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ASSESSING GLACIER DYNAMICS AND SNOW COVER CHANGES IN KASHMIR USING REMOTE SENSING AND GIS: A REVIEW

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By

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Abstract

The glaciers of the Kashmir region are vital freshwater resources; however, they are experiencing rapid retreat due to climatic challenges. The current review observes the role of remote sensing (RS) and Geographic Information System (GIS) technologies in evaluating the dynamics of glacial retreat and snow cover changes in the region, focusing particularly on the effects of climate change. Climate change, characterized by rising temperatures and altered precipitation patterns, is driving the accelerated melting of glaciers, which significantly impacts water resources, local agriculture, and ecosystems. Remote sensing technologies, including satellites such as Landsat, MODIS, and ASTER, enable the monitoring of glacier boundaries, surface temperature, and snow cover changes over time, providing valuable insights into the extent of glacial retreat. Synthetic Aperture Radar (SAR), particularly from Sentinel-1, is also used to monitor glacier movement and surface deformation.

GIS facilitates the integration of remote sensing data, enabling detailed analysis of glacier dynamics, including change detection and volume calculations. By analyzing spatial data, GIS tools offer insights into how retreating glaciers and reduced snow cover affect the region's hydrology, particularly in relation to snowmelt runoff and water availability. Studies have shown significant reductions in snow cover and glacier volume in Kashmir, with temperature increases and altered seasonal snowmelt patterns contributing to these changes.

1. Introduction

The Kashmir Valley situated in the northernmost region of the Indian subcontinent, is well known for its spectacular mountainous terrain containing several large glaciers that provide freshwater to numerous rivers in the region. Glaciers are integral to the hydrology of the region, serving as a key source of freshwater that sustains both the agricultural economy and local ecosystems (Mir et al., 2017). However, these glaciers are facing accelerated retreat due to the ongoing effects of climate change. Rising temperatures and altered precipitation patterns are contributing to the faster

than usual melting of glaciers, resulting in the loss of glacier volume and a reduction in snow cover (Ganjoo et al., 2020).

In order to better understand and quantify these changes, scientists have turned to modern technologies such as Remote Sensing (RS) and Geographic Information Systems (GIS). Remote sensing provides valuable spatial data through satellite observations, while GIS offers analytical tools to process and interpret these data (Liu et al., 2018). Through these technologies, scientists have been able to monitor glacier dynamics, track changes in snow cover, and assess the potential hydrological impacts of glacial retreat (Bisht & Rawat, 2018).

This review paper seeks to explore the current state of research on glacier dynamics and snow cover changes in Kashmir using RS and GIS technologies. It focuses on the affected regions within Kashmir, highlights the role of remote sensing technologies in tracking glacial retreat, and discusses the role of GIS in analyzing the resulting environmental changes.

2. The Kashmir Region and Its Glaciers

The Kashmir region, which forms part of the larger Himalayan Mountain range, is home to many large glaciers, including the **Siachen Glacier, the Gangbal Glacier, the Kolahoi Glacier, and the Haramukh Glacier.** These glaciers are located in the higher reaches of the Pir Panjal and Zanskar ranges, which dominate the topography of the region. Glaciers in these areas serve as a primary source of freshwater, particularly during the dry season when snowmelt feeds rivers like the Jhelum, Chenab, and Indus (Frey et al., 2013). Important glaciers of Kashmir are:

- **Siachen Glacier**: Located in the Karakoram range, the Siachen Glacier is one of the largest glaciers outside the polar regions. It has been a subject of scientific study for several decades due to its importance in understanding glacier dynamics in a high-altitude, arid environment (Azam & Singh, 2021).
- **Kolahoi Glacier**: Situated in the Pir Panjal range, this glacier is considered the lifeline of the region, feeding the Lidder River, which flows into the Jhelum River. Changes in the Kolahoi Glacier's size and volume significantly impact the water availability for agriculture and hydropower production (Kumar et al., 2019).
- **Gangbal Glacier**: Located near the popular alpine lakes in the Ganderbal district, this glacier is a key source of water for the region's agricultural sector. Its retreat is alarming as it directly impacts the local freshwater supply (Khan et al., 2017).

- **Haramukh Glacier**: Situated in the northern part of the Kashmir Valley, this glacier also feeds the Jhelum River. The glacier's retreat has been identified as a major concern for the valley's water supply (Wani & Ahmad, 2018).

These glaciers, along with others in the region, are shrinking at an alarming rate due to climate change, leading to significant alterations in the regional hydrology (Hussain et al., 2018).

3. Climate Change and Glacier Retreat

The impacts of climate change on glaciers in Kashmir are most visible in the form of rising temperatures and altered precipitation patterns. Studies have shown that the region has experienced a marked increase in temperature over the last few decades, especially during the summer months. The rise in temperature accelerates the melting of glaciers and leads to earlier snowmelt, reducing the amount of water available during the dry season (Frey et al., 2013; Kaur et al., 2019).

In addition to temperature rise, changes in precipitation patterns, specifically the reduction in snowfall and the shift in precipitation from snow to rain are also contributing to glacier retreat. While the region has witnessed a decline in annual snowfall, more precipitation is falling as rain, particularly at lower altitudes. This reduces the potential for snow accumulation and glacier formation (Mir et al., 2017).

The accelerated melting of glaciers in Kashmir has significant consequences for local water resources. As glaciers retreat, the volume of water stored in them diminishes, leading to a reduction in the volume of seasonal meltwater that feeds rivers during the summer months. This has a direct impact on agriculture, as many regions depend on snowmelt for irrigation during the dry season (Sharma & Tiwari, 2019).

The shrinking glaciers also affect the region's hydropower potential. As the glaciers shrink, the discharge from glaciers that feed hydropower stations may diminish, affecting energy production (Kaur et al., 2019). Additionally, the loss of glacier mass can lead to changes in river flow patterns, resulting in increased flooding risks and reduced water availability during critical periods (Bisht & Rawat, 2018).

4. Role of Remote Sensing in Monitoring Glacier Dynamics

Remote sensing is an effective tool for monitoring glacier dynamics and snow cover changes in Kashmir. Remote sensing technologies provide critical spatial data that allow for the analysis of glacier area, volume

changes, surface temperature, and snow cover extent over time (Zhang et al., 2020).

4.1 Satellite-Based Remote Sensing Technologies

The following satellite-based remote sensing platforms have been extensively used to monitor glaciers and snow cover in the Kashmir region:

- **Landsat Satellites**: The Landsat program, managed by NASA and the U.S. Geological Survey (USGS), provides a long-term archive of multispectral imagery that has been invaluable in tracking glacier dynamics. Landsat's thermal infrared sensors offer data on surface temperature, which is crucial for monitoring glacier melting (Chakraborty et al., 2020).
- **MODIS (Moderate Resolution Imaging Spectroradiometer)**: MODIS, aboard NASA's Terra and Aqua satellites, provides frequent observations of snow cover and glacier extent. MODIS offers daily data, making it particularly useful for monitoring seasonal snow cover changes and identifying trends in snowmelt timing (Liu et al., 2018).
- **ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer)**: ASTER provides high-resolution thermal and optical data, making it valuable for mapping glacier morphology and assessing surface temperature changes. ASTER's ability to capture fine details of glacier topography allows for more precise monitoring of glacier changes over time (Azam & Singh, 2021).

4.2 Synthetic Aperture Radar (SAR)

SAR, particularly from the Sentinel-1 mission by the European Space Agency (ESA), is a key remote sensing tool for monitoring glacier movement and surface deformation. Unlike optical sensors, SAR is capable of capturing data during both day and night, irrespective of weather conditions, making it ideal for monitoring glaciers in the cloudy Kashmir region. SAR data has been instrumental in tracking the velocity of glaciers, changes in ice flow, and glacier surface deformation, which are key indicators of glacial dynamics (Bisht & Rawat, 2018).

5. Role of Geographic Information Systems (GIS)

GIS provides a platform to integrate, analyze, and interpret remote sensing data in the context of glacier dynamics and snow cover changes. GIS technologies are widely used for change detection, volume loss estimation, and hydrological modeling (Sharma & Tiwari, 2019).

5.1 Change Detection and Glacier Retreat Mapping

Change detection techniques in GIS, using multi-temporal satellite images, allow researchers to quantify the rate of glacier retreat. By comparing images from different time periods, scientists can determine the extent of glacial shrinkage and track how glaciers in Kashmir have changed over several decades. This method is particularly useful for glaciers like the Siachen and Kolahoi, where changes are dramatic (Kumar et al., 2019).

5.2 Glacier Volume Estimation

GIS tools can integrate Digital Elevation Models (DEMs) with remote sensing data to estimate glacier volume and track volume loss over time. This is achieved through methods such as volume-area scaling, which relates the surface area of a glacier to its volume. GIS-based modeling helps estimate how much ice has been lost and predict future glacial volume changes (Ganjoo et al., 2020).

5.3 Hydrological Impact Assessment

GIS is an essential tool in assessing the hydrological impacts of glacier retreat in Kashmir. By integrating glacier data with hydrological models, GIS can simulate the effects of glacial retreat on river discharge and water availability. GIS models allow researchers to predict how the reduction in glacier volume will impact the timing and volume of river flows, particularly during the dry season when snowmelt is crucial for maintaining water supply (Bisht & Rawat, 2018).

6. Affected Regions in Kashmir

While glacial retreat is occurring across the entire Kashmir region, some areas are more heavily affected than others. These include:

- **Siachen Glacier Region**: The Siachen Glacier, located in the Karakoram range, has experienced significant volume loss. As one of the largest glaciers in the region, its retreat is of great concern to both local and international stakeholders, especially given its location near politically sensitive borders (Azam & Singh, 2021).
- **Pir Panjal Range**: Glaciers such as Kolahoi and Gangbal, situated in the Pir Panjal range, have experienced considerable retreat in recent decades. The retreat of these glaciers has direct implications for the water supply to the Kashmir Valley, particularly for the Lidder River (Kaur et al., 2019).
- **Himalayan Range (North Kashmir)**: Glaciers in the northern part of Kashmir, such as the Haramukh Glacier, are also showing signs of

retreat. These glaciers feed into the Jhelum River, which is crucial for the water supply of the valley (Wani & Ahmad, 2018).

7. Conclusion

Glaciers in the Kashmir region are retreating at an alarming rate due to the effects of climate change, particularly rising temperatures and altered precipitation patterns. Remote sensing and GIS technologies have proven to be invaluable tools for monitoring glacier dynamics, snow cover changes, and assessing the impacts on hydrology and water resources. This review has provided a comprehensive overview of the role of these technologies in tracking glacier retreat in Kashmir and highlighted the regions most affected by these changes. Future research should focus on improving the integration of remote sensing and GIS data with regional climate models to better predict future glacier changes and their impacts on water resources and local ecosystems.

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