

# Aspects of the modern biogens runoff formation in the central part of the Russian Plain

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**Abstract.** The removal of biogenic substances (mineral nitrogen and phosphorus) from river catchments and its modern aspects of formation are considered. A rough estimate of the annual water-biogenic balance for the Linda and Kudma river catchments, which are the tributaries of the Cheboksary reservoir, and the river catchments of the Kursk region is presented. It is shown that the diffuse removal of biogens from river catchments exceeds their removal into water bodies with wastewater. Not only anthropogenic, but also natural factors play an important role in the biogens export to the rivers and waterbodies. Recent changes in biogens removal from catchments are assessed.

## 1 Introduction

Further water resources development in the central part of the Russian plain, which is experiencing intense anthropogenic pressure, in many cases is complicated by their poor quality. Knowledge of water quality genesis is an important condition for effective water resources management. Despite the fact that quite a large number of studies have been devoted to this problem, the uncontrolled diffuse (dispersed over the territory) removal of biogenic substances from agricultural, forest and urbanized landscapes, promoting eutrophication and other negative consequences, remains insufficiently studied. But for the surface slope runoff, mainly spring runoff [1-3 etc.], the biogenic substances migration export by other elements of the river basin vertical hydrological structure [4], including underground runoff, usually is not analysed, assuming their contribution to be insignificant. However, very significant changes have occurred in the structure of the water balance over the past decades – the amount of surface slope runoff has significantly decreased and precipitation infiltration has increased [5, 6].

## 2 Methodological specifics and a baseline information

The theoretical and methodological basis of the study is founded on the idea of the river basin vertical hydrological structure [4]. The annual water-biogenic balance method is used as a tool to study its hydrochemical activity. The principle method of its calculation is given in [7]. In this article, on the example of the Linda (75% of the catchment area is occupied

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by forest) and Kudma (43%) river basins and the Kursk region territory (11%), an attempt is made to assess the diffuse removal of biogens, to determine the ratio of natural and anthropogenic factors in it, and to identify recent trends. Along with the surface runoff from the catchment area, the contribution of underground runoff and precipitation to this process is estimated.

The data of Federal Service of Russia for Hydrometeorology and Monitoring of the Environment, Federal State Statistics Service and Federal Agency for State Registration, Cadastre, and Cartography is used as a baseline information. Along with the data on runoff and precipitation for recent years (2008-2018), the data on the runoff structure [8] for the period of normal annual runoff calculation (the early 1960s) were used. The data on the total river flow as well as on its underground and surface components were analyzed. The separation of the runoff hydrograph by types of river alimentation allowed to calculate the underground runoff. The surface component of the runoff was determined by the difference between the river and underground runoff. The source data set also includes the results of field studies carried out in the 2000s by the members of the Institute of Geography RAS (IGRAS), hydrochemical records for recent years (2008-2018), and information about the anthropogenic supply of biogens to the Linda and Kudma river catchments, obtained in the works of the IGRAS on the Federal project "Improvement of the Volga". The assessment of the components of natural biogen supply to river catchments from tree and herbal waste and nitrogen biofixation by plants was performed according to published data [1, 9-11].

### **3 Results and discussion**

#### **3.1 Contribution of individual components of the annual biogenic balance in the Linda and Kudma river basins**

Calculations have shown that in total biogen export by the Linda water flow the share of biogen removal by diffuse flow significantly prevails over their share removed by wastewater which in recent years does not exceed 1%. The diffuse (nonpoint) removal of biogens with different elements of water runoff varies significantly over the years and depending on the seasons.

The current nitrogen anthropogenic load on the Linda basin is relatively low. It exceeds the climate nitrogen background induced by precipitation only by 1.2 times (Table 1). Especially significant is the phosphorus load, which exceeds eightfold the climate background. Moreover, in recent years with mineral fertilizers the Linda catchment receives almost the same amount of phosphorus as with atmospheric precipitation. Input of phosphorus from livestock is predominant (almost 7 times the climatic background), especially in recent years with a low level of fertilizer use.

A low level of mineral fertilization (40% nitrogen, 25% phosphorus of the peak in 1990) [11, 12] led to a negative balance of nitrogen and phosphorus on the arable land, due to their annual removal by crops in the 2000s. However, a significant reduction in the fertilizer use and livestock number has not led to a decrease in the removal of biogens from the Linda river catchment, on the contrary, it has even increased in recent years. This was mainly due to the climate-related increase in the flow of infiltration origin (underground and perched water).

Anthropogenic biogens input to the Kudma river catchment is significantly more than that to the Linda river catchment, and their diffuse outflow with surface and underground runoff also prevails. From the Kudma river catchment about 13% nitrogen and 5% phosphorus have been removed by wastewater in recent years.

**Table 1.** Annual balance of biogenic substances in the Linda and Kudma river basins, kg/km<sup>2</sup>.

Biogenic substances	Input						Export	
	urban population	agricultural population	livestock business	mineral fertilizers	total anthropogenic input	precipitation (climatic background)		
The Linda river basin							The Linda river – v. Vasilkovo	The Linda river – river mouth (1681 km <sup>2</sup> )
Mineral nitrogen	42	20	232	80	374	325	280	212
Mineral phosphorus	7	3	135	18	163	20	7	7
The Kudma river basin							The Kudma river – Kstovo	The Kudma river – river mouth (3246 km <sup>2</sup> )
Mineral nitrogen	102	50	401	367	968	284	298	170
Mineral phosphorus	17	8	196	80	314	20	7.7	10.3

The current phosphorus anthropogenic load on the Kudma catchment is especially high exceeding 16 times the climatic background induced by precipitation (Table 1). The nitrogen load is less – 3.4 times excess.

The cattle breeding and fertilization are the most significant sources of anthropogenic nutrient input to the Kudma river catchment. They make 84% nitrogen and 92% phosphorus in the total anthropogenic input. Moreover, the biogenic load induced by cattle breeding is almost the same in size as induced by crop production. The phosphorus load due to cattle breeding even twice as much.

A significant reduction in fertilizer use and farm stock, a decline of nitrogen and phosphorus in the soil of arable land did not lead to a decrease in the nutrients export from the Kudma river catchment, on the contrary, it even grew (as in the Linda basin) due to an increase in runoff of infiltration origin (underground and perched water). Natural factors in biogens export from the Kudma river basin to the Cheboksary reservoir also prevail. Especially this is the case of nitrogen (74%) and to a lesser extent of phosphorus (53%). The proportion of anthropogenic load is 26 and 47%, respectively.

### 3.2 Modern changes in the nutrients export from the Linda and Kudma river catchments

Compared to the mid-1970s the biogens export by surface and underground flow during the spring flood-time in the Linda basin increased by 26% in recent years (2008-2018). During this period the total flow from the Linda catchment brings to the Cheboksary reservoir 146

kg/km<sup>2</sup> of nitrogen and 3.9 kg/km<sup>2</sup> of phosphorus. The annual removal of nutrients has also increased significantly (by more than 25%, making 280 kg/km<sup>2</sup> of nitrogen and 7 kg/km<sup>2</sup> of phosphorus). The main reason is a significant increase (by 60%) in the hydrochemical role of underground runoff – the annual nitrogen export by it has raised up to 56% and phosphorus up to 46%. In recent years, the role of surface runoff in the removal of phosphorus from the catchment area remains more significant (0.6 kg/km<sup>2</sup> more than with underground runoff).

As for the Kudma basin the removal of biogens by surface runoff during the spring flood-time has not changed much in recent years (2008-2018). However, the role of underground runoff in their migration has increased significantly. 25% more nitrogen and phosphorus began to flow with the underground component of the runoff. As a result, in recent years, the Cheboksary reservoir received 110 kg/km<sup>2</sup> of nitrogen and 3.8 kg/km<sup>2</sup> of phosphorus, i.e. 8% more. Especially significantly increased the annual removal of nutrients (up to 298 kg/km<sup>2</sup> of nitrogen and 7.7 kg/km<sup>2</sup> of phosphorus, 28 and 20% increase, correspondingly), mainly due to a significant increase in underground runoff (by 60%), the contribution of which to the annual runoff of nitrogen increased to 67%, and phosphorus to 56%. In recent years, the river has received from each square kilometer of the catchment area an average of 104 kg more nitrogen with underground than with the surface runoff, and 1 kg/km<sup>2</sup> more phosphorus.

### **3.3 Contribution of individual components to the annual balance of nutrients in the Kursk region**

Diffuse removal of biogenic substances from river catchments of the Kursk region significantly prevails over removal with sewage, where there are only 7% nitrogen and even less phosphorus – 3%.

The calculations showed (Tables 2 and 3), that the anthropogenic input of biogens to river catchments significantly prevails over their natural input. The total amount of nitrogen input is 6792 kg/km<sup>2</sup>, 70% of it come due to anthropogenic load. Corresponding figures for phosphorus input are 2299 kg/km<sup>2</sup> and 95%, respectively. The fertilization and farm animal waste (especially pig factory and poultry wastes) induce the highest biogenic load. A road network gains value as a source of biogens load showing a tendency to increase. The density of hard surface roads is almost 1.5 times higher than the density of the river network. The input of nitrogen from the road network is 30% higher than that with wastewater, and of phosphorus it is 7 times higher.

The natural input of biogens in recent years remains quite high and exceeds the removal of nitrogen with the river flow by 17 times and of phosphorus by 9 times. Basically, nitrogen and phosphorus are supplied to river catchments by tree and herbal waste. Atmospheric precipitation is also a significant source of their income.

Annual average export of nitrogen from the river catchments of the Kursk region is 124 kg/km<sup>2</sup>, of phosphorus – 13 kg/km<sup>2</sup>. The share of the underground component in the removal of nitrogen with a total annual runoff prevails and amounts to 60% (phosphorus – 50%). The removal of biogens with the surface component of the runoff is maximum in the flood period, when the discharge of nitrogen and phosphorus reaches 80 and 65% of their annual value, correspondingly.

Under the influence of mainly climatic changes, the surface component of the annual river runoff over recent years (2008-2016) has significantly decreased as compared to normal annual discharge[8] by 60-70%. The underground component of the runoff has increased by 10-20%. As a result, the river runoff has significantly decreased (by 30–40%) and so has the nutrient removal.

**Table 2.** The main anthropogenic components of the annual water-biogenic balance of the Kursk region, kg/km<sup>2</sup>.

Balance components		Mineral nitrogen	Mineral phosphorus
Input	urban population	56	9.1
	agricultural population	26	4.4
	hard surface roads	11.2	2.1
	wastewater	8.5	0.3
	livestock business	1300	530
	mineral fertilizers	3021	1510
	biofertilizers (straw, crop remains, manure, cover crops, etc.)	263	132
	Total	4686	2188
Export by river flow		124	12.6

**Table 3.** The main natural components of the annual water-biogenic balance of the Kursk region

Balance components		Mineral nitrogen	Mineral phosphorus
Input, kg/km <sup>2</sup>	precipitation*	641	13
	rain washing from tree crowns	53	3.2
	tree waste	443	67
	biofixation of nitrogen in the sown area	700	-
	swamp vegetation waste	27	1.8
	meadow, pasture and abandoned agricultural land vegetation waste	243	27
	Total	2106	111
Export by the river flow, kg/km <sup>2</sup>		124	12.6
The share of natural nutrient input in the total input, %		31	5

\* anthropogenic factors also influence the supply of biogens with precipitation

## 4 Conclusions

The current hydroecological situation in the central part of the Russian Plain is largely conditioned by a decrease in the surface slope runoff mainly under the influence of climatic factors. Accordingly, its role in the migration of nutrients decreased. At the same time, the infiltration of precipitation into the soil has significantly increased and the role of runoff of infiltration origin (underground runoff and perched water) in the supply of nutrients to water bodies has increased.

The diffuse removal of biogens from the catchments of small and medium-sized rivers in the central part of the Russian plain in recent years (2008-2016) is 75-95% of their total export by the river flow. On the catchment area of the side tributary of the Cheboksary reservoir, the natural component in the migration of biogens prevails, accounting for 55-75% their total removal. Due to the intensive anthropogenic load in the Kursk region, the anthropogenic input of biogens to the river catchments (70% nitrogen and 95% phosphorus) significantly prevails over their natural input. The main negative anthropogenic factors are urbanized areas, including the road network, livestock business, mineral fertilizers (in the Kursk region), and wastewater discharges, especially directly into water bodies.

The restoration of currently closed water balance stations and the organization of new ones will help to answer a number of still unresolved issues. The study of water quality is to play an important role in the work program of these stations.

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