Influence of Permafrost Landscapes Degradation on Livelihoods of Sakha Republic (Yakutia) Rural Communities

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Abstract: Climate change and the degradation of permafrost prove to be severe challenges for humanity. At present, the northern communities and those living in rural areas are already facing the consequences. This article is based on field research conducted in the Yunkyur, Olyokminsky, and Amginsky Districts of Sakha Republic (Yakutia) during 2018–2020. These settlements have one of the richest agricultural traditions in the region; however, the inhabitants of these villages now face serious consequences of permafrost degradation. The authors rely on a mixed set of methods and approaches, including sociological surveys, expert and in-depth interviewing, and appropriate archival and museum materials. Methodology of remote sensing and landscape–geocryological research was integrated. The resulting studies made it possible to demonstrate increasingly widespread thermokarst processes in the key areas studied. The authors determined that the degradation of permafrost has led to problems with the safety and development of the housing stock, especially deformation of houses and outbuildings, and reduction of areas suitable for construction. Territories affected by thermokarst also drop out of agricultural use. Finally, the authors identify some adaptation mechanisms to mitigate the effects of changes in permafrost landscapes.

Keywords: Yakutia; permafrost; climate change; thermokarst; rural communities; life-sustaining system

1. Introduction

In the permafrost zone, ice-rich sediments occupy a significant territory, the main part of which is confined to the polar and subpolar regions of Eastern Siberia [1]. In the Republic of Sakha (Yakutia) (hereinafter–Yakutia), such regions occupy 31% of the total area of the region [2]. In the context of modern climate change, they are the most vulnerable to transformation. The most susceptible permafrost is located under open landscapes (mainly meadows) of the ice complex or yedoma. The thickness of the active layer almost every summer reaches the surface of wedge ice, which leads to the melting and degradation of permafrost with widespread development of thermokarst. In recent studies in Central Yakutia, we observe high intensity in thermokarst development, with rates reaching 10–15 cm/year [3,4].

Thermokarst refers to cryogenic processes resulting when characteristic landforms are changed due to the melting of ice-rich frozen sediments or ice complexes [5]. The study of the dynamics and distribution of modern thermokarst forms is essential due to their use as one of the main permafrost degradation indicators. The formation of such structures is associated with landscape transformations under climate change [3,6]. Currently, thermokarst...
is most active in open natural and anthropogenic landscapes [7,8], which are characterized by a thin protective layer (≈0.2 m). This transient layer occurs between the active layer and the top of the ice complex [9], and in areas covered with boreal forest, its thickness reaches 0.7–1.0 m [8]. This layer features a very high ice content of the enclosing soils (up to 60–70%), which is represented by massive-agglomerate and reticulate cryostructures. The lithological composition of the layer consists of silts [1]. This layer prevents the thawing of permafrost [10]. As a result of current climate warming, destruction of the protective layer occurs, leading to the rapid development of thermokarst processes [11].

The degradation of permafrost, including the development of thermokarst, is expected to affect 33.6% of the infrastructure in Yakutia by the middle of the 21st century. This entails high social and economic costs for the region [12]. As a result, numerous settlements, industrial facilities, and agricultural lands, located within the distribution of icy frozen rocks and the ice complex, fall into the risk zone [13]. In this regard, the study of the activation of thermokarst in such areas and its influence on various aspects of rural communities that are most dependent on the state of the environment is an urgent task of contemporary science. Its solution will allow developing timely measures to prevent or help mitigate hazardous cryogenic process impacts on the population and on business entities. We must consider the experience gained by representatives of local communities affected by thermokarst—experience in responding and adapting to adverse changes in the state of the environment. This enables us to develop practical recommendations based on the complex materials for the authorities at various levels.

It should be noted that the research on the problem of permafrost degradation and its effect has received a lot of attention in recent years. Focus has been not only rural communities but also urban ones. One of the key works in this field is the research of the Russian-American researcher N.I. Shiklomanov. Academic Shiklomanov has studied potential changes in Russia’s urban permafrost infrastructure, its stability under predicted climatic changes, and the adverse effects manifested by climate change in the Arctic in local urban settlements [14,15].

Covering both industrial and agricultural zones of the Arctic is the Permafrost and Culture (PaC) project, within which the researchers have published a series of essential publications. It is symbolic that this Yakutia project was launched in 2014 by studying the unique system of alas, which is traditionally of great importance in the life support of the most numerous ethnic groups in the region: the Sakha (Yakuts). Project leaders Habek I.O. and Ulrich M. explain the importance of consolidating natural and social science efforts to assess the dynamics of changes in permafrost soils in terms of their impact on land use [16]. We fully endorse their multi-disciplinary appeal to combine the methods of natural and social sciences in research on the relationship between permafrost and culture.

An excellent example of such a partnership is the collective article “Permafrost Livelihoods: A Transdisciplinary Review and Analysis of Thermokarst-Based Systems of Indigenous Land Use”. The International Permafrost Association (IPA) has supported this research as part of activities of the IPA Action Group “Permafrost and Culture (Pac): Integrating Environmental, Geo-, and Social Sciences to Assess Permafrost Dynamics and Indigenous Land Use” [17]. This extensive article contains the results of the authors’ long-term work, among whom the well-known scientists of Yakutia, the geocryologist A. Fedorov, and R. Desyatkin, an expert on alas landscapes, analyzed changes in the state of the thermokarst using alas historical materials. A comprehensive analysis of Sakha traditional alas-based economy is enriched by the long-term research of H. Takakura on the adaptation of pastoralist communities to climatic conditions [18,19].

Anthropological measurement of alas systems was carried out by S. Crate, who has researched the Viliui region, identifying the perceptions, understandings, and responses of residents to unprecedented climate change [20]. S. Crate should be recognized for accentuating perceptions of climate change by the Indigenous people themselves at the local community level and mobilizing local Indigenous knowledge in understanding the current natural processes. A previous article by Crate and Fedorov [21] documents the
vital dialogue and the “knowledge exchange” approach that the authors use between the scientists—an anthropologist and a permafrost researcher—and the indigenous populations.

To date, interdisciplinary collaboration has developed in the study of permafrost processes in Sakha Republic, which has brought together scientists from different countries. They have comprehensively studied various aspects of permafrost change impact on human life support systems. In particular, recent scientific achievements in study of the perception of the current climate and permafrost changes include the work of our colleagues Takakura et al. “Differences in Local Perceptions about Climate and Environmental Changes among Residents in a Small Community in Eastern Siberia” [22]. The high interest of researchers on the topic of “melting permafrost” is evidenced, in particular, by an article by French scientists Doloisio and Vanderlinden based on interview materials in Yakutsk “The perception of Permafrost Thaw in the Sakha Republic (Russia): Narratives, Culture and Risk in the Face of Climate Change” [23].

There are also exciting works of Russian researchers. Here, geographically, the research by A. N. Svinoboev and A. B. Neustroeva is closest to us. These researchers paid attention to the perception by rural residents of climatic changes that have occurred in the last decade, including the transformation of the state of permafrost. They note changes in the form of residential buildings, courtyard plots, and the landscapes of the villages of Megino-Kangalassky, Tattinsky, Ust-Aldansky, and Churachinsky regions of Yakutia [24]. Their tasks and results resonate with the tasks and conclusions of anthropological and sociological research conducted earlier in the same regions by one of the authors of this article [25,26]. In general, similar to ourselves, the researchers recorded the recognition by rural residents of the realities of climatic and temperature changes, which create challenges at various levels for everyday life and individual households.

A review of existing works on climate change and permafrost degradation effects in Yakutia shows that the focus of most investigations is on the Sakha people (Yakuts) and the areas where their traditional culture has best preserved. In this case, scientists dealing with the problems of sustainable rural livelihoods leave out an interesting part of the local community life. We are talking about territories located at the junction of agriculture and livestock raising: in these areas, not only economical but also ethnic traditions intersect. Historically, in Yakutia, agriculture was introduced by the Russian population, who began to migrate to these territories in the 17th century. They lived near the aboriginal communities of the Sakha (Yakuts), with each group maintaining animal husbandry, hunting, and fishing. This neighborhood gave rise to a select group of districts where two closely related ethnic groups coexisted—Russians and Yakuts. They adopted many economic and cultural traditions from each other. In our opinion, this economic and cultural symbiosis is a valuable civilizational experience.

We were inspired by the conclusion of colleagues studying life in permafrost conditions that “there is a need for more detailed information of settlement and land-use history” [17]. This article combines interdisciplinary observations of permafrost processes and covers geographical regions beyond the western or the central settlements of the republic. For the first time, it covers the life activity on permafrost soils of the Yakut cattle-breeder’s communities and the agricultural communities of Yakutia with a mixed ethnic population, which are in many ways unique in economic and cultural aspects.

The purpose of this study is to determine the influence of thermokarst processes on livelihoods in the Amga in Amginsky district and Yunkyr in Olyokminsksky district of Yakutia. The term “livelihood” is used here as defined by R. Chambers and G. Conway in 1992: A livelihood comprises people, their capabilities, and their means of living, including resources, stores, claims, and access. A livelihood is sustainable if it can cope with and recover from stress and shocks and when it maintains or enhances the capabilities and assets, provides for future generations, and has net beneficial effects on other livelihoods locally and globally in the short and long term [27].

This study is part of a project supported by the Russian Science Foundation aimed at identifying the evolution of the role of cold in the life of the rural population of Yaku-
tia: “Cryoanthropology: Natural Low Temperatures in the Life Support System of Rural Communities of Yakutia (Traditional Practices, Modern Challenges, and Adaptation Strategies)”. Considering the context of Cryoanthropology, we could not ignore the problem of the contemporary “cold deficit” (a consequence of climate change and an increase in the average annual temperature), its impact on the state of permafrost, and the life of local communities.

Several factors determined the choice of Amga and Yunkyur for the research of this project. Dynamic processes of degradation of permafrost characterize both settlements. These processes and their impact on local communities had previously been neglected. History unites both villages. It was on their territory where in the 1630s, Russian settlers had made the first attempts to introduce agriculture into the region.

On the one hand, agriculture has had a severe impact on the preservation of permafrost, far more than the traditional economic practices of the Indigenous peoples of the area—the Sakha (Yakuts), Evenkis, Evens, Yukaghirs, and Chukchi: cattle breeding, horse breeding, reindeer breeding, hunting, and fishing. On the other hand, of all rural practices, thermokarst primarily limits the possibilities for agricultural development. In addition, significant, direct descendants of the first settlers have survived in Amga and Yunkyur. It seems essential to us to find out how the problems that have arisen with implementing the primordial occupation of many generations of their ancestors affect the residents. These concerns are one reason why we chose to do our research on the territories of the most extended agricultural development in Yakutia.

There are also significant differences between Amga and Yunkyur, which are of comparative interest. First of all, they are located in different geographical regions of Yakutia. Amga is located in Central Yakutia. Yunkyur is in the Southwest. Winters are less cold here, and ice complexes are less powerful. Both settlements differ in their levels of access to water. In the case of the Amga, its location is on the bank of the eponymous rather large Amga River, which is one of the most ecologically untouched rivers of the republic. Near Yunkyur, there are only small lakes. Finally, ethnic composition differs. Amga is a mono-national village—the overwhelming majority of the population is Sakha (Yakuts). In Yunkyur, there are approximately equal numbers of Russians and Sakha (Yakuts).

Of course, not all of these factors are directly related to the issues discussed in this article, but they are essential in the broader context.

2. Materials and Methods
2.1. Research Area
2.1.1. Amga Village

The study area is located in the southeastern part of Central Yakutia, on the left bank of the Amga River (Figure 1). Geomorphologically, the study area is situated in the Prilenskoye Plateau on the above floodplain terrace of the left bank with a height of 149–213 m. It is composed of a loamy-sandy loam stratum with a large ice-wedge ice up to 15–20 m thick. The climate of the study area is sharply continental. The average annual air temperature for the “Amga” Meteorological Station is 8.3 °C. Average January values reach −40.8 °C, and in July, they reach +17.6 °C. The annual precipitation in the region averages 270 mm [28].

According to the Permafrost Landscape Map of the YASSR (Yakut Autonomous Soviet Socialist Republic) [29,30], the territory is located within the Amga-Aldan gently sloping central taiga, with a continuous distribution of permafrost. The thickness of permafrost here is 200–300 m [29]. The ground temperature at the depth of zero annual amplitude ranges from −2 to −3 °C. The active layer thickness varies from 1.0 to 1.5 m, depending on the landscape setting [29,30]. Cryogenic processes such as thermokarst, thermal erosion, solifluction, and frost heaving are widely developed in the study area.
Before the arrival of Russian settlers in Yakutia in the 17th century, Yakuts and Evenkis lived in the Amga basin. The type of settlement of both ethnic groups did not imply the creation of any large stationary settlements. Thus, the territories of the Yakuts were scattered mainly over the innumerable alas. Moreover, one or several families lived in them. The main economic occupation of the Yakuts was cattle breeding and horse breeding. The Evenkis led a nomadic lifestyle. Reindeer husbandry and hunting were at the heart of their occupations.

As noted, the Amga Village became one of the first places where Russians tried to adapt their agricultural practices. According to the leading expert on the history of Russian colonization of Yakutia, Safronov F.G., the first attempt to settle them in the middle reaches of the Amga dates back to 1652. In 1685, 17 families had already lived in the Amga Village, whose members were cultivating 164 hectares of land. By the middle of the 18th century, due to the natural increase and resettlement of peasants from other regions of Russia, the population of Amga reached several hundred people [31] (pp. 14–15). In 1862, approximately 798 people lived in the Amga Village. Agriculture and cattle breeding remained the leading sectors of the economy at the time.

After the revolution of 1917, the new government undertook significant administrative and territorial transformations and radical reform of the foundations of agriculture. In 1930, Amga became the administrative center of the created Amginsky District of Yakutia. In parallel, leadership carried out a collectivization policy in agriculture. The collective farm “Pobeda” appeared in Amga, which later became part of the state farm “Amginsky”, which existed until the USSR collapsed.

The Soviet period was marked by extensive development characteristic of the Soviet Union economy in general and the country’s agricultural sector in particular, which required the introduction of ever-larger areas into agricultural circulation. Indicative was the increase in the area cultivated by the Amga State Farm. In the period from 1957 to 1992, in the Amga state farm, 1702 hectares of stubble and about 4200 hectares of virgin and fallow lands fell under plowing [32] (pp. 18–25).

After the collapse of the Soviet Union and the socio-economic crisis in Russia, large state collective farms were liquidated, and they were replaced by significantly smaller enterprises, representing both state and private forms of ownership [33]. At the same time, there was significant sequestration of the area of cultivated land. The graph below (Figure 2) refers to the entire Amga District; however, it can also represent the district center itself. The territories of the formerly arable lands either remained abandoned or used for construction.
Another indicator that needs to be addressed is the dynamics of the Amga population. In the Soviet period, in this respect, it was also characterized by a significant increase. In Amga, in 1939, there were 1230 people, and in 1989, there were 5191 people. The population of Amga, with rare exceptions, increased annually in the post-Soviet period as well (Figure 3) because the village, as noted, is the regional center of the Amginsky Ulus. The population of Amga in 2018 was 6626 people, of which more than 90% were Sakha (Yakuts). The top place in the economy is agriculture: meat and dairy cattle breeding, cattle and horse breeding, growing crops—vegetables, grain, and fodder.

2.1.2. Yunkyur Village

The study area is located in the southwestern part of Yakutia, on the Lena River left bank, at a distance of 6 km northwest of the Olyokminsky District’s regional center city of Olyokminsk (Figure 4). Geomorphologically, it is located on an alluvial terrace (187–234 m a.s.l.) in the transition zone between the Lena-Aldan flat plateau and the Pre-Vilyui flat trap plateau. Its hypsometry correlates with the Magan terrace of the middle Lena River [37]. It is separated from younger terraces by a steep scarp with Cambrian limestone and dolomite exposed at the foot. The terrace material consists of silts that contain ice wedges up to 10 m thick. The surface is characterized by the presence of shallow depressions with no distinct margins, as well as the widespread occurrence of mid-Holocene alas basins, up to 15 m in depth. The climate of the study area is sharply continental. The average annual air temperature for the nearby Olyokminsk Weather Station is $-6.7 \, ^\circC$. Average January values reach $-32.2 \, ^\circC$, and July, they reach $+18.0 \, ^\circC$. Annual precipitation in the region averages 315 mm [28].
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Knowledge of permafrost conditions in the area is limited and is mostly contained in internal research reports of the Melnikov Permafrost Institute and geotechnical exploration records. According to the permafrost-landscape zoning, this area is located within the Olyokma Province of discontinuous permafrost [2] with a thickness of 100–150 m [28]. Permafrost temperatures at the depth of zero annual amplitude vary from −0.2 to −1.0 °C, and active-layer thicknesses vary from 1.6 m in wet boreal forests to 3.0 m in open areas [2].

The agricultural development of the contemporary territory of Yunkyur began approximately simultaneously with the development of the Amga village. Before the Russians’ arrival, the Sakha (Yakuts) and Evenkis living on the territory of the Olyokminsky region and Amga did not know agriculture.

In the 17th century, on the right bank of the Malaya Cherepanikha river near its mouth (which is now Yunkyur), the peasants founded the village of Olyokminskaya [38] (p. 113). At the end of the 18th century, by decree of Catherine II, the Vilyui and Amga peasants resettled due to poor harvests. They founded a new village, which the latter group named “Amginskaya” in memory of their original home. By the 1770s, about 400 people lived in both settlements; in 1864, there were 789 people [31] (p. 122). Their main occupation was agriculture and cattle breeding. According to the data for 1917, the inhabitants of the Amginskaya and Olyokminskaya villages sowed 655 hectares of land with rye, wheat, barley, and oats, as well as vegetables (Figure 5) [39] (pp. 5–6).

One important consequence of the Soviet transformations mentioned above was changing Amginskaya and Olyokminskaya villages into Yunkyur, Kuranda, and Olyokminskoye. In the course of collectivization, Yunkyur, since 1927, has been the center of various collective farms; since 1951, the center has been the united collective farm “Pravda,” and since 1971, it has been the state farm “Olyokminsky” [38].

During the USSR years, the essential branches of the Yunkyur economy were animal husbandry and grain growing, as well as vegetable growing, which had a significant development here. Similar to the Amga State Farm, the Yunkyur branch was characterized by a substantial increase in cultivated areas—up to 4697 hectares by 1977 [40]. By 2019, these indicators decreased to 2260 ha, i.e., more than a 200% decrease [41].
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The population of Yunkyur in the Soviet period increased consistently: in 1938, there were 335 people in the village [42]; in 1984, there were 1058 people [43]. After the collapse of the USSR, the number of residents in Yunkyur remained relatively stable for a long time, and in 2012, it was 1139 people [44]. However, in recent years, the population outflow has significantly accelerated, and now, a little less than a thousand people live in the village. As of 2018, 979 people lived in Yunkyur (approximately equally divided between Russians and Sakha). Simultaneously, by the standards of contemporary Yakutia, these indicators are relatively high for a rural settlement that is not the administrative center of a republic ulus (district). First of all, this fact is connected with the proximity of the regional center—the city of Olyokminsk, where, according to the information we received during an interview with the head of the village, about 3/4 of the able-bodied population of the village go to work from Yunkyur.

The basis of the economy of Yunkyur, which is the administrative center of the Malzhagarsky nasleg of the Olyokminsky district of Yakutia, is currently still based on meat and dairy cattle breeding, herd horse breeding for meat, dairy horse breeding, and grain crops cultivation.

Thus, summarizing the history of Amga and Yunkyur, we should note three critical characteristics for the issues discussed in the article. In both cases, for more than three centuries, there was an increase in the area of land introduced into agricultural circulation, which accelerated significantly in the Soviet period. With the collapse of the Soviet Union and the economic crisis, there has been a significant sequestration of arable land. The second point is the growth in the population of Amga and Yunkyur. Although in Yunkyur, population growth stalled yet remains significant, in Amga, growth continues. Finally, the economy of both settlements has come to be increasingly based on agriculture.
2.2. Research Methods

Field studies in Amga and Yunkyur were carried out in March 2018, September 2019, and 2020. The authors of this article have done sociological research involving 225 people. In the course of these studies, we have given out questionnaires and held interviews. The purpose of the survey was to learn the main problems in local community members’ lives, and it was focused on issues respondents associate with the consequences of climate change, including the degradation of permafrost. We identified expectations, experiences, and concerns in this regard. During the survey, the method of random sampling was used. The sample population in each settlement was 100 people. Representatives of various age groups were involved in the study, from 14 years old and older. Since we did not set ourselves the task of identifying the gender characteristics of the perception of the consequences of climate change at this stage, the ratio of women to men was not fundamental. Of the 200 respondents who took part in the survey, 116 (58%) were women, and 84 (42%) were men. Simultaneously, we tried to cover all the districts of Amga and Yunkyur as widely and relatively evenly as possible, since development of thermokarst processes, as will be shown below, occurs unevenly in them, and this may affect the assessment of climatic changes. There were 22 questions in the questionnaire we developed. For most of them, respondents had to choose one of two or more answers. Two questions (given below) provided for the possibility of choosing several of the proposed solutions, as well as supplementing them with your own. The processing of the materials obtained during the questionnaire and the formation of the final datasets were done using the specialized statistical program IBM SPSS Statistics v. 25.

Nine people took part in our expert interviewing. We interviewed leading specialists of the administration of villages and enterprises, including heads of small- and large-scale farms. Their primary purpose was to clarify the most critical problems faced by local authorities and key actors in agricultural activities due to the emerging “cold deficit” and the active course of thermokarst processes. It was also to determine the current practices of responding and adapting to emerging challenges.

Sixteen people participated in in-depth interviews based on a single questionnaire prepared by us. The in-depth interviews were for the elders of Amga and Yunkyur—those living there for the past 50 years. The questionnaire consisted of 14 items, among which an important place was given to the elucidation of the historical dynamics of the state of the environment, as witnessed by the respondents, and (if possible) recorded in the memories of their ancestors. We were also interested in the presence of any traditional knowledge about permafrost, the course of basic cryogenic processes. The “snowball” method was used to determine the respondents suitable for us. In local rural communities, neighborhood ties are strong, and the respondents could accurately indicate persons of interest in the study.

In our fieldwork, we examined rural buildings (residential and economic), infrastructure facilities, and the territory adjacent to villages affected by the degradation of permafrost. To create a more complete picture of the history of land use in the villages of interest, archival and museum materials were used. In particular, we used materials from the Amginsky District Museum of the History of the Civil War (Amga village), the Museum of the History of Agriculture of Yakutia, and the Municipal Archives of the Olyokminsky District (Olyokminsk).

In September 2019, we carried out landscape–geomorphological observations and created an orthomosaic of the village of Yunkyur. We obtained aerial photographs of the area using the DJI Mavic 2 Pro UAV, which has a 20-megapixel digital camera and captures coordinates. Unmanned aerial vehicle flights took place in an autonomous mode using special software. We made these observations at an altitude of 200 m above the earth’s surface, making it possible to achieve a 70% overlap of the images. We have taken a total of 1325 images. For more accurate georeferencing of orthomosaics, we created a network of control points made for each site, the coordinates of which were measured using a geodetic GNSS receiver (Trimble 5700) static mode. In total, we laid ten reference marks for each
site with a reference accuracy of less than 3 cm. The obtained aerial photographs were processed using the AgisoftPhotoScan software based on the reference network. As a result, we received an orthomosaic with a planned resolution of 1.5 cm/pixel, which covered an area of 1.2 km$^2$. We carried out further processing of the created orthomosaic in the ArcMap 10.1 software environment. To map the Amga Village, we used the ArcGis Online service (ESRI). High-resolution satellite images from the Spot image company and some Digital Globe Company products are available [45]. The resolution of space images was 50 cm/pixel. Interpretation was performed in manual mode, and statistical indicators were calculated automatically using internal software modules.

3. Results and Discussions

3.1. What Happens to the Permafrost in Amga and Yunkyur?

Based on the landscape–geomorphological study of the area and interpretation, the created orthophotomap, and high-resolution satellite images, a schematic map of the development of thermokarst processes in the village was drawn up—Amga on a scale of 1:20,000 and Yunkyur at a scale of 1:10,000 (Figure 6). The total land area covered by thermokarst reaches 0.66 km$^2$ in Yunkyur and 6.5 km$^2$ in Amga (Table 1). Within the study areas, according to the classification of P.A. Solovev [37], two types of thermokarst relief were identified: bylars (a flat area of the inter-lane, deformed by closed subsidence funnels and hollows) and alas (shallow depressions).

| Localities | Bylar Area, km$^2$ | Alas Area, km$^2$ | Number of Buildings and Structures within the Distribution of Modern Thermokarst Processes, Unit | Number of Courtyards Affected by Modern Thermokarst Processes, % |
|------------|--------------------|------------------|--------------------------------------------------------------------------------------------|-------------------------------------------------------------------|
| Amga       | 6.5                | 0.3              | 540                                                                                         | 18                                                                |
| Yunkyur    | 0.66               | 0.26             | 11                                                                                          | 8                                                                 |

The largest area is covered by bylars, which are the initial stage of the formation of alas and belong to the modern forms of relief, which began to develop from the beginning of the 1990s [4]. They are formed as a result of the thawing of the upper part of wedge ice and represent a subsidence–polygonal microrelief. On the territory of Yunkyur, such landforms occupy an area of 0.4 km$^2$, while in Amga, they occupy 6 km$^2$. As a result of the analysis of the created schematic maps, it was revealed that the formation of the bylars was confined to local areas throughout the entire area of settlements. Their highest concentration in Yunkyur is concentrated in the north-western part of the village, in Amga, such territories are mainly concentrated in the north-eastern and north-western parts. In the village of Yunkyur, they form in the interlake spaces and on the sides of the lakes of thermokarst lakes, and outside it includes the territories of abandoned agricultural lands. In the village of Amga, these occur in the formerly arable lands, which were formed by uprooting the larch forest.

There is an active form of subsidence troughs in interpolygonal spaces. Their depth in the studied areas varies from a few tens of centimeters to 3.87 m. According to literary sources, the subsidence rates of depressions can reach 12 cm/year [4]. According to residents, the process of subsidence began in the early 1990s. This process was facilitated by an increase in average annual air temperatures [46] and soil temperatures at a depth of 3.2 m by 0.4 °C [47]. This process led to an increase in the center of the seasonal thawing layer and activation of thermokarst processes.
Figure 6. Schematic map of the development of thermokarst processes on the territory of the village. Amga (a) and Yunkyur (b). Legend: 1—outlines of residential quarters, 2—buildings and structures, 3—dirt roads, 4—ravines, 5—territories with the development of bylars, 6—Holocene alas basins, 7—thermokarst lakes, 8—larch forest, 9—old lakes.
Along with modern thermokarst landforms, mature thermokarst basins—alases—are found in the study areas. Their total area is 0.56 km$^2$. The largest of them is located in the north-eastern part of the Yunkyur Village. It has a rounded shape with a diameter of 380 m. Its depth is 10 m. A lake with a water surface area of 0.05 km$^2$ was formed in the depression of the alas. By morphological characteristics, the age of thermokarst basins can be estimated as Holocene. According to some ideas, the formation of alas basins in Eastern Siberia began at the Pleistocene–Holocene boundary [48,49] and reached its peak during the Holocene optimum, the climatic parameters of which are compared with modern climate changes [50]. Warm conditions of this time contributed to the rapid development of thermokarst basins. According to some researchers, forming such forms with a diameter of 120–600 m and a depth of 7.5–15.0 m could take only $\approx$150 years [50].

Thus, in the studied villages, the formation of primary forms of alas relief—bylars—is observed. They are formed in the areas of ice-rich permafrost and, therefore, cover a significant area in Amga. In addition, Holocene alas basins are widespread in the study areas, which may indicate possible consequences if the climate development and degradation of permafrost are not reversible [37].

3.2. How Do These Processes Affect Local Residents?

The degradation of permafrost and active thermokarst processes in Amga, Yunkur, and adjacent areas directly impact the local livelihoods.

In Yunkyur, houses and buildings in the thermokarst zone are deformed (Figure 7a–c). Among the affected is the “Orphan House”, which is intended for socially vulnerable groups of the population (Figure 7d). In total, 11 buildings fall into the area of development of current thermokarst forms (bylars) in Yunkyur.

![Figure 7. Deformation of houses (a,b,d) and industrial premises (c) in the village of Yunkyur under the influence of thermokarst processes. Photo by the authors.](image-url)
A similar situation arose in Amga. The most affected by the degradation of permafrost is the new Molodezhny Microdistrict, which is located on the territory of the formerly arable lands of the Amginsky State Farm. Simultaneously, the primary recipients of land should be young specialists (this is evidenced by the micro-district’s very name: Molodezhny—Youth-Oriented), who, as a rule, do not yet have a reliable economic basis for comfortable living. As shown in Figure 8, the construction of a house is being carried out on a site that is already fully covered by thermokarst processes. The main reason is the lack of territory in Amga, which is superimposed on the aforementioned continuous growth in the village population. As a result, we observed a significant building density in Amga. There was also a somewhat atypical situation for standard households in rural Yakutia, when a second house was being built on one site that already had a dwelling house and several outbuildings for another family’s residence, the owner’s relatives.

Figure 8. House under construction in the Molodezhny Microdistrict, Amga Village, September 2019; Photo by the authors.

The reduction of areas suitable for construction due to the formation of bylars and surface ponding due to the degradation of permafrost pose severe problems for the spatial development of Yunkyur, which continues, despite the observed population decline. On the northern, eastern, and western sides, it is limited by active thermokarst processes occurring, as noted, mainly on the territory of abandoned arable lands, and from the south by deep ravines (Figure 9).
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Territories affected by thermokarst also fall out of the possible agricultural turnover. In addition to the impossibility of re-commissioning previously abandoned arable land, as noted, almost entirely now turned into bylars, the existing fields also suffer. We were able to identify one of the illustrative cases in the course of an interview with the head of an essential subject of Yunkyur’s economic activity—the Poisk agricultural production cooperative. The day before, there had been sudden subsidence of soil under one of his tractors during the harvest. Given the traditional agrarian orientation of the Amginsky and Olyokminsky districts, the current situation limits local enterprise development potential.

As a result of the degradation of permafrost, prerequisites are created for the deformation of communication lines, both within the investigated settlements and associated with residents’ agricultural and hunting grounds.

This problem is most acute in Amga. Here, in late July 2013, after heavy rains, there was a large landslide, which damaged the road connecting the village with the capital of the republic—Yakutsk. For about two weeks, residents of Amga were left with no traffic connection with the “outside world” and sufficient grocery supply. According to S. P. Gotovtsev, the landslide was primarily caused by permafrost thaw [51]. In this regard, it is evident why, according to the data of our survey, the inhabitants of Amga see the main threats from climate change impacts, first of all, affecting transport accessibility of their settlement (Figure 10).

The deformation of communication lines, albeit to a lesser extent, worries the inhabitants of Yunkyur. However, this primarily applies to traditional hunting grounds. According to the testimony of informants, in recent years, problems with habitual hunting trails, which are deformed due to the formation of a polygonal microrelief (based on the description—bylars) and underflooding of the territory, have become significantly more frequent. Processes that directly affect their economic activities, including the state of the environment, are of much greater concern to the population of Yunkyur (Figure 11).
Specific differences between the answers to the questions asked by us during the survey in Amga and Yunkyur are also observed in relation to the impact of permafrost degradation directly on the territory where the respondents live.

According to our data in Amga, 57% of respondents faced problems caused (in their opinion) by permafrost degradation (Figure 12). Meanwhile, in Yunkyur, this figure was 84% (Figure 13). In Amga, 30% were forced to repair and/or strengthen the foundations of the damaged structures. In Yunkyur, the figure was 36%. In addition, the Amga residents we interviewed were less likely to transfer vegetable gardens and buildings within their area. In the course of the survey, we did not record any cases of this kind of change for reasons related to cryogenic processes in Amga at all. In Yunkyur, 11% of the respondents were forced to resort to this measure.

Reduction or complete impossibility of using of ice cellars (or “lednik” in Russian, “buluus” in the Yakut language—underground storage facilities of various sizes) in private households is also becoming an issue. Here, due to proximity to permafrost, foodstuffs can be stored year-round. However, their shrinking availability is another of the problems faced not only by residents of Yunkyur but also of Amga.

Figure 10. Most urgent threat of climate change in the opinion of residents of the Amga Village.

Figure 11. Most urgent threats of climate change in the opinion of residents of the Yunkyur Village.

Figure 12.
Residents of the village take forced measures. Amga to eliminate the consequences of the degradation of permafrost rocks within their estates.

According to our data in Amga, 57% of respondents faced problems caused (in their opinion) by permafrost degradation (Figure 12). Meanwhile, in Yunkyur, this figure was 84% (Figure 13). In Amga, 30% were forced to repair and/or strengthen the foundations of the damaged structures. In Yunkyur, the figure was 36%. In addition, the Amga residents were forced to resort to this measure.

The ongoing transformations of the normal state of the environment negatively affect the local people’s social well-being and confidence in the future. In a reasonably rapidly changing environment, it is naturally challenging to build any long-term life strategies.

During our interviews, the data we received indicate a significant increase in the economic burden on local administrations, which are forced to carry out additional fill placement on public areas, dirt roads, and their restoration.

Relocating a vegetable garden or buildings, repair work, strengthening the foundation, and jacking of the affected structures have to be done annually. Of course, all this requires individual financial and physical costs from the local residents. The emerging need for preliminary filling of the territory to create an insulating “cushion”, the forced placement of goods in places that are difficult to access from a logistic point of view, also lead to an increase in the cost of construction work and place a burden on people and enterprises.

The question of the “contribution” of the observed cryogenic processes to the dynamism of the changes we observe is weaker, reveal changes proceeding faster in particularly illustrative ways. This is our assumption, based on the first results; it will be confirmed or refuted after processing data.
received by us during 2020–2022 from equipped data sites. There is a greater emphasis in Amga on transport accessibility problems (authors of “Sustainable Rural Livelihoods: Practical Concepts for the 21st Century”). In this regard, it is also necessary to consider that, despite the noted employment of 3/4 of the working-age population of Yunkyur in the city of Olyokminsk, the vast majority of them have household plots with vegetable gardens. Amga is a more urbanized settlement. Many residents of this village have already given up their fields and live on others’ products, including imported ones.

The question of the “contribution” of the observed cryogenic processes to the dynamics of the population of Yunkyur remains controversial. As we have shown, it was in the last decade that it began to bear a negative character, which, as it seemed, could have a direct connection with the acceleration of thermokarst. However, to date, we have not identified any confirmed cases of migration from the village for reasons related to permafrost degradation. Moreover, the survey results show that only 11% of the respondents admit the possibility of moving from their native village to another settlement in the event of further deterioration of the environment.

It seems to us that one of the main reasons for the absence of such an “acute” reaction is the mechanisms developed or continuing to form for the adaptation of local communities to emerging challenges.

In the work “Permafrost and Culture. Global Warming and the Republic of Sakha (Yakutia)”, the above-mentioned group of Japanese and Russian authors cites three measures that the local communities in the Churapchinsky and Gorny regions are taking to mitigate the consequences of permafrost degradation. These are leveling the earth surface in places where thermokarst develops: constructing embankments under houses, as well as making “the choice of cultivated crops and varieties correspond . . . to the ongoing climatic changes” [13], p. 40.

In our research, as noted, there was also the preliminary filling of plots for the construction of houses, which was previously uncharacteristic for Amga and Yunkyur. We did not record the use of two other means identified by the Russian-Japanese team.

The preliminary dumping of the territory before the construction of any buildings should be considered more broadly—in general, as a change in the construction technology customary for rural communities in the republic due to the activation of thermokarst processes. This is also evidenced by the construction of wooden houses on a pile foundation (Figure 14)

![Figure 14](image-url) A house under construction on a pile foundation in Amga, September 2020; the location chosen for its deployment also confirms a serious lack of territory for the spatial development of the village. Photo by the authors.

In the same series, one can consider another adaptation mechanism that we have noted. In the research, the authors of this article recorded new production facility locations in areas
where the permafrost has low ice contents. It was essential for us to understand the main driving force in choosing such a site—some traditional knowledge of local communities, including those that work at the level of intuition, or an accurate calculation based on rational information. In this regard, the most representative example of the largest enterprise Yunkyur “Kladovaya Olyokmy” LLC was a new farm building constructed by this enterprise in 2017 (Figure 15). According to the information we received from one of the leaders of “Kladovaya Olyokmy” during an interview, site selection included taking into account the active course of thermokarst processes. It was decided for the first time to involve specialists from Yakutsk to consult on construction in permafrost conditions. Our studies have shown that the territory for the construction of the farm was indeed chosen very well. In this regard, we believe that the significant interest of representatives of rural communities in the republic in scientifically substantiated data on the “interaction” with permafrost is now a fundamental mechanism for adapting to the emerging climatic challenges.

![Figure 15.](image1.png) Built in 2017 on a site with slightly icy permafrost rocks, the new farm premises of the largest economic entity in Yunkyur, Kladovaya Olyokmy LLC, is a successful example of adaptation to climate challenges.

Simultaneously, it should be noted that so far, accounting for these data remains insufficient. In particular, the aforementioned “Orphan House” in Yunkyur was built without a ventilated underground. Inadequate ventilation of the underground is also characteristic of the school building put into operation in 2012 in this village. The fate of the 16-apartment “Experimental House” built in Amga in 2009 without a pile foundation turned out to be sad. In 2016, due to critical deformations, it was decided to resettle its residents. By now, this house has been demolished.

Among other adaptive capacities identified by us, we can name the intensification of land use as land suitable for construction shrinks. Denser building distances qualitatively changes the appearance and structure of a settlement. We encountered a quite atypical situation for standard households in rural areas, when a second house was being built on one site that already had a residential building and several outbuildings for the residence of another family: the owner’s relatives.

In many respects, social relations and the traditional collectivism inherent in representatives of rural communities in Sakha Republic play an essential and perhaps decisive role in adapting to emerging challenges. Mutual support and strong family ties allow residents to endure various stressful situations more efficiently, reduce the threat of desocialization in the event of force majeure, and make the life support system of the population of Amga and Yunkyur more resilient to various shocks.

What else can representatives of local communities and self-government bodies do to mitigate the problems arising from thermokarst? As an immediate measure, we would suggest snow removal in winter and surface shading by planting trees and shrubs in problem areas. This measure might be effective in lowering the ground temperatures...
and reducing permafrost thawing. Additional recommendations will be devised after further research.

The assumption that the local rural residents in Yakutia have traditional ecological knowledge on permafrost processes stems from a legend recorded by ethnographer S.I. Nikolaev in the mid-20th century. According to this legend, the Sakha used controlled forest fires in areas of shallow permafrost so that alases would eventually develop for future generations to settle in [52]. Interestingly, the older parts of both Amga and Yunkyur are not affected by thermokarst, and this may provide an indirect evidence of the traditional knowledge. However, our study has not revealed the presence of such knowledge among contemporary representatives of rural communities in Yakutia. Whether it did not survive and whether it existed are good questions for discussion and further research.

The study of the perception of the problems that have arisen with land plots in agricultural circulation by residents, some of whom, as noted, are direct descendants of the first Russian settlers of the 17th century, requires further development, and we have begun. Most of the original settlers now self-identify as Yakuts (Sakha) in terms of their anthropological type and self-awareness. On the whole, to date, we have not identified any fundamental ethnic differences in perception, ways of responding to emerging climatic challenges, and mechanisms of adaptation to them on the part of Russians and Sakha (Yakuts). Considering the centuries-old fruitful interaction of the two ethnic groups in the studied areas, this seems understandable and well explained for the authors.

4. Conclusions

This study has shown widespread thermokarst development in the villages of Yunkyur and Amga. Permafrost degradation is affecting the local communities in many ways. The structural integrity of houses and farm buildings is threatened, and the land area suitable for new construction is reduced. Croplands and pastures heavily disturbed by thermokarst processes have to be abandoned. The accessibility of communities, farms, and hunting areas is deteriorated. Furthermore, permafrost degradation affects the social well-being of residents. Continuous efforts to cope with thermokarst consequences increase the financial burden on people, businesses, and local administrations. The study has identified a number of adaptation responses to the ongoing changes, including the adoption of construction technologies generally not common for rural housing in Yakutia with an increasing interest in research-supported decisions, as well as intensive use of suitable land for new construction. Social relations and traditional collectivism of the Yakutia’s rural communities are important adaptation resources.

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