Aster Stereo Images for Landslide Hazard Assessment in the Central Alborz Mountains, Iran

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Abstract

This research investigates and demonstrates the abilities of the ASTER stereo images using remote sensing techniques for detailed landslide hazard assessment in Central Alborz Mountains north of Iran. Since the most common methods of landslide hazard assessment using simple inventories and weighted overlays have been heavily depended on three-dimensional terrain visualization and analysis, stereo satellite images from the ASTER High Resolution sensor are used for this study. The Digital Elevation Models (DEMs) generated from ASTER stereo images appear to be much more accurate and sensitive to micro-scale terrain features than a DEM created from digital contour data with a 10 m contour interval. Stereo pair ASTER images permit interpretation of recent landslides as small as 10-15 m in width as well as relict landslides older than 30 years. A cost-benefit analysis comparing stereo air photo interpretation with stereo satellite image interpretation suggests that stereo satellite imagery is usually more cost-effective for detailed landslide hazard assessment over large mountain areas.

Keywords: *Landslide hazard, Remote Sensing, ASTER Stereo Images, DEM, Central Alborz.*

Introduction

ASTER as multispectral satellite remote sensors is providing high spectral and spatial resolutions for landslide hazard assessment. Nowadays, Methods for landslide hazard assessment need the collection of highly detailed information over large areas. The 14 bands of the ASTER data cover the visible and near infrared (VNIR; 3 bands with 15m

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spatial resolution), shortwave infrared (SWIR; 6 bands with 30m spatial resolution), and thermal infrared (TIR; 5 bands with 90m spatial resolution) and allow for 364 Red-Green-Blue (RGB) color combinations. ASTER imagery is along-track stereo. So the two images that make up the stereo pair have been taken very closely together in time. Thus atmospheric, ground surface condition and illumination changes between the two images will be minimal. The downside of along-track stereo is that the stereo separation of the images may not be as optimal for DEM generation as across-track stereo can provide.

Soeters and Cornelis[1] illustrated four scales of slope instability assessment for landslide hazard: national, regional, medium and local. At the local level, only a few tens of square kilometers can be studied, and areas as small as 10 ha or less should be clearly defined. The most useful direct indicators of landslide susceptibility are considered to be evidence of past landslides as well as tension cracks and other detectable earth movement. Therefore, the simplest type of landslide hazard assessment includes an inventory of previous landslides and signs of mass movement, based on the premise that an area with past landslides is landslide prone and has a high probability of new landslides.[2] McCalpin[3] showed that for planning purposes, any landslides with historic movement during the last 100 years have been considered active. Except in arid zones or under thick forest,[4] recent landslides can be readily identified on air photos due to high contrast with the darker vegetated background, although, they become increasingly indistinct with time.[5] The integration of observations, field measurements and stereo air photo interpretation can satisfy the demands for landslide studies. For example, approximately 230 photo prints at a scale of about 1: 8,000 are required for a complete stereo cover of an area of 80 km2. Moreover, such a detailed air photo cover is expensive, and manual methods of stereo air photo interpretation are time-consuming, especially if the results of the interpretation are to be input to a GIS database for weighted overlay analyses. In such a case, a DEM is also required for Ortho-rectification and the production of a slope map. Moreover, generation an accurate DEM is available, Ortho-rectification of a stereo pair air photo may take more than 6 hours of professional work. Although some researcher such as Mantovani et al.[6] implied that satellite images are unsuitable for landslide studies, But Nichol and Wong presented that most of landslides in forested areas could be detected by automated change detection using SPOT multispectral satellite images with a 20 m spatial resolution. The “identification” and “interpretation” of the features as landslides would require higher deductive processes based on stereo viewing of the topographic position and slope morphology. [8 9 10]

The stereo capability of air photos that aids interpretation of slope morphology, as well as their higher resolution has mitigated against the use of satellite images.

However, the improved spatial resolution and stereo capability of recent satellite sensors such as Terra ASTER, IRS P5, SPOT-5 HRG, and IKONOS may give topographic details comparable to air photos in both 2D and 3D, with the advantage of a single mapping base covering large areas. To enable precise interpretation and visualization of slope morphology, 3D viewing is available using one of several techniques such as (i) direct stereo viewing of the image on a stereo-plotter, (ii) anaglyph construction, and (iii) draping the image over the DEM created from the same stereo satellite images. Measurement of elevations can be done either from the generated DEMs, or if ERDAS Imagine and PCI Geomatica software are available, directly from the digital anaglyph. Manual technique is considered to be more accurate than automatically processed DEMs. However, if the DEM is accurate and detailed enough to show minor changes in terrain height, the traces of small landslides are able to be detected.

This study describes an approach using high resolution stereo satellite images for assessment of landslide hazard. This paper emphasizes on detecting of meter scale micro-relief features and differences in surface texture indicative of micro-scale surface. This paper also tries to evaluate the costs and benefits of applying techniques for detailed landslide surveys over larger areas.

Study area

The study area is situated in Haraz Highway, Central Alborz, and Northern Iran that covers a 60 km2 mountain area (Fig. 1). This area has high potential seism-tectonic activity. Rangelands and rocky outcrops cover most valleys in the study area. The area is underlain by Jurassic sedimentary rocks and Quaternary volcanic tuff and lava.

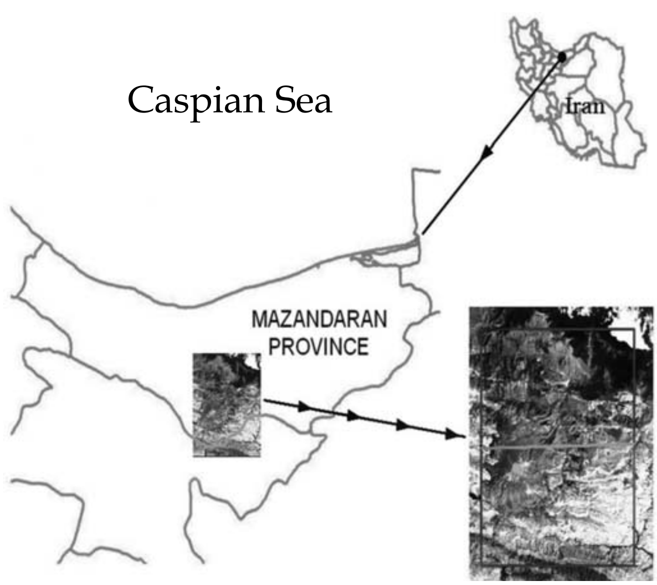

Fig. 1: Location of study area in Central Alborz, Northern Iran.

Materials and Methodology

Stereo ASTER L1A and L1B images acquired in August 2006 and have been used in this research. The DEM was generated at 15 meters resolution with the highest possible level of detail, and the holes are filled by automated interpolation.

24 well-distributed ground control points (GCPs) and 32 checkpoints were digitized from recent 1:10000 digital topography maps produced by the Iranian Survey Organization. The points correspond to clearly identifiable intersections and landmarks between roads or footpaths. The elevations of these points have been taken from a DEM with a grid resolution of 5 meters, produced from recent digital topographic maps (Iranian Survey Organization) with a contour interval of 5 meters.

Automatic image matching was conducted to define points in the overlap area between the two stereo images. Although the matching process has produced a number of tie points, small areas with highly variable terrain elevations could not be matched. Therefore, 32 additional points are manually digitized in these areas and are used for interpolation to produce a 5 meters DEM for the overlap area. The quality of the generated DEM (Fig2) was then assessed by comparing the elevations of 32 well-distributed checkpoints with those on a 5 meters DEM generated photogrammatically from false colour dispositive air photos with a very high (2 meters) resolution. The accuracy of this DEM is assessed by comparing the elevations of 14 locations along a longitudinal section of a landslide trail and four points along a section across the landslide crown (Fig. 3) with (i) the existing DEM from 2 m contour maps, (ii) measurements on the anaglyph generated from ASTER stereo images, and (iii) measurements on an anaglyph generated from the 2 m resolution air photos. The Landslide database of the Geotechnical Engineering Office of the Iran, Mazandaran Province Watershed Management Department and Natural Resources Research Center, Iran, which includes records of all landslides since 1972, has been also used as a reference for the proportion of landslides, which could be identified using either stereoscopic air photos or ASTER images with both planimetric and stereoscopic viewing.

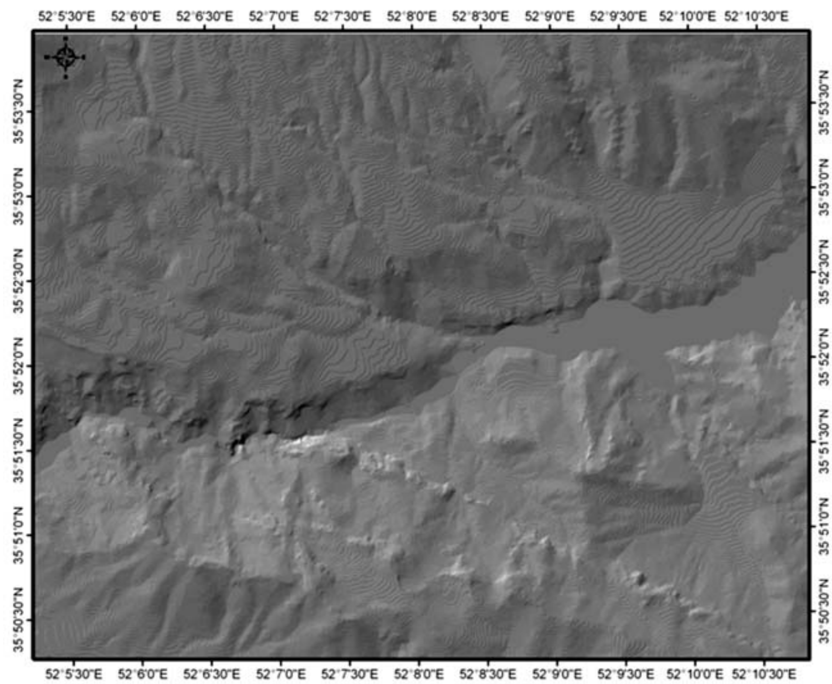

Fig. 2: Showing shaded relief models of DEMs generated from ASTER stereo images over study area (40 km2) with cell size of 5 m.

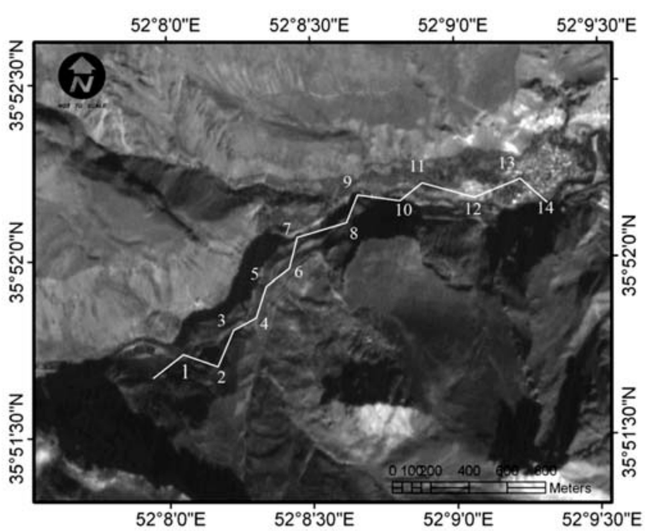

Fig. 3: Showing position of 14 traverse points and cross section on ASTER image.

Results and Discussion

The results of the orientation process gave total RMS errors at the checkpoints of 5, 8 and 15 m and maximum residual errors of 6, 9 and 18 m in X, Y and Z directions, respectively. This was achieved by using only four appropriate GCPs and there has been almost no improvement in the accuracy by adding more GCPs. Assessment of the ASTER 15 meters DEM at 32 checkpoints using the DEM from the air photos as reference shows that most of the points have height errors between 2.50 and 3.5 meters, but a few steeply sloping areas have larger errors up to 7.0 meters. The total RMS error and the linear error with a 79% level of confidence of the 15 meters DEM were 20 and 25 meters, respectively.

The mean height difference between the measurement on the ASTER anaglyph and that on the air-photo anaglyph was ca. 5.0 meters along the longitudinal section (Fig 4). The contour-based DEM suggests a 15 meters deep, V-shaped topography along the cross section, whereas the measurements from the ASTER anaglyph indicate a 15 m deep U-shaped topography (Fig 4). The difference would be crucial for volumetric studies, since the ASTER stereo suggests a much greater volume of material removed from the landslide crown. Thus, for detailed morphometric analyses, ASTER stereo images seem to be more useful than existing DEMs and give similar accuracy to the stereo air photos.

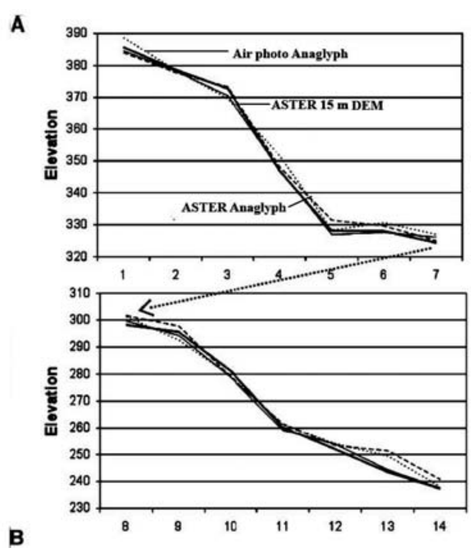

Fig. 4: Comparison of elevations (meter) obtained at statios along and across landslide trail among ASTER anaglyph, ASTER 15 meters DEM, existing DEM from 2 meters contour maps, and anaglyph from high-resolution air photos. (See Fig. 3 for their locations).

ASTER stereo images can be visualized using three different approaches: a. creating anaglyphs (Fig. 5), b. draping the ASTER ortho-images over the generated DEM (Fig. 6) and c. creating stereograms (Fig. 7). The main aim of the 3D visualization is to contribute additional contextual, locational and morphological information to planimetric image interpretation.

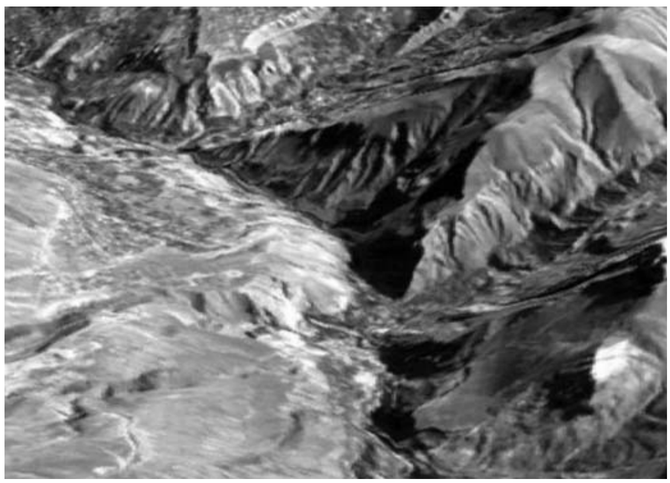

Fig. 5: Anaglyph produced from ASTER stereo imagery (See Fig6, Landslide Lake on two days after occurrence in 2001).

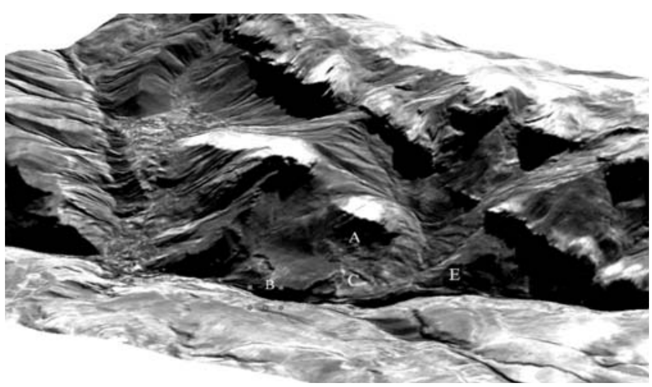

Fig. 6: Ortho-image draped over ASTER derived DEM showing detailed terrain information. Landslide trail in image centre is ca. 7 m wide, and footpath crossing from left to right is 1-2 meters wide. Landslides older than 50 years can be detected; inverted Vshaped scarp (A) and inverted spoon-shaped concavities (B, C, D and E).

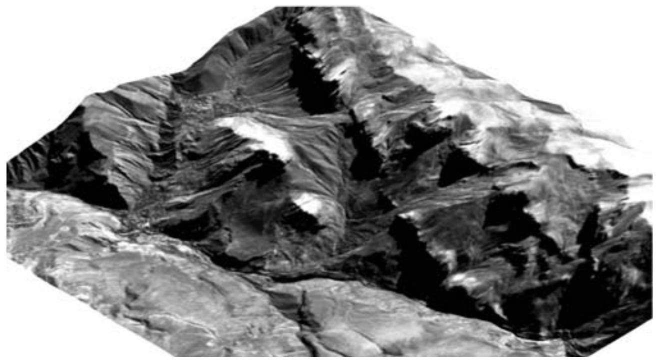

Fig. 7: Stereogram from ASTER stereo imagery, for 3D viewing using stereoscope.

Fig. 8: Showing Landslide in Ask, Haraz high way, Central Alborz two days after occurrence in 2001).

The database shows that 23 landslides occurred in the area covered by the 15 meters DEM, between 1972 and the image date (August 2006). Only the large and recent landslides (about 35%) can be identified on the ASTER image. However, with the direct 3D viewing of the ASTER images on the stereo plotter, the colour, shape, topographic position, and vegetative details are visible, permitting an experienced interpreter to identify approximately 50% of the landslides. Additionally, some old landslides which occurred before 1972 could be identified. These include a landslip at A on Fig. 6 and 8, in the form of a marked inverted V-shaped scarp, and smaller spoon-shaped concavities elongated downslope at B, C, D and E (Fig.8).

All the landslides less than eight years old including those with a small width of 20-30 meters are identified. Sub-meter features such as tension cracks are not visible. Although, the air photos potentially have a very high spatial resolution of 63 line pairs per mm, or 8 cm on the ground, they didn't lead to a significantly improved result. In addition, their interpretation is often tedious due to the restricted field of view under the binoculars and the fixed viewing base of standard mirror stereoscopes. On the other hand, ASTER stereo images are easier to manipulate since they can be viewed at various scales and fields of view. Anaglyphs are also available for detailed 3D viewing of small areas such as scarps, rocky outcrops and tension cracks. Furthermore, the 4-band, 11-bit data format of ASTER gives better image quality to air photos. The watershed and Natural Resources Center, Iran, database records only the length and position of landslides, not the width and volume. However, the volume of material removed are calculated automatically using digital cross sections from the ASTER DEM (Fig. 4) and can be used to estimate sedimentation rates and water quality in the lower catchments.

Conclusion

This study has shown that ASTER stereo images are satisfactory to study the requirements of landslide hazard and its assessment at local and medium scales where the scale of observations is between 10 and 100 meters. It can be used also for detecting micro-scale features that have dimensions of 10 to 20 meters. The ASTER images viewed in 3D were adequate for identifying all recent landslides as well as some very old landslides in the study area, based on slope morphology and re-growing vegetation. The level of 3D spatial detail achieved is deemed to be similar to that of 1: 10,000 scale air photos, but ASTER images surpass air photos in terms of spectral quality, ease of manipulation, a single image base for generation of a DEM, and cost. The DEM created from ASTER appears to be highly accurate, surpassing even that created from digital contour data with an interval of 15 meters. Since ASTER, IRS AND SPOT satellites can be programmed to image any area, and the repeat cycle of both is within three days (off-nadir mode), stereo satellite images now provide a viable alternative to air photos for creating detailed landslide inventories at a range of scales. Terms of structural integrity these are issues concerning fatigue design approaches i.e. infinite life, safe life, fail safe and damage tolerant design, which need to be resolved quickly. In countries such as Iran, air photos are routinely taken by the government and distributed free of charge to various institutes. It is easy to understand why air photos remain the preferred medium for creating landslide inventories. However, in areas where the availability of such data is low, or when the objective of the project is to integrate a landslide inventory with other digital data for regional landslide hazard assessment, the use of satellite images is a viable option. If air photos have already been taken and are available, the overall cost of the air-photo-based approach is similar to that of the ASTER-based approach. If flying costs to take new air photos are added, the cost of the air-photo-based approach becomes 46% higher or 41% higher if tasking of IKONOS is required. A comparison of all image types for the total job cost indicates that the use of Terra ASTER stereo images is incomparably cheap.

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