Precipitation in the catchment area of the Votkinsk reservoir: nature, type and temporal variability

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Abstract. The type and nature of precipitation in the catchment area of the Votkinsk reservoir are considered with taking into account its hydrological zoning. Intra-annual frequency, duration and intensity of precipitation are shown. It is determined that 321 days are observed with precipitation per year on average. Daily amount does not exceed 1 mm. In the catchment area, widespread and rain precipitations are observed with a frequency of 51 and 53% respectively. The daily duration of precipitation depending on its type was obtained, which equals 4–6 h for rain and mixed precipitations and 8–10 h for solid precipitation. High precipitation intensity is observed in the northern part of the catchment area, where the terrain contributes to the development of cloudiness and an increase in precipitation intensity.

1. Introduction

River run-off is one of the most important hydrological characteristics. During the year its value and distribution are influenced by a complex of natural factors and human economic activity.

The rivers of the Perm region which form the catchment area of the Votkinsk reservoir are mostly snow fed. This is determined by climatic and geological and geomorphological conditions. The river regime is characterized by a pronounced spring flood, irregular summer-autumn rain floods, summer-autumn low water and long-lasting winter low water [1; 2]. High spring floods are dangerous hydrological phenomena that cause the greatest damage in the Perm region [3; 4]. The intensity of floods depends on the weather conditions of the snowmelt period and the characteristics of the underlying surface [5; 6]. In general, modern approaches to assessing the sensitivity of river run-off characteristics to changes in the conditions of its formation are based on the results of hydrological models [7; 8].

The main natural factor in the formation of river run-off is climate, especially precipitation and evaporation. The general climate warming trend leads to an increase in the water vapor content in the atmosphere through an increase in the intensity of moisture exchange between the land surface and the atmosphere and an increase in the intensity and duration of precipitation [9; 10] especially in the cold season [11].

The spatial distribution of cloud fields and precipitation has been studied with taking into account the type of underlying surface [12; 13; 14; 15]. The contribution of the precipitation type and its intensity was estimated during the formation of snow cover [16], the circulation conditions for the formation of precipitation during the cold period were considered [17] for the catchment area of the Votkinsk reservoir within the Perm region. This study focuses on the type and genesis of precipitation, on the variability of their frequency and duration.
2. Data and methods

The present study is based on the morphological classification of precipitation. According to this classification, precipitation is divided into a rain form, solid form and mixed. Rain and drizzle is rain precipitation. Solid precipitation has large species diversity: snow, snow pellets, snow grains, freezing rain, hail and ice needles. Sleet refers to mixed precipitation [18].

Precipitation is divided into the following types according to the nature of precipitation, depending on the genesis, duration and intensity:

- widespread precipitations are characterized by medium intensity and fall out of the cloud system Ns–As in rain, solid and mixed form;
- shower precipitations are characterized by a sudden start and end with a sharp change in intensity and fall out of cumulonimbus clouds in the form of rain, snow or snow pellets and hail;
- drizzle or ice needles (at low temperature) fall out of dense clouds (St–Sc) [19].

The data of 22 meteorological stations and 39 hydrological posts from meteorological yearbooks and monthly reports for 2013–2017 was used as research material.

3. Results and discussion

Precipitation is connected with the frontal cloud system; stratocumulus clouds have the highest frequency (18–32%) in the catchment area of the Votkinsk reservoir within the Perm region. The formation of convective clouds (Cu and Cb) does not exceed 15% and is closely bound up with the season of the year.

Annually the precipitation in the catchment area is observed from 295 to 346 days. Daily amount does not exceed 1 mm in most cases. The average annual precipitation is 700 mm at one observation point. 68% of this amount of precipitation falls in the warm season. Rain and solid precipitations fall every month with different frequency of occurrence. Mixed precipitation is observed from September to May with a maximum frequency of 28% in October (figure 1a).

![Figure 1](image_url)  
*Figure 1*. Seasonal distribution of frequency of type (a), nature of precipitation (b) and duration (c) in the catchment area of the Votkinsk reservoir.
In the winter months rain precipitation takes place in the form of drizzle. Its daily duration does not exceed 3 hours. In summer solid precipitation falls rarely (with a frequency of not more than 3%) and is represented by hail or snow pellets. The form of clouds determines the nature of precipitation falling out of it. Thus, shower precipitations prevail from May to August; widespread precipitations prevail from September to April. Drizzle is an all-season phenomenon; the highest incidence is 15% and is registered in December (figure 1b). The daily duration of precipitation is seasonal: it makes 1 hour in the summer period, 6 hours in the spring and autumn period and 10 hours in the winter period (figure 1c).

The analysis of the nature of precipitation and its type was carried out with taking into account the zoning of the catchment area of the Votkinsk reservoir, where five hydrological regions are marked out according to the conditions of river run-off formation [3]. Thus, widespread precipitations prevail over other types throughout the catchment area (table). The average annual portion is 46–55% or 183–234 days. The proportion of drizzling precipitation does not exceed 11%.

| Hydrological region | Genesis classification | Morphological classification |
|---------------------|------------------------|-----------------------------|
|                     | widespread | shower | drizzle | rain | solid | mixed |
| I– north mountain   | 234 (47)   | 205 (42) | 54 (11) | 151 (55) | 109 (33) | 36 (12) |
| II– southern mountain| 183 (51)   | 151 (44) | 19 (5)  | 115 (41) | 118 (44) | 43 (15) |
| III– north plain    | 209 (46)   | 204 (44) | 48 (10) | 144 (43) | 151 (46) | 36 (11) |
| IV– central         | 210 (53)   | 154 (39) | 29 (8)  | 132 (43) | 131 (43) | 40 (13) |
| V– southern plain   | 201 (55)   | 139 (38) | 24 (7)  | 128 (46) | 119 (42) | 34 (12) |

By the type of precipitation, mixed precipitations have the lowest frequency (no more than 15% of the total). The recurrence of rain and solid precipitation has a complicated distribution (table). Rain precipitation is observed in the northeast and southwest of the catchment area. Their annual portion is 46–55%. Solid precipitation dominates the second and third hydrological region. Their frequency is 118–151 days or 44–46% of the total number of days with precipitation. A distinctive feature of the central region is precipitation with an equal frequency of 43% in both rain and solid form during the year.

The daily duration of rain and mixed precipitation is equally distributed throughout the catchment area and is 4–6 hours (figure 2).
region) where the daily duration of solid precipitation amounts to 16 h with a low annual frequency of 109 days or 33% of the total number of days with precipitation.

An assessment of precipitation intensity was performed for four hydrological regions (I, II, III and V) in the catchment area of the Votkinsk reservoir where the observation network is equipped with a rain recorder. These devices are installed weather stations of Vaya, Cherdyn, Biser, Kungur and Perm. Records can be received only during the warm season. Thus, the maximum intensity of rain precipitation is 0.58 mm/min on average in July, the minimum intensity is 0.13 mm/min on average in September (figure 3). This pattern is consistent with the distribution of precipitation according to the nature of precipitation within the warm season. High precipitation intensity is typical for the northern part of the catchment area (0.39 mm/min). This is due to the orography of the location of the meteorological station with the rain recorder. An additional contribution to the development of clouds and to an increase in the intensity of precipitation is made by orographic vertical movements in the foothills of the Northern Urals. Low precipitation intensity is observed in the southern lowland part of the catchment area (0.24 mm/min).

Figure 3. Intensity of precipitation in the catchment area of the Votkinsk reservoir in the warm season.

4. Conclusion
Atmospheric precipitation is mainly associated with the frontal cloud system in which Sc clouds dominate in the catchment area of the Votkinsk reservoir. This cloudiness determines widespread precipitations. In general, rain precipitation prevails by time and space. Taking into account the hydrological zoning of the catchment area, it was found that rain and solid precipitation is observed with equal intra-annual frequency in the central part, solid precipitation dominates in the north-west and southeast of the catchment area. High precipitation intensity is observed for the northern part of the catchment area, where orography affects the formation of additional vertical movements and an increase in precipitation intensity.

References
[1] Kalinin V, Sumaneeva K and Mekhanoshina E 2018 Gidrologicheskoye rayonirovaniye territorii vodosbora Votkinskogo vodokhranilishcha po vnutrigodovomu raspredeleniyu rechnogo stoka v mnogovodnyye gody Voprosy geografii 145 325–336
[2] Komlev A 2002 Zakonomernosti formirovaniya i metody raschetov rechnogo stoka (Perm: Perm State Univ. Publ.) p163
[3] Dolinov A and Berdyshev O 2014 Riski chrezvyachaynykh situatsiy prirodnogo kharaktera na territorii Permskogo kraya Vestnik Perm. nats. issled. polit. un-ta. Bezopasnost i upravleniye 4 18–35
[4] Pyankov S and Shikhov A 2014 Opasnyye gidrometeorologicheskiye yavleniya: rezhim, monitoring, prognoz (Perm: Perm State Univ. Publ.) p 296
[5] Kalinin V, Sumaneeva K and Rusakov V 2017 Analiz metodov interpolyatsii prostranstvennogo raspredeleniya meteorologicheskikh kharakteristik pri raschetakh vesennogo snegotayaniya Geograficheskiy vestnik 2 (41) 126–137

[6] Kalinin N, Shikhov A and Sviyazov E 2015 Simulation of snow accumulation and melt in the Volginsk Reservoir catchment using the WRF-ARW model Russian Meteorology and Hydrology 40 749–757

[7] Razavi S and Gupta H 2015 What do we mean by sensitivity analysis? The need for comprehensive characterization of “global” sensitivity in Earth and Environmental systems models Water Resour. Res. 51 doi:10.1002/2014WR016527

[8] Song X, Zhang J, Zhan C, Xuan Y, Ye M and Xu C 2015 Global sensitivity analysis in hydrological modeling: Review of concepts, methods, theoretical framework, and applications J. Hydrology 523 739–757

[9] Groisman P, Knight R and Karl T 2012 Changes in Intense Precipitation over the Central United States Journal of Hydrometeorology 13 (1) 47–66

[10] Zolina O, Simmer C, Belyaev K, Kapala A and Gulev S 2009 Improving estimates of heavy and extreme precipitation using daily records from European rain gauges J. Hydrometeorol. 10 701–716

[11] Khon Vand Mokhov I 2012 The hydrological regime of large river basins in Northern Eurasia in the XX-XXI centuries Water Resources 39 1–10

[12] Kalinin N and Pomortseva A 2014 Vliyaniye orografii na polya oblakov i osadkov v Permskom kraye Uchenyye zapiski Rossiy skogo gosudarstvennogo gidrometeorologicheskogo universiteta 37 84–93

[13] Kalinin N, Frick L and Smirnova A 2008 Issledovaniye vliyaniya relyefa Permskogo kraya na raspredeleniye polye osadkov Geograficheskiy vestnik 2 (8) 187–195

[14] Pomortseva A 2017 Vliyaniye vodokhranilishch na kharakteristiki vlazhnosti polye oblacnosti Sovremennyye problemy vodokhranilishch i ikh vodosborov (Trudy VI Mezdunarodnoy nauchno-prakticheskoy konferentsii vol 3) ed A Kitaev, O Larchenko and S Dvinskikh (Perm: Perm State Univ. Publ.) pp 138–140

[15] Shklyaev V and Shklyaeva L 2006 Klimaticheskiye resursy Uralskogo Priamalya Geograficheskiy vestnik 2 76–90

[16] Vetrov A and Smirnova A 2011 Kharakteristikii snezhnogo pokrova na Urale po dannym nablyudeniy i rezultatam gidrodinamicheskogo modelirovaniya Geoinformatsionnoye obespecheniya prostranstvennogo razvitiya Permskogo kraya (Perm: Perm State Univ. Publ.) pp 67–74

[17] Pishchalnikova E and Akilov E 2018 Vliyaniye tsiklonicheskoy deyateli'nosti na formirovaniye osadkov kholodnogo perioda na Srednem Urale Vestn. Udm. un-ta. Ser. Biologiya. Nauki o Zemle 4 434–440

[18] Nastavleniye gidrometeorologicheskim stantsiyam i postam 1985 (Leningrad: Gidrometeorizdat) p 298

[19] Matveev L T 1984 Physics of the atmosphere (Leningrad: Gidrometeoizdat) p 752