Flood hazard on the Upper Angara river

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Abstract. The article provides the results of studies on flooding in the rivers of the northern Baikal on the example of the Upper Angara river basin. Some information about the situation with floods and mudflows in the dynamics since 1933 is highlighted. Spatial and temporal patterns of maximum levels, water discharge, duration of high levels, intensity of the water rise have been studied using standard methods of processing hydrological information to assess risks and hazard. On the basis of long-term observation series, expedition surveys we considered classification geohydrological characteristics of floods by genesis of their formation, recurrence of extreme levels, intensity and depth of floodplain inundation. The areas of possible flooding and waterlogging have been determined on the basis of large-scale maps using GIS technologies using ArcGIS. Settlements and infrastructure facilities located in hazardous areas have been identified. Engineering measures to mitigate flood risks in the Upper Angara river have been proposed.

1. Introduction
Studies of extreme hydrological phenomena associated with high water availability in the rivers of the Lake Baikal basin are relevant because of the potential negative consequences of floods for the Republic of Buryatia (flooding of used coastal areas and economic facilities located on them). The transboundary Selenga river basin is undoubtedly a particular focus of research due to the periodic large-scale flooding of the most developed areas of the Baikal region, as well as its transboundary location.

The study of the hydrological regime of the northern rivers of the Baikal area has been associated with the development of the north and the construction of the Baikal-Amur Mainline. However, the interest was focused on the research of mudflow hazards of the territory as a result of catastrophic descent of mudflows. Today the relevance of the research of spatial and temporal patterns of maximum water levels formation on the Upper Angara river becomes especially important in connection with the approved intentions and the beginning of construction of the second branch of the mainline.

The Upper Angara river flows among the spurs of mountain ridges and flows into the Angarsky Sor of the northern part of Lake Baikal, forming an extensive delta together with the Kichera river. The upper reaches of the river and its tributaries are mountain rivers, while in the middle and lower reaches it becomes close to the mountain-plains ones. The floodplain in the upper reaches is discontinuous and partially developed. Downstream of the village Yanchukan the river enters the basin and the valley widens from 0.2 km to 20-25 km. The floodplain surface is swampy, dissected by channels and dead stream channels-lakes [1, 2].

Extreme hydrological phenomena can hamper the development of the area. Thus, according to the published data, significant damages were caused in 1978-1980 during the construction of the railroad not only floods, but also catastrophic mudstone mudflows. An emergency situation occurred in 2007.
when 12 houses in the village of Kumora and 12 houses in the settlement of Verkhnyaya Zaimka were flooded. The government of the Republic of Buryatia allocated 1 million rubles to eliminate the consequences. As a result of the 2019 floods, the residents of Kumora village were cut off from the mainland due to the destruction of the road and the bridge. Kumora. More than 600 people were in danger [3].

The purpose of this article is to study the spatial and temporal patterns of maximum water level formation and peculiarities of flood development in the Upper Angara river basin.

2. Models and Methods
The hydrological study of the Northern Baikal rivers is very poor. At present there are four hydrological stations (h.s.) in the Upper Angara River basin, and two of them are level gauges. An observation point in Verkhnyaya Zaimka settlement was established in 1932. The others were opened much later for the period of railroad construction and are currently inactive.

The source material for the study is a standard set of hydrological data of long-term observations of water levels and discharges, ice phenomena, etc. We used data from the records of the Buryat Centre for Hydrometeorology and Environmental Monitoring on the water regime of the river and a number of operational hydrological data. The electronic databases of various data on floods, created in the process of work, served as the information basis. Reference materials on the location of settlements, economic objects, as well as information on emergency situations, damages, etc. served as additional literature.

We used standard methods for processing hydrological information for accepted time periods, methods of analysis, systematization and geographical generalizations. Mapping techniques using GIS technologies play a key role in the spatial distribution of information.

3. Results and Discussion
Analysis of available historical, statistical materials shows a number of floods on the Upper Angara River, on mountain tributaries - mudflows (mud and mudflows). Major floods occurred in 1933, 1936, 1951, 1952, 1956, 1960, 1962, 1977, 1978, 1980, 1982, 1994, 2007, 2019. Occasional mudflows are registered on the right-bank watercourses of the Verkhneangarsky Range - the Anamokit, Inomakitan, Ogney, Ayakon rivers, etc.; on the left-bank watercourses of the North-Muysky Range - the Burunda, Sikeli, Gonkuli, Yanchui, Yanchukan, Amnunda, Kovokta rivers [1, 4].

According to the genesis of formation in the area under consideration are characterized by runoff floods associated with abnormally high floods and inundations. In general, flooding, due to considerable snow accumulation, is the main phase of the water regime of the northern rivers. It starts at the end of April/beginning of May and ends in mid-July. It usually comes in two waves, of which the first is of small volume and duration. Rainwater floods overlap with floodwaters to form a common wave [1, 5].

According to reference materials, the runoff during the high-water period averages 45-55% of the annual runoff. The maximum meltwater discharge is equal or slightly higher than the maximum flood discharge. During some years, depending on the volume of snow reserves and weather conditions, there may be a fairly significant predominance of snow or rainfall runoff.

The analysis of long-term dynamics of average monthly discharges on the Upper Angara confirms that the dates of the maximum runoff during the warm period are distributed unevenly with maximums prevailing in June-July. Increase of water levels above critical marks is registered during spring-summer floods with commensurable flood contribution. Extremely high levels, leading to overflows and flooding of coastal areas, are mainly observed during the first-mid summer. Thus, maximum instantaneous discharges on mountain tributaries are registered mainly in the first-second decade of June, whereas on the Upper Angara River (Verkhnyaya Zaimka settlement) in late June-early July, which is confirmed by diagram of intra-annual distribution of average monthly water discharge on the Upper Angara and left-bank tributaries (Figure 1).
Calculations of the frequency of exceedances of critical water levels also confirm the prevalence of mixed floods and floods. In the lower and middle reaches of the river (Verkhnyaya Zaimka, Uoyan) the share of floods dominates. In the upper-middle reaches, in some years there may be excessive levels with the main contribution of meltwater. However, they do not lead to large floods on the Upper Angara river.

On mountain tributaries due to mountainous relief with large fluctuations of absolute levels, moisture regime, as well as a number of other natural features of the territory, rapid powerful channel flows and mudflows are very common. In case of heavy rains and active snowmelt, flooding of the floodplain part of the river can result in huge water discharge from the slopes and mountain streams. Moreover, in the channel of the Upper Angara river the water level rise will not always be catastrophic. For example, in 1979 maximum immediate discharge in the Yanchuy river reached 304 m$^3$/s at an average annual of 25.2 m$^3$/s, at the same time in the lower reaches of the Upper Angara (Verhnyaya Zaimka) it was 1,190 m$^3$/s, but the water level did not exceed critical marks and the yield of water on the floodplain.

Abnormal rises begin in the upper reaches of the river and its many tributaries during intensive snowmelt in the mountains, complicated by the passage of heavy or prolonged rainfall. Increase in water levels above the critical level occurs here almost every year. The calculated recurrence rate of water outflow to the floodplain is 0.90-0.95. The height of water level rise can exceed 2.0-3.0 m above the low-water mark. Most of the basin’s watercourses take part in major floods.

When the river enters the Verkhneangarsk wide swampy basin, water spreads over the floodplain and levels in the river channel fall. A sample of long-term observations of maximum water levels shows that during the highest floods of the considered period (1936, 2019) the water level in the middle part of the river (Uoyan settlement) was 400 cm (the zero mark of the post 483.20 m BES) in the lower part of the river (Verkhnyaya Zaimka settlement) was 514 cm (elevation of zero of gauge 454.66 m BES).

Depth of floodplain flooding did not exceed 140 and 54 cm respectively. Frequency of excess of water levels above the critical marks can reach 0.8-0.9, in the middle stream - 0.3-0.5 and in the estuarial part up to 0.2. Extreme rises and consequently floods with flooding of coastal areas and infrastructure occur with the frequency of 0.04 – 0.10. For confirmation and clarity, the dynamics of maximum water levels for the period from the year of formation of the gauging station to 2019 is presented on a representative hydrological gauging station in Uoyan village (Figure 2).
In addition, an important characteristic of floods is the rate of water rise and the duration of standing of abnormal levels. Based on the official statistics of the surface water regime, the highest rate of water rise in the river is on average 74 cm per day, the decline is relatively fast (46 cm). On a number of mountain tributaries at the time of flooding rises are rapid and can reach more than 105 cm. Duration of stand of dangerous levels on mountainous tributaries is from 3-7 to 10 and more days, in the channel of the Upper Angara - from 8-10 days and very seldom up to 20-21 and more [1, 4].

Determination of flooding and underflooding zones was carried out on the basis of the vector topographic base at a scale of 1:100,000, and a digital elevation model using ArcGIS software. As hydrological information for obtaining absolute elevations of flood zone boundaries, the analysis and sampling of maximum levels from multi-year observation series was carried out, and calculated water levels in gauges obtained from the distribution curves of annual probabilities of exceeding maximum rainfall flood water levels for gauging hydrological posts were used. For sites without gauging stations, the maximum levels were determined by interpolation taking into account the longitudinal profile and river dip on the basis of large-scale maps.

It has been established that the maximum area exposed to floods is more than 814.6 km² or 3.8% of the basin area. These are mainly industrial and settlement lands, occupied by bridges, roads, residential and economic objects, as well as small areas of agricultural land. More than 1 thousand people are in danger of losing their livelihood.

In order to minimize the damage, an analysis of possibilities to minimize risks from the negative impact of water was carried out. Engineering protection is proposed for three settlements. Existing protective dams are in an emergency condition, so their repair and reconstruction is required.

4. Conclusion
The study demonstrates that floods and mud and mudstone mudflows are dangerous hydrological phenomena in the Upper Angara river basin. Their distribution and intensity largely depend on snow reserves in the mountains and weather conditions of the territory.

The peculiarities of the passage of floods vary depending on the river section. In the upper reaches, as well as on tributaries, sharp fluctuations in water levels with sudden high rises and powerful discharges into the valley are typical. In the basin and estuary parts of the river, fluctuations in levels

![Figure 2. Dynamics based on long-term data of maximum water levels (Verkhnyaya Angara-Uoyan): 1 – maximum water levels; 2 – critical water level of the floodplain outflow.](image)
have a smoothed character, which is due to the regulating influence of the extensive floodplain. Flood depths are shallow but there is widespread underflooding of the floodplain.

Important infrastructure facilities are at risk of possible destruction. Three settlements and strategically important infrastructure objects of the Severobaikalsky District of Buryatia are within the flood zone. To reduce the risk, it is necessary to take measures to repair the existing embankments and to clear sections of individual channels.

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