Abstract: The present work considers the use of an original integral method for evaluation of the climatic and anthropogenic impacts on the average annual water volume and on the maximum and minimum water flow of Mesta River in the Bulgarian territory. The level of impacts and the respective risk assessment is determined by the index $K_i$, flow module, which accounts for the deviation of the average annual water flow $Q_i$ from the flow norm $Q_0$. Another index $M_{max,i}$ reflects the deviation of the maximum water flow from the maximum flow norm $Q_{max,0}$ and the index $M_{min,i}$ considers the deviation of the minimum water flow from the minimum flow norm $Q_{min,0}$. In order to assess extreme events (floods, droughts) using the dynamics of the integral indices $M_{max,i}$ and $M_{min,i}$, histograms to estimate the frequency of appearance of their values in chosen time intervals were constructed. The function adequately describing the distribution of the frequency of appearance of $M_{max,i}$ and $M_{min,i}$ is a polynomial of third degree. The new approach offered includes an introduction of more specific indicators for assessing the risk of climatic impacts assessment on the river water flow ($K_i$, $M_{min,i}$ and $M_{max,i}$). This is made for the first time in risk assessment of climatic impacts and has been checked at two monitoring sites from the national monitoring net of Mesta River - Yakoruda site (at the spring of the river) and Khadzhidimovo site (at the Bulgarian/Greek border) for the period 1955-2008. It has to be stressed that the indices are integral in their nature because they reflect specific climatically caused events like abundant water years, dry years, floods and droughts.

Keywords: integral indices, climate impact, risk assessment, river flow, extreme event

Introduction

The transboundary Mesta River is located in Western Bulgaria, with catchment area of 2768 km², 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 EU Water Framework Directive (EU WFD) prescribes good water quality as a goal for all water bodies within a given catchment. To achieve this status, each EU country should develop an optimal management strategy [1-4].

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 Sea.

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.

The characteristics of the Mesta River natural flow are basically assessed according to the information coming from two typical hydrometric stations - the Yakoruda site in the upper river flow and the Khadzhidimovo site in the lower flow 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 [5].

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 [6-8]. Many authors believe that a period of warming will characterise the coming decades. Others are more reserved on the issue [9, 10]. 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 determine:

- the tendency of the annual average value dynamics of the Mesta River water during the period 1955-2008 with respect to climate impact;
- the tendency and the frequency of appearance of the multiannual dynamics of absolute maximum values of the river flow with respect to the risk assessment of flood events during the 1955-2008 period;
- the tendency and the frequency of appearance of the multiannual dynamics of absolute minimum values of the river flow with respect the risk assessment of drought events for the same period.

It is our conviction that principally difficult for prediction of climate changes at regional or even global level could be assessed. In previous papers, the authors investigate the dynamics of the module coefficients $K_i$ as a background for integral assessment of the climatic impact on the river flow formation [11]. Usually, these module coefficients are applied for calculation of the coefficient of variation of the flow for a certain period. The
risk assessment of flood events is a priority for all EU countries. A special Framework Directive 2007/60/EO of the European Parliament and Council for management of the flood risk has been recently accepted [12].

The main objective of this study is to help in improving the management of the surface water quality in a transboundary river basin. In principle, the results obtained could be used on a more large global scale.

**Experimental**

The retrospective analysis of the river water flow dynamics is performed on the basis of information collected at the two hydrometric stations. For this purpose the Origin 6.0 software [13] has been applied for data analysis.

Different functions were considered in the trend analysis for certain periods - linear, exponential, second and third degree polynomials. The type of the function describing the trend was determined on the basis of statistical criteria as correlation coefficients and Fisher tests [14, 15]. The function representing the trend can be used for short-term (up to 1 year) prediction of the river flow dynamics, if a statistically significant trend is found.

In principle, statistical methods are often used in hydrological studies for the assessment of climatic and anthropogenic impact on the river flow formation in a specific cross-section of the river basin [13-15]. Usually, a statistical comparison of the natural and disturbed state of the river flow is performed in order to assess the climatic impact on the flow.

In the present work, the integral approach to evaluating the level of climate impact on the river flow formation is applied following earlier studies of Diadovski et al [1, 11, 16]. The proposed approach is based on interpretation of the average multiannual river flow $Q_0$ (flow norm), the ratios between the annual average flow $Q_i$ and the flow norm. With respect to the risk assessment of flood or drought events, specific integral indicators are introduced, which are based on the ratios between the highest water discharge for the year $Q_{\text{max,i}}$ to the multiannual-average value of the maximum water discharge $Q_{\text{max,0}}$ and on the ratio between the minimum water discharge $Q_{\text{min,i}}$ to the multiannual-average value of the minimum water discharge $Q_{\text{min,0}}$.

These relations form indices used for determination of the effect of climatic and anthropogenic factors on the flow formation. The longer the period of observation, the less the error in calculation of the flow norm. The proposed approach is applied to the Mesta river catchment Bulgarian territory.

The proposed indices are as follows:

\begin{align*}
K_i &= Q_i / Q_0 \\
M_{\text{max,i}} &= Q_{\text{max,i}} / Q_{\text{max,0}} \\
M_{\text{min,i}} &= Q_{\text{min,i}} / Q_{\text{min,0}}
\end{align*}

The fluctuations of the $K_i$, $M_{\text{max,i}}$ and $M_{\text{min,i}}$ indices for a certain period give the possibility of making integral assessment of the climatic and anthropogenic impact on the river flow formation and risk assessment using extreme events of the past and the integral indices.
Fig. 1. Mesta River catchment with its monitoring net

Following background considerations were taken into account to construct the hypothesis for risk assessment:

• If the maximal water flow values are higher than the norm \(M_{\text{max,i}} > 1\), one could account for extreme events (floods) in the past; the higher the integral indices \(M_{\text{max,i}}\) than 1, the higher the flood risk. It means that the higher the level of deviation of the maximal water flow values from the norm \(Q_{\text{max,0}}\), the higher gets the risk of flooding \(M_{\text{max,i}} > 2\).
If the minimal water flow values are lower than the norm ($M_{\text{min},i} < 1$) for a certain period one could account for extreme events (droughts) in the past; the lower the integral indices $M_{\text{min},i}$ than 1, the higher the drought risk. It means that the higher level of deviation of the minimal water flow values from the norm, the higher gets the risk of drought ($M_{\text{min},i} < 0.5$).

This hypothesis was checked using data from the sampling stations: Yakoruda and Khadzhidimovo.

From the data sets, one can calculate the correlation between time and index values. Based on the results, one can specify different levels of correlation between time and index values. Due to the basic statistics of the input data, the Spearman correlation coefficient was used throughout the study. Although no exact numbers are given, according to different environmetric studies [17-19], the correlation could be interpreted in the following empirical manner:

- For $0.1 < r < 0.2$, insignificant tendency exists.
- For $0.2 < r < 0.3$, slight tendency is available.
- For $0.3 < r < 0.5$, moderate tendency is established.
- For $0.5 < r$, significant tendency is found.

These values have significance and interpretation only if the number of observations is above 30. In this study it is accepted that the length of the period of observation for calculation of the integral indices is equal to the period used for calculation of the river flow norm. In calculating the coefficient of variation of the hydrological parameters $C_V$, a period of observation $n > 30$ years is a necessary condition for calculation using the empirical formula:

$$C_V = \sqrt{\left(K_i - 1\right)^2 \frac{1}{n}} \quad (4)$$

For small changes in the values of the different hydrological parameters and of the integral indices, a shorter period of observation is needed, and vice versa. In order to check the significance of the correlation coefficient, the calculated value is compared with the theoretical one, which represents in fact the $r$ significance test [17, 18].

In order to assess extreme events (floods, droughts) using the dynamics of the integral indices $M_{\text{max},i}$ and $M_{\text{min},i}$ histograms, the frequency of their appearance in chosen time intervals were constructed. In dependence of the frequency of appearance of the values $M_{\text{max},i} > 1.75$, the probability for risk of floods could be assessed. The same approach can be used for assessment of the probability for risk of droughts if the frequency of appearance of the values $M_{\text{min},i} < 0.5$ is checked.

The function adequately describing the distribution of the frequency of appearance of $M_{\text{max},i}$ and $M_{\text{min},i}$ is a polynomial of third degree. No need for special procedures for fitting of a specific calibration curve to the numerical data is necessary.

By the use of the integral indices ($K_i$, $M_{\text{max},i}$, $M_{\text{min},i}$) for assessment of the climatic factors on the stream dynamics, it could be possible in future studies to estimate the role of climate on formation of high-water and low-water events and, hence, the risk of drought or flood. It might be assumed by our preliminary results that the indices are linked exactly with two latent factors - one explaining flood events and the other - drought events. This idea could find some resemblance with other multivariate statistical studies [19, 20], dealing with river water quality of the Struma River catchment.
Results and discussion

According to Amoros [6], the fluctuations of climate and physical geographic factors provoke trends, including leap-like (catastrophic) events.

In our study, the trends of the basic characteristics of river flow on the basis of integral parameter (\(K_i\), \(M_{\text{max},i}\), \(M_{\text{min},i}\) indices) at the Yakoruda and Khadzhidimovo sites are determined.

The theoretical correlation coefficient of the trend functions at degrees of freedom 54 and a probability of error \(\alpha = 5\%\) has a value \(r = 0.25\). The calculated values of correlation coefficients for the investigated period are in the interval \(0.2 \div 0.59\). This fact shows that the trend model characterizes adequately slight to significant tendency.

The assessment of the flow change in the hydrometrics stations of Yakoruda and Khadzhidimovo for period of 54 years (1955-2008) is made on the basis of integral parameter dynamics (Table 1).

### Table 1

<table>
<thead>
<tr>
<th>Site</th>
<th>Multiannual average river flow (Q_0) [m³/s]</th>
<th>Multiannual average maximum river flow (Q_{\text{max},0}) [m³/s]</th>
<th>Multiannual average minimum river flow (Q_{\text{min},0}) [m³/s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yakoruda site</td>
<td>3.314</td>
<td>31.408</td>
<td>0.580</td>
</tr>
<tr>
<td>Khadzhidimovo site</td>
<td>25.625</td>
<td>253.662</td>
<td>3.564</td>
</tr>
</tbody>
</table>

**Yakoruda site**

The trend in the dynamics of the \(K_i\) index for the Yakoruda point is described by a linear function with \(r = -0.61\) (Fig. 2). The \(K_i\) index shows a decreasing significant tendency.

![Fig. 2. Dynamics of the \(K_i\) index for the Mesta River at the Yakoruda site (\(r = -0.61\))](image-url)
The influence of climate and physical-geographic factors is determined by retrospective analysis of the $K_i$ index. The dynamics of $K_i$ index for Yakoruda point change from 2.3 to 0.25. Three typical periods are determined for this point: first (1959-1975) - period with years of high water resources ($K_i > 1$); second (1976-1999) - one with years of low water resources ($K_i < 1$); and third (2000-2009) - one with years of high water resources ($K_i > 1$).

The trend in the dynamics of the $M_{\text{max},i}$ index (Fig. 3) is described by a linear function with a correlation coefficient $r = -0.62$. A significant trend towards decreasing of the $M_{\text{max},i}$ index is outlined, which corresponds to the trends towards $Q_{\text{max},i}$ for the site.

![Fig. 3. Dynamics of the $M_{\text{max},i}$ index for the Mesta River at the Yakoruda site ($r = -0.62$)](image)

The values of $M_{\text{max},i}$ for this point varies within the range from 0.25÷2.4, which indicated that in the certain years, the maximum water flow $Q_{\text{max},i}$ significantly exceeds the
norm of the maximum water flow $Q_{\text{max},0}$ forming in this way hazardous floods. Years with hazardous flooding are 1955-1965, 1970-1972.

The trend in the dynamics of the $M_{\text{min},i}$ index for the point is described by a linear function with $r = -0.25$ (Fig. 4) - slight tendency is available. The values of $M_{\text{min},i}$ index for the point considered varies within the interval $0.2\pm 2.5$, which indicates that years with minimum water flow, significantly lower than the norm of the minimum water flow $Q_{\text{min},0}$, are observed this forming hazardous of drought periods. These years are 1955, 1960, 1962, 1975, 1992 and 2002.

Studying the dynamics of integral indices $M_{\text{max},i}$ and $M_{\text{min},i}$ we can find the extreme events of both types (floods and droughts).

Using the dynamics of integral indices $M_{\text{max},i}$ and $M_{\text{min},i}$ and information on extreme events from the past, a preliminary assessment of flood and drought events could be made:

- Flood effects during high water are observed in years with $M_{\text{max},i} > 2$.
- Drought effect during low water are observed in years with $M_{\text{min},i} < 0.5$.

Preliminary qualitative estimation of the relationship among the integral indications ($K_i$, $M_{\text{max},i}$, $M_{\text{min},i}$) is achieved by interpretation of the cross correlation table data (Table 2).

![Table 2](image)

**Table 2**

<table>
<thead>
<tr>
<th>Variable</th>
<th>$K_i$</th>
<th>$M_{\text{min},i}$</th>
<th>$M_{\text{max},i}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K_i$</td>
<td>1.00</td>
<td>0.29</td>
<td>0.69</td>
</tr>
<tr>
<td>$M_{\text{min},i}$</td>
<td>0.29</td>
<td>1.00</td>
<td>0.25</td>
</tr>
<tr>
<td>$M_{\text{max},i}$</td>
<td>0.69</td>
<td>0.25</td>
<td>1.00</td>
</tr>
</tbody>
</table>

Significant correlation relation between $K_i$ and $M_{\text{max},i}$, slight correlation between $K_i$ and $M_{\text{min},i}$, and slight correlation between $M_{\text{max},i}$ and $M_{\text{min},i}$ are found.

The distribution of the frequency of appearance of $M_{\text{max},i}$ for the chosen interval is described by a third degree polynomial with $r = 0.79$ (Fig. 5).

![Fig. 5](image)

Fig. 5. Distribution of the frequency of appearance [%] of $M_{\text{max},i}$ for the chosen intervals at Yakoruda site ($r = 0.79$)
The frequency of appearance of $M_{\text{max},i}$ for the interval $1.75 \div 2.0$ is two times, for the interval $2 \div 2.25$ - two times, for the interval $2.25 \div 2.5$ - six times. The probabilities of appearance of $M_{\text{max},i}$ in these intervals are respectively 3.7, 3.7 and 11.1%. The highest frequency of appearance of $M_{\text{max},i}$ is found for the interval $0.5 \div 0.75$ - 26 times with probability of 48%.

The distribution of the frequency of appearance of $M_{\text{min},i}$ for the chosen interval is described by a third degree polynomial $r = 0.73$ (Fig. 6). The frequency of appearance of $M_{\text{min},i}$ for the intervals $0.5 \div 0.25$ is 12 times, for the interval $0.25 \div 0$ is 2 times. The probability for appearance of $M_{\text{min},i}$ for these intervals is, respectively, 22.2 and 3.7%. The highest frequency of appearance of $M_{\text{min},i}$ is found for the interval $0.5 \div 0.75$ - 27 times with probability of 50%.

Fig. 6. Distribution of the frequency of appearance [%] of $M_{\text{min},i}$ for the chosen intervals at Yakoruda site ($r = 0.73$)

*Khadzhidimovo site*

The trend of the $K_i$ index values for the Khadzhidimovo point at the border with Greece are described by a linear function with the correlation coefficient $r = -0.57496$. The $K_i$ index shows a decreasing significant tendency (Fig. 7).

The influence of climate and physical geographic factors is determined by retrospective analysis of the $K_i$ index. The dynamics of the $K_i$ index for the Khadzhidimovo site changes from 2.25 to 3%. The typical periods are determined for this point: first (1955-1975), period with years of high water resources ($K_i > 1$); second (1976-2000) period with years of low water resources ($K_i < 1$) and third (2001-2008) one with years of high water resources ($K_i > 1$).

At Khadzhidimovo site the influence of the Mediterranean climate is most significant and it explains the differences observed.
Fig. 7. Dynamics of the $K_i$ index for the Mesta River at the Khadzhidimovo site ($r = -0.57$)

The trend in the dynamics of the $M_{\text{max},i}$ index is described by a linear function with a correlation coefficient $r = -0.57$ (Fig. 8).

Fig. 8. Dynamics of the $M_{\text{max},i}$ index for the Mesta River at the Khadzhidimovo site ($r = -0.57$)

A significant trend toward decreasing of the $M_{\text{max},i}$ index is outlined, which corresponds to the trend of $M_{\text{max},i}$ at the Yakoruda site.

The values of $M_{\text{max},i}$ for Khadzhidimovo site vary with the range 0.25–3.2, which indicates that in certain years the maximum water flow $Q_{\text{max},i}$ significantly exceeds the norm of the maximum water flow $Q_{\text{max},0}$, forming in this way hazardous floods.


The trend in the dynamics of $M_{\text{min},i}$ index is described by a polynomial third degree with $r = 0.10$ insignificant tendency (Fig. 9).
The values of $M_{\min,i}$ index for the Khadzhidimovo point considered varies within the interval 1.6÷0.5, which indicates that years with minimum water flow, significantly lower than the norm of the minimum water flow ($Q_{\min,0}$), are observed, thus forming hazardous drought periods. These years are 1965-1967, 1982-1988, 1992-1994.

Studying the dynamics of the $M_{\max,i}$ and $M_{\min,i}$ we can found that extreme events of both types (floods and droughts) are observed. This situation could be explained by the climate changes and the physical geographical conditions in the Mesta River catchment.

Preliminary qualitative estimation of the relationship among the integral indicators ($K_i$, $M_{\max,i}$ and $M_{\min,i}$) is achieved by interpretation of the cross correlation table data (Table 3).

<table>
<thead>
<tr>
<th>Variable</th>
<th>$K_i$</th>
<th>$M_{\min,i}$</th>
<th>$M_{\max,i}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K_i$</td>
<td>1.00</td>
<td>0.38</td>
<td>0.66</td>
</tr>
<tr>
<td>$M_{\min,i}$</td>
<td>0.38</td>
<td>1.00</td>
<td>-0.02</td>
</tr>
<tr>
<td>$M_{\max,i}$</td>
<td>0.66</td>
<td>-0.02</td>
<td>1.00</td>
</tr>
</tbody>
</table>

Significant correlation between $K_i$ and $M_{\max,i}$ and moderate correlation between $K_i$ and $M_{\min,i}$ are established. Using the dynamics of integral indices $M_{\max,i}$ and $M_{\min,i}$ and information on extreme events from the past, a preliminary risk assessment of future extreme events such as floods and droughts could be made: flood effects during high water are observed in years with $M_{\max,i} > 2$ and drought effect during low water are observed in years with $M_{\min,i} < 0.5$.

The distribution of the frequency of appearance of $M_{\max,i}$ for the chosen interval is described by a third degree polynomial ($r = 0.82$) (Fig. 10).
The frequency of appearance of $M_{\text{max},i}$ for the interval $1.75 \div 2$ is 2 times, for interval $2.25 \div 2.5$ is 4 times, for interval $2.75 \div 3$ is 2 times and for interval $3 \div 3.25$ is 2 times.

The probability of appearance of $M_{\text{max},i}$ in these intervals is respectively 3.7, 7.4, 2 and 2%.

The highest frequency of appearance of $M_{\text{max},i}$ is found for the interval $0.5 \div 0.75$ - 23 times with probability of 42%.

The frequency of appearance of $M_{\text{min},i}$ for chosen interval is described by a third degree polynomial $r = 0.79$ (Fig. 11).
The frequency of appearance of $M_{\text{min},i}$ for the interval 0.5÷0.25 is 17 times, for interval 0.25÷0 - is 3 times. The probability of appearance of $M_{\text{min},i}$ in these intervals is respectively, 31 and 5.5%.

The highest frequency of appearance of $M_{\text{min},i}$ is found for the interval 0.5÷0.75 - 20 times with probability of 37%.

Using the dynamics of integral indices $K_i$, $M_{\text{max},i}$ and $M_{\text{min},i}$, and information on extreme events and climate changes from the past, a preliminary risk assessment of future extreme events could be made.

**Conclusion**

The character of the changes of annual-average water flow at two river sites with respect to the average multiannual value of river flow $Q_0$ is the one and the same. The character of the changes in the maximum water flow at the river sites with respect to the average multiannual value of the maximum water flow $Q_{\text{max},0}$ is the same. The character of the changes in the minimal water flow at the same sampling points with respect to the average multiannual value of the minimum water flow $Q_{\text{min},0}$ is one and the same, too.

The proposed integral indices provide the possibility of evaluating the climate impact on the Mesta River flow formation but they may also be applied for other rivers on regional, national and transboundary level.

Using integral indicators, high water years, dry years, flood and drought effects are identified which is a preliminary estimation of the risk assessment of flood events and drought events.

With proposed integral indicators it is possible to investigate the influence of climate on the formation of the average annual maximum-minimum water flow and to establish and predict possible hazardous events along the river catchment.

**Acknowledgement**

The authors would like to express their sincere gratitude for the financial support (project DO-02-352) by the National Science Fund of Bulgaria.

**References**


OCENA RYZYKA WYSTĄPIENIA ZJAWISK EKSTREMALNYCH SPOWODOWANYCH PRZEZ RZEKĘ MESTA W BUŁGARI
NA PODSTAWIE ANALIZY WSKAŹNIKÓW INTEGRALNYCH

Abstrakt: Przedstawiono zastosowanie oryginalnej metody oceny wpływu czynników klimatycznych i antropogenicznych na średni roczny, maksymalny i minimalny przepływ wody w rzece Mesta, płynącej przez terytorium Bułgarii. Wpływ poziomu przepływu i ocena ryzyka jest określany przez wskaźnik $K_i$ modułu przepływu, który uwzględnia odchylenie wartości średniego rocznego przepływu $Q_i$ od normy przepływu $Q_{0}$. Indeks $M_{\text{max},i}$ odzwierciedla odchylenie maksymalnego przepływu wody od normy maksymalnej $Q_{\text{max},0}$, natomiast indeks $M_{\text{min},i}$ określa odchylenie minimalnego przepływu wody od normy minimalnego przepływu $Q_{\text{min},0}$. Do oceny częstości występowania zjawisk ekstremalnych (powodzie, susze) w wybranych przedziałach czasu za pomocą indeksów integralnych $M_{\text{max},i}$ i $M_{\text{min},i}$, zastosowano histogramy. Funkcją opisującą rozkład częstotliwości występowania $M_{\text{max},i}$ i $M_{\text{min},i}$ jest wielomian trzeciego stopnia. Proponowane nowe podejście zakłada wprowadzenie bardziej szczegółowych wskaźników oceny ryzyka oddziaływania czynników klimatycznych na przepływ wody w rzece ($K_i$, $M_{\text{min},i}$ i $M_{\text{max},i}$). Metoda została po raz pierwszy wykorzystana do oceny wpływu warunków klimatycznych na przepływ wód rzeki Mesta w punkcie pomiarowym Yakoruda (przy źródle rzeki) oraz w punkcie Khadzhidimovo (na granicy bułgarsko-greckiej). Badania prowadzono w latach 1955-2008. Należy podkreślić, że wskaźniki mają naturę integralną, ponieważ są one wyrazem szczególnych warunków klimatycznych powodujących lata wilgotne, lata suche, powodzie oraz susze.

Słowa kluczowe: wskaźniki integralne, wpływ klimatu, oceny ryzyka, przepływ rzeki, zjawisko ekstremalne