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ORIGINAL ARTICLE

Measurement of changes in glacier extent in the Rimo glacier, a sub-range of the Karakoram Range, determined from Landsat imagery

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Abstract Accurate estimation of the spatiotemporal surface dynamics is very important for natural resource planning. This paper discusses a novel approach for the study of the surface patterns of a particular glacier Rimo located at 35°21′21″N77°22′05″E, about 20 km northeast of the snout of Siachen. Change detection in multiple images of the same location taken at different time intervals are of widely circulated use due to a large number of applications in various disciplines such as climate change, remote sensing and so on. The proposed technique uses image processing to derive regression models of selected glacier segments, these models are then used to measure area under the curve to estimate the surface area changes of the glacier. The surface area changes thus obtained have also been validated by standard method of pixel counting. With the rise in the global warming, the net change in the surface area of the concerned glacier is estimated using statistical analysis from 1998 to 2011. The results obtained show a fair degree of accuracy as compared to the standard method of pixel counting. We also discuss important pre-processing methods used in extracting the final concerned region of interest from a large satellite imagery of fairly average resolution.

1. Introduction

World's freshwater prime source is cryosphere which stores 75% of the freshwater. Changes in sea level are caused mainly due to changes in ice mass. On a territorial order, freshwater availability depends primarily on glaciers and ice caps (IPCC, 2007). Freshwater availability for various purposes such as irrigation, domestic use, mountain diversion, animals and plants that depend on melting of glacier, is majorly affected by the retreat of glaciers. The extended glacier retreats will cause a number of quantitative wallops. There are many areas which are dependent on water released due to the retreat of glaciers during the hot summer seasons. If the glacier keeps on melting at the rate as it is melting in the present scenario then eventually many glacial ices will be wiped out causing severe situations for human beings. Such a decrease in water runoff will have an effect on the irrigation capabilities and will decrease the stream flows essential to keep water reservoirs refilled (Warning, 2012).

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The Siachen glacier has been retreating for the last 30 years according to the findings of Pakistan Meteorological Department in 2007 and is retreating at an alarming rate (Gupta, 2008). The glacier size has depleted by almost 35% and is melting at a rate of about 110 m a year as indicated from the studies of the satellite images (Sadangi, 2007; Rao, 2011). The glacier has depleted nearly 800 m (Kapadia, 1998) in a 11 year duration and the measure of retreat is 1700 m in 17 years period. Moran has estimated that Siachen glaciers will shrink to 20% of their current size by 2035 (Moran, 2011). Global warming is the most cited reason for the recent glacial retreat. The various construction and excavation activities have played a vital role in contributing towards global warming thereby causing the retreat of glaciers such as oil pipelines laid by India in 2001 inside the glacier for almost 250 km to provide kerosene oil and aviation fuels to the frontier outstations from base camps (Asad Hakeem, 2007).

Although the satellite imagery and topographic information can be used for glacier mapping, interpreting causal mechanisms for changing glacial boundary conditions and climate is difficult, as there is a significant disconnect between information on boundary conditions and process mechanics. Therefore, information integration and computer-assisted approaches to glacier mapping, parameter estimation, and numerical modelling are required to produce reliable results that go beyond traditional techniques (Bishop et al., 2007). Satellite remote sensing is a practical approach used in the assessment of glacier retreat. There are many remote sensing methods available for quantification of the glacier retreat. These methods include elevation changes observations, ice flux estimations, spatial extent change measurement, snowline elevation and accumulation–ablation area ratio calculations (Bamber and Rivera, 2007). Digital change detection is one of the popular processes in remote sensing applications aimed at identifying spatiotemporal surface dynamics (Coppin et al., 2004). Wherein, images acquired on the same geographical area at different time intervals are used for the analysis. Data transformation operations and analysis techniques are used to characterise various change detection methods to describe the area of substantial variability. A variety of digital change detection algorithms have been developed so far viz. background subtraction, image ratioing, image differencing, image regression, monotemporal change delineation, multitemporal linear data transformation, delta classification, multidimensional temporal feature analysis, change vector analysis, composite analysis and multitemporal biomass index (Singh, 1989). Measurements of the glacial retreat have been done by several researchers through different techniques (Bolch and Menounos, 1985; Karimi et al., 1955; Moholdt and Nuth, 2010; Klein and Isacks, 1999; Mas, 1999; Venteris, 1999; Paul et al., 2004, 2007; Bartholom and Belward, 2005; Khromova et al., 2006; Berthier et al., 2007; Mihalcea et al., 2008; Moran, 2011; Rao, 2011).

Rimo is a glacier which has been retreating over the period of time causing a danger for water scarcity in the nearby region. Until twentieth century, Rimo was an unknown and unvisited place. Due to various human activities going on in Rimo glacial region, the total surface area of Rimo glacier has reduced significantly since the end of the 19th century. There has been an increase in the glacier retreat rates and mass imbalance losses in the Siachen and nearby glaciers.

This work presents a novel technique for surface area change estimation of Rimo glacier based on monotemporal image regression, wherein standard image pre-processing techniques viz. intensity normalisation, registration and edge detection are applied to create temporal skeletal images. The skeletal segments of each temporal skeletal image are then segmented and regressed to obtain polynomial models of various orders. The multitemporal polynomial curves for each segment are then superimposed on each other and the area enclosed among them is calculated using integrals. The proposed methodology has been addressed as Integral Method (IM) henceforth. In the present study, the segmentation has been done manually which may be automated and invites research interests for optimum segment selection parameters. The results thus obtained by IM are comparable with the results of standard pixel counting method (PCM).

2. Methodology

Landsat 5 digital imagery were taken and studied for three time periods 1998, 2005 and 2011. The important steps in the proposed technique are input image description, cropping the area of study, intensity normalisation, radiometric correction, registration, skeleton formation, change detection, application of a statistical regression model for functional mapping of the segments of the mountain and finally estimation of the net shift in the area using definite integrals and PCM for accuracy assessment. Fig. 1 shows the schema of the steps involved in the pre-processing, modelling and validation. The proposed technique was implemented using image processing toolbox of MATLAB and custom scripts.

2.1. Study area characterisation

Rimo is the name of the glacier chosen for study purpose. It rests in the northern part of the Rimo Muztagh which is a sub range of the Karakoram Range and is located about 20 km northeast of the snout of the Siachen Glacier. The area is located at 35°21′21″N77°22′05″E. Fig. 2 shows the map of study area Rimo glacier. Karakoram Range is more glaciated in comparison to the Himalaya and European Alps. Glaciations and recession of mountain glaciers with long-term changes in temperature may signal climate change. Karakoram glaciers have been found mostly slugging according to a study done by the Universities of California and Potsdam, because many Karakoram glaciers are covered with junks produced as a result of various natural phenomena and human activities and it has insulated the ice from the warmth of the sun. The retreat rate is alarming wherever there is no such insulation.

2.2. Image processing

2.2.1. Input image characterisation

Input image is a grayscale satellite image. The input image is shown in Fig. 3 with area of interest circled in red colour Landsat 5 thematic mapper images have been taken for the study purpose. Landsat 5 TM image data files consist of seven spectral bands. The band channel is 5 as it is very sensitive to moisture content and is also good at differentiating between clouds and snow. The resolution is 30 m. Due to different acquisition dates and atmospheric conditions, scene differences exist in the