Features of the impact of thermal power plants on the environment on the example of the Uy River Basin

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Abstract. The probabilistic analysis of intra-annual and interannual variability of river flow in the Uy river basin is carried out using the theory of random processes. The results of the analysis are summarized in terms of a probabilistic model. The regulatory capacity of the catchment area and man-made structures is estimated. Materials of observations made it possible to assess the hydrological structure of flowing water bodies and the impact of waste water from thermal power plants. Analysis of the hydrological and hydrochemical regime of reservoirs has shown that dynamic mixing plays a significant role in the regime of water bodies.

1. Introduction
In the world a large share of electricity (63.2%) is generated by thermal power plants. The environmental impacts of thermal power plants vary significantly by fuel type. The impact factors of solid fuel thermal power plants are emissions from storage systems, transportation, dust preparation and ash removal systems. During combustion, most dust particles and sulphur oxides are formed. Up to 50% of harmful substances are accounted by sulphur dioxide, about 30% - by nitrogen oxide, up to 25% - by fly ash. However, there is nearly no accurate data about the behaviour of these substances in the air. One of the factors of thermal power plants’ interaction with the water environment is water consumption by technical water supply systems, including irrevocable water consumption. The main part of the water consumption in these systems is used to cool the condensers of steam turbines. The remaining consumers of industrial water (ash and slag removal systems, chemical water treatment, cooling and washing equipment) consume about 7% of the total water consumption. At the same time, exactly they are the main sources of the water environment’s impurity pollution. The identification of the features of the water bodies’ hydrological regime in the system: cooling ponds under the influence of the thermal effect of thermal power plants, taking into account climate changes, and the determination of the characteristic differences that arose during anthropogenic intervention, is particularly relevant in these conditions.

2. Materials and methods
Orographically, the territory of the Chelyabinsk Region is located on the borders of the upper reaches of three river basins: the Ural, Kama, and Tobol (Irtysh-Ob), so it is divided into three basins.
In the basin of the Uy River (Tobol-Irtysh-Ob), there are the Yuzhnouralskaya and the Troitskaya hydroelectric power plants operating on solid fuel, and the reservoirs of the same name are used as cooling ponds.

The data about the river flow from the hydro stations of the Federal Hydrometeorological Service were used in the work. To assess the climate, data on precipitation totals and the average monthly and average annual air temperature from observations of weather stations were analysed. The database was formed mainly with the help of publications of Hydrometeoizdat publishing houses and an information resource meteo.ru.

| Name of gauge station | F, catchment area, km² | Period         |
|-----------------------|------------------------|----------------|
| r. Uy – v. Stepnoye   | 3600                   | 1935-2019      |
| r. Uy – The Troitsky fruit-breeding state farm | 7660 | 1938-2019 |
| The Troitsky reservoir on the r. Uy (volume at NRL = 45.0 mln.m³) | 15100 | 1963-2020 |
| r. Uvelka - v. Krasnoselskoye | 3620  | 1965-2019     |
| r. Uvelka - s. Karsinsky | 5100 | 1969-2019     |
| The Yuzhnouralskoye reservoir on the r. Uvelka (volume at NRL = 71.55 mln.m³) | 4750 | 2010-2020 |

| Name of the weather station | Height in m BS | Period         |
|----------------------------|----------------|----------------|
| W.S. Troitsk, precipitation| 180            | 1936-2019      |
| W.S. Troitsk, temperature  | 180            | 1925-2019      |
| W.S. Yuzhnouralsk, precipitation | 207 | 1936-2018 |
| W.S. Yuzhnouralsk, temperature | 207 | 1935-2018     |

For reservoirs, the data provided by the hydraulic structures’ operating organizations were used [1].

3. Analysis of results
The parameters $\varphi_1$ and $\varphi_2$ are used to estimate the flow regulation, and their numerical values are shown in table 1. The parameter $\varphi_1$, which characterizes the correlation between adjacent months within the year, is significant during the low-water period for all points; this reflects the regulatory role of the catchment area.

To analyse long-term variability, we used series of average annual expenditures and annual sequences of values for characteristic months of the year, which were considered as stationary random processes, and used quantile data analysis and low-frequency Butterworth filtering methods [2;3;4].

To estimate the water content of rivers, quantiles were calculated: each time series was considered as the implementation of a random process $x(t)$, the main probability characteristic of which was the distribution function $F(x_p)$ and its quantiles $X_p$. Based on the five quantiles $X_{\text{min}}$, $X_{0.25}$, $X_{0.5}$, $X_{0.75}$ and $X_{\text{max}}$ we estimated $R$ – span, $Q$ – interquartile distance, $T^*$ - three – mean value, and $X_{\text{up}}$ and $X_l$ -the upper and lower bounds of the data distribution in the series.

To identify the features of intra-annual fluctuations, we used series of average monthly flow layers interpreted as periodically correlated random processes. To generalize the results of the analysis, probabilistic models were used in terms of assessing the impact of man-made structures on the water regime of the river.

To determine the trend or trend of increasing or decreasing time series values, digital low-frequency tangent Butterworth filtering was used.
Table 1. Numerical values of estimates of the mathematical expectation of the river flow layer \( m(t) \), variance \( D(t) \), autoregression parameters \( \varphi_1 \) of the intra-annual and \( \varphi_2 \) of the multi-year course of the river flow layer.

| Characteristics | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   | 9   | 10  | 11  | 12  |
|-----------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
|                 |     |     |     |     |     |     |     |     |     |     |     |     |
| m(t), mm        | 0.34| 0.2 | 0.58| 28.75| 9.93| 4.94| 4.36| 3.90| 2.32| 2.35| 1.81| 0.74|
| D(t), (mm)\(^2\) | 0.12| 0.1 | 1.83| 505  | 65.5| 27.14| 39.41| 38.66| 5.68| 4.83| 2.50| 0.31|
| \( \varphi_1 \)  | 0.86| 0.5 | 0.17| 0.41 | 0.36| 0.77 | 0.36 | 0.84 | 0.81| 0.76| 0.73| 0.75|
| \( \varphi_2 \)  | 0.18| 0.2 | 0.19| 0.31 | 0.21| 0.08 | 0.17 | 0.13 | 0.25| 0.43| 0.27| 0.36|
| r. Uy – v. Stepnoye |     |     |     |     |     |     |     |     |     |     |     |     |
| m(t), mm        | 0.93| 0.9 | 2.50| 57.06|16.79| 7.74 | 6.62 | 6.27 | 3.85| 3.93| 2.81| 1.39|
| D(t), (mm)\(^2\) | 0.48| 1.7 | 18.4| 1832 |162  | 65.8| 87.1 |142.7| 14.1|12.4 | 4.77| 0.81|
| \( \varphi_1 \)  | 0.53| 0.2 | 0.15| 0.41 | 0.36| 0.81 | 0.26 | 0.80 | 0.82| 0.82| 0.72| 0.88|
| \( \varphi_2 \)  | 0.42| 0.2 | 0.08| 0.24 | 0.20| 0.06 | 0.20 | 0.03 | 0.21| 0.38| 0.34| 0.38|
| r. Uy – The Troitsky fruit-breeding state farm |     |     |     |     |     |     |     |     |     |     |     |     |
| m(t), mm        | 2.41| 2.5 | 9.33| 94.59|21.26| 9.01 | 7.99 | 7.35 | 4.85| 5.36| 4.52| 3.05|
| D(t), (mm)\(^2\) | 2.73| 2.7 | 78.5| 4387 |253.2| 70.29|133.4 |155.4| 20.99|13.8 | 8.00| 3.93|
| \( \varphi_1 \)  | 0.87| 0.5 | 0.17| 0.50 | 0.37| 0.82 | 0.24 | 0.86 | 0.88| 0.81| 0.81| 0.89|
| \( \varphi_2 \)  | 0.35| 0.44| 0.14| 0.168|0.190|0.217 |0.164 |0.065|0.154|0.11 |0.24 |0.30|
| r. Uy – The Troitsky reservoir target (inflows) |     |     |     |     |     |     |     |     |     |     |     |     |
| m(t), mm        | 2.40| 5.5 | 9.4 | 94.5 |21.3 | 9.0  | 8.0  | 7.34 | 4.84| 5.37| 4.54| 3.05|
| D(t), (mm)\(^2\) | 2.70| 2.7 | 80.3| 4391 |253.3| 70.30|133.5 |155.4| 21.1 |13.8 | 7.87| 3.93|
| \( \varphi_1 \)  | 0.87| 0.49| 0.166|0.501|0.370|0.819 |0.241 |0.863|0.882|0.81 |0.81 |0.9 |
| \( \varphi_2 \)  | 0.34| 0.43| 0.14| 0.168|0.190|0.217 |0.164 |0.065|0.155|0.11 |0.23 |0.30|
| r. Uy – (wastewaters) |     |     |     |     |     |     |     |     |     |     |     |     |
| m(t), mm        | 74  | 70  | 54  | 16  | 94  | 125  | 118  | 121  | 109 | 79  | 51  | 67  |
| D(t), (mm)\(^2\) | 193 | 241 | 380 | 338 | 380 | 1547 | 2521 | 2078 | 1333 |1115 | 420 | 304 |
| \( \varphi_1 \)  | 0.175| 0.171 | -0.01| -0.03| 0.342| 0.215 |0.544 |0.522 |0.648 |0.33 |0.27 |0.15|
| \( \varphi_2 \)  | 0.046| 0.204| 0.15 | -0.11| 0.057| 0.221 |0.303 |0.371 |0.217 |0.38 |0.18 |0.03|
Figure 1. Implementation of hydrometeorological characteristics: A) the average annual air temperature of W.S. Troitsk, B) the amount of precipitation for the year of W.S. Troitsk, C) the average annual flow layer of the river Uy – The fruit-breeding state farm, D) evaporation from the Troitsky reservoir, E) the river Uy- The Troitsky reservoir target (wastewaters), F) the river Uy- The Troitsky reservoir target (inflows).
4. Conclusions

To cover the chemical composition of the Troitsky and the Yuzhnouralsky reservoirs, the materials of the Federal Hydrometeorological Service were used. The materials show that for all points of observation, the chemical composition of water has unambiguous indicators. The reaction of the medium in water changes from neutral to alkaline. The anions are dominated by sulphates, and the cations are dominated by calcium. In winter, the water has an increased hardness, with a dry residue in the range of 500-700 mg/l. A feature of the chemical composition of water is its significant contamination - the excess of the MPC is recorded for most of the components under consideration. The most significant and stable along the length of the water path are the excesses for phosphates, copper, fluorine, zinc and vanadium.

The rate of evaporation from the water surface for the territory of Troitsk in accordance with the full-scale series of observations on GGI-3000 is 700 mm. The average long-term calculated evaporation performed for the Troitsky Reservoir for the period (1963-2019) is – 977 mm.

During the periods of the greatest warming, the values of the average monthly water temperatures in some years exceed up to 29-30°C. Daily highs reach 34-35°C.

The intra-annual distribution of characteristics reflects the properties of Eastern European rivers.

The results of the quantile analysis allowed us to determine that the high-water and low-water years in the period from 1936 to 2019 years are grouped into phases of water content lasting from 3 – 4 to 10 years. In the last 10 years, there has been an asynchrony of fluctuations: high water content is accompanied by a period of low water content on the main river after the reservoir, where seasonal regulation is carried out (figure 1).

In the Uy River basin, there is a tendency to increase precipitation and temperature; this is consistent with the trend of precipitation amounts and the average annual temperature. Atmospheric precipitation is a factor that forms the quasi-cyclicity of processes.

The difference in the parameters of the probabilistic model describing the temporal variability of the flow layer at the point before and after the reservoirs reflects the anthropogenic impact on the flow.

Summarizing the results of the analysis of intra- and inter-annual fluctuations of the flow layer and precipitation in terms of a probabilistic model allows us to assess the regulatory capacity of the catchment area.

References

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