

System of geo-information mapping of debris flows hazard in the southern Baikal region

V P Stupin, L A Plastinin, B N Olzoev, N N Kutsy

Irkutsk National Research Technical University, Russia

E-mail kosmos@istu.edu

Abstract. The paper considers the principles and methods of GIS-mapping of debris flows based on the concept of morphological system, materials of remote sensing and geo-information technologies. It presents different results of geo-information mapping of debris flows in the southern Baikal region. The paper also justifies the need to use three components in mapping and monitoring of mudflow hazards as the integrating principle.

1. Introduction

At present, geo-information systems (GIS) are widely used around the world in different areas. It is beyond argument that the application of GIS technologies provides for advanced information processing almost in all branches that utilize the geographical data. Besides, there is a need to create a single information space that includes interrelated graphic (spatial) and descriptive (attributive) components to tackle various issues in this field. The tasks related to the efficiency analysis of the territorial utilization for further mapping of mudflow hazards shall consider a number of characteristics. Their solution requires the information database, mapping data reports and the study via geomatics of spatial-temporal links between phenomena, processes and actions. It is also advisable to solve these tasks using GIS-technologies.

Debris flows (mudflows) represent ravine mountain water flows differently impregnated with solid materials (blocks, crushed stone, saturated soil, tree remnants) that while moving with high speed, destroy natural and artificial barriers and carry out a large number of sediments to lower reaches.

2. Materials and methods

The study is based on the Landsat-8 satellite images of 2017-2018, digital topographic plans on a scale of 1:500 000, and a geologic map of the south of Eastern Siberia. Geo-information and satellite methods are used to illustrate the results in practice. The idea of geo-information mapping within the theory of cartography is governed by informative and communicative concepts. The automated space image interpretation is made in ENVI program via synthesizing in a combination 'infrared – red – blue' Landsat-8 to ensure vectorization of locations of torrential rivers and valleys.

3. Results and analysis

Debris flows suddenly appear under certain conditions, act a short period of time and are energy-intensive and destructive. The origin, type and character of debris flows define three groups of factors: climatic and landscape (meteorological factors, recent glaciation, soil permafrost, soil and vegetation cover), geological and geomorphological (composition of rocks, neotectonics, relief, recent volcanism, seismicity) and anthropogenic (deforestation, overgrazing, slope plowing, mining production,



industrial and civil engineering). The first defines the mudflow zonation and mode (duration and calendar terms of a mudflow period). The second group accounts for the volume and length of mass transport of mudflows, material composition and rheological types of debris flows. The third group defines the activity of debris flows and the area of mudflow territories.

All three groups of factors influence the repeatability of mudflows and generate their special genetic types: rain, snow, glacial, volcanogenic, seismogenic, limnogenic and anthropogenic mudflows of direct and indirect influence [1]. The similarity or distinction of groups of factors contribute to territorial zoning according to the degree of debris flow hazards, reveal similar types of territories and develop similar strategies of mudflow prevention measures. In general, the debris flows appear under three main conditions: highlands, broken rocks blocking water tracks and rare but heavy rains at a small annual amount of rainfall.

The most dangerous in terms of the debris flows hazards are mountains and taiga, as well as piedmont territories of the southern Baikal region characterized by natural conditions fostering the formation of mudflows. Strongly weathered Proterozoic rocks forming local ridges, as well as strong alluvial, proluvial and lacustrine deposits of intermountain basins and coastal plains serve as a good solid supplier of debris flows. The mountainous relief contributes to the accumulation of this material within drainage basins. Massive rainfalls typical for Siberia (1200-2000 mm/year) form a sufficient liquid component of debris flows [2-4].

Throughout the entire historical period the considered territory is characterized by numerous clearance of debris flows with high frequency, but unclear periodicity [5]. The last disastrous mudflow took place in 1971 and 1973 and since then the given territory was quite standard, which is unfavorable since the longer the interval between mudflows, the stronger and more dangerous they are. This was indirectly demonstrated on 28 June 2014 by a strong mudflow in Arshan village (Tunka Depression, Republic of Buryatia). In general, the mudflow traces preserved in different amounts over several hundreds of the past years (debris flow plains, marginal rampart and fossil cloudburst formed by unrounded coarse-grained loamy material and unrooted trees, damaged tree trunks) are typical for almost all rivers within the Khamar-Daban and the Tunka Ridge.

The coastal territories of the Lake Baikal stretching 60 km from the Kultuchnaya River to the Khara-Murin River and, to a smaller extent, the coast between the Khara-Murin and the Snezhnaya Rivers, which include drainage basins flowing into the Lake Baikal, are especially characterized by mudflow hazards. The Trans-Siberian Railway and the federal highway R-258 called the Baikal pass along the coast of the Lake Baikal. These roads have bridge crossings through numerous mountain streams with settlements and industrial facilities located in their cone delta. The most hazardous of them are settling sludge tanks of production wastes from the Baikal Pulp and Paper Mill (BPPM).

In general, the debris flows of the southern Baikal region belong to rain and, partially to seismogenic mudflows. At the same time, such debris flows also have their regional features considered below.

1. Degradation permafrost.

Most of the territory of the southern Baikal region lies in the permafrost zone with the frost depth of 120-250 m [6]. The soil temperature is generally defined by air temperature and is characterized by a sharp minimum at the end of January – beginning of February, and a maximum in July.

Permafrost generally prevents the development of debris flows. However, the current tendency includes the degradation of frozen rocks and their shift to a thawed state. This process is the most typical for old cryogenic lakes and appearance of new ones in mountain depressions. The degradation of permafrost in mountains is demonstrated by the increase in the seasonally thawed layer and its further strengthening due to excessive moistening caused by thawing water. Thus, the descent of Arshan mudflow on 28 June 2014 resulted in long rains causing the failure of the end moraine blocking the exits from corrie glaciers and the descent of accumulated water through old river beds of the First and Second Shikhtolayka [7]. These waterways generated thermoerosional influence and partially washed away the frozen soft cover of boulder pavement. The thawing of degrading permafrost became the reason of landslides and earthflows into old riverbeds. Along its movement through the slope this material was transformed to a structural debris flow, which mass stopped only at the suburb of Arshan village near the Hotel Saagan-Dali.

2. High seismicity of the territory.

The formation of the considered region as part of the Baikal rift area is characterized by high seismicity. The earthquake intensity reaches 7-11 points. Seismic shocks often serve as a trigger mechanism of many dangerous geological processes. Therefore, the descent of debris flows here is a standard phenomenon. Perhaps, the Arshan mudflow, besides intensive rains, is also caused by seismogenic factors. With high degree of probability, the simultaneous descent of six debris flows from the neighboring drainage basins of one tectonic block representing a rock mass could be provoked by the local seismic event.

3. Considerable forest coverage of potential mudflow channels.

The latest large-scale mudflow in the southern Baikal region happened nearly fifty years ago. Since then all old torrential swaths located on slopes, as well as floodplains and islands on rivers are covered with bushes and wood. Therefore, it is fair to say that the new solid phase of debris flows will contain wood and mudstone with at least 50 % of shrubby and wood remains of the total amount of a mudflow mass. Such amount of wood vegetation will cause wood debris and dams on rivers with further swell-like water breakthrough.

4. Soil features favorable for debris flows.

Widespread glacial and cryogenic deposits of the region are characterized by high concentration of clay reducing the modulus of deformation to 70 kg/cm^3 and the angle of internal friction to 17° due to heave rate, compressibility and subsidence, and increasing plasticity, porosity (0.65) and the natural angle of slope (10°), which determines the bearing capacity relief of waterlogged and broken soil and increases the probability of earthflows, landslides and debris flows [8].

Thus, it is urgent to ensure the study, zonation and forecast of debris flows hazards in the southern Baikal region on the basis of their continuous on-line monitoring. Geo-information mapping is considered the most efficient tool to monitor debris flows hazards in vast and remote areas. GIS-technologies and geo-information mapping provide for the study and analysis of complex formation and development of torrential processes and phenomena according to 2D, 3D and 4D (dynamics in time) digital mapping models (DMM). Geo-information mapping increases manifold the possibility of accumulating, updating, transferring, replicating and managing the information and data on torrential processes. It is regarded the irreplaceable, efficient and flexible tool for scientific, institutional, administrative and other organizations to study and assess the debris flows hazards, their forecast, planning of actions to fight against debris flows and mitigate their consequences.

Mapping and on-line monitoring of debris flows hazards require systemic and integrated approach to this complex natural phenomenon. The paradigm of organizing such mapping and monitoring is based on three principal components: methodological, information and technological [9-15].

The methodological component includes the theoretical study of GIS-mapping related to debris flows hazards. It is based on morphological systems and morphological-dynamic analysis of the earth surface that allow revealing natural divisibility and dynamic hierarchy of a relief and performing its mapping at three levels of generalization: morphostructural, basin and slope [16-20]. Regional mapping of mudflow morphological systems is generally performed at the basin-type level since the basins ensure spatial structure of mudflow hazards, accumulate solid component of future debris flows and distribute the flows of thawed and rain waters.

The information component of GIS-mapping represents the system of collection, systematization and on-line update of special databases using remote sensing data, topographic and special maps, digital relief models, prospecting and literature reference materials. For example, the current study is based on space images obtained by photographic systems from Resource-F Soviet satellites and modern images of optoelectronic scanners from Landsat satellites, as well as images obtained from unmanned aerial vehicles [21].

The technological component of systemic mapping represents GIS that processes the initial information at different scales and time intervals and solves the special problems related, for example, to isoline contouring, derivation of surface characteristics and hydrological calculation, creation of drainage networks, simulation of their dynamics, etc.

Genesis, density of debris flow network, their volume and recurrence belong to the main mapped characteristics of mudflow hazards. The three last characteristics allow assessing the mudflow intensity. The display system of these key characteristics in all direct or integral maps ensures

continuity of a plotting scale, as well as consolidation and comparison of maps. GIS implies four levels of mudflow maps.

1. Detailed (1:10 000 and larger scale) engineering and design maps and diagrams for certain operating and potential torrential basins and mudflow observation stations. They are aimed at protection measures and mudflow observation stations.

2. Large-scale (1:25 000-1:50 000) design maps and diagrams of mudflow regions. They are aimed at protection measures and monitoring of debris flows. They are based on the morphology of mudflow basins and streams.

3. Mid-scale (1:200 000-1:500 000) evaluation maps and diagrams of certain regions. They display the typology of mudflow basins and form the basis for mudflow hazard cadastral plans and databases.

4. Small-scale (1:1 000 000 and smaller scale) general scientific and reference maps and diagrams of states, continents and the world. They display the dominating genetic types of debris flows and mudflow intensity.

4. Discussion

Let us explain the principles of mid-scale mapping of debris flows using the map of a part of the southern macroslope of Tunkinskaya Range. This morphological system is located between the main watershed of the ridge and its bottom providing exits (old riverbeds) of its basin subsystems and basal facets of Tunkinsky end tail. The order of water currents forming these basin systems varies within I-IV, however the map shows only those basin subsystems, which are directly based on a source system without displaying any affiliated and elementary basins, which is implied by morphological system mapping. Besides water-parting lines of the displayed basins, which is implied by morphological system mapping. Besides water-parting lines of the displayed basins, the map shows their old riverbeds representing direct, temporary and disappearing water currents, historical debris flows (100-150 years old) revealed through satellite images according to light lines, as well as residential territories (Figure 1).

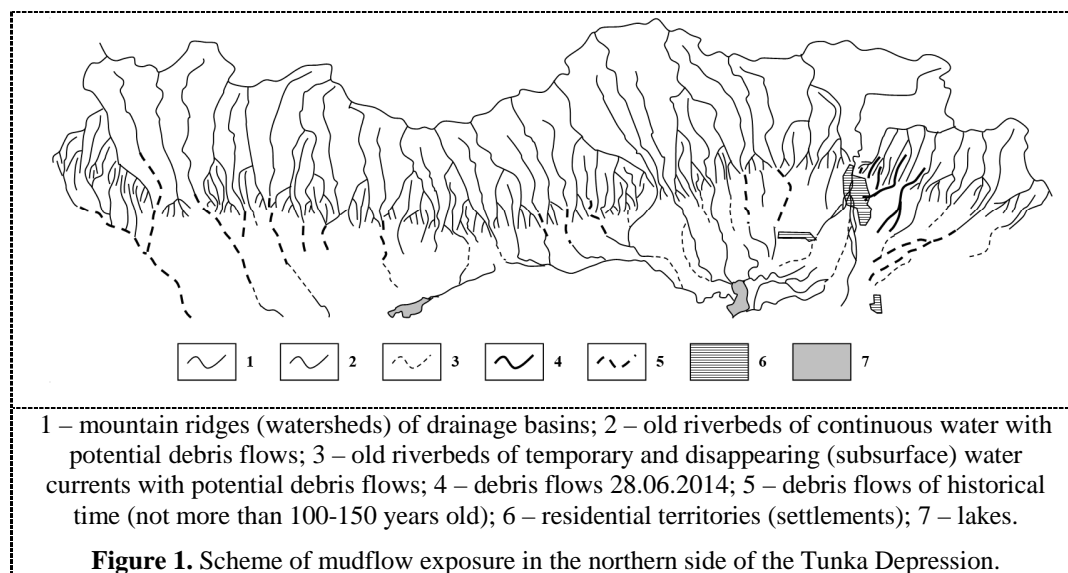
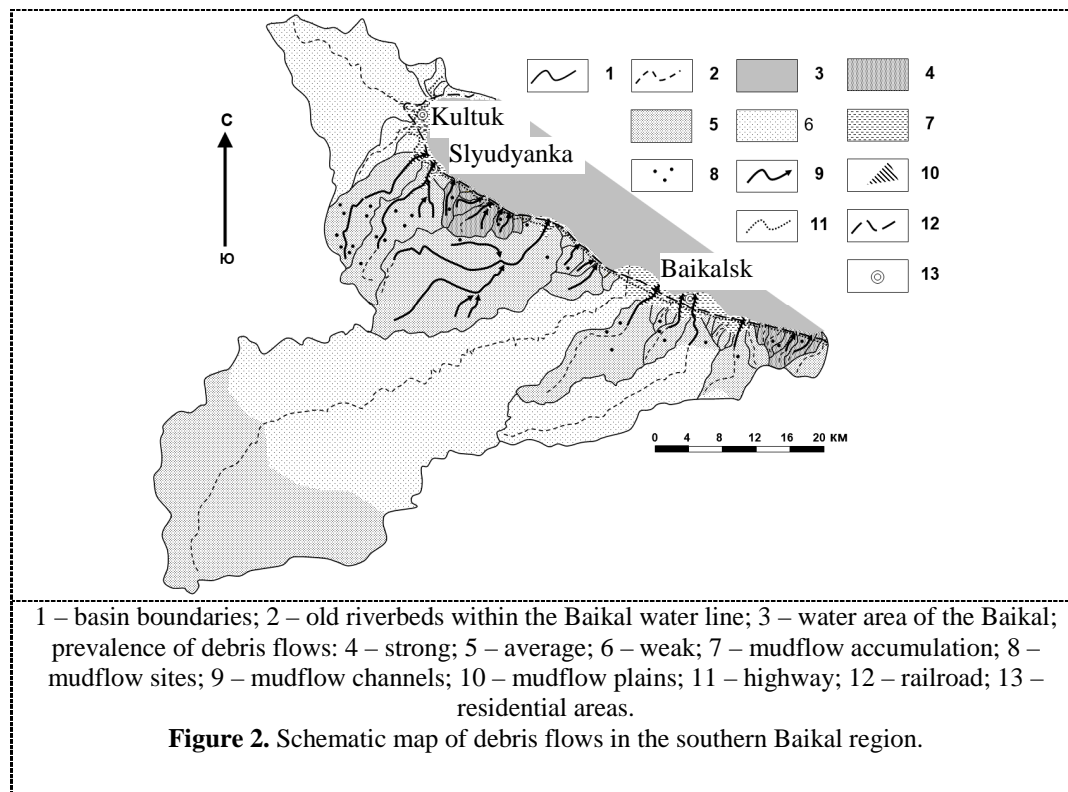


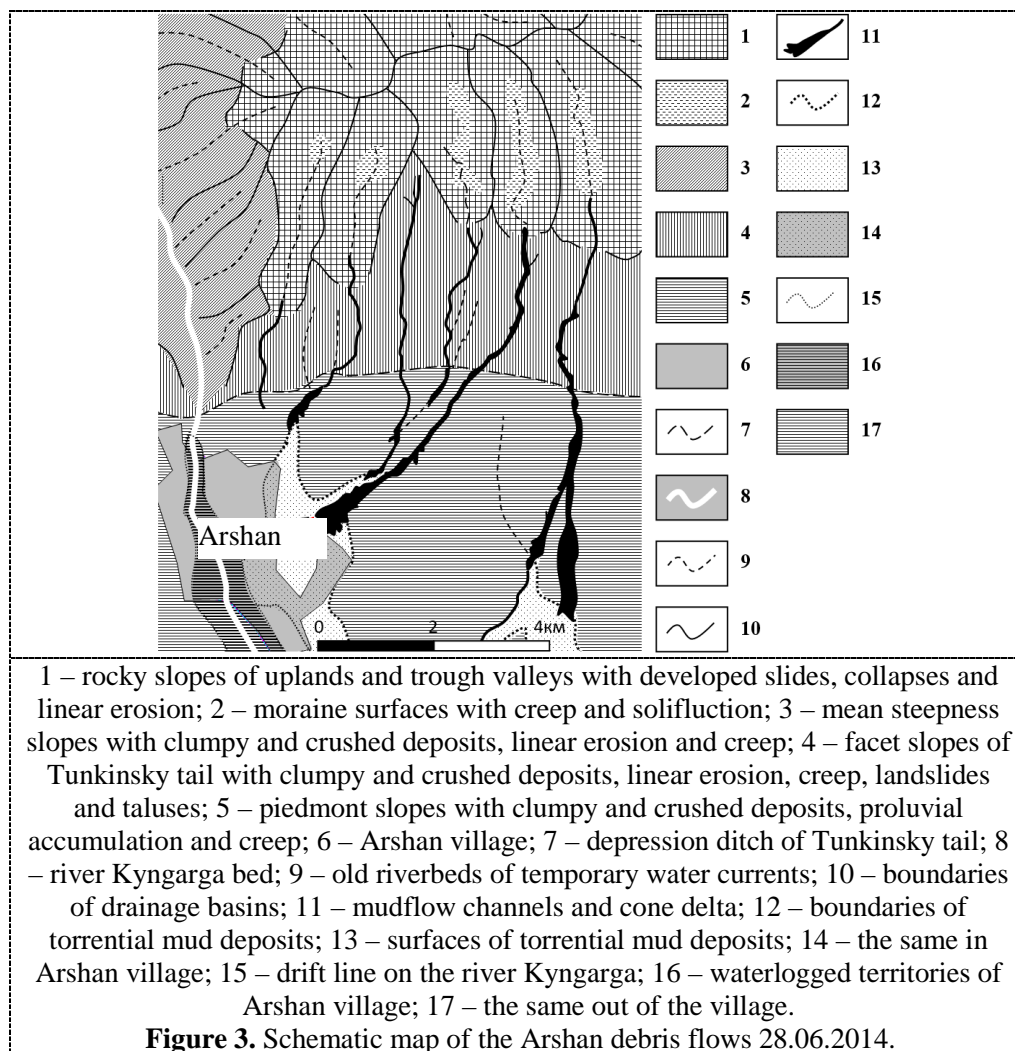
Figure 1. Scheme of mudflow exposure in the northern side of the Tunka Depression.



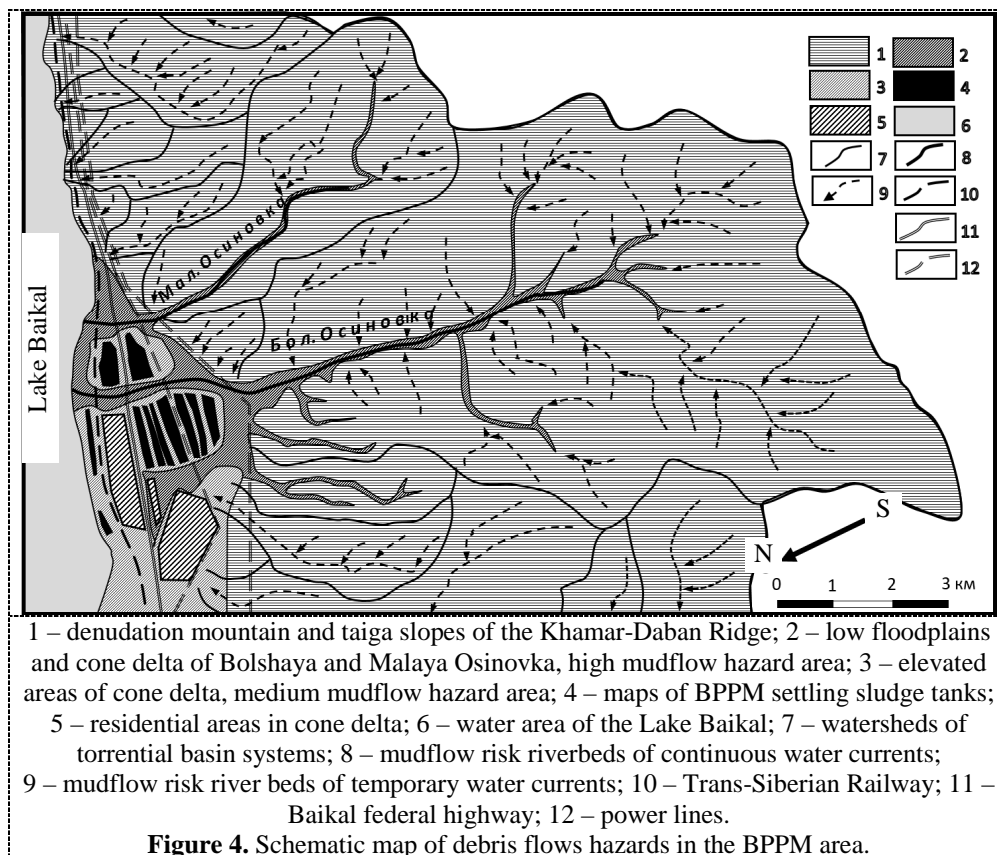
Another example of mid-scale mapping of mudflow hazards is the mid-scale mudflow map of the southern Baikal. Topographical maps of the following scale 1: 200 000 formed the basis of its thematic component. The basin subsystems are shown within the source morphological system of the northern macroslope of the Khamar-Daban Ridge. Similar to the previous example, the map only shows basins of the source morphological system. The map also shows mudflow sites, mudflow channels, mudflow tails and cone delta, the location of which is defined by the ERS and field data. Besides, the map shows old riverbeds of water currents in the Baikal low water line, residential areas, the federal highway R-258 and the Trans-Siberian Railway.

The map also demonstrates good mudflow zonation according to three levels of hazard: strong, average and weak. It is obvious that the small basins of the Khamar-Daban Ridge are mostly affected by debris flows, the medium-size basins – are moderately affected, and large water areas (Utulik River) – are almost not affected by debris flows. Besides, weak prevalence is also typical for the Kultuksko-Bystrinskaya closing dike with small relief energy (Figure 2).

The large-scale map of the Arshan debris flows shows structural lines, basin systems and slope systems of various steepness with their genetic and dynamic characteristics, mudflow channels and cone delta, and the boundary of mudflow deposits (Figure 3).



A special emphasis shall be placed on mudflow hazards caused by small river basins of the Bolshaya and Malaya Osinovka flowing into the Lake Baikal to the east of the Baykalsk city and the resulting destruction of settling basins and disposal of poisonous wastes to the Lake Baikal in case of extraordinary rise of water level (5 m and more) [8]. This nearly happened during the flood in 1971 when emergency measures were only able to prevent the irruption of high waters into settling basins. Figure 4 shows the map of the considered territory.



5. Conclusions

The considered GIS-mapping of mudflow hazards is designed for further study and analysis of mudflow hazards in the southern Baikal region, for setting new research tasks, model and forecast the debris flows, develop measures to protect the population and technical objects in the coastal zone of the Lake Baikal. It can also be used by various administrative, scientific and production organizations for on-line assessment of mudflow hazards and urgent administrative decision-making.

References

- [1] Perov V F 1996 *Debris flows: dictionary of technical terms*. (M.: Moscow State University)
- [2] Rogozin A A 1993 *Coastal zone of the Baikal and the Khubsugul (morphology, dynamics and history of development)*. (Novosibirsk: Nauka. Siberian Branch)
- [3] Laperdin V K, Kachura R A 2010 Geodynamics of hazardous processes in zones of natural and technogenic complexes of Eastern Siberia. (Irkutsk: Institute of the Earth's Crust, SB RAS)
- [4] Laperdin V K, Imayev V S, Verkhovzin I I, Kachura R A, Imayeva L P 2011 *Geological hazards in the south of Yakutia and adjacent territories*. (Irkutsk: Institute of the Earth's Crust, SB RAS)
- [5] Makarov S A 2012 *Debris flows of the Baikal region*. (Irkutsk: V.B. Sochava Institute of Geography, SB RAS)
- [6] Belousov V M, Bude I Yu, Radziminovich Ya B 2000 *Physical and geographic characteristic and environmental problems of the southwest branch of the Baikal rift area*. (Irkutsk: Irkutsk State University)
- [7] Laperdin V K, Levi K G, Lekhatinov A M, Kadetova A V, Pellinen V A, Rybchenko A A 2014 Reasons and consequences of disastrous debris flows of 28 June 2014 in the neighborhood of the Arshan village Republic of Buryatia. *Geodynamics & Tectonophysics* **5**, 3 799-816
- [8] Laperdin V K, Levi K G, Imayev V S, Molochny V G 2016 *Geological hazards in southwest Baikal region*. (Irkutsk: Institute of the Earth's Crust, SB RAS)

- [9] Stupin V P, Plastinin L A, Syrenov D G 2015 *Mapping and morphological-dynamic analysis of debris flows in Tunka Depression*. Interexpo GEO-Siberia-2015 (Novosibirsk: SSUGT) V.2, pp. 38-42.
- [10] Stupin V P, Plastinin L A, Olzoev B N, Kotelnikova N V 2015 Geo-information mapping of debris flows of the southern Baikal region. Proceedings of the 15th Meeting of Geographers of Siberia and the Far East. (Irkutsk: V.B. Sochava Institute of Geography, SB RAS) pp. 520-522
- [11] Plastinin L A, Stupin V P, Olzoev B N, Syrenov D G 2016 *Remote sensing and mapping of debris flows hazards of the southern Baikal region*. Debris flows: disasters, risk, forecast, protection. Proceedings of the IV International Conference. (Irkutsk: Institute of the Earth's Crust, SB RAS) pp. 203-207
- [12] Korniyakov M V, Plastinin L A, Stupin V P, Olzoev B N 2016 Cartography modeling and potential assessment of debris flows hazards of the southern Baikal region. Proceedings of the XXI International Conference "Current Problems of Life Safety Culture Formation". (Moscow) pp. 244-248
- [13] Stupin V P 2017 *Geo-information system mapping of debris flows hazards in the mountains of the southern Baikal (Russia) and the Khubsugul (Mongolia)*. Materials of the 3rd International Conference "Specifics of Territorial and Environmental Conditions within Social and Economic Development of the Country". (Ulaanbaatar: Mongolia State University) V.II, pp. 316-324
- [14] Stupin V P, Plastinin L A, Olzoev B N 2017 *GIS mapping of debris flows hazard based concept of morphosystems*. Geo-spatial technologies and Earth resources (GTER 2017) (Vietnam, Hanoi: Publishing House for Science and Technology) pp. 283-289
- [15] Stupin V P, Plastinin L A, Olzoev B N 2017 *New principles and methods of system mapping of debris flows hazards of the southern Baikal region using GIS and ERS from space*. From the map of the past to the map of the future. (Perm: Perm State National Research University) V.2, pp. 184-195
- [16] Stupin V P 2005 Morphological and morphometric analysis of topographic maps in the study and mapping of morphological systems. *Problems of the mineral base development in Eastern Siberia* **5** 154-160
- [17] Stupin V P 2009 *Mapping of morphological systems*. (Irkutsk: Publishing house of ISTU)
- [18] Plastinin L A, Stupin V P 2013 Morphological system mapping of exogenic geological processes of the Baikal highland. *Geodesy and cartography* **10** 17-21
- [19] Stupin V P, Syrenov D G 2016 *Mapping of debris flows hazards of the southern Baikal region on the basis of the basin morphological system*. Interexpo Geo-Siberia-2016 "Early Warning and Crises Management in the Big Data Era". (Novosibirsk: SSUGT) pp. 27-31
- [20] Stupin V P, Plastinin L A 2017 *Morphological systems as a methodological basis of debris flows hazard mapping*. Interexpo Geo-Siberia-2017 "Early Warning and Crises Management in the Big Data Era". (Novosibirsk: SSUGT) V.7, pp. 43-48
- [21] Okhotin A L, Tokin A A, Neverova A L 2014 *Unexpected shooting results of disastrous debris flows in Arshan village of the Republic of Buryatia*. 14th International Scientific and Technical Conference "From Imagery to Map: Digital Photogrammetric Technologies" (Hainan) pp. 21-23