Monitoring of Two Typical Glacier Lakes in Indus Basin

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***Abstract* - Indus basin is the watershed of the Indus river. A major part of this basin lies in Pakistan and remaining part lies in India. In the limelight of climate change taking place on earth, it is important to monitor the temporal and spatial change which takes place in these basins. In the present study monitoring of Gangabal and Konsarnag Lakes in Indus basin has been done forJune 2014 to September 2014 using satellite data. The objective of this study is to prepare inventory of glacial lakes/water bodies in the Himalayan region of Indus River basins using satellite data. The basic data required for the inventory of glacial lakes and water bodies are large-scale topographic maps, aerial photographs, and multi-date satellite images. This study mainly uses the satellite images of the Advanced Wide Field Sensor (AWiFS) of the Indian remote sensing satellite,Resourcesat-2.**

The inventory of glacial lakes and water bodies in the Himalayan region prepared by NRSC using AWiFS data shows the presence of 2028 glacial lakes and water bodies. A total of 477 glacial lakes/water bodies were considered by NRSC for monitoring and for future study during 2014.Out of these, 101 glacial lakes/water bodies could be monitored in Indus basin and among these, only 2 lakes namely Gangabal and Konsarnag lakes are considered in the present study. Monitoring of these two lakes is done by using of ERDAS Imagine and Arc GIS Software.Monthly monitoring was carried out from June to September during 2014. Maximum water spread area in this period was compared with inventory area i.e. October, 2012.

Gangabal Lake has shown decrease in water spread area more than 10% from June to September. It is also noted that KonsarnagLake have shown decrease more than 5% in June and July. Konsarnag Lake has not shown any significant change in August month. But Konsarnag Lake has shown increases by more than 10% in September.

I. INTRODUCTION

The Hindu-Kush Himalaya (HKH) is a large mountain system, influencing the interaction between climate, hydrology and environment. The total spread of Himalayas between latitude 25° and 35° N and longitude 60° to 105° E covers an area of 84.4 lakh km^{2}. The Hindu-Kush Himalaya (HKH) region stretches some 3500 km from Afghanistan in the west to Myanmar and China in the east, and runs through Pakistan, Nepal, India, Bangladesh and Bhutan. The glaciers of this region are one of nature's greatest renewable storehouses of fresh water.

Glacial lakes (GLs) are common in the high elevation of glacierised basins in Himalayan region. Water Bodies (WBs) are being formed by obstructions created in the drainage path due to landslides or manmade structures. They are formed when glacial ice or moraines expropriate water. The impoundment of the lake may be unstable, leading to unexpected release of huge quantities of stored water. Failure of these ice or moraine dams may lead to destructive events. The common natural calamity in the region are earthquake, landslide (due to seismicity), landslide induced flood, cloudburst, etc. For monitoring of glacial lakes HKH region was divided into three Indian River basins i.e. Indus, Ganga and Brahmaputra River Basins. The Ganga basin covers around 25% of the study area with a drainage area of 24.6 Mha. The major rivers in the Ganga basin are Kosi, Gandak, Ghaghara, Ramganga, Yamuna and main Ganga River. The area under Brahmaputra basin is 39.9 Mha covering around 40% of the studyarea. The major rivers in the Brahmaputra basin are Amo Chu, Dangme Chu, Dibang, Dihang, JiaBharali, Kuri Chu, Luhit, Manas Chu, Mangde Chu, NoaDihing, NyereAmaChu, Puna Tsang Chuand and the main Brahmaputra river.

The Indus River Originates from Tibetan plateau in the vicinity of Lake Mansarovar at an altitude of 5486m.The river runs a course through the Ladakh district of Jammu and Kashmir and then enters Pakistan via the Northern Areas (Gilgit-Balistan), flowing through the North in a southerly direction along the entire length of Pakistan, to merge into the Arabian sea near the port city of Karachi in Sindh on the south. The total length of the river is 3199km (BasitMasud2003) and it is Pakistan's longest river. The Indus River has a total drainage area exceeding 1,165,000 km^{2}. The drainage area lying in India is 321,289 km^{2} which is nearly 9.8% of the total geographical area of the country.Glacial lakes of these basins are generally located in remote areas, where access is through tough and difficult terrain. Remote sensing technology is best way to study these types of glacial lakes.

Remote sensing is the science of obtaining information about the Earth's surface without actually being in contact with it. Satellite data contributes significantly to the acquisition of Earth's resources and thus helps in better management of the resources.

In year 2009, National Remote Sensing centre (NRSC) found 2028 lakes having area more than 10 ha in Hindu-Kush Himalaya (HKH).Table 1 depicts the number of glacial lakes & Water bodies present in Indus, Ganga & Brahmaputra River
basin of HKH.

Table 1Basin wise details of glacial lakes & water bodies

Basin	Glacial Lakes(GL)	Water Bodies(WB)	Total
Indus	31	321	352
Ganga	178	105	283
Brahmaputra	294	1099	1393
Total	503	1525	2028

It is observed that around 1600 glacial lakes/water bodies are having water spread area less than 50 ha and around 200 water bodies have water spread area between 50 and 100 ha. There are 14 water bodies with water spread area more than 10,000 ha. All the glacial lakes are having water spread area less than 600 ha and 80% of them have less than 50 ha.

Out of these glacial lakes, having area more than 50 ha, are being monitored by NRSC since 2011. Based on October, 2012 inventory, 415 glacial lakes/water bodies with a water spread area more than 50 ha are monitored. Apart from this, another 62 glacial lakes/water bodies with water spread area in the range 44 to 50 ha also have been monitored. Accordingly, a total of 477 glacial lakes/water bodies were considered for monitoring during 2012 to 2014.For monitoring purposeHindu-Kush Himalaya region has following breakup:

Table 2 Basin wise details of glacial lakes & water bodies(Monitoring purpose)

Basin	Glacial Lakes(GL)	Water Bodies(WB)	Total
Indus	6	95	101
Ganga	48	35	83
Brahmaputra	65	228	293
Total	119	357	477

These all 477 lakes are being monitored by NRSC.The monitoring of glacial lakes and water bodies in the Himalayan region of Indian River basins was carried out through visual interpretation of satellite images from AWiFS sensor. Since 2011, every year NRSC publish report for CWC regarding“Inventory and Monitoring of Glacial Lakes / Water Bodies in the Himalayan Region of Indian River Basins”. Since 2014 these lakes are monitored by CWC in collaboration with NRSC. In the present study, focus has been given to monitor two glacier lakes of the Indus basin with the following objectives:

For the purpose of monitoring glacial lakes and water bodies from satellite images, it is preferable to have cloud free satellite images during the time of monitoring. Since the

1. To carry out inventory of glacial lakes in the HKH region of Indus River basins using satellite data of the recent past years. Glacial lakes with spatial extent greater than 44ha (during the October, 2012) will be considered and inventoried.
2. Monitoring the spatial extent of the glacial lakes/water bodies (identified/inventoried under Objective 1 on monthly basis during June to October months.
3. Monitoring the spatial extent of 2 selected lakes, if required, with high-resolution data on event basis, during the monitoring years of study under Objective

II. MATERIAL & METHODS

A. Study area

Gangabal(34°25'55.56"N, 74°55'27.12"E) and Konsarnag Lakes (33°30'47.16"N, 74°46'6.96"E)which is present in Indus River basin has been selected for the present study.According to “Inventory of Glacial Lakes/Water Bodies in Himalayan Region of Indian River Basin” prepared by NRSC (2009), Konsarnag Lake is abbreviated as 01_43K_014,whereasGangabal Lake is abbreviated as 01_43J_017. According to NRSC both lakes are water bodies. Srinagar is situated in the downstream side of Konsarnag Lake. Hence, if the lake will get uncontrolled monsoon rainfall at any specific period of the year,Srinagar will be affected. An example of this was observed in the month of September 2014, when flood water in Jhelum and Sind river has affected the lives of thousands ofpeople staying in the downstream (Srinagar) end of the above mentioned rivers. For this purpose monitoring of the above lakes is necessary.

The inventory of glacial lakes and water bodies was carried out using satellite images of the Advanced Wide Field Sensor (AWiFS) of the Indian remote sensing satellite, Resourcesat-2. The monitoring of these glacial lakes was also carried out using AWiFS data. The AWiFS data is acquired in four spectral bands, three in the visible and in NIR (VNIR B2, B3 and B4) and one in the short wave infrared (SWIR B5). The AWiFS camera is realized in two electro-optic modules viz. AWiFS-A and AWiFS-B, providing a combined swath of 740 Km. Each camera consists of four lens assemblies, detectors and associated electronics pertaining to the four spectral bands B2, B3, B4 and B5.

Table 3Specification of AWiFS Sensor

SPECIFICATION	AWiFS
Resolution	56 m
Swath	740 km
Revisit	5 days
No. of Bands	4

monitoring is carried out during monsoon period, probability of availability of cloud free data is less. Hence all the possiblesatellite data were browsed and checked for their coverage of the study area and cloud cover.

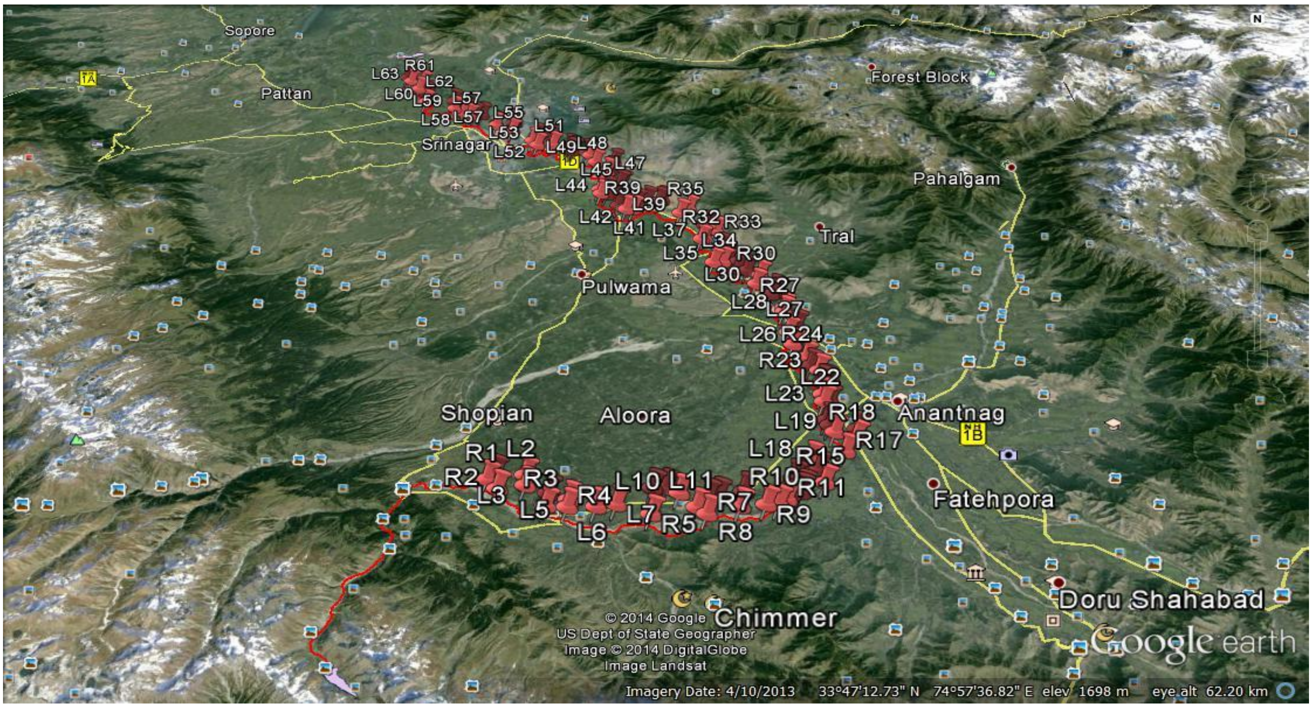

Fig. 1Konsarnag Lake and vulnerable location

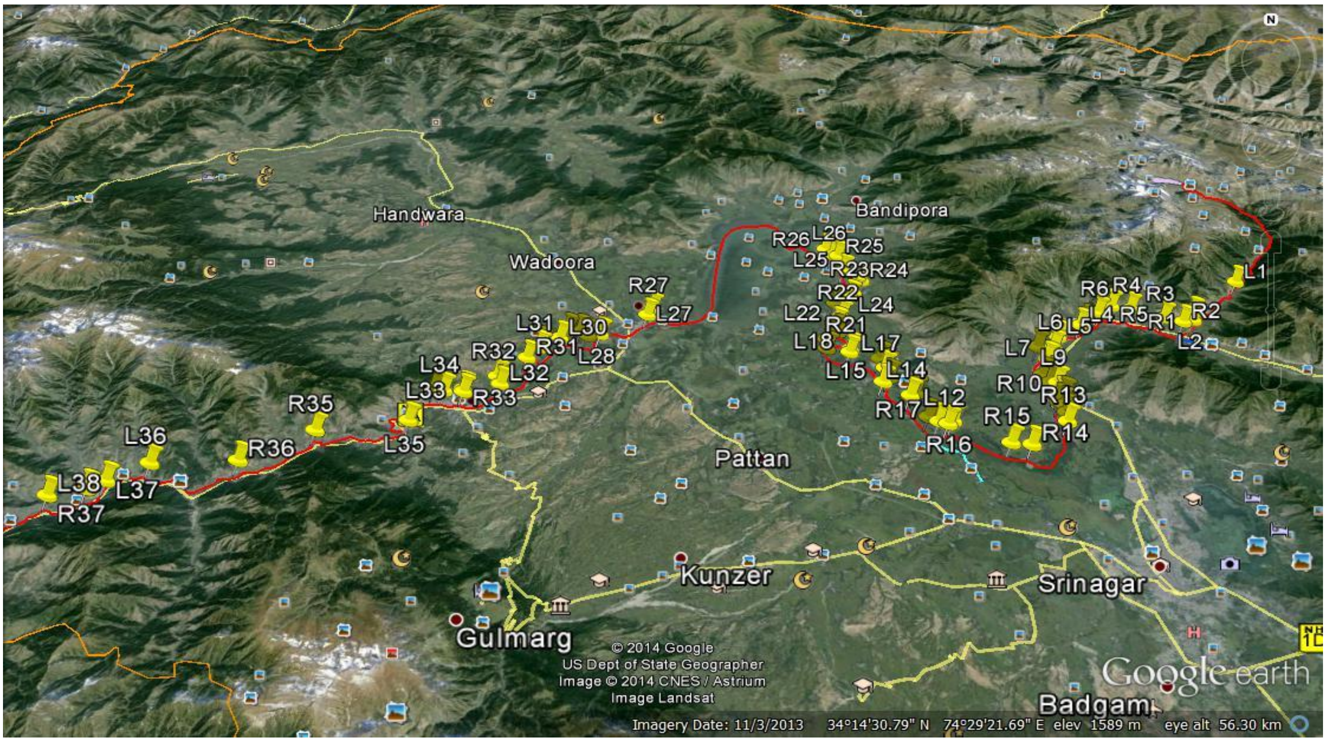

Fig. 2Gangabal Lake and vulnerable location

Table 4List of satellite data used in (June – Sept, 2014)

Path	Row	Date	Path	Row	Date
100	49	02-Jun-14	93	46	09-Jul-14
105	51	03-Jun-14	98	49	10-Jul-14
112	51	14-Jun-14	94	47	14-Jul-14
93	46	15-Jun-14	105	51	21-Jul-14
108	51	18-Jun-14	110	51	22-Jul-14
			106	51	26-Jul-14
			111	51	27-Jul-14
			116	52	28-Jul-14
112	51	01-Aug-14	104	51	02-sep-14
104	51	09-Aug-14	109	51	03-sep-14
95	47	12-Aug-14	100	49	06-sep-14
100	49	13-Aug-14	96	48	10-sep-14
92	46	21-Aug-14	92	46	14-sep-14
108	51	29-Aug-14	97	48	15-sep-14
			102	49	16-sep-14
			107	51	17-sep-14
			112	51	18-sep-14
			93	46	19-sep-14

III. METHODOLOGY

The monitoring of glacial lakes and water bodies in the Hindu-Kush Himalaya region using satellite images involves the following steps.

A. Orthorectification of satellite data

Orthorectification is the technique by which the geometric distortions of the image are modelled and accounted for, resulting in a planimetrically correct image. 3D world is imaged by most sensors in 2D and orthorectification corrects for many of the anomalies resultant from this conversion. Orthorectified imagery is particularly useful in areas with exacerbated terrain features such as mountains, plateaus, etc. The orthorectification technique yields map-accurate images which can be more useful as base maps and may be easily incorporated into a GIS. The success of the orthorectification technique depends on the accuracy of the DEM and the correction method. In this study, orthorectification of AWiFS data was carried out using Projective Transform model present in ERDAS Imagine software. The Projective Transform models are simulation models purely solved by the Ground Control Points (GCPs). The orthorectified Landsat ETM images were used as reference image for collections of GCPs and the elevation values for GCPs were collected from SRTM DEM.

B. Identification & digitization of glacial lakes

The glacial lakes & water bodies are delineated based on the visual interpretation of satellite data of Resourcesat-2 AWiFS sensor. Identification of features was done through panchromatic mode and/or different colour combinations of the multi-spectral bands namely green, red, near infrared and shortwave infrared.

To identify the glacial lakes & water bodies, different image enhancement techniques are used to improve the visual interpretation. With different spectral band combinations in false colour composite (FCC) and in individual spectral bands, glacial lakes and water bodies can be identified. The knowledge of image interpretation keys: colour, tone, texture, pattern, association, shape, shadow, etc. will also enhance the capability of identifying these features.

The water spread area of the lakes in false colour composite images ranges from light blue to blue to black. The frozen lakes appear white in colour. Sizes of water bodies are generally small, having circular, semi-circular, or irregular shapes with very fine texture. They are generally associated with glaciers in the case of upstream areas, or rivers in the case of downstream areas.

The present study proposed to monitor all the glacial lakes & water bodies that are larger than 50 ha in area. Even though during inventory, glacial lakes and water bodies having area more than 10 ha were digitised, monitoring was carried out only for the glacial lakes & water bodies that are larger than 50 ha. The boundary of glacial lakes and water bodies are digitized using on-screen digitisation techniques as polygon feature. The polygons are geoprocessed and the water spread area of glacial lakes/water bodies were computed digitally. These steps were repeated for each date of satellite data and water spread area was computed. The following criteria were followed while monitoring the glacial lakes and water bodies.

1. A Change in water spread area within +/- 5% is considered to be normal in remote sensing derivative inventory studies.
2. Partly or fully cloud covered or frozen water bodies have not been considered in monitoring process.
3. The spatial extent of water spread area during the current month has been mapped and compared with the spatial extent of water spread area mapped during October 2012.

C. Organisation of database

The study proposed to develop a digital database of glacier lakes using GIS. A digital database is necessary of monitoring of these lakes and to identify the endangered lakes. GIS is useful tool for spatial data input and attributes data handling. These digital databases will have following attributes:

- Glacial lake number (first two digits indicate the basin number),
- Latitude
- Longitude
- Area
- Length
- Width
- Altitude

IV. RESULTS

The monitoring of glacial lakes and water bodies in the Himalayan region of Indus basin was carried out through visual interpretation of Resoursesat-2 satellite images from AWiFS sensor. The basin covered under this study isGangabal and Konsarnag Lakes. Satellite images for the months of June 2014 to September 2014 have been shown in Figure 3 for the glacier lakes Gangabal and Konsarnag. This figure has been post processed from the raw image using ERDAS imagine software. As depicted from Figure 3, monthly status of the spatial variation in glacial lakes area is varying remarkably. In the month of June 2014,both lakes have shown decrease in water spread area. It is also observed that Gangabal Lake decreases by more than 10% in June w.r.t. October 2012 inventory area. Further, in the month of July, 2014, Gangabal Lake decreases by more than 15% w.r.t October 2012 inventory area. Similarly, the percentage change in area for the August and September has been studied and it has been found that KonsarnagLake has shown 20% increase in water spread area in august month and Konsarnag Lake has shown 30% increase in water spread area in September month w.r.t October 2012 inventory area.The change in water spread area of Konsarnag and Gangabal Lake in terms of percentage is also shown in table 5 and table 6.

Table 5 Comparison of water spread area of Konsarnag Lake (01_43K_014)during June2014 to September2014 with reference area (October, 2012)

	New area	Old area(oct,12)	% change	remarks
JUNE,14	104ha	112.354ha	-7.435%	decreases
JULY,14	104ha	112.354ha	-7.435%	decreases
AUG,14	115ha	112.354ha	2.355%	No change
SEPT,14	127ha	112.354ha	13.036%	increases

Table 6 Comparison of water spread area of Gangabal Lake (01_43J_017)during June2014 to September2014 with reference area (October, 2012)

	New area	Old area(oct,12)	% change	remarks
JUNE,14	143ha	164.468ha	-13.053%	decrease
JULY,14	139ha	164.468ha	-15.485%	decrease
AUG,14	144ha	164.468ha	-12.445%	decrease
SEPT,14	145ha	164.468ha	-11.987%	decrease

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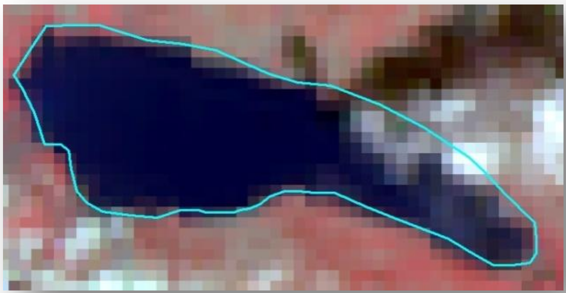
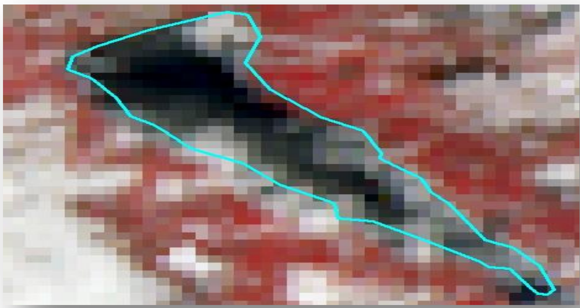
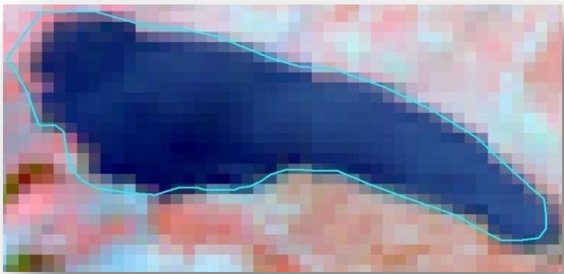
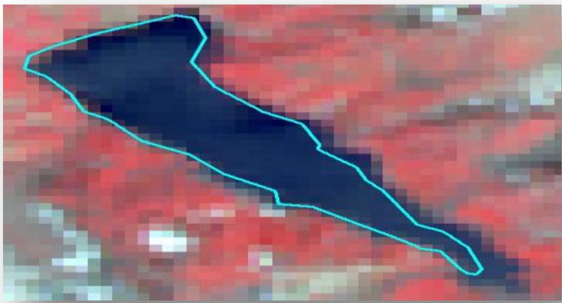
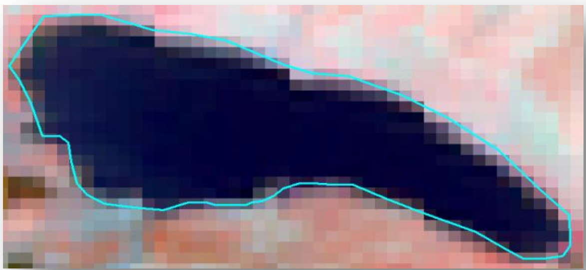
	Gangabal Lake(01_43J_017)	**Konsarnag Lake**(01_43K_014)
June 2014		
July 2014		
Aug 2014		
Sep 2014		

Fig. 3 Satellite images for the Gangabal and Konsarnag Lakes (June – Sept, 2014)

Shows the lake boundary in Oct, 2012

V. CONCLUSION

The analysis of water spread area of glacial lakes/water bodies monitored in 2013 was done for only 477 glacial lakes/water bodies using cloud free satellite data.The monitoring of glacial lakes and water bodies in the Himalayan region of Indusbasin using satellite images of June to September 2014 could be carried out using satellite imagesfor 101 lakes.Out of these, Gangabal Lake has shown decrease in water spread area more than 10% from June to September. It is also noted that Konsarnag Lake have shown decrease more than 5% in June and July. Konsarnag Lake has not shown any significant change inAugust month. But Konsarnag Lake has shown increases by more than 10% in September.

VI. SCOPE FOR FURTHER STUDY

In the present study, only monitoring of the selected lakes has been done. The post processed data obtained from remote sensing can further be used to study various characteristic of the basin. Some of the future scope for study in this regard is as follows:

1) Prediction of the glacial lake outburst flood phenomena (GLOF) can be done usingMIKE11 software.
2) One can also predict the time of concentration, stage value and flow rate in the vulnerable location as well as maximum velocity in the river section using the same software. The study will deliver the hydrograph at various locations in river stretch.
3) The study will further include the rainfall event occurring in downstream section in GLOF study.Longitudinal Profile of River will be generated by the MIKE11. Beside, Cross-section profile with initial and maximum water level will also be included in the final result.
4) Identification of locations and development of mechanism for installation of sensor based flood gauges for high decibel warning in affected area.

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