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A Satellite Visual Analysis of the Albedo Effect on Glacial Recession, and its Use as a Predictor of Glacial Lake Changes

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Abstract

This paper reviews recent studies concerning the relationship between glacial recession over the past 100 years, the weakened albedo effect, and the glacial lake changes in the Hindu Kush Himalayan (HKH) region. Geological indicators provided by NASA Worldview's satellite images were used to verify an inverse correlation between the albedo effect and glacial recession. Confirmation of this inverse relation suggests changes in glacial lakes, which increases the risk of glacial lake outburst floods (GLOF) over time. This article also examines the impact of past GLOFs on the HKH region's population and assesses the vulnerability of local communities and infrastructure near potentially dangerous glacial lakes (PDGL). Understanding these relationships can ensure the safety of disaster-threatened communities and provide potential proactive measures that could prevent possible future lake outburst disasters.

Keywords Environmental Science, Ecosystem, Glacial Recession, Glacial Lake, Meltwater

1 Introduction

Since the early 1900s, glaciers worldwide have experienced rapid melting –with human innovation being the source of this phenomenon. Glacial recession is the process in which the ice ablates faster than snow can fall to accumulate and form new glacial ice. This process can be seen when the terminus, the glacier's snout or lowest end, does not extend as far down-valley as it did in previous times.' Studies have shown that Anthropogenic global warming has caused increases in Earth-surface temperatures, which significantly impacts the rate of glacial recession. In the Himalayan region, it is imperative to recognize and address these problems as many people rely on local lakes and rivers as their primary source of water. Over 2 billion people, roughly 20In the HKH region (Figure 1), there are around 54,000 existing glaciers, consisting of clean and debris-covered ice, covering a total area of 60,000 km^2.' This cryospheric area, commonly referred to by the scientific community as the "Third Pole," has the highest concentration of snow and glaciers outside of Earth's poles. The HKH region is also built on one of the Earth's most dynamic river and mountain systems, enabling it to sustain complex hydrology and diverse environments. The ten central river systems include the Amu Darya, Brahmaputra, Ganges, Indus, Irrawaddy, Mekong, Salween, Tarim, Yangtze, and Yellow Rivers - all of which are fed by meltwater from the local glaciers.'The glaciers surrounding these rivers play vital roles in the availability of resources, the maintenance of the HKH region's diverse ecosystem, and the region's local infrastructure. Further glacial recession in the HKH region could profoundly impact the ecological equilibrium and present severe challenges to the communities that depend on them. An issue of acute concern regarding the glaciers in the HKH region, and more specifically the glaciers of the Tibetan plateau, is the rate of change in melt rate over time, which has been growing exponentially over the past 100 years. Many factors impact the glacial melt rate, but a large part of the problem is caused by debris and sediment build-up. Debris-covered glaciers are defined as glaciers with a continuous layer of supraglacial debris over the ablation area, typically increasing in thickness towards the terminus.' These types of glaciers are especially susceptible to the impacts of solar radiation; this is due to the albedo effect (Figure 2). The albedo effect refers to the ability of surfaces to reflect light, with light-coloured surfaces reflecting more light radiation and dark-coloured surfaces absorbing the light radiation.' One can see how the albedo effect factors into the melting of the glaciers as thin debris-covered glaciers see significantly faster rates of melt compared to clean glaciers. A3 /15 pt analysis of this effect on glaciers will be discussed later.

1.1 Tools

Satellite imagery provided by NASA Worldview was utilized to analyze the albedo effect on Earth's surfaces. NASA Worldview is a data archive and visualization system built on NASA's EarthObserving SystemData and Information System. It allows for in-depth visualization of different types of science data sourced from satellite images." The coloration defines the spectrum of albedo strength; deeper hues of red indicate a strong albedo effect, while paler greens indicate a weak albedo. The percentages represent how much light is reflected off of the surface. For example, an albedo value of 0.50 means that the surface reflects 50 percent of the incoming solar energy.

2 Results

The increasing glacial recession rates pose significant dangers to the local environment; however, another primary hazard that the melting glaciers have on the environment is the excess meltwater from the faster rates of melt. With rising regional temperatures of 0.15-0.60C per decade (over the last four decades), the HKH region has seen an increase in the average glacial mass recession rate of about 10-15m/year.'The excess meltwater from the glaciers leads to a drastic increase in water abundance, often creating new and altering existing glacial lakes. While this may seem to be a beneficial outcome for the environment, it is quite the opposite. Increasing temperatures, concomitant with excess meltwater, lead to much higher risks for GLOFs. This is a severe danger to downstream communities as they are openly subjected to devastating destruction. This review article aims to address the dangers of the chronic recession rates of the HKH region's glaciers, provide insight into potential solutions, and shine a light on how global warming is directly affecting humans. The article will also address the socioeconomic concerns regarding the local habitation near large melting glaciers. The review will attempt to verify the inverse correlation between the implications of the albedo effect on the HKH region glaciers, in turn, producing significant amounts of excess meltwater, creating new PDGLs and thus increasing the risk of GLOFs. Rates. Upon inspecting the MERRA-2 Surface Albedo (Monthly) layer on the HKH region, we found that the Albedo effect on Earth from 1980 (the earliest year with available data) to 2020 surface becomes much weaker. Figure 3.1 shows the surface albedo percentages of the HKH region on February 1, 1980. The left side of Figure 3.1, for example, shows high albedo for the Karakoram mountain range system of Kashmir, on the western side of HKH near the India-Pakistan border. This range contains the Siachen glacier, one of the world's largest mountain glaciers, also suffering from various anthropogenic effects. Since 1989, the Siachen glacier has been melting at high-speed rates, receding about 2 km in length and experiencing a 17% mass loss.' Today, the Siachen glacier spans 70 km and feeds into the Indus River system, one of the HKH region's ten largest rivers. On February 1, 1980, the albedo percentages of the Siachen glacier averaged around 65%, which is very high for land surfaces, indicating that large volumes of ice and snow were present. On the contrary, in Figure 3.2, the albedo effect in the same region is much more subtle; the albedo percentages around the same area, on February 1, 2020, average around 57%. This decrease in reflectivity indicates that the effect is much weaker in 2020, compared to the 1980's results, which was expected. This outcome is due to a combination of the Siachen glacier's high melting rates and the increasing amount of sediment build-up around the area. These results suggest a particularly interesting relationship between the albedo effect and the glacier recession: an inverse relationship. Figures 2 and 2.1 show that many of the glaciers in the HKH region are covered with debris as the albedo percentages around the area consistently dropped between 1980 and 2020. This is especially noticeable on the Fedchenko glacier in Pamir, Tajikistan (Figures 2 and 2.1). These results suggest a particularly interesting relationship between the albedo effect and th 3 36 an inverse relationship. Furthermore, revisiting the relationship between debris-covered ice and the albedo effect, figures 2 and 2.1 clearly show that many of the glaciers in the HKH region are covered with debris as the albedo percentages around the area consistently drop between 1980 and 2020. This is especially noticeable on the Fedchenko glacier in Pamir, Tajikistan (Figures 2 and 2.1).

3 Discussion

There is an inverse relationship established between the melt rate and the debris thickness. As presented in the case of Fedchenko glaciers, the melt rate is much slower than other glaciers because the glacier's terminus is fully covered by thick supraglacial debris. From 1978 to 2001, the area change of the Fedchenko glacier was only -2.91 km^2, with a total area of 580 km2. Compared to the smaller glaciers east of the area, which saw an area reduction of almost 20When glaciers recede in length, debris from the terminus gets transported to the front of the glacier, creating a type of sedimentary dam. As a result of the debris build-up, new glacial lakes were created, and GLOFs have been increasing in frequency over the last 100 years. In the last four decades, over 40 GLOFs have occurred in the HKH region.' Many of these disasters resulted in many deaths along with billions of dollars in infrastructure damage. In 2018, Prakash and Nagarajan did a GLOF risk assessment of the Chandra basin (Figure 3), identifying the different PDGLs in the area.' In the Chandra basin, there are 355 glaciers, all of which are melting at increasing rates, which dangerously creates new lakes and expands existing ones. Figure 3 suggests there are many settlements along the Chandra River, making them very vulnerable to GLOFs, and thus these threats must be mitigated. From 2000 to 2014, 18 new glacier-fed lakes appeared in the basin, which resulted in a 64% increase from 28 lakes in 2000 to 46 lakes in 2014. From these 46 lakes, seven of them were identified to be PDGLs, with two moraine-dammed lakes being declared to have high outburst probability, which was expected (Figure 4). Moraine-dammed lakes are the most dangerous as they are very poorly secured. The proglacial debris is comprised of loosely packed sediment, and they often show a low width-to-height ratio with the glacier, making them highly open to outbursts.'6 Along with outburst floods, the degradation of weak moraine dams can also create landslides or ice avalanches, posing an additional greater threat to downstream establishments. Supraglacial lakes are also hazardous as the water build-up on these glaciers drains through the debris and the glacier itself, creating fractures in the ice, which accelerates the ablation rate of the glacier. Consequently, a large outburst flood is created when the water build-up becomes too great for the ice dam. An example of moraine-bordered glaciers that can create landslides and even floods due to the glacial recession is the relatively recent 2013 GLOF in Uttarakhand. A study was done by Allen et al. (2015),2" focusing on the essential factors of this particular incident. On June 17, 2013, heavy precipitation and high temperatures caused the outburst of the Chorabari Lake in Northern Indi, near the Chorabari glacier in Northern India. The Chorabari lake initially formed due to the excess meltwater from the terminus of the Chorabariglacier. From 1962 to 2012, one year before the flood, the Chorabari glacier retreated 344 $\pm$ 24 m in length, leaving behind large piles of debris, which dammed in the lake.22 Before the burst, the lake was measured to be around 250m long and 150 m wide, with a water depth of 11 to 15 m, holding around 262 million liters of water, The actual outburst resulted from the heavy precipitation, combined with unusually rapid snow depletion, which eroded its moraine dam, discharging large volumes of water and carrying rocks downstream to the Kedarnath village. The flood claimed over 6000 lives and displaced over 100,000 people from their homes. In addition, roads and hydroelectric power projects were destroyed, leaving millions of dollars in damages. Four weeks before the flood, rapid snowmelt occurred due to the high summer temperatures, flooding the lake with even more water. The lake also lacked a stable outlet channel, which further added to the problem as the water had no way out. The moraine dam was also fragile as it was built on loose rocks and dirt left behind from the Chombari glacial retreat. As a result of these different factors, the disaster could have been foreseen due to the minor signs of outburst that the lake showed; however, no one investigated the issue. In summary, the 2013 Chorabari GLOF proves the positive relationship between the glacial recession and changes in glacial lakes. As the Chorabari glacier retreated and the snow melted, the meltwater flooded into the Chorabari moraine-dammed lake, which eventually outbursts and wreaked havoc on the land. In essence, the positive relationship between the glacial recession rate and the changes in glacial lakes has been verified. In the Chandra basin, the glaciers saw an average rate of retreat of 0.1 to 0.5% per year between 1988 to 2007.' Around the same time, in 2000, the number and area of glacial lakes increased by 64%, proving that glacial meltwater is the leading source of water for lake expansions. This further supports the direct relationship between glacial recession rates and lake changes: as recession rates increase, glacial lakes increase in size and quantity, which additionally endangers downstream communities. It can also be seen that the relationship is inversely related to the albedo effect on glacial recession rates: as the albedo effect gets weaker on glaciers, more debris is built up, and thus glacial lakes see greater changes, accelerating recession rates. These relationships are crucial to our understanding of how the environment is correlated with itself, allowing us to predict the different outcomes and threats imposed on the HKH region.

4 Conclusion

In conclusion, understanding the correlation between the albedo effect and anthropogenic glacial recession is critical to predicting future glacial lake outbursts. Throughout this review, past glacial recession data and satellite imagery from Google Earth and NASA Worldview were examined to determine the intercorrelation between the three variables: albedo effects, glacial recession, and glacial lake changes. The ChorabariGLOF was a key example of the severe human consequences of neglecting the early signs of glacial lake outburst. More accurate predictive tools such as albedo effect analysis could assist government officials and geologists in monitoring the Chorabariglacial Lake for potential GLOFs. On June 16, 2013, scientists checked the Chorabari lake; however, it was too late as it experienced an outburst the next day. After the destruction, the Uttarakhand government initiated a construction project to build a flood protection wall in 2015, two years after the disaster. Accurate prediction tools could have prevented the destruction of the patterns of the Chorabari Lake changes had been acknowledged. Possible solutions could include the extraction of water from PDGLs, which could be used by the community, or the construction of glacial lake drainage systems. Either of these solutions could have been implemented before the Kedarnath flood, benefiting the township with extra resources, as well as ensuring safety.

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