Hydrological regime of the urban Setun River

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Abstract. According to the results of 2019-2020 studies, we considered the features of hydrological, thermal, ice regime and water turbidity of the small urban Setun River, one of the largest right tributaries of the Moscow River, flowing in the western part of the city of Moscow. The specific discharge from the Setun watershed is 1.5-2 times and the turbidity is 3 times higher than in natural conditions in the upper Moscow River basin. Due to thermal pollution by wastewater, ice cover forms only in the upper reaches of the river during sustained frosts, and water temperature within the city is 1.5-2.5 degrees higher (up to 6 degrees in winter).

1. Introduction

As the urban impact on the environment, including the hydrology of urban rivers, increases with every year, urban hydrology becomes more and more vital in providing sustainable living in society. The results of hydrological studies in cities and towns provide a necessary basis for effective water resources management not only in the urban areas themselves, but in larger river basins as well [1].

The annual runoff from urban areas is on average 10-15% higher than in more natural conditions [2, 3, 4, 5]. The spring flood in large cities has a weaker connection to the total amount of snowfall and meteorological condition of the preceding winter, and if the snow is being transported outside of the city bunds, the annual runoff may even decrease. Urbanization also contributes to an increase in the frequency and size of rain floods [5, 6]. During low flow periods, the minimum flow in urban areas may decrease or increase depending on the structure of water use [3, 4, 5].

The water balance of urban streams is defined not only (and sometimes not so much) by the urban landscape, but also largely by the scale of water consumption and disposal [7]. In some of the small urban rivers and streams, the flow can be composed almost entirely by industrial or municipal wastewater (up to 80% in some seasons), which causes a decrease of seasonal variation of the water discharge [3].

Cities affect the thermal regime of urban rivers in numerous ways [8]. Urban development increases the temperature of water flowing from buildings and pavement [9]. The heat pollution of wastewater can also significantly alter the dynamics of water temperature and ice in urban streams [10].

The sediment yield of urban areas is usually elevated, and can experience an additional increase in periods of massive construction or road work [3, 4, 5]. In non-reinforced riverbeds, channel erosion may also act as a major source of sediment in urban rivers [5].
2. Materials and methods
The aim of this study was to investigate the hydrology of the urban river Setun and to identify its key differences from the regime of natural streams. The Setun River is the largest right-side tributary of the Moskva River within the Moscow City bounds and in all of its upper and middle reaches. It has a length of 38 km and watershed area of 190 km$^2$, and is located in the western part of the city (figure 1). The river flows through Svetlovo and Novo-Poredelkino districts of the city and through the Odintsovo district of the Moscow Region, crosses the Moscow Ring Road near Skolkovo highway, then Aminievo highway and Minskaya street, and flows into the Moskva River below the Burezhkovsky bridge. The main tributaries of the Setun River are rivers Setunka (in upper reaches), Navershka and Ramenka (in lower reaches).

A strip of land upon both banks of the river within the city (from the Moscow Ring Road to the mouth) with an area of about 7 km$^2$ is included in the largest nature reserve in Moscow – the Setun River's Valley wildlife sanctuary. Despite this, the Setun receives municipal runoff from several Moscow districts. For some of its tributaries, wastewater contributes to more than a half of the total runoff. For example, the Navershka River is characterized by unnaturally high runoff from a catchment area of only 8 km$^2$, which is almost entirely generated in the Ochakovo, South Ochakovo, and North Ochakovo industrial zones with many manufacturing facilities, factories, and thermal power plants.

Since August 2019, we conducted monthly water quality monitoring at 7 stations along the course of the Setun River and on two of its largest tributaries – rivers Setunka and Navershka. The procedure included measurements of water temperature and turbidity with YSI ProSolo and ProDSS probes (USA) and visual observation of ice conditions. At the Setun River upstream from its confluence with the Navershka, an Aqua TROLL 600 sonde was set up to log water turbidity every second.

In November 2019, autonomous water level loggers HOBO U20L and Solinst Levelogger 5 Junior were set up at 5 stations (C1, C3, and near C4, C6 and C7) with sampling rates of 30 minutes to provide data on the water balance. Adjustment for air pressure was made with the data from nearby weather stations (Vnukovo, Moscow State University and Balchug). Water discharge at all stations was measured using the velocity-area method with flow velocities measured with the ISP-1M flow meter at 3-6 points per station, depending on the flow. These measurements were used to obtain relationships between the stage (H, cm) and water discharge (Q, m$^3$/s), allowing to calculate daily water discharge values for the entire period of water stage recording. Individual hydrological events were distinguished from discharge hydrographs using the method of baseflow separation [11].
3. Results and discussion

According to the data of the Roshydromet gauging station “zavod Slozhnye Efiry” (0.8 km downstream from C7, 0.6 km from the river’s mouth; operated intermittently in 1974-1988), the Setun River has a typical east-European hydrological regime with a well-defined spring flood. In the reference book for this station [12], calculated hydrological means for the period of 1896-2010 are given: annual mean discharge 2.41 m³/s, discharge per unit area 12.9 L/s·km², coefficient of variation 0.38. In 2020, the mean annual discharge at the final gauge (C7) was estimated by our data as 3.39 m³/s, which approximately corresponds to the 85th percentile, exceeding all of the water discharge values calculated over the period of the Roshydromet station’s operation and is only comparable to the high-water year of 1983. The discharge per unit area increased from 8 L/s·km² above the Moscow Ring Road to 18 L/s·km² in the lower reaches, and seasonal variance was smoothened with coefficient of variation decreasing from 0.8-0.9 to 0.46.

In 2020, frequent winter thaws caused a significant loss of snow cover in the Moscow Region by the end of winter, leading to very minor snowmelt in spring and almost complete absence of a pronounced spring flood (figure 2a). The increase of runoff in the end of February caused by the melting of the remaining snow is almost imperceptible on the hydrograph. The more distinguished flood in early March was caused by rainfall. At the same time, May and June were abnormally rich in precipitation (on average 2 times higher than the long-term mean); in May the mean monthly rainfall was exceeded 3.7 times, with 100 mm of rainfall (200% of the mean) received over 3 days in May 29th – May 31st. This caused an extreme flood with peak discharge at the final gauge reaching the 96th-97th percentile: the measured volumetric flow on June 1st was 10 m³/s, the estimate from high water marks was 18 m³/s, and the discharge calculated from logger data using the rating curve was 22 m³/s.

![Figure 2](image-url) -- Daily water discharge Q, m³/s (a), monthly discharge per unit area M, L/s·km² (b) and water temperature T, °C (c) of the Setun River above the Moscow Ring Road (C3), upstream from the Navershka River (C4) and at the final gauge (C7) in 2020; short-term fluctuations of water turbidity NTU at C4 station in November 27th – December 1st 2019 (d). The dotted line on figure 2a represents the water discharge at “zavod Slozhnye Efiry” station in 1983.
Rivers Navershka and Ramenka significantly affect the Setun River runoff, while the annual flow in the upper (C3) and middle (C4) reaches of the river differ only slightly (figure 2a, b). The discharge per unit area in the upper reaches is comparable to typical values assessed for natural condition of the upper reaches of the Moskva River (watershed of the Mozhaysk Reservoir). However, below the mouths of Navershka and Ramenka the discharge per unit area increases 1.5-2 times – presumably due to a large contribution from industrial wastewater in their runoff, especially in the Navershka.

Tributaries (primarily the Navershka) also have a great impact on the thermal regime and ice conditions of the Setun River. Above Moscow Ring Road, winter water temperatures range within 0-3 °C, which is typical for natural rivers in the area, but in the Navershka it rarely falls below 10 °C, causing the water temperature in downstream Setun to increase almost by 3 °C compared to upper stations (to 4-6 °C) from fall to spring (figure 2c). In summer the water temperature of the Navershka can reach 28 °C, but its effect on the temperature of the Setun River is more local and can be observed only at station C5. Meanwhile, high water temperatures can be harmful to aquatic life; for example, the threshold value for trout, often used to assess unfavorable environmental conditions in aquatic ecosystems, is 21 °C [9]. Water temperature is also a key factor in the spread of bacteria and viruses in aquatic systems [13].

Thermal pollution from wastewater apparently causes a complete absence of ice cover on the Setun below the mouth of the Navershka throughout the entire winter. Stable ice cover was only observed at a small section above Moscow Ring Road with minimal human interference in landscape and flow formation. At the uppermost part of the river (near station C1) and at the section from Moscow Ring Road to the Navershka, incomplete ice cover with open patches of water forms from time to time during extremely cold weather. At C2 station, freezing of the river is hindered by hydraulic conditions (low depth and high flow velocity), as well as the presence of a snow melting facility in the vicinity.

The turbidity of the Setun River for most of the year varied within the range of 10-50 NTU with no clear pattern in its distribution along the length of the river, reaching 100-500 NTU during floods. The most unstable regime of turbidity was observed at the Navershka River due to irregular releases of wastewater. Only singular wastewater release events were observed directly and recorded; in one of these, the turbidity briefly exceeded 1000 NTU and specific conductance increased 30-fold to 20000 μSm/cm. Our logger data indicate that such events occured repeatedly not only at the Navershka, but also at the Setun itself (figure 2d).

4. Conclusion
Our research confirms that urbanized areas significantly affect the hydrology of the entire Setun River. The discharge per unit area in the upper reaches of the river is comparable to natural background values, but increases by 1.5-2 times below Moscow Ring Road. In 2020, an abnormally low spring flood and extreme summer rain floods caused an atypical seasonal distribution of runoff in the entire watershed of the Moskva River, and in the Setun River the contribution of summer runoff to its annual flow exceeded the norm 1.5-2 times.

Municipal and industrial wastewater affect the river’s thermal regime and ice cover as well as water runoff, increasing its mean annual water temperature by 2 °C and winter temperature by 4-6 °C, preventing freezing even during prolonged periods of extreme cold.

The turbidity in the Setun River is on average 3 times higher than in the upper reaches of the Moskva River. Sediment transport in highly urbanized areas is strongly affected by sporadic discharges of wastewater. Much more detailed monitoring is needed to localize particular pollution sources and thoroughly assess their effect on the water ecology of urban rivers.

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