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Glacier mapping based on rough set theory in the Manas River watershed

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Abstract

Precise glacier information is important for assessing climate change in remote mountain areas. To obtain more accurate glacier mapping, rough set theory, which can deal with vague and uncertainty information, was introduced to obtain optimal knowledge rules for glacier mapping. Optical images, thermal infrared band data, texture information and morphometric parameters were combined to build a decision table used in our proposed rough set theory method. After discretizing the real value attributes, decision rules were calculated through the decision rule generation algorithm for glacier mapping. A decision classifier based on the generated rules classified the multispectral image into glacier and non-glacier areas. The result of maximum likelihood classification (MLC) was used to compare with the result of the classification based on the rough set theory. Confusion matrix and visual interpretation were used to evaluate the overall accuracy of the results of the two methods. The accuracies of the rough set method and maximum likelihood classification were compared, yielding overall accuracies of 94.15% and 93.88%, respectively. It showed the area difference based on rough set was smaller by comparing the glacier areas of the rough set method and MLC with visual interpreter, respectively. The high accuracy for glacier mapping and the small area difference for glacier based on rough set theory demonstrated that this method was effective and promising for glacier mapping.

Keywords: Glacier mapping; Rough set theory; Decision table; Supraglacial debris

1. Introduction

Glacier change is considered the most reliable natural indicator of climate change (Lemke et al., 2007) and has therefore been selected as one of the essential climate variables (ECVs) in the global climate observing system (GCOS, 2003). The substantial glacier retreat that has been occurring since the Little Ice Age has accelerated over the last two to three decades with climate warming (Roger, 2006). Glacier and ice cap melting contribute considerably to the rise in sea level (e.g. Kaser et al., 2006; Lemke et al., 2007) and play an important role in controlling runoff amounts and water resources on a regional scale(Huss, 2011; Kaser et al., 2010). Glacier change is regarded as one of the most important study subjects in the field of global environmental change, therefore, obtaining precise glacier information is essential.

Conventional methods of automated glacier mapping include unsupervised and supervised classification, the Normalized Difference Snow Index (NDSI), and spectral band ratio and Principal Components Analysis (PCA). Methods of threshold multispectral band ratio with digital numbers (DNs), planetary reflectance, and atmosphere/terrain corrected reflectance for each channel such as TM band 3/5 ratio imaging (AST 2/4) and TM 4/5 ratio

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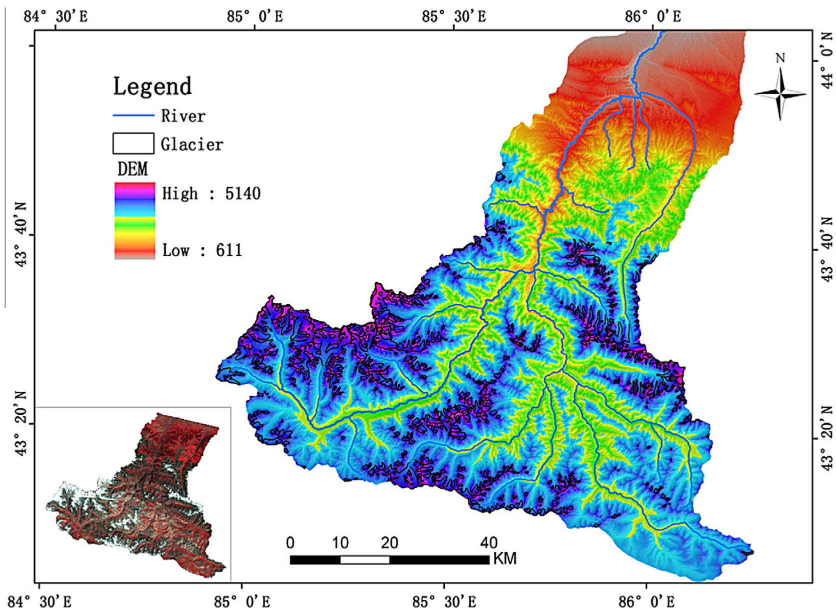

Fig. 1. Geographical position of the study area. The small image with a TM false color composite (bands 432) shows the distribution of glaciers in the study area. The large image shows the glacier boundary by visual interpretation from the panchromatic band overlaid on ASTER GEDM.

analysis proved to be superior to other traditional automated glacier mapping schemes (e.g. Jacobs et al., 1997; Sidjak and Wheate, 1999; Albert, 2002; Paul, 2002; Paul et al., 2007). The band ratio method is robust and can reveal reliable results for debris-free glaciers and glaciers in shadow zones; however, it also maps water bodies as glaciers, which requires additional post processing. Moreover, many valley glaciers are covered to a varying extent by supraglacial debris that has the same spectral characteristics as the surrounding terrain (Paul et al., 2004). Supraglacial debris was widely recognized as the main obstacle to glacier mapping, and all traditional approaches have failed in detecting partially debris-covered glaciers. Methods for mapping of debris-covered glaciers include the digital elevation model (DEM) as well as several factors such as the slope, aspect, and curvature extracted from DEM (Bishop et al., 2000, 2001; Paul et al., 2004), and a thermal technique based on the temperature difference between debris-covered glaciers and adjacent periglacial debris outside the glacial margins in optical imagery (Lougeay, 1974; Ranzi et al., 2004; Karimi et al., 2012). Morphometric parameters such as DEM, slope, aspect, and curvature data and temperature information were combined to delineate debris-covered glaciers (Bolch et al., 2008). Additional features and band combinations can provide useful information to improve the classification accuracy, whereas not all the spatial features obtained by various parameters or methods are helpful for the classification (Aguera, 2008). Large amounts of irrelevant features may result in over-fitting and poor performance by the classifier (Lei et al., 2007). In addition, a set of threshold values for every spatial feature based on empirical rules or visual observation is too coarse for improving accuracy and is not computationally cost-effective. Moreover, the bands or combinations most suitable for the situation need to be selected (Feng et al., 2010). Accordingly, a method that can reduce redundant information and extract decision rules from information systems for classification is needed.

With the advancement of artificial intelligence, a rule-based approach to classification has been developed as an alternative or complementary approach to image classification (Leung, 1997). Rough set theory, initially developed by Pawlak (1982), is a mathematical tool that deals with vague, uncertain, and incomplete information. Rough set theory can derive a classification or decision rules according to knowledge without prior data analysis information. It has been successfully applied in many fields such as machine learning, pattern recognition, control systems, data mining, and image classification (Holte, 1993; Hu, 1996; Jelonek, 1995; Dong et al., 2007). Traditional classification always obtains low accuracy because of the uncertainty of the remote sensing information as well as the process of data acquisition, analysis, and processing of the results. Rough set theory has become an important development in remote sensing classification and has been successfully applied in remotely sensed imagery processing such as feature selection (Pan et al., 2002), bands selection (Sun and Gao, 2003), and image classification (Zhang and Wang, 2008; Chen et al., 2010). It renders an effective methodology to optimally select features, such as selection of the most relevant spectral bands, constituting an optimal rule set for a classification task (Leung et al., 2007).

In this paper, we attempt a classification method based on rough set theory using integrated information from the optical images, thermal band and morphometric parameters to map the boundary of glacier. We first give a brief overview of the rough set theory, then consider additional features that enabled us to build a glacier