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Dynamics of Runoff in Permafrost Areas of Central Siberia

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Abstract

The paper is concerned with the hydrological regime of the North Rivers in the permafrost areas of Central Siberia. The spatial-temporal features of river runoff formation in different geographical conditions are discussed. Influence of landscape structure of the catchments and climatic factors on runoff were analyzed. Spatial variability of river flow is determined by the locations of the rivers; this relationship is clearly manifested in the seasonal dynamics of the hydrological regimes of the rivers. The impact of climate change on runoff in the permafrost zone has been revealed.

Keywords

Central Siberia; Climate Change; Dynamics of Runoff; Hydrology; Permafrost Zone

Introduction

River flow is of central importance to many human activities. The need to study river runoff and the causes of any its changes is required by catchment managers and environmentalists needing integrated assessments of terrestrial ecosystems. Siberian rivers, in particular, are under-represented in the international river-regime databases [1]. For local catchment management assessments, this gap needs to be filled. Runoff is known to be as the most important element of hydrological cycle, which is closely related to climate. As early as 1884, the Professor AI Voeikov in his famous paper "Climates of the Globe, especially of Russia" [2] pointed to the connection of water yield of rivers with climatic factors. The climatological conception up to now continues to take a key place in hydrology, since the river runoff dynamics is closely related to specific humidification and evaporation conditions. The AI Voeikov's idea about "river is a climate product" has been developed in the papers of Russian hydrologists [3-6].

Global climate changes in recent decades and increasing anthropogenic pressure on natural ecosystems make carrying out hydrological research in order to identify the specifics of the formation of runoff conditions very important, especially in the permafrost zone, where the effects of such changes are difficult to predict. Thawing of permafrost will cause significant changes in the hydrological regime of the territory. For Siberia, the problem is urgent, because vast areas of the region are in the permafrost zone. The task of our research was to determine the patterns of river flow formation in permafrost zone of Central Siberia comparing the spatial-temporal dynamics of runoff with meteorological characteristics.

Study Area and Methods

The study area is the northern part of Central Siberia (Figure 1). The investigated river basins are located within three landscape zones: forest-tundra, northern and middle taiga (Table 1). The climate of the region is extremely continental with large air temperature amplitudes of warm and cold seasons; it is characterized of severe frosty winters and moderately warm summers. The seasonal dynamics of air temperature for all weather stations is similar: an increase of air temperature from February to July and decrease from July to December. The temperature minimum is observed in January (-35.7°C), the maximum - in July (18.1°C). Due to the considerable extension of the region from north to south and advance of the continental climatic features from west to east, the average annual air temperature and monthly air temperatures registered at weather stations vary considerably. The average annual maximum and minimum air temperature differs by 8°C, spring month's differences amount to 2-15°C, and for August and September, they make up 4-5°C. Precipitation in the region at the same latitudes decreases from west to east due to the increasing of continental traits of climate and mountain terrain impact the distribution of atmospheric precipitation. A large mosaic pattern is characteristic of the spatial distribution of precipitation [7,8].

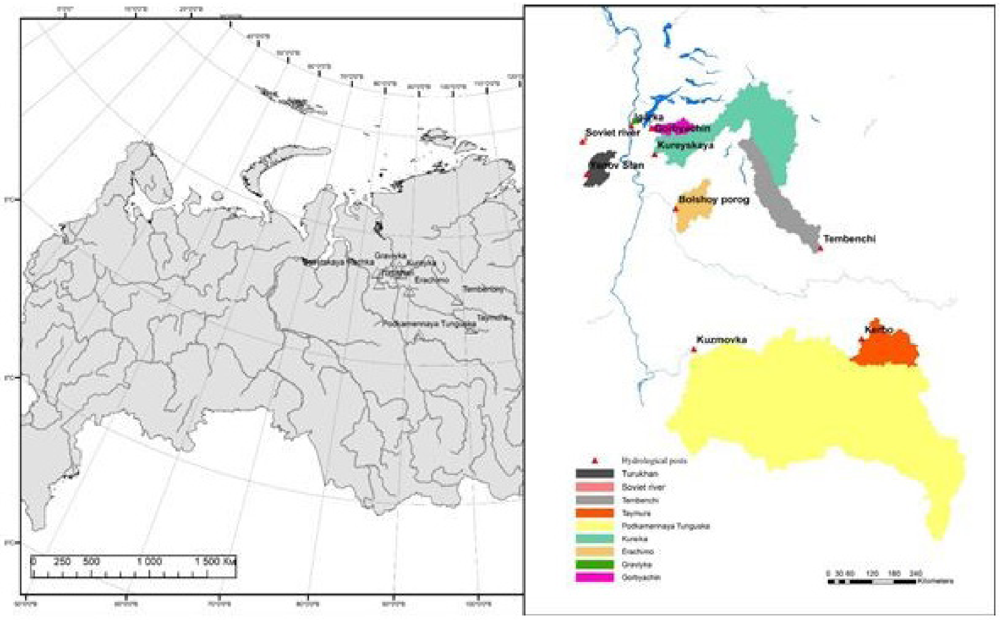

Figure 1: Study area.

River - point observations	Period observation	Latitude	Longitude	Catchment area, (km²)*	The average height of the catchment, (m)*
Forest tundra and woodlands					
Soviet Rechka - Soviet Rechka	1975-2012	66°48′	83°42′	1820	120
Graviyka - Igarka	1940-1993	67°44′	86°59′	337	94
Kureika - Kureiskaya Hydrostation	1968-1998	66°56′	88°20′	44700	658
Gorbiachin - Gorbiachin	1982-2000	67°28′	87°49′	62500	600
North taiga					
Turukhan - Factoria Yanov Stan	1968-2012	65°98′	84°33′	35800	150
Tembenchi - Tembenchi	1967-1994	64°56′	98°52′	21600	75
Erachimo - Big threshold	1968-2012	65°63′	90°01′	9140	375
Meddle taiga					
Taimura - Kerbo	1975-1993	62°73′	101°1′	14800	374
Podkamennaya Tunguska - Factoria Kuzmovka	1983-2012	62°31′	92°11′	240000	510

Table 1: Characteristics of the studied catchments.

*Data extracted from the Reference of Surface water resources of the USSR [9]

The long-term observations of the runoff at hydrological stations, average monthly values of precipitation and air temperature at representative weather stations in the region under study were used. Series of observations at the hydrological and weather stations continued from 10 to 60 years [9-12]. For data processing, we used the standard methods of hydrological calculations [3,4,13]. Taking into consideration the gaps in the runoff observations, we applied a few methods to restore missing data [14]. The hydrographs of annual and winter runoff were analyzed taking into account the dynamics of air temperature and precipitation regime. The methodology of hydrographs analysis is classical and based on publications of Russian and the USA researchers [5,13]. In order to consider the multifactorial process of formation of runoff at river catchments the regression analysis was used in Excel [15]. Linear regression model was used to identify the response of annual and low winter runoff on changing of climate conditions.

To assess the spatial variability of trends and intensity of changing hydro-climatic parameters we used the VA Shelutko methodology [16]. The analysis of the trends was conducted by the least-squares method. Statistical parameters needed for the analysis were obtained after preliminary functional antialiasing of the time series. The coefficients of the linear trends of the annual and average monthly runoff, air temperatures and precipitation were calculated by processing the time series of these quantities using the Microsoft Excel Statistics 10 program.

To solve the problem of unification of zonal climatic patterns of runoff formation and local peculiarities of hydrological regime of the territory within each geographical zone a comparative analysis of the actual and landscape runoff was carried out. Based on the concept of the influence of the landscape structure of the catchment on the water regime of the rivers, we calculated the landscape runoff taking into account the landscape differentiation of the catchments. Landscape differentiation of watersheds from the point of view of hydrological homogeneity includes the classification of the earth's surface according to their contribution to the water yield of the catchment area. In order to assess the contribution of the intra-basin landscape structures to runoff, we differentiated Landscape-Hydrological Complexes (LHCs) in each catchment area using the forest-vegetation zoning of Siberia [17].

We obtained the spatial distribution of precipitation and evapotranspiration for each landscape-hydrological complex [18,19]. Based on these data, a runoff was calculated for each (LHCs) using the water balance method. The landscape runoff of the catchment was determined as the integral runoff of all LHCs located in the catchment. The total runoff from catchments, including landscape runoff, was calculated in mm.

Season features of formation of river runoff in the study area: Hydrological regime of study rives are determined by regional climatic conditions, but common features characterize the seasonal dynamics of the hydrological regime of these rivers. This is - a high spring tide, summer and autumn periods of low-flow, interrupted by rain floods and low winter low water. An analysis of the hydrological regime of the rivers studied showed that 90-95% of the annual runoff is the flow of warm season, i.e., runoff of winter low water does not exceed 10% of annual runoff. For some rivers, such as the Tembenchi River the average value of winter runoff does not exceed 3% of the annual. The 60-70% of annual runoff accounted for spring high water. The dynamics of flow reflect the changes in both precipitation and air temperature. In this case, the important point is not only the magnitude of these changes, but also seasons (months) of their revealing. For some rivers, such as Taimura, Erachimo, flood peak occurs in May, for Podkamennay Tunguska - in May or June, and for other rivers - in June - July (Figure 2).

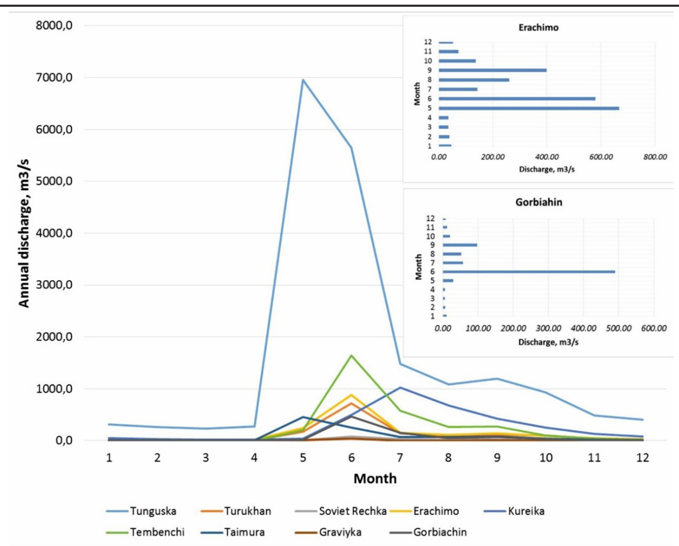

Figure 2: Seasonal dynamics of studied rivers' flow.

The duration of the spring-summer flood for rivers Turukhan and Podkamennay Tunguska is significantly longer than in the rivers with smaller catchment areas. In the time scale, the duration of the flood is primarily determined by the dynamics of daily temperatures and precipitation during this period of year. During the summer-autumn drought period there is a gradual decline of water level, which extends over the summer-autumn season and falls down to the freezing period of rivers. This reduction of flow is interrupted only by rain floods (Figure 2).

For all rivers, a significant interannual variability of runoff is typical; the average deviations from the average long-term runoff are ranging from 27 to 57%, except for Taimura (Table 2), where the deviation from the average annual flow reached 80%. This took place in 1964, 1974 and 1975.

The low-flow winter runoff, as well as the annual one, is characterized by significant interannual variability. The highest deviations (61-98%) are typical of the rivers of the northern and middle taiga: Erachimo, Tembenchi, Taimura and Turukhan (with the exception of the Podkamennaya Tunguska). Rivers in the forest-tundra zone show a more stable hydrological regime (Table 3). The Podkamennaya Tunguska is a river with the largest catchment area and, therefore, is characterized by the smallest deviations of winter runoff from mean.

Thus, the analysis of the studied rivers hydrographs showed that seasonal runoff dynamics vary by different geographic zones. This is mainly manifested in dates of high water: in the middle taiga zone the high water is observed in spring, in the northern taiga and forest-tundra zones - in summer. Seasonal dynamics of the hydrological regimes of the rivers also depends on the size of river basins. It should be noted that each river in the region displays specific features of the hydrological regime, due to the landscape structure of the catchment area.

Influence of landscape structure of the catchment on the runoff: River runoff in the plains is a product of the climate and, accordingly, its spatial distribution is subject to the regularities of geographical zoning. Study areas located in the Central Siberia are characterized by more complex spatial distribution of the hydrological regime than plain territories. Correlation of meteorological parameters with river flow is not subject to regularities of geographical zoning due to complex topography of the region and regional and provincial features of the spatial distribution of precipitation.

River	**Annual runoff, mm**			**Deviations from the average runoff, %**	
	average	maximum	minimum	maximum	minimum
Gorbiachin	597	768	419	28.6	29.7
Kureika	742	1168	452	57.1	40.3
Graviyka	501	709	268	41.3	46.6
Soviet Rechka	345	458	240	32.5	30.4
Turukhan	368	504	210	38.2	43.1
Erachimo	501	713	362	43.1	27.6
Tembenchi	434	665	302	53.2	30.4
Taimura	180	323	97	80.1	46.3
Podkamennaya Tunguska	232	335	164	45.2	34.1

Table 2: Variation of the annual runoff of the studied rivers.

Река	**Winter low-water runoff, mm**			**Deviations from the average low winter runoff, %**	
	average	minimum	minimum	maximum	minimum
Gorbiachin	27.6	11.3	11.3	39.9	51.8
Kureika	146.6	65	65	45.8	55
Graviyka	39.3	11.5	11.5	20.8	78.7
Soviet Rechka	21.5	8.5	8.5	45.1	60.4
Turukhan	22.5	5.8	5.8	88	74.6
Erachimo	47.9	15	15	98	68.7
Tembenchi	10.3	2.8	2.8	61.1	78.6
Taimura	9.7	2	2	74	77.3
Podkamennaya Tunguska	23.5	12.6	12.6	31.9	46.4

Table 3: Variation of winter low-water runoff of the studied rivers.

Based on the landscape differentiation of the study area, we determined the proportion of the runoff for every landscape-hydrological complex and calculated the integral landscape runoff for each studied catchment (Table 4). Comparison of the calculated and actual runoff shows significant discrepancies between these values. The results indicate possible errors in the differentiation of landscape-hydrological complexes. The minimum difference between the calculated and actual runoff was found only for three rivers: the Podkamennaya Tunguska, Taimura and Tembenchi. Obviously, this is due to the fact that the basins of these rivers are characterized by relative homogeneity of the earth's surface and, therefore, determination of the estimated runoff was more correct.

To compare the actual and calculated data more correctly we used the runoff coefficient. The main characteristic of surface watercourses is the runoff coefficient, i.e., the ratio of the runoff value to the sum of precipitation during the year and to the area of the catchment basin: $K = Q / P \times S$, where Q is total runoff, P is sum of precipitation for the same period, and S is catchment area. The change of this coefficient from north to south reveals how runoff changes with changing climatic conditions. The diagram in figure 3 shows the comparison of actual and landscape runoff coefficients.

River	Precipitation, mm	Actual runoff, mm*	Calculated landscape runoff, mm	Coefficient of runoff		
				actual	landscape	Mean value deviation
Soviet Rechka	466	173	250	0.37	0.54	-0.17
Graviyka	617	501	421	0.81	0.68	0.13
Turukhan	466	368	302	0.79	0.59	0.2
Gorbiachin	710	597	421	0.84	0.68	0.16
Kureika	749	524	416	0.7	0.68	0.02
Tembenchi	603	433	405	0.72	0.67	0.05
Erachimo	570	500	370	0.88	0.65	0.23
Taimura	489	180	188	0.37	0.38	-0.01
Podkamennaya Tunguska	489	232	204	0.47	0.53	0.06

Table 4: Actual and calculated landscape runoff of study river basins.

*Data of actual runoff are from the hydrological reference books [9,10]

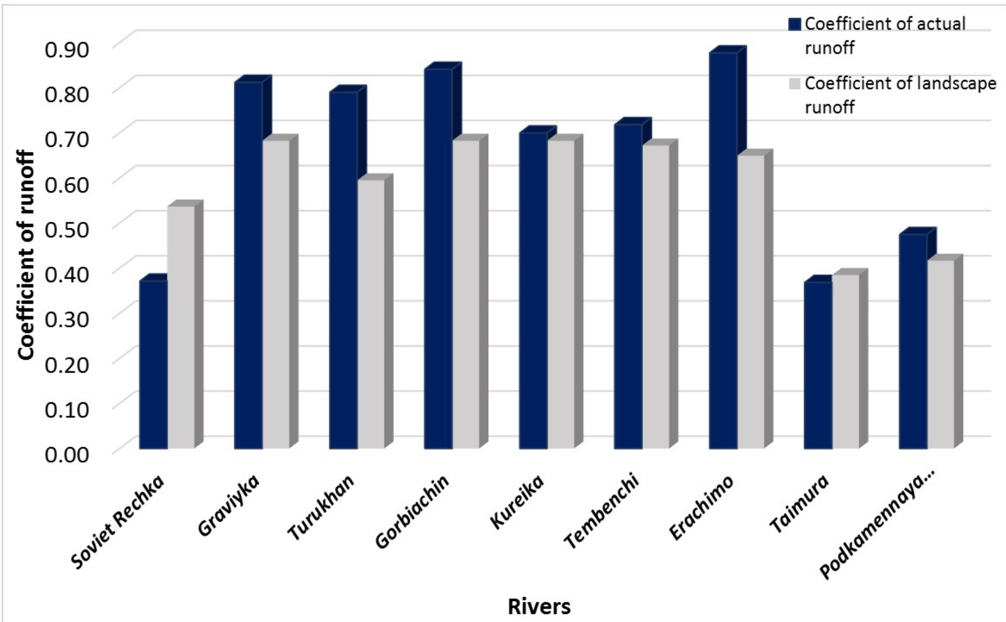

Figure 3: Comparison of the runoff coefficient (actual and calculated) for the different catchments under study. Runoff coefficient is the ratio of the total runoff to the sum of precipitation for the same period.

According to the diagram, the maximum differences in the coefficients are revealed for the rivers of the forest-tundra zone. In the taiga zone, the maximum difference in coefficients is characteristic of the Erachimo River. The results indicate not only of zonal-provincial regularities of flow formation, but also the impact of azonal factors (length of the river, catchment area, forest cover, permafrost, etc.) on this process. Permafrost is one of the most important azonal factors of river runoff formation. Thawing of permafrost destabilizes the steady-state hydrological regime of the northern rivers in Eurasia.

The effect of climatic factors on runoff: To assess the effects of global warming on the hydrological regime of the northern rivers at Central Siberia, we analyzed the impact of some climatic factors on river runoff formation and identified the contribution of each factor to this process [7]. Precipitation and air temperature, as well as the runoff of the previous year were used as predictors of annual flow in the regression models. The results of this study are published earlier [19]. Regression models reflecting the relationship of climatic characteristics and annual flow are shown in table 5.

River	Regression models	Model criteria
Gorbiachin	$Y = -517.5+0.69*X_j+2.9*X_t+5.7*T_7$	R^2=0.84; G =46.3; F=28.1
Taimura	$Y = -250.5+0.50*X_t+10.6*T_7+0.57*X_8$	R^2=0.73; G =27.7; F=13.7
Turuhan	$Y = 115.3+0.39*X_j+0.53*X_t-2.69*T_{(5+6)}$	R^2=0.45; G =44.0; F=10.9
Soviet River	$Y = 157.9+0.26*X_j+0.41*X_t-10.1*T_5$	R^2=0.30; G =46.6; F=4.9
Tembenchi	$Y = -447.7+1.5*X_t+32.0*T_7+1.7*X_9$	R^2=0.57; G =55.5; F=10.6
Graviyka	$Y = 62.7+0.50*X_j+1.1*X_t-12.2*T_5$	R^2=0.46; G =76.7; F=14.3
Erachimo	$Y = 154.5+0.37*Y_p+0.58*X_j-10.1*T_5$	R^2=0.46; G =57.5; F=11.4
Kureika	$Y=6.3+0.9*X_j+9.4*T_9+0.00108*(X_p*X_t)$	R^2=0.63; G =60.4; F=15.1
Podkamennay Tunguska	$Y = 51.3+0.15*X_j+0.41*X_t-3.2*T_5$	R^2=0.70 G =19.4 F=20.3

Table 5: Regression hydrological models [19].

where: Y - annual flow of the river, mm; X_j - the annual amount of liquid precipitation, mm; X_t - the annual amount of solid atmospheric precipitation, mm; $X_{8,9}$ - the average monthly rainfall in August and September; Y_p - flow of the river of the previous year; $T_{5,6,7}$ - average air temperature respectively in May, June and July,°C; t_9 - average air temperature in September, °C; R^2 - coefficient of multiple determination; G - the standard error of the equation; F - Fisher criterion.

Analysis of hydrological models (Table 5) shows that the annual flow of the rivers is significantly dependent on complex of hydro-climatic parameters. For all rivers, the increasing of runoff is correlated with a rising of total precipitation, especially snowfall. Effect of air temperature on the annual flow has a different result. The increase in air temperatures in the middle of summer and early autumn causes an increase in the annual runoff of the rivers. This is indirect evidence that moisture of periodically thawing frozen soils affects runoff formation of the studied rivers. In spring, the increasing air temperatures, combined with low humidity and wind activity, affects the reduction of annual flow. This is obviously due to the increase in evaporation from the surface of the snow cover, which in the forest-tundra and northern taiga continues until the beginning of summer. For watersheds of two rivers (Kureika and Erachimo), the increase in annual runoff significantly depends on value of runoff of the previous year. To identify the connection of runoff of winter low water with the climatic parameters we analyzed the interannual variations of low water with dynamics of air temperature and precipitation. The multiple regression analysis showed reasonable correlation coefficients between values of winter low runoff of studied rivers and the rainfall during the warm period and the air temperature in the period from August to February. The rainfall during the warm period is most significant for winter low flow of Gorbiachin, Erachimo and Podkamennaya Tunguska. For the Tembenchi and Graviyka rivers, this factor is not a major control in the formation of winter low runoff. The coefficients of correlations between the winter low runoff and the mean air temperature ranged from 0.5 to 0.6, except for the Podkamennaya Tunguska, which is 0.24. Along with the air temperature in August and September the average temperature of the winter months have a sufficiently high significance. This indicates that the layer of seasonal freezing of soils does not merge with the upper border of permafrost, and during the winter period, the rivers are charged by groundwater. Groundwater reserves replenished by thawing of frozen soils and ice lenses in the summer.

Analyzing the general climatic patterns of river flow formation in permafrost of Siberia it should be noted the following trends. The role of liquid and solid precipitation, as a factor in the flow formation is enhanced from the boreal forest to tundra zone, but the role of summer temperatures on the contrary becomes weaker. In the north region with a short and cool summer, heat is mainly spent on the melting of snow, warming and thawing of the upper soil horizons. Probably, in these conditions, the heat energy is not enough to provide high evaporative capacity and significantly, to re-distribute water balance components to increasing of total evaporation. The portion of runoff in any of the observed values of meteorological parameters is significantly higher than the proportion attributable to evaporation.

Trends river flow under global climate change. As we mentioned above hydrological regime in permafrost areas respond to global warming. In recent years, the study of the runoff dynamics of Siberian Rivers under Global Change has received considerable attention [20-24]. The data on the impact of Global Change on the hydrological regime of rivers, described in the above studies, are mainly considered at the macro-scale level and are generalized for the basins of large rivers. However, the regional changes in climate have a number of features related to local physical and geographical conditions.

To make clear the relationship of runoff dynamics with the change in climatic parameters in permafrost areas of Central Siberia, we calculated the coefficients of linear trends in air temperature and atmospheric precipitation for twelve weather stations of studied region (Table 6).

trends is observed both spatially and by seasons. In the eastern areas of study region with a severe (sharply continental) climate, air temperature trends in the cold period are more pronounced, whereas in the Prieniseysky part of the region with temperate climatic conditions, the air temperature trends prevail in the spring and summer. The results of our studies are consistent with the concept of AA Onuchin [25], that to better understand the climate change magnitude, its variability and spatial distribution, it is necessary to include in consideration geographical specifics of areas.

The coefficients precipitation trends of our study region have, not only considerable differences in absolute terms, but also they differ in sign. At five meteorological stations out of twelve, the coefficients of linear precipitation trends are negative, and for seven meteorological stations, precipitation has tendency to increase by 3.4-21 mm/10 years.

According to the literature data, positive precipitation trends are typical for many regions of the Earth [26,27]. The different

Weather station	1966-2012			1966-2012		
	I-XII	V-X	XI-IV	I-XII	V-X	XI-IV
	Air temperature, °C			Precipitation, mm		
Zone of forest-tundra and northern woodlands						
Khatanga	+0.053	+0.044	+0.051	+0.307	+0.247	+0.029
Volochanka	+0.051	+0.049	+0.041	+0.646	+0.243	+0.329
Dudinka	+0.053	+0.056	+0.04	-0.778	-0.113	-0.781
Igarka	+0.048	+0.047	+0.043	+2.007	+1.115	+0.884
Northern taiga						
Agatha	+0.044	+0.038	+0.044	-0.044	+0.313	-0.301
Yanov stan	+0.051	+0.056	+0.038	-0.953	-0.83	-0.108
Turukhansk	+0.046	+0.044	+0.042	+2.114	+1.79	+0.341
Tura	+0.042	+0.031	+0.048	+0.338	+0.122	+0.214
Middle taiga						
Verkhneimbatsk	+0.044	+0.039	+0.045	+1.362	+0.931	+0.51
Baikit	+0.036	+0.029	+0.039	-0.672	-0.43	-0.102
Bor	+0.041	+0.032	+0.053	-0.757	-0.491	-0.178
Vanavara	+0.046	+0.04	+0.049	+0.796	+0.868	-0.007

Table 6: Coefficients of linear trends in air temperature and precipitation according to data of representative weather stations.

Analysis of changes of air temperature at representative weather stations showed that from the 60s of the last century until 2012, a stable trend towards warming has been observed in the study area. The average annual air temperature increases by 0.40-0.60°C/10 years, the average air temperature for warm (IV-X) and cold (XI-III) periods have a positive tendency to increase by 0.30-0.60°C/10 years (Table 5).

It should be noted that the variability of air temperature

direction of precipitation trends in the northern regions of Central Siberia can be associated with various causes both at the regional and local levels. Above, we noted that the spatial distribution of precipitation in the study area is not subject to geographical zoning. It is possible that the complex topography of the earth's surface affects not only the spatial distribution of precipitation, but also changes in precipitation trends, which are due to the processes of atmospheric circulation at the global level. In the literature, there is no data on linear trends in the circulation of atmosphere in Siberia.

Some scientists associate the features of changes in atmospheric precipitation dynamics with atmospheric pollution [28-30]. For the Arctic regions of Siberia, AA Onuchin and co-authors [31,32] revealed that precipitation trends correlated with atmospheric pollution. The scale of this phenomenon depends on the characteristics of the atmospheric circulation in region and terrain; precipitation trends are not associated with changes in the global cyclogenesis.

It is known that changes of water yield, occurring under the influence of Global change, appear first on characteristics of river flow. A more sensitive indicator in the response of the hydrological regime to climate warming is minimal winter river flow [21,33]. We calculated the coefficients of linear trends of annual and winter low flow (Table 7).

River - point observations	Period observation, years	Annual flow, mm/year	Winter low flow, mm/year
		a	a
Zone of forest-tundra and northern woodlands			
Gorbiachin - township Gorbiachin	1982-2000	-0.16	-0.55
Graviyka - township Igarka	1970-1993	+4.76	+1.42
Kureyka - Kureiskaya HPP	1968-1998	+4.7	+1.37
Soviet Rechka - township Soviet Rechka	1975-2012	-1.35	+0.26
North taiga			
Turuhan - Factoria Yanov Stan	1968-2012	+1.27	+0.19
Erachimo - township Big threshold	1968-2012	+0.62	+1.26
Tembenchi - township Tembenchi	1967-1994	+2	+0.37
Meddle taiga			
Taymura - township Kerbo	1975-1993	-2.41	+0.09
Podkamennaya Tunguska - Factoria Kuzmovka	1983-2012	+0.57	+0.18

Table 7: Annual and winter low flow trends of studied rivers (y=ax+b).

Obtained data showed that six of the nine studied rivers have positive trend of annual runoff from 0.57 to 4.76 mm/year, the winter low flow of eight rivers is increasing from 0.09 to 1.42 mm/year. This indicates a general tendency to increase runoff in the study area. An exception is the river Gorbiachin for which in both cases negative trends were recorded. Rivers Taimura and Soviet Rechka with a negative annual flow trends are characterized by an increase in the winter low flow.

The analysis of our own data shows that the dynamics of annual runoff and winter low water on some rivers in the permafrost zone of Central Siberia is rather ambiguous. According to literature data [21,33], the patterns of development of winter flow depend not only on climatic conditions but also on the hydrogeological situation of the river watershed.

To eliminate the influence of non-climatic factors on the dynamics of the minimum winter flow, we analyzed how the ratio of winter flow to the annual runoff was changing in recent decades. This analysis showed that the relation between annual and winter low flow was changing during different time-intervals. In the period from 1949 to 1993, there was a slight increase in the portion of winter runoff as a percentage of annual runoff. From 1973 to 2012, a more significant increasing of winter runoff portion relatively to the annual flow has been at studied rivers (Figure 4). Thus, the study of the hydrological regime of North Rivers at Central Siberia showed a tendency to increase winter runoff, regardless of the trend of annual runoff.

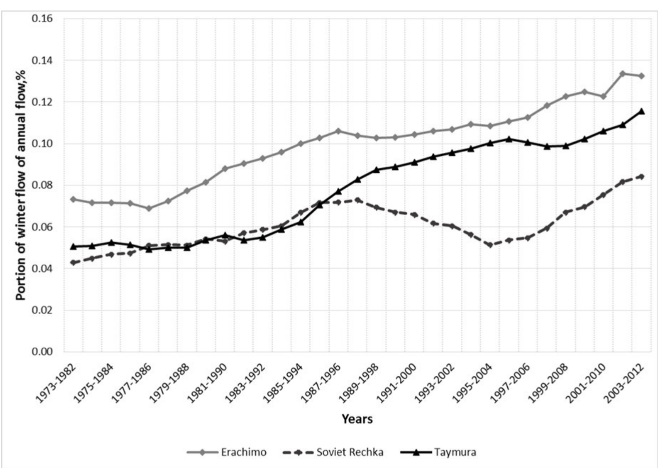

Figure 4: Winter low flow trends for the sliding 10-year-old mean values.

In our work [34] it was shown that, the annual run-off of the studied rivers is mainly dependent on precipitation. There is closest relationship between the runoff and winter precipitation, which is understandable. The snow accumulated during the winter is the main water resource of the northern rivers. The relationship between annual runoff and air temperature are differ by seasons of the year.

Based on the concept that the winter low water is the more sensitive indicator of changes in climatic conditions, we analyzed the correlation of changes in the series of meteorological parameters at weather stations of the region with the dynamics of the average value of low flows for rivers studied.

The relation of winter low water with winter precipitation and air temperature was discussed in publications [35-38]. These studies have shown that the connections of winter runoff with these factors is very weak. The regression analysis of our data also confirms a weak correlation between winter runoff and winter precipitation. This is due to the fact, that winter precipitation is practically not involved in the formation of the winter flow of rivers. As regards the connection between the trends of winter runoff and temperature trends, our results indicates that an increase in the winter low flow for the majority of studied rivers was significantly correlated with an increase in liquid precipitation of August, September and October and average air temperature in autumn and winter month [7].

Comparison of trends of the winter low flow with trends of average air temperature for December-February is of certain interest, because these trends showed that air temperatures of winter month have an influence on formation of the winter low flow (Figure 5). Thus, the analysis of the regularities of the formation of the winter low flow maintain idea that the important function in this process owes to two factors, precipitation and air temperature. Air temperature rise during warm season contributes to groundwater recharge due to thawing of permafrost, but an increase of winter temperatures can reduce the depth of frozen soil and be a factor affecting regulation runoff in winter. When the role of global warming on the affecting the northern rivers runoff is estimated, this concept must be taken into account.

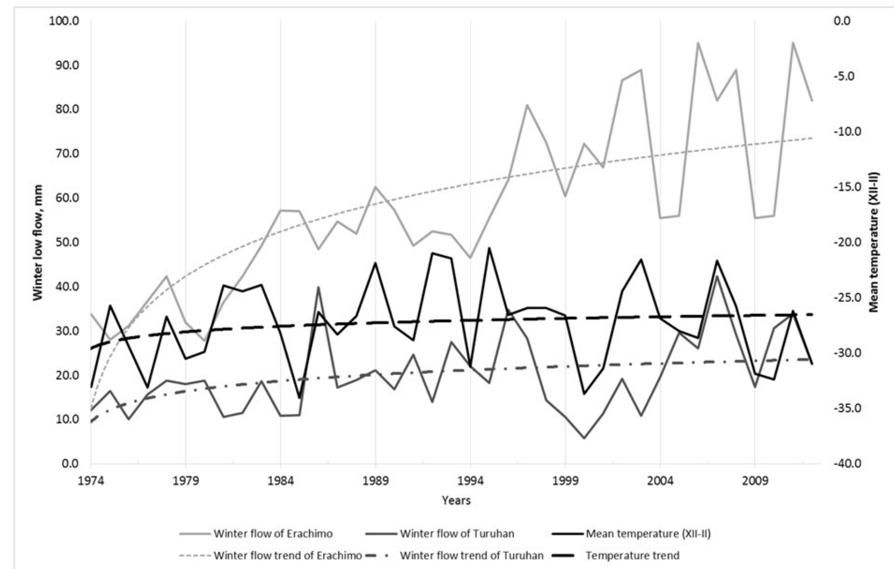

Figure 5: Trends of the winter low flow and winter air temperatures.

Conclusion

By the results of our researches, we can summarize that the trends of global climate change are revealed differently at the local level. We can identify different areas of permafrost zone of Central Siberia where the temperature and precipitation trends differ markedly. Seasonal dynamics of air temperature increase differs for the eastern and western regions of the study area. Coefficients of linear trends in precipitation showed different direction of long-time precipitation dynamics in Central Siberia that is associated with the spatial distribution of precipitation due to complex topography. The study's results allowed us to assume that the trends of local climate dynamics, to a certain extent, depends on the variation of spatial non-uniformity and seasonal specificity.

Studies have shown the response of river flow to changes in meteorological parameters. Significant trends in the annual runoff in the permafrost areas of Central Siberia are associated with the trends in climatic parameters, such as precipitation and air temperature in the summer. The winter low-water level is more dependent on temperature trends both in summer and in winter. Air temperature rise during warm season contributes to groundwater recharge due to thawing of permafrost, but an increase of winter temperatures can reduce the depth of frozen soil and be a factor affecting regulation runoff in winter.

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