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Integration of complex models for slope stability and landslide runout with GIS

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Geographic Information Systems (GIS) are common tools for landslide susceptibility and hazard analysis on various spatial scales, from global to local. Complex multivariate statistical methods are successfully used in combination with GIS for studies of landslide susceptibility at the regional scale. In contrast, relatively simple deterministic or semi-deterministic methods are often employed for detailed studies at the local scale (for example infinite slope stability models or two-parameter friction models for runout). These methods, however, are inappropriate in many cases, and more complex approaches would be required instead.

The main reasons for the scarcity of more advanced GIS-based deterministic modelling tools are that (a) in contrast to many statistical methods, which, though mathematically complex, rely on the simple overlay of maps, deterministic models for slope stability or landslide motion are often geometrically complex, and (b) that many deterministic models are expressed in non-rectangular coordinate systems. Whilst these, chosen by engineers, physicians, or mathematicians, are adequate for the problems to be solved, they seem to discourage geoinformation scientists. The work presented here is understood as an attempt to overcome these problems by involving geoinformation scientists, engineers, and mathematicians in a common project. The following two gaps were attacked:

(1) A GIS-based model for rotational slope failures. Infinite slope stability models, which are frequently used in combination with GIS, are suitable for the identification of shallow translational slope failures. Theoretically, they are only valid for cohesionless soil and a constant inclination of the slope. They fail for deep-seated rotational failures. Being more complex from a geometrical point of view, rotational failures are usually modelled based on a pre-defined longitudinal section, assuming a circular or elliptical slip surface. The most critical slip surface is often approached with a Monte Carlo simulation. Only few attempts have been made to develop GIS-based, three-dimensional software including such models, though this would be essential for allowing realistic simulations of landslides in complex terrain.

(2) A fully deterministic GIS-based model for the runout of debris flows and related phenomena, based on the Savage-Hutter theory. The motion of so-called granular flows is a highly complex phenomenon. Semi-deterministic approaches (e.g. two-parameter friction models) are frequently applied in combination with GIS, but fully deterministic models are required for detailed studies of travel distance, velocity, and energy of granular flows. The most advanced concept for understanding and modelling such flows is the Savage-Hutter theory, a system of differential equations based on the conservation of mass and momentum. The equations have been solved for a number of idealized topographies, but not yet satisfactorily for arbitrary terrain, and no attempts to use them directly with GIS were known up to now.

Both models were integrated with the Open Source GIS software GRASS GIS as raster-based modules. Tests with study areas in Italy and Argentina were promising, but also highlighted a strong need for further research.