ASSESSING FLOOD HAZARDS IN DESERTS USING SATELLITE IMAGERY

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Abstract

The piedmont zone is a focus of much development in deserts. However, the piedmont is crossed by numerous stream channels which are subject to flash floods from upland drainage basins, forming a pattern of localised hazards to people, property and road/railway links. Flood hazards are not uniform over the whole piedmont area, the highest risk being concentrated in contemporary depositional washes. Using an example in southern Tunisia, this paper shows how satellite images can be used to map flood hazards in deserts using standard image processing and GIS techniques, providing geomorphologists and engineers with a method for undertaking large scale flood hazard surveys over desert terrain.

1. Introduction

Deserts cover one third of the world's land surface, and have experienced a growth in human population of 63% between 1960 and 1974. By 1979, 15% (651 million) of the world's population lived in arid lands. This population is increasingly urbanised, with dryland cities experiencing 4% annual growth from 1960 to 1970. Much of this population increase concentrates on the piedmont (literally "mountain foot") zone, the surfaces that slope from mountains (where development is limited by steep slopes and inaccessibility) and lowland basins (where development is limited by periodic inundation, unstable substrate, saline conditions, and shifting dunes). Road and rail infrastructure linking these piedmont settlements also take advantage of the piedmont as a corridor.

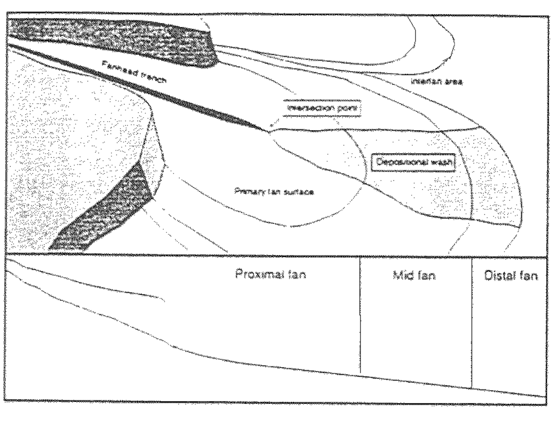

Figure 1. Physiographic zonation of alluvial fan.

Much of the piedmont zone is made up of alluvial fans, cone-shaped landforms radiating downslope from the point where streams emerge from upland drainage basins. The stream channel is usually incised into the fanhead, but has a lower gradient than the primary fan surface, so ultimately the stream emerges onto the primary fan surface at an intersection point, below which deposition occurs. This part of the fan, together with the entrenched channel reach, is known as the depositional wash, and is the area inundated by ephemeral floods. The remaining parts of the primary fan surface do not receive water or sediment during ephemeral flood events, and the spectral characteristics of these surfaces change over time due to soil formation and development of an iron-rich coating on the surface of rocks. This enables the distribution of active channels and inactive surfaces to be extracted by processing multispectral imagery. These physiographic features are illustrated in Figure 1. The alluvial fans selected for this work are formed on the southern flank of Djebel Orbata in the Tunisian Southern Atlas (Figure 2). The climate of the area is arid, receiving less than 150mm of rainfall per annum. The oasis of El Guettar, with its associated settlement, lies at the foot of the alluvial fans.

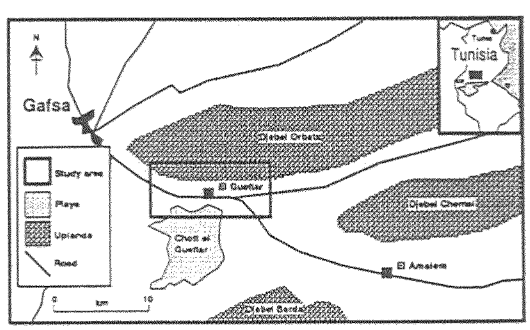

Figure 2. Location of the study area.

2. Flood hazards on alluvial fans

As outlined above, piedmonts are the focus of much of the development taking place in deserts. However, the piedmont is crossed by numerous ephemeral channels, which experience intermittent torrential flows with high energy conditions (flash floods) in response to heavy but infrequent rainfall. Some of the fastest developing areas of the United States are located in the arid and semi-arid southwestern regions of the country where alluvial fans occupy over 30% of the land area. Major urban areas such as Los Angeles, San Diego, Tucson, Phoenix, Salt Lake City and Las Vegas are important industrial and financial centres. Large parts of these cities are built on alluvial fans, and they experience frequent severe flooding causing extensive damage and often loss of life. Bridges constructed on the poorly consolidated alluvial sediments are easily washed away during flood events Instead, roads are usually built along the bottoms of the ephemeral piedmont channels (bridgeless crossings); they will be closed for the duration of the flood event but repair will be easier than bridge reconstruction. Railways cannot use the same system due to their more stringent engineering requirements. A method is needed for engineers and geomorphologists to perform large scale surveys at the planning stage to assess the distribution of flood hazards in dryland piedmonts, where access is often difficult.

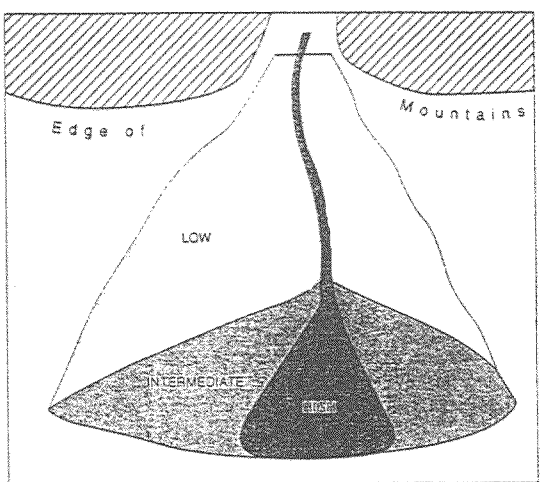

Figure 3. The pattern of flood hazard on an alluvial fan.

From the perspective of flood hazards, alluvial fans can be divided into two zones (Figure 3):
a) The primary fan surface is an area of low flood hazard, being subject only to sheetwash. For flooding to occur here would require catastrophic channel avulsion.
b) The depositional wash is an area of high flood hazard, as contemporary floods are most likely to occur in this area.

3. Image processing

A subscene from a Landsat Thematic Mapper image (Figure 4) was processed as follows:
a) Atmospheric correction to remove the effect of atmospheric path radiance and sensor calibration offsets.
b) Band ratioing. The ratio of band 3 (visible red) divided by band 1 (visible blue) gives the best discrimination of depositional wash and primary fan surface, due to the trans-opaque behaviour of the soil and rock varnish iron oxides in the visible part of the spectrum
c) Density slicing. The TM3/1 ratio produces an image of the gradually varying distribution of iron oxides. The depositional washes have the lowest TM3/1 values, due to the absence of soil iron oxides and iron-rich rock varnish. Examination of the DNs in both depositional washes and stone pavements identifies a suitable cut-off level to uniquely classify the wash areas. Adjacent upland and lowland basin areas are removed from the processing area at this stage. Residual small outliers corresponding to non-depositional wash areas of low iron-oxide content within the piedmont zone (usually resulting from clumps of vegetation) can be easily removed by majority filtering or weeding out groups of pixels below a threshold size. This produces a map of flood risk (Figure 5a). Subsequent processing is undertaken within a Geographic Information System (GIS) environment

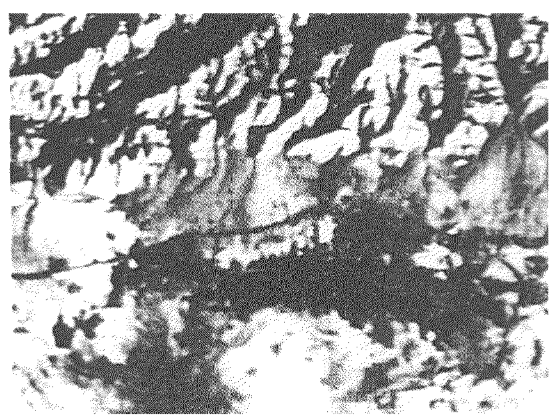

Figure 4 Landsat Thematic Mapper band 7 image of study area, showing the Djebel Orbata mountains at the top the Chott al Guettar playa at the bottom, and the oasis of El Guettar in the centre.

4. GIS processing

The next stage is to compare the flood risk map with the distribution of anthropogenic structures (roads, railways and built-up areas) to determine areas of specific flood hazard. These were digitised from 1:50 000 scale maps and registered to the image coordinate system. They were coded differently to recognise the different nature of hazards affecting the various anthropogenic structures (Figure 5b). The product of the flood risk map and the anthropogenic structure map produces a flood hazard map, coded to indicate differing degrees of hazard (Figure 5c).

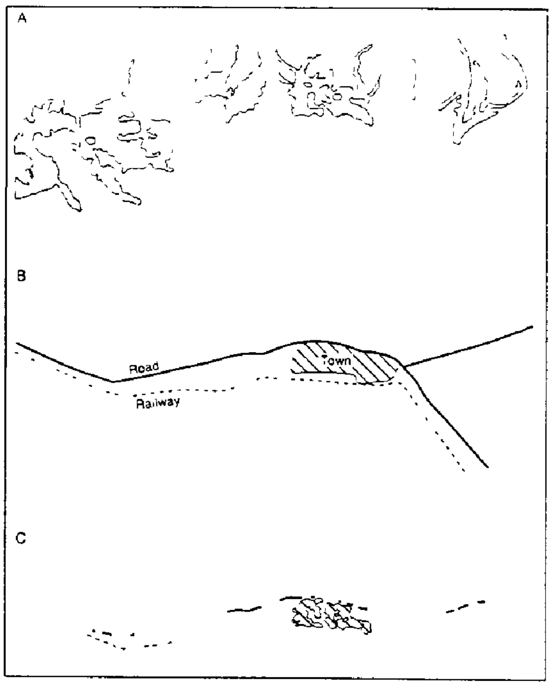

Figure 5. Flood hazard maps, El Guettar. (A) Depositional wash areas extracted from Thematic Mapper data (high risk of flooding), (B) Anthropogenic features, (C) Spatial coincidence of high flood risk and anthropogenic features (flood hazard areas).

5. Results

The resulting map of flood hazard (Figure 5c) shows the areas where railways and roads are prone to ephemeral flooding and potential damage, as well as where they may be inundated by floods resulting from channel avulsion, which have a lower probability of occurrence. The built-up area of the town of El Guettar is shown as a large area of flood hazard. Detailed field mapping has shown that the size of this area is overestimated. This is due to the misclassification of parts of the urban areas as depositional wash, resulting from spectral confusion between contemporary alluvial sediments and tracks between buildings. This is unsurprising, as the disturbance associated with these tracks removes the coatings formed on the rocks, making them identical to the depositional washes. This problem is likely to limit the use of this technique for mapping flood hazards in built-up areas, but this project has demonstrated the utility of multispectral remotely sensed data for identifying stretches of road and rail networks prone to flooding.

6. Conclusion

This paper has demonstrated the use of multispectral Thematic Mapper data in mapping areas of contemporary deposition in the dryland piedmont zone of southern Tunisia. Although only a pilot study, the results suggest that the synoptic capability of satellite imagery can be exploited for mapping flood hazard, particularly affecting roads and railways, over large areas using a standard methodology. Such data would be of significant use in the planning stage of road or rail building in drylands.

7. Further reading

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