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An example of landslide risk assessment in a historical site of Central Italy

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ABSTRACT

In a study of landslide risk assessment, one of the main problems is to define a univocal methodology for evaluating this risk and mapping it. Starting from the available data about this topic and, in particular, from the report of Varnes and IAEG (1984) edited by UNESCO and synthesised in Italy by Canuti and Casagli (1994), Crescenti (1998) published a critical review of the definitions related to landslide risk evaluation. In fact, treating "hazard" and "the probability of landslide occurrence" as synonymous, does not seem correct, since the term "hazard" corresponds to the real danger situation in a site for the advancing phenomenon. Instead, the probability does not show the real danger state, because not all the landslide phenomena are dangerous for the elements at risk. Furthermore, among the field experts (consultants and decision-makers) the term "hazard" is instinctively connected with the real danger, which is related not only to the probability of occurrence of a landslide phenomenon, but also to its intensity. It is therefore more reasonable to define landslide hazard on the basis of both aspects. With this hazard definition, the way to evaluate the landslide risk has to be reconsidered as well as a new definition of vulnerability is required.

In this paper, we applied this methodology for the study of landslides at the Guardiagrele Village, a historical site of Central Italy. The village may be considered to be a representative of other similar villages situated in this part of the Apennines.

INTRODUCTION

The assessment of landslide risk has been the object of particular attention in recent decades, above all on the part of the scientific community. Canuti and Casagli (1994) have well summarised the specialised literature. From the point of view of risk, any phenomenon of instability is characterised by certain intensity and by a particular probability of occurrence. The parameters of intensity and probability interact with the resources of the territory (population, buildings, economic activities, etc) indicated in the specialised literature as elements at risk, so determining the effective landslide risk (Fig. 1).

The elements at risk are classified in relation to their characteristics and to their value. The characteristics are strictly dependent on the capacity to tolerate the stress without damage. The degree of loss (damage) produced by the occurrence of a landslide on the risk elements is defined as vulnerability, which evidently depends on the intensity of the event and on the characteristics of the elements at risk. Fig. illustrates the sequence for the assessment of landslide risk according to the current literature.

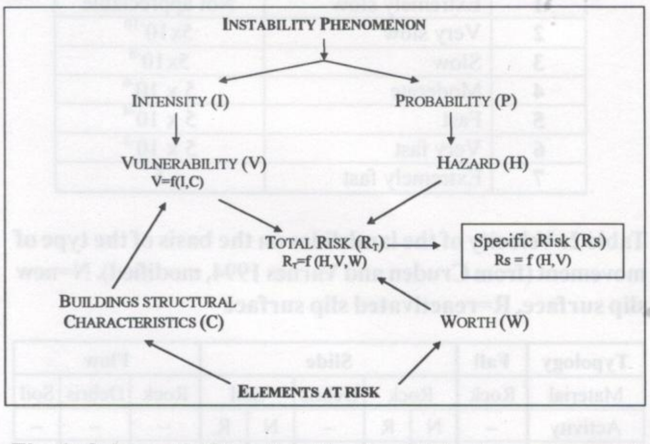

Fig. 1: Schematic flowchart for landslide risk assessment

Therefore, Crescenti (1998) proposed a different way to evaluate landslide risk, in particular concerning the definition of hazard. According to the author, it seems to be neither correct nor opportune to equate hazard with the probability of occurrence of a landslide phenomenon. It does not seem correct because the term "hazard" should be linked to the actual state of danger in a place of the phenomenon occurring. Probability on the contrary does not document the actual state of danger, because not all landslide phenomena are hazardous for public safety and for property, i.e. for elements at risk. It is not opportune because among the non-experts in the sector, e.g. public administrators, the term hazard is linked instinctively to actual danger, which does not derive only from the probability of occurrence of a landslide phenomenon, but also on its intensity.

It is therefore considered more correct and more opportune to define hazard on the basis of probability of occurrence as well as intensity of the landslide phenomenon (Canuti and Casagli 1994, page 35, Table 10). This definition is not coherent with the terminology of UNESCO, but is certainly more valid on a practical level. With this definition of hazard, the sequence for the assessment of landslide risk can be well expressed (Fig. 2).

Following this definition of hazard, the term specific risk disappears and corresponds to the new definition of vulnerability. For convenience, the definitions of the terms

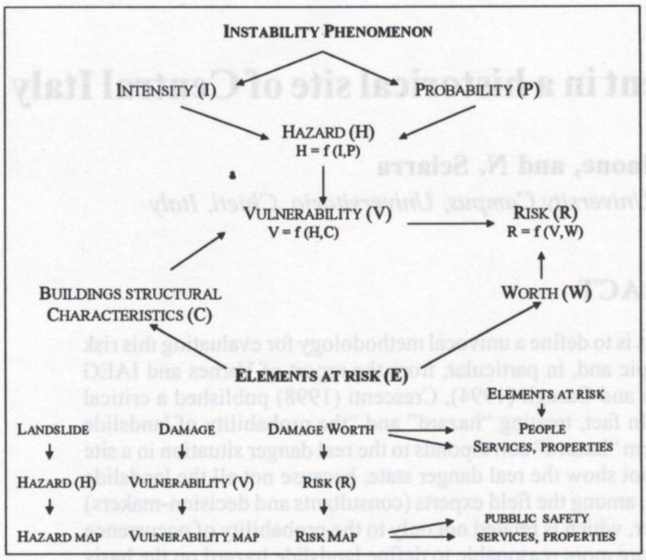

Fig. 2: Schematic methodology of Crescenti (1998) for the valuation of risk assessment

that appear in Fig. 2 are summarised below, and those differing from the UNESCO terminology (Varnes and IAEG, 1994) are italicised.

- Intensity (I): severity of the landslide phenomenon. It can be assessed in relation to dimensions, velocity, and energy of the phenomenon.
- Probability (P): probability of occurrence of the landslide phenomenon. In its assessment, in the case of active landslides, the return time must also be taken into account.
- Hazard (H): the degree of expected hazard for the elements at risk following the occurrence of a landslide phenomenon. It is a function of intensity and probability.
- Elements at Risk (E): they are represented by the population, property, and facilities exposed to landslide risk.
- Vulnerability [$V = F (H,C)$]: degree of loss (damage) produced or expected to elements at risk assessed according to their characteristics (C) for the occurrence of a landslide phenomenon of a given level of hazard (H).
- Risk [$R = f (V.W)$]: value of expected damage to elements at risk from the occurrence of a landslide event of a certain level of hazard. It is expressed in terms of annual cost and/or number of units (people) lost per year.

It follows from these definitions that intensity and probability are the parameters of hazard, whereas hazard and the value of the elements at risk are the parameters of risk. The assessment of the various parameters is then proposed, also taking into account the already-known criteria in the literature with some modifications. A simple, but practical and low-cost procedure that can be implemented in a limited time is proposed here.

The probability of occurrence (P) of landslide phenomena is derived from the "stability map" as follows:

- stable areas $P = 0$
- unstable areas $P = 1$
- medium stable areas $0 < P < 1$

The application of these subdivisions on the "stability map" yields the probability map.

For the unstable areas, in particular for the active landslides, data regarding the return period of the landslides can be included in the probability map, hence improving the information regarding the probability of occurrence of the event itself. For the assessment of intensity, the scale based on the velocity of landslides is proposed (Table 1) according to Cruden and Varnes (1994), as shown by Canuti and Casagli (1994). For this purpose, it does not seem appropriate to use the dimensions of landslides, because, as was said, the landslides of smaller dimensions that evolve at higher speeds are more dangerous than large and slow-moving landslides. Analogously, the consequences should also be used for the assessment of vulnerability, and therefore not considered here. The intensity classes for various predicted mass movement types are presented in Table 2. The application of these classes on the probability map (former "stability map") yields the hazard map.

The vulnerability map is obtained by including on the hazard map the damage produced or predicted to the elements at risk by the landslide phenomena. This is achieved by separating human vulnerability from that of property and facilities, thus obtaining two different vulnerability maps.

For human vulnerability, the velocity threshold equal to $5x10^{-2}$ m/s (about 3 m/min) is chosen as the limit to the damage to people (dead, wounded), accepting the proposal of Cruden and Varnes (1994), whereas Table 3 (based on Canuti and Casagli 1994, with some modifications) is recommended for the other elements at risk.

Table 1: Intensity scale (I) of the landslides based on velocity (from Cruden and Varnes 1994, simplified)

Class	Description	Velocity (m/s)
1	Extremely slow	Not appreciable
2	Very slow	$5x10^{-10}$
3	Slow	$5x10^{-8}$
4	Moderate	$5 x 10^{-6}$
5	Fast	$5 x 10^{-4}$
6	Very fast	$5 x 10^{-2}$
7	Extremely fast	5

Table 2: Velocity of the landslides on the basis of the type of movement (from Cruden and Varnes 1994, modified). N=new slip surface, R=reactivated slip surface

Typology	Fall	Slide					Flow		
Material	Rock	Rock		Debris	Soil		Rock	Debris	Soil
Activity	–	N	R	–	N	R	–	–	–
Velocity	6–7	5–6	1–5	1–6	5–6	1–5	1–2	1–7	1–4

It is possible to work out the relationships among damage, landslide type, and involved materials on the basis of Tables 1, 2, and 3. If V_t is the total vulnerability, V_1 human vulnerability, and V_2 vulnerability of goods and services, we derive from Table 3 that only class 6 can be attributed to V_1, with velocity of movement higher than 0.05 m/s. It is evident that the areas, although with danger of landslide shown on the hazard map, devoid of anthropogenic interventions do not present vulnerability, and will therefore be mapped with V equal to zero.

The quantification of the predicted damage, i.e. the value of goods and services subject to damage and the predicted number of human losses, makes it possible to transform the vulnerability map into the risk map. Since it is difficult to assess the value of damage and human losses in an absolute sense, the risk map may be drawn up with "relative" criteria, in the sense that the areas are zoned in relation to their different degrees of risk, i.e. of the value of the elements at risk subject to damage. The elements at risk can be assessed both on the basis of their economic and social values, and on the basis of subjective judgement varying from case to case.

Table 3: Classes of vulnerability in relation to the velocity of movement and observable damage

Classes of intensity	Classes of vulnerability	Observable damages
1	1	Low detectable without monitoring. Necessary to pay attention in building.
2	2	Some permanent structures could be stay safe.
3	3	Good quality constructions could be used again without fixing. Old buildings are damaged
4	4	Just only some both provisional and low damageable structures could be used again.
5	5	Possible evacuation necessity. Permanent structures failure
6	6	Struck buildings. Evacuation impossible. Human life losses.

The proposed methodology makes it possible to establish, on a geological-technical basis, the programme of management and mitigation of risk. This method can also be extended to the case of seismic risk. To this end the "instability" of an area is substituted by the relative "seismicity". Intensity (I) will be assessed on the basis of the magnitude of the historical earthquakes, probability (P) on the basis of the earthquake return period.

GEOLOGY OF THE STUDY AREA

The town of Guardiagrele is located on the upper Pliocene deposits (Donzelli 1997) belonging to the Apennine foredeep, opposite to the eastern front of the Maiella Mountain. This carbonate massif is a northeast-verging anticline with recumbent forelimb. The western limb is displaced by a southwest-dipping normal fault (Fig. 3). The upper Pliocene succession of Guardiagrele unconformably overlies the Pliocene deposits of the Maiella succession. In the study area (Fig. 4), the outcropping Pliocene deposits are represented by the following litho-stratigraphic units, from top to bottom respectively:

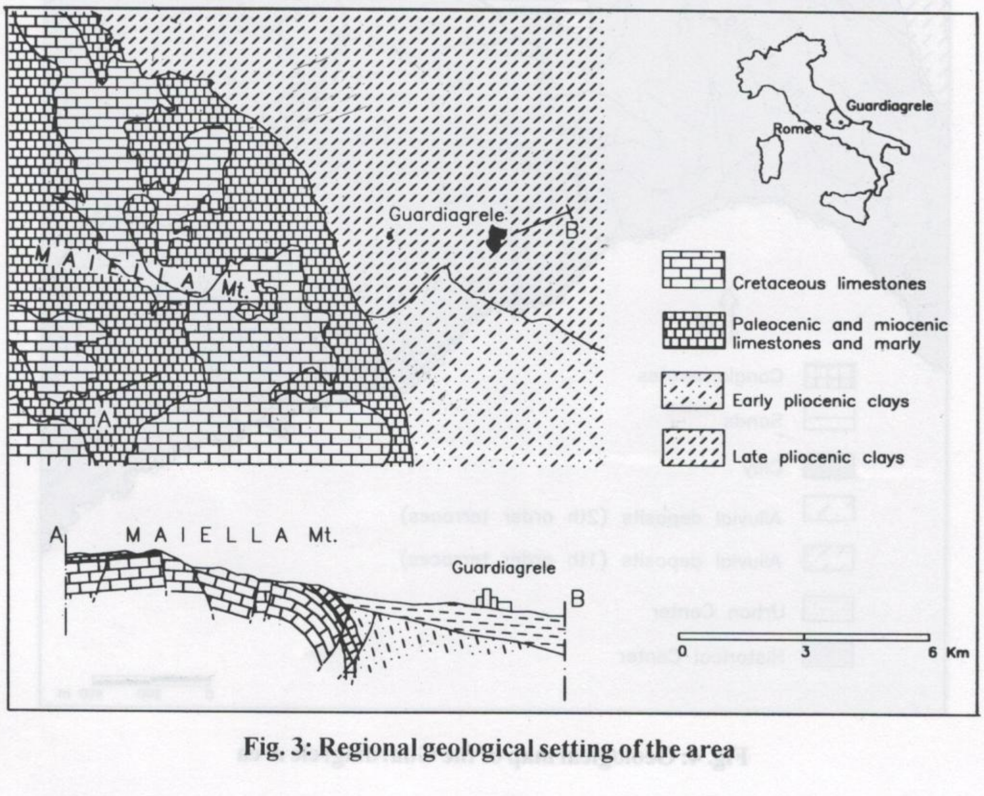

Fig. 3: Regional geological setting of the area

A. Conglomerates and sandy conglomerates with lenticular bedding and thin clayey intercalations; the maximum thickness is about 10 m;

B. Sand beds (from 10 to 50 cm), locally with lenticular bedding; the maximum thickness is about 20 m; and

C. Clays and marly clays, stratified with thin sandy intercalations.

Units A and B have an erosional contact. However, the geological fieldwork and the data collected by boreholes indicate that Unit B may be completely missing. In a borehole drilled in the built-up area, Unit A was found directly overlying Unit C. The Guardiagrele area is characterised by the presence of an N–NW dipping monocline, locally affected by N–S and E–W faults.

The settlement area occupies a hillock at an altitude of about 550 m. The nearby slopes are covered prevalently by clayey colluvial and landslide deposits of varying (from 2 to 20 m) depths (Fig. 5). The prevailing recent and old mass movements are represented by translational slides that often transform into flow-slides in the lower part. Surface-flows, generalised solifluctions, and slow surface-deformations are widespread on the clayey slopes.

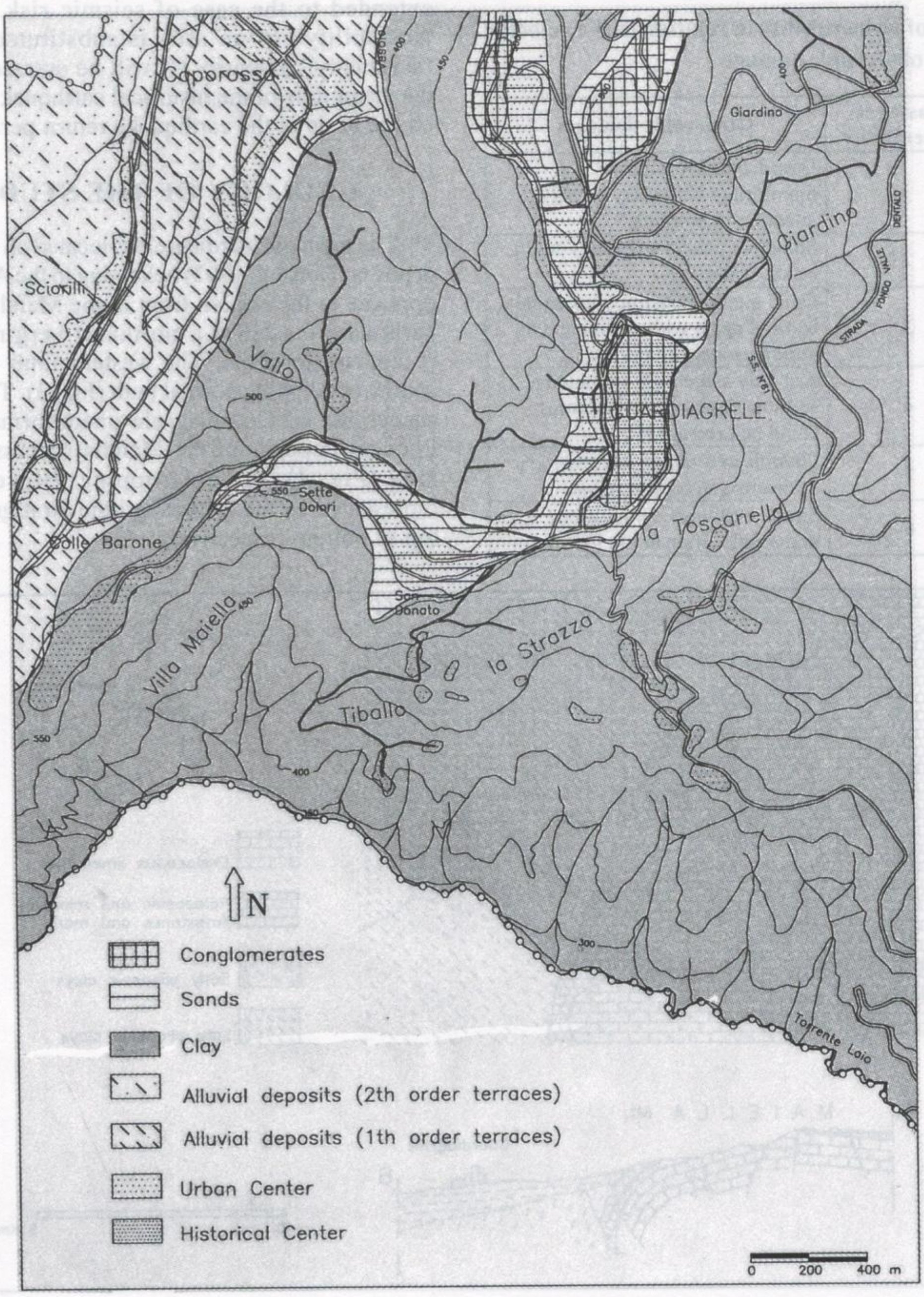

Fig. 4: Geological map of the Guardiagrele area

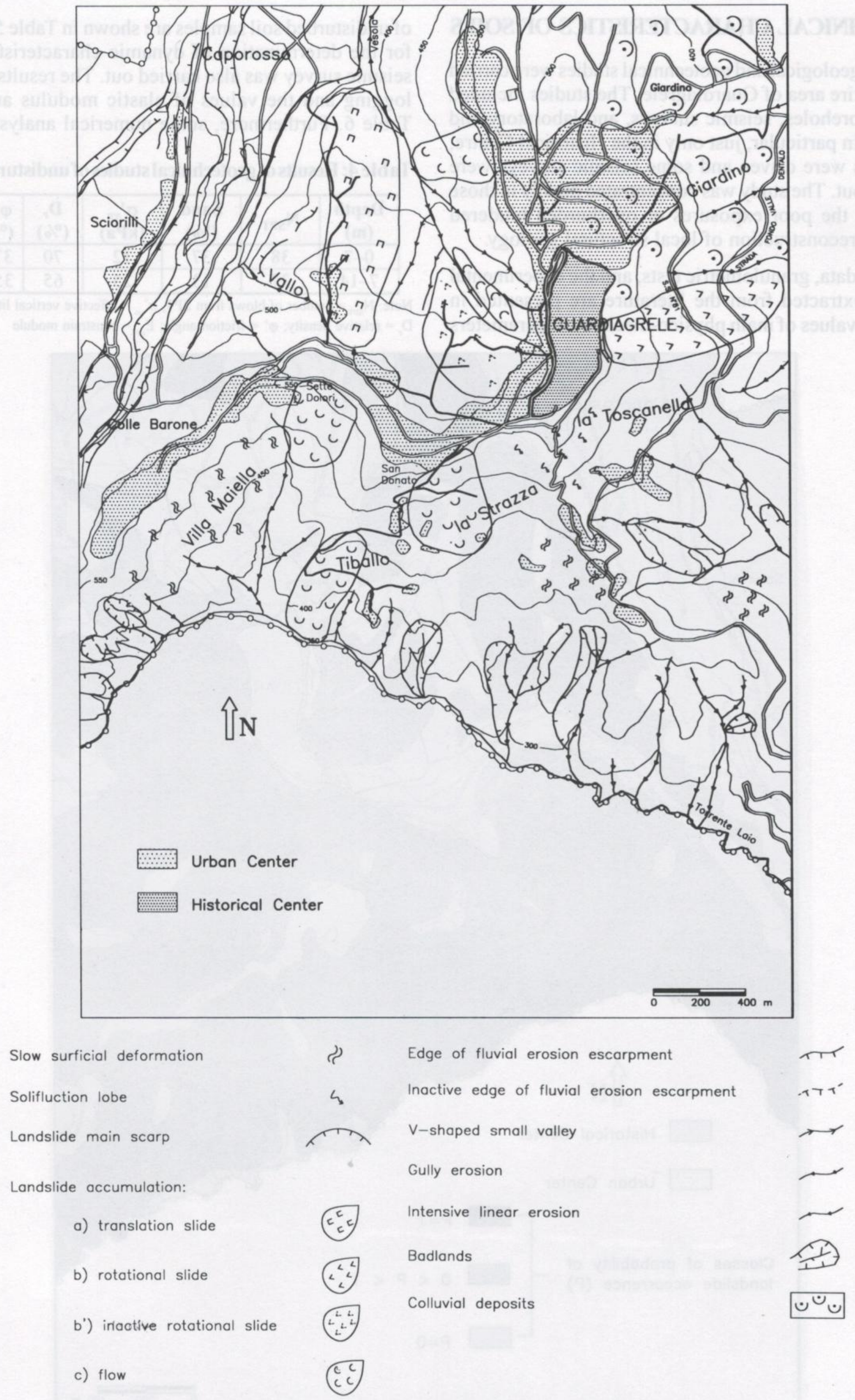

Fig. 5: Geomorphological map of the Guardiagrele area

GEOTECHNICAL CHARACTERISTICS OF SOILS

Detailed geological and geotechnical studies were carried out in the entire area of Guardiagrele. The studies included drilling of boreholes, seismic surveys, and laboratory and in situ tests. In particular, just only in the Historical Centre, 15 boreholes were driven and some seismic surveys were also carried out. The study was concentrated mainly in those zones where the poor exposures or overburden hindered the accurate reconstruction of local structural geology.

The SPT data, granulometric tests, and the experimental parameters extracted from the literature are presented in Table 4. The values of main physico-mechanical parameters of undisturbed soil samples are shown in Table 5. Moreover, for the determination of dynamic characteristics of soils, seismic survey was also carried out. The results of borehole logging and the values of elastic modulus are shown in Table 6. Furthermore, some numerical analyses based on

Table 4: Results of geotechnical studies of undisturbed samples

Depth (m)	N_{SPT}	Sand (%)	σ'_{vo} (kPa)	D_r (%)	φ' (°)	E_{ed} (MPa)
0–7	38	37	12	70	37	27
7–14	37	13	25	65	35	25

Note: N_{SPT} = number of blows from SPT, σ'_{vo} = effective vertical lithostatic tension; D_r = relative density; φ' = friction angle; E_{ed} = constrain module

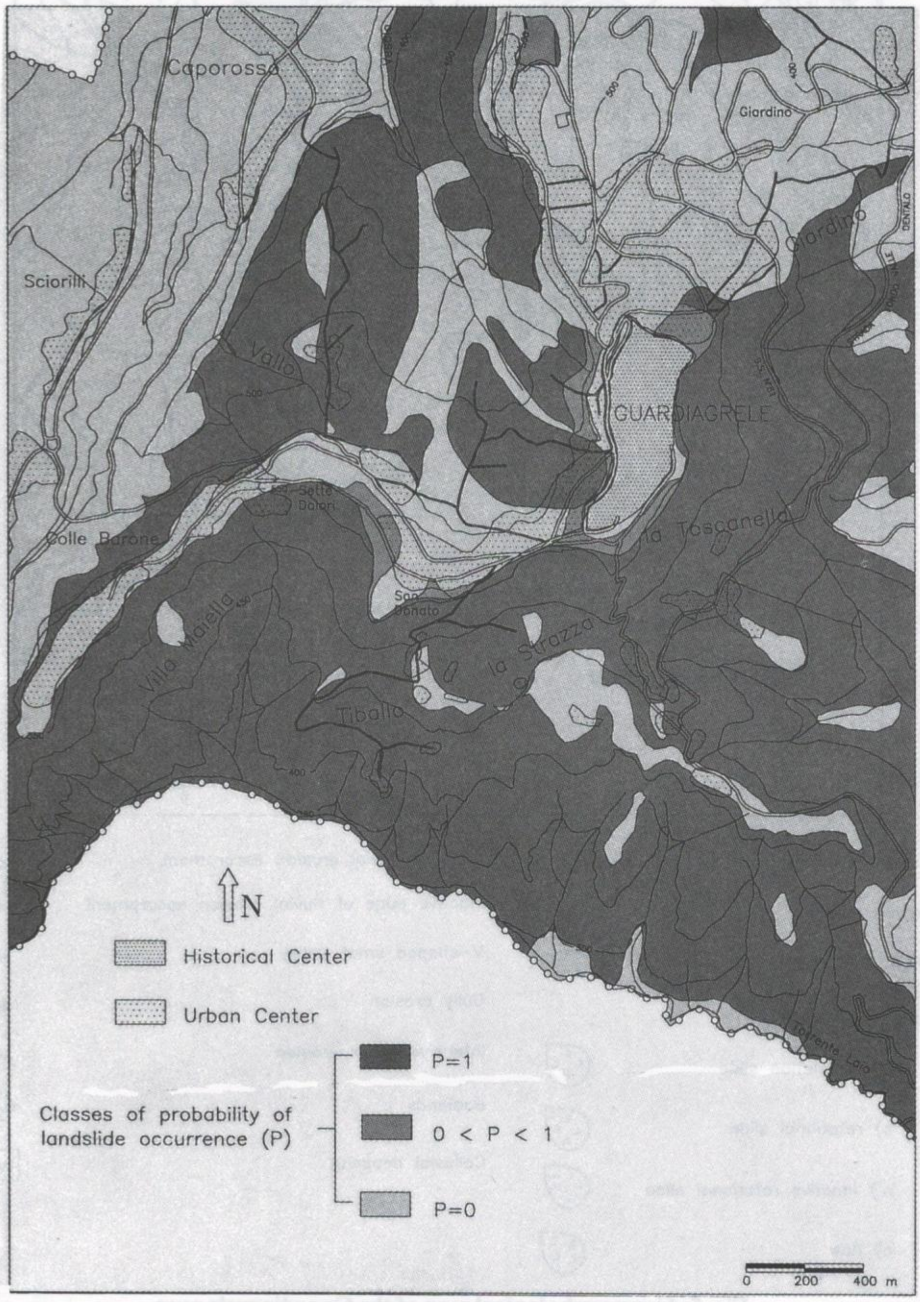

Fig. 6: Probability of occurrence map

experimental data for the hillside of the Historical Centre, were done using the computer software based on finite difference method (FLAC 1998).

The geotechnical parameters of the three different types of soil in the study area are shown in Table 7. The numerical models were built on the assumption of elasto-plastic behaviour of the material involved. Thus, both soil compressibility and soil strength parameters were considered.

RISK MAP

On the basis of aforesaid experimental data, a landslide risk map was prepared following the methodology proposed by Crescenti (1998). Apart from the risk map, the following other maps were also prepared: probability of occurrence map, hazard map, map of the elements at risk, and map of vulnerability.

The probability of landslide occurrence map (Fig. 6) involved the analysis of the geological map, slope map, soil management chart, and geomorphological map as well as the studies on the activity of the landslide phenomena, geotechnical characteristics of material, and engineering geological and geophysical surveys. Then, three probability classes of occurrence were worked out (i.e. $P=0$; $0<P<1$; $P=1$).

The hazard map (Fig. 7) was derived from the probability of occurrence map including both the present intensity state

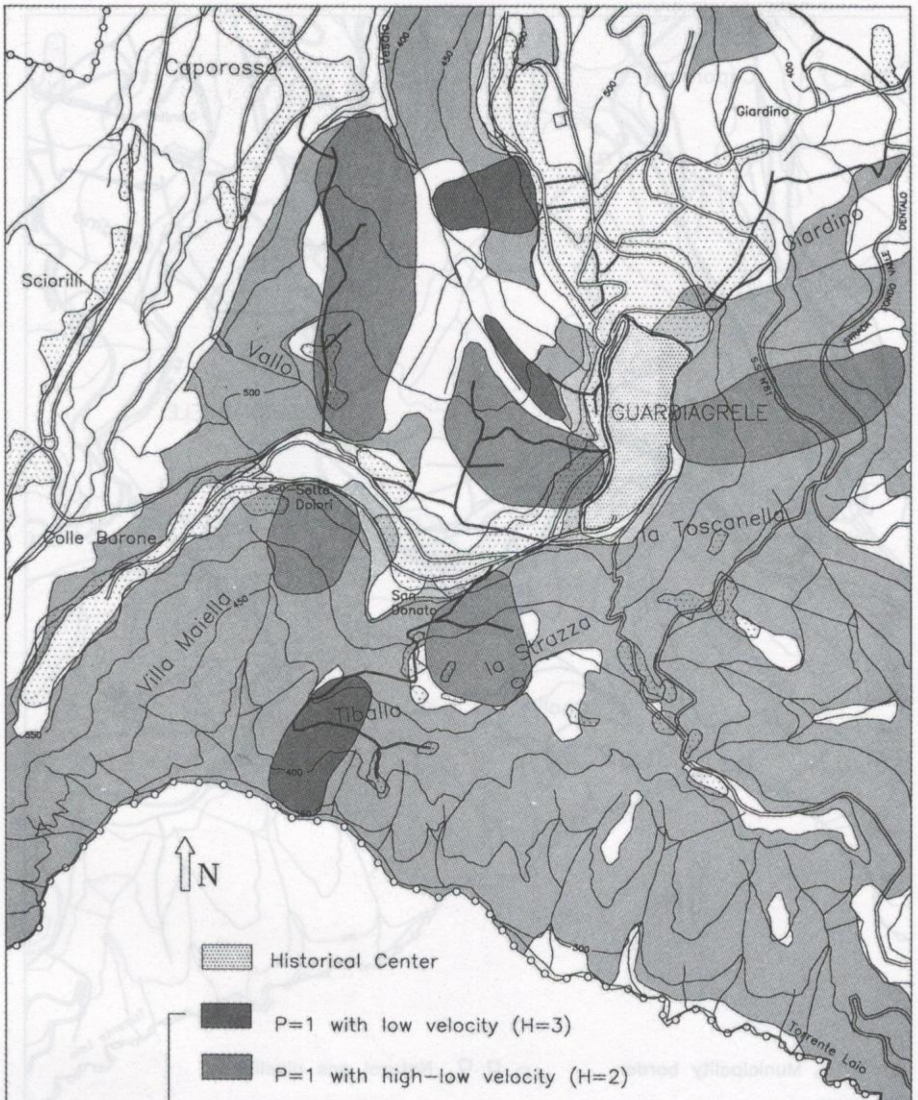

Fig. 7: Hazard map of the Guardiagrele area

Table 5: Results of geotechnical studies of clayey substratum

Depth (m)	γ kN/m³)	W (%)	WL (%)	IP (%)	c' (kPa)	φ' (°)	E_{ed} (MPa)
>14	20.76	23.1	38	21	58	24	15

Note: γ = unit weight; W = moisture content; WL = liquid limit; IP = plasticity index; c' = cohesion; φ' = friction angle; E_{ed} = constrain module referred to vertical effective lithostatic tension

of the active phenomena as well as the expected intensity state of events with some probability of occurrence. It shows the hazard class subdivisions related to the intensity defined only on the basis of the velocity parameter. For P=1, three different classes of hazard are introduced.

The map of elements at risk (Fig. 8) shows in a schematic way both infrastructure and social anthropogenic elements of the territory independently from the hazard conditions of the region. From this kind of map, it was possible to classify the areas into three categories (i.e. high, medium, and low) by giving an economical worth to each element (Fig. 9). The vulnerability map of the area is represented in Fig. 10, in which the hazard map (Fig. 7) and the map of elements at risk (Fig. 8) were superimposed.

The final risk map (Fig. 11) was intended as a chart to classify each area in relation to its economical depreciation grade (loss of worth). In particular, this map is obtained by

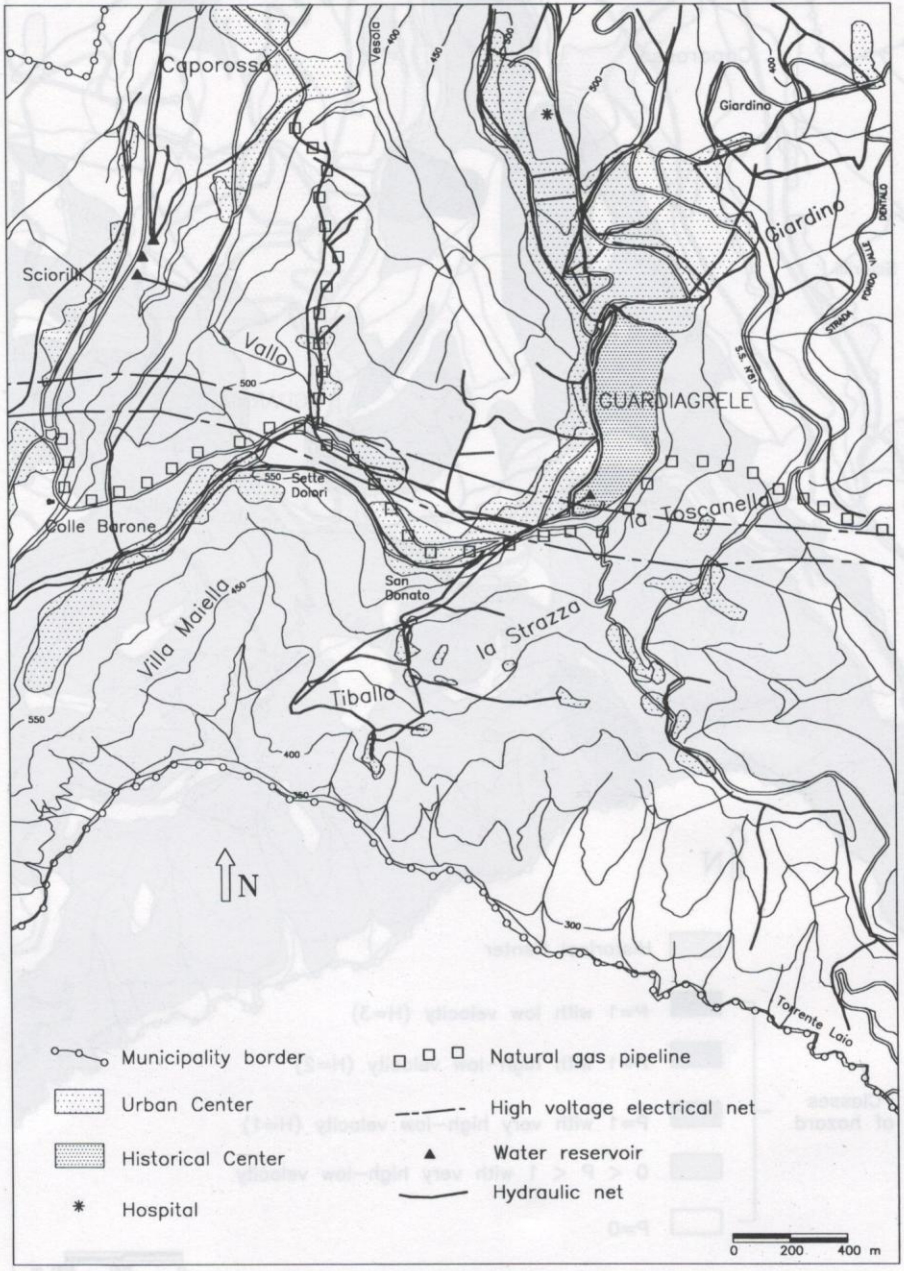

Fig. 8: Map of the elements at risk

Table 6: Results of borehole logging

Thickness (m)	γ (kN/m^3)	Vp (m/sec)	Vs (m/sec)	Vp/Vs	E_0 (N/m^2)	G (N/m^2)	ν
0 – 5	20	714	220	3.25	2.38E+5	8.22E+4	0.44
5 – 12	20	1820	125	14.56	9.82E+4	3.28E+4	0.49
12 – 14	20	1820	350	5.2	7.62E+5	2.57E+5	0.48
14 – 20	20	1340	350	3.83	6.81E+5	2.32E+5	0.46

Note: γ= unit weight; V_p = P waves velocity; V_s = S waves velocity; E_o = dynamic elastic modulus G = dynamic shear modulus; n = Poisson's coefficient

Table 7: Main geotechnical parameters used in the modelling

Soil type	γ (kN/m^3)	K (MPa)	G (MPa)	c' (kPa)	φ' (°)
Sands	21	33.4	28.6	0	45
Conglomerates	21	33.4	28.6	20	45
Clays	19.5	31.4	23.1	60	24

Note: γ = unit weight; c' = cohesion; φ' = friction angle; κ = Bulk modulus; G = shear modulus

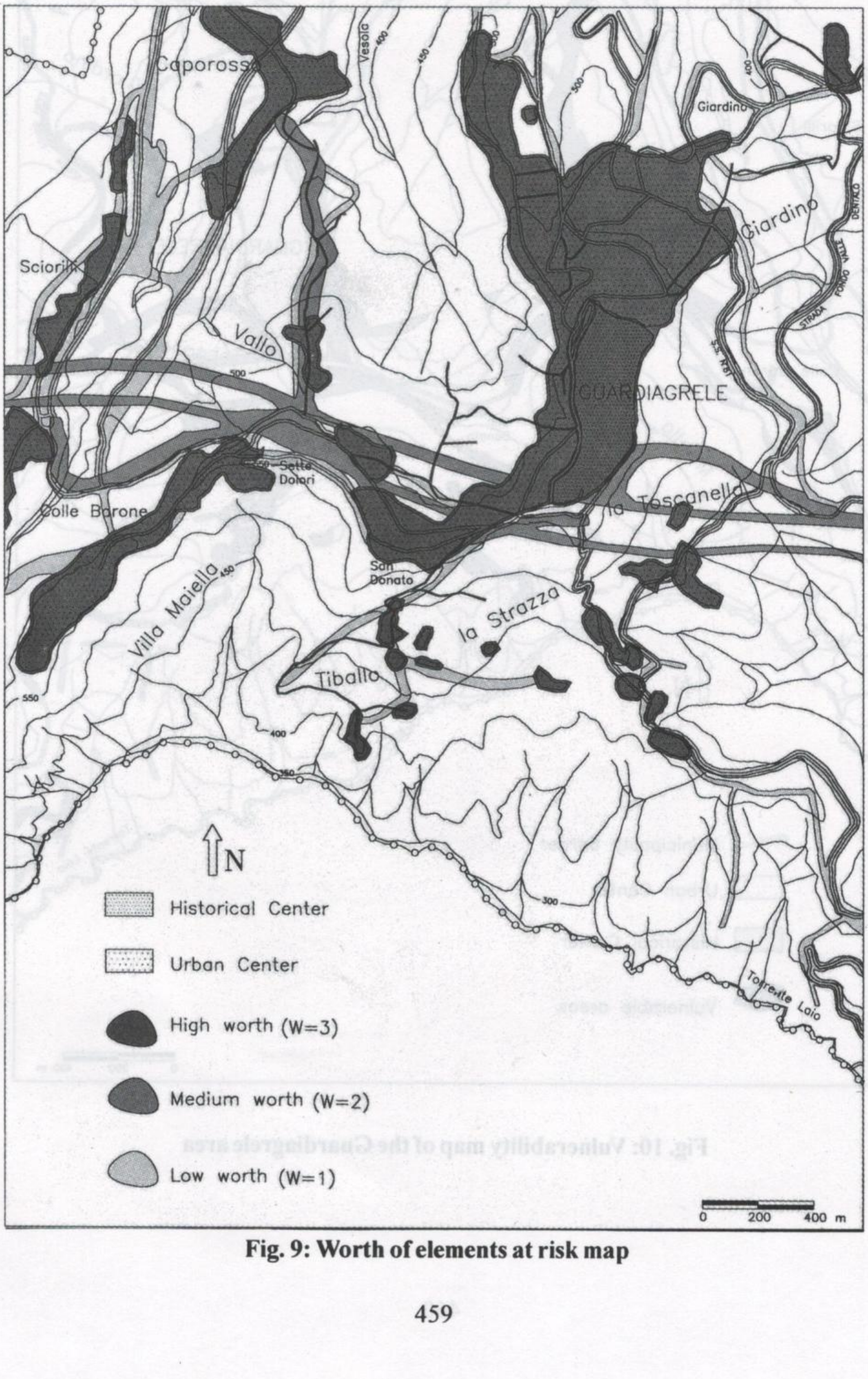

Fig. 9: Worth of elements at risk map

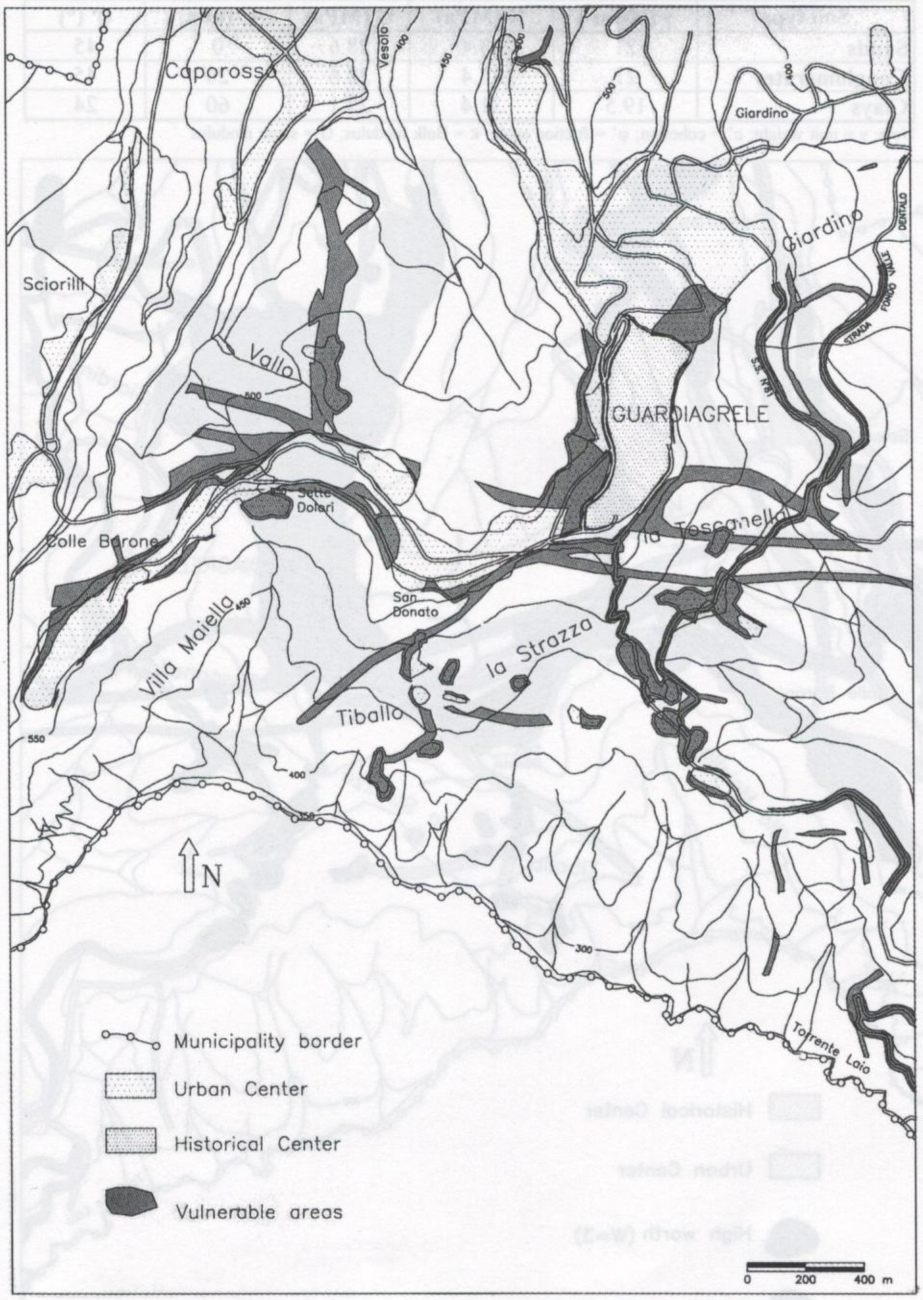

Fig. 10: Vulnerability map of the Guardiagrele area

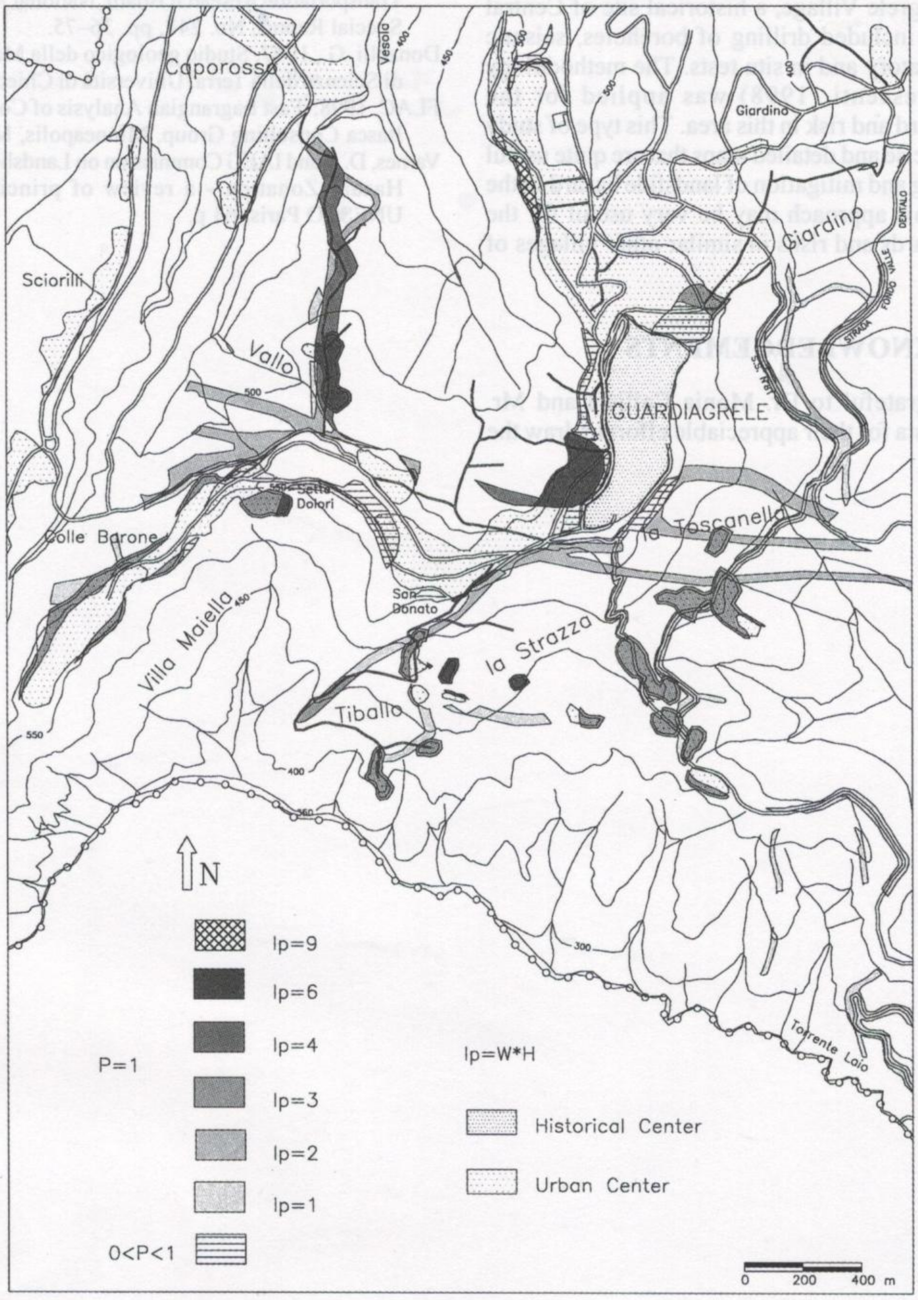

Fig. 11: Risk map of the Guardiagrele area

combining the hazard map (Fig. 7) and the worth of elements at risk map (Fig. 9). The Ip index (Fig. 11) represents, in fact, the product of V and W. Furthermore, six more subclasses of certain damage are proposed for P=1.

CONCLUSIONS

Detailed geological and geotechnical studies were carried out at the Guardiagrele Village, a historical site of Central Italy. The studies included drilling of boreholes, seismic surveys, and laboratory and in situ tests. The methodology suggested by Crescenti (1998) was applied for the assessment of hazard and risk in this area. This type of study produces more precise and detailed maps that are quite useful for further planning and mitigation of landslide hazard in the area. Therefore, this approach may be very useful for the assessment of hazards and risks in similar other villages of the Apennines.

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REFERENCES

Canuti, P. and Casagli, N., 1994, Considerazioni sulla valutazione del rischio di frana. C. N. R. - G. N. D. C. I. - Pubblicazione n. 846, Italy.

Crescenti, U., 1998, Il rischio di frana: appunti per la valutazione. Quaderni di Geologia Applicata, 5 - 2, Pitagora Ed. Bologna.

Cruden, D. M. and Varnes, D. J., 1994, Landslide types and Processes. In: “Landslide: investigation and mitigation”. Transportation Research Board. National Academy of Science, Special Report, No. 247, pp. 36–75.

Donzelli, G., 1997, Studio geologico della Maiella. Dipartimento di Scienze della Terra, Università di Chieti.

FLAC, 1998. Fast Lagrangian Analysis of Continua. Version 3.4, Itasca Consulting Group, Minneapolis, Minnesota, USA.

Varnes, D. J. and IAEG Commission on Landslides, 1984, Landslide Hazard Zonation - a review of principles and practice. UNESCO Paris, 63 p.