Detection of Potentially Dangerous Glacial Lakes in Mangde Chhu Sub-Basin

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ABSTRACT
The hazard assessment of glacial lakes in Mangde Chhu Sub-Basin based on the potential of the lake outburst has been presented in this contribution. Hazard Assessment of the glacial lakes in the region is hampered by debris cover on the glacier surfaces and cloud shadow. Supraglacial debris exhibits the same spectral properties like that of lakes and thus lakes cannot be clearly detected by means of multispectral classification alone. Lakes are extracted through digitizing in QGIS, neural network and through k-means segmentation.

Potentiality of the lake to outburst mainly was based on the lake area beyond the given threshold. A Multispectral and hyperspectral satellite image along with DEM has been used for effective detection of lakes.

Key Words: *Glacial Lakes, Sub-basin, DEM, Mangde Chhu.*

1. Introduction

In the Himalayan region, the Glacial Lake Outburst and Floods (GLOF) has become the major concern. Changes of mountain glaciers are among the best natural indicators of ongoing climate change (Haeberli et al., 1999; IPCC, 2001; Oerlemans, 1994). Since the outburst of a glacial lake in Mangde Chhu Sub-Basin in the year 1994, the Royal Government of Bhutan has been taking various measures to mitigate the effects caused due to the Glacial Lake Outburst and Floods. With the extension of human activities into high mountain regions, conflicting situations with changing glacier hazards are becoming more critical (Richardson and Reynolds 2000).

GLOFs can cause extensive damage to the natural environment and human property as it can drain rapidly and cause dramatic floods downstream. GLOF can be considered as a geomorphological risk because it is a natural risk which is connected to a geomorphological hazard. Glacial hazards attract attention for two main reasons: risk of loss of life and threat to the costly infrastructure such as hydropower, roads etc. (Shaun D. Richardson, 2000). Flood and debris flows caused from glacier lake outburst can be of highly destructive nature and may extend over several distances (Huggel et al. 2002; Kaab et al. 2005). The impact of such an outburst depends on the physical character of the dam, the lake size and depth and the rapidity of its drainage, and the nearby surroundings (ICIMOD, 2010).

Glacier lakes can develop within very short times, especially lakes dammed by landslide / avalanche deposits or surging glaciers form a tributary valley (Costa and Schuster 1988; Huggel et al. 2002; Kääb et al. 2005; Korup and Tweed 2007). The increase in the rate of melting of the glaciers caused the lakes to increase in areal extent and water storage capacity. Sudden discharge of large volumes of water and debris from these lakes poses a greater risk. Due to the rapid dynamics of formation and evolution of these lakes, there is a need for simple but robust approaches to quickly obtain an overview over large areas with only minimal input data and effort (Huggel et al. 2010).

The remote high altitude location of glaciers along with the accelerated changes of the environment requires the glacier lakes to be continuously monitored. However manual interpretation of the continuous image data is tedious and error prone, hence artificial intelligence coupled with remote sensing helps to automatically monitor the situation.

Lakes in glacierized areas show a wide range of turbidity, ranging from light blue or green to almost black due to the influences of sediment influx, water depth, the properties of the lake bottom, and the origin of the lake water (Wessels et al. 2002). This makes it very difficult task for the glaciologists to correctly identify lakes and non-lakes. However, many valley glaciers are covered to a varying extent by supraglacial debris, which has the same spectral characteristics as the surrounding terrain and, thus, cannot be spectrally discerned from it. As a consequence, previous studies related to quantitative assessments of glacier change (area/length) applied manual delineation of debris-covered glaciers, mostly by on-screen digitizing (e.g., Bayr et al., 1994; Hall et al., 1992; Jacobs et al., 1997; Paul, 2002a,b; Williams et al., 1997). Although manual delineation of debris-covered glacier ice generally produces accurate results, it is very time-consuming and labor intensive for studying a larger number of glaciers.

In the snow and glaciated terrain of the Himalaya, satellite remote sensing has proven to be the best tool because many of the glacial lakes are located at a very high altitude, cold weather and rugged terrain conditions, making it tedious, hazardous and time consuming task to monitor by conventional field methods. Satellite remote sensing technology facilitates to study the behavior of glacial lakes of the Himalaya systematically with a cost-to-time benefit ratio (K. Babu Govindha Raj, 2013).

Remote sensing techniques in combination with Geographic Information Systems (GIS) can satisfy the needs for large area detection and monitoring of such phenomena (Huggel et al. 2002; Kääb et al. 2005).

2. Data and Study Area

Lake detection and related hazard assessment with the proposed approach requires multispectral and hyper spectral image data along with digital elevation data. The Bhutanese and Indian Himalayan region were chosen as study area due to their accessibility for fieldwork and the high-quality data availability. The Mangde Chhu Sub-Basin was selected as the study area due to presence of highest number of small lakes. As the area increases the number of lakes decreases which indicate a possible merger of lakes over time. We have used Survey of India (SOI) topo sheets (1:25000), glacial lake inventory (ICIMOD, 2012), high quality DEM (30m resolution).

Satellite image datasets of LANDSAT-TM (30 m), Hyperion (30m), IRS 1D (5.6m) have been used along with the aerial images of the study area from UAV mounted hyperspectral and multispectral cameras. We have selected cloud and snow free scenes from the image datasets because snow cover hampers glacier mapping and cloud shadows may be misclassified as lakes.

3. Method

3.1 Automatic Lake Detection

The detection of lakes and glaciers can be done through various methods. In order to detect lakes and glaciers the data needed are satellite image which can be either multi-spectral or hyper-spectral but hyper-spectral images along with multi spectral images are preferred since it has high spectral resolution and it gives better accurate results. In satellite images objects can be detected based on their reflectance and their pixel values in each band that are red, green and blue bands. Lake detection in satellite images can be done using GIS tools or image processing tools and also through matlab. Classification and clustering methods are used to detect lakes and glaciers.

Due to different spectral information of lakes, unsupervised classification methods cannot be used for automated lake mapping. Normal Difference Water Index (NDWI) (Huggel et al, 2002) has been derived from the preprocessed imagery. Lake areas have low (dark) NDWI values (between -0.60 and -0.85), thus a scene dependent threshold can be defined and used as the classification criterion to distinguish between lake and non-lake pixels. For lake classification, a blue channel with maximum reflection (Bblue) and a NIR channel with minimum reflection (BNIR) are required.

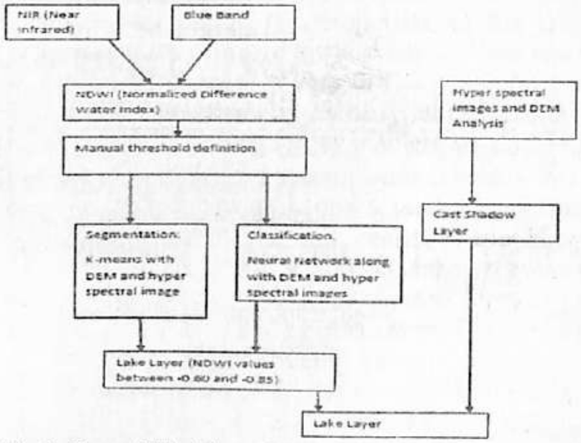

Fig 1: General Workflow of semi-automatic lake detection

The NDWI is calculated as follows:

$$NDWI = \frac{B_{NIR} - B_{blue}}{B_{NIR} + B_{blue}}$$

For threshold definition, lakes appearing dark (in a true-colour view) should be examined due to their higher NDWI values caused by lower reflection in the blue channel. In the given context of hazard assessment, it is important to detect all lakes, even if a lower overall accuracy has to be accepted. This can be justified by the higher feasibility to manually correct misclassifications than finding undetected lakes (Huggel et al. 2010).

Besides the erroneous classification of several isolated pixels, the prevalent misclassification of cast shadow regions is the main problem of the NDWI (purple circles in Fig. 2), especially in terms of an automatic application of the method. The reason is, that shortwave radiation (here blue) is susceptible to atmospheric scattering, thus even in cast shadow regions there is always a signal in the blue channel.

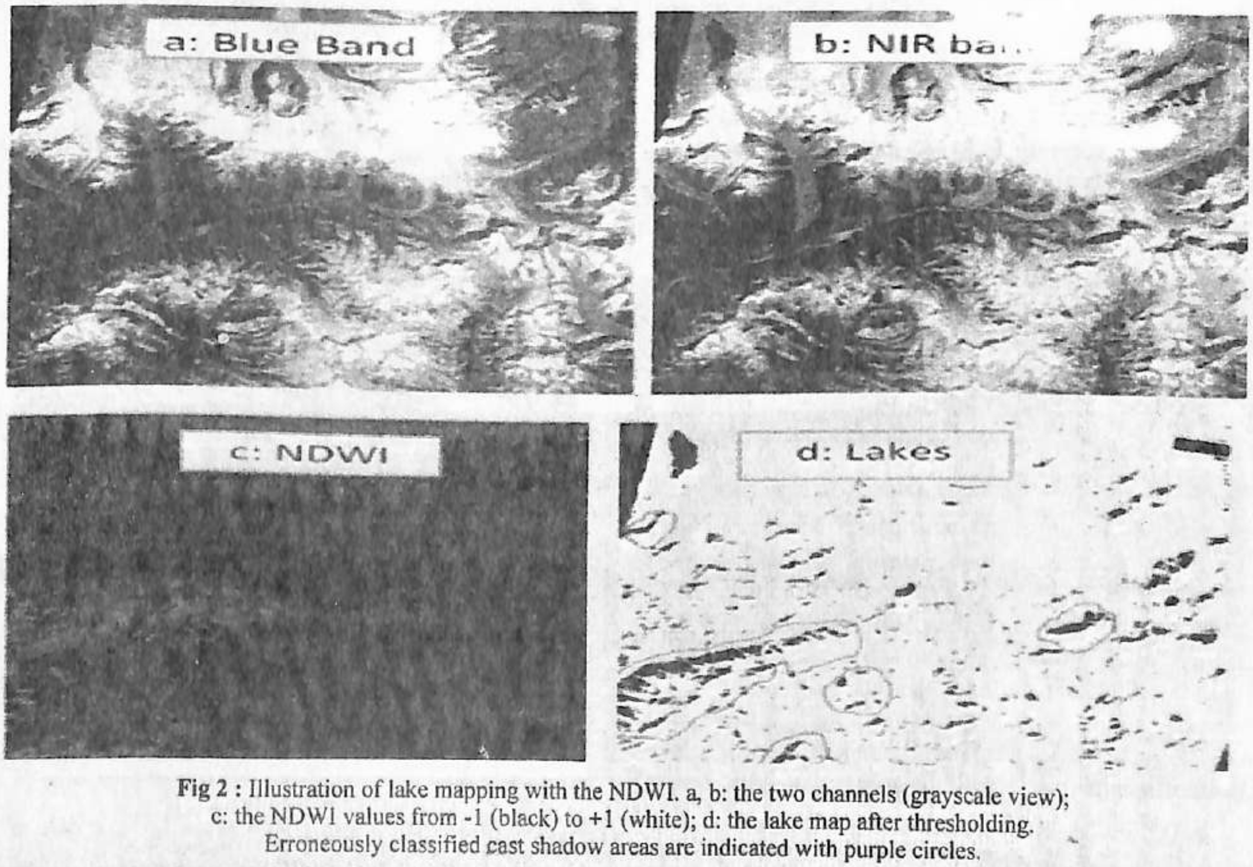

Fig 2 : Illustration of lake mapping with the NDWI. a, b: the two channels (grayscale view); c: the NDWI values from -1 (black) to +1 (white); d: the lake map after thresholding. Erroneously classified cast shadow areas are indicated with purple circles.

Classification methods like neural network and Segmentation using k-means are also implemented for detection of lakes. Neural network classification is done to classify lake pixels from non-lake pixels and obtain lakes. Neural network gives the accurate results (classified image) if the network is well trained. Segmentation to extract lakes is done in matlab and it has distinctively extracted lakes.

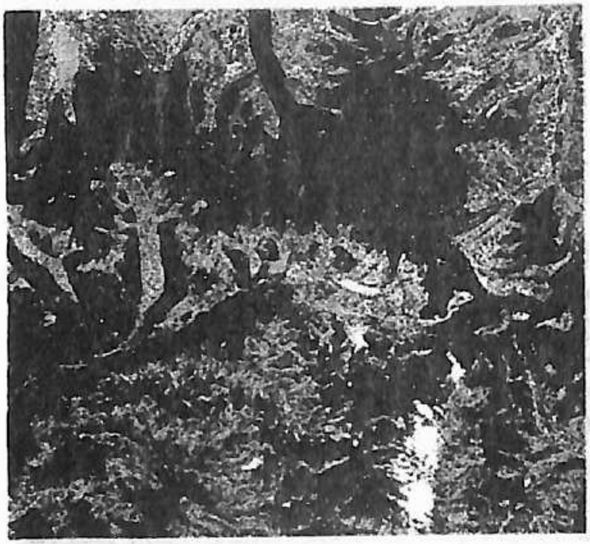

Fig 3 (a)

Fig 3 (b)

Fig 3: Neural Network Classification of lakes and **Fig 3 (b)** Segmentation using k- means.

3.2 Hazard Assessment

To identify potentially dangerous lakes, detected lakes along with relevant parameters are used (Fig.4). Change detection is also used as parameter for hazard assessment. The different parameters are then fed to a classifier for detection. Glaciers and drainages in the vicinity of detected lakes are assessed for detecting outbreaks. Potential lakes are identified by change in areas beyond a threshold.

Lakes are termed as potentially dangerous if its area is more than 0.02sq.km and in contact with or close to the main glacier. (Jack D. Ives May 2010). And lakes are immediately classified as potentially dangerous if its area is larger than 1 sq.km. (Jack D. Ives May 2010).

The slope values are also used as parameters for hazard assessment. From various literatures and empirical studies conducted over the study area, it has been found that the average slope angle (α) related to maximum run out distance does not fall below 11° (tan $\alpha = 0.19$) for granular debris flows from glacier / ice dammed lakes (Haeberli 1983; Huggel et al. 2002) and 17° (tan $\alpha = 0.31$) for ice avalanches respectively (Alean, 1985). To define starting zones for ice avalanche assessment, the mapped glacier areas are combined with a slope map derived from the DEM, to detect glacier parts steeper than 25° which are potential candidates (Alean, 1985).

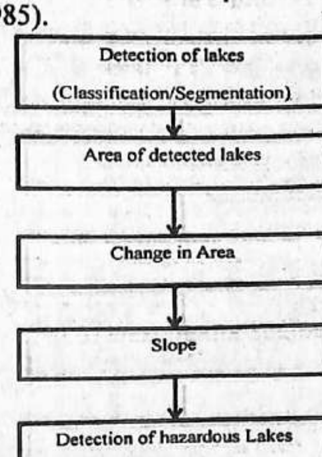

Fig 4 Algorithm to find potentially dangerous lakes.

4. Results

4.1 Manual Inventory

In manual inventory the lakes are digitized using QGIS. Though digitization, total number of lakes in the Mangde Chhu Sub-Basin is obtained (Fig.5).

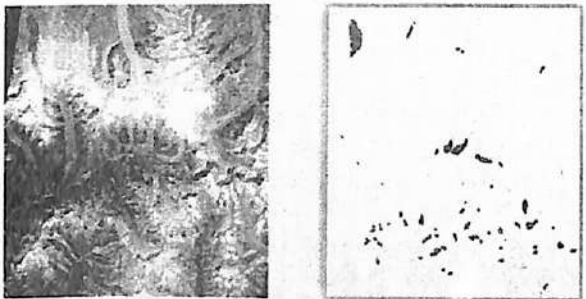

Fig 5 Digitizing the satellite image to obtain the number of lakes in the region.

Different classification methods in ERDAS and ENVI are used for calculating accuracy of each method. Table 1 shows the accuracy of different methods obtained by different classification methods in ERDAS and ENVI for the satellite image of our study. Maximum likelihood has the highest accuracy with accuracy of 97.7699% and 0.9590 of kappa statistics. Binary Encoding is the least accurate method with 45.3367% accuracy and 0.0180 kappa statistics.

Image processing tools	Classification Method	Overall Accuracy	Overall Kappa Statistics
ERDAS	Maximum Likelihood	97.7699%	0.9590
	Minimum Distance	89.0874%	0.8075
	Mahalanobis Distance	94.9818%	0.9081
ENVI	Spectral Angle Mapper	80.8729%	0.6703
	Parallelepiped	81.9226%	0.6455
	Binary Encoding	45.3367%	0.0180
	Spectral Information Divergence	63.4631%	0.3775
	Improved Neural Network (Classification)	98.1328%	0.9800
	Segmentation	88.3487%	0.7989

Table 1: Accuracy of classification methods in ENVI and ERDAS

4.1 Hazard Assessment

For evaluating the hazard assessment of the area, parameters like change detection and change in area beyond the given threshold are observed. Synthesis of change detection is the essential part to detect changes of the lakes and glaciers over the time (Fig.6). Comparing the image of the different years gives the changes that have happened to the lakes and will help in detecting the hazardous changes and plan the mitigations measure.

Figure 6: Classified image of lake before (left) and after (right).

The hazard assessment based on the above discussed parameters has given accurate results to a certain extent. However, there is a need for manual editing and / or expert judgment. The independence of the flow routing models from outburst / avalanche volumes is reasonable although small events and especially misclassifications e emphasized disproportionally.

The list of potentially dangerous lakes detected by our method is listed in Table 2 for Mangde Chhu basin. In order to compare with the standard inventory same names have been used.

Sub-basin	Number	Position		Length	Area
		Northing	Easting		
Mangde Chu	98	27° 54' 22.13"	90° 16' 45.88"	605	0.168
	105	27° 53' 19.45"	90° 17' 33.94"	1478	0.912
	268	27° 58' 09.32"	90° 20' 06.98"	847	0.320
	271	28° 00' 20.90"	90° 19' 50.77"	793	0.312
	304	28° 02' 21.01"	90° 21' 58.87"	1789	0.734
	314	27° 58' 49.87"	90° 23' 05.53"	578	0.223
	384	27° 58' 58.53"	90° 26' 21.90"	521	0.462

Table 2: Potentially dangerous lakes

The potentially hazardous lakes identified for Mangde Chu sub-basin is given in Figure 7.

a) Lakes filtered based on size b) Potentially dangerous lakes

Figure 7: Analysis of Mangde Chhu Sub-Basin.

5. Discussions

All of the lakes in the region were not obtained due to different spectral properties of glacial lakes and glacial lakes covered by debris. And some misclassifications were obtained due to cast shadow. Cast shadow modeling is the main cause of errors and implicates that a compiled lake inventory cannot be complete, that lake areas crossing shadow zone are underestimated and that small lakes within cast shadow are not detected at all (Arun et al. 2013).

The Quality of the applied hazard assessment over large area relies on the quality of the DEM as well as the lake detection and steep glacier classification. Lake misclassifications and mistakes in evaluation of avalanche-prone steep glacier parts (due to debris cover, unknown basal ice conditions and internal structure, and DEM errors) degrade the model output (Huggel et al. 2010).

A shortcoming of the hazard assessment presented here is the fact that only ice avalanches and water influx from upstream lakes are considered as triggers for lake outbursts but other processes like rock fall or landslides / debris flows originating in steep debris reservoirs (Huggel et al. 2004b) are ignored.

6. Conclusion

The automatic lake detection program using remote sensing techniques could help to detect lakes and glaciers of different places and also conduct hazard assessment on those lakes provided the multispectral and hyperspectral images of our study area, and DEM are available. The study areas for GLOF are very far from human settlements. It is impossible for anyone to do an on field study on those areas. Thus remote sensing is the only option to conduct study on those areas. Remote Sensing is basically defined as retrieving information about an object without being in contact with that object.

Our study using all the different methods specified in our reports, seven lakes in Mangde Chhu sub-basin are identified giving the same name as that of the ICIMOD inventory.

Though most of the lakes were detected, some miss-classifications as well as omissions occurred due to the cast shadow. Cast shadow modeling is the main cause of errors and the compiled lake inventory cannot be complete, that lake areas crossing shadow zone are underestimated and that small lakes within cast shadow are not detected at all. Time differences between the date of the satellite scene and DEM acquisition also affected the accuracy of detection.

A shortcoming of the hazard assessment presented here is because only ice avalanches and water influx from upstream lakes are considered as triggers for lake outbursts but other processes like rock fall or landslides / debris flows originating in steep debris reservoirs are ignored for the analysis. Further efforts will be directed to better include such potential outburst trigger processes and develop the user interface of our automated system.

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