



Creation of Landslide Inventory Map for the Toktogul Region of Kyrgyzstan, Central Asia

Namphon Khampilang and Malcolm Whitworth

Abstract

This project is reliant upon the use of remote sensing for the detection and delineation of landslides. Therefore optical satellite images, such as medium resolution ASTER, and high resolution SPOT 5, will be combined with topographic data to analyse the landslide prone areas. The specific objectives are to generate a landslide inventory distinguishing between different landslide types, and to use this map for GIS based spatial landslide hazard modelling in the Toktogul region of Kyrgyzstan. The project steps include: (1) detection and mapping of landslides at different scales using high resolution imagery and DEM data to generate a GIS landslide inventory database for the area, (2) ground truthing of this landslide inventory using field reconnaissance, (3) integrating morphological, lithological, structural, land use, hydrological and seismic data within a GIS environment (DEM data from SPOT will form an important component of this dataset), and (4) derivation of statistical landslide hazard models through the integration of the landslide inventory with the GIS datasets. The results will be shown in the form of landslide inventory maps including a GIS database at various scales and a landslide hazard model showing landslide prone areas and distinguishing different hazard levels. Consequently, these mapping results will be used to assist in making rational decisions regarding local evacuation plans in areas susceptible to slope failure.

Keywords

Landslide hazard assessment • ASTER • SPOT

Introduction

A landslide is a downward and outward movement of slope forming materials under the influence of gravity (Varnes 1978). Each year, landslides claim thousands of casualties and cause billions of dollars in infrastructure and property damage, a total that is, worldwide, larger than that from any other natural disasters (Guzzetti et al. 1999; Yang and Chen 2010). From a different point of view, landslides are natural events and play an important role in the evolution

of landforms. Landslide occurrence depends upon different parameters such as geological and geomorphological processes, changes in vegetation cover, land use and hydrologic conditions. Landslides are triggered by many factors including heavy precipitation, earthquakes and human activities (Safae et al. 2010; Alkeveli and Ercanoglu 2011).

Landslide detection including recognition and classification is a basis of the spatial and temporal occurrence which leads to the understanding of Landslide hazard and risk management (Martha et al. 2010). Many researchers have identified, classified and studied landslides and for this, they have produced landslide maps at different scales depending on the purpose and the available resources, using a variety of techniques, including the analysis of stereoscopic aerial photographs, geological and geomorphological field mapping,

N. Khampilang (✉) • M. Whitworth
University of Portsmouth, ad, Portsmouth PO1 3QL, UK
e-mail: namphon.khampilang@port.ac.uk;
Malcolm.whitworth@port.ac.uk

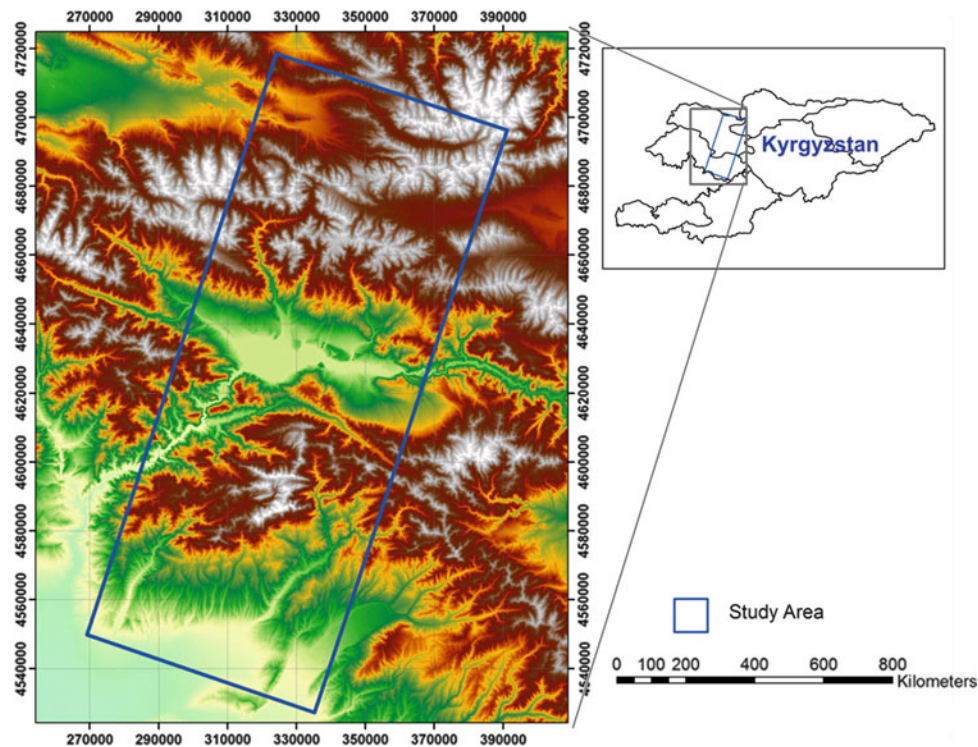


Fig. 1 Location map of the study area

engineering-geological slope investigations, and the examination of historical archives (Guzzetti et al. 1999; Galli et al. 2008). In addition, tools for handling and analyzing spatial data such as Remote Sensing software packages and GIS may facilitate the application of quantitative techniques in both landslide inventory mapping and hazard assessment. Several studies have been performed using remotely sensed data and GIS data integration in landslide assessment (Guzzetti et al. 1999; Ostir et al. 2003; Qi et al. 2010). Remote sensing techniques are preferable for landslide assessments because they provide up to date data and have the ability to show large areas, when integrated into a GIS environment (Alkevli and Ercanoglu 2011).

The data used in this paper was collected from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), using level 1B at 15 m resolution; the ASTER Global Digital Elevation Model (ASTER GDEM) at 30 m resolution; the SPOT-5 panchromatic at 2.5 m resolution and SPOT DEM at 20 m resolution. The purpose of this study was to investigate the use of ASTER and SPOT-5 satellite imageries to prepare landslide inventory maps in a landslide prone area in the Toktokul region of Kyrgyzstan in Central Asia. For this purpose, 2D and 3D visual interpretations were created to map landslides using the remote sensing programme ENVI 4.3. The landslide inventory map itself was produced using Arc GIS 10.2 software programme.

Study Area

The study area is situated in the Toktokul hydroelectric and irrigation scheme which is the largest in Central Asia, with a reservoir containing almost 20 km³ of impounded water behind a 230 m-high dam. Annually, the scheme generates 1,200 MW of electricity that is distributed over Kyrgyzstan, Uzbekistan, Tajikistan, Kazakhstan and Russia. This area is located in the technical and seismically active Tien Shan Mountains (Havenith et al. 2006). The Tien Shan is a Cenozoic orogenic belt in Central Asia with a basin and range structure caused by the post-collisional convergence of India with Asia. A major tectonic feature in the Tien Shan is the active Talas-Fergana fault crossing the mountain belt from NW to SE (Fig. 1). Due to being situated in a seismically active area, coupled with the complex interactions between tectonic, geological, geomorphological and hydrological factors present in the region, landslides frequently lead to serious damage to property, infrastructure and associated loss of life (Roessner et al. 2005). The area is associated with numerous deep-seated slope deformations, landslides, disruptions to superficial deposits and long run out debris flows. Although landslides have been identified in the Tien Shan mountains (Wetzel et al. 2000; Havenith et al. 2002; Roessner et al. 2005; Havenith et al. 2006; Roessner et al. 2006; Strom and Korup 2006; Torgoev et al. 2006;

Table 1 Technical specifications of ASTER sensor and Terra satellite orbital parameters (Hirano et al. 2003)

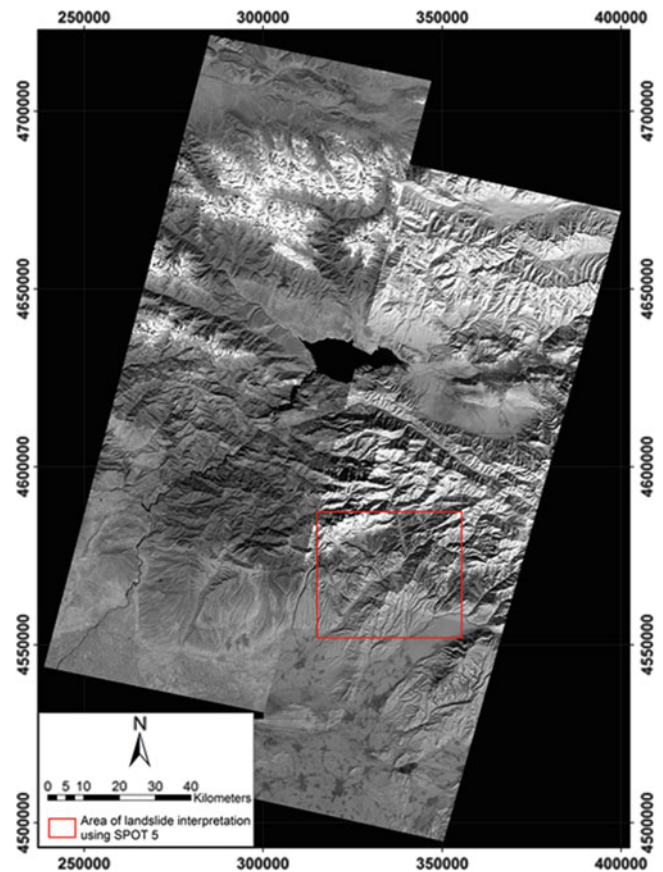
Technical specifications	Terra ASTER stereo
VNIR 0.52–0.86 μm , 15 m	3
SWIR 1.600–2.430 μm , 30 m	6
TIR 8.125–11.65 μm , 90 m	5
Stereo capability	Yes
	Bands 3N and 3B (nadir and aft-looking telescopes)
	0.78–0.86 Am
Stereo imaging geometry	Along-track
Base-to-height (B/H) ratio	0.6
Pixel size	15 m
Scene coverage	60 \times 60 km
Orbital path	Near-polar sun-synchronous
Orbital altitude	705 km
Orbital inclination	98.2°
Repeat cycle	16 days

Danneels et al. 2008; Strom 2010) no detailed landslide inventory is available to assist in the risk assessment for the area, mostly due to a restrictive data policy during the period of Soviet occupation (Roessner et al. 2005; Strom and Korup 2006).

Data

This study was undertaken to investigate the use of medium resolution ASTER satellite images and high resolution SPOT-5 satellite images to determine landslide locations. ASTER is a high performance optical sensor with 14 spectral bands that range from visible to thermal infrared bands (Table 1). It uses three radiometers such as VNIR (Visible and Near Infrared Radiometer; wavelength: 0.56–0.86 μm ; spatial resolution: 15 m), SWIR (Short Wavelength Infrared Radiometer; wavelength: 1.60–2.43 μm ; spatial resolution: 30 m), and TIR (Thermal Infrared Radiometer; wavelength: 8.125–11.65 μm ; spatial resolution: 90 m) (Fourniadis et al. 2007). Hirano et al. (2003) states that a major advantage of the along-track mode of data acquisition (as compared to cross-track) is that the images forming the stereopairs are acquired a few seconds apart (rather than days apart) under uniform environmental and lighting conditions, resulting in stereopairs of consistent quality that are well suited for DEM generation by automated stereocorrelation techniques which provides a greater amount of useful geomorphological information. This is a helpful feature in landslide studies (Alkeveli and Ercanoglu 2011).

Eight scenes of ASTER Level 1B data (Fig. 2) provided by NASA for educational purposes were used in the study. ASTER Global Digital Elevation Model (DEM) at 30 m resolution was also used in association with ASTER images in order to create 3D views.

**Fig. 2** Mosaic ASTER image of the study area band 3N

Furthermore, for a part of the study area (15 %) SPOT-5 panchromatic images at resolution 2.5 m will also be used to identify and classify landslides. Figure 3 shows the example of SPOT-5 image covering part of the study area.

Methodology

ASTER imagery is increasingly used in geological applications as it is one of the least expensive medium resolution satellite images available (Alkeveli and Ercanoglu 2011). In order to investigate the use of ASTER images for landslide mapping by visual interpretation, four different data sets were used:

1. False Colour Composites (FCC) using the 3N, 2, 1 bands in red, green, blue order. Different image processing techniques were applied to enhance the multispectral images. Only the VNIR portion of ASTER images was considered in the analyses because of their relative higher resolution when compared with the SWIR and TIR portions;
2. The 3N infrared band;
3. The Principal Component (PC) transformation. For the visual interpretation, only the first three PC images extracted

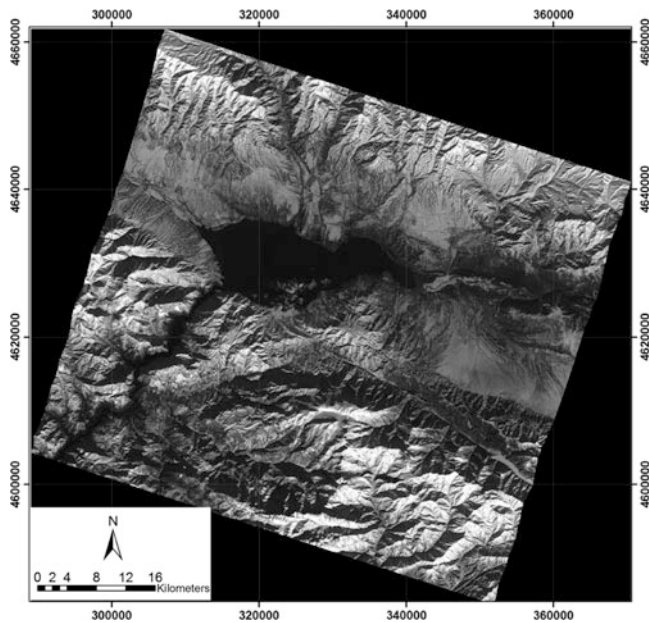


Fig. 3 Example of SPOT 5 image part of the study area

from the combination of the 3 VNIR and 6 SWIR bands were used because of their higher quality; and

4. The merged ASTER images and ASTER DEM to produce 3D view.

The different image processing techniques were performed using ENVI 4.3. Additionally, the visual interpretations were created and interpreted using Arc GIS 10.2 software.

Landslide information identified by remote sensing product using visual interpretation is related to the morphology, vegetation and drainage condition of the slope. In addition, tone and pattern of the surface, such as hummocky topography, may be taken into account as it may be related to slope failure. However, scales smaller than 1/15,000 demonstrated that FCC and infrared band assessments were insufficient to recognize landslide-related features during the visual interpretation.

SPOT-5 panchromatic band images at 2.5 m resolution (Fig. 3) are also used in this project. The image processing techniques such as interactive stretching will be used to enhance the spatial resolution of the image in order to easier identify landslides.

Results and Discussion

The landslide inventory map was produced by visual interpretation of ASTER level 1B data. Based on the 2D and 3D visual interpretation, 348 active and dormant landslides were identified in the study area. These are shown in the landslide inventory map (Fig. 5). The landslides identified are rotational slides, debris flows and rock falls, however, this information on landslide type could only be determined for large

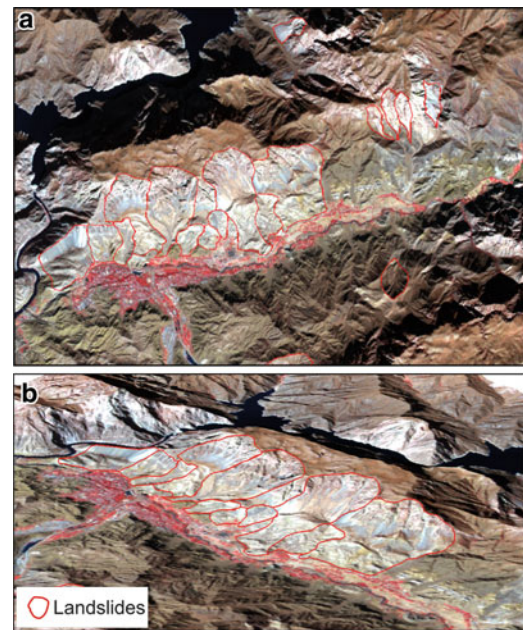


Fig. 4 Example of landslides overlaying on ASTER image (a) 2D view (b) 3D view

landslides. Small landslides did not produce sufficiently distinctive features to confirm whether they were rotational slides, debris flows or rock falls. The largest landslide found in the area was 15,869,692 m² and the smallest was 51,973 m². The landslide interpretation resulted as a landslide inventory map combining all data sets which were FCC, 3N infrared band, PC and 3D view (Figs. 4 and 5).

Based on 2D visual interpretation, FCC was found to be more useful than the 3N infrared band because landslides could be identified more easily due to their higher contrast to surrounding area in FCC images. However, for scales more detailed than 1/15,000, FCC, 3N infrared band and PC images derived from ASTER were considered insufficient for landslide identification and mapping. For identification of landslides on a larger scale, higher resolution remote sensing images are needed. Nevertheless, it could be sufficient in other areas depending on reflection of the landslide surface shown on the images.

In some areas landslides were difficult to detect on the 2D ASTER images due to a lack of distinctive traces, whereas the 3D view was consistently useful at showing the morphology of the landslides. Hence, 3D visual interpretation performed on ASTER imagery and ASTER DEM is useful for landslide inventory mapping.

SPOT-5 panchromatic 2.5 m resolution has shown a significantly more detailed representation of landslide features and morphological structures (Fig. 6). Consequently, the mapping of landslide location using SPOT-5 will be carried out in more detail at a later point and the landslide inventory map based on SPOT-5 interpretation will be produced in a larger scale.

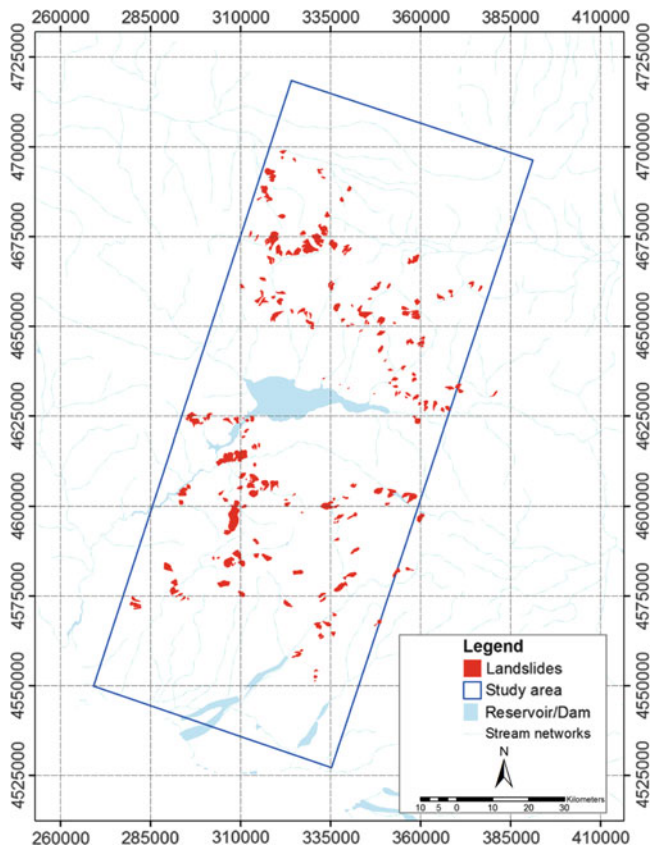


Fig. 5 Landslide inventory map of the study area produced from ASTER imagery

However, visual interpretation is a subjective methodology mostly depending on the interpreter's knowledge and experience using different criteria defined for the identification of landslides. The errors inherent in visual image interpretation may produce differences of between 60% and 90 % when different researchers are doing the interpretation (Saba et al. 2010). Therefore, field verification is needed in order to correct any errors in image interpretation.

Conclusion and Further Works

The purpose of this study was to investigate the use of ASTER and SPOT satellite imagery to prepare a landslide inventory map in a landslide prone area in the Toktogul region of Kyrgyzstan in Central Asia. The results showed that available ASTER images are suitable for identification of large (greater than 50,000 m²) landslides in the Toktogul region and that satellite remote sensing data are valuable in allowing better mapping and understanding of landslides especially when being merged with DEMs to produce 3D views.

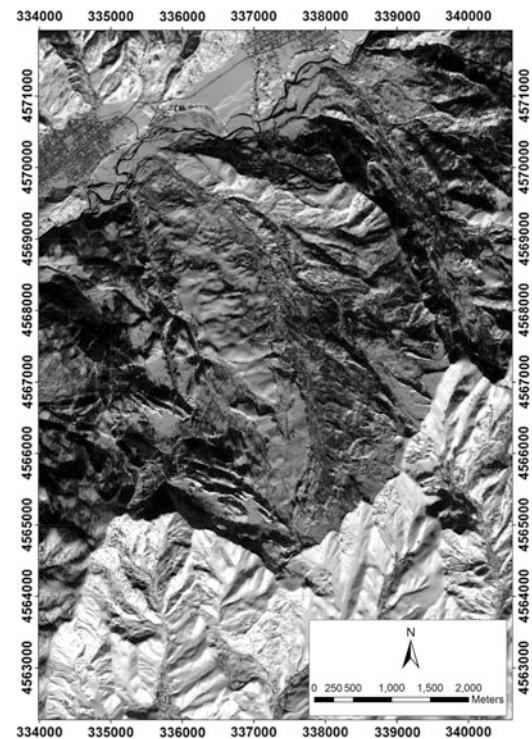


Fig. 6 Complex landslide identified on SPOT 5 Panchromatic image

Further Work

To complete the landslide hazard assessment of the area, the following work needs to be done:

1. Identify landslides from SPOT 5 data and produce a landslide inventory map from SPOT images,
2. Ground truth this landslide inventory using field reconnaissance,
3. Integrate morphological, lithological, structural, land use, hydrological and seismic data within a GIS environment. DEM data from SPOT will form an important component of this dataset, and
4. Derive statistical landslide susceptibility models through the integration of the landslide inventory with the GIS datasets.

The expecting results will be shown in form of a landslide inventory map including a GIS database at various scales and a landslide hazard map showing different levels of hazard prone areas. Consequently, this mapping result will be used to assist in making rational decisions regarding local evacuation plans in areas susceptible to slope failure.

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