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Influence of the Natural Landscape Conditions of Northern Yakutia on Flood Formation on the Alazeya River

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***Abstract* – The article assesses natural landscape conditions for forming floods on the Alazeya river and their influence on the hydrological regime. Evaluation of the moistening mode showed that an increase in the water volume is caused by an increasing amount of precipitation. The factor determining variability of the annual river flow is precipitation in the warm period of the previous year. The degree of susceptibility of the river landscapes to various changes was assessed. Permafrost, climatic and biological indicators (ice content of surface sediments, temperature of frozen rocks, biological productivity, conditions of heat supply and moisture) were taken into account. It was determined that tundra and northern taiga lake-thermocarstic landscapes are susceptible to anthropogenic effects.**

Keywords – arctic; global warming; floods; hydrological regime; landscape sustainability.

I. Introduction

The Arctic is extremely vulnerable. Serious environmental, sociological and economic changes are predicted [1]. The Arctic North is of great planetary importance for the ecological balance of the Northern Hemisphere. The North is characterized by huge, sparsely populated territories with intact anthropogenic impacts on the natural environment whose value increases in line with a growing ecological threat. The role of the North for sustainable development of Russia, preservation of natural systems and environmental quality is difficult to assess [2].

The territory of the Alazeya River basin is one of the most inaccessible Arctic regions of Northeastern Yakutia with natural complexes that have not been commercialized. The population, numbering several thousand people, is engaged in agricultural production, reindeer herding, fishing, meat and dairy cattle breeding and herd horse breeding.

The territory of the Alazeya River basin has become a scene of catastrophic natural processes caused by global warming - perennial flooding of settlements on the Alazeya River and on other rivers of the Arctic North of Yakutia.

The floods might cause degradation of frozen rocks, reorganization of orohydrography, disturbance of land cover, complete imbalance of all the natural links of the basin ecosystem.

Despite numerous scientific studies, predictions of the effects of the hydrological regime and changes in the cryosphere structure and functions of ecosystems remain uncertain [3].

In this regard, researchers have to the impact of natural disasters caused by global warming on the natural environment of the Arctic North of Yakutia. The purpose of this article is to assess natural landscape conditions of floods on the Alazeya River and identify patterns of river flow fluctuations in the context of global climate warming.

II. Methods

For balanced development of the territory and comprehensive assessment of all the most complex interrelationships existing within natural complexes, it is advisable to apply the landscape-ecological approach - geosystem analysis [4], analysis of the component-wise influence of the leading permafrost characteristics on landscape stability reduction [5] and assessment of landscape-ecological system susceptibility to technogenic impacts [6]. To calculate hydrological characteristics, conventional hydrological research methods were used.

III. DISCUSSION

In the northern territories of Yakutia, climate changes caused formation of natural landscape conditions and catastrophic floods in the Alazeya river Basin.

Over the past 40 years, the average annual temperature increased by 1.8 °C, and the average amount of precipitation increased as well.

An increase in these meteorological indicators increased thickness of the thawed layer with and caused thawing of the upper part of the ice complex of the permafrost layer [7]. These factors contributed to a sharp increase in the indices of permafrost flow and arbitrary drainage of water into the Alazeya river Basin which caused an overflow of the lake bowl. Water accumulated in the near-channel part of the valley is the main cause of large-scale flooding of low plains and human settlements. Thermocarstic, thermo-erosion and erosion processes are intensified which is accompanied by transformation of the floodplain part of the river valley.

Long-term flooding has a significant impact on various natural ecosystems - soil and plant cover, aquatic biota, fauna, changing their morphological structures, qualitative and quantitative composition, and dynamic states. Flooding caused flushing and degradation of the surface horizon of soils, overwetting, deterioration of their structures and thermophysical properties, disruption of the water regime and waterlogging. As a result, there was a decrease in biomass production, deterioration of nutrition and soil fertility.

Catastrophic floods had a great influence on the composition and structure of phytoecosystems of the territory. Long-term flooding had negative effects on the elements of the vegetation cover. A further increase in moisture will restructure the species composition and structure of forest and meadow vegetation, cause their degradation and change natural landscapes, causing further melting of the ice complex and regression of the fragile northern biome in the Alazeya River basin.

One of the most significant consequences of the disturbance of natural conditions is a sharp change in the hydrological regime of the Alazeya River and subsequent flooding of human settlements.

The Alazeya River is formed by the confluence of the Kadilchan and Nelkan rivers. The basin area is 64, 7 thousand km^2. The average flow is 320 m^3/sec. In the basin, there are over 24 thousand small lakes. The river feed is snow and rain. The river freezes in late September - early October. It is frozen from mid-December to mid-May. It opens in late May - early June.

The annual distribution of the flow of the Alazeya River reflects its relatively large regulation by the lakes. For the winter season (November-April), the stock is 4%, and for the entire period (September-April), it is 20%. Under continuous permafrost with a capacity of up to 500 m, surface water and groundwater are exchanged. Under these conditions, in winter time the amount of river flow depends on the degree of lakes in the catchment.

The formation of floods in watersheds with permafrost depends on the flow of spring thawed and summer rainwater along the slopes and the longitudinal slope of the free surface of the water flow.

During the spring flood, 63% of the annual flow of the Alazeya River is formed. This value ranges from 22% to 89%. The wide range of changes in the share of snow feed depends on fluctuation in the amount of rainfall. The share of underground flow is 4-6% of the annual one. The spring flooding begins in the middle of the third decade of May; the maximum water discharge is formed at the end of June and ends at the end of the first decade of August.

In dry years, the flooding ends in the third decade of July. In the conditions of heavy rains, it is very difficult to determine the end of flooding. The highest water flow can occur in mid-August. The maximum water levels for the year are observed in June-July, but over the last twenty years they have become frequent in August-September. The rise of the water level above the minimum winter level is 5 meters in the upper river, 4.5 meters – in the middle river, and 2.0 meters in the low river. In wet years, water reaches the floodplain and floods settlements.

In low-water years, summer runoff low is observed in August and September. In wet years, the surface runoff level increases only in October.

The observations of the hydrological regime of the Alazeya River were carried out at three hydrological posts: Argakhtakh, Andryushkino, Alazeya.

The observations are regular. Since 1962, they have been carried out only in Argakhtakh. In Andryushkino, measurements of water flow were carried out irregularly. Comparison of data on the flow identified synchronism of flow fluctuations in the upper river and in the middle river. The value of a runoff increment is about 38%; the same increment is typical of the drainage ditch area between these two posts. Comparison of the values of the maximum annual water levels for the entire observation period, measured near Argakhtakh and Andryushkino showed their close relationship (correlation coefficient r is equal to 0.80). At the same time, there is no correlation between these levels and the levels of the polar station Alazeya.

Thus, the data obtained in Argahtakh can be used to analyze conditions of formation of the flow of the Alazeya River in the upper and middle reaches of the river.

The mouth area where the flow regime and water levels are influenced by the sea is an exception. The rare network of hydrometeorological observations in the Alazeya River basin and adjacent river basins does not allow for determining the layer of sediments entering the basin surface, evaporation losses, soil infiltration and surface retention. Therefore, the regression (correlation) analysis is used to study relationships between the value of the runoff and factors causing it.

The analysis of dependences of the annual runoff on the main factors of its formation revealed high variability of the annual amount of precipitation. Suring the warm season, the amount of precipitation is more variable.

Significant annual variation gives reason to believe that the ability to absorb a part of the flow in the storage tank of the basin is variable. The analysis showed that it is higher when the amount of precipitation is low. Comparison of the runoff values with the amount of precipitation revealed their close relationship for June – September (r = 0.72) which indicates a greater dependence of runoff on the extent of the basin previous moisture content rather than on winter and summer precipitation of the current season.

The analysis of fluctuations showed that there are 2-3 summer cycles of high and low water content.

Thus, preliminary assessment of the basin moisture regime showed that an increase in the water content of the Alazeya River and the size of the floods are due to an increase in the volume precipitation. During the warm period, variation in the amount of precipitation is much higher than during the cold period, which makes it possible to consider precipitation of the warm period as a decisive factor in the variability of the annual flow of the Alazeya River. One of the options for reducing the scale of the flood may be the discharge of water accumulated on the surface of the basin, before the onset of the winter season [7].

It is necessary to carry out water-balance observations in the river basin.

The territory of the Alazei River Basin belongs to the physiographic country of Northeastern Siberia, two groups of landscape provinces: the Alazeya-Kolyma lake-thermocarstic tundra and the Kolyma lake-thermocarstic continuous tundra [16].

To preserve the natural environment, assessment of the degree of resistance of natural complexes to changes is of great importance. Over the past decades, there have been many studies on the stability in the field of cryolithozone [8–14], including the works by Yakut scientists. A distinctive feature of permafrost landscapes is presence of ice-saturated soils in their lithogenic basis, which contributes to their vulnerability. Therefore, stability of permafrost landscapes is an ability to resist to permafrost-geological processes caused by anthropogenic impacts [10].

We proceededed from the analysis of two complementary techniques of the landscape-ecological approach - the component-wise influence of the leading permafrost characteristics on landscape resilience reduction [5] and assessment of susceptibility of landscape-ecological complexes to anthropogenic impacts [6]. In the Far North, it is necessary to take into account specific conditions of northern landscapes, cryogenesis. Under these conditions, restoration or stabilization of natural complexes is determined by permafrost properties. Therefore, stability of permafrost landscapes depends on the ice content in surface sediments, as well as on temperature variability of the frozen rocks, thickness of the thawed and frozen layers, and lithogenic factors. Stability assessment for permafrost landscapes is based on the potential for development of cryogenic deformations of the soil.

Stability of permafrost landscapes depends on climatic and biological factors.

Thus, when assessing stability of northern landscapes, we used their permafrost, climatic, and biotic characteristics [15]. To assess stability of the provinces of the Alazeya River basin, the following main components of permafrost landscapes were used: average annual temperature of frozen rocks at the bottom of the annual fluctuation (0C) layer, ice content of surface sediments (%),thickness of seasonally frozen and thawed layers (m), distribution of permafrost, vegetation, topography, biological productivity (c / ha), heat supply conditions as a sum of average daily temperatures above 100^0C, humidification conditions expressed by radiative dryness index values (kcal. cm2 / year).

Permafrost characteristics and bioclimatic characteristics were obtained from [8, 11].

On the basis of [5], properties of landscapes characterizing sustainability were ranked.

By the degree of influence of a certain factor on the stability of the landscape, four grades were distinguished: no impact - 1 point; slight impact - 2; significant impact - 3; destructive impact - 4 points. The integral effect of all components was estimated by the sum of points. The greater the total score, the less sustainable this natural complex is.

Due to the fact that the main feature of permafrost landscapes is phase transition of water to ice causing thawing and movement of the soil, their stability is evaluated by the potential of this process. In other words, the lower the temperature of frozen rocks, the less likely they are to thaw. Therefore, soils with a temperature of “-50^0C were ranked at 1 point, while warmer soils were ranked at 4 points.

The following ranking scale was used: extremely unstable - 27-28 points; unstable - 22-23; poorly resistant - 19-20 and moderately resistant - 15-18 points. The use of points makes it possible to assess sustainability of the landscape provinces of the Alazeya River basin (Table 1).

TABLE I. SUMMARY ASSESSMENT OF THE DEGREE OF SUSTAINABILITY OF LANDSCAPE PROVINCES OF THE ALAZEYA RIVER BASIN

Landscape provinces	**Permafrost and bioclimatic factors of landscape formation**									
	Productivity	***Phytomass reserves***	***Heat***	***Dryness index***	***Power of seasonally frozen and seasonally thawed layers***	***Temperature of frozen rocks***	***Bulk ice content***	***The spread of permafrost***	***Total points***	***Degree of landscape sustainability***
Alazeya-Kolyma tundra lake-thermocarst	4	4	4	3	4	1	4	3	27	Extremely unstable
Kolyma north-taiga lakes thermocarstic	4	4	4	3	3	1	4	4	27	Extremely unstable

It was revealed that according to the total influence of permafrost and bioclimatic characteristics on the reduction of resistance to anthropogenic impacts, landscapes of the Alazeya-Kolyma lake-thermocarstic and Kolyma lake-thermocarstic provinces were ranked at 27 points.

IV. Conclusion

The catastrophic floods on the Alazeya River were a result of global climate warming increasing the water volume in the river due to thawing and degradation of permafrost and overflowing of the lake basin.

Preliminary assessment of the basin moisture regime showed that an increase in the water volume of the Alazeya River is due to an increase in precipitation. It was revealed that precipitation in the warm period of the previous year had the most significant effect on the river flow. To analyze the processes of formation of the flow of the Alazeya River, and individual components of the water balance, it is necessary to create a water balance station and perform water-balance observations.

The analysis results help assess stability of the natural complexes of the Kolyma River. Tundra alas water-dividing landscapes of the Alazeya-Kolyma tundra lake-thermocarstic province and northern taiga inter-alascade landscapes of the Kolyma northern taiga lake-thermocarstic provinces are susceptible to anthropogenic effects.

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