Ecological monitoring of water intake from Belaya river near city of Sterlitamak

N A Bykovsky, E A Kantor, P A Rahman, L N Puchkova and N N Fanakova

Ufa State Petroleum Technological University, 1, Kosmonavtov Street, Ufa, 450062, Bashkortostan, Russian Federation

E-mail: nbikovsky@list.ru

Abstract. Due to increasing anthropogenic impact on water resources, information about the quality of water in water sources is of great importance. This is necessary for both a water service company and for enterprises utilizing desalinated water. We have studied the condition of the source water in the Belaya River near the city of Sterlitamak. The monitoring was carried out by the method of time series analysis for 11 water quality indicators. Seasonal and random components of the water content for various substances were calculated. It has been shown that for some substances their content in water has a seasonal dependence due to a season of the year. This shows their natural origin. The ingress of substances into the river for which there is no seasonal dependence is associated with human's anthropogenic activity. The results obtained in the study of water quality indicators of the Belaya River in the cross section near the city of Sterlitamak can be the basis for increasing the efficiency of water treatment.

1. Introduction

One of the most important natural resources involved in human economic activities is water [1-3]. By the volume of annual consumption, it significantly exceeds all other extracted resources taken together. On the one hand, industrial and agricultural wastes, when getting into rivers, lakes and groundwater, cause their pollution [4, 5]. On the other hand, information about the water quality in the water source is the basis for controlling the operation mode of water treatment facilities, enabling one to predict the consumption of reagents and the sorption cycle of ion-exchange filters. In this regard, environmental monitoring of water bodies is of some interest.

2. Materials and methods

We have studied the condition of water source in the Belaya River section near the city of Sterlitamak. The monitoring was carried out upon 11 indicators, which include: hardness, permanganate oxidizability, alkalinity, the content of $\text{Cl}^-$, $\text{Ca}^{2+}$, $\text{Mg}^{2+}$, $\text{NH}_4^+$, $\text{Fe}^{2+}$, $\text{Na}^+$, $\text{SO}_4^{2-}$ and $\text{SiO}_3^{2-}$ ions. The studies were performed on the basis of analyzes carried out by the Novo-Sterlitamakskaya Heat and Power Plant Laboratory for the last 17 years. A number of researchers [6, 7] found that the water quality indicators of natural water sources have a random, seasonal and trend components, which are detected using time series analysis. To determine these components, sequences, representing time series were formed. Each sequence consisted of 204 values and had strict time limits - 12 values per year. Identification of presence or absence of a cyclic (seasonal) component in the time series is determined by calculating autocorrelation coefficients and constructing correlograms.
If there are cyclical fluctuations in the time series, the values of each subsequent level depend on the previous ones. The analysis of the autocorrelation function and the correlogram makes it possible to determine the lag at which the autocorrelation is the highest, and hence the lag in which the connection between the current and previous levels of the series is the closest. Thus, using the analysis of the autocorrelation function and the correlogram, it is possible to reveal the structure of the series [8]. If the first-order autocorrelation coefficient is the highest, the series under investigation contains only a trend. If the \( n \)-order autocorrelation coefficient is of the highest, the series contains cyclical fluctuations with a periodicity of \( n \) time intervals. If none of the coefficients is significant, we can conclude that the structure of this series does not contain cyclical fluctuations.

3. Results and discussion
According to the described technique, we calculated the autocorrelation coefficients. The results of the calculation are shown in Figures 1, 2.

![Figure 1](https://example.com/figure1.png)

**Figure 1.** Autocorrelation functions: a) hardness; b) oxidizability; c) alkalinity; d) chlorine \( \text{Cl}^- \); e) calcium \( \text{Ca}^{2+} \); f) magnesium \( \text{Mg}^{2+} \).
The data obtained make it possible to divide the content of the previously mentioned water impurities into three groups. The first group of indicators (see Fig. 1) includes hardness, oxidizability, alkalinity, chlorine $\text{Cl}^-$, calcium $\text{Ca}^{2+}$ and magnesium $\text{Mg}^{2+}$. For these, the highest correlation coefficients of 6, 12, 18, 24, 30, 36, 42 and 48-order prevail. This indicates the presence of cyclical (seasonal) fluctuations with a periodicity of 6 months.

Silicate $\text{SiO}_3^{2-}$ refers to the second group of indicators (see Fig. 2a). For this indicator, the highest correlation coefficients are 12, 24, 36, 48-order of magnitude, which indicates the presence of cyclic fluctuations with a periodicity of 12 months.
The third group includes (see Fig. 2 b, c, d, e) such indicators as ammonium $\text{NH}_4^+$, ferrous $\text{Fe}^{2+}$, sodium $\text{Na}^+$ and sulfate $\text{SO}_4^{2-}$. For these water quality indicators, the autocorrelation function varies chaotically, which indicates the absence of any cyclic dependence.

To separate the analytical observations from the data which are characterized by an explicit cyclic dependence, a regular and random component of the process, the theory of time series analysis and correlation-regression analysis was used [9]. Investigation of the influence of different types of trends on the values of seasonal indices in the seasonal decomposition procedure shows that the use of a step function of annual average values and the mean annual value as a moving average does not affect the calculated values of seasonal indices, while the trend values differ insignificantly. This allows us to consider the average long-term values of indicators as a trend and proceed to the consideration of the deterministic component during the annual cycle. Thus, an additive time series model was chosen in which the values of the seasonal component are assumed to be constant for different cycles.

Thus, the time period (17 years) was reduced to the "hypothetical" year, which is a model of the time period. Analysis of regular components variation makes it possible to identify periods, in the annual water cycle of the Belaya River, which have distinguishing characteristics.

So, for the indicators of hardness (Fig. 3a), alkalinity, content of $\text{Ca}^{2+}$, $\text{Mg}^{2+}$ and $\text{Cl}^-$ starting from January, there is an increase in concentration reaching its maximum in March (hardness - 2.4, $\text{Ca}^{2+}$ - 2.23, $\text{Mg}^{2+}$ - 2.13, alkalinity - 2.36, $\text{Cl}^-$ - 2.1 mg-eq/dm$^3$).

![Figure 3](image.png)

**Figure 3.** Determinated components of the Belaya River water quality indicators:

a) hardness; b) oxidizability.

Then, the content of these substances decreases to a minimum in May (hardness - 0.93, $\text{Ca}^{2+}$ - 1.57, $\text{Mg}^{2+}$ - 1.44, alkalinity - 0.96, $\text{Cl}^-$ - 1.6 mg-eq/dm$^3$). Subsequent increase in concentration ends up in August (hardness - 2.46, $\text{Ca}^{2+}$ - 2.13, $\text{Mg}^{2+}$ - 2.33, alkalinity 2.4, $\text{Cl}^-$ - 2.2 mg-eq/dm$^3$).

After that, the impurity content decreases again to a minimum value in October (hardness - 1.84, $\text{Ca}^{2+}$ - 1.9, $\text{Mg}^{2+}$ - 1.95, alkalinity - 1.9, $\text{Cl}^-$ - 1.9 mg-eq/dm$^3$). After that, the concentration increases again. This behavior of hardness, alkalinity, content of $\text{Ca}^{2+}$, $\text{Mg}^{2+}$ and $\text{Cl}^-$ corresponds to the dilution of these impurities during spring and autumn floods.

For the oxidizability (Fig. 3b), in the first period ($i = 1 ... 3$) the concentration drops and reaches its minimum value in March equalling to 1.36 mg/dm$^3$. Then ($i = 3 ... 5$) the concentration increases up to 2.78 mg/dm$^3$ in May, due to the flushing of organic matter into the river during the spring flood. In summer, a rather high COD value, determined by algae reproduction, is maintained. The third period is characterized by a drop in concentration to 1.84 at $i = 9$ due to dilution with autumn rainwater. The fourth period ($i = 9 ... 11$) is characterized by an increase in the concentration to 2.14 mg/dm$^3$ at $i = 11$ which is possibly due to the growth of some microorganisms.
The seasonal component of the indicator $\text{SiO}_3^{2-}$, in spite of pronounced cyclical dependence of the autocorrelation function, has no such characteristic ups and downs as in the previous case. There is a slight decline in concentration in April, June and September.

To clarify the full picture of the behavior of the elements, it is important to know the trend in the concentration change over the period under review. To this end, we calculated the trend and random components of water content of the substances under question [10-12].

Table 1 presents the contributions of the components to the variability of water quality indicators in the Belaya water intake of the city of Sterlitamak.

Table 1. Contributions of the components to the variability of water quality indicators in the Belaya water intake of the city of Sterlitamak.

| Indicators        | Contributions of the components, % |
|-------------------|-----------------------------------|
|                   | Trend  | Seasonal | Random |
| 1. Hardness       | 9.4    | 33.0     | 56.8   |
| 2. Oxidizability  | 0.6    | 20.9     | 78.0   |
| 3. Alkalinity     | 17.8   | 38.2     | 41.9   |
| 4. Chlorine $\text{Cl}^-$ | 1.1    | 33.6     | 64.4   |
| 5. Calcium $\text{Ca}^{2+}$ | 6.7    | 21.5     | 71.8   |
| 6. Magnesium $\text{Mg}^{2+}$ | 6.0    | 26.8     | 66.0   |
| 7. Silicate $\text{SiO}_3^{2-}$ | 0.2    | 23.4     | 76.4   |
| 8. Ammonium $\text{NH}_4^+$ | 5.0    | 5.8      | 89.0   |
| 9. Ferrous $\text{Fe}^{2+}$ | 0.2    | 13.5     | 86.1   |
| 10. Sodium $\text{Na}^+$ | 0.8    | 7.4      | 91.0   |
| 11. Sulfate $\text{SO}_4^{2-}$ | 3.9    | 13.7     | 83.0   |

4. Conclusion
To study the variability of water quality in the Belaya River near the city of Sterlitamak, the time series analysis method was used. Calculation of autocorrelation coefficients and the study of autocorrelation functions allowed dividing all the indicators into three groups.

The first group includes substances for which the highest correlation coefficients are 6, 12, 18, 24, 30, 36, 42 and 48-order. This is the hardness, oxidizability, alkalinity, $\text{Cl}^-$, $\text{Ca}^{2+}$ and $\text{Mg}^{2+}$.

Silicate $\text{SiO}_3^{2-}$ refers to the second group of indicators. For it, the highest correlation coefficients of 12, 24, 36, 48-orders are typical.

The third group includes indicators of $\text{NH}_4^+$, $\text{Fe}^{2+}$, $\text{Na}^+$ and $\text{SO}_4^{2-}$. For these substances, the autocorrelation function varies chaotically, which indicates the absence of any cyclic dependence.

The results obtained make it possible to conclude that for the first and second groups of indicators, their seasonal dependence due to a season is observed. In case of the third group of water quality indicators, the absence of a cyclical relationship means the accidental flow of these substances into the river during sewage discharges by industrial and agricultural enterprises.
The presence of seasonal dependence in substances belonging to the first group of indicators means the influence of autumn and spring floods on the quantity of these indicators. Moreover, for hardness, alkalinity, \( \text{Cl}^- \), \( \text{Ca}^{2+} \) and \( \text{Mg}^{2+} \) during spring and autumn floods, a decrease in their content in water, and for oxidizability - on the contrary - an increase in water content is observed.

The trend component characterizes the tendency of variation of water quality indicators, which has been outlined for the last 17 years. In this case, both an increase and a decrease in water quality indicators are observed.

The results obtained in the study of water quality indicators of the Belaya River near the city of Sterlitamak can be the basis for increasing the efficiency of water treatment.

Acknowledgements
This scientific paper was prepared on the basis of research work within government work No. 5.12863.2018/8.9 of the Russian Federation.

References
[1] Jie Wang, Guijian Liu, Houqi Liu and Paul K S Lam 2017 Science of the Total Environment 583 421-431
[2] Yingyuan Shi, Gaohong Xu, Yonggui Wang, Bernard A. Engel, Hong Peng, Wanshun Zhang, Meiling Cheng and Minglong Dai 2017 Agricultural Water Management 182 24-38
[3] Hovhannisyan Arpine and Shahnazaryan Gayane 2016 Physics and Chemistry of the Earth 94 2-9
[4] Ranran Li, Zhihong Zou and Yan An 2016 Journal of Environmental Sciences 50 87-92.
[5] Ahmed Barakat, Mohamed El Baghdadi, Jamila Rais, Brahim Aghezzaf and Mohamed Slassi 2016 International Soil and Water Conservation Research 4(4) 284-292
[6] Pedan V V 2003 Vodnye resursy 30(6) 688-695
[7] Kantor L I and Shemagonova E V 2002 Vodnye resursy 29(6) 743-744
[8] James A M 1978 Mathematical models in water pollution control (Chichester: John Wiley & Sons)
[9] Eliseeva I I, Kurysova S V, Kosteeva T V, Babaeva I V and Mihaylov B A 2001 Econometrics (Moscow: Statistika i finansy)
[10] Eliseeva I I and Yuzbashev M M 2004 General Theory of Statistics: Course book (Moscow: Finansy i statistika).
[11] Box G E P and Jenkins G M 1976 Time series analysis, forecasting and control (San Francisco: Holden-Day)
[12] Fuller W A 1976 Introduction to statistical time series (New York: John Wiley & Sons)