Estimation of peculiarities and long-term dynamics of Vasyugan mire water balance in Western Siberia

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Abstract. Examinations of water balance were carried out in the north-eastern part of the Vasyugan mire (Western Siberia) within the area of the small basin of the River Klyuch. Statistical analysis of long-term changes in water balance elements allowed us to identify a decrease of overall moistening in April-May, a gradual increase of evaporation in the autumn period, the growing duration of the transitional autumn-winter period and a corresponding reduction of moisture content in snow cover in November-December. As a result, redistribution of the hydrological regime, which is characterized by a definite flow decrease in November, December and April-June, and an increase in August-September is observed in the region.

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Introduction.

The bogs that occupy vast areas of Western Siberia play a powerful role as a climate regulation factor, facilitating the spatial distribution of thermal energy and water resources. Western Siberia mires deposit as much as a quarter of the carbon stored in our planet ecosystems. Western Siberia acts as the largest "trap" of atmospheric carbon and thus plays an important role in the global carbon cycle. In this regard, bogs research of Western Siberia is engaged in a number of scientists [1-3]. They noted that in the northern part of the West Siberian Plain the permafrost zone has an increase of termokarst activity and decrease of mire areas. In contrast, in southern part of the West Siberian Plain (in the southern taiga subzone) the increasing of the area of mire and forests displacement was observed. Progressive swamping and accumulation of carbon in peat deposits of the southern taiga subzone territory in Western Siberia are also noted by a number of other researchers [4-6]. Hydrological aspects of such important phenomena are identified in Western Siberia but poorly understood. Therefore, this article is supposed to carry out studies of the water balance of typical mire in a small river basin. The examination of moisture accumulation and consumption processes in river basins will allow us to estimate modern processes of climatic and hydrological condition changes in Western Siberia and to define the influence of progressive bog formation on changes of river runoff and groundwater flow. Examinations of water balance were carried out in the north-eastern part of the Vasyugan mire within the area of the small basin of the River Klyuch (Ob River watershed) (Fig. 1).

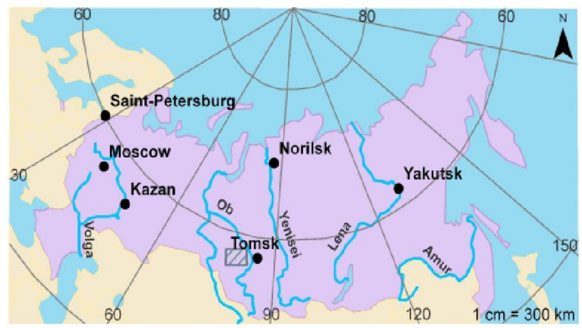

Figure 1. Investigation site

The study was conducted for two typical for Western Siberia pine-shrub-sphagnum plant association of mire – high riam, low riam and in sedge-sphagnum swamp. The total catchment of the area is based on the interpretation of satellite data which is 76 km^2. The total waterlogged watershed is 77 %.

Materials and Methods.

The determination of annual precipitation, snow cover water equivalent, evaporation amount and discharge was carried out separately for every dominant type of raised bog biogeocenoses during the estimation of water balance components: high riam, low riam and sedge-sphagnum swamp, as well as in general for the whole catchment of the River Klyuch. For estimation of long-term dynamics the monthly water balance model was used [7] to estimate the total value of moisture, water loss from snow (in spring), flow losses, and a statistical analysis of long-term changes in the water balance elements was conducted. Water balance for every dominant type of raised bog biogeocenoses was calculated by the general equation:

$$Y=X-E\pm W \quad (1)$$

where Y – runoff from mire; X – precipitation; E – evapotranspiration; W – change of moisture in peat deposit.

Evapotranspiration from the catchment area and from the surface of the mire was calculated by the method of V.S. Mezentsev [8]:

$$Z=Z_m\left(1+\left(\frac{\text{收} + W_1 - W_2}{Z_m}\right)^{-n}\right)^{-\frac{1}{n}} \quad (2)$$

where Z – evapotranspiration, mm; Z_m – maximum possible evaporation determined hygrometric intensity air - humidity deficit, KX - total moisture, W_1 - moisture reserves in the active layer at the beginning of the billing period, W_2 - moisture reserves in the active layer at the end of the billing period, n - parameter defined by the ratio, the actual and maximum possible evaporation of moisture at an optimum active layer of soil.

Runoff from the mire by the overland flow method [9] was calculated and compared with runoff from a receiving river to estimate the output component of the water balance for a long-term period (2006-2010). Runoff from the mire was calculated by the equations

$$Q=qL \quad (3)$$

$$q= ik_0\,(z_0 - z) \quad (4)$$

where Q - runoff from the mire; q – overflow in peat deposit; L – length of the runoff contour equal to the width of the River Klyuch watershed; z_0 – depth of the acrotelm layer, z – mire water level; i – slope of the river basin, k_0 – filtration coefficient. Satellite data taken within the study area, as well as data from long-term observations of mire water level were used for the calculation.

The total humidification of the catchment area per month t considered as the sum of liquid precipitation X (average monthly rainfall in air temperature T_a or equal to or above 0 ° C) and water loss from snow cover B:

$$H_t = X_t + B_t\,. \quad (5)$$

When the average air temperature is below 0 ° C, precipitation is regarded as snow, which is not directly involved in the water feeding the river, and goes to the formation of snow cover S

$$\frac{dS}{dt} = X - B - E_s\,, \quad (6)$$

where E_s – monthly evaporation from the snow (mm), calculated in this paper by the equation:

$$E_{s,t} = 0.34\; m\; d_t\,, \quad (7)$$

m - number of days in the month; d_t - the average monthly deficit of moisture hPa. For an approximate calculation of the monthly moisture content in the snow cover, we used an implicit finite difference scheme for solving equation (6).

Water loss from the snow cover B is approximately defined by Vissmen et al. [10] in air temperature equal to or above 0 ° C, by the equation:

$$B_t = min\left(\frac{k_T\, T_{a,t}\; m}{1-k_B} + k_X \sum_j^m X_j\, T_{a,j}\;; S_t\right), \quad (8)$$

where k_T – snow melting rate mainly due to sun radiation; k_B - snow melting rate at which water loss begins; $k_X \sum_j^m X_j\, T_{a,j}$ - monthly snow meltwater depth.

The total catchment humidification was calculated as a weighted average in the woods and in open areas. The value of the total runoff loss P was defined as the difference between total moisture H_t and total runoff for the current month.

The method of statistical analysis included: 1) random series of observations using the criterion of Pitman π and linear model of the form $Y = a\ T + b$, where Y - the quantity under investigation; T - year; a and b - empirical constants; 2) homogeneity by using the Student and Fisher criterion.

Results.

As a result of this study it was noted that differences in the water balance of the mire are defined by the vegetation structure, which defines the process of moisture accumulation in the bog peat deposit. A volume of precipitation with snow cover water equivalent to over 489 mm is investigated in high riam, but under conditions of intensive water flow, a minimum level of moisture accumulation is observed, owing to a powerful active layer. The less forested lower riam is characterized by about 143 mm, but with a more intensive level of annual evaporation, reaching 479 mm, a relatively high discharge module and water levels of -1 cm compared to the average surface level. Constantly high levels of bog waters, which are 3 cm higher than the average surface level, evaporation on an average of 399 mm and moisture accumulation in a peat deposit are characteristic of the open area of sedge-sphagnum bog (Table 1).

Table 1. Relation of mire water balance elements in the basin of the River Klyuch (1998-2010)

Observation point	Precipitation*, mm	Storage of water in snowcover, mm	Evapotranspiration, mm	Change of moisture, mm
High riam	490	141	348	-40
Low riam	490	143	479	24
Sedge-sphagnum swamp	490	110	399	16

Note: We used data from the Bakchar weather station.

It has been calculated that the average runoff rate from the mire in the Klyuch River basin for a long-term period (2006-2010) is 1.81 l/s km^2.

Analysis of the long-term dynamics shows that in dry years the runoff rate from the mire decreases to 0.70 l/s km^2. In wet years the runoff rate for the mire is 2.91 l/s km^2. The yearly dynamics shows a spring maximum level, at which the highest runoff value of the year is usually observed, as well as a summer-autumn low-water period with a low runoff rate (0.33 l/s km^2 on average). In some years, this period is characterized by higher runoff rates due to atmospheric precipitation as distinct from the winter low-water period, in which partial or full termination or runoff, or negligible runoff rates are often observed. The combined dynamics of the mire and river water levels in the basin of the Klyuch River were show that the runoff generation conditions are determined by the saturation pattern of the peat deposit. The river water level rises only after saturation of an active layer of the bog. Runoff from mires is 15 to 69% of the total river runoff.

Changes in the mire's water regime are determined by the ratio of the elements of the water balance and processes of water income and loss throughout the year. Analysis of long-term changes of mire water levels shows a statistically significant trend of increasing average levels (May-September) in the sedge-sphagnum swamp (Fig. 2).

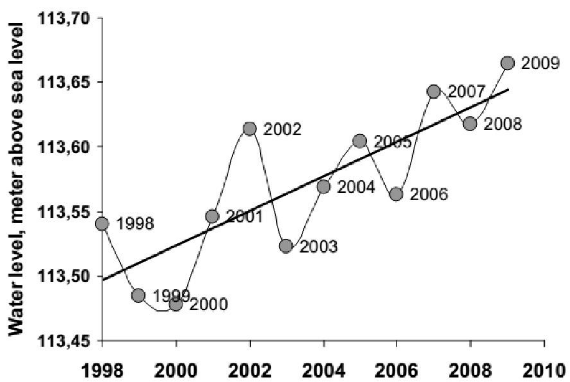

Figure 2. Long-term dynamics of the mean value of mire water level (May-September) in the sedge-sphagnum swamp

A positive trend was observed for the average water levels from June to September, with the most positive tendency noted in July and August. In contrast, in May there was a tendency to reduced water levels in the sedge-sphagnum swamp. For other biogeocenoses statistically significant trends in water levels were not detected. Keeping this in mind, in future we should expect further distribution of bogs, which are among the most stable components of the natural landscape.

No close correlation was found between the average mire water levels, river water levels and the discharge of Klyuch River and the air temperature at nearby weather stations. The highest correlation was observed for water levels with the amount of rainfall and mostly only for the border parts of mire occupied by the pine-shrub-sphagnum community. This kind of regularity indicates the complex functioning of the mire, its autonomy in relation to the surrounding area, its capacity for self-development and the creation of its own microclimate.

Analysis of long-term changes in the water balance elements in the Klyuch River basin has shown violations of series homogeneity associated with an increase of the total humidification of the basin in March, June, July, September and October (Fig. 3).

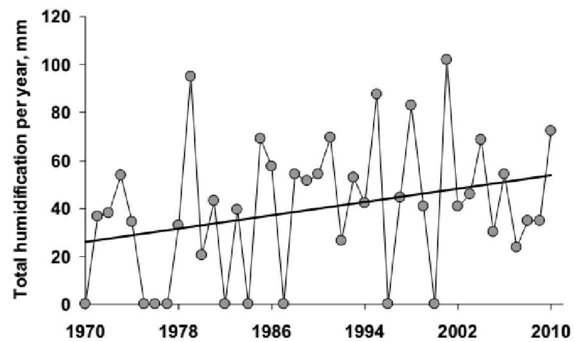

Figure 3. Dynamics of the total humidification (H) of the Klyuch River basin in October over a long-term period

Reduction of the total basin humidification was observed in April-May and August. Changes in humidity values were observed in the period 1982-1990. No statistically significant trends in changes to the total catchment humidification have been identified.

The river basin indicated a statistically significant trend of increasing losses in the June runoff, as well as a tendency to reduced runoff losses in May and August, which generally corresponds to the pattern of total moisture change in the studied area. Correspondingly, there is a violation of the homogeneity of the series in March, May and July, largely because of an increase in the volume of runoff losses. Thus, no violations of the homogeneity of the series through the redistribution of moisture reservoir size over time and loss of flow respectively are observed over the year. Increased runoff losses were determined mainly by increased evaporation and moisture on the territory in certain periods of the year.

Analysis of data for evaporation from mire in the basin of the River Klyuch revealed a pattern of decreasing evaporation from March to June and an increase in the second half of the year. In general, for the year a violation of series homogeneity associated with changes of the dispersion was indicated. In the long-term changes of flow depth a pattern could be observed, decreasing in April, May, June and November, December and increasing in August.

Discussion

The results of the investigations performed showed that differences in the water balance of biogeocenoses are defined by the vegetation structure, which defines the process of moisture accumulation in the bog peat deposit. The maximum atmospheric precipitation is observed in the more forested pine-shrub-sphagnum biogeocenosis which has high pines, although in conditions of intensive water drainage, a minimum level of moisture accumulation is observed, owing to the powerful active layer. Statistical analysis of the long-term changing of water balance elements allowed us to identify a decrease of overall moistening in April-May, a gradual increase of evaporation in the autumn period, the growing duration of the transitional autumn-winter period and a corresponding reduction of moisture content in snow cover in November-December. As a result, redistribution of the hydrological regime, which is characterized by a definite flow decrease in November and December, April-June and an increase in August-September is observed in the region. Nevertheless, the annual characteristics of the water balance remain statistically unchanged. Generally, conditions for the development of mire formation and peat accumulation processes owing to excessive moistening in the warm period of the year will remain favourable in the nearest and medium term prospect.

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