

6. CONCLUSIONS AND RECOMMENDATIONS

The Fiji pilot study represents a test of the combined remote sensing plus GIS approach to rapid landslide hazard mapping in an active area of landsliding. The basis of the method is that the distribution of past landslides, here determined from aerial photograph interpretation, can provide an indication of the likely extent and severity of future events given a high intensity of rainfall associated with a cyclone. The rationale involves establishing relationships with independent variables, such as geology and topography, which are then used to model landslide probability. The GIS is a convenient tool for (1) storing and displaying data, (2) analyzing relationships between variables, and (3) generating thematic hazard (and potentially risk) maps. The techniques are directed towards developing an operational methodology for producing provisional regional hazard maps quickly and cost-effectively.

Some specific conclusions are as follows.

1. Given the extent of landsliding in Fiji and the scale at which regional hazard maps are required, conventional aerial photography provides the most appropriate source of remote sensing data. Satellite imagery is probably less useful although cloud-free stereo SPOT coverage, if available, could provide an alternative. Aerial photographs enable older landslide-landscape terrain features as well as transitional and recent landslide events to be documented. They are also a source of information on regional fractures (lineaments), although this information was not utilised in the present study.
2. Prior to GIS analysis, it is necessary to build a database of spatially co-registered information. The extent of this database, and thus the reliability of the final hazard map, will depend on the type and quality of data available. There is already much GIS work going on in Fiji and various data sets are available. But where digital information does not exist, it must be digitised from existing analogue (usually map) sources. This is a time consuming, labour-intensive operation involving a large amount of effort. *The size of the task should not be under-estimated.*
3. Once a basic database is established, the GIS can be used to produce customised map outputs quickly and at low cost. As more data become available, new thematic interpretations can be produced, tailored to meet the specific user requirements.
4. The ideal GIS for landslide hazard map production, suitable for all situations, probably does not exist. Vector-based GISs are more efficient for storing data and providing high quality map output, but raster-based GIS systems are needed for analyzing spatial inter-relationships between variables (e.g. the significance of rock type to landslides). Developments are slowly moving towards combining both functionalities. The choice of GIS should take into account local support and systems already in use. However, there are penalties in choosing a system that is more complex than the task requires. In terms of a raster system, IDRISI is a simple, low-cost system that is likely to find increasing acceptance in the southwest Pacific region, especially when the new Windows version is released. (ILWIS is another, slightly more powerful PC-based system than IDRISI, but is more expensive and presently

less widely used in the region). For the present, both raster and vector systems are needed for different aspects of the work.

5. The analytical capabilities of the raster-based GIS provide a means of 'modelling' the distribution of landslides in terms of independent variables (e.g. geology, slope, etc). An important result of the present study was the development of a systematic statistical approach to achieve this. It begins by calculating the proportion of landslide to non-landslide pixels within each class of each variable (e.g. every lithology of the geology map), and comparing these values with the average for the area as a whole. This indicates whether landslide frequency in a class is higher or lower than expected. 'Weights' are calculated for each class of each variable according to the strengths of the correlations established. In the Fiji study, landsliding was separately correlated against geology, slope angle, slope aspect, elevation, soil type and forestry cover. In this approach, it is not necessary to enquire why a relationship exists, nor to understand what it means, only to demonstrate that it does. Once the relative weights are established, combinations of variables ('models') can be calculated across the entire area by adding the weights class by class. The effect of combining factors which individually influence (or at least relate to) landsliding to different degrees is to rank high risk areas. The statistics allow the combined variable map to be quantified in terms of relative hazard probability.
6. The validity of the model developed depends fundamentally on the extent, detail and reliability of the input data. Relatively few data layers were used in the pilot area; some of these were rather generalised whereas others contained detail that may be irrelevant to landsliding.
7. Time did not allow a complete evaluation of the observed statistical relationships resulting from the GIS analysis. There also remains some uncertainty regarding the best way to compare the hazard models, since different criteria can be used to measure performance. In the present study two different indicators were used: 'reliability' provides an overall measure of how likely a landslide is to occur, and 'accountability' provides an indication of the proportion of total landslides likely to be accounted for. Moreover, statistical measures may not tell the full story, and visual comparisons may be required. Nor did time allow all the available digital data to be evaluated. In particular, further work is needed on the separate categories of old, transitional and young landslides, landslide initiation points of the young slides, and other data supplied by the FGIP (e.g. erosion risk). However, these data exist on the GIS database and it is a relatively simple task to evaluate these factors. Further advancement of the ideas will critically depend on such assessments in order to achieve a fuller understanding of the data.
8. The remote sensing/GIS approach can provide (1) landslide inventory maps and (2) provisional hazard zonation maps. It must be stressed, however, that the approach is an empirical one. The hazard map produced is both preliminary, in the sense that further GIS analysis of the existing data is required, and provisional in that improved versions could be produced as more information becomes available. The assumption that past landsliding provides an indication of where future events are most likely, still requires validation. Indeed, the opposite could be true in some cases; certain

amphitheatre-like terrain features could in fact have attained relative stability and thus be *less* prone to slide. Another viewpoint is that remote sensing provides only a limited and subjective picture, and that in such rugged terrain, a landslide could occur almost anywhere given the right triggering event. Nevertheless, it is clear that, although the approach is less than rigorous, it provides the basis for providing provisional regional hazard maps in Fiji at reasonable cost and in a realistic time frame. Maps produced by such rapid methods have their limitations and should only be used to provide general information. They cannot be expected to provide reliable information at the detailed scale for which ground-based engineering geological/geotechnical surveys will be required.

This pilot study represents a preliminary test of the methodology. Despite certain practical difficulties usual in feasibility studies of this type, it is considered that the results justify the techniques being introduced operationally in Fiji. The following **recommendations** are made in the context of such possible implementation.

1. A review should be undertaken to define priorities for landslide hazard mapping in Fiji and to devise a long term strategic programme and timetable. Consideration should be given to areas most at risk in terms of infrastructure, new construction and population. Cooperation and support from developers should be considered. Flexibility should be included to allow responses to changing requirements.
2. A project needs to be defined, lead by the Mineral Resources Department but involving other Government departments concerned with planning, disaster preparedness and GIS, to implement hazard mapping on a realistic time scale. This is likely to involve the commitment of staff and resources dedicated to this work.
3. The project team will require resources and expertise to carry out a number of functions in-house or, failing that, to buy in the services as required. The following capabilities will probably be required:
 - (i) A team dedicated to landslide hazard mapping possibly comprising: project leader (engineering geologist), data manager (GIS specialist), project geologist(s), support technician, and field assistant(s).
 - (ii) Vector- and raster-based GIS systems (MapInfo possibly and IDRISI are recommended at this stage, but this will need to be reviewed in light of new developments and support e.g. that provided by SOPAC).
 - (iii) Additional computing hardware (high-level PC or workstation, scanner, digitiser, etc) and software to carry out in-house data capture and conversion may be required. A separate review may be needed to establish operational requirements; this should take into account systems already in use, or supported, in Fiji.
 - (iv) Recurrent funding for data purchase, computer maintenance and upgrades, and services as required in order to carry out the defined programme.

4. The methodology used in the pilot study needs to be critically reviewed, both in scientific terms and in relation to the work programme and time scale. This review should also consider which data are, or could be made, available that would improve the final hazard map. In order to achieve consistent results over a period of time, quality assurance procedures need to be established. This is particularly important in regard to the photointerpretation of landslides which, by its nature, is a subjective process; checks/procedures must be introduced to ensure that, as far as possible, different workers over periods of time adopt the same interpretative procedures. Cooperation with other GIS workers in the country should be strengthened and agreement reached nationally on data exchange procedures and formats.
5. Further work, including geotechnical field investigations and laboratory testing, is required to decide whether the hazard maps produced are meaningful and can be validated by more conventional techniques. The results of such work should be used, if necessary, to modify and improve the methodology.

In conclusion, the pilot study has demonstrated that rapid landslide hazard mapping using remote sensing and GIS is a practical possibility in Fiji. The results of the pilot study are encouraging and support the view that consideration be given to implementing the methodology more widely. However, the map produced is very much a first attempt and should not be regarded as a final product. It demonstrates only what can be done.

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