Technical Reports on Gangju La Glaicer

September-October 2019

Cryosphere Services Division
National Center for Hydrology and Meteorology

dGPS	differential Global Positioning System
FY	Fiscal Year
IDW	Inverse Difference and Weight
MSI	Multi Spectral Instrument
TBM	Temporary Benchmark
w.e.a^{-1}	Water equivalent per annum

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1. Introduction

Climate change refers to the long term change in the climate pattern encompassing oceans, land and ice sheets. It is a global concern that has the potential to lead to inevitable devastating consequences. Various anthropogenic activities are responsible for contributing to the growth of climate change.

Increased glacial lakes have been observed in Nepal and other Himalayan countries as a consequence of climate change (Chalise et al. 2006). According to Haeberli (2013), modern developed technologies and software encompass glaciers as the key indicator for climate change by demonstrating changes with the ongoing atmospheric traits. Therefore, it is important to monitor the mass balance of glaciers for its sustenance and long-term behavior.

Mass-balance data from the glaciers of Bhutan is very limited. The first program to monitor the glaciers of Bhutanese Himalaya was carried out in the late 1990s in collaboration with foreign institutes like Nagoya University, Japan and University of Vienna, Austria. Since then only longitudinal retreat were monitored and no specific mass balance on glaciers were reported until 2003 (Tshering & Fujita, 2016).

Gangju La glacier located in the headwater of Pho Chhu *(Chhu= river*) has been identified for mass balance studies in 2002 and 2003 deploying glaciological methods, installing stakes and approach using geodetic methods like differential Global Positioning System (dGPS) was used. Similar observation was conducted in 2014 after seven years of gap (Cryosphere Service Division, 2018). In the same line, mass balance study on the Benchmarked glacier was carried out by the National Center for Hydrology and Meteorology Annually from 2017, 2018, and continued the same program as per planned activity of FY 2018-19 of Cryosphere Service Division in 2019.

In this work, we present geodetic mass-balance of Gangju La glacier, determined by dGPS (Trimble R-10 2) method using Tshering.P et al 2010.

2. Objective

The main aim of field visit is to:

1. Conduct annual glacier mass balance on the Gangju La (benchmark glacier).
2. Set TBM near the Base camp

3. Study Area

3.1 Location

Gangju La glacier is located in the Northern frontier of Bhutan at 27.94°N, 89.95°E (Figure 1.) with an approximate area of 0.215km^2 (Tshering & Fujita, 2016). Gangju La glacier is one of the land-terminating glaciers in Bhutan. This type of land terminating glacier is a very important feature since the mass-balance of land-terminating glaciers are directly related to prevailing climate change. This Clean ice glacier extends from elevation of 4900 to 5200 m.a.s.l., referred to as “Pho_gr16” in inventory made by Mool and others (2001).

3.2. Accessibility

This glacier can be accessed via two routes; the first route is via Gasa –Laya- Tarina – Gangju La, which takes seven days on foot. While the other route is via Tshorimzam – Goenshari – Gangju La and takes five days to reach the study site. Unlike all other glaciers, Gangju La glacier can be accessed easily, except during winter and summer monsoon season. However, the team has visited during the month of September-October, when snow and weather conditions at glacier sites are better than any of the seasons in a year.

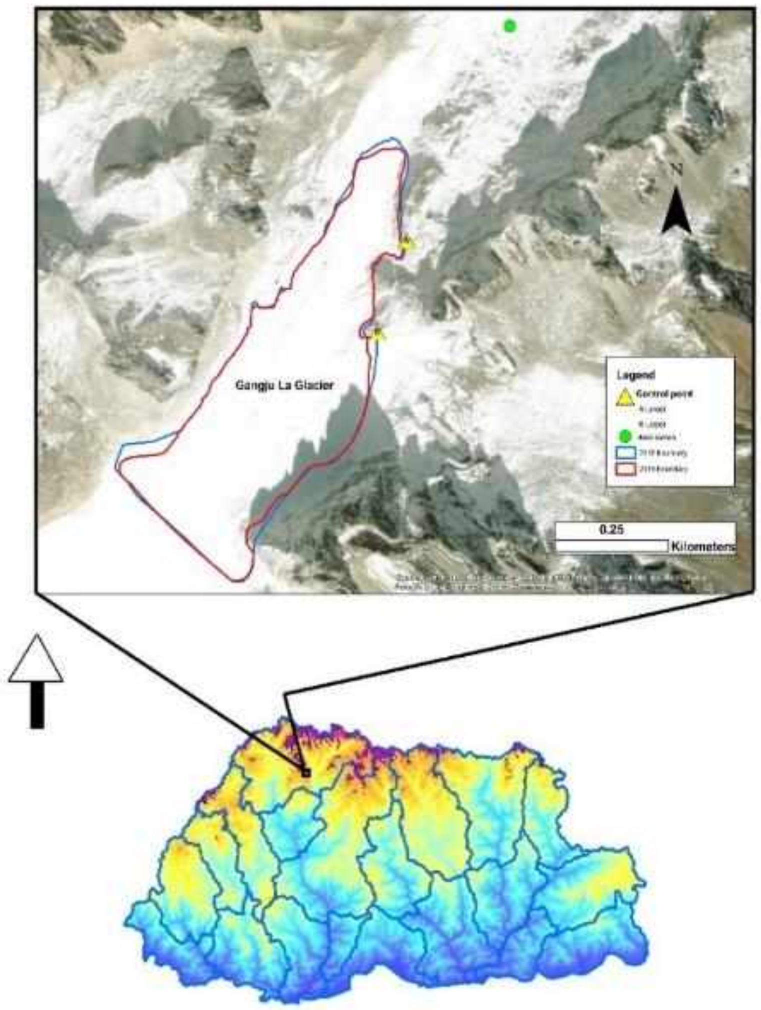

Figure 1 Location of Gangju La Glacier at 27.94^0 N,89.95^{0}E in the Northern Frontier of Bhutan

4. Data and Methodology

4.1 Data Acquisition

Measuring mass balance by direct method is a conventional method where annual mass balance is determined by measuring the stake changes for consecutive years. (Tshering & Fujita, 2016). Measuring mass balance by direct method has become impossible for this glacier, as the study site here falls through the walkway of Khatoed-Lunana people as result damaging the installed stakes.

In this regard, Annual Mass Balance of Gangju La glacier was carried out using geodetic method (differential Global Positioning System). During the survey, glacier surface elevation has been measured using differential Global Positioning System (Trimble R10-2). The base station was installed during each field campaign, which is < 1km from all survey points. The Base station here is set-up in Fast-Static mode with a logging interval of 1s and kept for at least 2 hours before commencement of survey work. A rover antenna was mounted on a backpack (Figure.2c) to survey the glacial surface by walking. The logging distance of 1m with a logging interval one second was set for all surveys in continuous Topo mode. Points were collected on the glacier by walking across the glacier making several profiles covering the whole length of the glacier surface. Profiles were made one through the main centerline of glacier and others in zig-zag manner on the glacier surface (Figure.2d). The same path of 2019 was followed for this year to get more connecting points and new additional paths were collected for future reference.

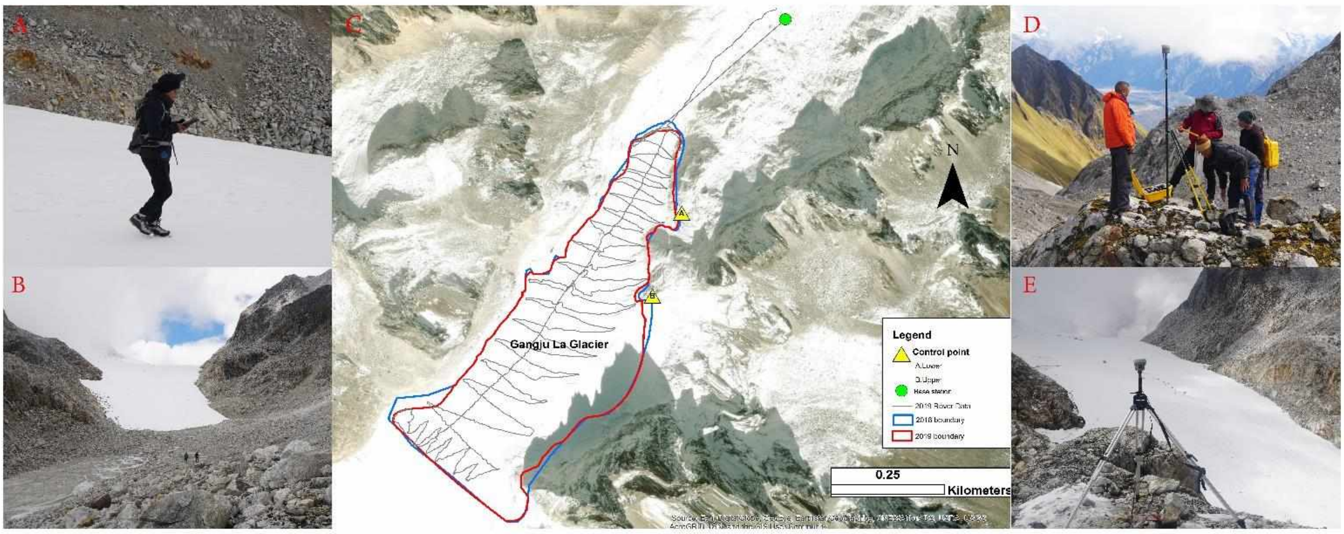

Figure 2. A) Collecting of data on Rover Mode (Continuous Topo) B) Gangju La Image 2019 from Photo point. C) Survey profile of Gangju La glacier overlaid on Online ArcGIS Base map. D) Setting up of Base Station in Fast-Static mode near the base camp. E) Collecting Control Point in Fast-Static Mode

4.2 Data Post Processing.

The raw data obtained in Trimble TSC7 as discussed in section 3.1.1 is were first analyzed and exported in csv using the Trimble access software inbuilt in the rover Trimble TSC7 controller.

This obtained data was checked for quality in excel sheet. This data is integrated to construct Digital Elevation Model (DEM), for the year 2018-19. 1 m DEM is generated from dGPS data, using inverse distance weighting (IDW) interpolation tool in ArcGIS with search result of 0.7 m. The DEMs produced this year and the last years DEM should have the same reference grid, and their difference provides change in elevation in each grid point. This technique of change in elevation is calculated using DEM differencing technique of two consecutive years using map algebra tool in ArcGIS.

The change in elevation is exported to excel sheet and cleansed to find average change of elevation i.e. Δh_g for every altitudinal band. The annual mass balance (geodetic) at a point is calculated following Tshering and Fujita, 2016 as follows:

$$b_g = \frac{\Delta h_g \rho_i + (S_{t2} - S_{t1})(\rho_s - \rho_i)}{(t2 - t1)} \qquad (1)$$

Where; b_g is the annual mass balance at a given point by the geodetic method (kg m^{-2} a^{-1} equivalent to mm w.e.a^{-1}).Δh_g is the elevation change (m) obtained from different DEMs.ρ_s and ρ_i are density of snow and ice (kg m^{-3}) respectively, where $\rho_s$is assumed to be 400 ± 100 kg m^{-3} and ρ_i is assumed to be 880 ± 30 kg m^{-3}. S_{t2} and S_{t1} are the thickness of snow (m) for years t_1 and t_2. t_2 are referred to recent year and that of t_1 for the past year.

From equation 1, the result obtained is the mass balance at a given point. So, to obtain the area averaged annual mass balance, area was calculated from the number of counts of pixels obtained from the IDW of DGPS data. Finally, the area averaged annual mass balance ($\overline{b_g}$; mm w.e.a^{-1}) estimated by:

$$\overline{b_g} = \frac{\Sigma_z A_z b_{gz}}{A_T} \qquad (2)$$

Where; A_z and A_T are glacier areas within 50 m altitude band and total area (m^2) respectively. Regarding the area (A_z), the average of the area within 50 m altitude band of two different survey years is considered.b_{gz} is the average mass balance within 50 m altitude band.

4.3 Hypsometry

In order to map the glacier boundary, recently available free Sentinel-2 image of 2019 has been used for delineating the boundary of glacier. The terminus of the glacier was mapped using the DGPS data collected during field survey. In order to get the hypsometry, the 1m DEM data from this year's field survey was used and extracted superimposing 2019 glacier boundary polygons on it as shown in Figure 3a&3b. Figure 4 shows altitude band wise distribution of glacier. Comparing the altitudinal glacier distribution between 2017, 2018 and 2019, the glacier has suffered a heavy mass loss in elevation band 5125 ,5075, and 4925. However, the terminus shows gain in elevation over 5025,4975,4875. However, the overall glacier surface area shows a net loss of 4.31724 % of the total glacier surface area.

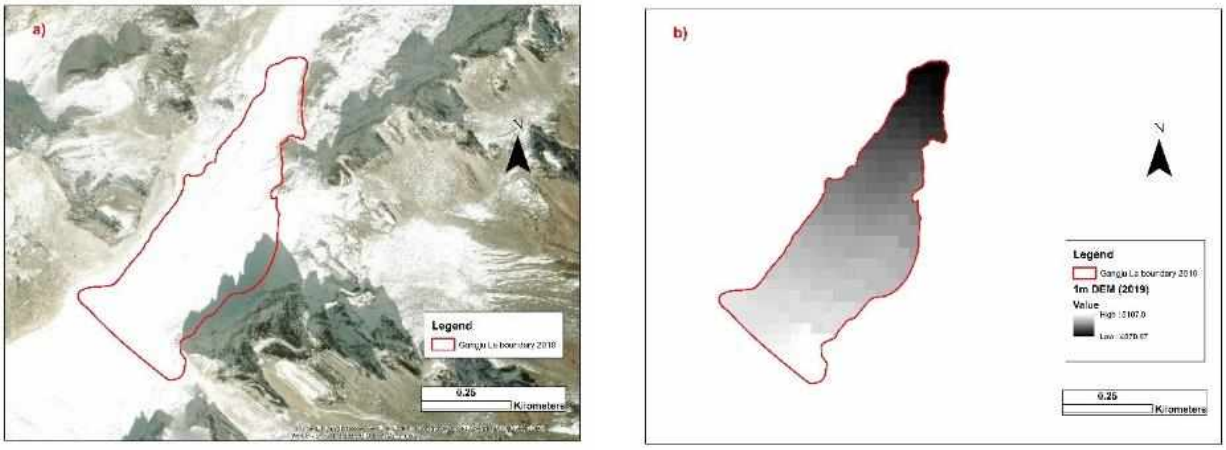

Figure 3. a) Gangju La glacier boundary overlaid on ArcGIS Base map .b) with this delineated boundary and 1m DEM of 2019 is extracted.

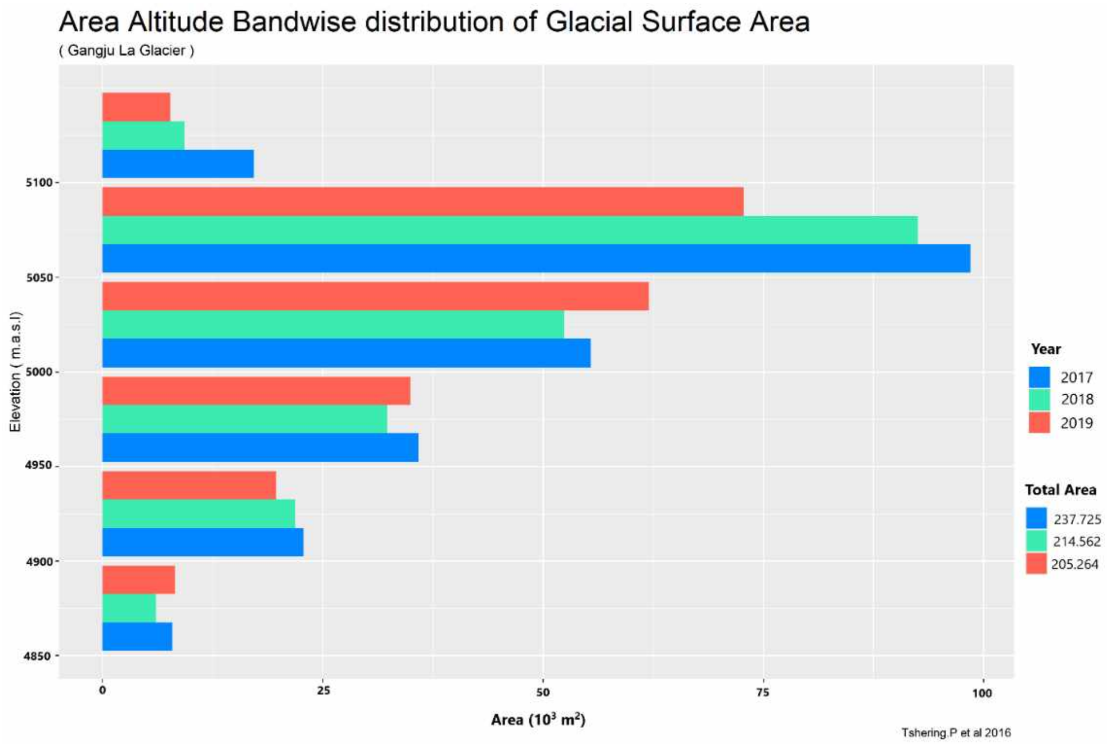

Figure 4. Area Altitude band wise distribution of glacier surface area. Green, Blue and Red bars are surface areal distribution in 2017 (Blue), 2018 (Green) and 2019 (Red) respectively.

4.4 Snow Measurement

During the 2017 survey, the glacier surface was bare ice without any snow. During 2018, surveys of the snow depth are taken through the central line of glacier after a certain interval because there was no stakes or any reference point from where snow depth was to be measured. This year the Snow depth was taken through random points throughout the glacier using the Trimble R-10 for the coordinates. This Figure 5. Shows the linear regression of snow depth with altitude.

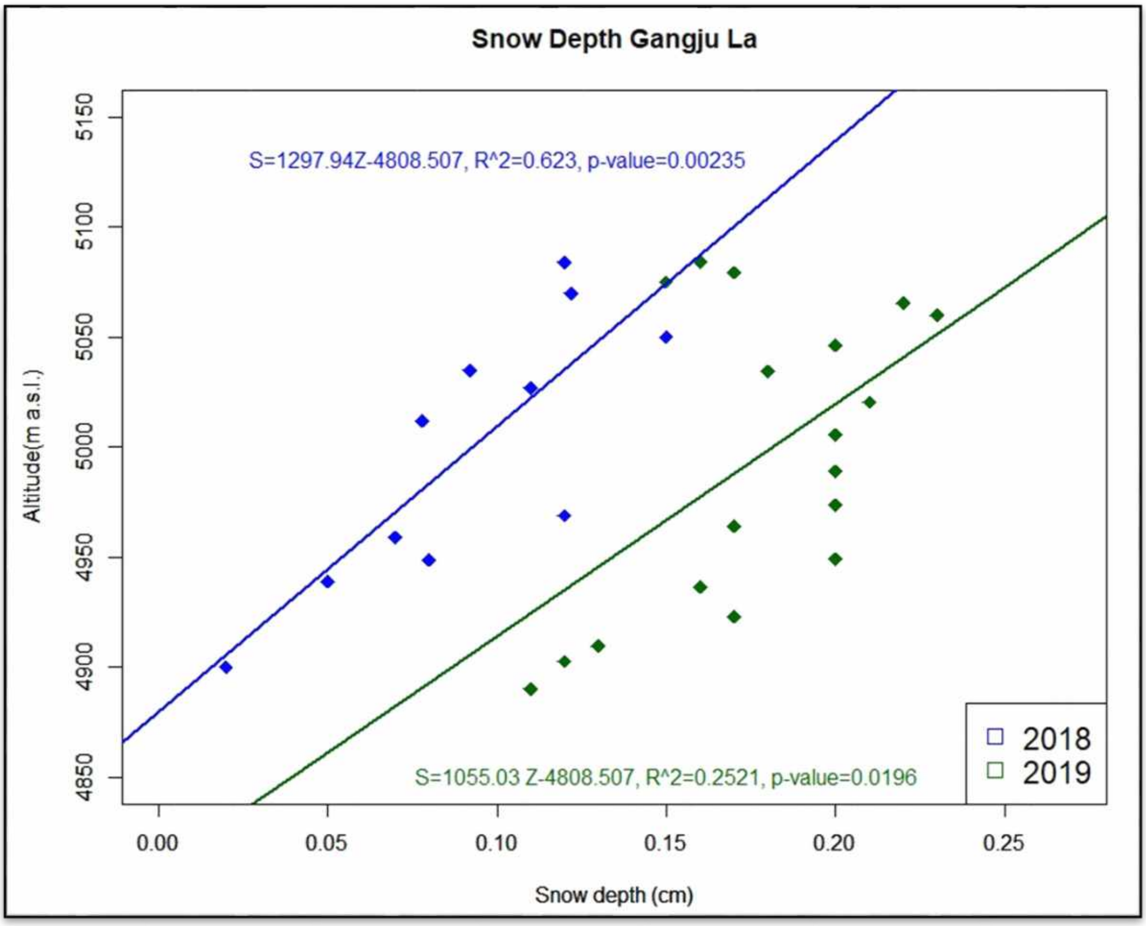

Figure 5 Linear regression of snow depth distribution of Gangju La glacier. Blue dots are the snow depth for 2018 and green dot snow depth for year 2019. The recessional line was then used to find the snow at each elevation.

5. Result

Earlier observation has shown that the Gangju La glacier exhibits negative mass balance since 2003. As reported by Phuntsho and team in 2017, the maximum surface lowering at lower altitude and lesser in higher altitude. The annual area-averaged glacier mass balance of Gangju La was reported to be -1350 mm w.e.a^{-1} from 2014-2017. While glacier terminus is retreating at a rate of 13.6m per year. However, with continuity in data collection from 2017 and 2018 it shows a mass balance rate of -2390$\pm$201.96 mm w.e. a^{-1}. This year's Glacier mass balance was found to be -**1470.5 $\pm$ 272.074 mm w.e.a^{-1}** with a terminus retreat rate of **13.4 m**.

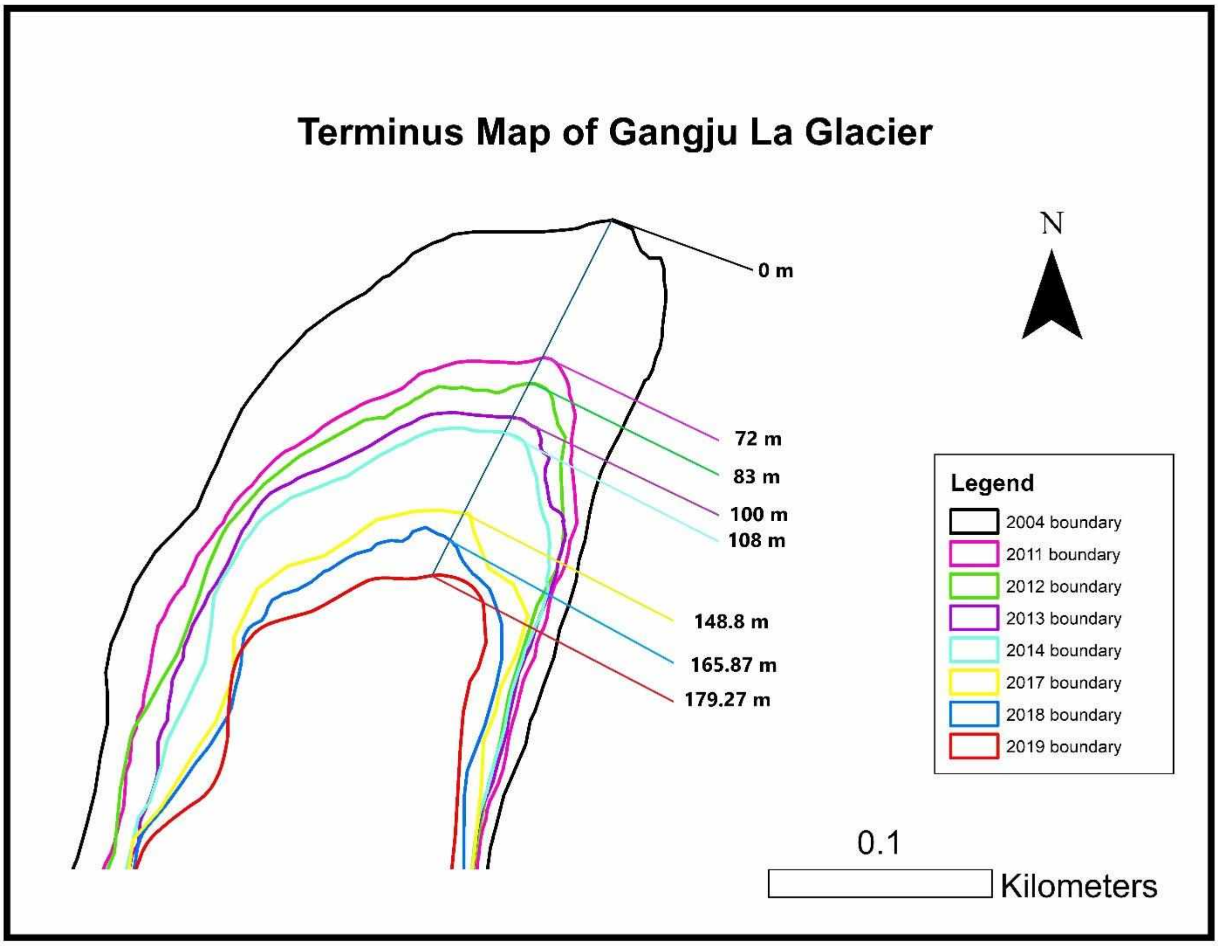

Figure 6. Terminus Map of Gangju La from 2004 to 2019.

6. Cumulative Glacier Mass Balance

The Cumulative Glacier Mass Balance of Gangju La glacier since 2003 (figure 8) exhibits linear receding line from 2004-2011 as there were no field data during that time interval. Annual glacier mass balance was arranged exhibiting through linear cumulative balance. The similar calculation was done in 2014-2017 where annual glacier mass balance was arranged. The figure shown below is the Cumulative Glacier Mass Balance of Gangju La Glacier since 2004.

Period	Annual Glacier Mass Balance (mm w.e.a^{-1})	Cumulative Glacier Mass Balance (mm w.e)
2004	-1230	-1230
2005	-1790	-3020
2006	-1790	-4810
2007	-1790	-6600
2008	-1790	-8390
2009	-1790	-10180
2010	-1790	-11970
2011	-1790	-13760
2012	-2040	-15800
2013	2020	-13780
2014	-1110	-14890
2015	-1350	-16240
2016	-1350	-17590
2017	-1350	-18940
2018	-2390	-21330
2019	-1470.5	-22800.5

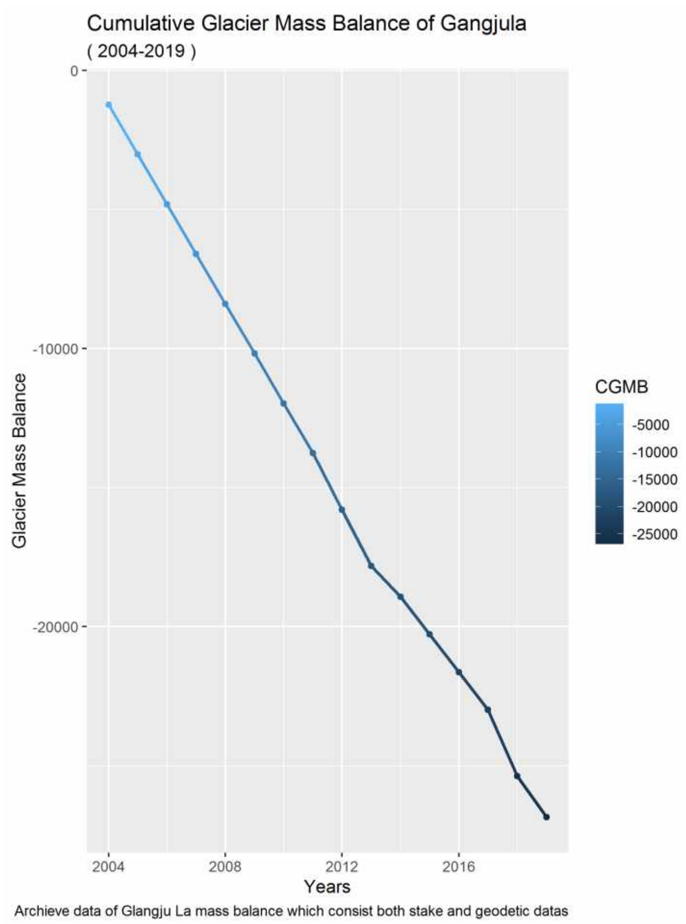

Figure 7. Cumulative Glacier Mass Balance of Gangju La Glacier from 2004 till 2019

7. Uncertainty Estimation

The mass balance of area average is assumed to associate with three types of uncertainties including uncertainty from the mass balance at each altitudinal band (db_z; mm w.e.a^{-1}) uncertainty from the boundary delineation (dA_z ;m^2), and uncertainty from the density assumption for ice and snow(db_ρ;mm w.e.a^{-1}). Uncertainties value depicts that the area average mass balance can vary with plus or minus of that value. It is calculated using the formula as per Tshering and Fujita, 2016;

$$\sigma = \frac{\sum A_z\, db_z + \sum dA_z |b_z| + \sum A_z\, db_\rho}{A_T} \qquad (3)$$

$$SD = \sqrt{\frac{1}{N}\Sigma(bz-\overline{bz})^2} \quad (4)$$

The uncertainty from the area average mass balance is the standard deviation (SD) of the mass balance at each altitude band. It is calculated as shown in equation 4. The uncertainty from the boundary delineation (dA_z) is calculated as half of pixel of Sentinel 2 MSI image (*10 m resolution*) multiplied by perimeter of boundary delineated at each 50 m altitudinal band. Moreover, the last uncertainty that is from density assumption for ice and snow (db_p), density uncertainties was assumed as 30 kg m^{-3} for ice and 100 kg m^{-3} for snow. From these two uncertainties are found and averaged to be considered as uncertainty from density assumption. A_z is the area within a 50m altitudinal band, A_T the total area and $|b_z|$ is the absolute mass balance.

The uncertainty estimation was **272.074** mm **w.e.a^{-1}**, which signifies that the area average mass balance for the glacier for the year 2019 can vary by ±272.074 mm w.e.a^{-1} i.e. the annual area-average mass balance is **-1470.5 ±272.074 mm w.e.a^{-1}**.

8. Conclusion

The field survey was carried out as part of annual glacier monitoring program for the fiscal year 2018-2019. In-situ geodetic method was used to measure glacier surface elevation change. The finding shows that Gangju La glacier has experienced disequilibrium and lost its mass continuously with an annual Glacier Mass balance of**-1470.5 ± 272.074** mm **w.e.a^{-1}**. Moreover, the glacier terminus has retreated at the rate of **13.40 m in 2019**.Comparing this with the previous reports, the total amount of glacier terminus retreated was **179.27m** from 2004 till date. Details of the annual terminus retreat are as follows:

- 70 m from 2004-2011
- 13 m from 2011-2012
- 17 m from 2012-2013
- 8 m from 2013-2014
- 40.8 m from 2014-2017
- 15.07 m from 2017-2018
- 13.40 m from 2018-2019

With the glacier being ablated every year, the Gangju La glacier shows a cumulative mass balance of **- 26840.5 mm we** from 2004 until 2019 and hence shows a declining trend in cumulative graph shown in figure 7. Statically the slope gradient of -1700.53 from the cumulative glacier mass balance indicate an annual glacial mass balance rate of -1700 mm w.e a^{-1} from 2004 till 2019.

9. Recommendation

As per the finding from current field program, team would recommend following:

- Only in-situ geodetic method is feasible for Gangju La glacier as this glacier comes in direct interference with human and direct methods like installation of stakes are not feasible for survey purpose in future.
- Since the present glacier is experiencing continuous loss in mass throughout the glacier surface, for long-term studies Center must explore new benchmark glaciers, but this glacier should be continuously monitored to get a glacier mass balance trend, which will be an important assert for Bhutan.
- With the upgrade of Equipment (Trimble R-10 2) this field survey found the highest number of points that intersected last year's point, so will recommend the field survey team to use this year's path as reference path in your Trimble Job while collecting the Continuous Topo data's in the following years to come.

10. References

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