoruda are within the range from 2.35 to 0.25. At

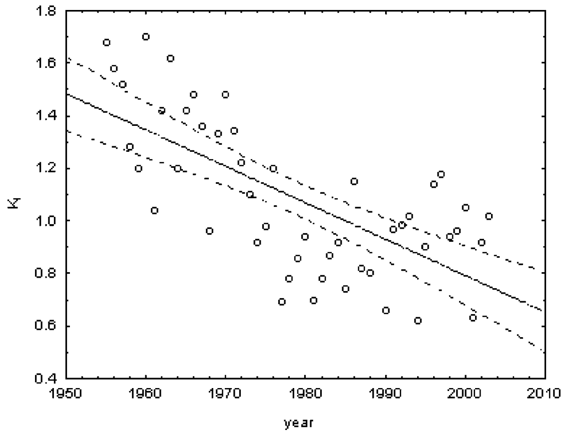

Fig. 5 Multi-year dynamics of the values of the index h_i for the Mesta River at Yakoruda point

the Khadzhidimovo point the fluctuations of the K_i index vary from 2.25 to 0.25 and the dynamics of the C_i coefficient is within the interval from 1.25 to 0.75. Two typical periods are determined. During the first one years of increased water resources are outlined ($C_i > 0$, $K_i > 1$ for 1955–1983) and during the second one years of decreased water resources ($C_i < 0$, $K_i < 1$ for 1984-2003) are observed.

The linear function describing the trend in the C_i coefficient fluctuations has turned to be an adequate model for the C_i dynamics during the considered period.

We would like to point out that the linear functions describing the trend in the dynamics of the K_i index and the C_i coefficient for the period 1955–2003 cannot be used for prognosis. The modelling of the K_i and C_i dynamics is not the goal of this survey.

The dynamics of the C_i and K_i values shows the influence of climate on the Mesta River basin under natural conditions of river flow formation for the case of negligible water utilization. The model describing the annual change of the Mesta River water flow (K_i index) at the points near Yakoruda and Khadzhidimovo show that a definite regularity in the river flow formation exists.

The multi-year average atmospheric precipitation (H_o) at Jakoruda station is 641 mm, at Razlog station is 638 mm and at Gotze Delchev station is 668 mm (TRANSKAT, 2005).

The fluctuations of the h_i index at Yakoruda station for the considered period (1955–2003) are given on Fig. 5.

The trend is presented by a linear function with a value of the correlation coefficient $R_t = 0.683$. The dynamics of the h_i index changes from 0.6 to 1.7. Two typical periods are determined: $h_i > 1$ for 1955–1985 (year of increased water resources) and $h_i < 1$ for 1986–2003 (year of decreased water resources). The dynamics of the h_i index is similar to the dynamics of the K_i index and C_i coefficient for 1955–2003. Again, the linear function describing the tendencies in the dynamics of h_i for the observed period cannot be used for prognosis.

The identified trend is obvious, regardless of the fact that from statistical point of view the studied period (49 years) is short and therefore it is difficult to draw conclusions for the impact of climate on the flow. Cyclic changes in the impact of climate on the flow are possible for a longer period, 100 years for instance. Wet, wetter, dry and drier years are distinguished in the studied interval. The multi-annual dynamics of the flow exhibits a decreasing trend for the studied period.

On the basis of the investigations carried out, the conclusion can be drawn that there is a stable trend towards decreasing the average annual water volume of the Mesta River (K_i, C_i) and decreasing the annual average atmospheric precipitation (h_i).

The present results confirm the importance of using the integral assessment of climate and human impact within a catchment area as a reliable tool for water management (Diadovski *et al.*, 1995; 2000).

Conclusion

1. Using the integral method, the changes in the flow of the Mesta River in Bulgaria have been evaluated. The changes in the levels of the proposed indicators: Q_i/Q_o, $(Q_i - Q_o)/Q_o$ and H_i/H_o for a multi-annual period allow the integral assessment of climate impact on the river flow formation. Periods of increased water resources (1955–1982) and decreased water resources (1983–2003) compared to the flow norm (Q_o) for the respective interval have been determined. It may be accepted that those changes represent the climate impact under conditions of insignificant economic activity in the catchment.
2. A decreasing trend is identified for the dynamics of the index K_i and coefficient C_i for the investigated stations Yakoruda and Khadzhidimovo during the period 1955–2003. This trend is related with

the decreasing trend in the fluctuations of the average annual atmospheric precipitation (h_i) for that period.

3. The linear function describing the trends in the changes of the index K_i and the coefficient C_i turns out to be an adequate model for their dynamics as well. This shows that there is regularity in the river flow formation and atmospheric precipitation. The linear functions cannot be used for prognoses.
4. The retrospective analysis of the Mesta River flow and of atmospheric precipitation is used for the integral assessment of the impact of climate factors on river flow formation.

The achieved results allow us to propose functionally simple for implementation indicators and criteria for integral assessment of the impact on river flow formation.

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