Geo-ecological aspects of water level extremums’ formation in the Don river waterways

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Abstract. The Don river basin has high population density, robust economy, but suffers from lack of water supply in low water level periods and seasons. This fact prompts researchers to study various aspects of the water resource dynamics. The analysis of the water flow volumes is demonstrating the decrease of the maximum spring flood water flows, the increase in the low level season water volumes, the leveling of the water flow volumes throughout the year and lower variance of the yearly water resource fluctuations. The duration of the spring floods and the summer-fall low water periods is increasing, but the flood maximums occur later (by 15-20 days), and the summer-fall low water periods start 15-25 days earlier compared to the previous century. The snow-related spring floods show anomalous patterns in terms of time of onset, duration, and height and shape of the flood wave. Autumn floods are episodic. The small rivers are showing signs of degradation, some of them are disappearing altogether. This is one of the reasons of the water resources depletion and the shift towards the earlier occurrence of the yearly low water level extremums. The low water flows and volumes of the current century pose risks for resource utilization.

1. Introduction
The Don river basin is constantly attracting the researchers’ attention, since the water runoff of the river and its tributaries plays an extremely important role in the economy of the region, covering 368.6 km\textsuperscript{2} in the European part of Russia with the population surpassing 13 million people. This is one of the most densely populated and economically active areas in the country, and the water availability in different seasons as well as sustained supply over multiple years are extremely important for the performance of various enterprises. The research of multiple aspects of the Don river system’s hydrological regimen, water resources formation and availability, water quality and utilization has resulted in publication of numerous articles [1-9], monographs [10-13], a special issue of the Water Resources (Vodnye Resursosy) magazine et al. Despite all the available research data, the modern mechanisms of seasonal water runoff minimums and maximums, multi year formation of high and low water extremums, geo-ecological aspects of water quality and the ways of sustaining water supply in extreme water level formation periods in modern climate are still inadequately studied and require further investigation.
2. Materials and methods
The data for runoff characteristics (monthly and yearly water flow volumes, absolute daily water level minimums and maximums) was obtained from 27 Upper Don water monitoring stations from the onset of observations up to and inclusive of the year 2019. We have also used the cadastral sources like “Surface water resources, Don region, Vol.7”, “Hydrology annual” reports from various years, the regional branch archives of the Federal State Budget Enterprise “Central Black Earth Department of hydro-meteorology and environment monitoring”, as well as internet resources. The information on Voronezh Region water resources utilization has been obtained from the “Annual reports of the Department of Natural Resources and Ecology”, the materials provided by the Voronezh region water resource department of the Don Basin Water Management, yearly state reports “On the status and protection of the environment in the Russian Federation” (internet resources).

The statistical analysis and graphic representation were performed using the generally accepted methods of hydrology information assessment with Statistica and Excel software packages.

3. Results and Discussion
The modern regimen of the river water runoff is a direct and indirect reflection of the global and regional climate dynamics. The decreases in maximal and increases in minimal water flow volumes during summer and winter low water level periods typical for the rivers in the European part of Russia are representative of the pan-European consequences of the global warming in the northern hemisphere. The general tendencies in the minimal and maximal runoffs are well documented, but the genesis of the extremums has not been adequately researched. The geo-ecological consequences of those processes deserve a deeper look.

The spring flood and low water level in the winter are the two phenomenons subject to the biggest changes in the modern climate conditions. The spring snow flood, being a very prominent phase of the water regimen, undergoes changes in the water volumes, duration, timing and extremum’s genesis [3].

The current century more and more often brings the high water season anomalies that were not typical in the previous one. Let’s take a look at the Don river data from the city of Zadonsk.

The Zadonsk hydrology station is located in the upper part of the Don river on the territory of Lipetsk region. The around the clock data collection has been in effect since 1927, so in the year 2020 we have a 94-year worth range of observations. The continuity and consistency of observations, with the exception of the years 1941 and 1974, conforms to the hydrology data statistical requirements and allows for reliable and confident results with the necessary degree of precision.

Let’s take a look at the hydro-graphs of some prominent years: high water 1970, low water 2019, close to average 1973, and 2016 with anomalous timing and genesis of the spring flood (figure 1).

1970 was a very high water flow year in Zadonsk. The hydrology station has registered the most powerful historical spring flood with the term maximum of 6120 m³/s, not seen in the following years up to the current time. The next record year was 1979 with the maximum flow of 4590 m³/s. The flood graph has a typical two-peaked shape due to an early ice breakdown in the Sosna river, the right Don tributary, that lead to an early flood formation. A few days later it was followed by the Don proper flood wave. The flood onset timing in 1970 was statistically average. It began on March 26 with the first peak on April 1. It was followed by a brief decline and another rise to the April 7 historical maximum. The decline lasted till April 27. The flood duration was 33 days. The duration of the spring snow melting was less than average, especially for such a powerful flood.

2019 was an exceptionally low water year. The snow melting lasted for 31 days between February 3 and May 6. The maximal daily water flow of 123 m³/s was only twice as high as the pre-flood (66.0 m³/s) and minimal low level season value (65.0 m³/s), but lower than the multi-year average of 125 m³/s. Considering the fact that according to B.D. Zaikov’s river classification, the ratio between the maximal and
yearly average water flow volumes for Eastern European type of rivers is 20-30, the spring flood of 2019 was anomalous and absolutely atypical.

![Figure 1. Hydrographs of daily Don river water flow volumes in Zadonsk in different years (the numbers depict maximum spring flood water flow values in the respective years).](image)

2016 spring flood was special due to it’s exclusively anomalous genesis. The water level started unusually early on February 16 (daily average flow volume of 86.4 m$^3$/s), and the first peak was registered on February 27 (daily average flow volume of 531 m$^3$/s) followed by a little decrease until March 3, and then another rise from March 4 and the peak on March 6 with the term daily flow of 604 m$^3$/s (daily average flow volume of 545 m$^3$/s). The slow decline to the low water values continued until March 31. Therefore the flood lasted for 46 days and effectively was a winter-spring one.

It is worth mentioning that the flood of 2016 was unusual for many Upper Don basin rivers, like the Bityug river one. It was fueled by rain and snow, started on January 28 (an exceptionally early onset) and lasted until July 7, making it a spring-summer flood. The long period of intense rain 1.5 months in duration was a big contributing factor. There was no other riverbed in the Upper Don Basin that experienced such a merger between the spring snow flood and rain-induced high water season [8].

The modern day spring floods are characterized by increase in duration, decrease in volume and extremums. The flood maximums are influenced not only by the precipitation values, snow cover' thickness and water saturation, but also to a great degree the state of the soil in the previous fall and before the onset of thawing [3,5,6,11]. In the winter of 2016-2017 the soil froze only to the depth of 33cm. The typical value for Voronezh region is 68-98cm. This became the main factor in very low spring flood and maximum water level. The most of the melted snow infiltrates the soil, adds to the groundwater volume replenishment. The residual water runs off to the rivers, forming the riverside and riverbed runoff. The riverside runoff sharply decreases [5].
The spring flood runoff decrease is compensated by the increase in the low season water levels. Some of the above-mentioned articles noted the water level increases during the summer-fall and winter low level periods, the latter demonstrating the biggest changes. The increased winter runoff is due to the multiple February thaws that have become typical in the current century.

The decrease in the maximal and increase in minimal runoff values is accompanied by protracted low overall water volume, that is becoming even worse in the second decade of the current century. After 2006 that saw the maximal water runoff volume surpass the multi-year average by 1.37 times, the values have been seeing a steady decline, and in the low water years of 2015 and 2019 the average annual water runoff volumes were respectively 65.0 and 65.4% of the multi-year average (figure. 2). Figure 2 shows the multi-year average line almost matching the trend line.

**Figure 2.** Average annual water flow volumes of the Don River as measured in Zadonsk for the course of observations

Between 2009 and 2019 the average annual values were equal to or lower than the multi-year average. The Don river water resources as measured in the city of Zadonsk varied between 2.61 km$^3$ (2015) and 5.41 km$^3$ (2012) for the multi-year average of 3.97 km$^3$ a year.

The modern water runoff dynamics bear positive as well as negative hydro-ecological consequences. The decrease in the maximal spring runoff values poses less risk of flood water damage, that leads to higher safety levels for the population and the economy. On the other hand, the long periods between anomalous high water level spring floods can lead to less vigilance exerted by the general population and the authorities in water utilization and management control. The lack of population awareness only exacerbates the potential risks of the fallout from the changes in the river water regimen.

The chronic low water flow volumes of the previous decade create some geo-ecological and water management issues due to seasonal deficits of the water resources. The Upper Don river basin is home to multiple agricultural and production facilities. Municipal and urban engineering has a high demand for water. The commercial wastewater treatment depends on proper wastewater dilution requiring respective optimum water volumes in the rivers and other water objects. The low water years expose the issues of sustaining the reliable water quality and supply, preventing the exhaustion of the water resources.

One could a priori presume that the years of low water extremums’ formation would be the ones of increased hydro-ecological tensions. The calculations demonstrate [1], that the month of August, with some
left and right Don tributary variability, is the one with the highest water resources depletion in the current century. In the previous century it used to occur in September. We are witnessing a contradictory situation: on one hand there’s an increase in the spring flood and summer-fall runoff duration, but on the other – the runoff minimums are forming earlier and the low water period resources are depleted. The decrease of the riverside, spring flood and the spring runoff is causing a synchronous river water level decrease, drying of the smaller water-flows that leads to the river network degradation, the water resource depletion and the increase in hydro-ecological tensions.

The modern problem of the water protection zone and river catch zone utilization for residential construction is neither unique nor specific to the Don river [7]. The buildings and other structures create a buffer zone, obstruct the riverside water runoff and redirection to the river catch, negating the intended role of the water protection zones. The result is that even a slight increase in the spring flood volumes causes the flooding of the neighboring territories. Such conditions were observed in the Don river basin in Voronezh and Lipetsk regions in 2018. The spring river flood that had the levels barely exceeding the multi-year average, caused the flooding of 1500 settlements in the Voronezh region. Our data and the analysis of the reports of the Ministry of Emergency Situations suggest a high probability of the adjacent areas’ flooding starting with just a 5% increase in the maximal water flow volumes.

One of the negative consequences of the lower level spring floods for the agricultural sector is the lack of filling of the multiple ponds, temporary water catchment reservoirs. They play a crucial role in the meliorative agriculture, summer water supply of the cattle farms and the pasturing of cattle. The ponds in the water depleted areas help somewhat overcome the water deficit in the dry periods. But the filling and further functioning of those natural/technogenous water reservoirs strongly depend on the weather conditions. For instance, the anomalously dry 2010 summer season lead to complete or partial pond drying in some areas of the Voronezh region, and the situation was repeated in harsher spring of 2020, that was observed in Voronezh and neighboring regions.

Besides the hydro-geological changes, the filling and functioning of the ponds causes, among other things, the changes in the hydro-chemical composition of the smaller water-flows. For instance, commercial fish breeding causes the increase in nitrogen, phosphorus and organic load content. The periodic emptying of the ponds leads to those compounds penetrating the Don river system, negatively impacting the water quality [15].

The low water quality level in the majority of the Upper Don basin water flows (predominantly class 3 and 4) has been observed in the last 6-10 years. The Donskoy city station reports the water quality as consistently “contaminated” class 4a or 4b [16, 17], that reflects a high anthropogenic load on the water objects, surpassing their self-cleaning capacity, further exacerbated by direct water retrieval and water resource deficit. The deterioration of the water mass quality is caused by the suppression of the capacity of the compound transfer and the assimilating flow dilution capacity. Urban engineering, metal and chemical processing plants and agricultural enterprises are the major sources of water contaminants. The copper, ferrum, phosphorus and phosphate compounds, ammonia and nitrate nitrogen, sulfates and other organic compounds often exceed the threshold limit values and create the critical contamination level [17].

Don river water meets class 3 criteria (“contaminated” and “very contaminated”) further downstream, within Voronezh and Lipetsk regions. Despite 2018, compared to the previous year, being more favorable in terms of water runoff volumes, it has not registered any improvement in the water quality. On the contrary, the amount of discharge section lines carrying “very contaminated” water has increased and amounted to 56.3% of the total. The right side of the Don river water in the city of Voronezh is periodically classified as “very contaminated” due to non-standard wastewater treatment by OOO “Rosvodokanal-Voronezh” [16].
However, some discharge section lines, like in the city of Liski, have seen some water quality improvement, and the amount of negative factors identified in complex assessment has decreased to 5 from 7 out of 12 basic ones [17].

2019 saw little difference in water quality compared to the previous year. There was more variance of quality classes, ranging from “conditionally clean” (class 1) to “contaminated” (class 4 “a” and “b”). The discharge section of the city of Donskoy is consistently demonstrating the most unfavorable ecological situation. The water quality farther downstream is generally better, yet most of the control stations have registered sporadic extreme levels of ferrum compounds, nitrate and ammonia nitrogen, phenols, organic compounds (by biological oxygen demand), and copper [17].

Despite the fact that in the studied periods of time there seems to be no direct relationship between water volumes and water quality, and no correlation can be drawn between the timing of hydrological and chemical changes in the water, one could presume that the decrease of the water runoff volumes without improvements in the quantity or quality of the waste water could lead to sustained or increased hydro-ecological tensions. The observations and calculations based on the 2015-2017 open water data for small rivers Tavrovka and Peschanka in Voronezh city area confirm the hypothesis of risks of critical situation’s development in low water seasons [18]. Those changes are quite possible considering the modern water runoff volume dynamics.

4. Conclusions

The modern Upper Don river basin regimen sees high and low water season’ transformations. The volumes of the spring flooding and spring runoff decrease, the flood extremums also decrease while the duration of the flood increases with anomalous water wave formation. The duration of the summer-fall low level season increases along with the water runoff and extreme runoff values for the summer and winter low level periods. The summer-fall river water depletion starts about a month earlier, leading to shallower rivers and decrease in water resource availability. The critical water volume decreases of 2010, 2019 and 2020, as well as prolonged low water period of 2007-2020 form a potentially dangerous hydrological state that could lead to summer-fall water resources deficiency and problematic water utilization sustainability. This can threaten the success of the state program of environmental and healthcare stability of the Russian people. Preventative measure are needed to preserve the quantity and the quality of the rivers of the Don basin.

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