Changes in runoff and water quality in the catchment areas of the reservoirs

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Abstract. According to experimental data, a significant decrease in the surface slope runoff from agricultural land in recent decades in the southern part of the Russian plain, including the Volga basin, as a result of mainly climate change has been shown. Part of the decrease in surface runoff entering rivers and water bodies from agricultural land is offset by increased runoff from urban areas. In general, the diffuse removal of biogens (nitrogen and phosphorus) has decreased, although in many areas it exceeds their flow into rivers and wastewater reservoirs, in particular in the catchment area of small tributaries of the Cheboksary reservoir.

1. Introduction
Water balance and runoff, water quality on a large part of the Russian plain are no longer natural, and changed as a result of economic activity in the catchments, especially agricultural.

In the forest-steppe and steppe regions, up to 70-80% of the entire territory is plowed and sown; various agrotechnical and agroforestry methods of influence on surface runoff are used. In recent decades, the area of urban territories has been growing rapidly. Climatic conditions are also changing. All this affects the elements of water balance, primarily the flow and water quality.

2. Materials and methods
The data of water balance stations and the results of field studies of the Institute of geography of the Russian Academy of Sciences served as the basis for the judgment on hydrological changes taking place in agricultural fields and urban areas.

For the period of spring flood – the main hydrological phase on the territory of Russia, the comparison of surface slope runoff from the fields occupied by autumn plowing and other fields plowed in the spring, after the end of the spring flood is of particular interest. On the basis of generalization of data of more than 30 water-balance stations located in the European (mainly) and Asian parts of the USSR by "binding" to the size of the river flow for the flood in the areas of their location, the values of the zonal spring surface slope flow were obtained for the two soil types (loamy and sandy), that characterize the river flow up to the beginning of the 1960s, i.e. during the period of calculating the norms of river runoff [4], and for subsequent years. The weighted average values of zonal slope runoff from agricultural fields are obtained using the percentage of different lands and soil types.
Literature data was also used, including data on runoff from individual agricultural lands [1-3], urban areas [4-6], data on the content of biogens in natural waters [7], on water statistics [8], as well as information on the landscape structure of river basins.

The volume of biogens removal from catchments to rivers and reservoirs was determined by multiplying the value of runoff from individual elements of the landscape to the concentration of biogens in flowing water.

3. Results
In the forest-steppe zone during the period of calculation of the river flow rate the flow from the plowland on the loam was less than from the fields unplowed in autumn (winter crops, stubble, perennial grasses) 1.3-2 times, and in the steppe zone – up to 6 times or more. A weighted average of slope surface runoff amounted to the following value (figure 1).

![Figure 1](image-url)

**Figure 1.** Surface slope runoff during different periods in the southern part of the Russian plain. Legend: 1 – northern part of the forest-steppe zone (river flood runoff 80-100 mm); 2 – central part of the forest-steppe zone (river flood runoff 60 mm); 3 – steppe zone (river flood runoff 20 mm)

Later, until the early 1990s, the area of autumn ploughing and the level of agricultural technology increased, while under relatively little changing climatic conditions the weighted average slope flow decreased accordingly (see figure 1).

In subsequent years and up to the present time on a significant part of the Russian plain there is the essential change in climatic conditions, which affects the size of the flow from surface slope and river runoff. Due to the onset of warmer winters, less freezing of the soil, the surface slope runoff of snow origin continued to decline, despite the reduction in the area of autumn ploughing. As a result, the surface slope runoff during the flood period compared to the period of calculation of the runoff rate showed 2-3 times decrease in the forest-steppe and 4-10 times decrease in most of the steppe zone (see figure 1). The decrease in the surface slope flow also led to a decrease in the flow of the river flood, which is well shown in [9, 11]. The influence of autumn ploughing and other agrotechnical methods on the river flow decreased. The calculation according to the method described in [2] shows that the current decrease in the flow of the Volga under the influence of those agrotechnical methods can be estimated at 1-1.5%, that is, at least twice lower than at the level of the 1980s. Surface runoff from urban areas is several times higher than from agricultural land, especially during the warm season. Full river runoff is also higher in urban areas, despite lower underground runoff. Calculations show that 1% increase of the urbanized area leads to the same increase in river flow, and 1% of the waterproof area – to 2-3%. For the Volga basin, urbanized by an average of 1.5-2%, with an increase in the area of urbanized areas compared to the period of calculation of the norm by 1%, the current increase in runoff is estimated to be the same value.
Average concentrations of biogens obtained in recent years as a result of field studies in different areas of the Russian plain are presented in the table 1.

Table 1. The average concentration of nutrients in the modern surface of slope runoff during floods on the territory of the Russian plain (mg/l).

| Type of land                                                                 | Mineral nitrogen | Mineral phosphorus |
|------------------------------------------------------------------------------|------------------|--------------------|
| Forest (deciduous and coniferous)                                            | 3.35             | 0.20               |
| Winter tillage (soil ploughed in autumn)                                    | 7.05             | 0.66               |
| Fields unplowed in the autumn (winter crops, stubble, perennial grasses) and the hydrographic network | 3.22             | 0.39               |
| Non-forested slopes, average                                                 | 4.37             | 0.47               |

In the upstream and underground runoff, the nutrient content is almost twice lower than in the surface runoff from agricultural fields.

The multiplication of the concentrations of biogens presented above by the amount of runoff from individual lands (taking into account its retention in closed negative forms of relief) and their area gives preliminary values of biogen removal in the southern part of the Volga basin (area 610 thousand km²): steppe zone – 4.4 thousand tons of mineral nitrogen and 0.35 thousand tons of mineral phosphorus, forest steppe - 38.2 thousand tons and 3.3 thousand tons respectively, the southern part of the forest zone – 53.0 and 6.5 thousand tons respectively. The total amounts are 95.6 thousand tons of nitrogen and 10.1 thousand tons of phosphorus. Per unit area, the corresponding values would be 157 kg/km² and 17 kg/km². Rough estimates for the whole basin of the Volga give the following value of the removal of mineral nitrogen in the Volga basin –180-190 thousand tons (130 to 140 kg/km²), and phosphorus – 15-20 thousand tons (10-15 kg/km²).

A preliminary calculation of the removal of biogens from urban areas in the Volga basin as a whole for the year was also performed. The estimated value of biogen removal is calculated on the basis that the area of urban territories in the Volga basin is about 2%, and the average concentration of biogens in urban areas (determined by sampling) is 2 mg/l for mineral nitrogen and 0.23 mg/l for mineral phosphorus. From urban areas for the entire Volga basin such removal is estimated at 6-7 thousand tons in the cold period of the year and 10-11 thousand tons in the warm season for mineral nitrogen and 0.8-1.2 thousand tons for phosphorus. This is significantly less than is carried out with runoff from agricultural and forest land, at least during the flood. In terms of mineral nitrogen and phosphorus, the removal of nutrients with wastewater amounted to 70 thousand tons of nitrogen and 3-4 thousand tons of phosphorus in the Volga basin in 2012-2015 [8]. The total (mineral plus organic) amount of nitrogen is 140 thousand tons and phosphorus -10 thousand tons, that is much less than what gives diffuse removal.

More detailed calculations were made for the Cheboksary reservoir, which showed that the determining role in the balance of the biogens in this reservoir is played by the biogen inflow with the flow of the Volga and the Oka rivers, the share of diffuse intake of biogens in which is to be studied. The diffuse removal of biogens from the catchments of small rivers of the Cheboksary reservoir (the rivers Sura, Kudma, Linda, etc.) is 75-95% of the total removal with the flow of these rivers.

4. Discussion
The revealed decrease in the surface slope runoff in the forest-steppe and steppe zones of the Russian plain, explained in 1960-1980 by the increase in the level of agricultural machinery, the growth of the areas of autumn ploughing, and since 1990 mainly by the change in climatic conditions, is quite
obvious. It has contributed to the decline in river runoff, removal of pollutants, nutrients in rivers and water bodies. Less definitely it is possible to judge about the processes occurring in a forest zone.

Above was compared the total diffuse removal of nutrients in the Volga basin and coming from wastewater. However, the actual contribution of nitrogen and phosphorus that are brought with the wastewater in the eutrophication of reservoirs of the Volga is a lot more that shows a comparison with the magnitude of the diffuse removal. Most of the major "suppliers" of wastewater (enterprises and large settlements) are located directly on the banks of the Volga, its reservoirs and large tributaries. Biogens, initially coming mainly to small rivers, travel a long way to the main channel of the Volga and its large tributaries. During this travel self-purification of water takes place and only part of the biogens reaches large rivers and reservoirs. The amount of this part is to be defined during the more detailed research. It is necessary to solve a number of other issues, such as the removal of nutrients with runoff from agricultural and forest lands in the warm seasons during the years with different water content, the ratio of removal from natural lands and as a result of economic activity, the flow of nutrients from livestock complexes, as well as to clarify the value of their concentrations in runoff from individual lands.

5. Conclusion
In recent decades, there has been a significant decrease in spring surface runoff from agricultural area in the southern part of the Russian plain and the Volga basin, mainly due to changes in climatic conditions. It led to a decrease in annual river runoff and especially flood runoff with an increase in runoff of infiltration origin. Part of the decrease in annual runoff was offset by increased runoff from urban areas. In general, the removal of biogens from catchments decreased, but in the basins of small rivers flowing into the Cheboksary reservoir, the share of diffuse removal accounts for the overwhelming majority of the biogens input. The total diffuse removal of biogens to the river network as a whole in the Volga basin has been estimated, but it still to be studied how much of it reaches the reservoirs of the Volga-Kama cascade. The restoration of the currently closed and the organization of new water balance stations, in the programme of work of which an important role should be assigned to the study of water quality, will contribute to the answer to a number of outstanding issues.

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