

Basin Model of Total Dissolved Salts Transformation in Water of a Small River (the Kirgizka River, Tomsk, Russia)

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Abstract. The basin model of total dissolved salt transformation in river water has been developed. It was tested in the Kirgizka River, the right tributary of the Tom River (Russia, Western Siberia, Tomsk). It was shown that the river system has the capacity of self-purification and is characterized by rather stable salt composition. It is explained by the fact that the growth in dissolved salt concentration in river water is limited to some extent by, firstly, dilution of more mineralized groundwaters drained by rivers, and, secondly, relatively low solubility of some compounds.

1. Introduction

The effective wastewater treatment is a necessary condition for sustainable development of natural-manmade systems of all levels. However, it is not only quantity and type of treatment facilities that are of great significance, but also standard development for treated wastewater discharge into water bodies within river basins or large water sites. This development includes both administrative and management measures as well as techniques of accumulation and processing of initial information and calculation of permissible concentrations (PC) of pollutants in treated wastewater, at which discharge impact on water body would not result in sufficient deterioration of water quality. Common techniques of PC determination have been developed, described in detail in literature, and included in the list of current regulations in the sphere of environment protection [1–4]. Yet, the technique of basin calculation has not been sufficiently developed, because of which, firstly, it is still a nontrivial problem [2, 5]. Secondly, PC basin calculation is performed relatively rare and, in most cases, the effect is calculated for a single source.

Similar situation is observed in the watershed of the Bolshaya Kirgizka River, a component of “the Bolshaya Kirgizka River – the Tom River – the Ob River – the Kara Sea” system. This area, included into the Northern Industrial hub (NIH) of Tomsk agricultural agglomeration (fig. 1), is characterized by sufficiently high density of residential and industrial sites, which are the sources of great amount of wastewater and pollutants [6–8]. Taking it into account, the authors have developed and tested pollutant transformation model in terms of total dissolved salts (TDS) discharged into the Bolshaya Kirgizka River and its tributaries from lumped sources (discharge of treated and untreated effluents) using average long-term data. Selection of average long-term values is explained by the need for hydrochemical balance calculation based on the average long-term values of hydrological and hydrochemical factors with model parameter optimization not determined directly by experiment, but selected by minimizing the sum of squared differences of calculated and measured concentrations [9].

2. Initial data and research methods



The Bolshaya Kirgizka River flows into the Tom River 58 km from its mouth; the river length – 85 km, catchment area – 898 km²; major tributaries – the Malaya Kirgizka, Omutnaya, Chernaya, Kamenka, Topkaya Rivers (fig. 1).

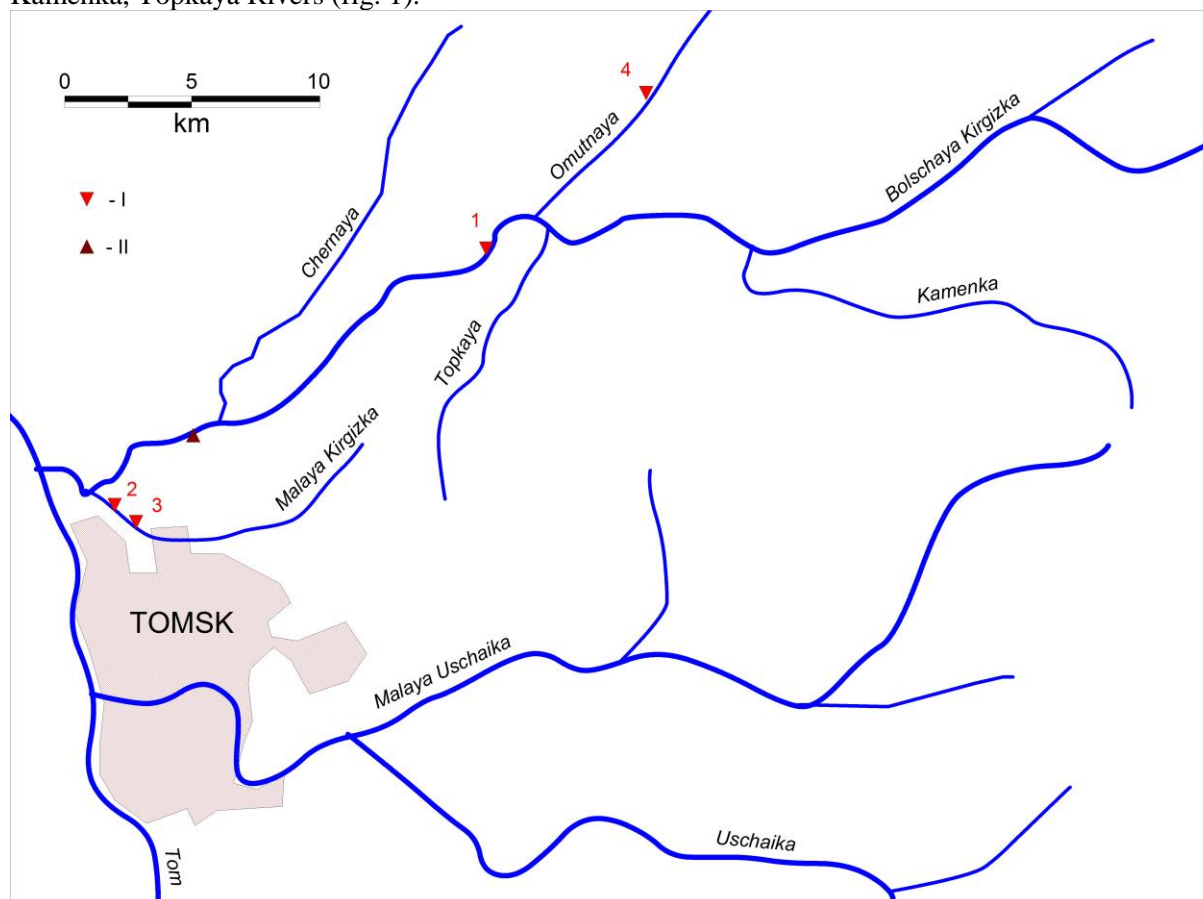


Fig. 1. The scheme of the river network of the study area; symbols: I – wastewater inflow (the number of inflow corresponds to table 1); II – point of hydrological observation on the Bolshaya Kirgizka River

The basic inflows of wastewater of lumped sources come from treatment facilities of Tuganskaya poultry plant (discharge into the Bolshaya Kirgizka River), Tomsk poultry plant (discharge into the Omutnaya River) and JSC “Tomsk plant of chipboard production” (discharge into the Malaya Kirgizka). Wastewater is treated, but the treatment effectiveness is not sufficient enough for a number of substances: maximum – for suspended matter and easily oxidized organic substances in terms of 5 day biochemical oxygen demand (BOD₅); minimum – for nitrogen and phosphorus compounds (in many cases post-treatment is required to remove organic decomposition products; concentration of substances resistant to oxidation in terms of chemical oxygen demand value (COD) and sum of total dissolved salts (TDS) after treatment virtually do not change or change within the margin of error for average value determination [10]. Being the first stage of research, the current paper deals with the changes in sum of total dissolved salts as a basic hydrochemical indicator for assessment of general geochemical condition of the river ecosystem.

The initial data on composition of waste and river water used for calculation of total dissolved salt transformation in water of the Bolshaya Kirgizka River are presented in tables 1 and 2. TDS values of the Malaya Kirgizka and Omutnaya Rivers sources are taken according to table 2 for the upstream points of wastewater discharge, for the sources of the Bolshaya Kirgizka, Chernaya, and Kamenka Rivers – using average values of TDS (467.7 mg/dm³) calculated for downstream points of

the Bolshaya Kirgizka, Malaya Kirgizka, and Omutnaya Rivers from the water discharge. Wastewater discharge is taken as an average value without taking into account daily and hourly irregularity, m^3/sec : wastewater treatment facilities (WTF) of Tuganskaya poultry plant – 0.0110; WTF of Tomsk poultry plant – 0.0151; WTF of JSC “Tomsk plant of chipboard production” – 0.0139; discharge of untreated storm and melt waters – 0.0016. In addition, water abstraction from the Bolshaya Kirgizka River is taken into account in two points in the amount of 0.0048 and 0.0265 m^3/sec .

Table 1. The total dissolved salts in the Bolshaya Kirgizka, Malaya Kirgizka, and Omutnaya Rivers (according to [7, 10])

The number of outlet in fig. 1	Water users	Wastewater receiver	Wastewater description	A , mg/dm^3	N
1	Tuganskaya poultry plant	The Bolshaya Kirgizka River	Before treatment	1189.2	29
			After treatment	1023.4	29
2	“Tomsk plant of chipboard production”	The Malaya Kirgizka River	Before treatment	460.5	8
			After treatment	369.1	8
3	Thermal Power Plant -1	The Malaya Kirgizka River	Sewage system without treatment	473.4	6
4	Tomsk poultry plant	The Omutnaya River	Before treatment	1382.9	17
			After treatment	835.9	18

Note: A – arithmetic average; N – the number of samples

Table 2. The total dissolved salts in the Bolshaya Kirgizka, Malaya Kirgizka, and Omutnaya Rivers (according to [7, 10])

River	Point (the number of outlet in fig. 1)	Point	A , mg/dm^3	N
The Bolshaya Kirgizka River	Rassvet settlement, WTF of Tuganskaya poultry plant (1)	above the outlet	447.1	15
		below outlet	524.6	13
	Tomsk	inlet	265.7	16
The Malaya Kirgizka River	Tomsk, WTF of JSC “Tomsk plant of chipboard production” (2)	above the outlet	516.2	15
		below outlet	454.7	14
The Omutnaya River	Molodezhny settlement, WTF of Tomsk poultry plant (4)	above the outlet	439.8	10
		below outlet	492.4	10
	Tomsk city	inlet	358.7	2

Note: A – arithmetic average; N – the number of samples; WTF – wastewater treatment facilities

Hydrological parameters are taken according to the observation data of the Bolshaya Kirgizka River at Kuzovlevo settlement (fig. 1): mean water discharge $Q=5.17 \text{ m}^3/\text{sec}$; mean unit discharge $M=6.27 \text{ L}/(\text{s}\cdot\text{km}^2)$; mean slope of water surface $S=1.35 \text{ m}/\text{km}$; roughness code of free channel $n_{M,OR}=0.16$. the calculation of hydrological parameters of the Bolshaya Kirgizka River and its tributaries in other points is carried out using the unit of water flow $6.27 \text{ L}/(\text{s}\cdot\text{km}^2)$, catchment area, and dependencies of water discharge, discharge cross section area, flow velocity, and mean depth calculated at the point of Kuzovlevo settlement. In this case, it is sure to be an oversimplified but acceptable assumption based on similarity of morphometric parameters of water flows.

The TDS transformation is calculated by means of the model according to [1, 5]:

$$C_p = C_1 \cdot \exp(-k_C \cdot t_m) + \sum_{i=1}^{N_w} \frac{(C_{w,i} - C_1)}{n_{C,i}} \cdot \exp(-k_C \cdot t_i), \quad (1)$$

where C_p and C_1 – substance concentration in the control point and sources of the Bolshaya Kizgizka River; C_w – substance concentration in wastewater; N_w – the number of pollution sources; k_C – self-purification factor of river water in natural condition and under the impact of i -th outlet or inlet; t_m and t_i – the time of water movement from the source of the Bolshaya Kizgizka River and pollution sources (junctions); n_C – wastewater dilution factor (or water inflow) calculated by Frolov-Rodziller method [3]. The calculation method applicable to the set of sources is described in detail in [5]. The same model is applied to calculate TDS transformations of water inflow. In this case, the TDS value in the junction is presented in the form of source together with wastewater outlets.

3. Results and discussion

The calculation performed has shown that, firstly, the model (1) is an adequate description of average long-term changes in TDS of the Bolshaya Kizgizka River and its tributaries (fig. 2). Secondly, changes in total dissolved salts in river water along the river length are best described by $k_C=0.093 \text{ day}^{-1}$. Therefore, TDS value should be considered as nonconservative. Thirdly, the river system is determined as rather resistant to dissolved salt discharge with wastewater. One of the explanations of this phenomenon is a combination of, on the one hand, dilution of more mineralized groundwater drained with rivers and precipitations, but, on the other hand, interactions in the “water – rock – organic matter” system.

According to Kolubayeva [8], the total dissolved salts in groundwaters of the area ranges from 507 mg/dm³ on average (loose deposit water) to 527 mg/dm³ (rock waters), whereas that of precipitation, the sum of principle ions is typical for this area: rain water in the Tom River basin within Kemerovo Oblast (to the south from Tomsk) – 73.6 mg/dm³; melt water in the territory of Tomsk Oblast – 31.6 mg/dm³ [7].

The effect of the second factor is shown and explained in detail for groundwaters in some works [11–13]. But, the same explanation is applicable for average long-term values of river water. In particular, in [14] it was stated that the most intensive interaction of river water and sediment is observed spatially – in the upstream river flow, but in time – in the flood periods. In this case, the following peculiarities are identified:

1) the state close to equilibrium is mostly observed only in interaction of water with calcite, clay minerals, quartz, metal compounds with humic acids;

2) as for primary aluminosilicates, river waters are undersaturated everywhere and during the whole year, since equilibrium state is limited by calcium extraction from solution in combinations with carbonic and humic acids;

3) the growth of dissolved salt concentrations in the river water – wastewater receiver is limited to a definite extent by relatively low solubility of some principle ion compounds that prevents from increasing total dissolved salts or even results in its decrease [14].

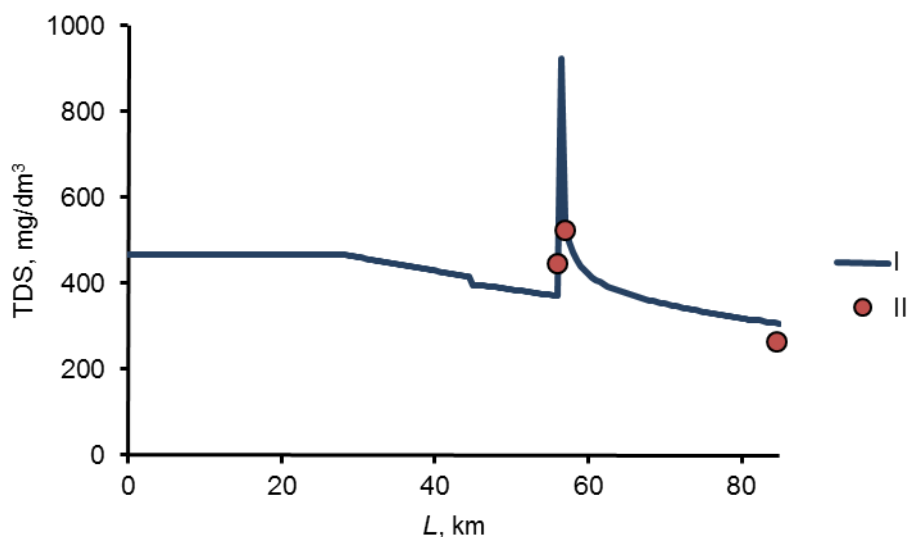


Fig. 2. Changes in predicted (I) and mean measured values of TDS (II) along the length (L) of the Bolshaya Kizgizka River (from the source)

On the whole, the analysis of modeling results (fig. 1) confirms these conclusions and reflects the significant river system capability of self-regulation.

4. Conclusions

In the course of study, the model of total dissolved salt transformation has been developed and tested in the Bolshaya Kizgizka River under the impact of wastewater discharge and the effect of tributaries (the Malaya Kirgizka, Omutnaya, Chernaya, Kamenka, Topkaya Rivers). It is stated that the river system has a significant capacity of self-purification (from inorganic salts) and is characterized by sufficiently stable salt composition. It is explained by the fact that the growth of dissolved salt concentrations in river water is limited to some extent by, firstly, dilution of more mineralized groundwater drained by the rivers and, secondly, relatively low solubility of some compounds. One more important conclusion supported by the modeling results consists in the fact that total dissolved salts should be considered as nonconservative hydrochemical factor that, according to [14], is a complex function of a number of physical, chemical, and biochemical processes in “river water – sediment – river load” system at the surface of catchment basin and active groundwater exchange zone.

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