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MELTING MOUNTAINS: THE FATE OF THE HIMALAYAS IN A WARMING WORLD

Annotation: in our increasingly globalized world, the most comprehensive scientific investigation to date indicates that the effects of climate change are causing the world's glaciers to melt more quickly than ever before.

Climate change is the primary factor contributing to the retreat of glaciers in mountainous regions, evidenced by rising global temperatures, changing precipitation patterns, and an increase in the frequency of extreme weather events. According to the Intergovernmental Panel on Climate Change (IPCC), the average surface temperature of the Earth has grown by roughly 1.1°C since the pre-industrial era.

In this article, we conduct a comprehensive investigation into the principal driver of contributing to the retreat of glaciers in mountainous regions, with a particular focus on the Himalayas. In addition, the adverse consequences associated with the disappearance of these vital ice masses will be analyzed thoroughly. Our aim is to provide a comprehensive understanding of the ramifications of glacier retreat, not only for the environment, but also for the communities that rely on glacier resources.

Keywords: retreat of glaciers, global temperature, extreme weather events, the Himalayas, detrimental consequences, vital ice masses.

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Annotatsiya: bugungi tobora globallashib borayotgan dunyoda olib borilgan keng qamrovli ilmiy tadqiqotlar shuni ko'rsatadiki, iqlim o'zgarishi ta'siri natijasida dunyo muzliklari misli ko'rilmagan tezlikda erimoqda. Iqlim o'zgarishi tog'li hududlardagi muzliklarning qisqarishiga olib kelayotgan asosiy omil bo'lib, bu global haroratning oshishi, yog'ingarchilik rejimlarining o'zgarishi hamda ekstremal ob-havo hodisalari chastotasining ortishi bilan tasdiqlanadi. Iqlim o'zgarishi bo'yicha Hukumatlararo ekspertlar guruhi (IPCC) ma'lumotlariga ko'ra, yer yuzasining o'rtacha harorati sanoatlashuvdan oldingi davrdan buyon taxminan 1,1 °C ga oshgan.

Ushbu maqolada tog'li hududlardagi muzliklarning qisqarishiga olib kelayotgan asosiy omillar har tomonlama o'rganilib, ayniqsa Himalay mintaqasiga alohida e'tibor qaratiladi. Shuningdek, ushbu muhim muz massalarining yo'qolishi bilan bog'liq salbiy oqibatlar batafsil tahlil qilinadi. Tadqiqotning asosiy maqsadi muzliklar qisqarishining oqibatlarini nafaqat atrof-muhit, balki muzlik resurslariga tayanadigan aholi uchun ham keng qamrovda yoritib berishdan iborat.

Kalit so'zlar: muzliklarning qisqarishi, global harorat, ekstremal ob-havo hodisalari, Himolay tog'lari, salbiy oqibatlar, muhim muz massalari.

Аннотация: в условиях возрастающей глобализации наиболее комплексные научные исследования на сегодняшний день свидетельствуют о том, что воздействие изменения климата приводит к ускоренному таянию ледников по всему миру. Изменение климата является основным фактором, способствующим отступлению ледников в горных регионах, что подтверждается повышением глобальной температуры, изменением режимов осадков и увеличением частоты экстремальных погодных явлений. Согласно данным Межправительственной группы экспертов по изменению климата (IPCC), средняя температура поверхности Земли с доиндустриального периода возросла примерно на 1,1°C.

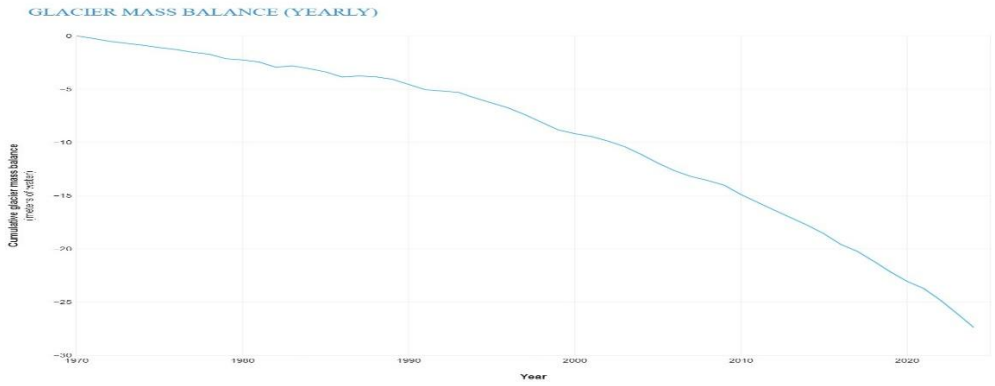
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В данной статье проводится всесторонний анализ основных факторов, способствующих сокращению ледников в горных районах, с особым акцентом на Гималайский регион. Кроме того, подробно рассматриваются негативные последствия, связанные с исчезновением этих жизненно важных ледяных массивов. Целью исследования является формирование комплексного понимания последствий отступления ледников не только для окружающей среды, но и для сообществ, зависящих от ледниковых ресурсов.

Ключевые слова: отступление ледников, глобальная температура, экстремальные погодные явления, Гималаи, негативные последствия, жизненно важные ледяные массивы.

Introduction: although mountain glaciers comprise merely approximately 3% of the globe glacial area [1] the necessity for accurate areal and volumetric assessments of these glaciers is widely acknowledged. They represent crucial freshwater reserves and play a critical role in meeting the water needs of a considerable population in South Asia and neighboring countries. Therefore, understanding the dynamics of these glaciers, particularly in the face of accelerating melt, is paramount. Unfortunately, the glaciers across the globe are undergoing a significant and concerning rate of melting. Consequently, this phenomenon can be attributed primarily to human activities. Since the Industrial Revolution, the release of carbon dioxide and other greenhouse gases has led to a substantial increase in global temperatures, with polar regions experiencing even more significant warming. Glaciers in the climate reference network of the World Glacier Monitoring Service have lost ice in comparison to 1970. The annual balance between the accumulation of snow on a glacier and the ablation (melting, sublimation, or calving of ice) is known as glacier mass balance. More than 26 meters of water equivalent have been lost by these glaciers through 2023,

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The Himalayas are often referred to as the world's "third pole ", due to their vast expanse of thousands of glaciers. The Himalayan glaciers, situated at a considerable average elevation exceeding 4000 meters and spanning more than 100,000 square kilometers, function as vital perennial sources of water for Asia's major river systems, including the Indus, Ganges, Brahmaputra, Mekong, Yangtze, Yellow River, and Salween, which span countries such as India, Pakistan, Bangladesh, China, Nepal, Tajikistan and Afghanistan [2]. Collectively, these nations are home to approximately 42% of the global population. The significance of these glaciers extends far beyond simply water supply: they significantly influence the environmental, social, and economic spheres of the region [3].

According to the fact that in the HKHK region (Himalaya, Karakoram, and Hindu Kush), the Indus and Brahmaputra basins stand out as the most significant in terms of the estimated number of glaciers, the extent of glaciated areas and the volume of ice reserves. Collectively, these three basins account for approximately 70% of the total number of glaciers, 74 percent of the overall glaciated area, and nearly 80% of the estimated ice reserves in the HKHK region. This underscores the crucial importance of these basins in understanding the dynamics of glacial resources in the region.

Table: glaciers within the Major Basins of the Himalaya, Karakoram, and Hindu Kush Region

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Basin	Number of glaciers	Glaciated area (square kilometers)	Estimated ice reserves (cubic kilometers)	Average area per glacier (square kilometers)
Amu Darya	3,277	2,566	162.6	0.8
Indus	18,495	21,193	2,696.1	1.2
Ganges	7,963	9,012	793.5	1.1
Brahmaputra	11,497	14,020	1,302.6	1.2
Irrawaddy	133	35	1.3	0.3
Salween	2,113	1,352	87.7	0.6
Mekong	482	235	10.7	0.5
Yangtze	1,661	1,660	121.4	1.0
Yellow	189	137	9.2	0.7
Tarim	1,091	2,310	378.6	2.1
Qinghai-Tibetan Interior	7,351	7,535	563.1	1.0
Total	54,252	60,054	6,126.9	1.1

Source: ICMOD 2011.

Note: Totals may not sum due to rounding.

However, these vital glaciers are currently facing a significant threat due to rapid melting, a phenomenon that poses a severe risk to the health and livelihood of nearly 1.9 billion individuals dependent on these river systems [4]. As these glaciers continue to melt, they will invariably contribute to the rising sea levels, raising concerns, and implications for ecosystems and human populations alike.

Moreover, the retreat of glaciers represents a major concern, presenting a multitude of challenges extending far beyond the immediate impacts on ice mass. The detrimental effects extend across numerous domains, including water resources, ecosystems, agriculture, hydropower, livelihoods, community structures, and various related activities [5]. Particularly alarming is the melting of the Himalayan glaciers, which poses a serious threat to the planetary health of the entire region. Planetary health is primarily concerned with illuminating the interconnections between human-induced disruptions to the Earth's natural systems and the subsequent ramifications for public health [6]. Furthermore, it encompasses the pursuit of the highest attainable standard of health, well-being, and equity globally, necessitating careful attention to the human systems – political,

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economic, and social – that shape the trajectory of humanity alongside the Earth's natural systems that define the safe environmental boundaries within which humanity can flourish. The fate of humanity and natural systems within the Himalayan region is closely linked to the state of the Himalayan glaciers [7]. As a gradual phenomenon, the impacts of glacier melting on the planetary health of the Himalayan River basins are complex, interconnected, and multi-dimensional, affecting both present and future generations across various spatial scales. This emphasizes the pressing need for comprehensive and cohesive strategies to tackle these interconnected challenges, ensuring a sustainable future for both the people and the environment of this vital region.

Observed Trends in Mean Surface Temperature and Precipitation

A significant increase in surface temperatures has been observed across the Hindu Kush Himalaya (HKH) region over sixty years [8]. This warming trend has been recorded consistently across both the western and the eastern Himalayan river's basins. Notably, the long-term trend indicates that minimum temperatures are rising at a marginally higher rate than maximum temperature. Furthermore, the observations indicate that the recent warming rates across the Hindu Kush Himalaya (HKH) region exhibit significant variability, particularly in relation to altitude. This phenomenon is commonly described as the elevation dependency of climate warming (EDW) [9]. The intricate relationship between altitude and warming underscores the complexity of climate dynamics, emphasizing the need for further research and comprehensive assessments to address the complex challenges posed by these changes.

Observed Changes in Temperature and Precipitation Extremes

In recent decades, a notable increase in extreme warm events has been documented, alongside a significant decline in extreme cold events across the Hindu Kush Himalaya region. Specifically, the trends in warm events demonstrate

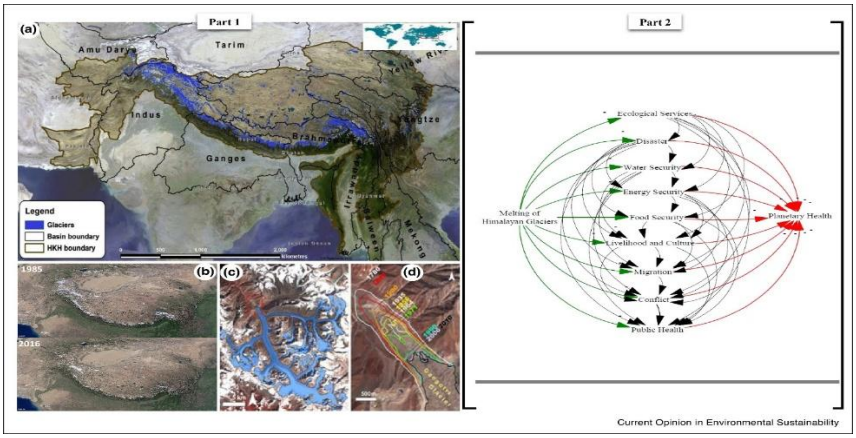
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a greater magnitude compared to those associated with cold events. Since the early 1990s, there has been a marked increase in the frequency of warm nights, coupled with a decline in the frequency of frost days. Additionally, throughout the HKH region, anomalies in the annual mean diurnal temperature range (DTR) displayed a dramatic decrease prior to the 1980s, followed by a discernible upward trend in DTR from the mid-1980s onward. The spatial analysis of linear trends of extreme temperature indices reveals that extremely cold days and nights in the Tibetan Plateau region have diminished at rates of -0.85 days and -2.3 days per decade, respectively. Conversely, the frequency of warm days and warm nights has grown by 1.2 and 2.5 days per decade, respectively. Furthermore, the frequency and intensity of observed precipitation extremes in the HKH region have undergone striking transformations since 1960s. Specifically, light precipitation amounts, categorized as being below the 50th percentile, exhibit a significant upward trend in the northern Tibetan Plateau and the southern Tarim Basin. Conversely, a declining trend is evident in southern China, as highlighted in the research conducted by Zhan et al. (2017).

Negative impacts of melting glaciers in Himalayas

Following our comprehensive review, we have identified and categorized the planetary health impacts associated with the melting glaciers in the Himalayas into nine interconnected natural and social subsystems. These subsystems are 1) ecological services, 2) disaster, 3) water security, 4) food security, 5) energy security, 6) livelihood and culture, 7) migration, 8) conflict, and 9) public health. The implications of these subsystems are detailed below, highlighting the profound and often complex consequences of glaciers melt on both the environment and human societies. Each subsystem interacts with others, creating a complex web of challenges that require the urgent attention and coordinated responses.

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Ecological Services: the fragile ecological balance of the Himalayan region is intricately based on its distinctive geological formations, varied topography, and specific climatic conditions. The glaciers that adorn this majestic landscape play a crucial role in shaping both the regulatory and provisioning ecological services provided by the Himalayan ecosystems. The phenomenon of glacier melting significantly disrupts the intricate structure, composition, and functionality of the fragile ecosystems found in the Himalayan region [10]. This process leads to continuous degradation of these ecosystems, consequently weakening their biophysical resilience. The implication of such environmental changes is profound, as the health of human populations in the Himalayas is intricately linked to a diverse array of robust ecosystem services. These services play a crucial role in disease prevention and the enhancement of overall human well-being [11].

Disaster: melting glaciers poses significant risks that may heighten the frequency of heavy rainfall and cloudbursts in high-altitude regions, thereby triggering catastrophic events in downstream areas. This was starkly illustrated by the catastrophic floods that struck Kedarnath, India, highlighting the dire consequences of such climatic change. Furthermore, the melting of glaciers is poised to influence the projected increase in flooding events within the Indo-Gangetic region in the short term, while concurrently contributing to extended drought conditions in the long term.

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Water security: melting glaciers have a significant impact on the hydrological cycle across various scales. In the Himalayan region and the adjacent plains, millions of individuals depend on glacial meltwater as a crucial resource for ensuring water security, which encompasses both the quality and quantity of available water [12]. The process of glacier melt plays a vital role in regulating and enhancing river discharge [13], as well as, replenishing groundwater supplies. Moreover, it serves as a critical source of water during the dry season. The accelerated melting of glaciers in the Himalayan region is projected to intensify water stress, leading to health repercussions for the local population. The ensuing water shortages may pose substantial challenges to social and environmental sustainability, furthermore, to public health and developmental efforts [14]. Human health is intricately linked to both the quality and quantity of water resources, besides access to these vital resources.

Food Security: food and nutrition security continue to be pressing issues in the countries located within the Himalayan region, as well as in those that rely on its abundant water resources. In these regions collectively, it is estimated that nearly 50% of the population is afflicted by malnutrition. Due to the scarcity of water during the dry season, numerous areas within the Himalayan region are projected to experience a dramatic reduction in groundwater availability for irrigation purposes [15]. This decline in water resources is likely to impede agricultural productivity, negatively impacting the nutritional status of approximately 38 million people residing in the mountainous areas [16]. Consequently, this situation may lead to food insecurity and undernutrition among these vulnerable populations. Moreover, the repercussions of glacier melting presents a significant threat to the sustainability of food production, as the Himalayan region contributes to 25% of the global cereal supply.

Energy Security: the Himalayan glaciers have a significant influence on the production of hydroelectric power within the Himalayan region. Importantly, about

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52% of India's hydroelectric power is derived from rivers that have their origins in these majestic mountains. However, the ongoing melting of glaciers presents a considerable threat to electricity generation. This phenomenon is expected to result in reduced, highly variable, and unpredictable river flows, thereby compromising the stability and reliability of hydroelectric power output. It is imperative for all stakeholders to recognize the implications of these environmental changes on energy generation and take proactive measures to address these complex challenges.

Livelihood and Culture: in the Himalayan region, the sustenance of the livelihood of approximately 240 million individuals is intricately dependent on the provision of ecosystem services. The degradation of these crucial ecological services has extensive negative consequences, particularly impacting communities engaged in agriculture and forestry. Furthermore, the changing patterns of water availability pose considerable challenges to a wide array of livelihoods, both upstream and downstream, despite numerous recent advancements in the region. The Himalayan glaciers constitute a vital foundation for a rich array of cultures, languages, religions, and traditional knowledge systems. These imposing formations are profoundly intertwined with the emotional, cultural, spiritual, environmental, and ritualistic values of the communities that inhabit the region. However, the continued melting of these glaciers poses serious threats to these multifaceted values. For instance, the Nepalese people hold a deep-seated belief that a powerful deity resides at the summit of the Himalayan. This belief underscores that glacial decline transcends mere material considerations; it profoundly affects how local populations perceive their identities and derive meaning from their environment.

Public Health: public health issues related to water are intensified by water stress. Because of limited fresh water, vector-borne diseases can proliferate downstream and into previously unsuitable altitudes in the altered ecosystem. The

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poorest populations will be excessively affected by these diseases. Glacier-influenced landscapes will transform as a result of melting glaciers, and people may experience health issues such as stress, anxiety, and depression.

Future of Himalayan Glaciers: recent research indicates that the rate of glacier ice loss in the Himalayas has experienced a two-fold increase over two decades, reflecting the global rate of ice loss. Contrary to the prior assumption that extreme altitudes would shield glaciers from the effects of climate change, it has become evident that high mountain regions are warming at a rate that is double that of the rest of the planet. The substantial availability of data has allowed glaciologists to develop sophisticated computer models that project future changes in glacier dynamics. According to these models, it is anticipated that between one-third and one-half of the glacier ice in the Himalayas will be lost by the year 2100. Moreover, if decisive measures are not taken to mitigate climate change in accordance with the ambitious goal outlined in the Paris Agreement of 1.5 °C, projections suggest that as much as two-thirds of the glacier ice will be lost within the same period.

Conclusion: Himalayan glaciers are crucial for sustaining the ecological integrity and well-being of the Himalayan region. While the melting of these glaciers may offer potential advantages, such as warmer climatic conditions conducive to agriculture for some local inhabitants, the absence of glacial water presents significant threats to livelihoods, development, and the overall stability of the region. The issues surrounding planetary health in the Himalayan region are complex and require urgent and thorough attention. Therefore, bolstering collaborative research is essential for addressing global health challenges and promoting sustainable development. This requires investing research efforts to develop a comprehensive planetary health framework and risk model, enabling us to forecast, prepare, and make better decisions.

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