APPLICATION OF REMOTE SENSING DATA TO LANDSLIDE MAPPING IN HONG KONG

V. K. Vohora and S. L. Donoghue

Department of Earth Sciences, The University of Hong Kong, Pokfulam Road, Hong Kong, SAR, China
vijay@hkucc.hku.hk, donoghue@hkucc.hku.hk

Commission IV, WG IV/6

KEY WORDS: Landslides, Vegetation, Environment, Multispectral, High resolution, Correlation

ABSTRACT:

Rapid encroachment of Hong Kong's urban areas into natural terrain creates a considerable potential risk from landslides. In recent years, considerable effort has been directed towards identifying geological parameters that pre-dispose natural terrains to landsliding and the assessments of landslide risk. There has, however, been little investigation of other possible causative factors, specifically, the role of vegetation type and disturbance, particularly hill fires, in promoting shallow landsliding. Fire-denuded hill slopes may be subject to more frequent landsliding events. Today, much of Hong Kong's hill slopes are covered in fire-prone grasslands, and hill fires associated with cultural festivals are common place. This paper presents an approach to using remote sensing techniques to model areas of disturbed vegetation and detect associated shallow landslides in natural terrain. The research uses data from two satellites, LANDSAT TM and IKONOS. LANDSAT TM is used to detect disturbed vegetation using visible, near and mid-infrared bands and to obtain vegetation indices NDVI and NDMIDIR that indicate plant vigor. IKONOS high resolution multispectral data are used to prepare a color composite image to locate shallow landslides, that are correlated to LANDSAT depicted vegetation indices. Results show that this approach can be used to correlate landslides to areas of disturbed vegetation. Potentially this work has application in defining landslide prone regions.

1. INTRODUCTION

Hong Kong is one of the world's pre-eminent cities with a present, but rapidly expanding population of nearly 7.5 million. Its population is mostly nestled on the lowland coastal fringe, giving this coastal city one of the highest population densities in the developed world. Within a few kilometres of its urban centres is an expansive hilly terrain comprising deeply weathered Mesozoic granites and volcanics. Steep slopes, deeply weathered profiles, and a humid tropical climate predispose this terrain to landsliding events. Heavily scarred hillsides are testimony to the rapidity and severity of landslides in both natural and man-modified landscapes. Increased demand for livable space now sees major urban developments and infrastructural projects being located nearer to natural terrain hill slopes. Such developments have been affected by historical events and are at risk from future events (Ng *et. al*., 2002). Historic landslides have been mapped from aerial photographs in order to define landslide risk (Ng *et. al.*, 2002). The potential use of digital remotely sensed data to the mapping of landslides and determination of temporal associations between landsliding events and surface conditions has, however, not previously been examined. This paper thus represents a first foray into the application of digital remote sensing data to natural terrain landslide studies in Hong Kong.

2. BACKGROUND

2.1 Natural Terrain Landslides in Hong Kong

'Natural' terrain that covers about 60% of the land area of Hong Kong is defined as terrain that has not been substantially modified by human activity but does include areas where grazing, hill fires and deforestation have occurred. Much of the natural terrain is only marginally stable over large areas with 27,000 landslides recorded between 1945 and 1997. The Hong Kong Geological Survey, Civil Engineering Department (GEO, CED) has compiled a Natural Terrain Landslide Inventory (NTLI) for 1945-2000 from high altitude aerial photographs. There is also a Large Landslides Database (defined by source areas of >20 m wide) compiled from low altitude aerial photographs.

Ng *et. al*., (2002) recognize that the NTLI suffers from certain limitations (poor aerial photograph resolution, perspective distortion, ground shadows and vegetation cover) inherited in the coverage due to the quality of the high altitude aerial photographs. Ng *et. al*., (2002) also recognize that for the purpose of an a assessment of hazards the NTLI database, needs to be supplemented with data on corresponding rainfall history and any environmental changes (e.g. anthropogenic effects such as hill fires) that have affected the mapped areas.

Limitations of the existing natural terrain landslide mapping programme potentially can be overcome through application of remotely sensed data. Remotely sensed data has many advantages over traditional aerial photography for mapping landslides and other natural hazards. The capability of remote sensing data to provide synoptic information over wide areas is a particular advantage (Richards, 1993). From a single, high-resolution satellite image in digital format, with multispectral information, a range of ground surface features can be identified, classified, and mapped directly. By comparison, a large number of aerial photographs are required to view a similar area, and tedious image rectification (geometric correction) is required before features can be spatially located on the ground surface (Moffit and Mikhail, 1980; Lillesand and Kiefer, 1999). The ability to 'detect' and classify features using different multispectral bands is a further, specific advantage of remote sensing data.

2.2 Vegetation Indices

Spectral indices of vegetation, based on satellite observations in the near-infrared and visible (red) wave bands, are widely employed as measures of green vegetation density (Jensen, 2000). Healthy vegetation reflects strongly in the near-infrared region of the electromagnetic spectrum, whereas burnt, dying, or diseased vegetation has a decreased reflectance in this region.

LANDSAT TM data, which uses near and mid-infrared is therefore useful to establishing vegetation indices that distinguish burned areas, and to classifying these into damage classes (Siegert and Hoffman, 2000; Rogan and Yool, 2001). Vegetation monitoring by remotely sensed data has been carried out using vegetation indices that are mathematical transformations designed to assess the contribution of green plants to multispectral observations (Bannari *et. al*., 1995; Jensen 2000). Vegetation indices (VI's) are mainly derived from reflectance data from discrete red (R) and near-infrared (NIR) bands. A commonly employed VI is the normalized difference vegetation index NDVI = [NIR-R]/[NIR+R] (Bannari *et. al*., 1995). NDVI values fall between –1 and +1. Higher NDVI values (> 0) indicate more green vegetation, and appear 'bright' in images. Soils have values close to zero, and water bodies have values less than zero.

Advanced Very High Resolution Radiometer (AVHRR) imagery from the National Oceanic and Atmospheric Administration (NOAA) satellite series (available since 1981) is also used to measure vegetation indices for global vegetation mapping. AVHRR thermal and optical data have been used to locate fires in real time (Li *et. al*., 2000) and to detect recent fire scars of up to one year old (Eva *et. al*., 1998; Barbosa *et. al*., 1999). Detecting older scars using optical data, is, however, difficult (Steyaert *et. al*., 1997). SPOT mid-infrared vegetation reflectance values are useful in this regard (Fraser *et. al*., 2000) as an indirect measure of fire-denuded surfaces. Mid-infrared reflectance values are sensitive to canopy moisture such that any increase in the exposed soil surface (*e.g.* post-fire) will realize increased values.

2.3 Remote Sensing Applications in Landslide Studies

Remotely sensed data (LANDSAT TM; interferometric SAR [InSAR]) has found specific application in documenting landscape change through surface erosion (Metternicht and Zinck, 1998; Pickup and Marks 2000; Meyer *et. al*., 2001), landslide mapping (Lillesand and Kiefer, 1999; Singhroy and Mattar 2000) and in identifying causative factors in landsliding events (McKean *et. al*., 1991).

To recognize small-scale, shallow landslides, data that provides at least 10 m spatial resolution is required. LANDSAT TM data can be used (*e.g.* Metternicht and Zinck, 1998; McKean *et. al*., 1991) but higher resolution SPOT PAN (10 m) (Liao and Lee, 2000), IKONOS (4 m) or InSAR (Singhroy and Mattar 2000) data is preferred for this application.

3. OBJECTIVES

Remotely sensed data appear to have tremendous potential in natural terrain studies (landslide mapping and ecology management) in Hong Kong, but as yet, this potential has not been evaluated. The purpose of this paper is to describe a methodology developed for using remotely sensed data in landslide mapping and risk assessment studies in Hong Kong. Our specific objectives are to use remotely sensed data to depict small-scale natural terrain landslides, and to identify disturbed vegetation across land surfaces and relate these to landslide incidence. In Hong Kong, over the past many decades, anthropogenic disturbance of forests (principally tree cutting and burning) has resulted in an expansion of degraded fire-prone grassland and shrub land hillsides (Hau and Corlett 2002, 2003). In Hong Kong, there may be a causal and temporal relationship between natural terrain landslides and vegetation disturbance, including hill fires (*e.g.* Savage, 1974; Dyrness, 1976; Cannon 1997). Such relationships are important to landslide prediction studies.

3.1 Study Area

The area selected for study is the Pat Sin Leng Range (within Pat Sin Leng Country Park), which traverses the northeastern New part of the Territories district of Hong Kong region (Fig. 1). In this area, optimum conditions exist (geology. topography, vegetation and hill fire history) for developing a methodology.

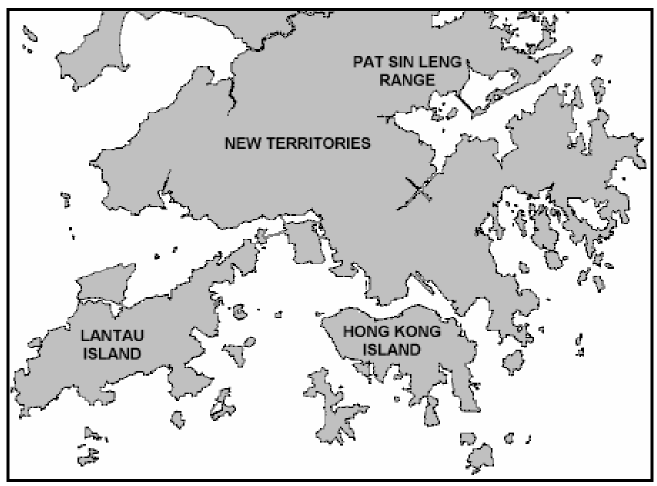

Figure 1. Location of Pat Sin Leng Range (study area).

The local geology comprises Lower Cretaceous sedimentary rocks of the Pat Sin Leng Formation. This Formation occupies a fault-bounded block with beds dipping steeply to the northeast. A prominent escarpment developed on the south side of the Range marks the unconformable contact with the underlying Tai Mo Shan volcanics (Lai *et. al*., 1996; Fyfe *et. al*., 2000; Sewell *et. al*., 2000. Numerous small landslide scars are evident (in the field and in aerial photographs) on the upper and mid-hill slopes of the Range. Colluvial deposits flank the escarpment and upper reaches of stream valleys. The lowland valleys are wooded, but upper hill slopes are covered by fire-prone grasslands and shrublands. The Agriculture, Fisheries and Conservation Department of Hong Kong keeps records of hill fires within the territory's Country Parks, although it does not provide specific information on fire distribution within any given park. Hong Kong citizens, however, remember all too well a particularly tragic hill fire that swept across Pat Sin Leng Country Park in 1996 killing members of a school party.

4. METHODOLOGY

Two types of remotely sensed data are used in this study. Georeferenced LANDSAT TM data (dated 10-01-03) and IKONOS data (dated 4-11-02).

LANDSAT data has visual, near-infrared and mid-infrared bands. Mid-infrared bands (TM5 and TM7) are sensitive to canopy moisture content and may be linked to vegetation type and canopy structure. They are therefore are useful to establishing vegetation indices that identify burned or stressed vegetation; Fraser *et. al*., 2000). Two indices are determined in this study. They are NDVI normalized difference vegetation index), (Bannari *et. al*., 1995) and NDMIDIR (normalized difference mid-infrared). High-resolution IKONOS data has visual and near-infrared bands and is used to create a false colour composite image to detect shallow landslides. The spectral resolution of LANDSAT TM and IKONOS bands used is 30m and 4m, respectively.

The following components were used to develop a methodology (this study) to identify disturbed vegetation (including fire scars) and detect associated shallow landslides:

- Produce NDVI image using LANDSAT TM data
- Produce NDMIDIR image using LANDSAT TM data
- Identify scars on NDMIDIR image and compare the indices values with the NDVI image
- Produce False Color Composite (FCC) using IKONOS multispectral data and identify landslides
- Locate fire scars on NDMIDIR image
- Ground check for the verification of shallow landslides and fire scars

The equations for producing NDVI and NDMIDIRIR using LANDSAT TM bands are: as follow:

$$NDVI = \frac{(TM4 - TM3)}{(TM4 + TM3)} \quad (1)$$

$$NDMIDIR = \frac{(TM4 - TM7)}{(TM4 + TM7)} \quad (2)$$

5. RESULTS AND DISCUSSION

5.1 Vegetation Indices and Disturbed Vegetation

NDVI and NDMIDIR images generated using equations (1) and (2) above are presented as Figures 2 and 3 below. Relevant statistics for these indices are given in Table 1.

Healthy vegetation shows higher values in the NDVI image, but from the index values, it is difficult to discriminate between healthy vegetation and the disturbed vegetation types (Fig. 2). The values from the NDMIDIR image, however, do very clearly discriminate vegetation vigor (Fig. 3). Disturbed (burned) or stressed vegetation is indicated by values between zero and 0.235 (mean value) and healthy vegetation by values greater than the mean. In the NDMIDIR image (Fig. 3), disturbed vegetation is seen as dark pixels. These areas are not depicted in the NDVI image within vegetated areas.

Indices	Minimum	Mean	Maximum
NDVI	-0395	0.235	0.512
NDMIDIR	-0.135	0.395	0.635

Table 1. Statistics of NDVI and NDMIDIR indices.

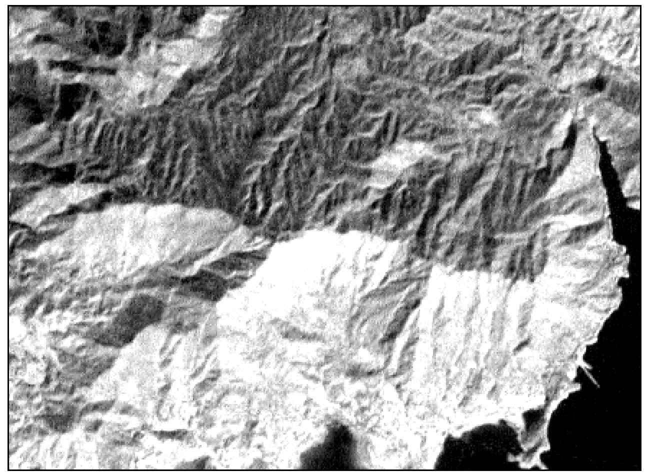

Figure 2. NDVI image showing healthy vegetation (bright white tonal areas).

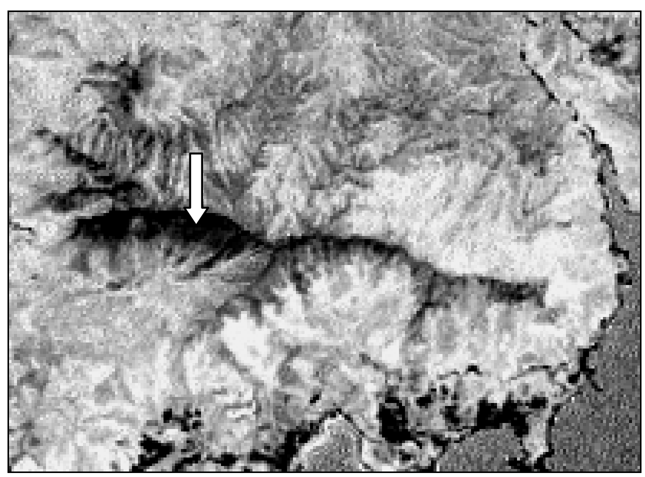

Figure 3. NDMIDIR image identifying possible fire scars principally along the south and west Pat Sin Leng Range (arrowed; black pixels). Small areas of disturbed vegetation are also seen to the north. Fire scars and landslides were identified in ground thruthing studies, particularly along the western Range.

IKONOS multispectral near-infrared, green and blue bands were used to produce a false colour composite (FCC) image (Fig. 4). Red areas depict healthy vegetation. Pale colours (yellow, blue), prominent to the south of the Pat Sin Leng escarpment (Figs. 4-6), identify exposed denuded hill slopes.

5.2 Landslides

Denuded hill slopes (Figs. 5, 6) correlate to areas of disturbed, possibly burned, vegetation seen in Fig. 3. LANDSAT TM resolution (30 m) precludes detection of shallow landslides in NDMIDIR images, however, numerous fresh shallow landslides are detected in the higher resolution IKONOS FCC image (Fig. 6). Landlides are identified on the basis of tone (indicating exposed surfaces) and feature shape. Collectively, these results demonstrate correlation of landslides to denuded surfaces. This correlation is significant to establishing a causal and temporal relationship between episodes of vegetation disturbance and landsliding.

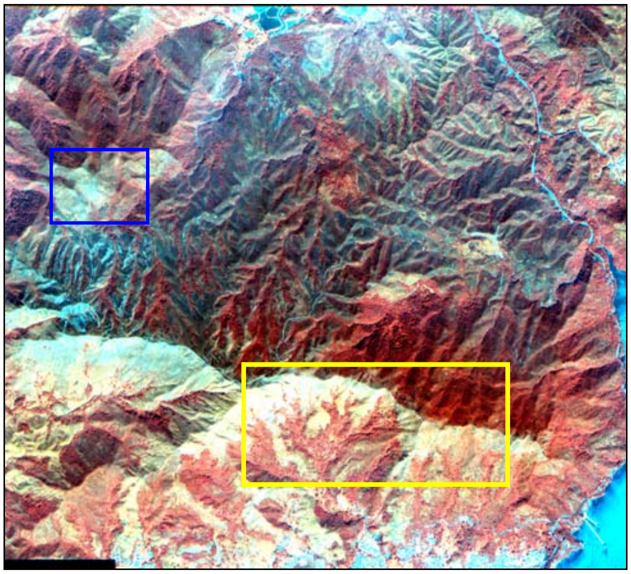

Figure 4. FCC using IKONOS imagery, Pat Sin Leng Range. Yellow Insert - see Figure 5. Blue insert – see Figure 6.

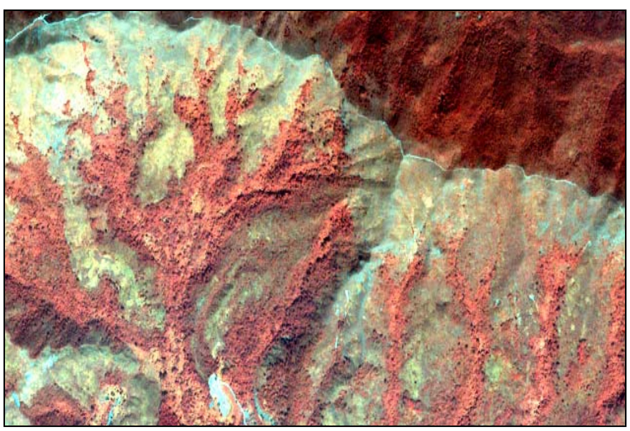

Figure 5. FCC highlighting eroded surfaces and disturbed vegetation (pale colours) south of the Pat Sin Leng escarpment. The Pat Sin Leng trail that traverses the escarpment crosses the image from top left to centre right.

6. CONCLUSIONS

Using remotely sensed data we are able to depict disturbed vegetation, denuded hill slopes, and shallow landslides in natural terrain. Our preliminary work indicates positive correlation between these factors. This is an important finding in support of the use of remotely sensed data to predict landslide-prone terrain in Hong Kong. This work compliments that of the GEO, CED natural terrain landslide mapping programme by providing synoptic environmental information (particularly anthropogenic effects) for large areas of natural terrain, and a means to investigate specific causative factors.

We have restricted our investigation here to LANDSAT TM and IKONOS data, but there would appear to be great potential in using this and other remotely sensed data, such as airborne radiometrics (Cranfield, 2003, pers. comm.) to map specific ground conditions including the identification of areas of alteration and deep weathering that may be additional pre-disposing factors for landsliding. In the longer-term, such work will serve to inform relevant sectors of local government of the potential risks associated with major land development projects.

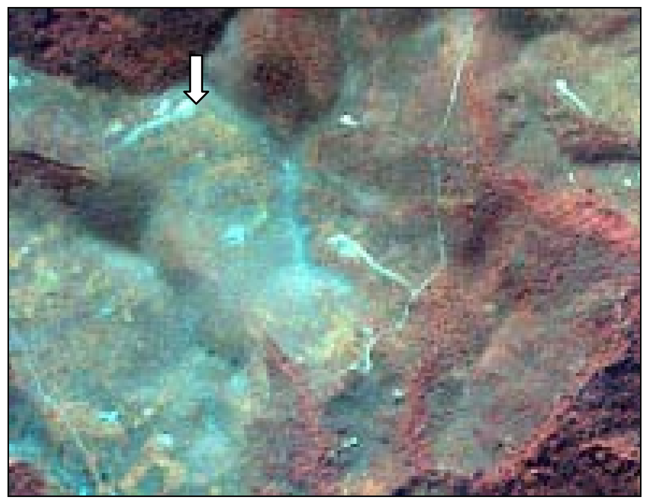

Figure 6. FCC highlighting shallow landslide scars (*e.g*. arrowed) in a denuded area, northern Pat Sin Leng Range. Note the absence of landslides within the red areas depicting healthy vegetation cover.

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ACKNOWLEDGEMENTS

The authors extend their thanks to Mr Len Cranfield (Natural Resources and Mines, Australia) for helpful discussion and suggestions. This work is supported by a CRCG Small Project Grant, The University of Hong Kong.