Evaluation of water dissolved oxygen under climate change and its modeling in Bodrog River at Streda nad Bodrogom

Veronika BAČOVÁ MITKOVÁ*

The oxygen is one of indicators of water quality that plays a crucial role in affecting the biological processes in surface water. In the context of the climate change, there are also changes in the oxygen regime of the water in the streams. The paper presents an evaluation of the changes in long-term data of the dissolved oxygen (DO), water temperature $T_w$, biochemical oxygen demand (BOD) and chemical oxygen demand (COD), and flows ($Q$) in the Bodrog River at Streda nad Bodrogom, during the period of 1965–2021. The aim of the study is to detect whether significant trends occur in the time series of analyzed data. The first part of the paper dealt with the trend analyses of monthly and annual data. The results can be useful to quantify the possible threat to its balanced regime. The study showed an increasing trend in the long-term trend of the DO and a decreasing trend in biochemical oxygen demand. The following section is focused on regression between selected components of the hydrosphere and modeling them. The ability to model the components of the hydrosphere is an essential part of water resource management.

KEY WORDS: flow, oxygen water regime, water temperature, long-term trends, interrelationships

Introduction

Water is a renewable but limited natural source, an important component of natural ecosystems. As a result of human activity and climate change, growing of the extreme hydrological and meteorological phenomena in their frequency of occurrence, duration and severity are expected (Dai, 2013; Trenberth et al., 2014; Alfieri et al., 2017; Baiardi and Morana, 2021; Gorbachova and Khrystiuk 2021 or Blaškovičová et al., 2022). That may directly or indirectly affects water quality in surface waters. Due to the multifunctional and multiple use of water, inconsistency between the temporal and spatial distribution of the water sources and requirements as well as from water reuse along the streams it is necessary to coordinate the water managements and use of water resources (Vitaku et al., 2013). In practice, the efforts of all participating actors should be focused on the use, development and protection of water resources in a fair and appropriate way, by applying the concept of sustainable development in the field of water management using the most modern methods at least at the European level (Heinz et al., 2007).

In October 2000 the Water framework Directive (WFD 2000/60/ES) of the EU parliament was adopted. The implicate objective of the Directive is to achieve good status for all water bodies. The EU Water Framework Directive (WFD 2000/60/EC) applies the principle "one-out-all-out" it means that good status must be achieved by each monitored element. The many EU Member States have „forgotten“ to work with the concepts of quantity/quality/condition/potential of surface waters, their interrelationship and interconnection. The EU Water Resources Concept (COM, 2012) states „it is important to recognize that water quality and quantity are closely linked in terms of good condition". On 12th May 2021, the European Commission adopted the EU Action Plan: „Towards zero air, water and soil pollution“ (COM, 2021).

Slovak Hydrometeorological Institute (SHMI) provides the national monitoring and assessment of hydrological characteristics and water quality in Slovakia according to NV No. 269/2010 Z. z. Regulation of the Government of the Slovak Republic. Pekárová et al. (2004) processed a method for identifying long-term trends of individual water quality indicators in surface streams. The methodology was based on the requirements of Directive 2000/60/EC and existing data from the database of the SHMI. In recent years, the evaluation of quality elements on selected profiles of Slovak rivers or the transport of pollution in surface waters was investigated by Pekárová et al. (2009); Noskovič et al. (2013); Hrdličová (2016); Ondrejka Harbuľáková et al. (2017) or Siman and Velísková (2017). These works concluded that the state of water quality after 1989 has generally improved. However, it is still necessary to monitor trends in water temperature, surface pollution
and, in the case of small streams, the trend of pollution by organic or inorganic substances. The type and concentration of chemical elements in the surface waters of streams are changed due to different types of natural processes, which depends on environmental factors influenced by still changing natural and anthropogenic activities. Monitoring of the trends in surface water quantity and quality deserves special attention in the research to quantify the possible threat to its balanced regime.

The DO concentration of the water is one of the important indicators of the water ecosystems status. The oxygen is essential for respiration and survival of the aquatic organisms. The source of the oxygen in water comes primarily from atmosphere by physical diffusion between water-air interface. This process is substantially enhanced by the turbulent mixing of water with air, facilitated by wind and water waves. The oxygen uptake is significantly higher in fast flowing, large and turbulent streams compared with slow-moving streams and lakes. Gas-transfer modelling (Gualtieri and Pulci Doria, 2012) or, if the transferred gas is oxygen, reaeration is most relevant in water quality modelling. Air-water gas transfer velocity determines the transport rate of oxygen, carbon dioxide, methane, and volatile pollutants entering or leaving streams and rivers via the free surface (Raymond et al., 2012). This, affects basic ecological processes in water and has tremendous implications for the global climate system (Bernhardt et al., 2018; Ulseth et al., 2019). Wang et al. (2021) presented physically based scaling models to predict gas transfer velocity for 35 streams and small to medium-sized rivers in the United States based on DO data using an inverse modelling approach.

It is also known that the concentration of DO in water is affected by water temperature, where oxygen has a greater solubility in colder water than in warmer water. As the result of this, the concentration values of DO in the rivers during the colder seasons are higher than during the warmer seasons. The concentration of the DO can be further reduced by adding oxygen-demanding organics to the river systems (e.g. sewage, agricultural waste, lawn clippings, etc.). The impact of climate change on water temperature and oxygen regime has been addressed in papers by Harvey et al. (2011); Danladi et al. (2017) or Rajesh and Rehana (2022). The effects of water pollution are complex and vary depending on the nature and concentration of contaminants (Artemiadou and Lazaridou, 2005). Understanding and analysing their interconnectedness and dependencies deserves equal attention. As was mentioned above, the climate change and anthropogenic activities affect the water quantity and quality with negative impact on hydrological regime of streams. Therefore, it is necessary to know and analyse their changes and the mutual relationship of quantitative characteristics and indicators of water quality. Such knowledge enables prevention and response to a crisis phenomenon and is one of the prerequisites for a quick and correct solution in elimination of its consequences. While the potential impacts of climate change on water availability have been widely studied in recent decades, their impact on water quality is still less researched.

The first objective of the paper is to detect and analyse the changes in the long-term trends of the oxygen regime of surface water in the selected river: Bodrog at the Streda nad Bodrogom station to quantify the possible threat to his balanced regime for the period 1965–2021. The input data were monthly samples of selected water quality indicators (dissolved oxygen DO, water temperature \( T_w \), biochemical and chemical oxygen demand (BOD and COD) and the corresponding daily flows \( Q_d \) on the sampling days. In addition, analysed water temperatures are those at the time of the sampling for water quality.

The second part of the paper is focused on the cross-correlation analysis of selected components of the hydrosphere and to model them effectively. An autoregressive model with a selected regressor was tested in the presented work. For modelling dissolved oxygen depending on water temperature, the model is designed to capture and account for patterns and trends within time series data, including seasonality and periodicity. The ability to model the components of the hydrosphere is an essential part of water resource management.

**Material and methods**

**Study area and data**

To analyse the development, assessment and interrelationship of selected components of the hydrosphere and taking into account the length of observations of the selected components we selected the Bodrog River at the Streda nad Bodrogom station. The period of 56 years (1965–2021) was analysed. From a hydrological point of view, the Bodrog river basin represents a complex river system of four main rivers (Latorica, Laborec, Uh, Ondava). These main rivers meeting each other in a small area, which has an adverse impact on the formation of large waters and flood situations in this location. The Bodrog River itself is formed by the confluence of the rivers Ondava and Latorica near Zemplín. It is a right-hand tributary of the Tisa River. Bodrog has a length of 65 km to the mouth of the Tisza, of which only 15 km is in Slovakia area. Bodrog leaves our territory at an altitude of 94 m a. s. l., which represents the lowest place in Slovakia and crosses the border with Hungary near the villages of Klin nad Bodrogom and Borša. The Bodrog River is the only waterway in Eastern Slovakia (Fig. 1) (it is navigable by larger ships; depending on the water level it reaches a depth of at least 230 cm).

**Hydrological conditions of the Bodrog River in the Streda nad Bodrogom station 1950–2021**

The year 2010 (204.2 m³ s⁻¹) we can classify as wettest year and the driest was 1961 (46.5 m³ s⁻¹) at Bodrog in Stanica Streda nad Bodrogom. The highest flood in Bodrog was in 1979, when the peak flow reached a value of 1200 m³ s⁻¹, but the longest-lasting flood wave occurred in 2006 with a peak flow of 846.4 m³ s⁻¹ and
Bačová Mitková, V.: Evaluation of water dissolved oxygen under climate change and its modeling in... a duration of approx. 61 days. September is the driest month in Bodrog, with a share of 4.1% of the annual runoff. The wet months are March and April, when on average around 31% of the annual runoff flows. Fig. 2 shows the deviation of annual flows from the long-term annual flow for the period 1950–2021, as well as 5-year moving averages.

**Development of selected indicators of the oxygen regime at Bodrog in Streda nad Bodrogom station**

The input data for analysis were monthly samples of selected water quality indicators (dissolved oxygen, water temperature, biochemical and chemical oxygen demand) and the corresponding daily flows on the sampling days. In addition, analysed water temperatures are water temperatures at the time of sampling for water quality. Daily flow values on the day of water quality sampling on the Bodrog at the Streda nad Bodrogom station in the period 1965–2021 are plotted in Fig. 3. The long-term development of monthly values of selected water quality indicators of the Bodrog at the Streda nad Bodrogom station in the period 1965–2021 are plotted in Fig. 4. In order to obtain basic information about water quality, monthly sampling intervals can be considered sufficient, but the case of very significant transport of substances by a flood wave may not be captured.

**Table 1. Basic geograpical characteristics of the Bodrog River: Streda nad Bodrogom**

<table>
<thead>
<tr>
<th>River</th>
<th>Gauging station</th>
<th>Catechment area [km²]</th>
<th>River kilometer [r.km]</th>
<th>Elevation [m a. s. l]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bodrog</td>
<td>Streda nad Bodrogom</td>
<td>11474.25</td>
<td>5.20</td>
<td>91.4</td>
</tr>
</tbody>
</table>

![Fig. 1. Scheme of the main river network of Slovakia with Bodrog River location and scheme of the Bodrog river catchment.](image)

![Fig. 2. Annual and monthly flows of the Bodrog River: Streda nad Bodrogom during the period 1950–2021 (red line – 5-year moving average).](image)
Methods

Trend analysis of the selected monthly and annual oxygen indicators of the surface water

The Mann-Kendall nonparametric test (M-K test) was used for determining the significant trends detection of monthly and annual confrontations of selected indicators of oxygen river regime. The nonparametric tests are more suitable for the detection of trends in hydrological time series, which are usually irregular, with many extremes (Hamed, 2008; Yue, et al. 2002; Gilbert, 1987). MAKESENS 2-tailed test is used for four different $\alpha$ significance levels. The significance level of the test $\alpha$ is a chosen number from the interval from 0 to 1, or 100% (the smaller the better, but $\alpha = 0.05$ or 5%) is most often
used. A significance level of 0.05 means that there is a 5% probability that the values of xi are from a random distribution, and with that probability we make an error in rejecting H0 (the null hypothesis) of no trend. A significance level of 0.001 means that the existence of a monotonic trend is very likely.

We evaluated the significance of the trend in our study at selected significant levels or levels of trend significance.

- ******* – if the trend is at \( a = 0.001 \) – the validity of H0 is improbable.
- **** – if the trend is at \( a = 0.01 \)–1% error in rejecting H0.
- * – if the trend is at \( a = 0.05 \)–5% error in rejecting H0.
- + – if the trend is at \( a = 0.1 \)–10% error in rejecting H0.

Empty – the level of significance is greater than 0.1, we cannot rule out that H0 is true.

The most important trend is assigned three stars (*****), with the gradual decrease in importance, the number of stars also decreases. Statistically, we evaluate the significance of a trend using the Z value. A positive Z value indicates an upward (growing) trend, while a negative value indicates a decreasing trend. If the absolute value of Z is less than the significance level, there is no trend.

**Cross-correlation analysis of selected components of the hydrosphere**

To assess the strength of interdependence between individual selected components of the hydrosphere, the equation (1) was used (Prohaska et al., 2000)

\[
\sigma_R = \frac{1-r^2}{\sqrt{N}}
\]

where
\( \sigma_R \) – correlation coefficient error \( R \);
\( N \) – number of years included in the analysis.

For a significantly different correlation coefficient from zero, criterion (2) must be valid

\[
|R| \geq 3.\sigma_R
\]

By standardizing the random variables, we obtained a new dimensionless measure of dependence, which takes on values from the interval \((-1; 1)\). The sign of the correlation coefficient depends on the covariance, according to which we interpret the value of the coefficient:

- \( R(x,y) > 0 \) ⇔ direct dependence,
- \( R(x,y) < 0 \) ⇔ indirect dependence,
- \( R(x,y) = 0 \) ⇔ independence (correlation).

The most commonly developed models for predicting river oxygen concentrations may be difficult for calculation, e.g. dynamic mass balance models (Gelda et al., 2001), models of artificial neural networks (Rounds, 2002), or extended harmonic analysis, so-called algorithm models (Abdul-Aziz et al., 2007). The simplest model is the regression model, which indicates a linear relationship between water temperature \( T_w \) and DO:

\[
O_2 = a_0 + a \cdot T_w + \varepsilon \quad (3)
\]

or

\[
O_2 = a_0 + a \cdot T_w + WL + \varepsilon \quad (4)
\]

where
\( a_0, a \) – are the parameters of the regression curve,
\( T_w \) – is the water temperature,
\( WL \) – is the height of the water level (enters the equation if it is a significant element),
\( \varepsilon \) – is the error (residue).

Linear and nonlinear modelling for simultaneous prediction of DO and biochemical oxygen demand in surface water was analysed in Basant et al. (2010). Pekárová et al. (2020), used an empirical-regression relationship to indirectly estimate nitrate nitrogen concentrations based on the average daily flow in the sampling days.

Another type of models can be autoregressive models, which forecast future behavior based on past behavior data and there correlation between the time series values and their preceding and succeeding values exists (Faruk, 2010; Wongsathan and Seedadan, 2016; Soltani et al., 2021). For the modelling of DO depending on water temperature, an autoregressive ARIMA model with the selected regressor was tested. The model is designed to capture and account for patterns and trends within time series data, including seasonality and periodicity. The seasonal component is particularly important in the SARIMA model because it allows modelling data with seasonal fluctuations or cycles. The model involves fitting a regression equation to the data, where the dependent variable is the time series data and the independent variables are the series lags and lagged errors. The model is usually estimated using the maximum likelihood estimation, and the accuracy of the model can be evaluated using various statistical criteria. To identify this model, it is necessary to analyze the individual components of the time series in the following order:

- trend identification,
- choosing the type of model and determining the order of the model,
- estimation of model parameters,
- model validation.

The general form of the SARIMA\((p, d, q)\times(P, D, Q)\) model takes the following form:

\[
\phi(B) \varphi(B^d) \varphi(B^D) \psi(B^q) \psi(B^Q) Y_t = \Theta(B) \Theta(B^d) \psi(B^Q) \varepsilon_t, \quad (5)
\]

where:
\( \varepsilon_t \) – independent and normally distributed random variable with zero mean value \( \mu=0 \) and variance \( \sigma_\varepsilon^2 \); 
\( p \) – trend autoregressive order,
\( d \) – trend difference order,
\( q \) – trend moving average order,
The first part of the paper is aimed to evaluate water temperature development and oxygen regime of the Bodrog River at Streda nad Bodrogom during the period 1965–2021. Long-term monthly concentration of selected indicators and as well as water temperature are illustrated in Fig. 5a, b. The maximal long-term monthly concentration of DO was found from December to March. The minimum long-term monthly concentration of DO was observed in July. The analysed corresponding water temperatures show long-term maximum value in summer months (July and August). In terms of long-term monthly concentration of biochemical and chemical oxygen demand, the maximum reached the value 4.1 mg l\(^{-1}\) and 22 mg l\(^{-1}\).

The development of annual concentrations of selected indicators and as well as water temperature are illustrated in Fig. 6a–d. The development of annual DO concentrations shows a significant increasing long-term trend during the period 1965–2021 (Fig. 6a) and Table 2). The development of annual biochemical oxygen demand concentrations shows a significant decreasing long-term trend during the period 1965–2021 (Fig. 6c) and Table 2). The annual values of water temperature in days of sampling and chemical oxygen demand do not indicate a change in the long-term trend (Fig. 6b, c).

The development of monthly concentrations of DO indicates a significant increasing long-term trend in all months of the year (Table 2). The development of monthly concentrations of DO and long-term linear trend in the selected months of February and August are plotted in Fig. 7 a, b. The development of monthly values of biochemical oxygen demand indicates a significant long-term decreasing trend in all months of the year (Table 3). The development of monthly concentrations of biochemical oxygen demand and the long-term linear trend in the selected months of October and August are plotted in Fig. 8 a, b.

**Results and discussion**

**Trend analysis of selected monthly and annual indicators of the oxygen flow regime**

The first part of the paper is aimed to evaluate water temperature development and oxygen regime of the Bodrog River at Streda nad Bodrogom during the period 1965–2021. Long-term monthly concentration of selected indicators and as well as water temperature are illustrated in Fig. 5a, b. The maximal long-term monthly concentration of DO was found from December to March. The minimum long-term monthly concentration of DO was observed in July. The analysed corresponding water temperatures show long-term maximum value in summer months (July and August). In terms of long-term monthly concentration of biochemical and chemical oxygen demand, the maximum reached the value 4.1 mg l\(^{-1}\) and 22 mg l\(^{-1}\).

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![Fig. 5. Long-term monthly values of DO, water temperature \(T_w\), biochemical oxygen demand (BOD) and chemical oxygen demand (COD) in the Bodrog River: Streda nad Bodrogom during the period 1965–2021.](image-url)
Fig. 6. Annual values of selected water quality indicators in the Bodrog River: Streda nad Bodrogom during the periods 1965–2021 and 1991–2021.

a) DO February [mg.l⁻¹] Year Data Sen’s estimate 95 % conf. min 95 % conf. max

b) DO August [mg.l⁻¹] Year Data Sen’s estimate 95 % conf. min 95 % conf. max

c) BODy biochemical oxygen demand y = -0.0568x + 116.76 R² = 0.6042

d) CODy chemical oxygen demand y = 0.1371x - 256.26 R² = 0.1198

Fig. 7. Monthly concentration of the DO and long-term linear trend (black line) with confidence interval (dot line) in the Bodrog River: Streda nad Bodrogom during the period 1991–2021, a) January and b) August.

Fig. 8. Monthly concentration of the biochemical oxygen demand and long-term linear trend (black line) with confidence interval (dot line) in the Bodrog River: Streda nad Bodrogom during the period 1991–2021, a) October and b) August.
Table 2. Results of the M-K test for long-term trend of monthly and annual concentration of DO in the Bodrog River: Streda nad Bodrogom during the period 1991–2021

<table>
<thead>
<tr>
<th>Month</th>
<th>First year</th>
<th>Last year</th>
<th>n</th>
<th>Test Z</th>
<th>Sign.</th>
<th>skew</th>
<th>Corell. R</th>
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<tr>
<td>January</td>
<td>1965</td>
<td>2021</td>
<td>57</td>
<td>4.52</td>
<td>***</td>
<td>0.056</td>
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<td>March</td>
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<td>+</td>
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<td>**</td>
<td>0.029</td>
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<tr>
<td>October</td>
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<td>57</td>
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<td>***</td>
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<td>0.58</td>
</tr>
<tr>
<td>November</td>
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Table 3. Results of the M-K test for long-term trend of monthly and annual concentration of BOD in the Bodrog River: Streda nad Bodrogom during the period 1991–2021

<table>
<thead>
<tr>
<th>Month</th>
<th>First year</th>
<th>Last year</th>
<th>n</th>
<th>Test Z</th>
<th>Sign.</th>
<th>skew</th>
<th>Corell. R</th>
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<tr>
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<td>March</td>
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<tr>
<td>October</td>
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</table>

Correlation analysis of the selected components of hydrosphere

The correlation coefficient between the flow rate $Q_d$ and the selected qualitative indicators reached values in the interval -0.278 to 0.241 (Table 4). According to the criterion (2) some correlation coefficients were significantly different from zero (Table 5). The scatter plots of the dependencies of individual indicators showed, that more of them does not have a linear course. For example, the dependence between the flow $Q_d$ and DO is plotted in Fig. 9 a. From the graphical comparison of all correlation dependencies, the highest linear correlation emerged between qualitative indicators: water temperature $T_w$ and DO when $R$ = -0.845 (Fig. 9b).

Modeling of the dissolved oxygen DO

Several auto regression models were tested to identify a suitable model that would model the DO concentration with water temperature as a regressor. Monthly DO concentrations and monthly corresponding water temperatures were used to calibrate an auto regression model for period 1990–2021. Monthly values of water temperature as a linear ($R_{DO,T_w}$=0.904) and exponential ($R_{DO,T_w}$=0.902) regressors were used. The period 2012–2021 was used for model validation.

Selected SARIMA auto regression models:
(A) SARIMA(0,0,0)x(0,1,1)$_{12}$ constant + 1 lin. regressor,
(B) SARIMA(0,0,0)x(0,1,1)$_{12}$ constant + 1 exp. regressor.
Table 4. Correlation coefficient $R$ between the selected components of the hydrosphere in the Bodrog River at the Streda nad Bodrogom station (1965–2021), (red values - criterion applies $|R| \geq 3. \sigma_R$)

<table>
<thead>
<tr>
<th>$R$</th>
<th>$Q_d$ [m$^3$ s$^{-1}$]</th>
<th>DO [mg l$^{-1}$]</th>
<th>BOD [mg l$^{-1}$]</th>
<th>COD [mg l$^{-1}$]</th>
<th>$T_w$ [°C]</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Q_d$ [m$^3$ s$^{-1}$]</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DO [m$^3$ s$^{-1}$]</td>
<td>0.241</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BOD [m$^3$ s$^{-1}$]</td>
<td>-0.118</td>
<td>-0.158</td>
<td>1.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>COD [m$^3$ s$^{-1}$]</td>
<td>0.166</td>
<td>-0.031</td>
<td>0.202</td>
<td>1.000</td>
<td></td>
</tr>
<tr>
<td>$T_w$ [°C]</td>
<td>-0.278</td>
<td>-0.845</td>
<td>-0.057</td>
<td>-0.004</td>
<td>1.000</td>
</tr>
</tbody>
</table>

Table 5. Values 3. $\sigma_R$ between selected components of the hydrosphere in the Bodrog River at the Streda nad Bodrogom station (1965–2021)

<table>
<thead>
<tr>
<th>$R$</th>
<th>$Q_d$ [m$^3$ s$^{-1}$]</th>
<th>DO [mg l$^{-1}$]</th>
<th>BOD [mg l$^{-1}$]</th>
<th>COD [mg l$^{-1}$]</th>
<th>$T_w$ [°C]</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Q_d$ [m$^3$ s$^{-1}$]</td>
<td>0.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DO [m$^3$ s$^{-1}$]</td>
<td>0.103</td>
<td>0.000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BOD [m$^3$ s$^{-1}$]</td>
<td>0.113</td>
<td>0.112</td>
<td>0.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>COD [m$^3$ s$^{-1}$]</td>
<td>0.149</td>
<td>0.154</td>
<td>0.147</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td>$T_w$ [°C]</td>
<td>0.106</td>
<td>0.034</td>
<td>0.115</td>
<td>0.154</td>
<td>0.000</td>
</tr>
</tbody>
</table>

Fig. 9. Correlation a) linear and logarithmic between corresponding daily flows $Q_d$ and DO, and b) linear and exponential between corresponding water temperature $T_w$ and DO in the Bodrog River: Streda nad Bodrogom (1965–2021).

Table 6. The model estimation errors of selected models and model parameters of the SARIMA (0,0,0) x (0,1,1)$^{12}_{constant}$ + 1 exp. regressor($T_w$) used to model the DO in Bodrog at the Streda nad Bodrogom

<table>
<thead>
<tr>
<th>Model</th>
<th>RMSE</th>
<th>MAE</th>
<th>MAPE</th>
<th>ME</th>
<th>MPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>(A)</td>
<td>0.869626</td>
<td>0.655725</td>
<td>7.6103</td>
<td>0.020077</td>
<td>-0.724278</td>
</tr>
<tr>
<td>(B)</td>
<td>0.810823</td>
<td>0.599878</td>
<td>6.79626</td>
<td>-0.0145233</td>
<td>-0.957048</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Estimate</th>
<th>Std. Error</th>
<th>$t$</th>
<th>$P$-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>SMA(1)</td>
<td>0.905768</td>
<td>0.018092</td>
<td>50.0644</td>
<td>0.000000</td>
</tr>
<tr>
<td>exp regres $T_w$</td>
<td>0.683492</td>
<td>0.101812</td>
<td>6.71327</td>
<td>0.000000</td>
</tr>
<tr>
<td>mean</td>
<td>0.0281473</td>
<td>0.0111421</td>
<td>2.52621</td>
<td>0.012218</td>
</tr>
<tr>
<td>Constant</td>
<td>0.0281473</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

For both selected models the $P$-value values for in their estimated parameters as well as in the simulations were not statistically significant. The model estimation errors and model parameters SARIMA (0,0,0) x (0,1,1)$^{12}_{constant}$ + 1 exp. regressor are listed in Table 6. The graphical result of the validation of the modelling of the monthly concentrations of DO depending on the water temperature by the selected model are illustrated in Fig. 10. The selected model subsequently can be used to predict the concentrations of DO depending on the water temperature $T_w$. Fig. 11 illustrates changes in the DO concentrations if the water temperature is higher about 2°C and long-term monthly residuals from the measured DO concentrations.
Fig. 10. Validation of the selected SARIMA model for modelling monthly DO concentrations with water temperature $T_w$ as exponential regressor of the Bodrog: Streda nad Bodrog (2012–2021).

Fig. 11. Comparison of modelled DO concentrations using the SARIMA(0,0,0) x (0,1,1)12const+1exp model, at recorded temperatures and when water temperature is higher about 2°C in river Bodrog: Streda nad Bodrogom (a) monthly concentrations, b) long-term monthly residuals).

Conclusion

The oxygen is one of the indicators of the water quality and plays a key role in biological processes in surface water. Organic substances in water cannot be monitored and determined individually, because they are capable of oxidation. But we can express their amount/sum by the amount of oxygen for their complete oxidation. Such substances can oxidize, either chemically or biochemically. Chemical oxygen demand is a qualitative estimate of organic water quality and should not be used as the sole parameter for measuring organic loading. Biochemical oxygen demand is an empirical test that measures oxygen demand by bacteria over 5 days. In connection with climate change, there are also changes in the oxygen regime of water in streams. Firstly, the present paper dealt with long-term trend analysis of the development of the monitored indicators of the oxygen regime of the surface water showed a significant long-term increasing trend of annual concentrations of DO, while the indicator of biochemical oxygen demand showed a significant long-term decreasing trend in annual values. The similar course was detected in monthly concentrations of DO, and of biochemical oxygen demand. The indicator of chemical oxygen demand for the period 1991–2021 showed a balanced trend.

Secondly, we determined the correlation dependence of selected components of the hydrosphere and modelled the concentrations of DO in the flow depending on the selected regressor. The results of the correlation analysis showed the closest relationship between monthly concentrations of DO and corresponding water temperature $T_w$. The correlation coefficient for the entire period reached a significant value of $R = -0.845$ (the "−" sign indicates indirect dependence between the variables). The relationship between DO and water temperature is strongly negative (Harvey et al., 2011).
Johnson et al. (2016), state that the exponential model may be more suitable for modelling low DO concentrations at higher water temperatures such as polynomial relationship. The results of our analysis on the Bodrog River in the Streda nad Bodrogom station did not show a significant difference in the correlation coefficient of the linear and exponential dependence of the concentrations of DO and water temperature $T_w$ up to 30°C.

Subsequently, we used an autoregressive model with a different mathematical expression of the water temperature $T_w$ as a regressor on data for the period 1990–2021 to model the monthly concentrations of DO depending on the water temperature of the Bodrog River at the Streda nad Bodrogom station. In the first model, the regressor $T_w$ had linear expression and in the second, it had exponential expression. Model SARIMA(0,0) x (0,1,1)12const+1exp. the regressor achieved slightly better results in the statistical parameters of the estimation during validation with a good fit indicated by a high correlation coefficient of $R=0.931$. In conclusion, however, we can state that both selected regressors can subsequently be used to predict the concentrations of DO depending on the water temperature $T_w$ up to 30°C. An autoregressive model with the appropriate selected regressor is able to model and predict dissolved oxygen as a function of water temperature, captures and takes into account trends in time series data, including seasonality and periodicity. The ability of this model can predict risk states associated with the increase in water temperature and subsequent changes in dissolved oxygen in the water, which allows for early implementation of economically less demanding environmental and water management measures to reduce their negative impacts.

Acknowledgement

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References


