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Himalayan Glacial Retreat– An Interpretation of the Glacial Mass Balance Model

Arghadeep Dasgupta[1], Dr. Shyamoli Sen[2]

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ABSTRACT: Glaciers are often regarded as prime parameter of climate change, especially the increase in temperature, global warming, changes in the weather cycle etc. As the Earth warms, frozen water in its many forms is affected. In mountainous regions of the Hindu Kush Himalayas, one of the most visible signs of climate change is evident. In the Hindu Kush Himalayan region – which includes the mountain ranges of the Pamirs, the Tien Shan and the Tibetan Plateau – the glacial field is a vital source of freshwater. Approximately 2 billion people rely on the rivers that flow from these mountain ranges, with more than 240 million people living in the mountain areas. As well as providing a water supply for humans, livestock and wildlife in the region, freshwater originating in the glacial belt is essential for agriculture, hydropower, and inland navigation, religious and cultural uses.

Keywords: Himalayan glacial retreat, third pole retreat,glacial Black Carbon deposit, Glacial Mass Balance Model,GLOF, glacial ablation etc.

I. INTRODUCTION:

The Hindu Kush Himalayan region has the largest concentration of frozen water on Earth after the North Pole and South Pole, hence it is referred to as the third pole. The Himalayan region, which covers eight countries across Asia, is home to some of the world's largest and most spectacular glaciers. This region is the source of the 10 major river systems that provides irrigation, power and drinking water to over 1.9 billion people in Asia approximately covering 24% of the world's population. The meltwater generated from these glaciers each summer supplements the rivers and streams of the region, including several of Asia's great river systems such as the Indus, Ganges, and Brahmaputra**.**

Since industrialization, human activities have significantly altered the atmospheric composition, leading to climate change of an unprecedented character. The global mean temperature is expected to increase between 1.4 to 5.8ºC over the next hundred years. The consequences of this change in global climate are already being witnessed in the Himalayan glaciers and glacial lakes. The Himalayan glaciers are retreating at rates ranging from 10 to 60 metres per year and many small glaciers have already disappeared. These lakes pose a threat of glacial lake outburst flood (GLOF), and GLOFs are often catastrophic on life and property of the mountain people living downstream. At least, thirty-two GLOF events recorded in Himalaya that resulted in heavy loss of human lives and their property, destruction of infrastructure besides damages to agriculture land and forests. The global warming in the coming decades will amplify the GLOF events with the accelerating retreat of glaciers and formation of many potentially dangerous glacial lakes.

Glacier loss is difficult to project over the whole of the Hindu Kush Himalayas. Rates of glacial melt depend on a number of variables, including elevation and elevation dependent temperature, precipitation and debris cover, among others.

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Glacier Melting and Retreat Process

Glaciers grow and shrink as seasons change over the course of each year. Glacier mass is lost when summer temperatures cause glacier melting, and mass is added when precipitation such as snow and rain freezes. When a glacier is in steady state with the climate, glacier melt is offset when precipitation freezes, and overall glacier mass and volume stay about the same. Glacier retreat occurs when rising temperatures caused by climate change lead to permanent reduction in glacier mass and volume. Global warming has also altered the precipitation forms mostly from snowfall to rain which is also impeding the maintenance of glacial mass.

There are thousands of glaciers in the Hindu Kush Himalayan region. As per the glacial inventory of Space Applications Centre (ISRO), there are 32,392 glaciers distributed over three main glacier basins of the Indus, the Ganga, the Brahmaputra and there are widespread anomalies in terms of glacial melt. The glaciers in the eastern part of the region are at a lower elevation on the whole than those in the western part, leaving them relatively more vulnerable to melting. In the Karakoram region, which hosts a number of high-altitude glaciers, there have even been some glacial surges, leading to discussion of a Karakoram anomaly.

The Himalayan region is warming faster than the global average. On the whole, glaciers across the Hindu Kush Himalayas have lost mass since the 1970. In the near year, by 2030, glaciers in the Hindu Kush Himalayan region are expected to lose between 10-30% of their mass. By 2050, this figure is expected to increase to 25-35%. In the long term, by 2080-2100, glacial mass loss is predicted to reach 35% in the Karakoram, 45% in the Pamir mountains, and as high as 60-95% in the eastern Himalayas in a business as usual scenario with world governments failing to implement aggressive emissions-reduction policies. All of these figures are based on a moderate emissions scenario. Given different emissions scenarios and modelling methods, there will be significant variations between longer-term projections.

The paper has attempted to focus upon the glacial retreat and loss of glacial mass as a direct impact of accentuated climatic changes triggering glacial melt, shrinkage, formation of lakes, GLOFs, etc. further leading to alteration of stream flows, changes in agricultural patterns, problems associated with green energy production and increased disaster events like floods in the entire Himalayan Region. These discussions are based on previously done studies providing evidence on possible climate change. In addition, the paper puts forth a glacial mass balance model to numerically interpret the loss of glacial mass as a result of retreating and shrinking glaciers.

II. MATERIALS & METHODS:

This is a research paper that provides an assessment of the retreat of Himalayan glaciers primarily attributed to climate change and associated issues discussed earlier. The paper has completely relied on secondary sources to present this commentary on Himalayan glaciers. The following are some of the secondary data sources:

1. IPCC
2. ICIMOD
3. ISRO
4. World Bank
5. WWF
6. TERI
7. MoEF
8. UNEP
9. Books, journals, newspapers, internet etc.

Numerous research works both published and unpublished undertaken by organizations, agencies, independent researchers have been used in the documentation process.

III. LITERATURE REVIEW:

Glacial retreat resulting in glacial shrinkage and increased streamflow is one of the most compelling reasons to study the devastating impacts of climate change. One can thus find numerous research works on this topic and associated issues. Out of several recent study commissioned by a Research Foundation, concluded that the retreat of glaciers in the Himalayan Hindu Kush region is now affecting the surface water and groundwater availability in the region, and has adversely affected springs – a lifeline for the population in hill areas. Prakash, 2020 discussed the contribution of glacial decline on the river systems in the HKH region. Climate change was seen as the most attributable factor causing glacial melt and increased water flow in the rivers. Temperatures have increased around 0.60C in Nepal Himalayas. The warming rates are progressively higher for steeper elevations, resulting in the rapid shrinking of most glaciers in Nepal.

In addition, in one of the studies conducted by ISRO it is seen that approximately 75 per cent of the Himalayan glaciers are retreating at an alarming rate. These retreats will increase the variability of water flows to downstream areas and endanger the sustainability of water use in the earth’s most crowded basins. Receding glaciers would also have an impact on the rates of groundwater recharge in some areas, says the study. The decline in groundwater due to anticipated decline of glacial meltwater is likely to affect the Ganges basin the most, then, Brahmaputra and Mekong basin.

Glacial decline is closely related to climate change. Another study by Kulkarni, et.al, 2007 closely observes at the interconnectivity between glacial retreat, groundwater, and surface water in the area. There are five million springs in the Himalayas and they are showing a decline because of overuse by an increasing population, but also because of retreating glaciers and depleting ground water levels.

In another study by Baracharya, et.al, 2008, it was concluded that the consequences of 1.4 to 5.8ºC warming of global climate is already being witnessed in the Himalayan glaciers and glacial lakes. The Himalayan glaciers are retreating at rates ranging from 10 to 60 metres per year and many small glaciers (<0.2 sq. km) have already disappeared. Vertical shift of glaciers as great as 100m have been recorded during the last fifty years. With the result of retreating glaciers, the lakes are growing in number and size as well in the Himalaya. A remarkable example is Lake Imja Tsho in the Everest region; while this lake was virtually non-existent in 1960, now it covers nearly 1 sq. km in area.

Another important assessment conducted by the International Centre for Integrated Mountain Development ICIMOD, the glaciers of the Hindu Kush Himalayas are facing another problem, the accumulation of black carbon. This is essentially released from fires in the surrounding lowlands which rises in the air and settles on glaciers. Because of its dark colour, black carbon absorbs solar radiation faster. Black carbon, other short-lived climate pollutants such as dust and aerosols are produced by a range of human activities, including biomass burning, brick factories, cement industries, other industries using coal as a heating agent and coal-based, thermal electricity plants. Not only do they darken the glaciers, these pollutants can also lead to warming of the air mass, leading to higher temperatures around the cryosphere and melting of its ice. Rising temperatures are melting glaciers and other frozen water across the Hindu Kush Himalayas. Urgent action to curb emissions is needed to secure water supplies, protect livelihoods and prevent disasters across the region.All these research works have contributed in deeper understanding of the issues discussed in this paper relating to climate change and glacial retreat, melting, mass loss, etc.

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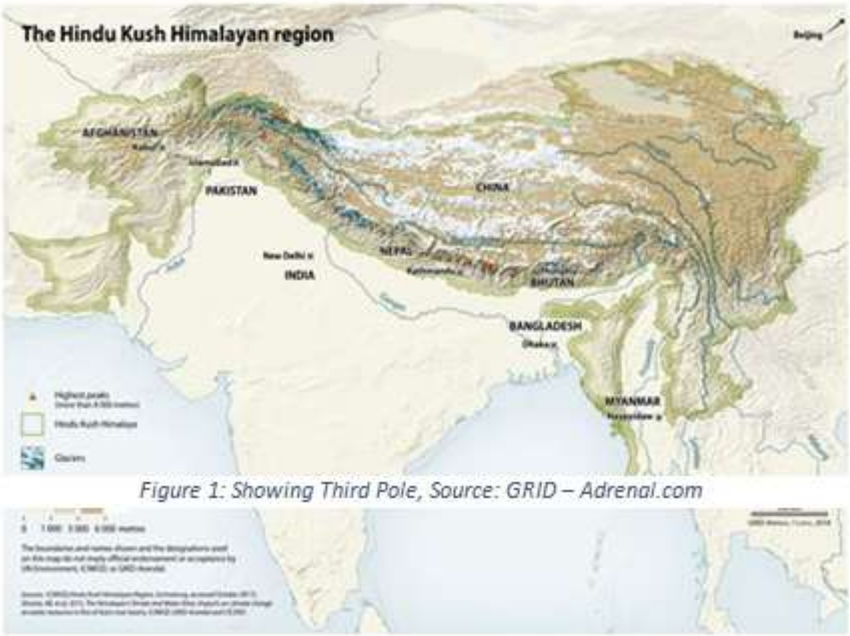


Figure 1: Showing Third Pole, Source: GRID – Adrenal.com

Topographical Review: The HKH region extends across 3,500 km over eight countries—Afghanistan, Bhutan, Bangladesh, China, India, Myanmar, Nepal and Pakistan. It has the biggest reserves of water in the form of ice and snow outside the Polar Regions, and is the source of 10 of the largest rivers in Asia.

About 1.3 billion people directly depend on the HKH ecosystems, including for irrigation, power and drinking water. For the upper Indus basin, glacier melt may contribute up to 41 per cent of the total runoff, 13 per cent in the upper Ganga basin and 16 per cent in upper Brahmaputra. While initially the retreating glaciers will not have a direct impact on water flow in rivers, except in the Indus where 26 per cent flow is from glacier melt, this is likely to change soon, according to ongoing studies.

Glacial Retreat: Himalayan glaciers are receding faster today than the world average (Dyurgerov and Meier, 2005). In the last half of the 20th Century, 82% of the glaciers in western China have retreated (Liu et al. 2006). On the Tibetan Plateau, the glacial area has decreased by 4.5% over the last twenty years and by 7% over the last forty years (CNCCC, 2007), indicating an increased retreat rate (Ren et al., 2003). Glacier retreat in the Himalayas results from "precipitation decrease in combination with temperature increase. The glacier shrinkage will speed up if the climatic warming and drying continues" (Ren et al., 2003).

Another study in the Chhota Shigri, Patsio and Samudra Tapu glaciers in Chenab basin, Parbati glacier in Parbati basin and Shaune Garang glacier in Baspa basin also indicates shrinkage and meltdown of glaciers the major findings were:

- There is an overall deglaciation of 21% with a reduction in glacier area from 2077 sq. km in 1962 to 1628 sq. km by 2007.
- The number of glaciers have increased due to fragmentation.
- Mean area of glacial extent has reduced from 1.4 to 0.32 sq. km between the 1962 &2001
- The number of glaciers with higher areal extent has reduced and lower areal extent has increased during the period.
- Small glaciarates and ice fields have shown extensive deglaciation. For example, 127 glaciarates and ice fields less than 1 sq. km have shown retreat of 38% from 1962.

Figure 1: Showing Third Pole, Source: GRID – Adrenal.com

Glacier	Period	Retreat of snout in metres	Average retreat of glacier (in mt/yr)
Triloknath Glacier (Himachal Pradesh)	1969 to 1995	400	15.4
Pindari Glacier (Uttarakhand)	1845 to 1966	2,840	23.5
Milam Glacier (Uttarakhand)	1909 to 1984	990	13.2
Ponting Glacier (Uttarakhand)	1906 to 1957	262	5.1
Chota Shigri Glacier (Himachal Pradesh)	1986 to 1995	60	6.7
Bara Shigri Glacier (Himachal Pradesh)	1977 to 1995	650	36.1
Gangotri Glacier (Uttarakhand)	1977 to 1990	364	28.0
Gangotri Glacier (Uttarakhand)	1985 to 2001	368	23.0
Zemu Glacier (Sikkim)	1977 to 1984	194	27.7

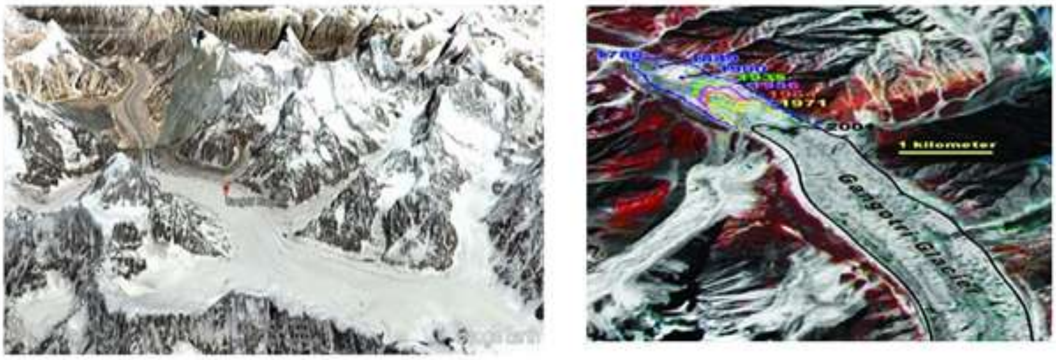
Table 1: Recession of Glaciers (India), Source: IPCC.org

		Glacier Area (sq.Kms.)		
Basin	**Glacier No.**	**1962**	**2001-04**	**Loss%**
Chenab	359	1414	1110	21
Parbati	88	488	379	22
Baspa	19	173	140	19
Total	466	2077	1628	21

Table 2: Basin-wise Loss in Glacier Area, Source: IPCC.org

Figure 2: A Comparative Picture of Severe Shrinkage of ChotaShigri Glacier in Lahaul-Spiti from 1988 to 2003

The 30.2 km long Gangotri glacier has been receding alarmingly in recent years. Between 1842 and 1935, the glacier was receding at an average of 7.3 m every year; the average rate of recession between 1985 and 2001 is about 23 m per year (Negi, 2012).



Source: Google Earth Source: IPCC.org

Figure 3: Recession Gangotri Glacier

In a more recent study by Maurer, et.al, 2019, focussing on the accelerated ice loss over the last 40 years, it was seen that over a 2000 km transect, loss of ice doubled between 2000-2016 (-0.43 m/year) as compared to 1975-2000 (-0.22 m/year). The study also found atmospheric warming as the most dominant determinant of glacial loss.

Past & Present Scenarios of the Retreated Kolahali Glacier in Kashmir Region

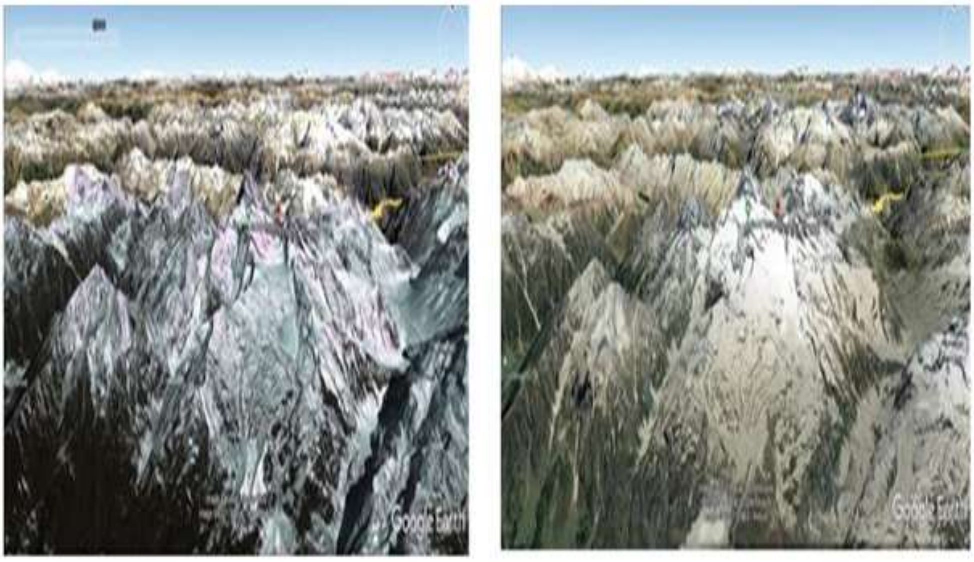


Figure 4: Kolahali Glacier *Source Google Earth*

Thus it is seen that almost all the Himalayan glaciers are retreating and thus facing shrinking resulting in excessive ice loss and increasing stream flows. The primary causes and resultant impacts will be discussed in the forthcoming sections.

Causes of Himalayan Glacial Melt: The Himalayas in India and beyond have come under close attention in recent years. Several recent studies have shown that the situation could be much worse than originally feared. Most of the issues are related to climate change triggering retreat of glaciers.

Climatic Changes - A forecast was made that up to a quarter of the global mountain glacier mass could disappear by 2050 and up to half could be lost by 2100 (Kuhn, 1993a; Oerlemans, 1994; and

IPCC, 1996b). For example, with the temperatures rise by 1°C, Alpine glaciers have shrunk by 40% in area and by more than 50% in volume since 1850 (IPCC, 2001b & CSE, 2002). The kind of warming experienced by the northern hemisphere experienced after 1990 is unprecedented and most damaging. The amount could be anything from 1.4 to 5.8°C in 2100 depending on the climate model and greenhouse gases emission scenario. Evidences have been conclusive enough to attribute this kind of warming as the major cause of glacier melting which is one of the important indicators of climate change. In an interesting study by Banerjee, et.al, 2016, temperatures were reconstructed from the glacier length fluctuations. They concluded that there has been a continued trend of warming in the region between1860–2010 with a total temperature change of ~1.6 K. However, since 1990, the warming has been particularly severer pushing the averages to a higher side.

Increased concentration of Greenhouse Gases - One study, in particular, found that if CO_2 emissions are not cut drastically, around two-thirds of the Hindu Kush-Himalaya region glaciers could disappear. Glaciers in the Himalayas lost billions of tons of ice between 2000 and 2016, double the amount that took place between 1975 and 2000. Rising global temperatures are majorly to blame the result of carbon dioxide and other greenhouse gas emissions. Air pollutants from unclean energy sources are also contributing. The dirty air then deposits black carbon dust on the ice. This dust means the glaciers absorb more heat and thaw more rapidly.

Presence of Black Carbon on Glaciers – Black carbon is a constituent of soot that is generated from the combustion of unclean energy sources such as fossil fuels. Black carbon when deposited over glaciers increase the albedo effect thereby absorbing more light and infra-red radiation. This increases the onsite temperatures over the glaciers thus causing accentuated melting. According to a research done by the Wadia Institute of Himalayan Geology, another impinging factor causing retreat of Himalayan glaciers is the concentration of black carbon on the glaciers. Scientists have been monitoring black carbon through two weather stations on way to Gangotri glaciers - namely Chirbasa station at a height of 3,600 m, and Bhojbasa station at a height of 3,800 m - for the last few years. Their studies found that this concentration on Gangotri glacier has almost doubled in the past few years primarily because of agricultural burning and forest fires. The concentration of the black carbon increases in summer months due to varied factors. Scientists have found a range of black carbon up to 4.62 micrograms per cubic metre. In the non-summer months, the concentration comes down to about 2 micrograms per cubic metre. The main reasons of black carbon generation are forest fires, agricultural and tourism related activities.

These changes in climate will inevitably interact with changes in glaciers and glacial lakes and increasing incidents of GLOFs as results have revealed a positive correlation between recession rate and rising temperatures. These changes in climate will have effects ultimately on life and property of mountain people.

Impact of Rapid Glacial Melt

Direct Impacts

Loss of Ice Cover - One of the most convincing and direct impacts of glacial retreat is loss of permanent ice cover, which is considered to be storehouse of fresh water and which is why the Himalayas are known as the 'Water Tower of the World'. It is difficult to speculate how exactly this melting of the third pole's glaciers will cause spiralling impacts on water flow and availability across the regions that depend on Himalayan rivers. This is because multiple factors influence water flow, including the stability of monsoons that are responsible for precipitation both rain and snow in the region.

Changes in Streamflow - Climate warming has been affecting hydrological regimes in the HKH region because of factors like changes in seasonal extremes, increased evapo-transpiration, and changes in glacier volume. However, the studies forecast that there would be a decrease in snow and a rise in glacier melt by the middle of the century. Initially, this will result in an increased amount of meltwater available, but this quantity will decline abruptly as the glacier storage is reduced. There is a difference caused by elevation factor as well. Since areas of lower elevation are more endowed by monsoon rains, the water availability may not be altered greatly. In contrast, areas of higher elevation, with current retreat rates, there could be severe alteration of water availability in certain basins (http://dels.nas.edu/basc).

Glacial Lake Outburst Floods (GLOFS) - One of the most devastating impacts is increase in glacial lakes and associated glacial lake outburst floods, GLOFs. While it is very difficult to predict individual GLOFs, it is clear that their frequency will go up as the climate warms. Since the 1990s, glacial lakes across the Hindu Kush Himalayan region have increased in both number and size. Given the regional disparity in elevation, the greatest increase has been in the eastern and central

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sections of the Hindu Kush Himalayas. As more meltwater enters the water system of pro-glacial or glacial lakes, leading to the rise in sedimentation and shallowing of the lake bed, chances of flash flood occurrence is increased tremendously .Above all, these lakes are often unstable, and when the moraine dams or the lake boundaries break owing to additional hydrostatic pressure they can cause catastrophic glacier lake outburst floods, GLOFs. Similarly, more water in the glacier-fed rivers increases the risk of flooding in the downstream area.

Figure 5: Glacial lake of Lake Imja Source: Montagna.TV

A remarkable example is Lake Imja Tsho in the Everest region; while this lake was virtually nonexistent in 1960, now it covers nearly 1 sq km in area. Similar observations were made in the Pho Chu basin of the Bhutan Himalaya, where the change in size of some glacial lakes has been as high as 800 per cent over the past 40 years. At present, several supraglacial ponds on the Thorthormi glacier are growing rapidly and consequently merging to form a larger lake.

These lakes pose a threat of glacial lake outburst flood (GLOF), and GLOFs are often catastrophic on life and property of the mountain people living downstream. At least thirty-two GLOF events recorded in Himalaya that resulted in heavy loss of human lives and their property, destruction of infrastructure besides damages to agriculture land and forests. The global warming in the coming decades will amplify the GLOF events with the accelerating retreat of glaciers and formation of many potentially dangerous glacial lakes.

Indirect Impacts

Extreme Weather Phenomenon: With more glacial melt water and a warmer global temperature, the risk of extreme weather events increases. Many researcher have already started to notice changes in temperature and precipitation extremes, like changes in the monsoon cycle.

Lower agricultural yields: Global warming means that snow and glaciers melt earlier in the year, leading to floods in spring. However, by summer, when crops need more water, volumes of water are decreased as there is no adequate monsoon. As a result, agricultural yields are lower, arid zones are increasing and likewise fishing in the region gets badly affected. Another problem is the availability of gradual snowmelt water in the thawing season of summer due to lack of or very limited snow accumulation as a result of climate change (ICIMOD, 2011)

Reduction in Green Energy Production: As an outcome of all these effect, in the downstream area volume of water in dams directly impacts the production of hydroelectricity. During the summer when there is always a peak demand for electricity, due to variable snowmelt water coupled with inadequate monsoon, less water in dam reservoir resulting in lesser head and insufficient production of electricity. On the other hand, extra monsoon in the lean season, results in more water accumulation, demands for the release of excess water through spillway, as provision for storage of excess hydro-electricity is not developed and made in to use anywhere in Asian sub-continent commercially.

Discussion: So, the current and future danger of melting glaciers is evident. But the real concern addressed by current research revolves around the fact that what all measures need to be undertaken to improve the present situation. In reality, the only real solution is to prevent further global warming.

There are many climate change solutions, and many of these focus on reducing carbon footprint. Although individuals can take steps to reduce emissions, governments and corporations need to make far-reaching changes to policies and practices. As we stand on the edge of a climate crisis, there is much work to be done to improve the situation. Timely interpretation of Kyoto Protocol could be a starting point in this direction.

A proper Glacial Mass Balance model should be designed numerically considering all possible parameters and then 3D simulation of the same model showing the retreating rate and the outcome. This model needs to be addressed adequately and proper corrective measures should be implemented by all Himalayan countries, for better future sustainability.

Numerical Model: Glacier models are used to investigate the important processes creating the world around us and for making predications for what the world might look like under different conditions like global warming, the last glacial retreat etc. Glaciers are generally investigated using numerical, rather than physical models to describe relationships between mass balance, ice dynamics and climate change.

A numerical model is a simplification that allows us to identify and test the sensitivity of a glacier to a range of variables, such as seasonality in mean annual air temperature, black carbon deposition, precipitation intensity, topography, metamorphism etc.

Glacier mass balance is a numerical models of calculating glacial retreat. It is an empirical method to estimate how much melting occurs on a glacier's surface over the course of a year. Most of this melt or ablation will occur during the long summer season. Understanding the relationship between glacier accumulation and glacier ablation provides an empirical value for the mass balance of a glacier. If the mass balance of a glacier is positive, the glacier will advance. If the mass balance of a glacier is negative, the glacier will shrink and recede. The mass balance at a point on a glacier initially can estimated as:

$$\mathbf{B_n = P - R - E_A}$$

Where B_n is the net balance of a glacier, expressed in metres water-equivalent, P is precipitation, R is runoff and E_A is evapo-ablation.

In addition, there are other pre dominant factors which regulate the Glacier's average net mass balance. The amount of carbon black accumulation on the glacial surface, height of the glacial field from the m.s.l, meltwater at the base of a glacier controls entrainment, transfer and deposition of debris, as well as being an important factor in controlling glacier velocities and ice deformation. Glacial sediments and landforms vary widely between different terrestrial systems.

The thermal regime of a glacier is a function of ice temperature which again is a function of air and ground temperatures below the ice-sheet, with some glaciers being heated from below by geothermal heating and the pressure of the ice.

Generally glacier models combine a surface mass-balance model with a model that adjusts glacier geometry in response to mass change. Most models adopt a simple temperature index approach for calculating glacier melt and derive snow accumulation from precipitation using an air temperature threshold to discriminate snow and rain. Air temperature and precipitation input are generally taken from the climate data grid-cell closest to the glaciers, gridded data sheet or from technical literatures.

The Mass balance of a glacier can be thought of as the health of a glacier. Mass balance is the total sum of all the accumulation snow, ice, freezing rain and melt or ice loss from the entire glacial. If glaciers have a mass balance that is inequilibrium with climate, then the inputs are equal to the outputs. The glacier remains the same size, and does not grow or shrink.

Ice continues to be transferred from the top of the glacier the accumulation zone to the bottom of the glacier ablation zone. If the amount of melting across the glacier increases, then the glacier will have a negative mass balance, and the glacier will shrink, subsequently rise in water in the downstream channels or rivers.

With analysing various existing literature and field data, numerical model needs to be devised and which later can be simulated in computer model. This empirical formula can be represented as

$$\mathbf{B_n = \Sigma\ [\{(\int dP/dt) + (\Delta H)\ X\ (dp/dt)\} - \{(R + E)/dt\} - \{\underset{\sim}{e}+\acute{w}\}]}$$

$$B_n = [(\int dP/dt) - \{(\Sigma\, BC) + (H^{*})\,(dp/dt)\} + \Sigma(R + E) +$$

$\int dP/dt$ Total precipitation, Snowfall in a specific time period

H^{*}Height of the Glacier from mean sea level subjected to metamorphism

Σ BC Accumulated black carbon on glacial surface, subjected global warming owing transportation along with wind cycle

(R+E)/dt Reduction in glacial mass subjected to runoff and evaporation, time depended consideration

ȩDebris entrapment factor

ẃ Under Glacial sheet enthalpy resulting in glacial melt

r Rainfall on freshly accumulated snow layer

Now, with this empirical formula, time period for calculating glacial retreat of the Himalayan can be estimated, alongside a futuristic projection for estimated time gap for entire glacial belt runoff considering the impact of moderate negative factors.

$$T_s = \int dB_n$$

This numerical model is subjected to validation with numerous field experiment and computer simulation and such numerical models will enable to develop more accurate early warning models towards restoration of Himalayan Glaciers.

IV. CONCLUSION:

To conclude, the paper highlighted that glaciers in Himalaya are retreating in totality. The impacts of such retreat will have far reaching consequences and it will affect biodiversity, ecosystem functioning, socio-economy and livelihood of the people living in downstream regions. The negative impacts will further be compounded by glacial lakes outburst floods. Thus there needs to be more comprehensive studies on the glacier area / volume changes and formation of glacial lakes in the Himalaya so as to have an actual level understanding of the risk associated and potential impact downstream to other countries. Since, Himalayan glaciers are crucial not only to the surrounding regions but also to the billions of people whose lives are dependent on it, it is of utmost importance that Himalayas are preserved in their pristine state to maintain its, geographical, geo-political, economic and socio-cultural relevance. To achieve this, Governments are largely required to tackle the issue of global warming, black carbon emission, etc. in order to slow down the issue of Himalayan glacial retreat for better future sustainability of mankind.

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