Assessment of The Eco-Geomorphological Conditions of Udmurtia, European Russia

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Abstract

The territory of Udmurtia located in the European part of Russia between the River Volga and the Urals was chosen for assessment of its eco-geomorphological conditions, because it's well-developed region (ferrous and non-ferrous metallurgy, machine-building and oil production) with a quite high population density. A combined approach, based on standard geomorphological methods (field work, remote sensing and GIS technologies) and analysis of time-space population distribution, was used. The region is located in a relatively comfortable eco-geomorphological conditions: areas with comfortable and relatively comfortable conditions make up 63% of the study region, while areas with poorly comfortable and uncomfortable conditions, where the relief worsens ecological conditions, account for 37%. The most acute eco-geomorphological and ecological problems are characteristic of southeastern Udmurtia, where the relief contributes to a poor ecological situation. 57% of rural settlements are located in areas with comfortable and relatively comfortable eco-geomorphological conditions. Hence, 43% of settlements are located in areas with less comfortable conditions. In spite of the prevalence of comfortable and relatively comfortable living conditions, most people of Udmurtia live under uncomfortable conditions.

Introduction

The first researches, devoted to geomorphology and environmental problems, were published in the late 20th century: Cooke, Doornkamp 1990; Timofeev 1991; Panizza 1996; Rivas et al. 1997; Marchetti, Rivas 2001; Likhacheva et al. 2002 and others. Their authors drew the attention of the reader to the fact that vigorous social and economic development, backward production technologies, the active growth of cities and human activities result in the rapid qualitative deterioration of the environment.

The ecological-geomorphological approach is often used for assessment of living conditions (Likhacheva and Timofeev 2004; Kuzmin 2014), because the relief as a major distributor of matter and energy streams affects meteorological processes (Geomorphometry 2007; Kruzhalin et al. 2009) and the formation of landscapes' ecological potential (biotic conditions) – habitat conditions. An eco-geomorphological approach to the study of coastal ecosystems is commonly used (Marani et al. 2006; Doll et al. 2014; Tare et al. 2017; Sonkar et al. 2019; Arienzo et al. 2020). Furthermore, according Thoms and Parsons (2002), eco-geomorphology is an interdisciplinary branch of geomorphology, which studies river systems that integrates fluvial geomorphology, ecology and hydrology. Authors of the article «The role of geomorphology in environmental impact assessment» (Cavallin et al. 1994, p.152) say, that the suitability of a certain location, mainly with respect to its morphography and morphometry, and the geomorphological landforms and processes must be assessed to geomorphological hazards and geomorphological assets (elements forming the educational and cultural heritage of the landscape).

There are still no standard methods for conducting such studies. A combined approach is often employed. Multi-criterion decision analysis (Zhi Yang et al. 2019), stepwise analysis of each constituent (Likhacheva and Timofeev 2004; Anikina et al. 2013), a qualitative scale (Mokrinets 2012) and graded assessment with a weigh indicator (Kochetkova 2013) are also carried out. Key factors of assessment

are: geology, relief, microclimate, water resources, soil, environment, ecology, dangerous processes and others. Li He Chai, Dron Lha (2018) reports that indicators for ecological environmental quality assessment are pollution, heavy metal, model, sediment, management, water quality, soil, influence, health, economy, policy and emission.

Individual assessment criteria should be worked out for each study region with regard for their physico-geographic and social-economic characteristics. Udmurtia, a region located in the Vyatka-Kama interfluvium, was chosen for assessment of its eco-geomorphological conditions. It is located in the European part of Russia lying between the River Volga and the Urals. Udmurtia is a well-developed region with the ferrous (450 000 t of steel and 350 000 of rolled products per year) and non-ferrous industries (Atlas 2015), machine-building and oil production (maximum production rate in 2013 was 10.86 Mt). Also, there are two facilities for storing and utilizing Russia's chemical weapons in the region (Kizner, Kambarka). All of these factors have increased an impact on the natural environment and deteriorated living conditions. So far, no assessment of eco-geomorphological conditions in the study region has been attempted. Attention was focused on some parameters of environmental assessment of the region such as atmospheric air (Gabdullin and Semakina 2011; Semakina 2012; The nature 2013), water and soil pollution (The nature 2013) and dangerous geomorphological processes (Rysin 1998; Petuhova 2006; Egorov and Egorova 2007; Egorov and Gleyzer 2012, 2013; Kirillova 2017).

Study Area

Udmurtia is situated in eastern European Russia, near the Urals Mountains (Fig. 1). The total area is 42000 km². Located in the eastern Russian Plain, Udmurtia lies in the near-N-S-oriented Vyatka-Kama interfluvium. Geomorphologically, it is an elevated ridgy step-like plain heavily dissected by a valley-ravine network (Dedkov et al., 1974; Geography 2009) (Fig. 1). A remnant relief, occurring as «pugs» (rounded-topped landforms, made up of sandy-gravel and gravel-pebbly conglomerate-pebbly strata, is encountered. It is the Upper Pliocene alluvium of the parental Kama (Borodatiy 2010). The study region consists dominantly of Permian rocks of the Kazan and Tatar layers: sandstones, clays, siltstones, conglomerates (State 1999). Triassic rocks are abundant in the northwesternmost part of the region. Quaternary rocks are mainly up to 5 m thick (occasionally up to 8 m), but in large river valleys they are 5 to 40 m (occasionally up to 80 m) thick. It was not glaciated during the Last Glacial Maximum (Sturman 1992). Eluvial-deluvial deposits on hill slopes and in interfluviums, composed of sandy loam, loam and sand are most common. Eluvial gravel-pebbly deposits occur as remnants («pugs») on the top surfaces of interfluviums. Aeolian strata (sand and sandy loam) are abundant in interfluviums and river valleys.

The region has a temperate continental climate. The average annual temperature increases gradually from 1.6°C in the north to 3.4°C in the southwest (Perevedentsev et al. 2009). Westward air transfer prevails all year round. Southwest and west winds predominate in winter and all year round, while northwest and lesser northeast winds prevail in summer (Geography 2009). The average annual rainfall decreases from the north to the south from 640 to 540 mm. All the rivers are in the Kama and Vyatka basin, forming part of an internal runoff basin. The largest rivers are Kama, Cheptsa, Kilmez and Izh.

They are dominantly fed with snow during well-defined spring flood, and their water level in summer and winter is low (Geography 2009). Soddy-podzol, podzol, grey forest and other soils are most common (Atlas 2015).

Materials And Methods

The study was carried out using a combined approach, which comprises standard geomorphological methods and analysis of a spatial-temporal population distribution pattern and eco-morphological conditions. Assessment of eco-geomorphological conditions in Udmurtia is based on the procedure developed at Institute of Geography, Russian Academy of Sciences (Likhacheva and Timofeev 2004). It comprises analysis of natural and natural-anthropogenic conditions comfortable for people living in a humid climatic region at temperate latitudes (Table). The provinces were all described, using the assessment structure proposed. Each province was described in detail. A matrix model was constructed and eco-geomorphological zoning was done.

Geologo-geomorphological conditions were assessed, using field descriptions and a map compiled by the authors of the paper. Mechanical ground composition was analyzed using publications (Geographic 2010). Dangerous geomorphological processes were assessed, based on field studies and the relevant literature. Hydrological and hydrotechnical conditions were described, based on the literature and maps (Geographic 2010; Atlas 2015). Microclimatic conditions were assessed from the morphometric maps compiled and data on settlements, which was created by authors of the paper. Published ecological maps were also used to estimate the proximity of settlements relative to major pollution sources (Geographic 2010; Atlas 2015). Soils were described using the literature (Geography 2009; Geographic 2010, Atlas 2015). The condition of trees and bushes was assessed in the field. In the natural and anthropogenic characteristics block, the use of topography for planning settlements was assessed as part of field work; the morphometric maps, which were created by authors of this article, compiled were also helpful. The geomorphological location of cultural and historical monuments was assessed as part of the study, because monuments indicate the most comfortable geomorphological conditions for the present time. They were assessed during field work and from 1:100000 scale topographic map (The Udmurt 2009) and digital elevation model (DEM). The availability of transport infrastructure and the percentage of forests were estimated from publications (The nature 2013; Atlas 2015) and during field work.

Relief was studied by standard methods: collecting and analyzing the data available in the literature, analyzing remote sounding data, field description and profiling (Fig. 1), geomorphological mapping and division. Morphometric maps (a hypsometric map, a map showing the slope angles of the earth surface and variably exposed slopes) were compiled on the basis of DEM, which was constructed using ArcGIS 10.3 on the base of SRTM image, which was downloaded from the USGS, which has a pixel resolution with 90 m (<https://srtm.csi.cgiar.org/>). A 1:100000 scale topographic map was also used (The Udmurt 2009). Using the ArcGIS 3D analysis tool was used to compile a digital map of topographic contours with a relief section of 50 m in the projection Pulkovo1942 GK Zone 9N. Morphometric analysis of the relief on

a scale of 1:1000000 and basin analysis on a scale of 1:2500000 were performed to assess the degree of comfort of the areas chosen for settlements, to trace the migration of pollution and to compare the evidence obtained with rural population density. This work was done to estimate the population of areas with uncomfortable eco-geomorphological conditions. Straler-Filosofov's principle was used in basin analysis for indexing orders (Simonov and Simonova 2004). To provide information for this assessment, a 1:1000000 geomorphological map was compiled.

Geomorphological Analysis Of The Territory

Morphometric analysis

Elevation map

Udmurtia is located on the southern offshoot of the Verkhnekamskaya Upland and on smaller uplands (the Krasnogorskaya, the Lysvo-Tylovayskaya, the Sarapulskaya and the Mozhginskaya) and ridges (the Kuligo-Pudem, the Sharkano-Multanskaya), the Privyatskaya Plain, the Kilmezhskaya, the Kamsko-Belskaya and the Central Udmurt Lowlands. This area is divided into an elevated (northern) portion and a large low-lying (southern) portion. Maximum absolute altitude is 284 m (DEM). Sites located at an altitude of 150 to 200 m cover the largest area. Sites lying at an altitude of 150–200 m (39%) are most common in Udmurtia and those at an altitude of 300–334 m are least common (0.2%) (Fig. 1).

Slope map

In Udmurtia, areas with surface slope angles of 2–5° predominate, making up 36% of Udmurtia's total area (Fig. 2a). In accordance with Simonov's and Kruzhalin's classification (1993), they are understood as fairly gentle slopes good for construction from the engineering point of view. Surfaces with slope angles of 0–2° (14% of Udmurtia's area) are in the same group. Slopes with a steepness of 5–10° make up about 6%. Slopes with a steepness of 10–15° cover a much smaller area (0.22%). Steep slopes (15–35°) cover the smallest area (0.01%).

Aspect

In Udmurtia, the diversity of slope exposures displays a normal distribution. East-facing (13.9%) and south-facing (13.2%) slopes are most common (Fig. 2b). Southwest-facing (9.9%) and south-facing (11.5%) slopes cover the smallest area. Flat surface without well-defined exposure is represented by areal (water reservoirs, ponds) and linear (rivers) water bodies making up 1.9% of Udmurtia's area. These areas are occupied by Izhevsk Pond, Votkinsk Water Reservoir and large streams. The prevalence of cold-exposed slopes in Udmurtia is bad for its agriculture.

Geomorphological map of Udmurtia and geomorphological zoning

A 1:1 000 000 scale geomorphological map, based on the unity of morphometric, lithological, genetic and dynamic characteristics, was compiled (Fig. 3). Thus, the legend is based on a morpholithodynamic

principle. Udmurtia's present relief was produced mainly by fluvial and slope processes. Therefore, a key role in the legend is played by genetically, lithologically and morphometrically related river bed, river valley slopes and interfluvial complexes (top surfaces and their slopes) (rocks making up the surface are specified in parentheses) and the exogenic processes typical of them. Seven geomorphological provinces, consisting of 15 subprovinces, were distinguished. Each province is described in detail in the paper (Kirillova 2015).

Dangerous geomorphological processes

The erosion of temporary and permanent streams, a leading exomorphodynamic process in Udmurtia, is the most common deleterious process. The study region is part of a belt with a considerable washout modulus (over 3 t/ha), and lands susceptible to erosion make up 65–80% (The map of erosion 1980). Ravine erosion evolves actively in well-developed agricultural and poorly forested areas – 6 and 5 geomorphological provinces, also 3d subprovince (Rysin 1998) (Fig. 4a-4b). Relief, dissected by minor erosional forms, impedes the nature management in the southern part of the study region.

Valleys in the humid temperate zone are dominated by linear denudation; lateral and deep erosion is widespread here (Dedkov et al. 1977). The river bank washout rate, affected by lateral bed erosion, displays an average of 1.2-3 m and a maximum of 5–10 m/year on the River Kama, 1-1.8 m/year on the River Cheptsa, 0.4–0.7 m/year and a maximum of 2–3 m on the rivers Kilmez, Vala and Izh, and 0.1–0.3 m/year on the smallest rivers (Petuhova 2006). Landslides are common in the Kama River valleys and on the banks of Votkinsk Water Reservoir: near Galevo and Mazunino, in Doksha villages, near Golyany, in the Cheptsa River valley near Soldyr and Zolotarevo and Krymskaya Sludka villages, in Dulesovo and near Sukharevo, Kolesnikov and Cheganda villages (geomorphological provinces and subprovinces 6, 3d, 3e, 16, 2). Landslides are dangerous, because they occur in permanent residential areas, e.g. in Sarapul town and near houses in the villages of Doksha, Zolotarevo and Berkuty villages (Fig. 4c-e). The construction of closely spaced houses built near the water edge also affects weakened grounds. It's not only natural factors contribute to deleterious geomorphological processes, also human activities take a large part.

Other hazardous processes are: talus, which commonly occurs on the steep slopes of water reservoirs, quarries and ravines. Talus is most common in the Sarapulskaya Upland and the Central Udmurt Lowland areas; paludification is confined to the bottoms of large river valleys (Kama, Izh, Kilmez and Cheptsa); it is less conspicuous on flat interfluvial surfaces (north of the Kuligo-Pudem Ridge); abrasion is common on the banks of Votkinsk and Nizhnekamskoe Reservoirs in the Central Udmurt Lowland and the southern Sarapulskaya Upland, respectively. Therefore, various types of deleterious geomorphological processes are typically concentrated in southeastern and southern Udmurtia. Therefore, various types of deleterious geomorphological processes are typically concentrated in southeastern (the Sarapulskaya Upland) and in general southern Udmurtia. They are contributed to by both natural factors and human activities. Dangerous processes are least common in Central and Western Udmurtia.

Kama and Vyatka rivers basin / watershed management

The authors have compiled a map of current population density (scale 1:1000000) in the municipalities of Udmurtia based on the 2010 census (<http://www.gks.ru>) and gis-lab.info. The map shows differences in density within river basins followed by those within geomorphological provinces (Fig. 5). Also, they have constructed a database for assessing the geomorphological location of 562 modern settlements with a population of 500 to 20000 people and all 6 cities with a population of 95 000 to 642 000 people, which were analyzed separately. Modern residential areas were analyzed, using morphometric relief indices, a series of morphometric maps and a geomorphological map. The analysis of modern settlements was carried out according to the morphometric indicators of the relief on the basis of morphometric maps and a geomorphological map.

Geomorphological conditions of settlement's location

The map compiled by the authors shows that 6% of modern settlements are located on valley bottoms, 83% on river valley slopes (bedrock banks) and 11% in interfluvies. The interfluvies in Udmurtia are poorly developed for two reasons: firstly, they are often paludified; secondly, they display a remnant relief in some parts of Udmurtia (geomorphological subprovinces 1a, 1b on the Fig. 3). However, because they are commonly better «aired» and because the shortage of space in low-lying landforms is felt, the interfluvies could be made relatively comfortable for living, provided some improvements are made. The study has shown that settlements in Udmurtia are now mainly located at an altitude of 100–200 m, lesser at 200–250 and 50–100 m, extremely seldom at 250–300 m and practically do not occur at altitudes of more than 300 m, which are least comfortable for living (Fig. 6a). Most of them (69%) lie on gently sloping surfaces and gently dipping slopes (29%). South-facing slopes are most commonly chosen for living, because they are warmer in the Northern Hemisphere and are well insolated, which is vital for agriculture. Only 6% of residential areas are located on north-facing slopes (much less than those located on other slopes).

Calculation of morphometric indices for most settlements located at an altitude of 100–200 m (71% of the total number of the settlements studied, i.e. most towns and villages) has shown that east-facing slopes (E, SE) are more preferable. As west and southwest winds predominate in Udmurtia (Perevedentsev et al. 2009), settlements located on east- and southeast-facing (E, SE) slopes are in the wind shadow (Fig. 6b).

Discussion And Analysis

This paper focuses on combined assessment of Udmurtia's eco-geomorphological conditions based on remote, published and field data. The study has shown key factors for assessing the eco-geomorphological conditions in the humid climatic zone at temperate latitudes for economically developed areas.

Geomorphological conditions, which were preferable for the economic development of Udmurtia from the 18th century onwards, now restrict the development of the urban infrastructure and eco-geomorphological conditions in big cities and the densely populated parts of Udmurtia. Soil and

atmospheric air pollution increased when plants (Izhstal, Izhmash, Votkinsk plant, etc.), built on low-lying landforms, and boiler plants using solid fuel began to operate and when the number of vehicles began to grow.

Assessment of eco-geomorphological conditions has shown that 63% of Udmurtia's total area are occupied by provinces with *comfortable* and *relatively comfortable* conditions, and 37% of Udmurtia's areas are occupied by *less comfortable* and *uncomfortable* conditions (Fig. 7). Provinces with *the most comfortable* (3c, 3a, 4b, 4c) and *comfortable* (1b, 5, 3b) eco-geomorphological conditions (Fig. 7–8) typically display undulating-ridgy surfaces, the predominance of warm-exposed gentle slopes or the homogeneous distribution of all slope exposures, the non-existence or minor occurrence of exogenic processes, remoteness from major air pollution sources and comfortable natural-anthropogenic conditions. Most settlements are located on well-aired elevations and commonly match the topography. Medium and high comfort indices prevail in *relatively comfortable* areas (3e, 6b, 7). Settlements on the Kamsko-Belskaya Lowland are located on Kama River terraces, which are less comfortable because of possible flooding and low altitudes at which pollutants may accumulate. Two provinces (6b, 3) are affected by deleterious processes such as ravine erosion and landslide. *In a poorly comfortable* (6a) eco-geomorphological environment with relatively good geomorphological indices there occur major air pollution sources located on valley bottoms. As a result, the air is purified slowly, forming a stagnant regime. Some surface water zones are heavily polluted (allowable chloride, sulphate and other pollutant concentrations are exceeded). The active agricultural development of the area contributed to the growth of deleterious geomorphological processes. Ravine erosion and landslides detected (Fig. 8d).

In provinces with *the most uncomfortable* (3d) and *uncomfortable conditions* (1a, 2, 4a) large areas are occupied by relatively flat, typically paludified terranes, where cold-exposed slopes are common, deleterious geomorphological processes are widespread and atmospheric pollution indices are high. Relief is commonly disregarded when planning industrial and residential zones. Small settlements are often located on the bottoms of small poorly “aired” valleys affected by major atmospheric pollution sources. The relief of these areas makes their living conditions even less comfortable (Fig. 9b).

The analytical results of eco-geomorphological assessment of conditions have shown that 57% of rural settlements are located under comfortable and relatively comfortable eco-geomorphological conditions. Hence, 43% of settlements are located under less comfortable conditions. Two out of 15 geomorphological provinces (3d, 6) with uncomfortable conditions display a high population density. Analysis of the size of the population of settlements has indicated that 24% of local residents (of Udmurtia's total population) live under comfortable eco-geomorphological conditions. 76% of Udmurtia's population live under poorly comfortable, uncomfortable and extremely uncomfortable conditions. About ½ of the population live under extremely uncomfortable conditions, due to the high population density. It would be valuable to conduct a similar large-scale study in the most heavily populated geomorphological provinces (3d, 6a).

Udmurtia's environment is affected by the ferrous and non-ferrous industries, oil exploitation, facilities for storing and utilizing chemical weapons. It is clearly evident how the anthropogenic pressure is higher in the south and the south-east parts of the Udmurtia. Management strategies should be focused on protecting the fragile ecological landscape. So, we propose the following *management recommendations*: 1. Environmental monitoring with regard for the geomorphological conditions of the region, primarily in urbanized areas located on the Izh and Vyatka River valley bottoms, in areas where pollutants are accumulated (on the high flood plain and terraces above the flood plains of the rivers Izh, Votka and Cheptsya); 2. The results of eco-geomorphological assessment should be used for locating dumping sites in Udmurtia. 3. In the Mozhginskaya and Sarapulskaya upland areas most susceptible to erosion the authors recommend to take erosion-preventive measures: to plant forest, to terrace steep slopes and to do dump-free and transverse ploughing of slopes. 4. Monitoring of heavy metal and radionuclide concentrations in the soils of Glazov town and strict monitoring of water quality in the River Tyzhma and in a spring at Kizner. 5. Sites with unique landforms (continental dunes in the Kilmez, Izh and Kama river valleys; «pugs» in the Krasnogorsk, western Lysvo-Tylovayskaya and Mozhginskaya upland areas and in the Kuligo-Pudem Ridge; and nival cirques in the Sarapulskaya Upland area) should be announced as strictly protected areas.

Conclusions

Vigorous industrial development, such as ferrous and non-ferrous metallurgy and other industries, has worsened the eco-geomorphological conditions in Udmurtia. Therefore, the conditions were analyzed and the results were used for assessment of eco-geomorphological conditions in the Udmurt Region. Combined assessment of eco-geomorphological conditions was performed, and field work, remote sensing and GIS technologies were combined. The authors have drawn the following conclusions:

A quite high intensity development has worsened the eco-geomorphological conditions in Udmurt region. Combined assessment of eco-geomorphological conditions was established, using field work, remote sensing and GIS technologies. We made the following conclusions:

1. Relief as the basis of landscape and a major distributor of matter and energy in it affects the formation of the degree of comfort of a living environment. Assessment of modern eco-geomorphological conditions has shown that the region is located in a relatively comfortable eco-geomorphological environment: areas with comfortable and relatively comfortable conditions make up 63% of the study region and areas with poorly comfortable and uncomfortable conditions, where major industrial centers and infrastructure are concentrated, account for 37%. The most acute eco-geomorphological and ecological problems are characteristic of southeastern Udmurtia, where the relief contributes to a poor ecological situation.

2. 57% of rural settlements are located in areas with comfortable and relatively comfortable eco-geomorphological conditions. Hence, 43% of settlements are located in areas with less comfortable conditions. Two out of 15 geomorphological provinces (the Central Udmurt Lowland and the

Sarapulskaya Upland) with uncomfortable conditions display a high population density. In spite of the prevalence of comfortable and relatively comfortable living conditions, most people of Udmurtia live under uncomfortable conditions.

3. In the 19th -21st centuries, Udmurtia's industries were developing rapidly, and gently sloping surfaces and south- and southeast-facing gentle slopes, composed of loam, sandy loam and sand in first- and second-order river basins and located at an altitude of 100–200 m, were in great demand for living. The highest modern rural population density is observed in the Izh and Kama river basins and in small first- and second-order rivers.

Declarations

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Authors' contributions. All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Aino Kirillova. The first draft of the manuscript was written by Aino Kirillova and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Tables

Table Description and assessment structure eco-geomorphological conditions of Udmurtia

Conditions and characteristics	The degree of comfort for human life		
	Low	Middle	High
1. Geologo-geomorphological			
Earth surface pattern	terraces, flood plains	flat, highly rugged watershed surfaces	gently undulating, undulating-ridgy surfaces
Slope	> 12°	6-12°	< 6°
Mechanical ground composition	muds, weak grounds	sand, clay, medium and heavy loam	light and medium loam, sandy loam
Exogenic processes: erosion, landslides and talus, abrasion, paludification	widespread	common	uncommon or non-existent
2. Hydrological and hydrogeological			
Depth of occurrence of groundwater	< 2 m	2-5 m	> 5 m
Surface water quality	heavily polluted	mildly polluted	slightly polluted
3. Microclimatic			
Aspect	predominance of cold-exposed slopes (N, NE, E, NW) and flat surfaces	uniform slope exposure distribution (without well-defined prevalence)	predominance of warm-exposed slopes (S, SE, SW, W)
The geomorphological location of most settlements	abundance of kettleholes, a closed type of the area, river beds near or in a residential area	lower portions of slopes, poorly aired areas	watershed areas and the open upper portions of slopes from the windward side to pollution

The location of most settlements relative to major pollution sources with regard for a wind rose		from the leeward side relative to pollution sources	sources
4. Soil			
Soil fertility	non-fertile (soddy-, medium- to heavily podzol)	relatively fertile (soddy-, medium- to heavily podzol)	fertile (soddy-podzol, soddy-carbonate, grey forest)
	unsatisfactory	satisfactory	fairly satisfactory
The condition of trees and bushes			
Natural-anthropogenic characteristics			
5. Taking relief of residential areas into account in planning residential areas	they were planned with little attention to topographic characteristics	surface slope and dissection depth were taken into account	residential areas were planned in good agreement with topography
6. Assessment of location in relief of cultural and historic monuments	does not affect the aesthetic properties of the area	partly improves the aesthetic properties of the area	makes the area look aesthetically more attractive
7. Availability of transport infrastructure	infrastructure is poor	infrastructure is not well-developed	well-developed road-and-transport infrastructure
Percentage of forests as a degree of agricultural development	>75	45-75	< 45

Figures

Figure 1

a) Location of the study area. The valley bottoms: 1 – Cheptsya, 2 – Loza, 3 – Ita, 4 – Kilmezh, 5 – Ut, 6 – Vala, 7 – Nylga, 8 – Uva, 9 – Izh, 10 – Kyrkmas, 11 – Kama, 12 – Siva, 13 – Umyak, 14 – Lyuga. Watershed: 15 – the Kuligo-Pudem ridge as part of the Verkhnekamskaya Upland, 16 – the Krasnogorskaya Upland, 17 – the Sharkano-Multanskaya ridge, 18 – the Lysvo-Tylovayskaya Upland, 19 – the Mozhginskaya Upland, 20 – the Sarapulskaya Upland; b) The elevation profile of Udmurtia. Geomorphological districts are indicated above

Figure 2

a) Slope map; b) Aspect map

A legend to the geomorphological map of Udmurtia

Morphology		Deposits	Current processes
Interfluvial surfaces (slope of less than 5°, altitude (abs.) 150-334 m)
Top surfaces	Eluvial (loam, sandy loam and sand)	Weathering, minor paludification
Interfluvial slopes	Deluvial (loam, sandy loam)	Poorly evolved surface washout
Top surfaces	Aeolian (sand)	Paludification, the limited distribution of aeolian processes
Interfluvial slopes		The limited distribution of aeolian processes
Top surfaces of remnants («pugs»)	Older alluvial (gravel-pebbly)	Weathering
Slopes of remnants («pugs»)		Erosion and surface washout
Top surfaces	Subaerial covering deposits (loess-like loam, sandy loam)	Minor paludification
Interfluvial slopes		Erosion and surface washout
Top surfaces	Bedrocks (clays, siltstones, sandstones, marls, conglomerates)	Weathering
Interfluvial slopes		Poorly evolved surface washout

River valleys bottoms (slope 0-2°, altitude (abs.) 50-150 m)

	Morphology	Deposits	Current processes
An undivided alluvial complex of large rivers	Sand, sandy loam, loam	Erosion, accumulation, paludification
Small rivers	Loam, sandy loam	Erosion, accumulation

River valley slopes

Altitude (abs.), m		Slope	Deposits	Current processes
100-200	200-300
<5°	Sand, sandy loam, loam	Surface washout, poor erosion
>5°		Gravity flow, active erosion, talus and landslides at steep sites

Relief elements:

A cuesta scarp
Steep bedrock slopes of river valleys
Remnants
Large ravines
Relict dunes

Other:

Cities
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Figure 3

A map of geomorphological zoning. Geomorphological provinces are indicated by black numbers and subprovinces by numbers with indices: 1 – the Kuligo-Pudem Ridge (1a – north the Kuligo-Pudem Ridge, 1b – south of the Kuligo-Pudem Ridge); 2 – the Krasnogorskaya Upland; 3 – the Kilmezhskaya and the Central Udmurt Lowland (3a – east of the Krasnogorskaya Upland, 3b – north of the Kilmezhskaya Lowland, 3c – south the Kilmezhskaya Lowland and east of the Central Udmurt Lowland, 3d – the Central

Udmurt Lowland, 3e – the Privyatskaya Plain); 4 – the Lysvo-Tylovayskaya Upland (4a – east of the Lysvo-Tylovayskaya Upland, 4b – west the Lysvo-Tylovayskaya Upland, 4c – the Sharkano-Multanskaya ridge); 5 – the Mozhginskaya Upland, 6 – the Sarapulskaya Upland (6a – the Sarapulskaya Upland , 6b – south of the Sarapulskaya Upland); 7 – the Kamsko-Belskaya lowland

Figure 4

a) Dangerous geomorphological processes on the territory of Udmurtia; b) A ravine near Mazunino village (the Sarapulskaya Upland); c-e) The results of the landslide, which occurred in Doksha village on 13 April, 2016. Right Kama River valley slope

Figure 5

A combined map showing rural population density and river basin in Udmurtia and the Kirov region

Figure 6

a) Morphometric pattern of the location in Udmurtia's largest settlements (%); b) Location of settlements on variably aspect slopes

Boundaries:

- geomorphological provinces
- geomorphological subprovinces

Eco-geomorphological conditions:

- extremely uncomfortable
- uncomfortable
- poorly comfortable
- relatively comfortable
- comfortable
- fairly comfortable
- the most comfortable

Figure 7

Map of the eco-geomorphological zoning of Udmurtia

Figure 8

A scheme of eco-geomorphological conditions assessed by the degree of comfort: A – the most comfortable, B – the most uncomfortable, C – relatively comfortable, D – poorly comfortable