Russian Arctic Permafrost Degradation Effects Public Life

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There are more than 200 Siberian anthrax cattle burial grounds in the Russian permafrost regions. Permafrost degradation poses the risks of thawing of frozen carcasses of the infected animals and propagation of infectious diseases. Permafrost degradation leads to infiltration of toxic waste in the environment. Such waste contains mercury, which migrates into the rivers and forms methylmercury (MeHg) in fish. Other risks associated with permafrost degradation include damage to the existing social infrastructure (housing, health-care facilities, roads, etc.).

Keywords: public health-care ; infectious diseases ; Siberian anthrax ; toxic metals

1. Introduction

The rate of climate warming in the Arctic is greater than elsewhere in the Russian Federation. This rate is approximately twice as much as the world's average, as was shown by the linearization of the trends in annual average temperatures of the North Polar Region over the past 40 years (1976–2018) [1].

Further warming will lead to even faster degradation of the permafrost layer [2]. According to the IPCC, it will lead to a 90% reduction of permafrost area by 2100, and even faster degradation will happen with 20% of this area [3]. The rate of permafrost degradation will depend upon local conditions and greenhouse gas emission dynamics.

An extensive network of 250 weather stations monitors ground-level air temperatures in the North Polar Region. The annual average temperatures increase, with the greatest rates along the coast of the Arctic Ocean, especially in Siberia (between +0.8 °C/10 years and +1.2 °C/10 years in the Taymyr Peninsula and the East Siberian Sea). The largest temperature anomalies have been observed in East Siberia and West Siberia. The spatially averaged values of mean annual temperature anomalies in these regions reached 5.9 and 3.7 °C, respectively [4]. Since 2007, annual average ground-level temperatures have increased by 2.8 °C in East Siberia and Yakutia [5]; this caused an increase in the temperatures of the upper permafrost layer by 0.4–1.3 °C [6]. Annual average temperatures in West Siberia grew at the rate of 4.0–5.5 °C/100 years [7]. **Figure 1** presents the results of monitoring of correlations between the rates of increase in annual average air temperatures and permafrost degradation.

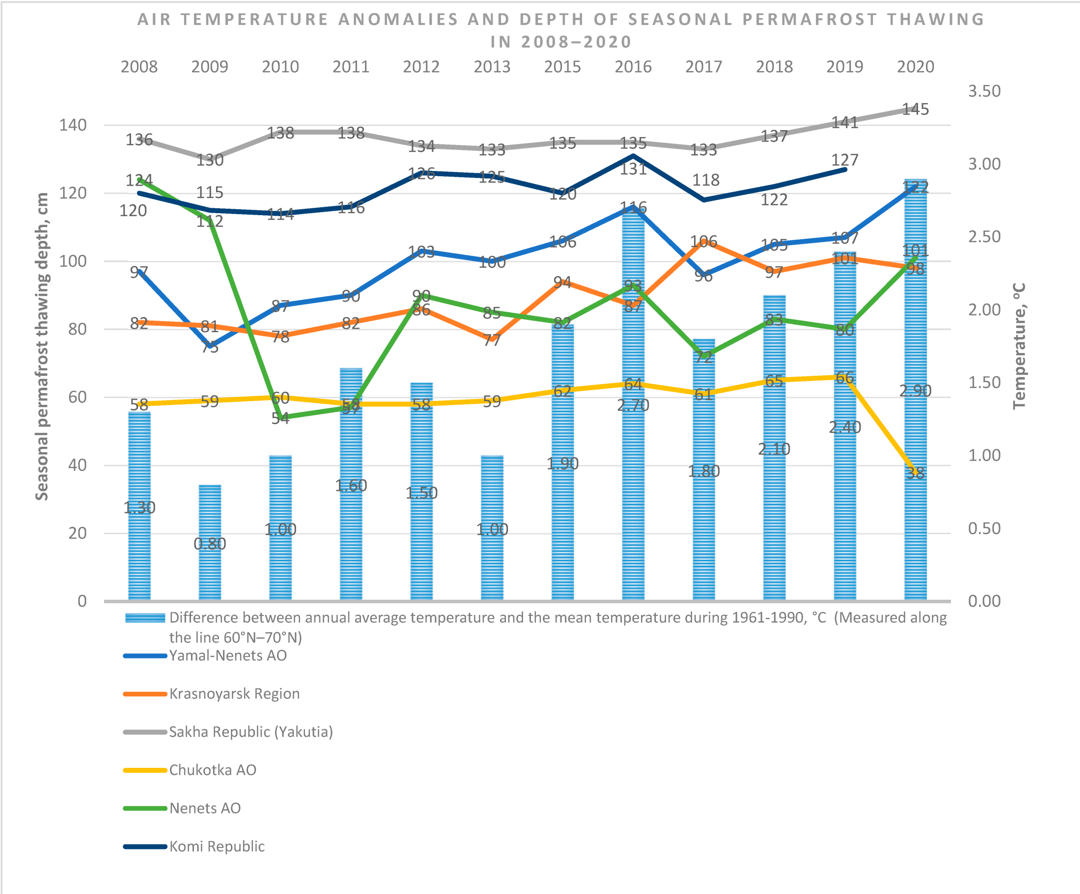

Figure 1. Air temperature anomalies and depth of seasonal permafrost thawing in 2008–2020. Seasonal thawing depths were averaged by region based on the data reported by the Circumpolar Active Layer Monitoring (CALM) program. Available online: https://www2.gwu.edu/~calm/data/north.htm (accessed on 21 March 2022). Incomplete time series from several monitoring stations were excluded. AO—Autonomous Oblast (Region).

In Russia, the processes of permafrost degradation are most pronounced in Nenets Autonomous Oblast (AO), North Urals, West Siberia, Yamal Peninsula, and a major part of East Siberia: Krasnoyarsk region, Sakha Republic (Yakutia), Chukotka, and Kamchatka. For example, permafrost soil temperatures measured at 1.6 m depth have already increased by 0.1–1.2 °C above the norm [8]. A 2 °C increase in the mean global temperature will lead to complete thawing of 15–20% of Arctic permafrost areas [9]; some other researchers predicted even greater loss [10].

The consequences of climate change to public health in the Russian Arctic will be quite diverse, including the following: an increase in the number of heat waves will lead to excess mortality among urban populations [11][12][13][14]; traditional lifestyles of the indigenous peoples of the North will be disrupted [15]. A survey of Central Yakutia residents identified their concerns about the ongoing changes in the landscapes and weather in 2006–2016. The residents indicated that they experienced problems with accessibility of medical services and shopping; the foundations of their houses were crumbling, which was considered a direct consequence of warmer winters; and there was loss of reliable ice crossings that they used for transportation [16]. There are many risks to public health caused by permafrost degradation: re-emergence of outbreaks of Siberian anthrax, and, possibly, other infections, as a result of thawing of cattle burial sites; development of infections caused by changes in vegetation (northward propagation of taiga); destruction of engineered infrastructure, including hospitals, residential houses, and roads; possible infectious contamination of foods used by the indigenous peoples of the North, as a result of thawing of glaciers; risks to deer breeding, such as injuries of the deer caused by permafrost thawing; possible destruction of shoreline constructions caused by coastal abrasion; and other types of risks.

2. Russian Arctic Permafrost Degradation Effects Public Life

2.1. Global Warming, Permafrost Degradation, and Infectious Diseases

There are indications that global warming leads to permafrost degradation, and this may facilitate the possible release of various microorganisms including pathogens. Recent research showed that prokaryote and eukaryote bacteria might remain viable in the conditions of year-round negative temperatures of permafrost soils that are from several thousand to 2–3 million years old. Viable cysts of Paleolithic bacteria have been identified that had been in a cryptobiosis state for several hundred thousand years. This finding confirmed a possibility of reactivation of vectors of infectious diseases that remained frozen in permafrost for a very long time and can be released in the environment as a result of climate changes [17].

The part of West Siberia beyond the Polar Circle was plagued by Siberian anthrax in the past; more than 70 large outbreaks have happened there since 1760. Such outbreaks typically occurred in the summer when the deer contracted this disease from the contaminated soils. The outbreaks became less common after a massive vaccination of domestic animals in the 1940s. There were several registered cases of Siberian anthrax among people in 1931 and 1941. After a long period of sanitary well-being without the outbreaks, the total vaccination of deer was abolished in 2007. An extremely hot summer of 2016 caused a 2 meters' deep seasonal thawing of permafrost and, possibly, vegetation of Siberian anthrax bacteria, its migration from the active permafrost layer to the surface soil, and a consequent large-scale outbreak of Siberian anthrax among deer. Permafrost degradation may lead to migration of these bacteria to the surface with groundwater.

Paleolithic viruses can also be released in ambient air during permafrost degradation. This potential source of health risks has been insufficiently studied so far, but there are limited data on the circulation of paleoviruses between ecosystems [18]. Russian biologists have published several studies of the microbial communities in permafrost ecosystems [19]. High prevalence of the pathogen and 'suspected pathogen' bacteria in the Arctic ecosystems creates a demand for epidemiologic surveillance, including monitoring of ecosystem compartments and media (water, snow, air, soil, and frozen soil). The collected samples should be screened by molecular genetics methods, and the pathogenic properties of the collected microbial communities should be thoroughly studied. There are also other directions of research [20].

A permanent loss of permafrost areas drives the taiga north, where it replaces the tundra ecosystems, which, from an epidemiological standpoint, has its negative consequences. The habitats of rodents and insects shift northward, and many such species transmit infectious diseases. Global warming influences the prevalence of natural focal infections changing the environmental conditions and the life cycles of diseases' vectors and agents. Climate-dependent infections become the important sources of health risks. These infections include hemorrhagic fever with kidney syndrome, tick-borne encephalitis, and Lyme disease. Under the ongoing changes in climate and land use, assessment of risks for people and animals becomes a quite sophisticated and difficult task due to lack of knowledge about the prevalence, diversity, and distribution of the pathogens. The regional studies of quantitative relationships between climate change and disease prevalence are still quite limited.

The results of the long-term program of environmental and epidemiologic monitoring of tick-borne encephalitis (TBE) showed a statistically significant increase in the prevalence of this disease near the northern border of the tick habitat. A nearly 60-fold increase in TBE incidence was reported between the baseline period of 1980–1989 and the observation period of 2000–2009 in Archangelsk Oblast. Climate change could be the most important contributing factor for this increase. The northern boundary of the ixodid tick (*Ixodidae*) habitat shifted approximately 150–200 km north during the 40-year period of monitoring in Archangelsk Oblast. A similar, albeit less pronounced, increasing trend in TBE incidence was reported in the neighboring Komi Republic [21] and North Sweden [22]. Air temperature principally limits the northern boundary of the tick habitat in the taiga because this species can develop only if the mean daily temperature exceeds 5 °C [23]. An analysis of the blood serum of the donors who never had this disease or a vaccine against it showed a three- to fourfold increase in the prevalence of IgG (immunoglobulin G) antibodies to tick-borne encephalitis during the 12-year period between 2001 and 2013. The prevalence increased from 3.5% to 13.7%. The increase was most pronounced for those donors who lived in the south districts, which confirmed the hypothesis about the northward migration of the infected tick and adaptation of both the virus and the tick to a harsh northern climate [21].

Global warming may bring about deterioration of drinking water quality in the Arctic because melting of ice leads to water erosion of contaminated lands, including household and industrial waste dumps, fuel depots that store gasoline, kerosene, diesel fuel. Poor quality of drinking water may cause the spread of intestinal infections. Such infections may also be triggered by the changes in the temperature regime of frozen food storages. The food products are stored in underground ice storages in the Russian Arctic, Northern Canada, and Alaska. The largest storage of frozen food in Chukotka (its area is 330 square meters) was constructed in the 1960s. Since then, the air temperature, monitored at the nearest weather station, has increased by 3.8–4.4 °C (0.67–0.77 °C per 10 years). A smaller-size storage has already broken down because of permafrost degradation [24]. A microbiologic analysis of air samples taken from such low-temperature storages identified the *Yersiniaceae bacteria*, which survive and retain viability at temperatures between −15 °C and −20 °C. These samples contained not only *Yersinia* but also toxic fungi (*Aspergillus, Mucor*), which may contaminate the foods of indigenous peoples of the North [25].

2.2. Climate Change and Permafrost Degradation Pose Risks of Contamination of Ambient Air with Toxic Metals

Numerous metal works, mining companies, coal-fired power plants, and other industrial facilities release large quantities of toxic metals in ambient air in many regions of the Russian Arctic. The residents of industrialized areas are exposed to the combined effects of toxic metals in the air and extreme heat during the heat waves, which become more frequent. There are plans to increase the production of polymetallic ores, especially zinc and lead, in Spitsbergen Island and Novaya Zemlya. A new ore-mining plant is being constructed in Chukotka for the production of tin, copper, wolfram, and other metals. It is likely that new plants will be constructed in Yakutia for the mining of lead, mercury, copper, and other metals.

The problem of mercury pollution in Arctic ecosystems deserves special attention, as the estimated reserves of this metal in the Russian Arctic are 800,000 tons [26]. Health risks of mercury and its organic compounds have been thoroughly studied, which resulted in the adoption of the Minamata Convention on Mercury in 2009, aimed at the control and eventual prohibition (by 2020) of the manufacture, export, import, and utilization of this metal. The Russian Federation signed this convention in 2014 and ratified it in 2017. Mercury can be released in the Arctic environment during its direct mining in Yakutia and Chukotka or, alternatively, during gold mining in Magadan Oblast. Mercury is also emitted in ambient air by large metal works and refineries and copper and nickel smelters.

Mercury emanations from permafrost may become a new source of environmental pollution, as permafrost remains the largest global reservoir of this metal. Permafrost degradation will inevitably release large quantities of mercury in the aquatic ecosystems. An estimated global annual release of mercury as a result of the current degradation of permafrost is 20 tons/year, and this metal ultimately goes to the largest rivers of the Russian Arctic (Yenisei, Kolyma, Ob, Lena) and North America (Mackenzie and Yukon), which flow into the Arctic Ocean; the releases of mercury increase every decade [27]. At the same time, a net decrease in total mercury content (including methylmercury) in the *Lota* fish tissue has been reported. The measurements of total mercury were averaged for the low reaches of the three rivers of European Russia (Northern Dvina, Mezen, Pechora) and the five Siberian rivers (Yenisei, Kolyma, Pyasina, Ob, Lena). During the period between 1980 and 2001, the mercury content decreased by 2.6% per year on average. The total reduction was 39% (from 0.171 to 0.104 mkg/g of wet weight). Interestingly, the total lead content in *Lota* fish tissue in the North American Arctic increased during the same period [28][29]. Possible reasons for the opposite trends in the Russian and American Arctic could be tied to the general circulation patterns in the atmosphere, sedimentation of airborne aerosols, consequences of climate change, anthropogenic factors, nature conservation activity, and specific measures aimed at the control of mercury-containing waste in the environment in the Western and the Eastern Hemispheres.

2.3. Climate Change, Permafrost Degradation, Stability of Buildings, and Engineered Infrastructure

The accessibility of health care services remains an important contributor to overall life quality and public health of the Arctic residents. Another aspect of life quality is related to comfort living conditions, including stability of residential houses and hospitals, and year-round road conditions vital for transportation. Permafrost degradation affects the stability of buildings' foundations and various objects of engineered infrastructure. The risks for infrastructure are the greatest in Nenets AO, Yamal-Nenets AO, the northern part of the Krasnoyarsk region, Sakha Republic (Yakutia), Magadan Oblast, and Chukotka AO.

Expected economic damage in the health-care sector was actually quite small, less than 0.001% of the regional GDP. However, the indirect losses could arise from relocation of health-care centers, temporary unavailability of health-care services and hospitals, additional demands for health-care services where the hospitals are still available, increase in waiting times, and so forth. Transport accessibility of medical services can become a crucial issue in the conditions of low population density and a scattered network of health-care facilities. For example, the settlements in the north of the Krasnoyarsk region near the Arctic Ocean can only be accessed by air. A temporary closing of a hospital would require additional air transportation expenses and would lead to an increase in waiting times.

The greatest portion of the expected economic loss falls to the residential sector. The estimated annual costs vary between USD 0.5 and 3.8 billion. Again, the possible consequences can be far-reaching.

The economic loss in the road transportation sector due to permafrost degradation can be USD 0.5–0.6 billion annually. The greatest damage is expected in Yakutia because of its well-developed motorway network. The economic estimates presented here are based on the existing road networks and do not account for any future changes. The existing motorways in the permafrost regions are already old enough; the scholars estimated the total length of these roads to be 35,471 km, of which only 3% are paved and 97% are dirt roads.

2.4. Climate Change and Adverse Weather Conditions

Extreme weather events create significant risks to environmental health in Russia due to its very large territory and complex geographical and environmental conditions. In Russian Arctic, such events include snowstorms, ice tsunami, coastal erosion, white mist, and abrupt changes in weather in time and space induced by varying local conditions. Extreme weather events cannot be avoided, but their adverse consequences to public health can be mitigated by the implementation of early warning systems, preparedness, and rapid response of health-care system to such events. The health-care sector and public administration in general should ensure their stable and sustainable operations in the conditions of global warming. One of the possible improvements in the public management could come from the optimization of transportation between the settlements and the hospitals. The scholars applied the modern mapping methods in Archangelsk Oblast and Nenets AO and showed that 25% of local residents experienced considerable delays in emergency transportation to the nearest hospital or ambulatory. Health risk distribution maps were developed for these territories. Implementation of road network graphs in the public health sector helped to optimize the locations of health-care centers, including specialized hospitals, and emergency transportation logistics. Even a short-term closing of the existing hospitals poses significant health risks for the residents of the remote settlements in the Krasnoyarsk region, Sakha Republic (Yakutia), Nenets AO, Yamal-Nenets AO, Magadan Oblast, and Chukotka AO. Most medical services there are offered by the obstetric and paramedics stations and small polyclinics usually stationed in the administrative centers of municipal districts. The distances between the nearest stations can reach several hundred kilometers [30].

4. Conclusions

Permafrost is an important environmental feature of the Russian Arctic, which significantly affected and still affects the lifestyles, public health, and economy of both the indigenous and migrant populations in this region. The specific permafrost conditions determined the methods for the construction of residential housing and engineered infrastructure. Frozen soils contain harmful bacteria, viruses, and toxic chemicals, including mercury. In several past decades, global climatic changes and, most importantly, rapid increase in ground-level air temperatures dramatically affected the stability of permafrost and caused its thawing and degradation. Permafrost degradation turned the whole region in the zone of high investment risk, undermined social well-being, and contributed to health risks experienced by a significant portion of the Arctic population.

The existing problem of permafrost degradation needs to be addressed, but the minimization of the adverse consequences of permafrost degradation requires considerable financial outlays and administrative efforts. The prediction of the extent and rate of future changes is accompanied by high uncertainties and unresolved scientific problems; it is also quite difficult to estimate the ability of the state and the people to adapt to such changes. The assessment of costs of restoration of the infrastructure objects in different economic sectors, which may be destroyed due to permafrost degradation, has been conducted under several climate change scenarios. Total costs may vary between 0.21% and 0.91% of the annual gross regional product in the selected regions. The economic consequences of permafrost degradation can actually be even more far-reaching. The costs in the health-care sector due to permafrost degradation may reach 3% of the total annual health-care budget. Depending upon the rates of permafrost degradation, the demand for new housing construction will be between 280,000 m^2 and 1,500,000 m^2 [31][32]. New housing will be needed to compensate for the losses in the residential sector due to permafrost degradation. For comparison, the total area of residential housing in the Russian North is currently 2800 m^2, so this will be quite a challenge for the regional economies. About 3.2 million people live in the permafrost regions of the Russian Arctic, and 81% of these people live in the cities. Urban populations are usually more susceptible to contagion of infectious diseases. COVID-19 provided an example of such vulnerability, because the highest infection rates were detected among workers in oil and gas mining companies who work in small isolated teams and live together in dormitories. The risks associated with permafrost degradation include the release of mercury, and other toxic substances, to the environment during permafrost thawing, as well as destruction of buildings' foundations, water supply and wastewater disposal mains, and deterioration of housing and living conditions. There are concerns over possible closing of medical facilities, inaccessibility of health-care services, increase in patients' waiting times, and emerging infectious diseases. While certain direct economic losses and risks can be identified, predicted, and assessed, it is hardly possible to foresee numerous indirect consequences and the associated economic costs. There are reasons to believe that indirect damage to the economy as a result of permafrost degradation can be much greater than direct losses.

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