

# Fixing the Unfixable? Geographic Barriers to Environmental Restoration in Russia's Heavy Industry Regions

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## ABSTRACT

The long-term environmental damage from Russia's large-scale industries has caused serious environmental problems throughout Russia's heavy industry areas — including in the Arctic city of Norilsk and the Ural industrial belt — because of the way geography, climate and infrastructure combine to hinder remediation of damaged environments. Through an examination of existing literature on this subject, this article will analyze and document the ways in which geographic elements (geography) create barriers to environmental restoration, and develop proposals for policy responses to overcome those barriers. The research demonstrates that the extreme climate conditions of the north; the legacy of previous industrial activities; the difficulty of accessing many remote areas where environmental pollution exists; and inadequate compliance with regulations for environmental protection, have created a difficult set of circumstances that make it very difficult to implement successful remedial actions. As part of developing sustainable approaches to the cleanup of damaged environments, the authors recommend using additional regulatory requirements; upgrading the technology being used; increasing monitoring capabilities; and improving communication between local communities and government agencies.

**Keywords:** Geographic Barrier, Environment, Pollutants, Russia, Industrial Regions, Heavy Industries, Spatial Concentration

## INTRODUCTION

Amongst Russia's environmental issues, the ecological degradation of its industrial zones is considered amongst the most significant and long-term environmental problem in the country (Nikitina & Kotov, 2002) The regions characterized by the predominance of heavy industries — including the Norilsk region in the Arctic and the Ural Industrial Belt — experience chronic pollution as a result of their high levels of air pollutants, heavy metals in soil and water, and disruption to their ecosystems (Zhulidov et al., 2011). Although there have been attempts at reducing pollution through the introduction of new technologies and modernizing existing ones, despite the efforts made by the Russian government to reduce pollution, pollution remains a major issue for many of Russia's industrial regions; so much so that Norilsk has been included on the list of the most polluted cities in the world (Revich & Kharkova, 2023).

The widespread ecological damage caused by pollution in Russia's industrial regions is primarily due to the prioritization of industrial production over ecological sustainability in the Soviet era, which still influences Russia's current environmental policy ("Notes," 2024). Furthermore, the persistence of environmental deterioration in these regions is also exacerbated by Russia's continued reliance on raw mineral resources for export purposes and the fact that environmental considerations continue to be secondary to economic priorities in policy discussions concerning the export of raw materials from the economically depressed northern regions where unemployment rates are high and incomes are low (Vladimirova, 2017).

Therefore, this research will investigate the geographical barriers that make it difficult to restore areas damaged by environmental pollution and examine how they influence economic, institutional and climatic factors to contribute to the continued deterioration of the environment.

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## Geographic and Environmental Context

### Heavy Industry and Spatial Concentration

The industrial heartland of Russia is geographically confined to an area of rich natural resources designated in the course of Soviet planning. In the same vein, the Norilsk nickel complex, owned by Norilsk Nickel, is one of the largest non-ferrous metal producer globally, polluting millions of tons of pollutants annually. Rivers such as the Daldykan nearby are continuously polluted by industrial effluents and have become visible by contamination. Cities like Cherepovets, Novokuznetsk and Lipetsk have experienced pollution levels that are ten times higher than permissible levels, primarily due to industrial activities (Volovich & Skatov, 2024). Due to its original territorial structure, which resulted from the location of heavy industry in areas with aged equipment and the location of areas with large-scale mining, the territorial patterns of pollution continue (Bityukova, 2022). Moreover, this concentration of industrial activity — mainly in areas such as the Altay, Omsk and Krasnoyarsk regions — continues to contribute to local environmental degradation (Chu et al., 2022). The history of Soviet policies which emphasized rapid industrialization and resource extraction has resulted in a legacy of entrenched environmental problems, especially in the Arctic zone of Russia, where ecosystems are highly sensitive (Bislev et al., 2018). Additionally, the environmental impacts of the continued focus on export of raw materials can lead to depleting of mineral resources, causing serious damage to the ecosystems in these locations (Забелина, 2021). In addition to this, the environmental impact is worsened due to the continuous use of old and damaged industrial equipment, and because there is little financial incentive to implement sustainable practices (Голова & Sukhovey, 2019).

Similarly, the Ural industrial region contains numerous sites of steel, chemical and metallurgical production, resulting in many different pollution sources for air, soil and water from decades of intensive production. As previously mentioned, the combination of historic pollution, lack of regulation, and limited use of advanced environmental technology has created a long-standing geographic pollution structure (Bityukova, 2022; Vorontsova et al., 2021). A notable statistic is that currently, 85% of all pollution comes from only 3 major sectors of Russia's economy: the fuel and energy minerals sector, the metallurgy sector, and the electricity generation and transmission sector. These sectors produce massive amounts of air pollution compared to their output volumes (Bityukova, 2022). Thus, the concentration of heavy industrial complexes in many Russian cities, including Norilsk, has produced some of the world's most polluted urban environments (Shevchuk, 2024).

### Geographic Barriers to Environmental Restoration

#### Harsh Climate and Limited Pollutant Dispersion

The extreme climate of the Arctic reduces both the rate at which pollutants are broken down by biological processes as well as the ability of the atmosphere to disperse pollutants. Both stable atmospheric conditions and regular temperature inversions that result in pollutants being trapped near the ground level for months maximize the area over which local exposure occurs while severely impede an ecosystem's ability to clean itself naturally. As a result of these combined effects, the air quality in many northern industrial cities, including some of Russia's most polluted cities, is among the worst in the world due to years of accumulated emissions in a region characterized by climatic stagnation (Shevchuk, 2024). Extremely low temperatures further reduce the rates of chemical reactions that degrade pollutants, leading to longer duration impacts on both ecosystems and human health (Shevchuk, 2024). Permafrost regions have very low levels of biotic activity, which limits the amount of natural degradation that can occur in the presence of contaminants, and therefore results in an increase in the concentration of contaminants in both the soils and waters of those regions (Bislev et al., 2018). Examples of the long-term impacts of the combination of low temperatures and minimal biotic activity include extensive pipeline systems, large tracts of barren land and large quantities of surface oil in regions such as Usinsk; all of which demonstrate the difficulty associated with restoring damaged ecosystems in remote and extreme locations (Bislev et al., 2018). Although the term "arctic synergy" has been used to describe the unique combination of negative climatic and anthropogenic factors that interact with the low self-purification capacities of arctic ecosystems (Vorontsova & Воронцов, 2020), it is generally accepted that even relatively minor disturbances to fragile and highly interdependent ecosystems can produce cascading, long-term impacts. Therefore, there is a need for restoration strategies that are specifically designed to address the challenges presented by arctic ecosystems (Voronina, 2021). In regions such as Norilsk, these same climatic conditions amplify the cumulative

impacts of industrial pollution, producing widespread degradation of arctic environments—dead forests and acidified ecosystems, for example—which illustrate the low assimilative capacity of arctic environments (Hønneland & Jørgensen, 2003). In addition to slowing the rates of microbial activity and soil processes that help to break down contaminants, cold temperatures and permafrost also inhibit the rates at which contaminants are degraded by microorganisms in the soil. This results in an increase in the bioaccumulation of toxic substances within the arctic food web, which pose significant risks to both wildlife and indigenous populations (Shevchuk, 2024). Furthermore, the fact that permafrost inhibits the movement of pollutants allows them to accumulate and potentially be released into new areas through the process of cryoturbation and other cryogenic processes during thawing (Tishkov, 2012).

### **Legacy Pollution and Soil/Sediment Contamination**

Long-lasting and large-scale soil pollution with heavy metals at Norilsk is a result of many years of continuous fallout from metallurgical and mining waste, primarily directly deposited from smelters and mines. The presence of high or very high environmental risk levels has been reported by other researchers in the heavily contaminated soils found in urban areas of the Norilsk region; particularly heavy metals, i.e. nickel, copper, cobalt and lead are present in soils even when there may be mechanisms in place to potentially immobilize them. As well, the extreme seasonal freeze-thaw cycles common in permafrost regions will continue to mobilize these contaminants into both terrestrial and aquatic ecosystems (Langer et al., 2023), which in turn pose serious long-term threats to the continued health of local ecosystems and human populations since they will eventually enter the food chain (Sidorstov et al., 2025).

For example, research has shown that environmental contaminant levels of heavy metals were significantly higher in all environmental compartments studied, e.g. fish, mosses, and soils, along the Taymyr Peninsula near the center of the Norilsk industrial complex than would be expected due to natural processes (Zhulidov et al., 2011). Contaminated zones exist in vast quantities surrounding industrial core areas, limiting vegetation growth and biological recovery in affected areas for many years after emissions reduction. Furthermore, recent evidence suggests that permafrost thaw can release harmful chemicals into the environment, as was demonstrated by the 2020 Norilsk diesel spill, which resulted in the release of approximately 17,000 tons of fuel into the Arctic ecosystem (Langer et al., 2023).

### **Remote Accessibility and Logistic Constraints**

Norilsk is an extremely remote and isolated site in the Arctic Circle that has no permanent connection to mainland Russia via a roadway. Therefore, transportation infrastructure does not exist at this location to support larger scale restoration technology deployment and reliance upon seasonal river navigation on the Yenisei River or costly air cargo is necessary (Bislev et al., 2018). The extreme remoteness greatly increases costs associated with deploying restoration technologies at this location by anywhere from two to five times the cost of similar technologies deployed at more accessible locations; creates substantial challenges with the execution of long-term remedial action due to harsh winter conditions and the presence of permafrost (Langer et al., 2023); and severely limits the ability to deploy critical restoration personnel and large equipment needed to execute remediation (Langer et al., 2023). The 2020 diesel spill in Norilsk, which spilled approximately 17,000 tons of diesel fuel into rivers, lakes and tundra, was an example of how these limitations can create substantial delays in responding to an incident and increase the severity of the environmental impact across a large area of a permafrost watershed (Langer et al., 2023).

### **Weak Regulatory Enforcement and Institutional Gaps**

Although there are federal standards for environmental protection, the enforcement of those standards in remote areas such as the Arctic region of Norilsk is greatly hampered by lack of monitoring capabilities, institutional shortcomings, and a priority on the economic output of industries compared to the compliance with environmental regulations (Bislev et al., 2018). The above-mentioned regulatory gaps cause continuous emission of pollutants and poor adherence to established regulations. Evidence for this includes that Norilsk remains one of Russia's most polluted cities, even though the city has experienced an overall reduction in its level of production during a period of recession (Shevchuk, 2024; Bitjukova, 2022). Due to low levels of investment in new technology or assets, many of the enterprises operating in these locations still use old, "end-of-pipe"

methods of pollution control, instead of transitioning to integrated systems of environmental management (Bityukova, 2022).

## Challenges to Restoration in Specific Regions

### Norilsk: Arctic Extremes and Industrial Legacy

The extreme Arctic environmental conditions of Norilsk have created a major barrier to restoration. The industrial history of Norilsk is dominated by the Norilsk Nickel complex that has resulted in the release of tens of millions of tons of sulfur dioxide, in addition to metals such as nickel, copper, cobalt, and lead. This has caused massive soil acidification, killed millions of trees over thousands of square kilometers, and has damaged plant growth over very large areas (Hønneland & Jørgensen, 2003; Bislev et al., 2018; Shevchuk, 2024). On the Taymyr Peninsula to the east of the complex, studies found increased levels of heavy metals in soils, mosses, fish, and all other components of ecosystems. This illustrates long-term contamination north of the industrial complex (Zhulidov et al., 2011). Restoration in this environment faces significant challenges, including the presence of permafrost that reduces microbial activity and biodegradation and the movement of pollutants through repeated freeze/thaw cycles and other disturbance processes (Tishkov, 2012; Langer et al., 2023; Shevchuk, 2024); long periods of winter that reduce chemical reactions and biological recovery (Shevchuk, 2024); and limited infrastructure that includes lack of roads to the site during the year, significantly increasing the cost of cleanup (2-5x) and response time (as illustrated by the 2020 diesel spill of 17,000 tons into the permafrost tundra) (Bislev et al., 2018; Langer et al., 2023).

### The Ural Belt: High Industrial Footprint and Mixed Pollution Sources

Pollution from the metallurgical complex is among the worst in Russia's industry; located in the Ural region, it is an area with a multitude of pollutants (chemical plants, steel mills, mines) that overlap and create complicated pollution profiles for each location (Bityukova, 2022). The combined density of population and industrialized urban areas in the Ural region also increases the number of exposure pathways for pollutants from these locations, and makes difficult the selection of remediation targets due to the close proximity of the pollution source to residential areas.

## Policy Recommendations for Overcoming Geographic Barriers

### Strengthen Environmental Regulation and Monitoring

- **Tougher Regulatory Compliance:** Strengthen enforcement mechanisms for federal and regional regulatory bodies (for example, Rosprirodnadzor), so that they can regularly inspect sites at the least developed industrial locations.
- **Satellite And Ground Sensor Systems for Remote Emissions Detection:** Implement systems with sensors and/or satellites to monitor emissions and pollutants in real-time, particularly where it is challenging to be physically present.

### Promote Technological Modernization

- **Clean Technology Subsidies:** Governments should provide money for companies to utilize high-end pollution control devices to cut down emissions at their sources.
- **Best Practice Standards:** The U.S. should have the same or better standards as other countries (such as the E.U.) in terms of how they handle hazardous materials and smelting, and move past just reducing pollutants after the fact and focus on systemic reductions of pollutants.

## Restore Ecosystems through Tailored Remediation Strategies

- **Phytoremediation:** Using plants specifically chosen based on a location's climate to remove pollutants from contaminated soils, especially when traditional remediation is impossible.

- **Soil Amendments:** Add organic matter to the soil through amendments to prevent heavy metals from being released into waterways and to make them less mobile and/or toxic to plants.

### Community Engagement and Economic Diversification

- **Local Participation:** Involve local communities in all aspects of environmental monitoring and restoration efforts so that environmental goals are aligned with public health goals.
- **Economic Transition Support:** To help shift local economies away from heavy industrial reliance and towards new areas such as services, clean/renewable energy, and environmental technology and assist communities that may be economically resistant to stringent environmental regulations.

## CONCLUSION

A combination of geographic constraints — extreme climate, past industrial legacy, physical remoteness and lack of enforcement — have resulted in de facto conditions that allow pollution to continue, even with sporadic (ad hoc) mitigation techniques. While it is difficult to overcome these past legacies, there are several inter-related policy initiatives that can be employed to provide for effective restoration of areas that have been environmentally degraded as a result of heavy industrial activity. Through a combination of regulatory reforms, technological upgrades, community outreach/engagement and specific ecological remediation activities, Russia can begin to address what appear to be "unfixable" environmental degradation issues within its heavy-industry regions.

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