GEOHAZARD MONITORING IN SOUTHEAST SPAIN USING INTEGRATED IMAGERY AND DIGITAL ELEVATION MODEL *

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ABSTRACT

The semi-arid terrain of South-eastern Spain is vulnerable to geohazards, including flash-flood erosion, landslides and seismic risk. Developing urbanisation, quarrying and mining, road building and changing agricultural practices are affected by geohazards and in some cases create them. For example, instability on new road cuts and embankments, and ploughing of natural, regolith-soil surfaces renders previously stable terrain vulnerable to 'badland' gully erosion, soil loss and causes increased reservoir siltation.

This paper reports the results of a comparative study of the uses of Landsat TM, and SPOT Pan, in conjunction with a Digital Elevation Model (DEM) for geohazard identification and mapping. We have also investigated aspects of geo-hazards caused by changes in land use and infra-structure development since Landsat TM imagery became available in 1984.

Study targets include:

- terrain at risk from mass movement
- 'badland' terrain in unconsolidated sediments
- disturbance of land surfaces by agricultural development.
- Expansion of communications infrastructure and quarrying in relation to natural hazards.

The methodology for integrated hazard mapping involves directed enhancement, merging and draping of multi-spectral, and panchromatic imagery with the DEM to create three dimensional image products for mapping. The paper concludes with recommendations for combined image and DEM usage in geohazard assessment.

INTRODUCTION

Parts of Almeria, Jaen and Granada Provinces in the Andalucia semi-autonomous region of SE Spain are undergoing a period of rapid economic growth. This involves an extensive urban industrial and agricultural development, together with major programmes of communications improvement, notably local road and new highway construction. Widespread and varied mineral extraction is an important part of the region's economy.

Southeast Spain is semi-arid and includes the only part of Western Europe technically classified as 'desert'. Geologically, the area consists of mountain ranges composed of metamorphic rocks, separated by fault-controlled basins, filled with relatively soft and unconsolidated Miocene or

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younger ‘molasse’ sediments (Figure 1). The area has environmental problems similar to those in other tectonically active, semi-arid parts of the world. These include the climatic hazards of ‘flash flooding’ and its effects in terms of erosion and slope stability effects. A rapid expansion of agriculture over the last two decades has created problems of water resources and their conservation and management. In addition, the area is at risk from earthquakes, of which there have been some catastrophic examples in historical times (Riley, 1993).

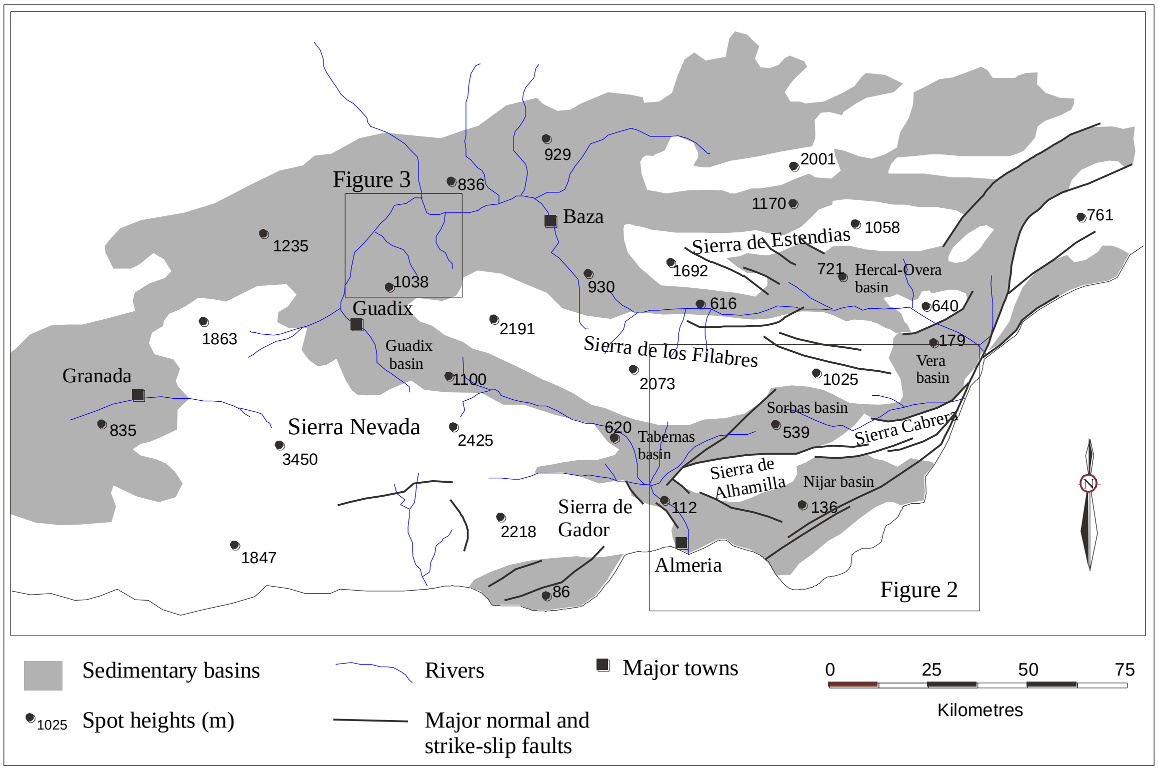

Figure 1 Regional geomorphological map of south east Spain, showing main sedimentary basins, basement complexes and major faults; derived from regional DEM and slope map.

This study reports development of a simple methodology to use remotely sensed imagery, with a DEM, to amplify the two and three dimensional information currently available from published maps and to assess areas at particular risk from a selection of geohazards. By using multi-temporal imagery, temporal change can be incorporated in a digital geo-hazard geographical information system (GIS).

TARGETS FOR GEOHAZARD ASSESSMENT

A selection of geohazard environments have been chosen to demonstrate the use of imagery and digital elevation models for two and three dimensional appraisal, and to illustrate change with time.

These are:

- Elevated terrain in incompetent rocks, containing engineering works, dam sites, major road works, which are at risk from landsliding (triggered by rainfall or seismic vibration).
- Agricultural areas in which there has been disturbance of stable, mature regolith surfaces by agricultural ploughing, industrial or urban development, leading to accelerated soil/regolith erosion and consequent reservoir siltation.
- Reservoir catchments, roads and other infrastructure features, subject to torrential flash flood erosion and other damage associated with badland terrain processes.

GEOLOGICAL AND GEOMORPHOLOGICAL ASPECTS OF GEOHAZARDS

Two groups of rocks are mechanically weak and vulnerable to instability in conditions of steep slopes. These are the unconsolidated marl sequences, locally with intercalated limestone and gypsum beds which are the major constituents of the Tertiary inter-montane molasse basin fill (Figure 2) and the Permo-Triassic purple and grey, fissile phyllites which mantle several of the basement mountain massifes. It is these rocks which are particularly vulnerable to landsliding and badland erosion. Several new highway routes traverse vulnerable, unlithified molasse sediments and Permo-Triassic phyllites. A number of major dams and their reservoir catchment areas have been sited on these mechanically weak rocks, rendering them liable to rapid siltation. in circumstances where erosion is accelerated by agricultural development or road engineering.

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Late Tertiary, tectonic uplift and trans-tensional faulting, following the Alpine Orogeny caused major changes to the morphology of the terrain and drainage systems of SE Spain (Harvey, 1978 & 1984; Harvey & Wells, 1987). Quaternary modification of the relative levels of sea and land, notably Pleistocene glacially related eustatic and isostatic events, induced rapid incision of rivers, over-steepening of valley sides and widespread landsliding as badland terrain developed in large parts of the Tertiary inter-montane basins. It is in the areas of relatively steep slopes flanking over-deepened valleys and in the badland terrain, that landsliding and flash flood erosion occur most actively.

Fault movement during late Tertiary and Quaternary times has dislocated Quaternary land surfaces (Mason *et al*., 1994), together with drainage systems and coastal platforms. This evidence, together with historical records and records of widespread modern seismicity in this tectonically active region, located approximately 100km from the Eurasian plate boundary, makes this an earthquake hazard area. The active tectonics increase the risk to slope stability and engineering structures.

Our image processing and DEM studies concentrated on delineating badland areas in Tertiary (Miocene and Pliocene) marl and Permo-Triassic phyllite terrain (based on spectral information), badland terrain (based on textural information). Using a DEM we have also identified areas where the vertical interval between Tertiary basin fill surfaces and present day sea level is greatest, creating the steepest potential run-off gradients to base level.

IMAGERY AND DIGITAL ELEVATION MODELS.

Landsat TM

Landsat Thematic Mapper imagery has been used to identify and delineate areas of Miocene-Pliocene marl dominated sediments and Permo-Triassic phyllite outcrops using standard image enhancement techniques (Crosta and Moore, 1991). Fortunately, both Miocene-Pliocene strata and Permo-Triassic metamorphic phyllite outcrops have distinctive spectral signatures, which allow them to be classified spectrally. The Alicante-Almeria highway section annotated A to B in Fig.2 crosses terrain composed of Tertiary marls and Permo-Triassic phyllites identifiable in enhanced Landsat TM imagery. The value of Landsat TM imagery for identifying outcrop areas of Tertiary and Permo-Triassic rocks potentially vulnerable to erosion and landsliding was verified by comparison with published geological maps (IGME Almeria-Garrucha sheet 84-85, scale 1:200000).

Landsat TM imagery has also been used to identify mature, natural terrain surfaces where regolith or calcrete protective cappings have been disturbed or destroyed by agricultural ploughing, leaving the substrate vulnerable to flash-flood erosion. TM image data also permits identification of 'broken ground' created by excavations for urban development, engineering works, mineral extraction or recent, large scale landslide scarring (Eyers *et al*., 1998). Digital number (DN) values of pixels in disturbed terrain are consistently higher than for undisturbed terrain with the same but weathered mineralogy. The mixed spectral signature effect on DN values caused by scattered and sparse vegetation on natural soil and regolith surfaces is lost as surfaces are ploughed, pits and foundations excavated and freshly broken mineral waste rock dumped. This is partly responsible for the significantly stronger (higher DN value) and spectrally 'purer' signatures of broken ground, compared with natural, partially vegetated surfaces.

Drainage channel beds greater than two pixels in width are also spectrally distinctive in TM imagery because of the unweathered and unvegetated debris they contain. This phenomenon is of use in separating channel beds clogged by dense vegetation from active channels in which recent sedimentation has occurred.

SPOT PAN IMAGERY

SPOT Panchromatic imagery was used to enhance and delineate areas of badland terrain, typified by widespread gully and ridge shadowing (high frequency edge information).

A classified SPOT-Pan image and sketch map of the Gor valley (Guadix-Baza Tertiary sedimentary basin) are shown in Figure 3. The image (left) has been texture classified using a standard laplacian filter to compute total tonal change within the pixel neighbourhood, using a 3x3 kernel window. The filtered result was thresholded to separate pixel values representing high tonal variation or 'rough' texture from those of low tonal variation or 'smooth' texture (Mason, 1998). The 'rough' areas (white pixels) characterise the badland terrain in the dissected Miocene-Quaternary sediments whereas the 'smooth' areas (black pixels) represent the undissected surface of the Guadix-Baza sedimentary basin.

The boundary of the badland terrain in the Guadix-Baza Tertiary sedimentary basin area is illustrated in the sketch map in Figure 3 (right). The pre-Quaternary surface of the basin in this area is more than 1000 metres above sea level and badland erosion has excavated deep canyons from which Miocene and Quaternary sediments are being rapidly removed by flash flood gully erosion. Note the Negratin Reservoir whose catchment lies in badland terrain and is vulnerable to accelerated siltation in conditions of increased erosion rates..

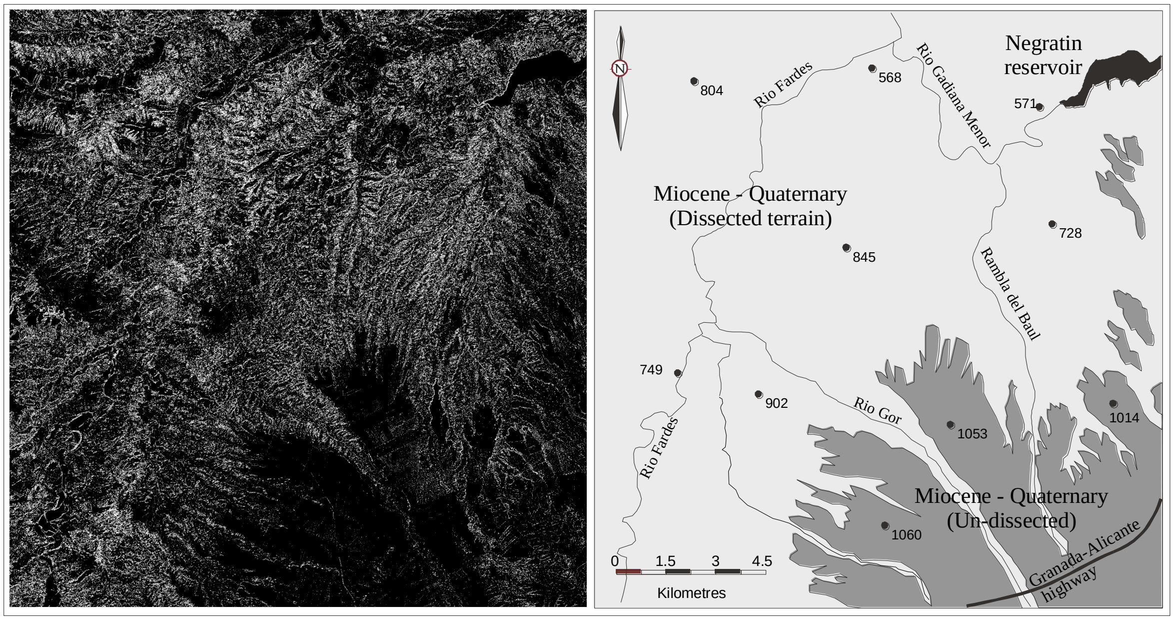

Figure 3 Dissected badland terrain is clearly distinguishable from the undissected basin fill in the texture classified SPOT Pan subscene (left) and illustrated in the sketch map (right).

DIGITAL ELEVATION MODEL

The DEM used is the USGS public domain GTOPO30 which has a pixel size of approximately 1 km. The dataset was compiled from several data sources. The SE Spain segment derives from Digital Terrain Elevation Data (DTED) which has a vertical accuracy of 30 metres.

The digital elevation model shows the distribution and relative elevation of the surfaces of the major Tertiary (Miocene/Pliocene) age inter-montane sedimentary basins of SE Spain. The boundaries of individual basins are modified by large alluvial 'bajada' type, terrestrial debris fans of which were deposited on the Pliocene marine sedimentary surface during Quaternary times. Late Tertiary and Quaternary fault movements have also dislocated the Pliocene land in some basins e.g. Tabernas. Nevertheless, on a regional scale, the position of breaks in slope at the foot of adjacent mountain ranges, provide a reasonable indication of the form of the Tertiary/Quaternary molasse filled basins. Also, the average elevations of the central areas in individual basins give an indication of the Pliocene land surface elevation relative to current sea level.

PRACTICAL USES OF IMAGERY AND DEM

Identification and delineation of terrain at risk from flash-flooding erosion and sedimentation, together with landsliding, requires integrated use of imagery and DEM data.

Landsat Thematic Mapper imagery has been used in several ways for our geohazard investigations. These include classification of anomalously high DN value pixels to identify and map 'broken ground' caused by ploughing, mining, quarrying and other engineering excavations including road building. Standard image processing techniques including false colour composite and difference or ratio images have been used to map the distribution of rock types known to be mechanically weak and fissile e.g. marls and phyllites in the area of Fig.2. The marl and phyllite lithologies are susceptible to mass movement on unusually steep slopes under natural conditions and particularly in over-steepened engineering excavations. Topographical information beyond that provided by TM imagery is therefore necessary to identify the areas of marls and phyllites which are at particular risk from landsliding and gully erosion.

The use of multi-temporal images of all types, particularly TM and SPOT Pan provide a useful tool to monitor changes in terrain over significant periods of time (currently 14 years in the case of Landsat TM). This facility provides a considerable archive of supplementary information to investigate changes in the area of 'broken' ground disturbed by rapidly expanding and changing farming practice, mineral extraction and urban development, together with sediment and water levels in reservoirs,

Figure 3 illustrates some of the potential uses of SPOT Panchromatic imagery. It shows the extent and boundary of active badland erosion and encroaching knick point location in along the northern edge of the undissected part of the Guadix-Baza Basin. The texture classified SPOT Panchromatic image serves to identify terrain at risk from badland terrain processes to in several different ways. The texture enhanced SPOT image shows an area crossed by a recently completed section of the Granada-Alicante highway. The highway route is crossed by the channel system, which drains the nearby Sierra de Baza mountains, a catchment area for potentially damaging flash flood run-off. Flash flood events also periodically dislocate the minor road systems serving the numerous small villages on the floors of the tributary canyons and along the fertile alluvial valleys of the Guadiana and other rivers which traverse the area. Erosion within the badland terrain has consequent adverse effects in terms of siltation in nearby reservoirs.

The regional DEM provides an important source of elevation data to complement plan view spectral and textural image and map information. In this study the DEM has been used on a regional scale to identify those areas of Tertiary basin terrain which are highest above current sea level. It is within these basins that erosion is currently most active and it is on the vulnerable, Miocene molasse, badland terrain within these basins that some of the slopes most vulnerable to landsliding occur and where erosion is most actively taking place.

More detailed DEM information is in preparation from space and air photography, as part of this project. It will be used to investigate inclination and aspect of individual slopes in mechanically vulnerable rocks.

CONCLUSIONS

Used individually, Landsat TM and SPOT Panchromatic imagery can provide useful information about the distribution of lithologies susceptible to rapid erosion under flash flood conditions in a semi-arid, terrain of SE Spain. Enhanced TM imagery has also been used to delineate areas of broken and disturbed ground potentially susceptible to erosion in areas with an otherwise mature and stable land surface. Landsat imagery also clearly shows the extent of recently deposited sediment in silting reservoirs and their feeder drainage channels.

A regional DEM has been used in conjunction with Landsat TM imagery to identify those sections of the new Almeria-Alicante highway which are potentially at risk from landslide because of combinations of the bedrock lithology and the elevated and incised nature of the terrain crossed by part of the road. Viaducts and high bridges some of which span deeply incised valleys along a shorter section of the road are also at risk from earthquake vibration related to faults, some of which are revealed in the imagery by dislocated Quaternary sediments and irregularities in modern drainage systems.

Enhancement of textural information in SPOT Panchromatic imagery shows the distribution and extent of badland terrain in parts of Tertiary molasse basins currently undergoing active erosion. The regional DEM of the Guadix-Baza area illustrates the relatively high elevation of the basin in relation to sea level (1100metres). The mechanical (gravity) mechanisms of erosion in the Guadix area, in terms of the drop from the undissected basin surface to local canyon floors (500metres) are the largest in the area studied. Erosion rates in the canyon land of the Guadix basin, sedimentation in the nearby reservoir and potential risk from flash flood damage to the highway bridges crossing the drainage channels from the Sierra de Baza is probably as high as anywhere in the area studied.

The results of these preliminary investigations are an encouragement to continue investigations of the ways in which digital imagery and elevation models can be used together, in geohazard investigations.

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