IDENTIFYING THE THREAT OF DEBRIS FLOW TO MAJOR ARTERIAL ROADS USING LANDSAT ETM+ IMAGERY AND GIS MODELING – AN EXAMPLE FROM CATANDUANES ISLAND, REPUBLIC OF THE PHILIPPINES

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Abstract

Debris flows are destructive events, caused when loose geological materials are saturated with precipitation to the point when they become fluid enough to flow down a gradient. The power and destructive forces of such events is well documented, causing damage to buildings, roads and bridges, as well as leading to the loss of human life. One of the main problems faced by engineers trying to identify where a debris flow will occur, is that although the effects are often seen locally, the possibly multiple sources of the debris flow may be located many kilometres away, often in steep and dangerous terrain. This makes the task of manually identifying all the possible sources of a debris flow during field expeditions both costly and time-consuming. Due to the spatial nature of the problem, it was considered that GIS and Remote Sensing could hold a timely and cost-effective solution to identifying the potential sources of a debris flow. This study tests the abilities of these geo-spatial technologies to identify the risk posed by debris flow to a planned dual carriageway circumferential road that will be constructed along the route of an existing single-track road around Catanduanes Island in the Republic of the Philippines. By combining one-time multi-spectral data and a digital elevation model, it was possible to identify areas of bare earth on slopes between 5°-15° and 15° - 25° inclination. These areas were deemed as being potential sources of geological material available for debris flow. By calculating the percentage area and total area of these potential debris sources for each watershed draining out either immediately onto or above the planned new road and modelling the gradient of the land surrounding the route, it was possible to identify those watersheds that undergo a high level of slope failure activity and an indication of the amount of geological material available that may contribute towards a debris flow event. In this way, the watersheds were classified according to those that may be considered as having a high propensity to debris flow and those that posed little or no risk. At the spatial resolution that this study was performed (Landsat 7 ETM+ 30m resolution), the results provide information to slope engineers and surveyors of

where to concentrate their field survey and the extent of any slope protection measures that may be necessary.

1. Introduction

Debris Flows (also known as Mud-flow and, when caused by volcanoes, Lahore) are destructive events caused when eroded and other loose geological materials are mixed with water to the point where they begin to move down a gradient as one semi-cohesive mass, usually defined where sediment concentrations are greater than 60% by volume or 80% by weight (Vallance and Scott, 1997).

The extreme damage caused by these events is well documented, as are the wide range of geo-physical and civil engineering practices employed in various parts of the world to reduce their likelihood and prevent the mass destruction of the natural and man-made environment that they are capable of producing. However, in order to apply these preventative measures, it is first necessary to identify areas where the risk of Debris Flow is high. The problem here is that while the effects of a Debris Flow may be readily identified by, for example, the destruction of a road or river crossing, the source(s) may be located a significant distance away from these features for which protection is necessary. Added to this, the fact that by their nature, Debris Flows occur in areas of steep terrain, where field exploration is time consuming, expensive and often dangerous.

Remote sensing and GIS have the potential to tackle this problem, combining the broad spatial and multispectral viewing capabilities of satellite imagery with the ability of GIS software to evaluate a variety of criteria at a single location to assist in modeling the real environmental conditions at that point.

Several previous studies have attempted to identify land surface instability from multi-temporal satellite imagery, comparing before and after images of a known event (Nagarajan R et. al., 1998). The multi-temporal method does present problems in areas of heavy rainfall and persistent cloud cover, where even one sufficiently cloud-free image is hard to find, and also requires a certain amount of knowledge regarding the timing of land surface failures.

This study aims to utilize one-time multispectral satellite imagery (Landsat 7 ETM+) and a GIS database to develop a prospective debris flow risk map for Catanduanes Island (located between 13°31'02" N - 14°06'02" N and 124°01'30" E - 124°25'10" E) in the Philippines, where a new circumferential road, essential for the economic development of the island, is being planned.

2. Methodology

In order to create the GIS database, the contour lines and coastline of 7 1:50,000 topographic sheets were manually traced and scanned. Extensive cleaning of the data was required to eliminate errors at the tracing stage. Once the data was vectorised, each contour vector was assigned an ID value representing height, then geo-referenced and mosaiced to create a seamless vector contour dataset. A Digital Elevation Model (DEM) was created from the contour and coastline vectors, using Arcview 3.2a TIN and GRID tools. From this 30m DEM, various features were extracted, such as drainage channel network, slope angle and slope aspect.

Two Landsat 7 ETM+ scenes were obtained giving coverage of the entire Catanduanes landmass. Once the image had been georeferenced, mosaiced and clipped to the region of interest (i.e. Catanduanes Island), a Maximum Likelihood Classification (running a 95% confidence threshold) was applied to all 6 visible and infrared channels to identify 7 land-cover classes (cloud, upland vegetation, lowland vegetation, bare earth, water, urban areas and partial cloud) and 1 unclassified category. The classes were subject to selection of training pixels, which were chosen from aerial photography.

Integration of the satellite classification product and the GIS data within ESRI's Arcview3.2a allowed extraction of pixels classified as bare earth that occurred on slopes of between 5-15 & 15-25 degrees gradient. These pixels were identified as being potential sources of debris flow sediment.

Watersheds surrounding the proposed route of the circumferential road were delineated from the DEM and grouped as either exiting directly onto the road, or exiting from a valley some distance away from the road. It was assumed that any debris flow that exited from a valley above the road, but that encountered a gradient < 3° before reaching the road would cease flowing – or at least that the rate of flow would be reduced to such an extent that the risk may be considered negligible.

Two measurements for each watershed were extracted from this data;

1. The percentage land area of potential surface failure
2. The total land area of potential surface failure.

Each watershed was then classified according to these results and displayed along with field-collected information showing the locations of existing debris flows. The percentage land area of potential surface failure gives an indication of the amount of slope failure activity in an area, whereas the total land area of potential surface failure provides an idea of the actual amount of material that may be available to contribute towards a debris flow.

In addition to these analyses, a brief field survey was conducted on Catanduanes Island. During this visit, GPS locations of past and present Debris Flows were recorded – either where a Debris flow was directly observed at the road or away from the road, or where evidence of a possible debris flow was present (e.g. collapsed bridges). The locations where the current road crosses a drainage channel sufficiently large to require bridging were also recorded

The GPS locations were collected using a Garmin handheld GPS III Plus receiver, which has a claimed horizontal accuracy of between 7 – 15 metres (http://www.garmin.com/). The data was downloaded in the field to a laptop and imported into Arcview 3.2a using AVGarmin 2.1.74 – an Arcview extension developed by the California Department of Fish and Game obtained from the ESRI support centre (http://www.arcscripts.esri.com).

A vector layer of the existing road was obtained from a set of Adobe Illustrator files, which were created during a hydrographical survey at an undetermined time. The method of survey is not known and during the field survey for the present study, it was not possible to take GPS readings for the entire circumferential road. However, a small portion was mapped, using the GPS, to test for the accuracy of the location of the road (see section XX – discussion)

3. Results

A visual comparison of the map displaying the total land area of potential surface failure and known locations of debris flow events illustrates that there is correlation between areas identified as being particularly susceptible to debris flow and areas where debris flow activity is high. In Catanduanes Island, the West coast is identified, from the risk maps as being highly susceptible to debris flow, and this is where the majority of recent debris flows have occurred, as determined by the field survey. There is also a large watershed in the centre of the island, which demonstrates a high capacity for producing debris flow. The exit point of this watershed has been the site of repeated debris flows, resulting in the destruction of a sizeable road bridge at that location.

The map showing the percentage land area of potential surface failure doesn't correspond as clearly to locations where debris flow has occurred, but still identifies the west coast of the island as showing the highest potential for debris flow.

By taking account of the fluvial dynamics involved with a debris flow, using GIS spatial analysis techniques, it was possible to determine whether a future debris flow from a particular watershed would be likely to affect specified features. This is an important point for civil engineering applications, where, for financial reasons, preventative measures may only be applied to locations where there is a real risk to the feature of interest – in this case a road.

4. Discussion

The classification of watersheds into risk categories was made on a subjective basis, according to the statistical distribution of the percentage and total pixels identified as exhibiting bare earth on 'steep' slopes within those watersheds. The notion of risk, in this instance is therefore a relative one. To gain an estimate of the absolute risk of debris flow within a specific watershed, the exact conditions surrounding a debris flow event must be more clearly investigated and modelled within the constraints of a modern GIS framework. For example, it is necessary to determine an idea of the amount of material necessary for a debris flow to occur in such proportions as to be a threat to man-made structures. It would also be beneficial to know the relationship between the amount of available material and the size, speed and distance travelled of any resulting debris flow.

As the accuracy of this method depends very clearly on just two factors – steepness of slope and the identification of pixels representing bare earth, it is important that these factors are identified accurately.

Possible sources of error can occur during contour line extraction and subsequent digitising, which can create inaccuracies in the calculation of DEM and slope angles. In the event of hand-tracing contour lines, reducing the required contour resolution – while this does have implications for the detail that can be exhibited by the DEM, may reduce the possibility of error. Auto extraction of contour lines directly from the Topographic sheets is an option that needs to be explored further – carrying assumed advantages of speed and accuracy.

5. Conclusion

The fact that the risk maps developed using this technique show areas displaying a high percentage and high total number of bare earth pixels on 'steep' slopes in each watershed occurring in areas where known debris flow have occurred, and which have been identified as being the most geologically active on the island (Yokoyama, Personal Communication, 2002) indicates that this method has good potential for identifying regions where there is a high likelihood of debris flow occurring. In addition, by developing this methodology purely from a remote perspective, using existing topographic maps, aerial photography and satellite imagery, we have identified a tool that can be used to significantly reduce surveying time and costs for civil engineering projects in areas where little geographical information is available. However, there is a pressing need to quantify a number of processes and factors pertaining to debris flow events if this method is to be refined to such an extent where it may be applied on a broader and standardized scale.

6. References

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