A TEMPORAL ASSESSMENT OF THE ALTITUDINAL DYNAMICS AND AREA OF GLACIERS IN THE NORTHERN PAKISTAN

Submitted by: Rahman Gul (PhD Scholar, NCEG)

Supervisor: Dr. Saad Khan

Co-Supervisor: Dr. Muhammad Ali

Abstract

Mountain glaciers are a freshwater reserve in high mountain Asia and are the major sources for Pakistan's hydrological system, which are vulnerable to global warming. The safety of vital infrastructure and the long-term feasibility of local populations residing in the basin are at risk due to changes in glacier-related resources and risks brought about by recent global warming. In the high peak ranges, including the Himalayas, Karakoram, and Hindukush (HKH), stream/river water supplies are directly affected by change in the rate of glaciers melting. However, focusing on the challenging terrains of Himalayan and Karakoram glaciers, processing of the data from spatial observations are quite challenging because of the limited Spatio-temporal exposure and data scarcity. Particularly, climatology of the HKH region has high variations as the eastern and southern portions are generally under the effect of monsoon while western and northern portions are frequently affected by the westerlies. The HKH, in the Northern areas of Pakistan comprises the longest glacial mountains, are particularly subjected to these unprecedented impacts. In addition, monsoon, the westerlies, elevation impacts, debris covered glaciers features and dynamics, and environmental surroundings are other factors that can affect glacier oscillations. However, according to the glaciation mass balance established during the 2000 year for the entire Hindukush Karakoram and Himalaya area, these glaciers are at risk due to their six-fold decline. Because of their regional significance as a primary source of available water and for prospective water management, the HKH glaciers require continuous assessment both on spatial and temporal basis, comprising a portion of the extensive and substantial glaciers in the biosphere. The major valley glaciers of this region are the Biafo, Siachen, and Baltoro glaciers, covering an area of 540, 750, and 535 km2, respectively. Therefore, this glaciated zone is very crucial for investigating dynamics related to past changes, as well as to the establishing and confirming the consequences of current climatic and environmental transformations and their manifestation in the spatio-temporal evaluation of the glacier dynamics.

In this study, we investigated the dynamics of three important glaciers in the Hunza river basin (Western Karakoram) from the perspective of temporal evolutions, snout variations, and statistical analysis-enhanced assessment of climate trends using monthly-based remote sensing data for the years 2016-2021. Digital Elevation Model and Sentinel-2 satellite images (cloud free) of minimum snow cover season were processed in GIS environment. The glacier covered area was evaluated with respect to temperature and the results depicts rise in temperature and decreasing tendency of glaciers. Higher glacier retreat was observed in the Hinarche glacier by -3.1% as compared to Barpu and Bualtar glaciers by -2.9% and -1.8 %, respectively. From 2016 to 2020, an extreme decrease of the terminus position was noted as 192 m in Barpu glacier, 108 m in Bualtar glacier, and 255 m in Hinarche glacier. Maximum advances in Barpu glacier (305 m

in March 2019) and a highest retreat in Bualtar and Hinarche glaciers of 298 m were found in March, 2021. The results and the methodology of the present study provides valuable information, and an applicable and insightful approach for further regional studies of climate change impacts on glaciated zones.

About 2000 kilometers long Himalayan region hosts thousands of glaciers which covers around about 40,000 km^2 as per last update in September 2021. Estimation of snout variation positioning, statistical analysis of climate trends, and the Equilibrium Line Altitude (ELA) of most of the glaciers is challenging due to the rough terrain, higher altitudes and scarcity of Spatio-temporal field observations. Moreover, without the climatic data and separating contour between glacier's accumulation and ablation zones, estimation of the net variation in glacier mass loss or gain over a fixed year, leads to ambiguous results. Therefore, a quarterly trend analysis was carried out on climate data (temperature and precipitation) and river discharge to evaluate the climate pattern in the Astore Basin. Moreover, this study uses the accumulation area ratio, AAR (0.6 ±0.5) (used for high-altitude mountain glaciers), and accumulation area balance ratio, AABR (2.24 ±0.9) with an interval of 0.05 and 0.01 to estimate ELAs, respectively. The results show that the Bazhin glacier retreat (-2.1 km^2) as compared to the Chhongpher (-1.1 km^2) and Chongra (-1.2 km^2) glaciers. A maximum retreat of the snout position of Bazhin glacier was 1595 m, 3260 m in Chhongpher glacier, and 960 m in Chongra glacier. An increase in the ratio of annual AAR from 0.4 to 0.8 results in reductions of the accumulation area of three major glaciers in the study area. We conclude that the largest glaciers (e.g. Bazhin, Chhongpher and Chongra) stretched between lower to higher altitudes are likely to be more vulnerable, due to the highest AAR and AABR values reported between 5000-5600 meters above sea level (masl). However, the ice-lost estimates vary greatly depending on their three-dimensional surfaces.

Additionally, this study investigates the impact of black carbon (BC) on glacier albedo in the Himalaya and Karakoram regions. Environmental pollutants are an increasingly important problem due to their impacts on the cryosphere and the ecosystem. In the Himalaya and Karakoram region, mountain glaciers are receding and are projected to continue doing so as concentrations of black carbon (BC) and other air pollutants increase, contributing to global warming. Concentrations of BC and air pollutants were evaluated between June 2019 and May 2020. The Himalayas and Karakoram two glaciers have all had an inventory of various contaminants taken using Aeroqual 500 and TSI DRX 8533 which are fallow as: ozone absorption in Karakoram and Himalaya was 27.40 ± 4.87 and 35.05 ± 5.98 µg/ m3, Himalayas highest average CO_2 (265.03 ± 33.29 ppm), followed by Karakoram at 198.81 ± 40.44 ppm. Sulfur dioxide with average values of 3.15 ± 1.01 and 2.25 ± 0.85 ppm for the Himalaya and Karakoram, respectively. At Hinarche glacier (Karakoram), BC concentrations were noted as 2.38µg/ m3 in June 2019, 1.6µg/ m3 in October 2019, 2.18 µg/ m3 in December 2019, and 4.22 µg/ m3 in May 2020. At Bazin glacier (Himalaya) it was 0.058 µg/ m3 in June 2019, 0.032 µg/ m3 in October 2019, 0.031µg/ m3 in December 2019, and 0.041µg/ m3 in May 2020. A combination of satellite-based white-sky albedo (WSA) and the DRI Model 2015 Multi-Wavelength Thermal/Optical Carbon Analyzer was used to determine BC. The average BC values recorded at Himalayan and Karakoram glaciers were 23.75± 0.80 µg/ m3 and 23.75± 0.80 µg/ m3, respectively, whereas the average values of WSA at the sampling time (same as black carbon) along with the standard deviation of 0.0272 and 0.0191 (μg/m3) for the Karakoram and Himalayas, respectively. The relationship between WSA and BC concentrations at Himalaya Karakoram glaciers indicates an inverse correlation, with increased BC concentrations leading to decreased WSA and glacier surface warming.