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Geospatial Technique Based Glacial Inventory of Bhutan Himalayas, Bhutan

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Abstract

The glaciers of the Himalayan region have gained a lot of importance in the recent past as they play an active role in climate change. Keeping an account of the glaciers, which are considered as the store house of solid fresh water has become essential as they actively contribute to the perennial rivers of the country. This task of monitoring and delineating the glaciers of Bhutan Himalayas was therefore implemented by IRS LISS III, AWiFS and SRTM DEM data using Geographic Information System (GIS). The focus of the present study was towards inventorying the glaciers of Bhutan Himalayas and statistically analyzing the results of the various glacial parameters. It was inferred that, out of the total glaciated parts of the Brahmaputra Basin, 17.97% volume of ice was trapped in the glaciers of Bhutan sub-basin. The glaciers were further sub-divided into smaller units and classified into three physiographic divisions. This categorization helped in the better understanding of the glacier behavior according to the size - number ratio giving an important result that, maximum number (432) of glaciers with largest glacier size (50 sq. km. to 121 sq. km) were concentrated in the Chomolhari-Kulha Gangri region which is a part of the Greater Himalayas.

Keywords: Accumulation, Ablation, Orientation.

Introduction

The Himalayan Mountain range was sometimes termed as the "Third pole", as it equaled the icy cold conditions that existed in the Polar regions[1] and also had the largest agglomeration of snow and glaciers out of the two poles. Nowadays the Himalayan region has become a global hotspot for hydropower development and environmental management for the future. These glaciers which are a unique reservoir for water storage[2] not only enrich the rivers of the young fold mountains through their melt waters but they also provide direct source of information on climate change[3]. For that reason, studying their evolution becomes an important issue as glacier melt may significantly contribute to ongoing rise in sea level[4]. Therefore, a systematic, reliable and scientific health assessment of these glaciers is the need of the hour.

The initial step towards forecasting the future water resources of this area were to measure the ongoing glacier depletion[5]. This calculation was possible using certain climate series indicators (temperature and precipitation), but incase of the unavailability of this kind of data, use of certain other indicators like mass balance, changes in glacier length or areal extent will help to forecast the stored glacial resources[6,7].

Till the recent past the Himalayan glaciers were poorly sampled on the field because of the use of manual methods. With the advent of remote sensing techniques in glacial studies, extensive glacier mapping with utmost accuracy was possible[8-10]. Many government and private organizations along with large number of scientists throughout the world are working towards mapping the glaciers of the Eastern Himalayan region.

Thus, this present work aims to make a small contribution towards the glacier community by inventorying these glaciers and related features for the Bhutan Himalayas.

Materials and Methods

Study area: The area under study i.e. the Kingdom of Bhutan stretches between 27°N to 29°N latitude and 89°E to 92°E longitude with an aerial coverage of about 40210.63 sq. km. in the Eastern Himalayan region.

This small land-locked country with an east-west extent of 320 km. and a north-south coverage of 150 km. Figure-1 is geopolitically quite significant as it shares the international boundaries with China (Tibet) in the north and northeast and with the Indian sub-continent (between Assam-Bengal plains) in the east, west and south. Geomorphologically, the topography of the study area is quite sketchy, from the subtropical plains in the south to the sub alpine snow capped ranges in the north attaining heights of more than 7500 m.[11].

Regional sub-divisions made by R.L. Singh[12] were thus accepted and considered for the current study where the focus was on the three glaciated physiographic units. i. The Chomolhari-Kulha Gangri region (North), ii. The Trongsa region (West), iii. The Punakha-Thimphu region (East)

Methodology: Datasets used for Glacier Mapping: For the present study, Geocoded Indian Remote Sensing satellite datasets for the years 2006-2008 were referred for the end of ablation season which was from July to September. False Colour Composites (FCC's) of standard band combinations of Band 2 (0.52-0.59 µm), Band 3 (0.62-0.68 µm), Band 4 (0.77-0.86 µm) and Short Wave Infrared (SWIR) band (1.55-1.70 µm) of Linear Imaging Self Scanning (LISS) III and Advanced Wide Field Sensor (AWiFs) were used. Most of the mapping part was completed using the LISS III dataset but for some gap areas AWiFs data was also referred.

Inventory data of Bhutan sub-basin was created for each glacier in a well defined format with 37 parameters recommended by United Nations Temporary Technical Secretariat (UNESCO/TTS)[13] which also included elevation information, which was sought from the Digital Elevation Model (DEM) generated from the Shuttle Radar Topography Mission (SRTM) (Figure-2). Later 11 additional parameters were incorporated which contained information related to the glacial lakes.

Datasets used for Base map preparation: Collateral data such as Survey of Bhutan (SOB) topographical maps at 1:50,000 scale, trekking routes, guide maps, political maps were referred for the delineation of political boundary to define the study area. Drainage maps[14], Basin boundary maps from the Department of Survey and Land Records[15] were used to define the basin boundary and identify mountain ranges along with the network of streams and rivers flowing in the basin. Available Snow and Glacier maps (at 1:250,000)[16,17] were referred for identification of already mapped glacial data.

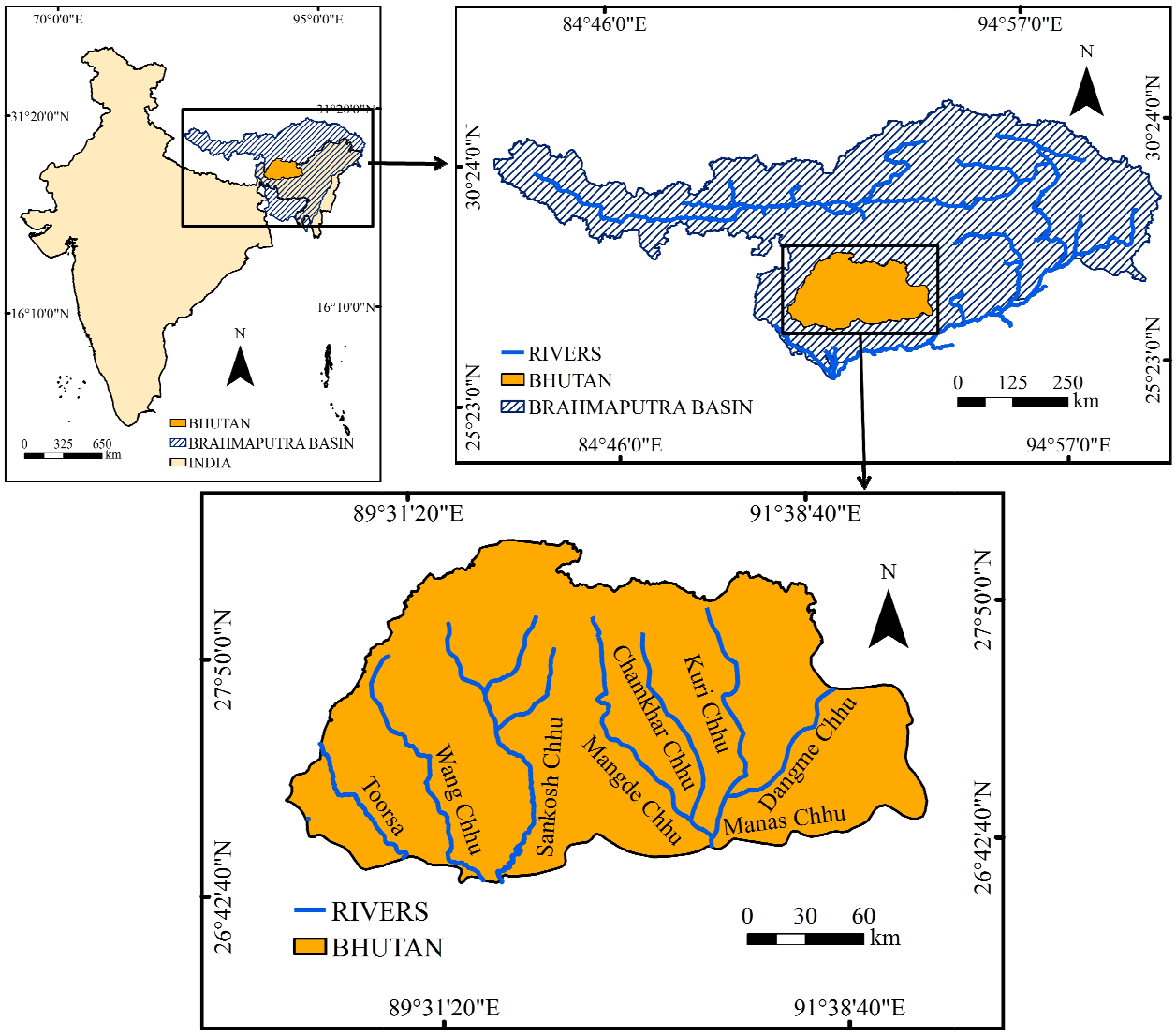
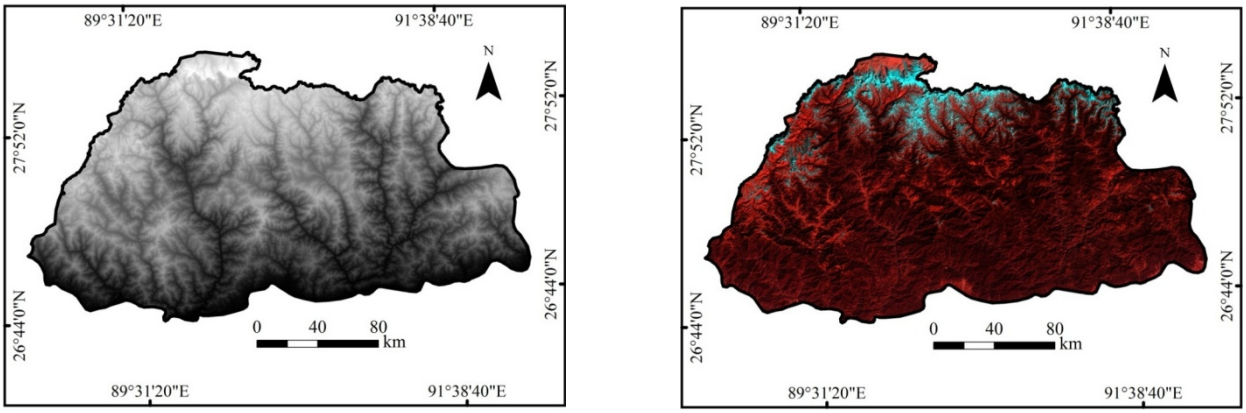


Figure-1
Study Area

Preparation and integration of these primary layers through visual interpretation was carried out in GIS and these layers were grouped into three categories: i. Base Map Information, ii. Hydrological Information, iii. Glacier and De-glaciated valley features[18].

On screen visual interpretation was carried out for mapping and delineation of the glaciers and their morphological features. The first set of satellite data was used for mapping all the glacial features. For any gap areas or in case of non-availability of cloud free data the second set of satellite data was referred. Thus, for the preparation of final datasheet in GIS environment, for each glacial feature systematic observations were made and their areas were recorded in a tabular format which was then linked via unique glacier identification number to the corresponding glacier. The approach followed in the present work was depicted in the flowchart (Figure-3).



(A) Shuttle Radar Topography Mission (SRTM) DEM (B) Advanced Wide Field Sensor (AWiFs) Image

Figure-2
Satellite data used for Glacier analysis (A & B)

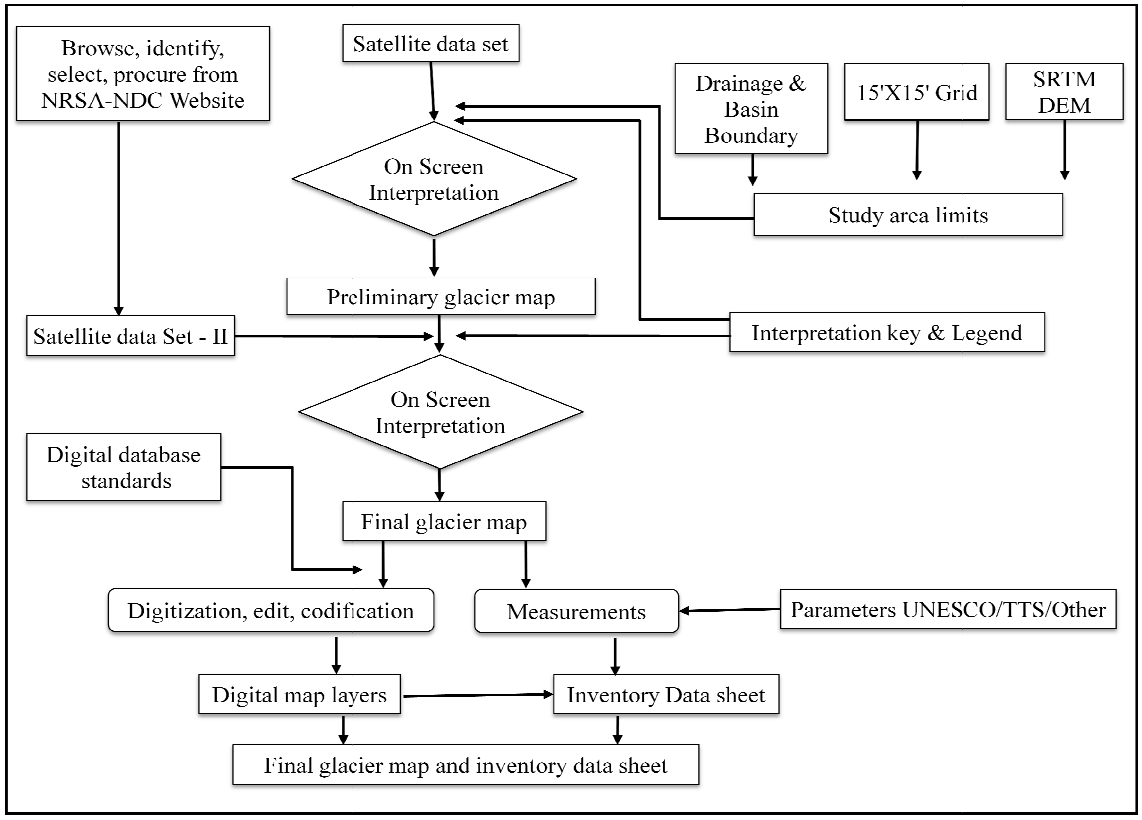


Figure-3
Workflow for glacier inventory and datasheet

Results and Discussion

Bhutan: The glaciated area of Bhutan was only 3702.33 sq. km. which is approximately 9% of the total area of the study area (Table-1); similar results were computed by GLIMS (Global Land Ice Measurements from Space) as well[19]. Inventory of 1151 glaciers was prepared where glaciers of varying sizes exist ranging from very small "Simple Basin" glaciers of 0.11 sq. km. to very large "Compound Basin" glaciers of 121 sq. km.. The total accumulation area was recorded as 60.22% of the total glaciated area which was much higher than the total ablation area of the basin i.e. 39.34% of the glaciated region. The ablation area-debris covered (79.76%) was much higher than the ablation area – ice exposed (20.25%) pointing towards the overall stability of these glaciers. The study area was dotted with numerous small supra-glacial lakes, a total of 60 lakes were mapped covering an area of 0.42% of the total glaciated area (Figure-4.), indicative of the fact that though large in numbers but these lakes cover a very small part of the glaciated region.

The regional scenario is better understood by dividing the glaciated areas of Bhutan into three major Physiographic divisions.

Chomolhari-Kulha Gangri Region (North): As this region was located in the Greater Himalayas the number of glaciers recorded were maximum (432) with extensive glaciated area (2471.46 sq. km.). In this region the total accumulation area (62.73%) exceeded the total ablation area (36.97%) (Table-2). Supra Glacial Lakes in the Chomolhari region though huge in number (43) were not a potential danger for lake outbursts as they covered a very small area of about 0.51% only. The Rose diagram (Figure-5) which was plotted to show the direction of the glaciers, indicated that approximately 41.20% glaciers were oriented towards the north-east and east direction.

Table-1
Broad Approach for glacier inventory and Datasheet of Bhutan

No. Of Glaciers	1151
Glaciated Area (sq. km.)	3702.33
Accumulation Area (%)	60.22
Ablation Area (%)	39.34
Ablation-Debris (%)	79.76
Ablation-Ice Exposed (%)	20.25
No. of Supra Glacial Lakes	60
Supra Glacial Lakes (%)	0.42
Source: Computed	

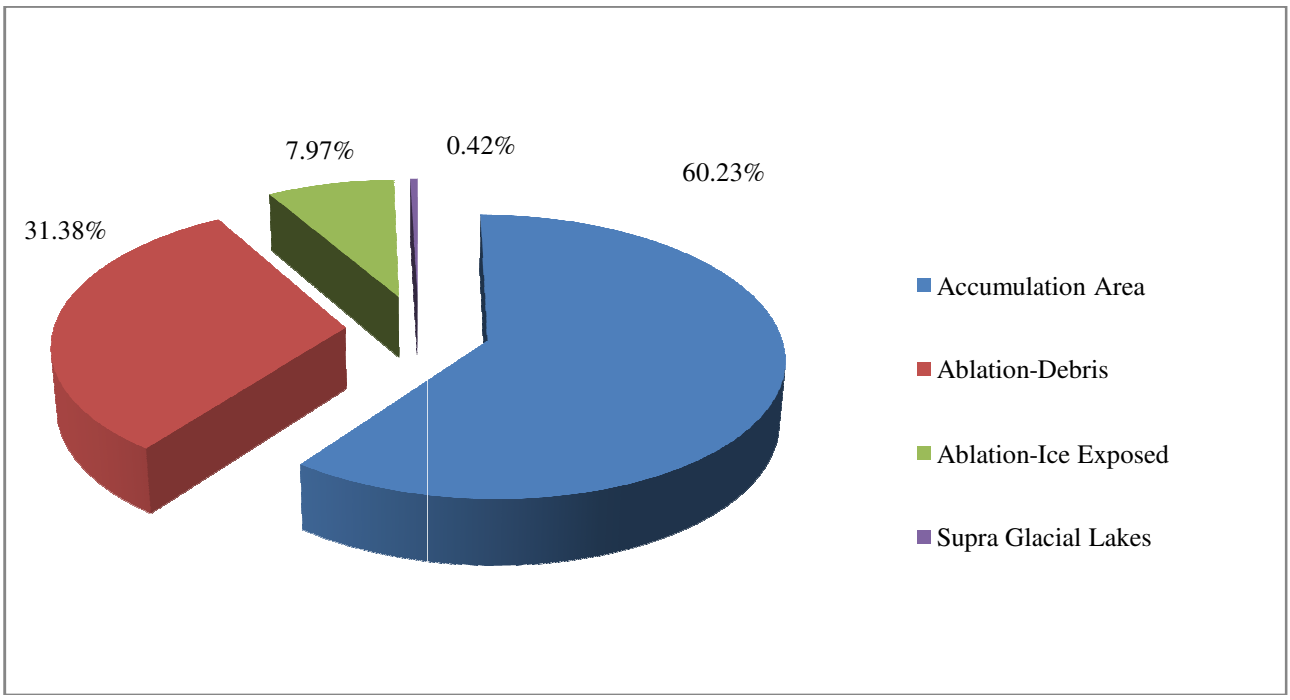


Figure-4
Sub-Basin Characteristics of Bhutan

Table-2
Glacier Statistics of Chomolhari-Kulha Gangri Region

No. Of Glaciers	432
Glaciated Area (sq. km.)	2471.46
Accumulation Area (%)	62.54
Ablation Area (%)	36.97
No. of Supra Glacial Lakes	43
Supra Glacial Lakes (%)	0.51
Source: Computed	

Trongsa Region (West): In line with the Sikkim Himalayas this region had the second highest number of glaciers in Bhutan (378) with a glaciated area of 594.87 sq. km. The accumulation area was 55.70% whereas the ablation area was 43.76%. In comparison with the Chomolhari-Kulha Gangri region the supra glacial lakes were the second highest in number (10) but the area covered by them (0.37%) was greater (0.37%) (Table-3). Here again most of the glaciers were oriented to the north-east (approximately 37.30%) and east (approximately 34.60%) while 48 glaciers were observed to be oriented towards the north (Figure-6).

Table-3
Glacier Statistics of Trongsa Region

No. Of Glaciers	378
Glaciated Area (sq. km.)	594.87
Accumulation Area (%)	55.70
Ablation Area (%)	43.76
No. of Supra Glacial Lakes	10
Supra Glacial Lakes (%)	0.37
Source: Computed	

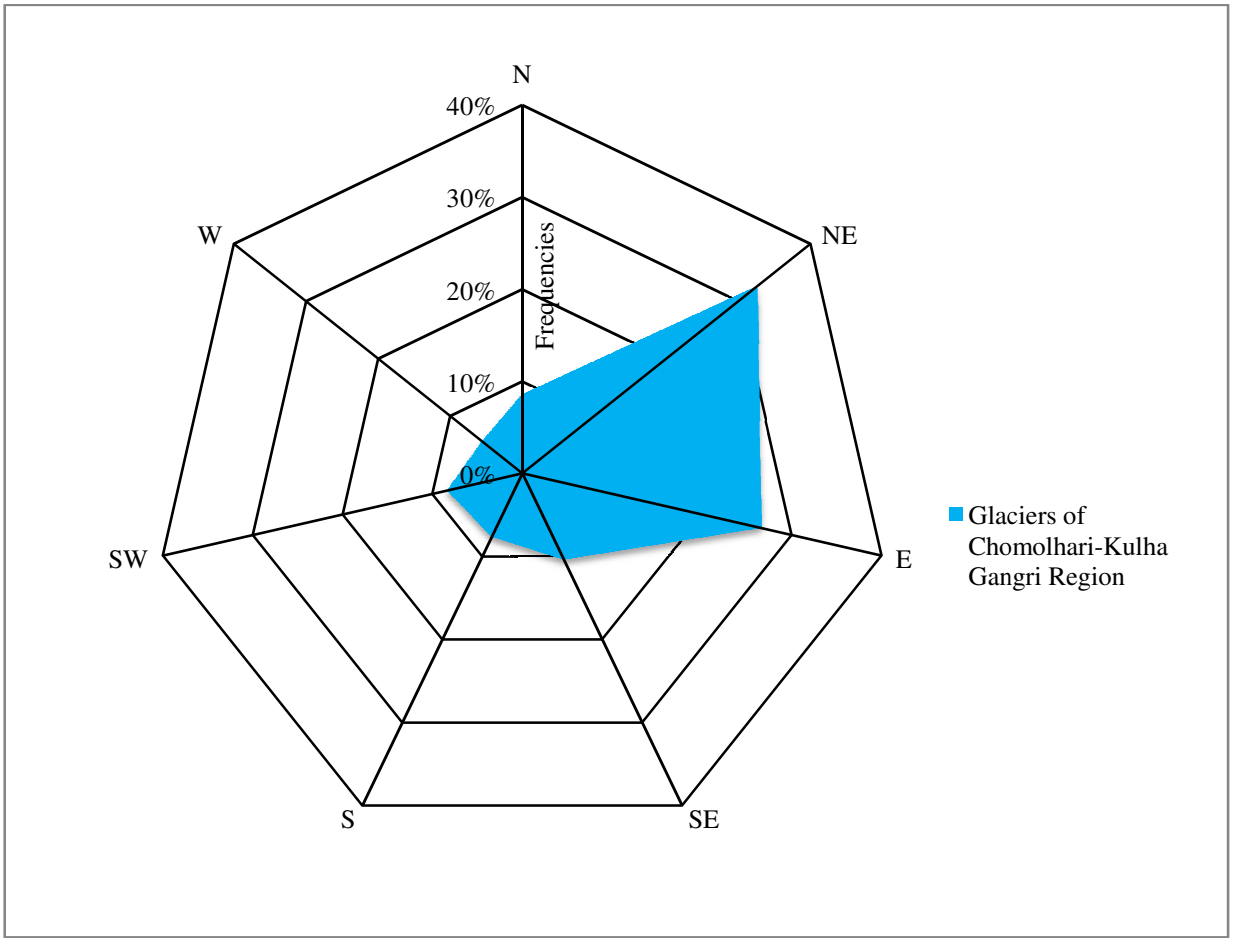


Figure-5
Rose Diagram representing Glacier Orientation of Chomolhari-Kulha Gangri Region

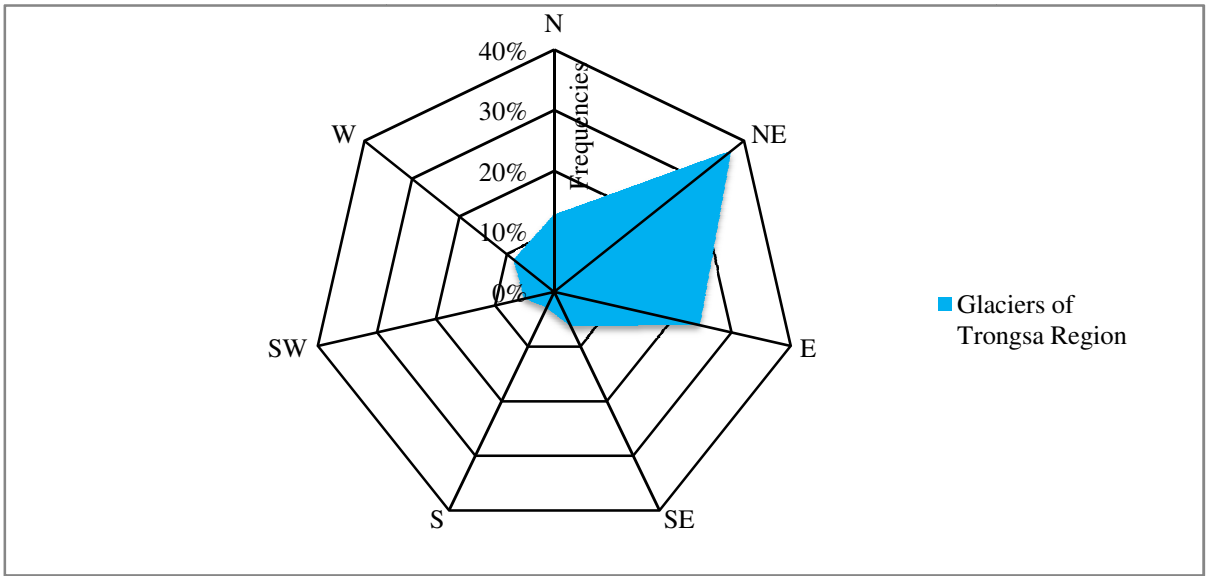


Figure-6
Rose Diagram representing Glacial Orientation of Trongsa region

Punakha-Thimphu Region (East): Located in the eastern part of the Kingdom of Bhutan this region had the least number of glaciers (341), but the total glaciated area was more (636 sq. km.) than the Trongsa region (Table-4). This is thus indicative of the fact that the average glacier size of the Punakha-Thimphu region is higher than the Trongsa region. The ablation area was recorded 44.41% and the accumulation area calculated was 55.47%. The number of Supra glacial lakes was the least in this region occupying an area about 0.12%. Maximum number of the glaciers in this region had their orientation towards the north-east (40.47%) followed by east and north oriented glaciers (Figure-7).

Table-4
Glacier Statistics of Punakha-Thimphu region

No. Of Glaciers	341
Glaciated Area (sq. km.)	636.00
Accumulation Area (%)	55.47
Ablation Area (%)	44.41
No. of Supra Glacial Lakes	7
Supra Glacial Lakes (%)	0.12
Source : Computed	

Figure-8 symbolized the comparative analysis of the three glaciated physiographic regions of Bhutan. This statistical analysis in the form of graph made the fact apparent that positive mass balance existed in this region as the accumulation area was much higher than the ablation area[20]. The observations of the rose diagrams were therefore related with the belief that North facing glaciers increase in thickness (although some decrease, but at a slower pace) than the South facing glaciers[21].

Conclusion

Glacier Inventory of Bhutan represented the glacial status of the time when the glaciers were mapped. It was a compilation of digital vector lines, points and polygons in the form of separate layers. Compilation and calculation of various glacial parameters like orientation, dimensions and area calculations for ablation areas, accumulation zones, supra glacial lakes, etc. were carried out in detail.

The extensive glaciated area (3702.33 sq. km.) of Bhutan Himalayas was covered by 1151 glaciers giving an average glacier size of about 3 sq. km. Approximately 0.42% of the total glaciated area of Bhutan was covered with supra glacial lakes, which seems to be a small area but the danger of Glacial Lake Outburst Floods (GLOFs) still persists.

The statistics showed that the accumulation area was much greater than the ablation area (inclusive of debris covered and ice-exposed) which points towards the good health of the glaciers of this region. Maximum large glaciers were concentrated in the northern part of Bhutan where the great Himalayas exist. The general orientation of the glaciers irrespective of the regional distribution was north-east and east with some glaciers facing towards the North too.

This enormous amount of data generated needs to be utilized, and thus the challenging task would be to use this data for specific tasks like, models for identifying potential sites for hydroelectricity generation, irrigation water needs and other industrial and domestic uses.

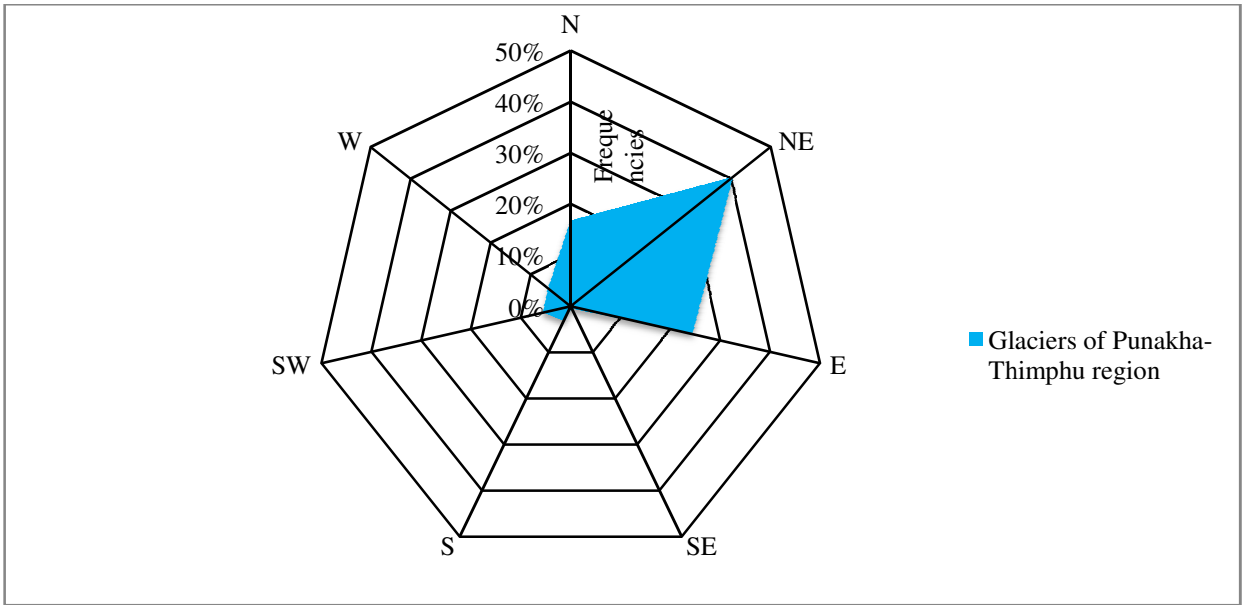


Figure-7
Rose Diagram representing Glacial Orientation of Punakha-Thimphu region

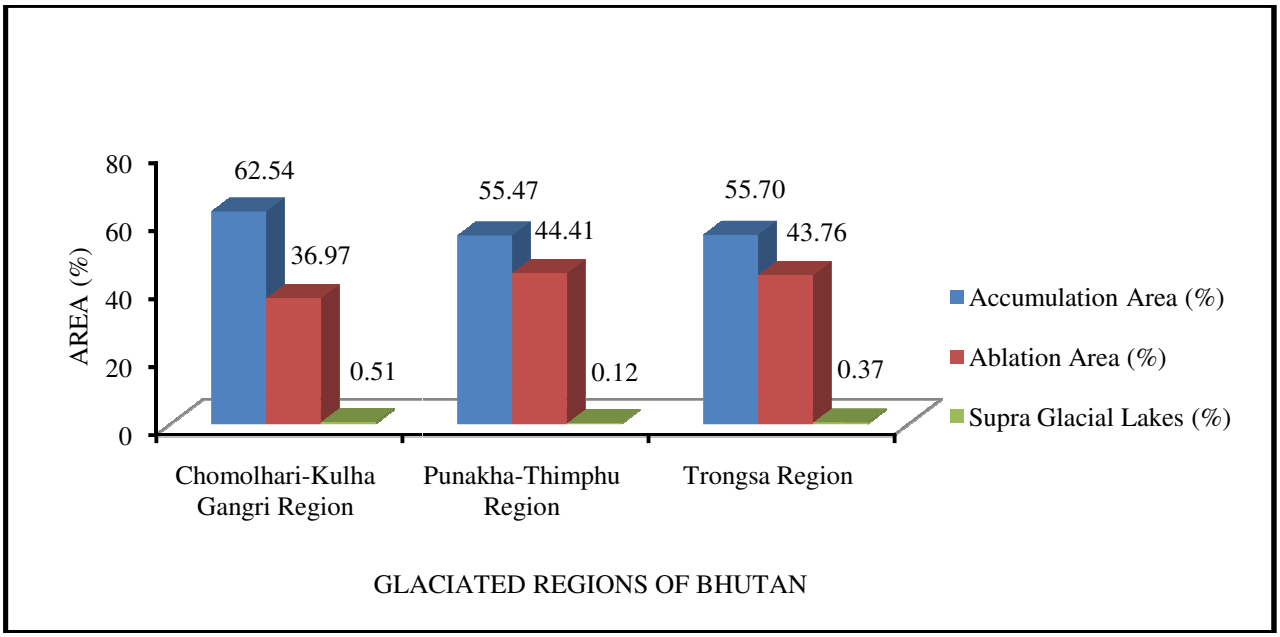


Figure-8
Comparative Analysis of Glaciated regions of Bhutan

References

1. Shrestha K.L. (2005). Global change impact assessment for Himalayan mountain regions for environmental management and sustainable development. Global Environmental Research-English Edition, 9(1), 69.
2. Shrestha A.B. and Aryal R. (2011). Climate change in Nepal and its impact on Himalayan glaciers. *Regional Environmental Change*, 11(1), 65-77.
3. Nesje A., Dahl S.O., Andersson C. and Matthews J.A. (2000). The lacustrine sedimentary sequence in Sygneskardvatnet, western Norway: a continuous, high-resolution record of the Jostedalsbreen ice cap during the Holocene. *Quaternary Science Reviews*, 19, 1047-1065.
4. Kaser G., Cogley J.G., Dyurgerov M.B., Meier M.F. and Ohmura A. (2006). Mass Balance of glaciers and ice caps Consensus estimates for 1961-2004. *Geophysical Research Letters*, 33, 1-5.

5. Barnett T.P., Adam J.C. and Lettenmaier D.P. (2005). Potential impacts of a warming climate on water availability in snow dominated regions.*Nature*, 438(7066), 303-309.

6. Roy S.S. and Balling R.C. (2005). Analysis of trends in maximum and minimum temperature, diurnal temperature range, and cloud cover over India. *Geophysical Research Letters*, 32, L12702, doi: 10.1029/2004 GL022201.

7. Yadav R.R., Park W.K., Singh J. and Dubey B. (2004). Do the western Himalayas defy global warming?. *Geophysical Research Letters*, 31, 17, 10.1029/2004GL020201.

8. Dozier J. (1984). Snow reflectance from Landsat-4 Thematic Mapper. *IEEE Trans. Geosciences and Remote Sensing*, GE-22, (3), 323-328.

9. Hall D.K., Chang A.T.C. and Siddalingaiah H. (1988). Reflectance of glaciers as calculated using Landsat-5 Thematic Mapper data. *Remote Sensing of Environment*, 25, 311-321.

10. Ostream G. (1975). ERTS data in Glaciology-An effort to monitor glacier mass balance from satellite imagery. *Journal of Glaciology*, 15(73), 403-415.

11. Central Intelligence Agency (2015). The World Factbook 2014-15. Government Printing Office.

12. Singh R.L. (2008). India: a regional geography. National Geographical Society of India, 489-492.

13. Muller F. (1978). Instructions for compilation and assemblage of data for a world glacier inventory Supplement identification/glacier number. Department of Geography, Swiss Federal Institute of Technology, Zurich, 25.

14. Norbu C. (2003). A provisional physiographic zonation of Bhutan. University of Cambridge, http://www.dspace.cam.ac.uk/handle/1810/226999.

15. RGOB (Royal Government of Bhutan) (1991). Land Act of Bhutan. Thimphu, Bhutan, Department of Survey and Land Records.

16. Bahuguna I.M., Kulkarni A.V., Arrawatia M.L. and Shresta D.G. (2001). Glacier Atlas of Tista basin (Sikkim Himalayas). SAC/RESA/MWRGGLI/SN/16, Ahmedabad, India.

17. Kulkarni A.V., Rathore B.P., Mahajan S. and Mathur P. (2005). Alarming retreat of Parbati Glacier, Beas basin, Himachal Pradesh. *Current Science*, 88(11), 1844 1850.

18. Sharma A.K., Singh S. and Kulkarni A.V. (2008). Approach for Himalayan Glacier Inventory using remote sensing and GIS techniques. Proceedings of International Workshop on Snow, Ice, Glacier and Avalanches, IIT-B. Tata McGraw-Hill Publishing Company Ltd, New Delhi, 177-185.

19. Kargel J.S. (2014). Global Land Ice Measurements from Space. Springer.

20. Dixon L. and Ambinakudige S. (2015). Remote Sensing Study of Glacial Change in the Northern Patagonian Icefield. *Advances in Remote Sensing*, 4(4), 270.

21. Phan V.H., Lindenbergh R.C. and Menenti M. (2014). Orientation dependent glacial changes at the Tibetan Plateau derived from 2003–2009 ICESat laser altimetry. *The Cryosphere Discussions*, 8(3), 2425-2463.