Identification of landslides in clay terrains using Airborne Thematic Mapper (ATM) multispectral imagery.

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ABSTRACT

The slopes of the Cotswolds Escarpment in the United Kingdom are mantled by extensive landslide deposits, including both relict and active features. These landslides pose a significant threat to engineering projects and have been the focus of research into the use of airborne remote sensing data sets for landslide mapping. Due to the availability of extensive ground investigation data, a test site was chosen on the slopes of the Cotswolds Escarpment above the village of Broadway, Worcestershire, United Kingdom. Daedalus Airborne Thematic Mapper (ATM) imagery was subsequently acquired by the UK Natural Environment Research Council (NERC) to provide high-resolution multispectral imagery of the Broadway site.

This paper assesses the textural enhancement of ATM imagery as an image processing technique for landslide mapping at the Broadway site. Results of three kernel based textural measures, variance, mean euclidean distance (MEUC) and grey level co-occurrence matrix (GLCM) entropy are presented. Problems encountered during textural analysis, associated with the presence of dense woodland within the project area, are discussed and a solution using Principal Component Analysis (PCA) is described.

Landslide features in clay dominated terrains can be identified through textural enhancement of airborne multispectral imagery. The kernel based textural measures tested in the current study were all able to enhance areas of slope instability within ATM imagery. Additionally, results from supervised classification of the combined texture-principal component dataset show that texture based image classification can accurately classify landslide regions and that by including a Principal Component image, woodland and landslide classes can be differentiated successfully during the classification process.

Keywords: Airborne Thematic Mapper (ATM), remote sensing, texture, GLCM, entropy, landslide, UK.

1. INTRODUCTION

Landslides pose a threat to engineering projects and frequently necessitate detailed investigation by ground survey and remote aerial photographic methods. Airborne remote sensing offers a tool suitable for investigations where the spectral and spatial resolution of the sensor allows landslide features to be resolved. Several authors have described the application of airborne multispectral imagery for landslide mapping. Such achievements were based on the use of textural enhancement, principally spatial filtering [1, 2, 3, 4] and statistical measures [5].

In this paper we evaluate the textural analysis of Airborne Thematic Mapper (ATM) imagery for landslide mapping on the Cotswold escarpment. Initially, three textural measures were adopted, variance (VAR), mean euclidean distance (MEUC) and grey level co-occurrence matrix (GLCM) entropy and applied to the Broadway ATM imagery. Using GLCM entropy, a texture based image classification was then evaluated as a method for landslide identification. We also highlight problems associated with textural enhancement of landslides in ATM imagery, caused by the presence of highly variable woodland and hedgerow systems and describe how these difficulties have been resolved during this study.

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2. STUDY AREA

This study has concentrated on an area of potentially difficult ground conditions on the escarpment slopes to the east of the village of Broadway (OS Grid Reference 410,000 237,500). The village itself is located in the Vale of Evesham, within the Wychavon region of Worcestershire and lies between 80 m and 100 mOD on the west facing scarp slope at the foot of the Cotswold escarpment (Figure 1). The Broadway site has been the location of a number of landslide and remote sensing investigations [6, 7].

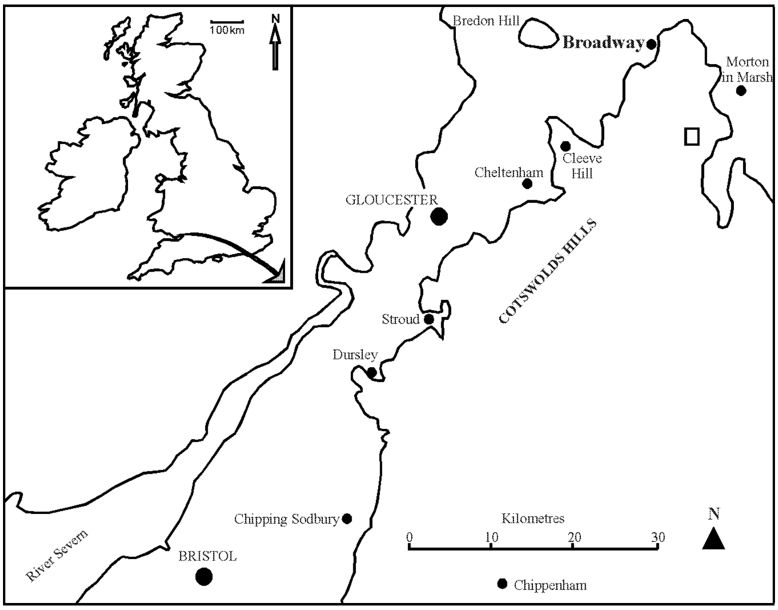

Figure 1. Location of the Broadway study site (Worcestershire, UK) in relation to the Cotswolds Hills.

2.1 Geology and geomorphology.

The geology of the site is dominated by Lower Jurassic strata of Lower, Middle and Upper Lias age [8]. These rocks are overlain by the Lower Inferior Oolite (Middle Jurassic) which caps the escarpment above Broadway (Table 1). The site has been subject to periglacial conditions during the Quaternary. Such cold periods have induced extensive terrain modification in the form of frost shattered bedrock, periglacially derived soil material, relict solifluction landforms and relict landslides. There is also considerable evidence for more recent landslide activity.

Unit	*Age (Ma)*	*Thickness*	*Lithological Description*
Inferior Oolite	183	25 m	Oolitic and Sandy LIMESTONES.
Upper Lias	187	6 m +	Dark grey silty CLAY and strong oolitic LIMESTONE.
Middle Lias	193	55 m	Moderately weak orange brown SANDSTONE with subordinate bands of hard laminated silty CLAY and clayey SILT. Capped by strong brown closely jointed fossiliferous LIMESTONE (*Marlstone Rock Bed*).
Lower Lias	200	40 m +	Dark grey silty CLAY.

Table 1. Stratigraphy of the A44 Broadway study site with some generalised engineering geological descriptions of the soils and rocks.

The slopes of the Cotswolds are affected by a range of landslide types. Using the EPOCH classification [9], these slope failures can described as mudslides, translational and rotational slides. The landslide sequence involves large rotational landslides on the upper slopes involving the Inferior Oolite, which degrade down slope into shallow multiple rotational landslides and mudslides which mantle the lower basal slopes of the escarpment. Within the Broadway valley evidence exists of a range of slope instability types, including lobate mudslides, shallow irregular mudslides, translational and rotational landslides. A number of geomorphological and geological features can be seen to be promoting slope instability in the area. These are:

1. The presence of a distinct permeability boundary between the permeable Inferior Oolite and the impermeable Lias formations as well as other permeability boundaries present within the Middle and Upper Lias strata.

2. The presence of relatively weak, clay-rich rocks underlying stronger more competent rock masses.

3. The presence of weak surface materials created and modified under a periglacial climatic regime.

Recent investigations suggest a broad history of landslide activity at Broadway [6], from relict movements evident as solifluction lobes on lower slopes, through to suspended landslide features which are clearly evident on many of the slopes above Broadway and active movements which have been documented using instrumentation maintained as part of a ground investigation by Mott Macdonald Consulting Engineers [10].

3. IMAGE DATA

Daedalus Airborne Thematic Mapper (ATM) imagery was acquired as part of an airborne survey of the Broadway study site on 8th February 1997 at a flying height of 800 metres. The imagery consists of 11 bands (Table 2), bands 1 to 5 are visible wavelengths, 6 to 8 are near infrared, 9 and 10 and middle infrared and band 11 is in the emitted thermal infrared. The instrument has a instantaneous field of view (IFOV) of 2.5 milliradians and for this study was re-sampled to a pixel size of 2 metres (NERC Airborne Remote Sensing Facility, flight reference number 97/2).

Band	Band Width (μm)	Band Name
1	0.42 – 0.45	Visible
2	0.45 – 0.52	
3	0.52 – 0.60	
4	0.60 – 0.62	
5	0.63 – 0.69	
6	0.69 – 0.75	Near Infrared
7	0.76 – 0.90	
8	0.91 – 1.05	
9	1.55 – 1.75	Near–Middle Infrared
10	2.08 – 2.35	Middle Infrared
11	8.50 – 13.00	Thermal Infrared

Table 2. Summary of the Airborne Thematic Mapper (ATM) sensor.

Image acquisition was made during early season in February to enhance subtle topographic features associated with slope instability. Excavation of the new A44 Broadway road bypass further constrained flight planning since image acquisition had to be made prior to the start of site excavation in order to image the study site in an undisturbed state.

4. IMAGE PROCESSING

4.1 Textural analysis.

The irregular boundaries and surface textures of landslides mean that they often produce characteristic features that can be distinguished using remote sensing. Table 3 summarises common landforms that can provide landslide signatures in digital imagery. These landslide features and associated surface expression are best enhanced in airborne imagery through textural analysis, this usually involves either textural filtering of an image or the use of statistical measures.

Terrain landforms	Relation to slope instability
Hummocky or irregular slope morphology.	Relief associated with shallow slope movements or small retrogressive slides blocks.
Step-like slope morphology.	Retrogressive landsliding.
Arcuate backscarp and crown wall.	Head part of landslide with exposure of failure plane.
Back tilted slope facets.	Rotational movement of landslide blocks.
Differential vegetation associated with changing drainage conditions.	Stagnated drainage in back tilted block, seepage at frontal lobes, differential conditions and ponding within landslide body.
Sharp break of slope at main landslide scarp.	Landslide scarp generated through rotational or translational movement.
Pressure ridges and transverse ridges.	Landslide toe and overriding of surface by landslide material.

Table 3. Landforms commonly associated with mass movements [11, 12].

Several authors have used textural filters to enhance landslide features within airborne imagery, Mason [3, 4] found that the hummocky main body and the accumulation toe could be identified in airborne ATM imagery that had been texturally enhanced using a Sobel filter. Further edge enhancement of both Landsat TM and ATM revealed the arcuate crown and back scarp of the landslides in south east Spain. Eyers [1, 2] found that simple Laplacian textural filters were successful in landslide mapping, revealing crown wall shape, translated material and the texture of disturbed ground for identification of slope instability in south east Spain.

Statistical methods have been similarly successful in landslide investigations, Hervas and Rosin [5] applied grey level co-occurrence matrix (GLCM) derivatives to landslides in south east Spain. They concluded that textural measures were able to discriminate between rough and smooth surfaces and that the use of 'texture spectrum' method of Wang and He [13] provided an optimum method for landslide detection in arid environments.

4.2 Image texture and woodland stands.

An ATM scene often contains features other than landslides which are highly variable in appearance which therefore also produce strong textural expressions, most commonly, the presence of woodland stands and hedgerows. Therefore, the presence of woodland within an ATM scene can present problems for the use of textural analysis in landslide mapping since textural filters are unable to distinguish between highly variable woodland stands and landslide features.

Hervas and Rosin [5] overcame similar problems when applying textural analysis in landslide investigations in south east Spain through the use of a 'texture spectrum' method [13] which was able to successfully differentiate between closed pine stands and landslide features.

Dense woodland and hedgerow systems are common on the Cotswolds escarpment above Broadway, so if textural enhancement is to be successful then the investigation required a image processing technique for the removal of woodland and hedgerow regions from the airborne imagery. This was achieved in the current study though the use of Principal Component Analysis (PCA) of the ATM scene. The resulting PC image could be used either as a mask for the removal of woodland or as in this study, form part of an image classification scheme to help the classifier distinguish between woodland and landslide regions.

5. METHODOLOGY

The study consisted of three main stages:

1. Application of textural filters: variance, mean euclidean distance (MEUC) and grey level co-occurrence matrix (GLCM) entropy to the Broadway ATM scene and interpretation of output texture images.
2. Application of Principal Component Analysis (PCA) to the Broadway ATM imagery to enhance woodland and hedgerows systems and production of an output PC image.

3. Supervised image classification of a combined GLCM texture image (bands 3-11) and Principal Component image dataset using 3 training groups; landslides, woodland and stables slopes.

5.1 Textural analysis.
The first stage of the study involved the textural analysis of ATM imagery, three textural filters were initially adopted; variance, mean euclidean distance (MEUC) and grey level co-occurrence matrix (GLCM) entropy measures (Table 4).

Texture Measure	Formula
Variance	$Variance = \frac{\sum (x_{ij} - Mean)^2}{n-1}$
Mean Euclidean Distance	$MEUC = \frac{\sum \left[\sum_{\lambda} (x_{c\lambda} - x_{ij\lambda})^2 \right]^{1/2}}{n-1}$
GLCM Entropy *P(i , j)* = GLCM	$ENT = -\sum_{i=1}^{N} \sum_{j=1}^{N} P(i,j) * \log(P(i,j))$

Table 4. Local texture measures [14, 15].

Each output texture image was assessed for landslide identification and from the initial three images, GLCM entropy was chosen as the texture input parameter for the supervised classification scheme.

5.2 Principal Component Analysis.
The second stage involved processing the ATM image in order to enhance woodland and hedgerow regions at the expense of other image features. This was achieved using Principal Component Analysis (PCA). Principal Component images were generated using the image correlation coefficient matrix for bands 3 to 11, bands 1 and 2 were ignored due to varying degrees of noise evident within these bands. From the resulting Principal Component images, PC image 4 (PC_CORR4) was chosen since it clearly enhanced regions of highly variable woodland and hedgerows within the ATM scene. This Principal Component image was then combined with the GLCM entropy image to produce a input dataset for a supervised image classification of the Broadway imagery.

5.3 Image classification.
The final part of the study involved a texture based supervised image classification of the combined GLCM entropy and PC image dataset. Three general training regions were used to train a Mahalanobis classifier (Table 5). The resulting classified image was compared to a reference dataset generated from a field based geomorphological map of the Broadway site. Classification accuracy for landslide, woodland and stable slopes classes were then assessed using a Kappa statistic and a confusion matrix generated by comparing the classified and reference images.

Class	Sub-class	Description
Landslide	Lobate mudslide	Lobate mudslide landslide.
	Shallow mudslide	Shallow mudslide movements.
	Complex landslide	Complex translational landslide.
	Landslide scarps	Degraded landslides scarps.
Stable	Stable bench	Flat lithological bench with no evidence of slope instability.
	Stable slope	Stable south facing slope with no evidence of slope instability.
Woodland	Woodland stands	Dense woodland stands, wooded hedgerows and individual tree stands.

Table 5. Terrain classes used in Broadway ATM image classification.

6. RESULTS

Results from this study have shown that the spatial and spectral resolution of ATM sensor provide detailed images of the Cotswold escarpment capable of resolving landslide features and that through the use of textural analysis, landslide features can be enhanced within airborne imagery.

The chosen texture measures, variance, MEUC and GLCM entropy, can all be used to enhance landslide features within ATM imagery. Each is able to highlight landslide scarps, the main hummocky landslide body, zones of shallow mudslide movement and mudslide accumulation zones, as well as delineating landslide boundaries within the imagery. These texture measures are also able to distinguish between stable slopes which show no evidence of current instability and slopes affected by landslide movement. While the variance method is computationally the most efficient, more advanced measures including MEUC and GLCM entropy appear to present the optimum textural method of landslide enhancement (Figure 2c & 2d).

It is clear from Figure 2 that the presence of dense woodland and hedgerows in the ATM imagery presents a significant hurdle for the use of textural measures in landslide mapping, since these textural measures are unable to differentiate between occurrences of slope instability and dense woodland and hedgerow systems. This can be solved by Principal Component Analysis, which is able to enhance regions of woodland and hedgerows (PC_CORR4; Figure 3a) within the ATM imagery at the expense of other terrain features. The classified woodland image (Figure 3b) demonstrates the power of the PC_CORR4 image in discriminating woodland and hedgerow pixels.

Results from the texture based supervised classification of the combined GLCM texture and principal component image (PC_CORR4) show an overall classification accuracy of 89.5 percent from 199,791 observations and a Kappa statistic of 0.838. The confusion matrices show high classification accuracy for individual classes; woodland stands (97%), stable slopes (92%) and landslides (83%) (Table 6). This suggests that landslides in clay dominated temperate terrains can be accurately classified using texture as the main classification parameter and that woodland and landslide classes can be differentiated successfully by the inclusion of Principal Component image (PC_CORR4) in the classification process.

%	Woodland stands	Stable slopes	Landslide
Woodland stands	97.25	0.45	5.67
Stable slopes	0.081	92.20	10.68
Landslides	2.66	7.35	83.65

Table 6. Confusion matrix for 3 terrain classes.

7. CONCLUSIONS

Results from this study have shown that:

- Textural analysis of airborne multispectral imagery is an effective tool for landslide mapping on the Cotswolds escarpment.
- The texture measures adopted for this study proved effective for highlighting slope instability within the ATM imagery.
- Principal Component Analysis of ATM imagery and the resulting PC_CORR4 image can be used successfully to enhance woodland and hedgerow regions. This is important for landslide mapping on the Cotswolds escarpment where such dense woodland and hedgerow systems are common.
- Supervised classification of a combined GLCM entropy texture and PC_CORR4 dataset has proven successful at identifying landslide regions within ATM imagery, producing good overall accuracy for all three classes; landslide, woodland and stable slopes.
- Textural measures such as GLCM entropy can form an important parameter for identification of landslides in ATM imagery using supervised classification.

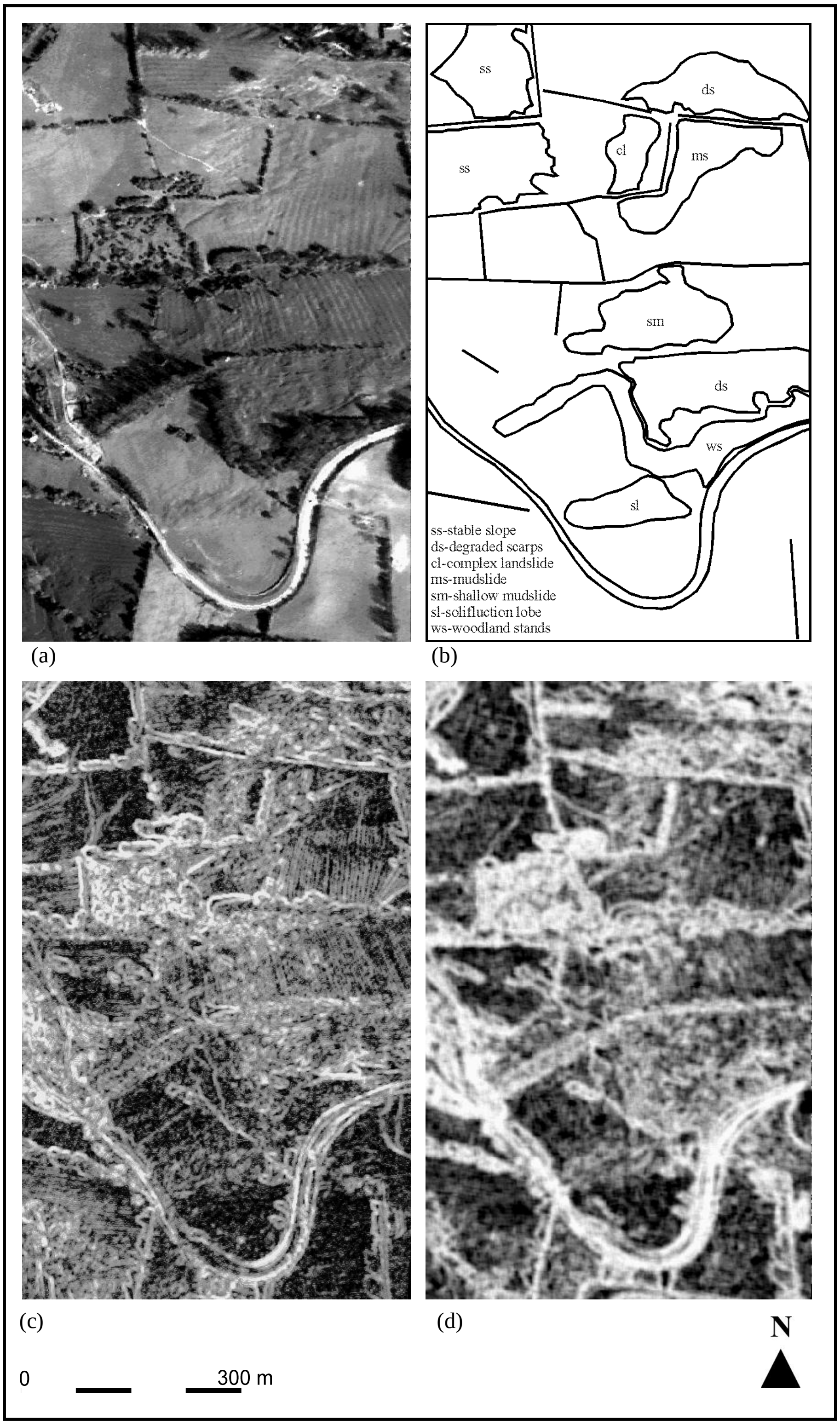

Figure 2. (a) Airborne Thematic Mapper (ATM) imagery visible band 4 (b) corresponding landslide, woodland and stable slope localities (c) mean euclidean distance (MEUC) texture image and (d) grey level co-occurrence matrix (GLCM) entropy texture image.

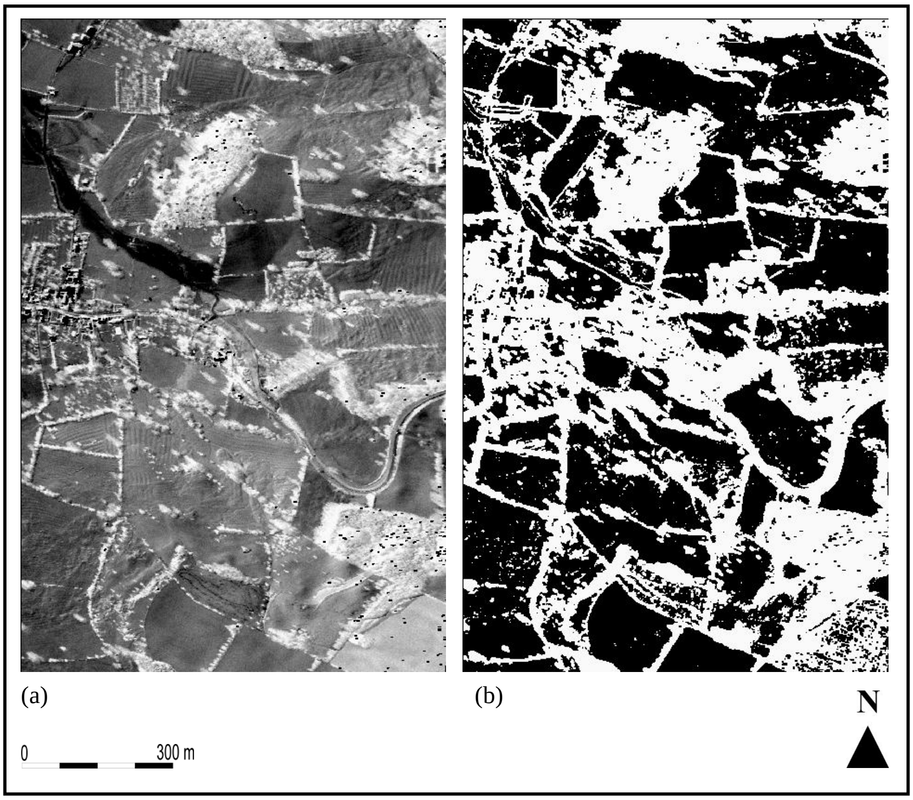

Figure 3. (a) Principal Component 4 (PC_CORR4) image used to enhance woodland stands and hedgerows systems and (b) corresponding classified image using a Mahalanobis classifier.

- Principal component data (PC_CORR4) provides an important discriminant parameter when identifying landslides using texture based image classification since it helps the classifier distinguish landslides from highly variable woodland and hedgerow systems.

Textural analysis of ATM alone is an effective tool for landslide mapping and represents an important parameter when attempting supervised image classification of a landslide site based on ATM data. Clay dominated slopes are common in southern United Kingdom and the associated slope instability represents a significant problem in engineering geology. Airborne remote sensing and the use of textural enhancement can be effective for rapid landslide mapping of a large area. The ability to enhance landslide features and remove erroneous woodland using airborne ATM imagery means that it offers a technique that can be employed effectively by engineering geologists for landslide mapping in clay dominated temperate terrains.

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