Journal of Nepal Geological Society, 2000, Vol. 22, pp. 429–434

Landslide hazard zoning in the Jerzu Hillside (Sardinia, Italy)

F. Ardau, G. Barbieri, and S. Fantini

Dip. Ingegneria del Territorio, Università degli Studi di Cagliari, Piazza d'Armi, 09121 Cagliari, Italy

ABSTRACT

The landslide hazard zoning method described in this paper is a modification of the method developed by the Italian Geological Service for mapping geological hazards associated with gravitational instability. For this purpose, at first a preliminary zoning is done by dividing the study area into a discrete number of smaller units that have sufficiently similar susceptibility to instability. Semi-quantitative field surveys are then conducted in each unit to evaluate the geological, morphological, vegetative, and geotechnical factors, which contribute to the hill slope susceptible to sliding. The final landslide hazard zoning is obtained by assigning a numerical weight to each factor in relation to the degree of instability determined. The weights assigned to these factors are then added up for each unit.

The method was applied to the hillside of Jerzu in Sardinia (Italy), where landslides of varying dimensions are present. The validity of the proposed method was examined by comparing the resulting landslide hazard map with the actual distribution of landslides in the area.

INTRODUCTION

The landslide hazard zoning method proposed here is a modification for the hillside-scale (covering an area of about 10 km^2) of the method developed by the Italian Geological Service for mapping geological hazards due to gravitational instability in large (about 500 km^2) areas (Amanti et al. 1992). The first step consists of a rapid preliminary zoning. Considering some fundamental factors, such as lithostratigraphy, slope angle, and vegetation cover, the study area is divided into a discrete number of smaller units with sufficiently similar susceptibility to sliding. The geotechnical factors influencing the physico-mechanical behaviour of rocks are then evaluated by means of semi-quantitative field measurements in each of these units.

The geological, morphological, geotechnical, and vegetative factors are then parameterised according to their relative importance by assigning arbitrary numerical weights. Then, by adding up for each unit all the numerical weights of the factors examined, the relative landslide hazard zoning is obtained.

The method was applied to the hill slopes of the village of Jerzu, which has landslides of varying dimensions. The validity of the method was then checked by comparing the landslide hazard map with the actual distribution of landslides in the area.

GEOLOGICAL SETTING OF THE JERZU HILLSIDE

The village of Jerzu is situated in the Ogliastra region of central-east Sardinia. It lies on the right flank of the Rio Pardu Valley. The rocks of the area are represented by a Hercynian monocline that strikes due NNE-SSW. The valley runs along an almost straight line between very steep slopes, where ongoing degradation processes are clearly visible. In addition to the main fracture, there are a number of multidirectional fault systems trending prevalently due NE-SW. Morphologically, these are indicated by the irregular path of the river and some of its tributaries. The Palaeozoic schists are overlain by the Mesozoic sequence known as *Tacchi*, which forms the ancient and unique dolomitic limestone tableland (Fig. 1).

The Palaeozoic psammitic and pelitic schists, and black phyllites have undergone complex deformation in successive phases as a result of the numerous deformation episodes during the Hercynian orogeny. Their schistosity is invariably wavy or crenulated (Maxia et al. 1973). The foliation generally dips due southwest. Consequently, the schists on the left flank of the valley constitute dip slopes and those on the right flank make up counter dip slopes.

The Mesozoic carbonate cover of *Tacchi* rests with an angular unconformity on the Palaeozoic basement. The Mesozoic sequence is composed of quartzose conglomerate, arenaceous dolomite, and dolomitic limestone from bottom to top, respectively. At the contact between the Palaeozoic and Mesozoic rocks, a more-or-less continuous layer of Permo-Triassic palaeosol is encountered (Maxia et al. 1973). The Quaternary cover consists of debris deposits on the slopes and alluvium on the valley floor. Frequently, the weathered schist produces a cover composed of a clayey terrigenous material of strongly variable depth containing angular pebbles and blocks of various sizes. Talus deposits are frequently found near Jerzu, on the right bank of the Rio Pardu River beneath the steep rocky slopes of *Tacchi*. They contain carbonate blocks of up to a few metres in size (Fig. 1).

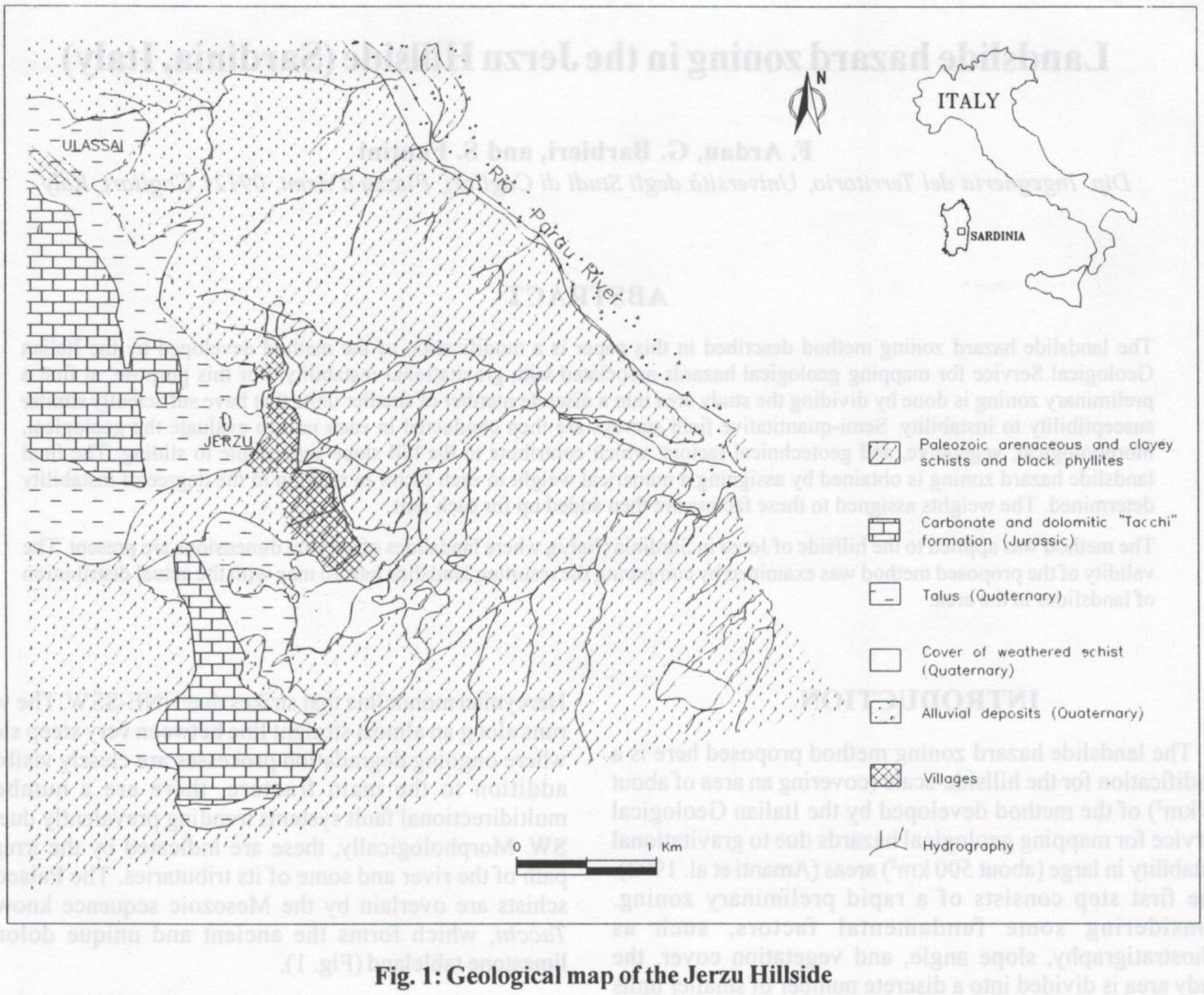

Fig. 1: Geological map of the Jerzu Hillside

LANDSLIDE HISTORY

A number of landslides of varying dimensions have occurred on Jerzu Hillside. They are essentially debris falls and debris slides on the weathered mantle overlying the bedrock. Table 1 shows the types of landslide and the damage caused by them. It has been possible to reconstruct landslide events through detailed investigations and research conducted in particular at the local-level technical departments of the government (Fantini 1998).

The village is included in the list of vulnerable areas that need landslide control or whose inhabitants require resettlement at the expense of the State (Act No. 445 of 9 July 1908). Several factors are responsible for the occurrence of instabilities in the area, including slope angle, depth of weathering, and the depth of debris cover as well as their poor mechanical properties, poor drainage, and the fact that the natural equilibrium has been upset by human activities.

LANDSLIDE HAZARD ZONING

The following three important factors were considered during the preliminary hazard zoning in the area:

Table 1: History of landslide occurrence at Jerzu

Event no.	Year	Season	Type of landslide	Type of damage
1		Winter	Debris fall	
2			Landslides	Collapse of retaining wall
3			Landslides	Partial collapse of road
4			Landslides	Cracks in buildings of the Santa Maria District
5			Failure	Failure of roadbed in ring road
6	1950		Landslides	Cracks in stone wall in pizza Europa
7			Erosion scarp rim	
8			Earth flow	Collapse of retaining wall in via Alfieri
9			Sheet erosion	Undermining of road
10	1990		Sheet and rill erosion	Collapse of wall in nursery school
11			Sheet erosion	Debris fall
12		Winter	Failure of talus	Debris fall

- lithostratigraphy of the formations, representing the influence of the geology on landslides;
- slope angle, representing the geomorphological processes that have taken place in the course of time and space; and
- vegetation cover, representing the influence of soil type and land use on landslides.

A numerical weight (ranging from 1 to 4) was assigned to each of the factors that were further divided into 4 classes (Table 2). The study area (about 6.5 km^2) was divided into a grid of 650 plots each measuring 100x100 m^2. The numerical weights for each plot were added up by superimposing the respective thematic maps of lithostratigraphy, slope, and vegetation. The plots were then classified according to weights and adjacent plots of the same class were grouped together. By so doing, a simplified grid was obtained containing 58 areas having similar susceptibility to gravitational instability. In each of these areas, semi-quantitative field surveys were conducted to evaluate several other geotechnical factors, which affect the physico-mechanical behaviour of the rocks and their susceptibility to sliding, namely:

- degree of weathering of rocks or degree of cementation of soils (roughly evaluated by means of field observations);
- depth z of the weathered layer or of the debris mantle (measured on fresh cuts and incisions);
- compactness (expressed as the joint spacing in the rock);
- attitude of the main joints (evaluated in relations to the hillside slope);
- 'geotechnical complexity' (evaluated as shown in Table 3), intended as that feature for which the lithological complex cannot be described using standard geotechnical tests (Esu 1977);
- drained shear strength (evaluated for hard rocks by means of rapid field tests, using the Bieniawsky (1973) criterion). This yields shear strength from joint spacing and uniaxial compressive strength (Tables 4 and 5). For soils, this factor was rapidly assessed on site on the basis of literature data;
- risk of progressive failure, defined as a decrease in the shear strength of rock as a result of geological and engineering stresses over time (evaluated as shown in Table 6); and
- permeability (determined by means of rapid field observations based on experience and knowledge of the terrain).

Similarly, each of the above factors was divided into four hazard classes, to which a numerical weight was assigned, corresponding to the number of the class, in increasing order of hazard (Table 7).

Table 2: Factors used for preliminary landslide hazard zoning

Factor	Class 1	Class 2	Class 3	Class 4
Rock type	Limestone	Schist	Debris	
Plant cover	Woods	Crops	Bush	Bare soil
Slope	0°–15°	15°–30°	30°–45°	> 45°

Table 3: Preliminary determination of 'geotechnical complexity'

	Types of 'geotechnical complexity'
A	Clays and clayey schists (with or without fissility), more-or-less fissured and/or jointed
B	Regular or chaotic sequences of competent rock, more or less fissured, containing clay, and clay and argillite
C	Blocks or fragments of more or less weathered rock in a clayey matrix, residual and colluvial soils

Table 4: Determination of approximate uniaxial compressive strength

	Class	Hardness	Field inspection	Uniaxial compressive strength (kPa)
Soils	S1	Very soft	Easy to break	< 100
	S2	Soft	Can be broken with the fingers	> 100
	S3	Compact	Can be broken with a spade	> 200
	S4	Hard	Can be broken with a pickaxe	> 450
	S5	Very hard	Can be broken with a pneumatic hammer	> 700
Rocks	E	Very soft	Easy to break with a knife	< 5000
	D	Soft	Hard to break with a knife	> 5000
	C	Hard	Can be broken in the hand at the blow of a hammer	> 10000
	B	Very hard	Can be broken in the hand with several blows of the hammer	> 25000
	A	Extremely hard	Repeated hammering needed to detach a sample	> 50000

Table 5: Rough determination of shear strength (c', ϕ') of rock masses

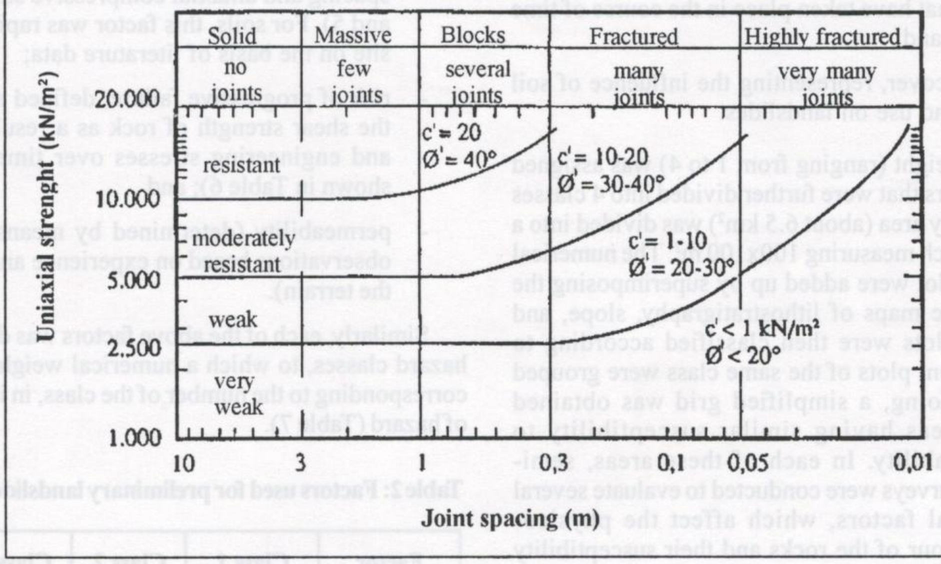

Table 6: Predicted progressive failure hazard

Material	Type of rock	Weathering	Progressive failure hazard
Soils (after Bjerrum 1967)	Over consolidated plastic clays with weak diagenetic bonds	Fresh Weathered	High High
	Over consolidated plastic clays with strong diagenetic bonds and clayey schists	Fresh Weathered	Low Very low
Rocks (After Colosimo 1982)	With permanent and strong diagenetic bonds	Fresh Weathered	Very low Low
	With weak diagenetic bonds (evaporites, weakly cemented rocks)	Fresh Weathered	Low Moderate
	With non-permanent diagenetic bonds		From moderate to high

Table 7: Geotechnical factors evaluated by means of semi-quantitative field tests

Factor	Class 1	Class 2	Class 3	Class 4
Degree of weathering	Fresh rock	Moderately weathered rock	Strongly weathered rock	Completely weathered rock
Depth of weathering, z	z < 1 m	1 m < z < 3 m	3 m < z < 5 m	z > 5 m
Compactness (Joint spacing, s)	s > 100 cm	30 cm < s < 100 cm	5 cm < s < 30 cm	s < 5 cm
Attitude of main joints	Joints dipping in the counter dip direction of slope or horizontal	Vertical joints	Joints dipping with angle of dip > slope angle	Joints dipping with angle of dip < slope angle
'Geotechnical complexity'	'Geotechnically simple'	Complexity Type A	Complexity Type B	Complexity Type C
Drained shear strength	Resistant rocks	Moderately resistant rocks	Weak rocks	Very weak rocks
Progressive failure hazard	Very low hazard	Low hazard	Moderate hazard	High hazard
Permeability	Impermeable rocks	Slightly permeable rocks	Moderately permeable rocks	Highly permeable rocks

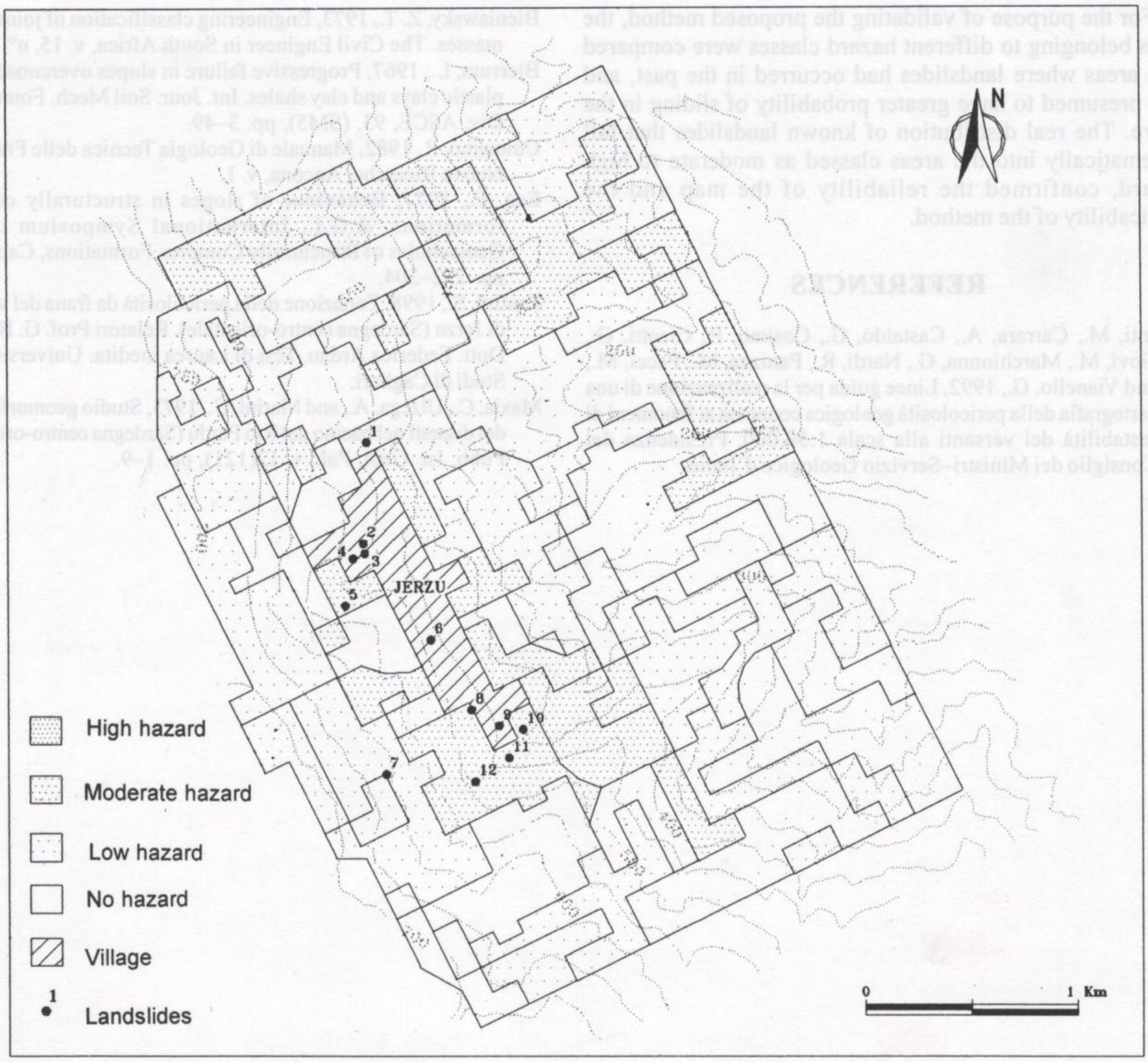

Fig. 2: Landslide hazard zoning in the Jerzu Hillside

Next, for each of the 58 areas, a numerical instability index X was calculated, by evaluating the ratio of the sum of numerical values for all the considered factors (i.e. geological, geomorphological, vegetative, and geotechnical) to the actual number of factors. In this way, we obtained the values of X ranging from 1.889 (maximum stability) to 3.345 (maximum instability). The interval between these two values was divided into four equal parts, obtaining four classes from I to IV in increasing order of instability (Table 8). The results are shown in the landslide hazard map of the Jerzu area (Fig. 2).

Table 8: Landslide hazard rating for the Jerzu Hillside

Class	Hazard type	Value of X	Areas
I	No landslide hazard	1.889–2.253	9
II	Low landslide hazard	2.253–2.617	10
III	Moderate landslide hazard	2.617–2.981	23
IV	High landslide hazard	2.981–3.345	16

CONCLUSIONS

A landslide hazard map was drawn up for the village of Jerzu by modifying the method devised by the Italian Geological Service for assessing geological hazard in large areas. The map is based on semi-quantitative field measurements of the geological, morphological, vegetative, and geotechnical factors influencing the susceptibility to sliding. The interest and usefulness of the method lies in the fact that it can be applied even when, as happens, laboratory analyses and tests are not available for univocally characterising the physico-mechanical behaviour of the rock.

However, as an arbitrary numerical scale was used to evaluate the degree of stability of each factor, the map does not claim to provide "absolute" values of landslide hazard. It is intended to represent the relative distribution of the degree of landslide hazard in a merely local context.

For the purpose of validating the proposed method, the areas belonging to different hazard classes were compared with areas where landslides had occurred in the past, and thus presumed to have greater probability of sliding in the future. The real distribution of known landslides that fall systematically into the areas classed as moderate to high hazard, confirmed the reliability of the map and the applicability of the method.

REFERENCES

Amanti, M., Carrara, A., Castaldo, G., Cosimo, P., Gisotti, G., Govi, M., Marchionna, G., Nardi, R., Panizza, M., Pecci, M., and Vianello, G., 1992, Linee guida per la realizzazione di una cartografia della pericolosità geologica connessa ai fenomeni di instabilità dei versanti alla scala 1:50,000. Presidenza del Consiglio dei Ministri–Servizio Geologico d'Italia.

Bieniawsky, Z. T., 1973, Engineering classification of jointed rock masses. The Civil Engineer in South Africa, v. 15, n° 12.

Bjerrum, L., 1967, Progressive failure in slopes overconsolidated plastic clays and clay shales. Int. Jour. Soil Mech. Found. Eng. Div. ASCE, 93, (SM5), pp. 3–49.

Colosimo, P., 1982, Manuale di Geologia Tecnica delle Frane. Ed. Nuove Ricerche, Ancona, v. 1.

Esu, F., 1977, Behaviour of slopes in structurally complex formations. A.G.I., International Symposium on The Geotechnics of Structurally Complex Formations, Capri, v. 2, pp. 292–304.

Fantini, S., 1998, Zonazione della pericolosità da frana del versante di Jerzu (Sardegna centro-orientale). Relatori Prof. G. Barbieri, Dott. Federica Ardau. Tesi di Laurea inedita. Università degli Studi di Cagliari.

Maxia, C., Ulzega, A., and Marini, C., 1973, Studio geomorfologico dei dissesti nel bacino del Rio Pardu (Sardegna centro-orientale). Pubb. Ist. Geol. Pal., v. 12(121), pp. 1–9.