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Influence Of Rising Temperature On Glacier Ice

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Abstract

Climate change has a significant impact on health's social and environmental determinants. It's frequently linked to our environment and man-made stressors, both of which have already had an impact on public health in a variety of ways. Climate change has a direct impact on our basic needs for clean air, clean water, sufficient food, and safe shelter. Global warming, rising sea levels, extreme weather, natural disasters, and other new health-related threats are all becoming more prevalent in our daily lives. These effects appeared to be unrelated at first, but they are in fact intertwined. Global warming has now overtaken all of the other threats as the most serious issue in almost every country. Icebergs and glaciers may melt as a result of global warming, raising sea levels, and there are theories that more ancient viruses and animal corpses are being discovered. On a long-term scale, the problems and damage that come with environmental issues are harmful to humans. Climate change has a significant impact on health's social and environmental determinants. It's frequently linked to our environment and man-made stressors, both of which have already had an impact on public health in a variety of ways.

Climate change has a direct impact on our basic needs for clean air, clean water, sufficient food, and safe shelter. Global warming, rising sea levels, extreme weather, natural disasters, and other new health-related threats are all becoming more prevalent in our daily lives. These effects appeared to be unrelated at first, but they are in fact intertwined. Global warming has now overtaken all of the other threats as the most serious issue in almost every country. Icebergs and glaciers may melt as a result of global warming, raising sea levels, and there are theories that more ancient viruses and animal corpses are being discovered.

Climate change is causing glaciers to melt, which is a major contributor to sea level rise. Glaciers are also a vital water source for communities and ecosystems. Glaciers are shrinking or disappearing in many parts of the world. They are flowing into the ocean. Melting glaciers and ice sheets are the biggest cause of sea level rise in recent decades and threaten natural and human water supplies in many parts of the world. Support legislation that creates favorable market conditions for the carbon-free energy industry. Glaciers and the environment are severely affected by global warming. The forecast for the year 2022 -2025 is that the winter season will see only 10-15% of winters, which makes it clear that rapid melting of old ice sheets and glaciers is confirming that climate change will lead to many issues.

This study used a scoping review methodology to explore the integrated impacts of climate change on glaciers from the academic literature. The findings showed that some glacial landscapes are experiencing a decline in beauty or attractiveness, while some landscapes are likely to experience continued decline or even disappearance.

Key Words: Shrinkage, Calving, Decade, Law, Integrated Effect

Introduction

Climate change refers to long-term shifts in temperatures and weather patterns. Such shifts can be natural, due to changes in the sun's activity or large volcanic eruptions. But since the 1800s, human activities have been the main driver of climate change, primarily due to the burning of fossil fuels like coal, oil and gas. Burning fossil fuels generates greenhouse gas emissions that act like a blanket wrapped around the Earth, trapping the sun's heat and raising temperatures.

The main greenhouse gases that are causing climate change include carbon dioxide and methane. These come from using gasoline for driving a car or coal for heating a building, for example. Clearing land and cutting down forests can also release carbon dioxide. Agriculture, oil and gas operations are major sources of methane emissions. Energy, industry, transport, buildings, agriculture and land use are among the main sectors causing greenhouse gases.

Climate change can affect our health, ability to grow food, housing, safety and work. Some of us are already more vulnerable to climate impacts, such as people living in small island nations and other developing countries. Conditions like sea-level rise and saltwater intrusion have advanced to the point where whole communities have had to relocate, and protracted droughts are putting people at risk of famine. In the future, the number of people displaced by weather-related events is expected to rise.

Many climate change solutions can deliver economic benefits while improving our lives and protecting the environment. We also have global frameworks and agreements to guide progress, such as the Sustainable

Development Goals, the UN Framework Convention on Climate Change and the Paris Agreement. Three broad categories of action are: cutting emissions, adapting to climate impacts and financing required adjustments.

Switching energy systems from fossil fuels to renewables like solar or wind will reduce the emissions driving climate change. But we have to act now. While a growing number of countries is committing to net zero emissions by 2050, emissions must be cut in half by 2030 to keep warming below 1.5°C. Achieving this means huge declines in the use of coal, oil and gas: production and consumption of all fossil fuels need to be cut by at least 30 per cent by 2030 in order to prevent catastrophic levels of climate change. A glacier is any large mass of perennial ice that originates on land by the recrystallization of snow or other forms of solid precipitation and shows evidence of past or present flow. One international group has recommended that all persisting snow and ice masses larger than 0.1 square kilometer (about 0.04 square mile) be counted as glaciers.

Glaciers are classifiable in three main groups: glaciers that extend in continuous sheets, moving outward in all directions, are called ice sheets if they are the size of Antarctica or Greenland and ice caps if they are smaller; glaciers confined within a path that directs the ice movement are called mountain glaciers; and glaciers that spread out on level ground or on the ocean at the foot of glaciated regions are called piedmont glaciers or ice shelves, respectively. Glaciers in the third group are not independent and are treated here in terms of their sources: ice shelves with ice sheets, piedmont glaciers with mountain glaciers. A complex of mountain glaciers burying much of a mountain range is called an ice field.



Fig1: Effects of climate change

The cause of the fluctuation of the world's glacier cover is still not completely understood. Periodic changes in the heat received from the Sun, caused by fluctuations in the Earth's orbit, are known to correlate with major fluctuations of ice sheet advance and retreat on long time scales. Large ice sheets themselves, however, contain several "instability mechanisms" that may have contributed to the larger changes in world climate. One of these mechanisms is due to the very high albedo, or reflectivity of dry snow to solar radiation. No other material of widespread distribution on the Earth even approaches the albedo of snow. Thus, as an ice sheet expands it causes an ever-larger share of the Sun's radiation to be reflected back into space, less is absorbed on the Earth, and the world's climate becomes cooler. Another instability mechanism is implied by the fact that the thicker and more extensive an ice sheet is, the more snowfall it will receive in the form of orographic precipitation (precipitation resulting from the higher altitude of its surface and attendant lower temperature). A third instability mechanism has been suggested by studies of the West Antarctic Ice Sheet. Portions of an ice sheet called ice streams may periodically move rapidly outward, perhaps because of the buildup of a thick layer of wet, deformable material under the ice. Although the ultimate causes of ice ages are not known with certainty, scientists agree that the world's ice cover and climate are in a state of delicate balance.

Only the largest ice masses directly influence global climate, but all ice sheets and glaciers respond to changes in local climate—particularly changes in air temperature or precipitation. The fluctuations of these glaciers in the past can be inferred by features they have left on the landscape. By studying these features, researchers can infer earlier climatic fluctuations.

Climate change is causing glaciers to melt and retreat worldwide, which contributes to sea level rise.

How is climate change affecting glaciers?

- **Warmer air:** Causes ice to melt faster and flow more quickly to the sea
- **Warmer ocean water:** Melts the edge and base of the ice sheet, and weakens floating ice shelves
- **Changes in precipitation:** Alter the buildup and melt of snowpacks

What are the consequences of melting glaciers?

- **Sea level rise**

Melting glaciers and ice sheets are the biggest cause of sea level rise in recent decades

- **Threat to water supplies**

Glacier loss is a serious threat to natural and human water supplies in many parts of the world

- **Threat to ecosystems**

Melting glaciers can impact river communities and the species that live in them.

Top 10 largest Glacier in the world are as following-

Ranking	Name	Region Name	Area(km)	Year
01	Seller Glacier	Antarctica Mainland	7018	2002
02	Thurston Island Glacier No.1	Antarctica and Subantarctic Islands	5261	1972
03	Alexander Island Glacier No.1	Antarctica and Subantarctic Islands	4766	1997
04	Alexander Island Glacier No.2	Antarctica and Subantarctic Islands	3980	1997
05	Mercator Ice Piedmont	Antarctic Mainland	3499	2002
06	Malaspina Seward Glacier	Alaska	3363	2010
07	Wykeham Glacier South	Arctic Canada North	3176	1999
08	Bering Glacier	Alaska	3025	2010
09	Hubbard Glacier	Alaska	2834	2010
10	South Dome on the Northern Slope of Barnes Ice Cap	Arctic Canada South	2771	2002

Methodology

This research paper is conceptual. It is made on the bases of published research paper. Conceptual research framework constitutes of a researcher's combination of previous research and associated work and explains the occurring phenomenon. It systematically explains the actions needed in the course of the research study based on the knowledge obtained from other ongoing research and other researchers' points of view on the subject matter.

As I had narrowed down a topic, to collect relevant information about it. This is an important step, and much of my research is dependent on this particular step, as conceptual research is mostly based on information obtained from previous research. Here collecting relevant literature and information is the key to successfully completing research.

The material that I preferably use is taken from the scientific journals, research papers published by well-known scientists, and similar material. There is a lot of information available on the internet and in public libraries as well. I had identified the specific variables that are related to my research study that I want to

conduct. These variables give my research a new scope and can also help me identify how these can be related to my research design.

At last, I start building the required framework using the mix of variables from the scientific articles and other relevant materials. The research problem statement in my research becomes the research framework. My attempt to start answering the question becomes the basis of my research study. The study is carried out to reduce the knowledge gap and make available more relevant and correct information.

Discussion

A glacier is an accumulation of ice and snow that slowly flows over land. At higher elevations, more snow typically falls than melts, adding to its mass. Eventually, the surplus of built-up ice begins to flow downhill. At lower elevations, there is usually a higher rate of melt or icebergs break off that removes ice mass.

Alpine glaciers are frozen rivers of ice, slowly flowing under their own weight down mountainsides and into valleys. Glaciers also exist on the fringes of ice sheets. Ice sheets cover entire continents. During the Last Glacial Maximum, roughly 20,000 years ago, the Laurentide Ice Sheet covered much of North America, and its weight created basins that now hold the Great Lakes. Currently, there are only two ice sheets on Earth: the Antarctic and Greenland Ice Sheets.

Exact limits for the terms large, perennial, and flow cannot be set. Except in size, a small snow patch that persists for more than one season is hydrologically indistinguishable from a true glacier. One international group has recommended that all persisting snow and ice masses larger than 0.1 square kilometers (about 0.04 square mile) be counted as glaciers. The cause of the fluctuation of the world's glacier cover is still not completely understood. Periodic changes in the heat received from the Sun, caused by fluctuations in the Earth's orbit, are known to correlate with major fluctuations of ice sheet advance and retreat on long time scales. Large ice sheets themselves, however, contain several "instability mechanisms" that may have contributed to the larger changes in world climate. One of these mechanisms is due to the very high albedo, or reflectivity of dry snow to solar radiation. No other material of widespread distribution on the Earth even approaches the albedo of snow.

Types of Glaciers

There are two main types of glaciers: continental glaciers and alpine glaciers. Latitude, topography, and global and regional climate patterns are important controls on the distribution and size of these glaciers.



Alpine glacier



Continental glacier

Fig3: Types of glaciers**Alpine Glaciers**

Alpine glaciers (aka valley glaciers) originate high up in the mountains, mostly in temperate and polar regions, but also in tropical regions in high mountains (e.g. in the Andes Mountains of South America).

The flow of alpine glaciers is driven by gravity, and primarily controlled by the slope of the ice surface. Alpine glaciers grow due to accumulation of snow over time. In the zone of accumulation, the rate of snowfall is greater than the rate of melting. In other words, not all of the snow that falls each winter melts during the following summer, and the ice surface in the zone of accumulation does not lose its annual accumulation of snow cover over the course of the year. In the zone of ablation, the rate of melting exceeds accumulation. The equilibrium line marks the boundary between the zones of accumulation (above) and ablation (below).

Firm is a form of ice that forms when snowflakes lose their delicate shapes and become granules due to compression. With more compression, the granules are squeezed together, and air is forced out. Eventually the granules are “welded” together to create glacial ice. Downward percolation and freezing of water from melting contributes to the process of ice formation. Alpine glaciers move because they are heavy, and the force of gravity acts on the ice in the glacier to pull it down the slope of the mountains where they form. The movement of the glacier generates stress in the ice, which is proportional to the slope of the glaciers surface features of the underlying rock surface, and to the depth within the glacier.

Continental glaciers -

It covers vast areas of land. Today, continental glaciers are only present in extreme polar regions: Antarctica and Greenland. Historically, continental glaciers also covered large regions of Canada Europe, and Asia, and

they are responsible for many distinctive topographic features in these regions. Continental glaciers can form and grow when climate conditions in a region cool over extended periods of time. Snow can build up over time in regions that do not warm up seasonally, and if the snow accumulates in vast amounts, it can compact under its own weight and form ice. Earth's two current continental glaciers, the Antarctic and Greenland Ice Sheets, comprise about 99% of Earth's glacial ice, and approximately 68% of Earth's fresh water. The Antarctic Ice Sheet is vastly larger than the Greenland Ice Sheet and contains about 17 times as much ice. If the entire Antarctic Ice Sheet melted, sea level would rise by about 80 m and most of Earth's major coastal cities would be submerged.

Continental glaciers generally cover areas that are flat, but the force of gravity still acts on them and causes them to flow. Continental glacier ice flows from the region where it is thickest toward the edges where it is thinner. In the central thickest parts, the ice flows almost vertically down toward the base, while at the edges of the glacier, it flows horizontally out toward the margins. In continental glaciers like the Antarctic and Greenland Ice Sheets, the thickest parts are the areas where the rate of snowfall, and therefore of ice accumulation, are greatest. In Antarctica, the ice sheet flows out over the ocean, forming ice shelves. Ice shelves can slow the flow of continental glaciers outward. Conversely, if ice shelves break down continental glacier flow can speed up.

Distribution of Glaciers

A most interesting aspect of recent geological time (some 30 million years ago to the present) has been the recurrent expansion and contraction of the world's ice cover. These glacial fluctuations influenced geological, climatological, and biological environments and affected the evolution and development of early humans. Almost all of Canada, the northern third of the United States, much of Europe, all of Scandinavia, and large parts of northern Siberia were engulfed by ice during the major glacial stages. At times during the Pleistocene Epoch (from 2.6 million to 11,700 years ago), glacial ice covered 30 percent of the world's land area; at other times the ice cover may have shrunk to less than its present extent. It may not be improper, then, to state that the world is still in an ice age. Because the term glacial generally implies ice-age events or Pleistocene time, in this discussion "glacier" is used as an adjective whenever reference is to ice of the present day. Glacier ice today stores about three-fourths of all the fresh water in the world. Glacier ice covers about 11 percent of the world's land area and would cause a world sea-level rise of about 90 meters (300 feet) if all existing ice melted. Glaciers occur in all parts of the world and at almost all latitudes. In Ecuador, Kenya, Uganda, and Irian Jaya (New Guinea), glaciers even occur at or near the Equator, albeit at high altitudes.

The total area of the Earth's surface covered by glaciers is 14.9 million km²

- Antarctic ice sheet: 12.5 million km²
- Greenland ice sheet: 1.7 million km²
- All the rest: 700,000 km² (many ice caps, mostly less than about 10,000 km²; many thousands of small glaciers, mostly valley glaciers)

Aside from the Greenland ice sheet, most of the larger glaciers in the Northern Hemisphere are mostly on Iceland and the Arctic Islands of Canada, because of the distribution of land and sea.

It's a lot more difficult to get the *volumes* of ice in glaciers than to get the *areas* covered by glaciers. Things have gotten better in this respect, though, because of use of echo sounding, similar to oceanographic depth sounding. But one still has to go out there to the glacier to do it.

- *Antarctica*: 21.5 million km³ (sea-level equivalent about 60 m) *Greenland*: 2.4 million km³ (sea-level equivalent about 5 m)
- *All other*: 180,000 km³ (largest ice cap: Vatnajökull, Iceland, 3100 km³, and fairly accessible).

Formation and Characteristic of Glacier ice

Transformation of Snow to ice-

Glacier ice is an aggregate of irregularly shaped, interlocking single crystals that range in size from a few millimeters to several tens of cm. Many processes are involved in the transformation of snowpacks to glacier ice, and they proceed at a rate that depends on wetness and temperature. Snow crystals in the atmosphere are tiny hexagonal plates, needles, stars, or other intricate shapes. In a deposited snowpack these intricate shapes are usually unstable, and molecules tend to evaporate off the sharp (high curvature) points of crystals and be condensed into hollows in the ice grains. The process of evaporation and condensation may continue: touching grains may develop necks of ice that connect them (sintering) and that grow at the expense of other parts of the ice grain, or individual small grains may rotate to fit more tightly together.

These processes proceed more rapidly at temperatures near the melting point and more slowly at colder temperatures, but they all result in a net densification of the snowpack.

Energy balance-

The mass balance and the temperature variations of a glacier are determined in part by the heat energy received from or lost to the external environment—an exchange that takes place almost entirely at the upper surface. Heat is received from short-wavelength solar radiation, long-wavelength radiation from clouds or water vapors, turbulent transfer from warm air, conduction upward from warmer lower layers, and the heat

released by the condensation of dew or hoarfrost or by the freezing of liquid water. It is incorrect to think of snow or ice melt as directly related to air temperature; it is the wind structure, the turbulent eddies near the surface, that determines most of the heat transfer from the atmosphere.

Glacier flow-

In the accumulation area the mass balance is positive year after year. Here the glacier would become thicker and thicker were it not for the compensating flow of ice away from the area. This flow supplies mass to the ablation zone, compensating for the continual loss of ice there. Glacier flow is a simple consequence of the weight and creep properties of ice. Subjected to a shear stress over time, ice will undergo creep, or plastic deformation. The rate of plastic deformation under constant shear stress is initially high but tapers off to a steady value. If this steady value, the shear-strain rate, is plotted against the stress for many different values of applied stress, a curved graph will result. The curve illustrates what is known as the flow law or constitutive law of ice: the rate of shear strain is approximately proportional to the cube of the shear stress. Often called the Glen flow law by glaciologists, this constitutive law is the basis for all analyses of the flow of ice sheets and glaciers.

Response to climatic change-

The relationship of glaciers and ice sheets to fluctuations in climate is sequential. The general climatic or meteorological environment determines the local mass and heat-exchange processes at the glacier surface, and these in turn determine the net mass balance of the glacier. The dynamic response causes an advance or retreat of the terminus, which may produce lasting evidence of the change in the glacier margin. If the local climate changes toward increased winter snowfall rates, the net mass balance becomes more positive, which is equivalent to an increase in ice thickness.

The result is known as a glacier fluctuation—in this case an advance—and it incorporates the sum of all the changes that have taken place up-glacier during the time it took them to propagate to the terminus.

The process, however, cannot be traced backward with assurance. A glacier advance can, perhaps, be related to a period of positive mass balances, but to ascertain the meteorological cause is difficult because either increased snowfall or decreased melting can produce a positive mass balance.

The dynamic response of glaciers to changes in mass balance can be calculated several ways. Although the complete, three-dimensional equations for glacier flow are difficult to solve for changes in time, the effect of a small change or perturbation in climate can be analyzed readily.

Glacier and Sea level-

Sea level is currently rising at about 1.8 millimeters (0.07 inch) per year. Between 0.3 and 0.7 millimeters (0.01 to 0.03 inch) per year has been attributed to thermal expansion of ocean water, and most of the

remainder is thought to be caused by the melting of glaciers and ice sheets on land. There is concern that the rate in sea-level rise may increase markedly in the future owing to global warming. Unfortunately, the state of the mass balance of the ice on the Earth is poorly known, so the exact contributions of the different ice masses to rising sea level is difficult to analyze. With global warming, the melting of mountain glaciers will certainly increase, although this process is limited: the total volume of small glaciers is equivalent to only about 0.6 meter (2 feet) of sea-level rise. Melting of the marginal areas of the Greenland Ice Sheet will likely occur under global warming conditions, and this will be accompanied by the drawing down of the inland ice and increased calving of icebergs; yet these effects may be counterbalanced to some extent by increased snow precipitation on the inland ice.

Mass Balance-

Glaciers are nourished mainly by snowfall, and they primarily waste away by melting and runoff or by the breaking off of icebergs (calving). In order for a glacier to remain at a constant size, there must be a balance between income (accumulation) and outgo (ablation). If this mass balance is positive (more gain than loss), the glacier will grow; if it is negative, the glacier will shrink.

Because the processes of accumulation, ablation, and the transformation of snow to ice proceed so differently, depending on temperature and the presence or absence of liquid water, it is customary to classify glaciers in terms of their thermal condition. A polar glacier is defined as one that is below the freezing temperature throughout its mass for the entire year; a subpolar (or polythermal) glacier contains ice below the freezing temperature, except for surface melting in the summer and a basal layer of temperate ice; and a temperate glacier is at the melting temperature throughout its mass, but surface freezing occurs in winter. The value of the surface mass balance at any point on a glacier can be measured by means of stakes, snow pits, or cores. These values at points can then be averaged over the whole glacier for a whole year. The result is the net or annual mass balance. A positive value indicates growth, a negative value a decline.

Amount of Glacial ice on Earth

- ❖ Presently, 10 percent of land area on Earth is covered with glacial ice, including glaciers, ice caps, and the ice sheets of Greenland and Antarctica. Glacierized areas cover over 15 million square kilometers (5.8 million square miles).
- ❖ During the maximum point of the last ice age, which ended about 12,000 years ago, glaciers covered about 32 percent of the total land area.
- ❖ The Antarctic continent has been at least partially covered by an ice sheet for the past 40 million years.

- ❖ Starting around the early fourteenth century, and lasting to the mid-nineteenth century, the world experienced a “Little Ice Age,” when temperatures were consistently cool enough for glaciers to advance in many areas of the world.
- ❖ In the United States, glaciers currently cover over 90,000 square kilometers (35,000 square miles).
- ❖ Most of those glaciers are located in Alaska, which holds 87,000 square kilometers (34,000 square miles) of glacial ice.
- ❖ Greenland Ice Sheet has a sea level equivalent ice volume of 7.42 m, and covers 1.2% of the global land surface.

Effects of Climate change on Glacier

Climate change, driven mainly by human activities such as burning fossil fuels and deforestation, has a profound impact on glaciers worldwide. These impacts include glacial retreat, rising sea levels, and disruptions to ecosystems and human societies. Below is a detailed analysis of how climate change is affecting glaciers.

1. Glacial Retreat and Ice Loss

Glacial retreat refers to the shrinking of glaciers due to increased melting and reduced accumulation of snow and ice.

Causes: Rising Temperatures: Higher global temperatures accelerate the melting of glacial ice.

Reduced Snowfall: Warmer temperatures can lead to increased rainfall instead of snowfall, reducing ice buildup.

Black Carbon Deposition: Soot from burning fossil fuels and wildfires settles on glaciers, reducing their reflectivity (albedo) and causing faster melting.

Impacts: Most glaciers worldwide are losing mass, with some disappearing completely. Major glacier systems, such as those in the Himalayas, Alps, Andes, and Rockies, are retreating rapidly. Ice shelves in Antarctica are breaking apart, accelerating glacial ice loss.

2. Rising Sea Levels

Melting glaciers contribute to the rising of global sea levels, which poses a threat to coastal communities and ecosystems.

Causes: Melting of Ice Sheets: The Greenland and Antarctic ice sheets are melting at an unprecedented rate.

Thermal Expansion: As ocean temperatures rise, water expands, contributing further to sea level rise.

Impacts: Increased coastal flooding and erosion. Displacement of millions of people living in low-lying coastal areas. Loss of freshwater sources as seawater intrudes into groundwater supplies.

3. Disruption of Freshwater Supplies

Many rivers and lakes depend on glaciers for their water supply, particularly in regions with dry seasons.

Causes: Reduced glacier size results in decreased runoff over time.

Faster melting causes an initial surge in water supply, followed by long-term shortages.

Impacts: Threatens water security in regions like South Asia, where rivers such as the Ganges, Indus, and Brahmaputra depend on glacial meltwater. Disrupts hydroelectric power generation, which relies on consistent water flow from glaciers. Affects agriculture, as irrigation systems depend on glacial-fed rivers.

4. Ecosystem Disruptions

Glacier-fed ecosystems support unique wildlife and plant species, and their decline disrupts food chains and habitats.

Causes: Temperature shifts affect species adapted to cold, glacial environments.

Changing water availability alters aquatic ecosystems.

Impacts: Cold-water fish species, such as trout and salmon, struggle to survive in warming waters. Elevation plant and animal species lose habitats as glaciers shrink. Glacial-fed lakes change in chemical composition, affecting biodiversity.

5. Increased Risk of Natural Disasters

Glacier melt increases the likelihood of natural disasters such as floods, landslides, and avalanches.

Causes: Formation of unstable glacial lakes, which can burst and cause floods (Glacial Lake Outburst Floods - GLOFs).

Loss of ice that stabilizes mountain slopes, leading to landslides. Increased flow of meltwater, causing river flooding.

Impacts: GLOFs have caused severe destruction in regions like Nepal, India, and Pakistan. Avalanches have become more common in mountainous areas. Infrastructure damage, including roads, bridges, and settlements, leads to economic losses.

6. Impacts on Human Societies and Culture

Communities that depend on glaciers for tourism, cultural identity, and livelihoods face major challenges.

Causes: Melting glaciers reduce tourism revenue in areas known for ice trekking, skiing, and glacier sightseeing. Indigenous communities that rely on glaciers for spiritual and cultural reasons are affected.

Impacts: Popular tourist destinations (such as the Alps, Patagonia, and Glacier National Park in the U.S.) are losing glaciers. Cultural traditions linked to glaciers are disappearing. Economic struggles for communities relying on glacier-related tourism.

7. Global Climate Feedback Loops

The melting of glaciers contributes to a cycle that further accelerates climate change.

Causes: As glaciers melt, they reflect less sunlight (lower albedo), causing further warming. Melting permafrost releases methane, a powerful greenhouse gas.

Impacts: Faster warming of the Arctic and Antarctic regions. Increased global temperatures, worsening the effects of climate change.

Conclusion

Glaciers are an important part of a linked global system involving global energy sources and sinks, the hydrological cycle, the atmospheric and oceanic circulation, climate, crustal rheology and sea level. The system is internally complex and poorly understood, rich in feedback loops and non-linearities. Glaciers both drive and are driven by elements of this system, and can by their characteristics and behavior give us insight

into the dynamics, history and possible future of the physical environment. Successful modelling of the global environment requires an understanding of the role of glaciers in the environmental system, of glacier dynamics and of the glacial response to environmental inputs. The remainder of this book explores the properties and characteristics of glaciers as far as they are known.

Glaciers occupy an important position in the world tourism system, having shown great economic benefits for many mountainous countries, even in the Polar Regions. However, the rapid retreat of glaciers as a result of climate warming has or is about to limit the sustainable development of tourism in mountainous countries. In the 21st century, climate change is undoubtedly the toughest challenge for glacier tourism. Glacial resources are the most important for tourism and the livelihoods of indigenous populations in mountainous countries or regions. These areas are experiencing the severe challenge of shrinking glaciers. Under current climate conditions, glacial melting and its integrated impact on future sustainability is unavoidable, and is the primary consideration in planning for glacier tourism. Tourism stakeholders should not only be aware of the opportunities and problems of glacier tourism, but also of the risks associated with climate change in the future.

Glaciers come in a huge range of shapes and sizes. Different glaciers, and even different parts of the same glacier, can have a variety of different thermal, hydrological and dynamic characteristics. Glaciers occur in locations ranging from the poles to the equator, and most parts of the world have experienced the direct effects of glaciation at some time in the past. Glaciers currently occupy less of the planet than they have done in geological history, but nevertheless exert a profound influence on the global environment. Our developing understanding of glaciers will play an important role in our understanding of the global environmental system.

The characteristics and behavior of glaciers are determined to a large extent by the properties of the material from which they are made, so an understanding of the properties of ice is the necessary basis of a sound understanding of glaciers. However, glaciers comprise more than ice alone. Huge, long-lasting masses of polythermal, polycrystalline glacier ice, incorporating particulate debris, gas, solutes, and water under self-generated thermal and pressure gradients are complex physical and chemical systems. The physical, chemical and thermal properties of glaciers do exert a control on glacier behavior, but are also controlled by it. Glacier dynamics, thermal regime, hydrology, chemistry and rheology are all complexly interrelated. The interrelationship between the physical, chemical and dynamic properties of ice and of glaciers remains a major area in which our understanding and modelling of glacier behavior is imperfect.

Glaciers can be characterized in terms of their morphology and their structure. Gross glacier morphology is largely controlled by glacier dynamics and, except in the case of large ice sheets, topography. Glacier structure is a function of the way in which glaciers in general are formed and behave

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