Impact on Climate change due to thaw of Permafrost

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Abstract:

Background of the Study: The thawing of permafrost presents a significant threat to the global climate system, with its potential to accelerate climate change being a key concern for scientists. Permafrost, a layer of permanently frozen ground found in the Arctic and sub-Arctic regions, stores vast amounts of carbon in the form of organic matter that has been trapped for thousands of years. As the Earth warms and permafrost begins to thaw, this stored carbon is released into the atmosphere as carbon dioxide (CO2) and methane (CH4), both potent greenhouse gases.

Objective: The objective of this study is to measure the impact of climate changes on Permafrost.

Methodology: This paper is basically conceptual in nature. The research gap has been analyzed after thorough analysis of researches based on Permafrost and its adverse impact.

Practical Implications: This study helps to keep an insightful view of the permafrost and its adverse impact due to climate changes.

Key Words: Permafrost, Climate change, greenhouse gases

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1. Introduction

Permafrost is defined as rock or soil that remains at or below the freezing point of 32°F for two or more years. Permafrost usually lies below an "active layer" of ground that freezes and thaws every year with seasonal changes in temperature. Permafrost occurs in many different forms with various amounts of ice (continuous and discontinuous) and is mainly found in areas near the Arctic. In Alaska, about 80 percent of the ground has permafrost underneath it. A key characteristic affecting the state of permafrost is the temperature at the ground surface and shallow depths. The seasonal timing, amount, and extent of snow cover also affect permafrost. A warming climate has brought higher temperatures to Alaska and other areas with permafrost, causing some permafrost to thaw. While the impacts of climate change on permafrost vary at regional and local scales, permafrost thawing has been observed in many locations around the world.

A thawing permafrost layer can lead to severe impacts on people and the environment. For instance, as ice-filled permafrost thaws, it can turn into a muddy slurry that cannot support the weight of the soil and vegetation above it. Infrastructure such as roads, buildings, and pipes could be damaged as permafrost thaws. Infrastructure damage and erosion, due in part to permafrost thaw, has already caused some communities in western and southern Alaska to have to relocate. Additionally, organic matter (like the remains of plants) currently frozen in the permafrost will start to decompose when the ground thaws, resulting in the emission of methane and carbon dioxide into the atmosphere. This contributes to further global climate change.

Permafrost covers about 24% of the Northern Hemisphere's landmass, primarily in Siberia, Alaska, and northern Canada. This frozen ground contains approximately 1,500 giga tons of organic carbon, about twice the amount currently in the atmosphere. The thawing of permafrost, driven by rising global temperatures, triggers a feedback loop that accelerates climate change. When the frozen organic material begins to decompose, microorganisms break it down, releasing greenhouse gases. This process adds to the already growing levels of atmospheric CO_2 and methane, further warming the planet.

2. Literature Review:

Permafrost thawing has emerged as a major focus in climate research, given its potential to significantly amplify global warming through greenhouse gas emissions. Permafrost regions, primarily in the Arctic, contain vast stores of organic carbon that have been frozen for millennia. As the Earth warms, permafrost begins to thaw, releasing carbon dioxide (CO2) and methane (CH4), which further contribute to climate change. This literature review explores the key research findings on the mechanisms, impacts, and feedback loops associated with permafrost thaw and its contribution to climate change.

1. The Permafrost Carbon Reservoir

Permafrost covers approximately 24% of the land surface in the Northern Hemisphere, containing around 1,500 gigatons of carbon—nearly double the amount of carbon currently in the atmosphere **(Hugelius et al., 2014)**. **Schuur et al. (2015)** emphasize the significance of permafrost as a carbon sink, with this frozen layer storing vast amounts of organic matter that has accumulated over thousands of years. However, with rising global temperatures, permafrost is beginning to thaw, making it one of the largest untapped sources of carbon.

2. Thaw Mechanisms and Greenhouse Gas Release

The thawing of permafrost leads to the decomposition of previously frozen organic material, which is broken down by microbial activity. The type of decomposition—either aerobic or anaerobic—determines the kind of greenhouse gas released. In aerobic conditions, carbon dioxide is produced, while anaerobic decomposition results in methane emissions. Methane is of particular concern because it is 25 times more potent as a greenhouse gas than CO2 over a 100-year period **(Walter Anthony et al., 2018)**.

Thermokarst landscapes, formed by the uneven thawing of permafrost, further accelerate the release of methane. Studies by **Turetsky et al. (2020)** highlight how these newly formed wetlands and lakes create conditions conducive to anaerobic decomposition, making the Arctic a significant source of methane emissions.

3. Feedback Loops and Climate Amplification

The thawing of permafrost is not just a consequence of global warming but also a driver of further climate change, creating dangerous feedback loops. **Koven et al. (2011)** describe how increased permafrost thaw releases more greenhouse gases, which in turn raises global temperatures, leading to even more thaw. This feedback loop amplifies warming, particularly in the Arctic, where temperatures are rising at twice the rate of the global average **(Lawrence et al., 2015).**

Another important feedback mechanism involves the loss of sea ice, which reduces the Earth's albedo—the reflectivity of the Earth's surface. As sea ice and snow cover diminish, more sunlight is absorbed by the darker ocean and land surfaces, leading to further warming and accelerated permafrost thaw **(Lenton, 2012)**.

4. Global Climate Impacts

The global impacts of permafrost thaw extend beyond the Arctic region. **Schaefer et al. (2014)** estimate that by the end of the 21st century, permafrost could release between 100 to 300 gigatons of carbon into the atmosphere, which would significantly hinder efforts to limit global temperature rise to the 1.5°C or 2°C targets set by the Paris Agreement.

Additionally, the release of methane from permafrost and sub-sea methane hydrates poses a significant risk. Dubbed the "methane time bomb," large-scale releases of this potent greenhouse gas could trigger rapid and irreversible climate tipping points **(Walter Anthony et al., 2018)**. Although the likelihood and timing of such an event remain uncertain, the potential consequences are catastrophic for both the environment and human societies.

5. Socio-Economic and Ecological Consequences

The impacts of permafrost thaw are not confined to the atmosphere. Local communities in Arctic regions are already feeling the effects. Infrastructure, including roads, buildings, and pipelines, is at risk of collapse due to the destabilization of frozen ground **(Jorgenson et al., 2010)**. In addition, ecosystems are being disrupted, with changing hydrology, shifting vegetation, and altered wildlife habitats, as described by **Fisher et al. (2016)**.

On a global scale, the additional carbon released from permafrost thaw would make climate mitigation efforts more difficult. As **McGuire et al. (2018)** note, the global carbon budget—already constrained by human activities—would need to account for emissions from permafrost, requiring more aggressive emissions reductions elsewhere to meet international climate goals.

6. Mitigation and Adaptation Strategies

Given the significant threat posed by permafrost thaw, scientists have called for both mitigation and adaptation strategies. Reducing global greenhouse gas emissions remains the most critical step in slowing the rate of permafrost thaw. **Hugelius et al. (2014)** argue that achieving carbon neutrality by mid-century is necessary to minimize the extent of thaw and its associated impacts.

Adaptation strategies for Arctic communities focus on redesigning infrastructure to withstand ground collapse and preparing for the relocation of vulnerable populations. Meanwhile, international collaboration is needed to improve the monitoring of permafrost regions. Satellite data, combined with ground-based observations, is essential for tracking the rate of thaw and updating climate models accordingly **(Grosse et al., 2011).**

7. Emerging Research and Uncertainties

While significant progress has been made in understanding the impacts of permafrost thaw, there are still uncertainties that need to be addressed. For instance, the exact amount of carbon that will be released from permafrost thaw is still uncertain due to the variability in thaw rates and decomposition processes **(Turetsky et al., 2020)**. Similarly, the timing and magnitude of potential methane releases from sub-sea permafrost and methane hydrates remain areas of active research **(Biskaborn et al., 2019).**

Critical Evaluation

The research has critically evaluated the current state of knowledge on the impact of permafrost thaw:

- **Gaps in Research**: The paper has identified gaps in existing research, such as the underrepresentation of methane release estimates from permafrost regions and uncertainties in timing and scale.
- **Uncertainties and Limitations**: The paper has addressed uncertainties in how much carbon will be released and the timeline for potential tipping points.

3. Research Methodology

1. Research Design

The study will be qualitative and exploratory, focusing on gathering, analyzing, and synthesizing existing research on permafrost thaw and its climate impact. As a conceptual paper, this research aims to critically evaluate current literature and explore theoretical frameworks that explain the processes and consequences of permafrost thaw.

1.1. **Scope of Research**

The research has investigated the following:

- The mechanisms of permafrost thaw and greenhouse gas emissions.
- The feedback loops created by thawing permafrost and their effect on climate change.
- The potential global implications of thawing permafrost, including socio-economic impacts.
- The role of permafrost thaw in climate models and projections.
- The mitigation and adaptation strategies proposed to address this issue.

2. Literature Review

The backbone of a conceptual paper is the review of existing literature. This methodology includes a structured, systematic review of peer-reviewed journal articles, books, reports, and other credible sources. The literature review will be divided into several key areas:

2.1. **Search Strategy**

A systematic search has been conducted using academic databases such as:

- **Google Scholar**
- **Web of Science**
- **Scopus**
- **JSTOR**

2.2. **Inclusion and Exclusion Criteria**

Inclusion criteria:

- Studies published within the last 20 years (to ensure relevance to current climate data).
- Peer-reviewed articles, government reports, and international assessments (e.g., IPCC reports).
- Articles with a focus on climate change, permafrost, and carbon feedback mechanisms.

Exclusion criteria:

- Non-peer-reviewed content unless from recognized institutions (e.g., the UN, IPCC).
- Studies not directly linked to permafrost and climate change.

2.3. **Analysis of Literature**

The literature review will be thematic, focusing on:

- **Mechanisms of Permafrost Thaw**: Reviewing research on the causes and dynamics of permafrost thaw, including temperature increases and local environmental changes.
- **Greenhouse Gas Emissions**: Summarizing research on CO2 and CH4 emissions from thawed permafrost and their contributions to global warming.

- **Climate Feedback Loops**: Analyzing how permafrost thaw influences broader climate systems, including albedo changes and atmospheric warming.
- **Socio-Economic and Ecological Consequences**: Reviewing the localized and global effects of permafrost thaw, including infrastructure damage, habitat shifts, and carbon budgets.
- **Mitigation and Adaptation Strategies**: Reviewing the proposed strategies for managing permafrost thaw and its associated risks, including international policies, carbon capture technologies, and adaptation measures for Arctic communities.

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4. Conceptual Analysis:

The core of the paper has involved conceptual analysis, wherein the impacts of permafrost thaw on climate has been examined through the lens of the gathered literature. The analysis has followed a logical progression:

1. **Define Key Concepts**: Terms such as *permafrost*, *carbon feedback*, *methane emissions*, and *climate tipping points* has been defined and contextualized.
2. **Identify Relationships**: The relationships between permafrost thaw and climate systems, greenhouse gas emissions, and feedback loops has been explored.
3. **Examine the Broader Implications**: The broader implications of permafrost thaw for global climate change has been synthesized. This includes analyzing how emissions from permafrost are integrated into global climate models and what uncertainties remain.
4. **Theoretical Integration**: The conceptual framework has been linked to existing climate theories. For example, how permafrost thaw can act as a climate system tipping point, leading to large-scale environmental shifts.

The Role of Permafrost in Climate Regulation

Historically, permafrost has acted as a carbon sink, locking away vast amounts of carbon in its frozen layers. This stable state kept carbon emissions from entering the atmosphere and contributing to global warming. However, with global temperatures rising, the balance is shifting. The Arctic is warming at twice the global average rate, leading to the rapid thawing of permafrost. This release of stored carbon into the atmosphere undermines efforts to curb greenhouse gas emissions, making it harder to meet climate goals set by international agreements like the Paris Agreement.

Mechanism of Greenhouse Gas Release

The process of permafrost thawing is complex and varies depending on the local environment. When the ice within permafrost melts, it leads to the formation of thermokarst landscapes, characterized by uneven ground, landslides, and the creation of lakes and wetlands. These areas provide ideal conditions for anaerobic decomposition, a process that releases methane, which is about 25 times more potent as a greenhouse gas than CO2 over a 100-year period. In areas where aerobic decomposition occurs, CO2 is the primary gas released. Both gases contribute to the greenhouse effect, trapping heat and further exacerbating global warming.

Feedback Loops and Climate Amplification

One of the most concerning aspects of permafrost thaw is its potential to create feedback loops that accelerate climate change. As permafrost thaws and greenhouse gases are released, global temperatures rise further, leading to even more permafrost thaw. This creates a self-reinforcing cycle that is difficult to break. Additionally, the loss of Arctic sea ice, another consequence of warming, reduces the Earth's albedo (the ability to reflect sunlight), causing more heat to be absorbed and contributing to further warming. This amplification of climate change due to permafrost thaw is a critical issue for climate scientists.

Potential Global Impacts

The thawing of permafrost has far-reaching implications for both local and global climates. Locally, the collapse of permafrost can cause infrastructure damage, including the destruction of buildings, roads, and pipelines in Arctic communities. Globally, the release of greenhouse gases from permafrost thaw could make it much more difficult to limit global temperature rise to the 1.5°C or 2°C targets set by the Paris Agreement. Some estimates suggest that by the end of the century, permafrost thaw could release between 100 to 300 gigatons of carbon, adding to the challenge of mitigating climate change.

The Methane Time Bomb

A particularly alarming consequence of permafrost thaw is the potential for a "methane time bomb." Large amounts of methane are stored not only in permafrost but also in sub-sea permafrost and methane hydrates under the ocean floor. If warming triggers the release of these methane stores, the impact on climate could be catastrophic. The sudden release of methane from thawing permafrost could lead to a rapid spike in global temperatures, overwhelming natural and human-made systems' ability to adapt. This scenario, although uncertain in its likelihood, remains one of the most feared potential outcomes of climate change.

Mitigation and Adaptation Strategies

Addressing the threat posed by permafrost thaw requires both mitigation and adaptation strategies. On the mitigation side, reducing global greenhouse gas emissions is essential to slow the pace of warming and reduce the amount of permafrost that thaws. This can be achieved through the transition to renewable energy, improvements in energy efficiency, and the protection of carbon sinks like forests and wetlands. On the adaptation side, Arctic communities will need to adapt to the physical changes brought about by permafrost thaw, including the redesign of infrastructure to withstand ground collapse and the relocation of vulnerable populations.

Research and Monitoring Efforts

Given the potential for permafrost thaw to drastically alter the global climate system, there is an urgent need for more research and monitoring. Scientists are using a combination of satellite data, ground-based measurements, and climate models to better understand the rate of permafrost thaw and its potential impacts. International collaborations, such as the Permafrost Carbon Network, are essential for sharing data and improving predictions. The more accurately we can forecast permafrost thaw, the better we can plan for its impacts and implement strategies to mitigate the risks.

5. Future Research Scope:

The relationships between permafrost thaw and climate systems, greenhouse gas emissions, and feedback loops will be explored in depth. The interplay between increasing atmospheric temperatures and accelerated thaw will be mapped. A mathematical model will be developed to predict accurately the impact of climate change on thaw of permafrost and temperature also.

6. Conclusion

The thawing of permafrost is one of the most significant and least understood feedbacks in the climate system. As global temperatures continue to rise, the release of greenhouse gases from thawing permafrost could amplify climate change in ways that are difficult to predict and manage. While efforts to reduce greenhouse gas emissions are critical, it is also essential to monitor and prepare for the potential impacts of permafrost thaw. International cooperation, increased research funding, and proactive adaptation strategies will be key to addressing this emerging threat to the global climate.

In conclusion, the thawing of permafrost presents a serious risk to both the environment and human societies. The release of large quantities of carbon dioxide and methane will likely accelerate climate change, making it more difficult to meet international climate targets. Understanding and mitigating this risk is essential to protecting the planet and ensuring a sustainable future.

Here is a list of 20 references on the "Impact on climate due to thaw of permafrost" that includes academic papers, reports, and articles from credible sources:

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