Influence of natural factors and human impact on water quality in the river Kudma – small tributary of the Cheboksary reservoir

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Abstract. In this paper we present the results of water quality studies in the Kudma River – a small tributary of the Cheboksary reservoir (Middle Volga). The water quality of the river is formed under the influence of karst processes, widespread in its catchment area, as well as heavily polluted wastewater discharge from municipal sewer systems without nutrient removal facilities. Geological features of the catchment cause a significant increase in total dissolved solids and changes in the major ions content from the headwaters to the confluence with the Volga. At the same time, there is a rapid increase in the phosphorus and especially nitrogen content in the water below the places of domestic sewage release into the river. As a result, the Kudma River contributes to the nutrient pollution of the Cheboksary reservoir – one of the most eutrophic lakes in the Volga basin.

1. Introduction

The Volga and most of its tributaries have been subject to significant anthropogenic impact for decades. The construction of dams cascade resulted in increased algal blooms, and presently the trophic status of most of the Volga reservoirs is assessed as eutrophic [1]. According to various researchers, the worst situation is observed in the Gorky and Cheboksary reservoirs, where dangerous outbreaks of blue-green algae bloom occur every year [2-3]. The influx of large amounts of municipal and industrial wastewater into the Volga itself, and into its tributaries makes a significant contribution to this process. At the same time, most of the sewage treatment plants in the region still do not remove nutrients from wastewater, so they remained a major source of nutrient pollution for several decades.

Natural factors also contribute to the chemical composition of the rivers in the Volga basin. E.g., the distribution of karst in the Middle Volga area largely determines the increased total dissolved solids (TDS) and the major ions content in the tributaries of the Cheboksary and Kuibyshev reservoirs [4-5]. When federal agencies measure the level of water pollution, they do not take these aspects into account and classify these natural anomalies as a pollution factor too [6].

Distinguishing between natural factors and human impact, and determining the anthropogenic pollution’s actual contribution to the quality of water in such catchments is necessary to develop effective water quality management strategies.
2. Materials and methods

2.1. Site description

The object of this research is the river Kudma – a small tributary of the Volga in its middle reaches, flowing through the territory of the Nizhny Novgorod Region within the boundaries of the East European Plain (figure 1). The length of the river is 144 km, the basin area is 3,220 km². The river Kudma is fed from various sources with a predominance of snow; the maximum flow occurs during the spring flood. The river Kudma catchment is located within the moraine plain in the north and the fluvioglacial plain in the southeast. Since the western part of the river basin is composed of limestone and dolomite, the territory is subject to karst [7].

![Map of the Kudma River and its tributaries with the sampling points in July 2018](image)

**Figure 1.** The Kudma River and its tributaries with the sampling points in July 2018.

The water quality of the Kudma is a result of the natural karsting and anthropogenic pollution alike, and it changes along its course due to both of these factors. In the upper reaches, before the confluence of the river Setchuga, the Kudma catchment is waterlogged, with practically no economic activities under way there. In the middle and lower reaches, the Kudma and its tributaries flow through the area used mainly for agriculture. Several centuries of agricultural use in the catchment area led to deformation of the Kudma tributaries’ channels, their siltation, and increased inflow of various substances, including nutrients. Also, the river Kudma and its tributaries receive wastewater from more than 20 water consumers, mainly municipal wastewater and sewage from livestock farms. Major pollutants of the Kudma river basin include municipal sewage discharges by the towns of Bogorodsk, Kstovo, and a number of other communities. According to the Russian monitoring service (Roshydromet), due to wastewater discharges the content of organic substances in the river Kudma in recent years exceeded the guidelines more than 100 times. Pollution with nitrogen and phosphorus was also noted.
2.2. Data

To analyse the longitudinal transformation of water quality, at the end of July 2018 we collected water samples at 13 points along the river Kudma from the headwaters to the mouth. Sampling points were appointed at the confluences with the main tributaries, and downstream from largest towns.

The content of inorganic (TIP) and total (TP) phosphorus in the samples was measured using Murphy-Riley method [8]. The content of dissolved inorganic and total phosphorus (DIP and TDP, respectively) was measured the same way using samples filtered through filters with 0.45 μm pore diameter. The content of chlorides, sulphates, calcium, magnesium, potassium, sodium, nitrate nitrogen (NO$_3$-N) and ammonium ion (NH$_4$-N) was measured using the ion chromatography technique [9]. The spectrophotometric method in the ultraviolet range after oxidation using potassium persulfate in alkaline medium was applied to measure the total nitrogen content (TN). The concentration of silicon was measured using the photometric method based on the yellow form of molybdenum-silicic acid. The amount of chemical oxygen consumption (COD$_{oc}$), determined using the bichromate oxidation method, was used as an indicator of the total organic matter content. The concentration of chlorophyll-a (photosynthetic pigment which indicates the level of phytoplankton activity) was measured using the spectrophotometric method. Additionally, general physico-chemical water quality indicators such as electrical conductivity (corrected to 25° C), pH, turbidity, alkalinity, and water colour were measured.

3. Results and discussion

Average value of electrical conductivity in the samples was 1,197 μS/cm, while in the upper reaches of the river (at point 1) it was only 352 μS/cm. The sharpest increase in electrical conductivity (up to 1,017 μS/cm) occurred after the confluence of the river Setchuga. The highest values of electrical conductivity (up to 1,704 μS/cm) were observed closer to the mouth. As for other right-bank tributaries such as the rivers Sundovik and Sura, the main reason for the high water salinity was the geological structure of the territory: water with high TDS concentrations flows into the Kudma from tributaries located in the karst areas (figure 2).

Water turbidity decreases from the headwaters to the mouth from 5.68 to 0.72 NTU, but a noticeable increase was observed at the last sampling point near the village of Vetchak. This may be due to the confluence of the river Ozerka whose waters are highly turbid. Agricultural use of the river Ozerka catchment resulted in increased runoff from the fields, erosion of the banks, and a change in the morphodynamic type of the river bed, which in turn has led to siltation of the river.

![Figure 2. Physico-chemical parameters of water in the Kudma river in July 2018.](image-url)
Water colour in the river Kudma varies from 82.4 TCU in the upper reaches to 27.5 TCU at the village of Vetchak. In the headwaters located in the forest zone the high colour is due to the presence of humic and fulvic acids, while in the eastern part of the basin it is agricultural land use.

In terms of pH, the river Kudma water is slightly alkaline. The range of pH values is rather narrow, from 7.30 to 7.95 with an average value of 7.70. The minimum pH values were observed in the upper reaches of the river, which is due to the high content of humic substances and correlates with the high water colour. Downstream there was a gradual increase in pH values, with the highest ones noted near the mouth of the river at the village of Vetchak.

The alkalinity of water in the river Kudma increases from the headwaters to the mouth in line with the longitudinal changes in electrical conductivity. In particular, at the confluence of the river Setchuga, which flow comes from karst areas, the water alkalinity was doubled. The bicarbonate content is quite high, averaging at 209 mg/l. At points 10-13 a non-zero carbonate content was also noted (on average at 5.88 mg/l), which is probably due to the high photosynthetic activity of phytoplankton in the lower reaches of the river, given the low flow rates.

The major ions content and their ratio significantly change along the length of the river, mainly due to the geological structure of the western part of the catchment. Upstream of the confluence with the river Setchuga, bicarbonates dominate among anions, and calcium (about 30 percent by equivalents) and magnesium (up to 16 percent by equivalents) among cations (figure 3), which corresponds to 18.5 and 5.8 mg/l. Below the confluence of the river Setchuga the major ions ratio in the river Kudma water changes: sulphates become the predominant anion (up to 25 percent by equivalents, or 200 mg/l), while the share of bicarbonate ions decreases to 20 percent by equivalents, magnesium to 11 percent by equivalents, and the calcium content increases to 40 percent by equivalents. Downstream, the proportions of calcium and sulphates continue to increase, against the background of declining shares of bicarbonate ions and magnesium.

![Figure 3](image-url). The content of the major anions and cations in equivalents (sampling points 1, 3 and 13).

Among other major ions, the distribution of chlorides along the river Kudma valley is of particular interest. Their content in the upper reaches of the river is small and amounts to about 2 mg/l; at the confluence of the river Setchuga, it grows to 6 mg/l and does not change until the confluence of the river Velikaya into which the heavily polluted wastewater of the town of Bogorodsk is discharged. Due to this sewage, the chloride content in the Kudma more than doubles, reaching 14.7 mg/l. Further downstream, flowing through the town of Kstovo and its surrounding area, the river receives a large amount of wastewater which raises the chloride concentration in the mouth area to 33.6 mg/l. A similar situation is observed for sodium: its content in the upper reaches is 2.7 mg/l, while due to the polluted waters of the river Velikaya it increases to 15 mg/l, and at the mouth of the river Kudma reaches 25 mg/l.

Changes in COD, which provides an indirect measure of the total organic substances content, allow assessing the organic pollution of the river. The exception is the uppermost reaches of the catchment where high COD values combined with high water color are due to natural humic substances. At the confluence of the river Setchuga COD value almost halves, but then gradually increases all the way to...
the mouth which, judging by the low water colour, is due to human impact. Drastic changes in COD values occur downstream from the confluence of the tributaries (the Velikaya, the Shiloksha, the Unkor, and the Ozerka) that experience significant anthropogenic impact (wastewater discharges, intensive agricultural use), and after the town of Kstovo, due to municipal wastewater discharged directly into the river Kudma (figure 4).

The most striking evidence of anthropogenic pollution of the Kudma is the distribution of nitrogen and phosphorus content in the water [10-13]. In the upper reaches of the Kudma, organic nitrogen dominate, of natural origin and coming from populated catchment areas alike. The predominant inorganic nitrogen form here is ammonium: the ratio of ammonium to nitrate nitrogen is about 2, and the total nitrogen content is 0.88 mg/l. At the confluence of the river Setchuga the ratio of various nitrogen forms changes: the content of nitrates and ammonium increases, while the proportion of organic nitrogen decreases. At the confluence of the river Velikaya in the Kudma, the total nitrogen content increases 2.5 times, with the predominance of ammonium nitrogen (1.6 mgN/l) and low concentration of nitrate nitrogen (0.2 mgN/l); thus the ratio of ammonium to nitrate nitrogen reaches 8.5. All this indicates nitrogen pollution by wastewater discharged by the town of Bogorodsk.

**Figure 4.** COD, silicon, phosphorus and nitrogen content in the river Kudma in July 2018.

Downstream, the changing ratio of nitrogen forms allows to assess the nitrification process (in the course of which ammonium nitrogen is gradually oxidized to nitrates): the ratio of ammonium to nitrate nitrogen is reduced to 0.1 while the total nitrogen content remains almost unchanged. At point 12 the ammonia nitrogen content increases to 0.432 mgN/l again, due to wastewater discharges from the town of Kstovo. The town's municipal sewage is treated for organic matter, but the facilities are not equipped with nitrification and denitrification units, so mineral forms of nitrogen do get into the river. Finally, in the mouth area, at the sampling point near the village of Vetchak, the influence of the river Ozerka can be identified. The catchment area of this river is actively used for agriculture, so organic nitrogen from fertilizers prevails in its waters. Still, the Ozerka waters have a diluting effect on the Kudma, and the total nitrogen content in the mouth area decreases from 2.3 to 2.0 mg/l.

Changes in the phosphorus content are similar to nitrogen, and also reflect the impact of Bogorodsk municipal wastewater (the town is located on the Velikaya river). At its confluence the TP content in the river Kudma almost doubles, from 0.103 to 0.180 mg/l; note that inorganic phosphorus prevails in the dissolved form, while in the organic phosphorus predominates in the suspended form. Further downstream, the proportion of TIP in the total phosphorus content reaches 90%, which indicates
gradual decomposition of organic matter. Diffusive flow from the agricultural area provides an additional source of inorganic phosphorus inflow into the river [14-15].

No anthropogenic effects could be traced in the spatial distribution of silicon in the Kudma water. The most significant fluctuations in the Si content were noted at the confluence of the rivers Setchuga and Ozerka, whose runoffs originate in karst areas. In general, the silicon content in the river water is quite high, growing from 5 mg in the upper reaches to 9 mg/l closer to the mouth (figure 4).

In July 2018 the chlorophyll-a content in the river Kudma was low, despite the favorable weather conditions and increased nitrogen and phosphorus content. The river's trophic state by the average chlorophyll content (2.2 µg/l) is estimated as oligotrophic, and by the maximum (4.2 µg/l) as α-mesotrophic. The low photosynthetic activity of phytoplankton appears to be due to turbulent water movement in the river and increased TDS concentrations, which are unfavourable for the active growth of algae.

4. Conclusion
Chronic water pollution with ammonium nitrogen adversely affects fish populations and other aquatic organisms, slowing down their growth and reproduction and thus making a toxic impact on the entire Kudma river ecosystem [16-17]. The intake of inorganic nitrogen and phosphorus in the Cheboksary reservoir provides an additional source of anthropogenic eutrophication.

At the same time, increased sulphate and TDS concentrations also have natural origin, and should not be seen as pollution. In the federal environmental pollution surveys, sulphates are annually included in the list of the river's anthropogenic pollutants, which is incorrect. An appropriate assessment of the river Kudma water quality is required, primarily to make key decisions on water quality management in the river basin. It was established that the main issue with the quality of the Kudma river water was the discharge of polluted domestic and industrial wastewater into the river and its tributaries by the local communities. Therefore, the priority step in dealing with the Kudma pollution in the framework of the federal targeted programme «The Healthy Volga» should be equipping the municipal wastewater treatment plants with nutrient removal units, to reduce the nutrient load of the Cheboksary reservoir.

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