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QUALITATIVE ANALYSIS OF THE SAN LORENZO LANDSLIDE IN THE SANT' ARCANGELO REGION SOUTHERN ITALY

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ABSTRACT

This study is applying qualitative analysis based on the multitemporal evidence for generating the expected landslide hazard map. The study was carried out in San Lorenzo area, Sant'Arcangelo, Southern Italy. The main objectives of this study are: 1) to identify and generate old-landslide map year 1976 and recent-landslide map year 2002, and 2) to generate the expected hazard map based on multitemporal evidence. Interpretation of the aerial photographs has been used to determine the type of landslide and landslide activity in 1976, and fieldwork has been done to check type of landslide and to determine the landslide activity in 2002. The comparison between activity 1976 and 2002 have been done in order to generate the expected hazard map. Most of the active landslide in 1976 and 2002 are complex and rockfalls type and only small part are spread; slide and flow. Some active landslides in 1976 are still active in 2002 and even inactive landslides in 1976 become active in 2002 and leading to the extended high and moderate hazard area.

Key words: qualitative analysis, landslide, and San Lorenzo

INTRODUCTION

San Lorenzo is located in the Sant' Arcangelo region and between two rivers, Sauro River on the Northern part and Agri River on the Southern part and between two small towns Aliano Town on the Northern part and Alianello Town on the Southern part. Geological and structural point of view, the San Lorenzo area is located in the Sant'Arcangelo Basin and situated on the lower and middle

Pleistocene lacustrine succession. The Sant'Arcangelo Basin is a satellite basin, backing the south Apennines thrust belt in Southern Italy, and east verging accretionary wedge composed of deformed Mesozoic and Tertiary units [*Sabato et al.*, 2005]. According to *Mattei et al.*, [2004] this basin is a thrust-top basin located in the external part of the southern Apennines, close to the boundary between the continental lithosphere of the Adriatic foreland and the subducting oceanic Ionian plate. Its geometry mainly derives from the Pliocene-Pleistocene eastward propagation of the Apennines outer thrusts over the Adriatic foreland. The Sant' Arcangelo Basin in a structural setting of Southern Italy is shown in Fig 1.

The study area is composed of different cycles both marine and continental in origin, all deposited on different environments, and dominantly characterised by the Sauro and San Lorenzo Cycle. Detail geological map of Sant'Arcangelo basin and geological map of San Lorenzo are presented in Fig 2. The Sauro Cycle is compound of three heterotrophic units deposited in tectonic discordance. These three units are Silty clay, Sands and conglomerates. The cycle represents a fan delta system with faces that is very heterogeneous type from proximal to distal [*Sabato et al.*, 2005]. Meanwhile, San Lorenzo Cycle is composed of silty clays-stones and conglomerates, reaches a thickness of over 500m. They form a syncline structure whose ax has a NW-SE direction. This cycle can be divided into three stratigraphic units. The lower (a) is alluvial origin and composed of poorly sorted and well-stratified conglomerates. In some parts contain decimetre thick clayey beds and massive sandstone layers. This unit has a thickness of about 150m. Unit (b) is lacustrine deposits and primary composed of claystones and silty claystones. This unit has a thickness of about 200m. This lacustrine unit crops out over a 5 km-long and 2 km-wide area, in a NW-SE trending synclinal basin and unit (c) is alluvial origin and overlies unit (a) with an erosional contact and unit (b) with a gradual contact. It is over 150m thick and it composed of poorly sorted and massive reddish conglomerates which are interlayered with gravely sandstones [*Sabato et al.*, 2005].

From the geomorphic point of view, the study area is composed by three principal origins: 1) alluvial (fluvial process), and it have 3 units of alluvial landform, 2) denudational, and it have 26 units of denudational landform, and 3) structural, where the structural landform is normally found as structural denudational landform due to the geological-tectonic complexity. This landform comprises 11 units [*Marfai*, 2005a]. The denudational and the structural denudational landforms are very dynamic landforms which is responsible for different form of slope instability and inducing landslide hazard. This phenomenon is particularly due to the very thick deposit material, above 150 m on the hilly area. Furthermore, the structure of the Apennines, which is originated from recent tectonic movement, is still responsible for intense morphodynamic processes, such as slope movement, rockslides, slumps, slide, and also deep gravity-induced deformations [*Gerevois et al.*, 1994; *Martino et al.*, 2004]. The geological setting, material and characteristics, which are mentioned on the previous paragraphs, play an important rule for the landslide.

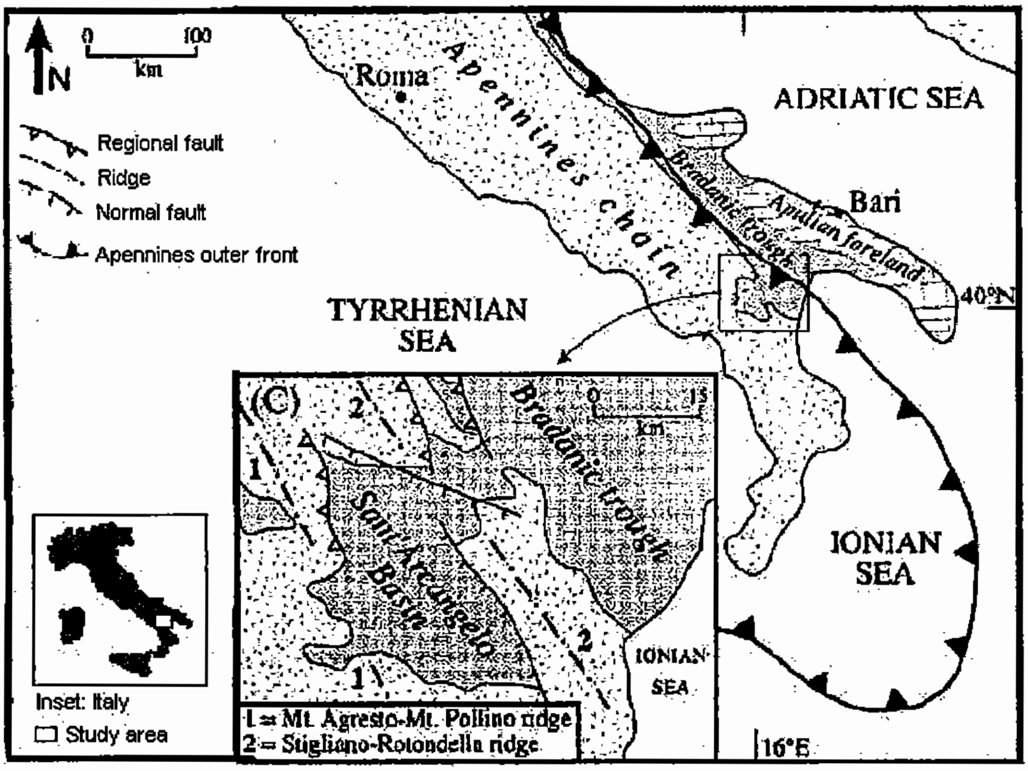

Figure 1. Sant` Arcangelo Basin location in a Structural setting of Southern Italy modified from *Sabato et al.* [2005].

Geomorphological hazard survey and mapping in Sant'Arcangelo region Southern Italy was conducted by the Department of Earth System Analysis, International Institute for Geo-Information Sciences and Earth Observation (ITC), Enschede, The Netherlands, in June 2002. The article is part of the hazard survey and mapping specifically in the San Lorenzo area, which aerial photographs were used and fieldwork has been done to identify the recent landslide processes. This study aims to identify and generate old-landslide map based on the aerial photo year 1976 and recent-landslide map year 2002 based on the fieldwork, as well as to generate the expected hazard map based on multitemporal evidence (1976 and 2002).

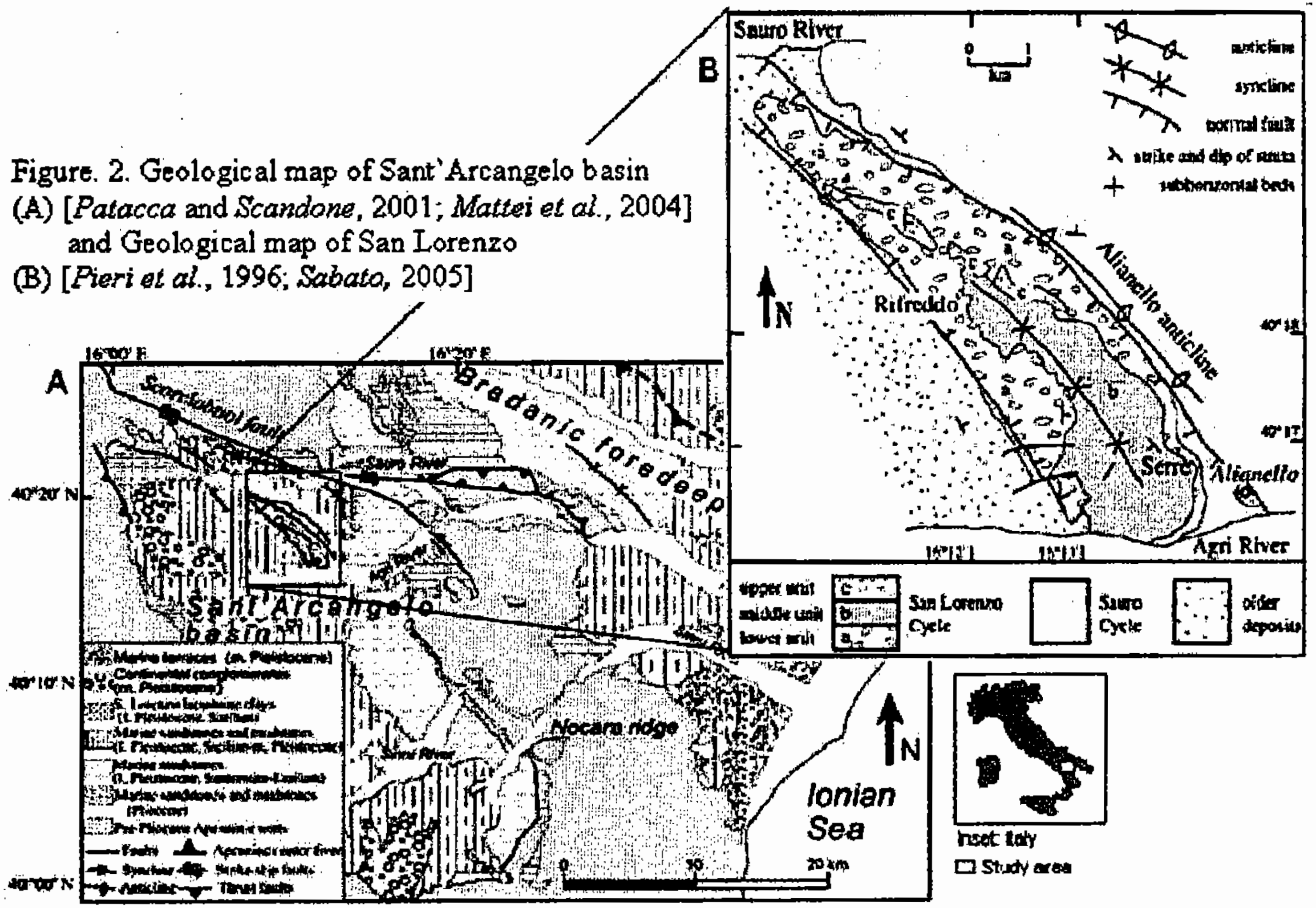

Figure. 2. Geological map of Sant'Arcangelo basin
(A) [*Patacca* and *Scandone*, 2001; *Mattei et al.*, 2004]
and Geological map of San Lorenzo
(B) [*Pieri et al.*, 1996; *Sabato*, 2005]

THE METHODS

Many researches pertaining about landslide have been done using various approach and methodology, such as Geomorpological approach [*VanWesten* and *Getahun*, 2003; *Korup*, 2004; and *Noeyersons et al.*, 2004], GIS technology [*Fabbri, et al.*, 2003; *Fernández et al.*, 2003; *Marqunez et al.*, 2003; *Sŭzeu et al.*, 2003; and *Marfai*, 2005b] assessment using remote sensing data [*Hervás et al.*, 2003], artificial neural network [*Lu* and *Rosenbaum*, 2003] and qualitative analysis [*VanWesten et al.*, 2003].

On this study, qualitative analysis has been used for landslide assessment of the San Lorenzo area in the Sant′Arcangelo region Southern Italy. Images interpretation using aerial photos (scale 1:15000) year 1976 has been done to identify the type of landslide and old-landslide activity in the year of 1976. Fieldwork has been carried out in year 2002 to check the type of landslide and determine the landslide activity in 2002. Every landslide was delineated as an individual polygon. Polygons were numbered assigning a unique identifier to each one; therefore it was compatible and easy operated in GIS environment. Qualitative analysis of the attribute map has been done using table operation function in GIS package software, where each polygon maps had its own attribute table, to determine landslide type and activity. Polygons activities of 1976 and 2002, as multitemporal evidence, were compared and qualitatively analyzed as well as depicted in expected hazard map. In this study, the ILWIS package [*ILWIS*, 2000] was used for all the GIS operation.

RESULTS AND DISCUSSION

Type of landslide in the study area

Landslide describes a wide variety of processes that result in the downward and outward movement of slope-forming materials by gravitative forces including rock, soil, artificial fill, or a combination of these. The materials may move by falling, toppling, sliding, spreading, or flowing. The various types of landslides can be differentiated by the kinds of material involved and the mode of movement. A classification system based on these parameters is shown in Table 1. This classification system of landslide will be used on this study.

There are several factors influencing the occurrence of the mass movements in the whole area of San′t Àrcangelo basin. Since the tectonic point of view, this area is a relatively active zone with recent uplifts in short period of time, lithological units of poor geotechnical quality, and lack of vegetative cover. These factors have effects in different ways in the slope stability. The San Lorenzo area has been affected by diverse kind of wasting which comprises several kinds of mass movements, closely related with lithology, faulting, inclination of the slopes, behavior of runoff and percolating water, and changes in the landcover trough recent time. The main types of movement in the study area are:

Table 1. Type of Mass-movement

TYPE OF MOVEMENT		TYPE OF MATERIAL		
		BEDROCK	ENGINEERING SOILS	
			Predominantly coarse	Predominantly fine
FALLS		Rock fall	Debris fall	Earth fall
TOPPLES		Rock topple	Debris topple	Earth topple
SLIDES	ROTATIONAL	Rock slide	Debris slide	Earth slide
	TRANSLATIONAL			
LATERAL SPREADS		Rock spread	Debris spread	Earth spread
FLOWS		Rock flow (deep creep)	Debris flow	Earth flow
			(soil creep)	
COMPLEX		Combination of two or more types of movement		

Source: *Varnes* [1978], *Highland* [2004].

(1) Slides; there are the two major types of slides, namely rotational slides and translational slides. Dominant type of slide in the study area is rotational slide. This is a slide in which the surface of rupture is curved concavely upward and the slide movement is roughly rotational about an axis that is parallel to the ground surface. When they are very deep (>25m) usually have also a translational component with the surface of rupture following the bedding of the strata, and turning complex. Sometimes they are translational in origin but due to water content and plastic behavior of the debris, it becomes fluid and turning in flow-like deposits. They are more common in the sandy member of the Sauro Cycle, in which the intercalations of materials with different permeability (sands, silts, clays) creates differential pressures and overweight during rainfalls or in the rainy season, leading the rocks and soils to lose mechanical resistance, turning cohesionless and sliding. Presence of water in the contact of two different layers also brings a wet-lubricate surface to slide. Fig. 3 shows an example of the slides type on the study area.

(2) Flows; debris flow and debris avalanche are dominant flow processes on the study area, especially on the Sauro Group Rock. However mudflow also occurs especially on the clays material after the heavy rain. According to *Highland* [2004], a debris flow is a form of rapid mass movement in which a combination of loose soil, rock, organic matter, air, and water mobilize flows downslope. Debris flows include <50% fines. Debris flows are commonly caused by intense surface-water flow which erodes and mobilizes loose soil or rock on steep slopes. Debris flows also commonly mobilize from other types of landslides that occur on steep slopes and consist of a large proportion of silt- and sand-sized material. The bodies of flow type in the study area are recognized as a tongue shaped, smooth, gentle dipping following the original slope and exhibit a hummocky inner drainage. This

kind of movements has been happening through geological time, some of them occurred probably during the uplift and fold phases of the area. Other flows are originated in the interface soil-rock due to changes in permeability during rainy seasons. In steep slopes the clay rich soil becomes saturated and heavy due to the overweight. It slides and flows suddenly when the liquid limits of the clays are reached and overtopping. In this case, the flow generally is confined in a small basin and the debris are transported along a previous existing channel (ephemeral streams and rivers) and deposited far away from the scarp. Due to the high capacity of abrasion, this kind of movements also produces riverbank erosion and undercutting in the base of the slopes, creating instability in the valley sides along the track. Fig. 4 shows the example of the flows on the Sauro Group rocks in San Lorenzo area.

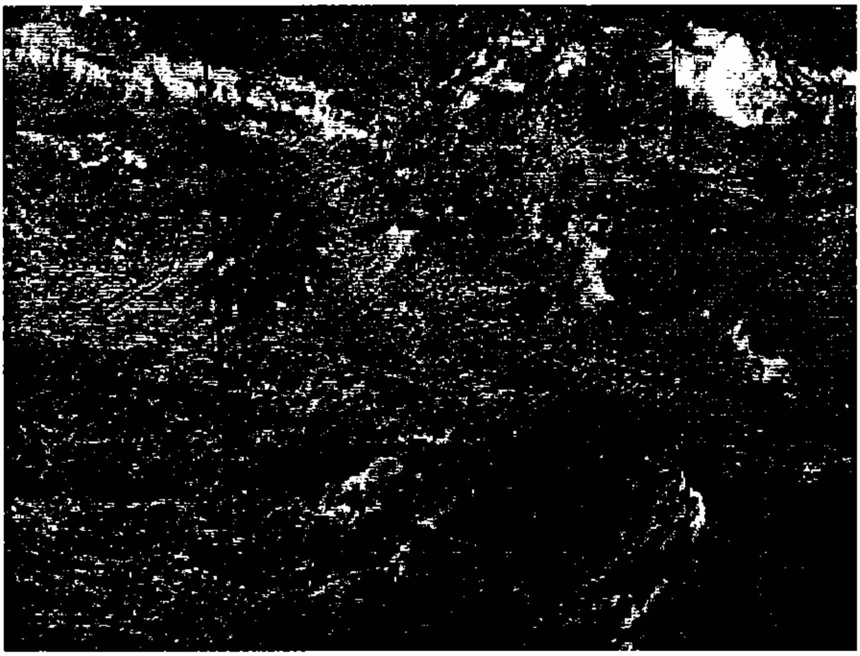

Figure 3. Slides type on the San Lorenzo area

(3) Falls; are abrupt movements of masses of geologic materials, such as rocks and boulders that become detached from steep slopes or cliffs. Separation occurs along discontinuities such as fractures, joints, and bedding planes, and movement occurs by free-fall, bouncing, and rolling. Falls are strongly influenced by gravity, mechanical weathering, and the presence of interstitial water. Falls are precipitous movements of blocks of conglomerates of the lower and upper San Lorenzo Group members. They occur usually due to undercutting for roads construction or undercutting due to stream erosion during rainy season. They also occur in the cliffs formed on Sauro sand member. Figure 5 shows an example of the falls type.

Figure 4. Flows on the Sauro Group rocks in San Lorenzo area

(4) Spreads; are distinctive because they usually occur on very gentle slopes or flat terrain. The dominant mode of movement is lateral extension accompanied by shear or tensile fractures. According to *Highland* [2004], the failure is caused by liquefaction, the process whereby saturated, loose, cohesionless sediments (usually sands and silts) are transformed from a solid into a liquefied state. When coherent material, either bedrock or soil, rests on materials that liquefy, the upper units may undergo fracturing and extension and may then subside, translate, rotate, disintegrate, or liquefy and flow. Lateral spreading in fine-grained materials on shallow slopes is usually progressive. The failure starts suddenly in a small area and spreads rapidly. Often the initial failure is a slump, but in some materials movement occurs for no apparent reason. This kind of movements is present, most of the times, on the gentle sloping sensitive clays of San Lorenzo Group. The failure starts in the lower part of the slope as a result of overstepping due to incision processes or stream bank erosion. The landslide develops retrogressive and extending laterally with gravitational remolding. Fig. 6 shows an example of spreads type.

Figure 5. Example of the falls type.

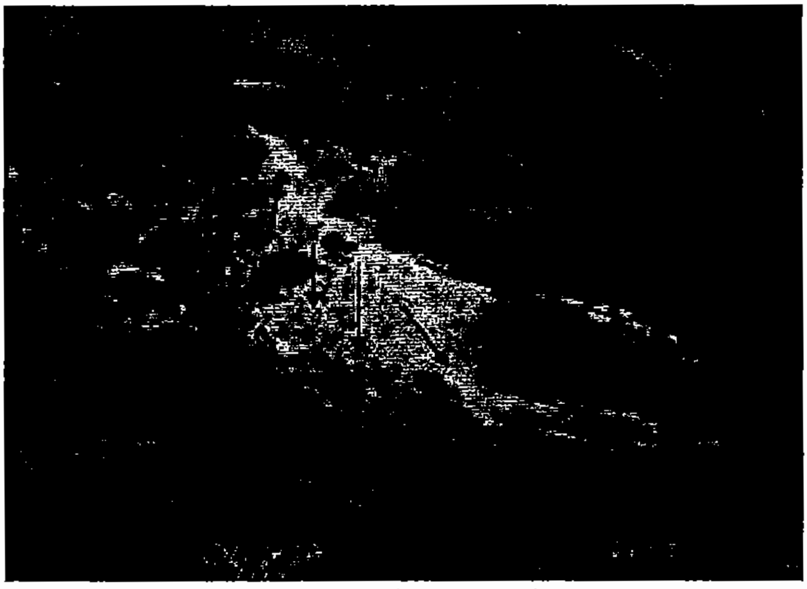

Figure 6. Example of spreads type.

(5) Complex landslide; is a combination of two or more of the above types. Type of landslide on the San Lorenzo area is not always easy to identified and recognized due to the combination of the mass movement processes, which occurs together and mix up each other. Therefore, this process pointed as complex landslide. Fig. 7 shows an example of the complex type of landslides, which situated on the southern part of the study area. This landslide was visible on the 1976 aerial photos and was interpreted as big complex type. This slide was

reactivation of 2002 fieldwork and some small landslide activity were also developing in the centre of the landslide body. The new slide started as rotational movement on the scarp and further downslope changed into flow that went a relatively long distance down the valley.

San Lorenzo Landslides have been recognized and identified using aerial photo and have been checked during the fieldwork. Based on the aerial photo and field check, 86 landslide-polygons have been generated. Each polygon has been evaluated in detail in order to identify the main type of the landslide. Figure 8 shows the spatial distribution of the landslide types on the San Lorenzo area. From Figure 9 it can be seen that the majority of landslide is Slide type and several big polygons of slide were located on the western part of the sudy area. Rockfalls dominated on the northern part near the Town of Aliano. Meanwhile several polygons of complex slide can be seen on the middle part and northern part of the study area.

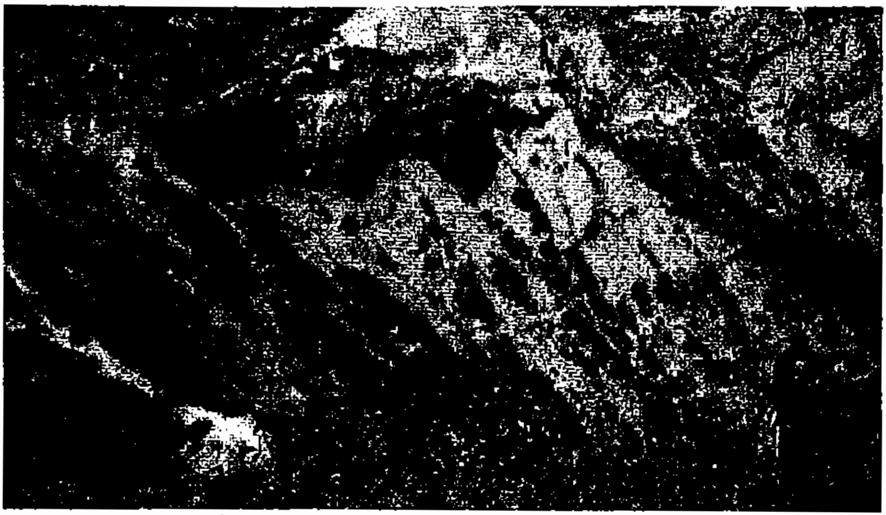

Figure 7. Example of the complex type

Activity of landslide and expected hazard in the study area

The landslide activities can be divided into 2 main categories, namely active and inactive. Active landslide is a landslide process which occurs recently and still can be easy recognized, whether from aerial photo or from the field check. Meanwhile, inactive is landslide process which is not occurs again on the long time or dormant but still have a potential landslide. The evidence of landslide activity was derived from terrain features like morphology, vegetation, inner drainage, texture, and tone. Active landslide is recent exposed surfaces of rupture and scarps are light in color, and display surficial erosion like rills due to the relative impermeability of the soil and the general drainage is disintegrated. Scarps and terraces have sharp edges; there is no soil development on recent exposed surfaces. Therefore vegetation is absent or just fast growing species on slide area. On the active process resultant soil and debris are still remaining on the slope and foot slope. From the aerial photo active landslide also identified in bright white color, clearly textures, explicit shape and distinct form of the body and head of slide.

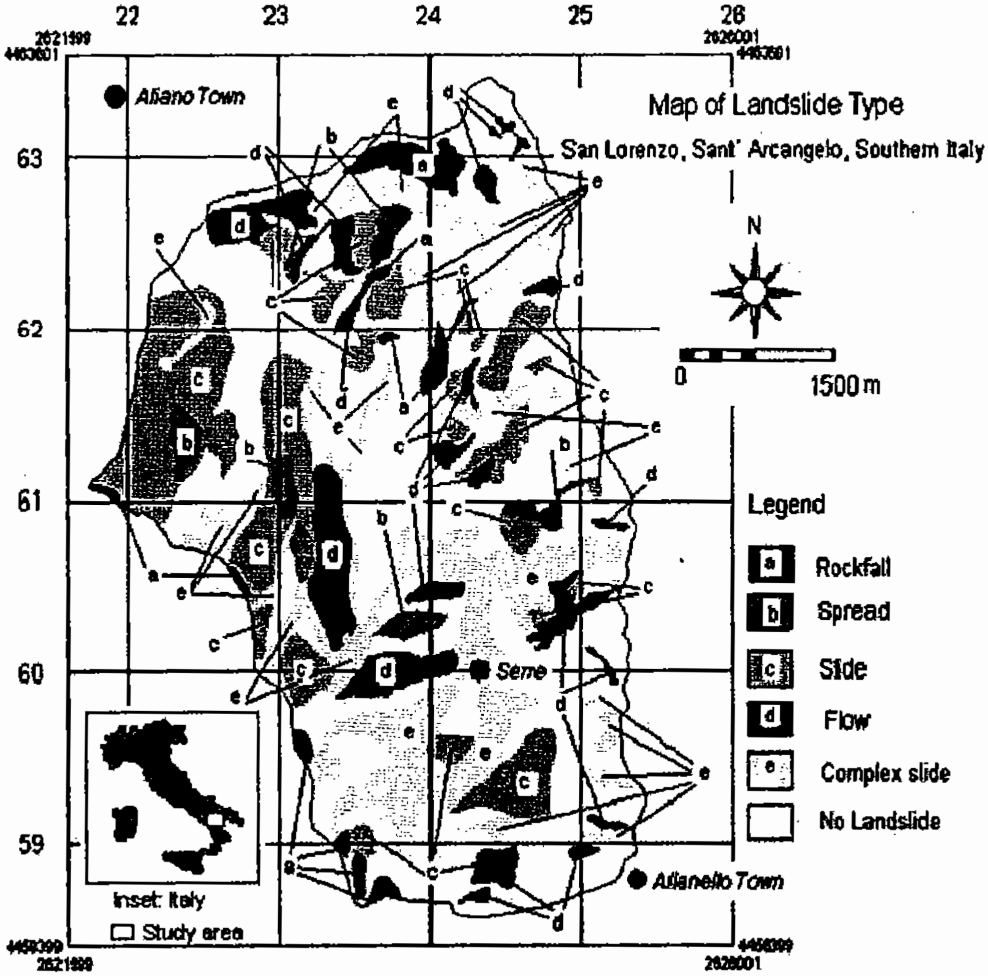

Figure 8. Map of Landslide Type on San Lorenzo area

Meanwhile on the inactive area, borders are slightly reshaped and rounded. Photo tones are still light but more uniform. The vegetations, such as shrubs and small to medium size trees, are distributed and cover the entire landslide polygon. The drainage is still not completely integrated but more consistent and activities like agriculture could be already established. Only small part of the body and head of landslide are still remaining on the site location. Resultant material, such as gravel, soil, and debris, are gone by water flow, run off, and erosion process. Heavy vegetated cover may expose on some part of this area. In a little part of landslides are difficult to be identified because of the landslides are relatively old. On these sites the borders are smooth and rounded, with soil development on both surfaces of rupture and body of the slide, the drainage is again integrated, and there is no distinction between vegetation on and off slide, the depressions have been filled with secondary deposits and activities like agriculture and crops are well developed. From the aerial photo inactive landslide is identified in gray or dark color, with indistinct shape of body and head of slide.

The activity of the landslide 1976 was interpreted from aerial photograph and is shown on Fig. 9. From Fig. 9 it can be seen that active landslides mostly located on the southern and north-eastern part of the study area. Spatially can be analyzed that in general on the southern part are complex-type, only small part flow and spread slide. Some polygons of complex landslide began as multiple rotational landslides and changed into a large flow-type that extended down and filling-up the valley and some part became spread-type especially on the gentle slope. Meanwhile on the north-east part are covered by rockfalls and small part by slide types. Inactive landslides were on the west part and middle part of the study area. These inactive were recognized from the scarps and body of the landslide which almost of the entire area covered by vegetation and grass. Some parts of the inactive landslide were slide type and several parts were spread and flow.

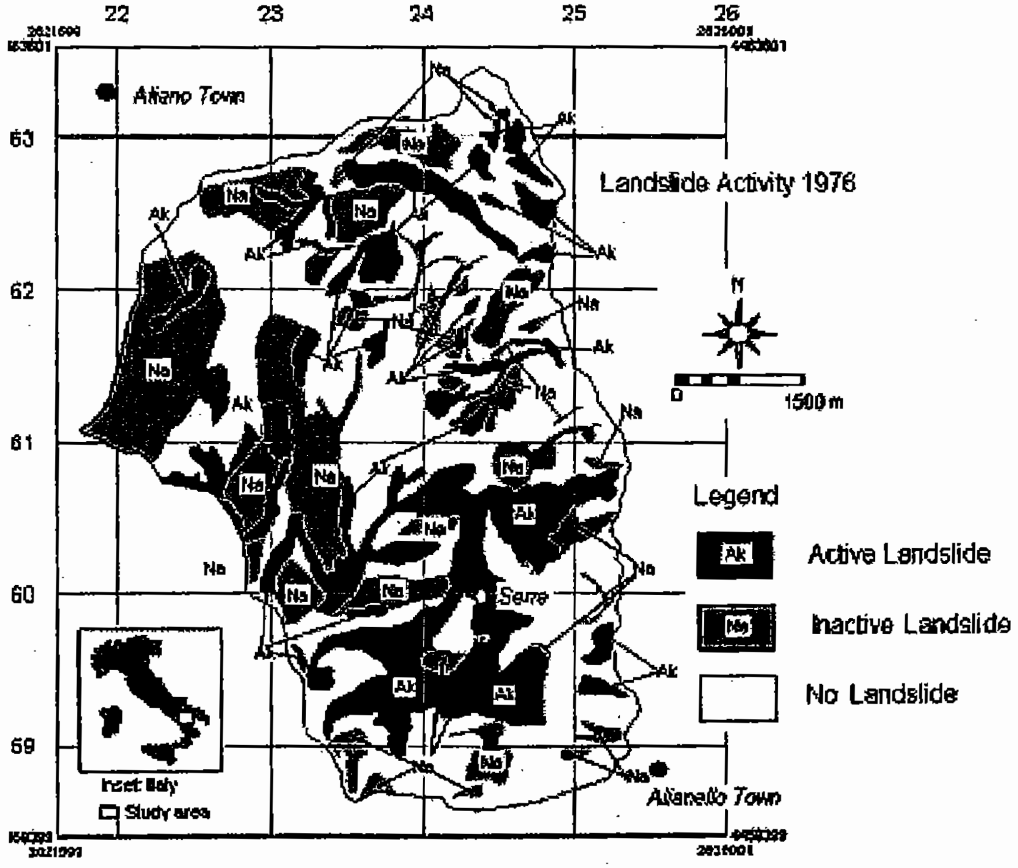

Figure 9. Attribute Map of Landslide Activity 1976

The activity of the landslide in 2002 was identified during the fieldwork. Spatially can be analysed Active landslides mostly also located on the southern part of the study area and only small part on the north-east. Some reactivations took place with nearly similar magnitudes as the initial one from 1976, especially on the complex-slide on the southern part. Part of the landslide accumulation was reactivated as a flowslide. In the north-east part, the active rockfalls visible in the 1976 photos were still active in 2002, as evidence by the existence of fresh scarps and debris as well as lack of vegetation on the scarps. A number of Rockfalls extending upslope to the vertical cliffs and several scarps reactivation and leading to new rockfalls on the upper slope. This reactive scarps follow the old scarps where were active in 1976. Several complex landslides on the middle part of the study area were moved yet again as observed during the fieldwork but no large volume of materials was removed. On the same part some landslide become dormant or inactive compared to the activity in 1976. The body of the landslide and the accumulation zone are relatively more vegetated than in the 1976 photos. Therefore inactive slide extend in year 2002. Fig. 10 shows the attribute map of the activity of landslide in 2002.

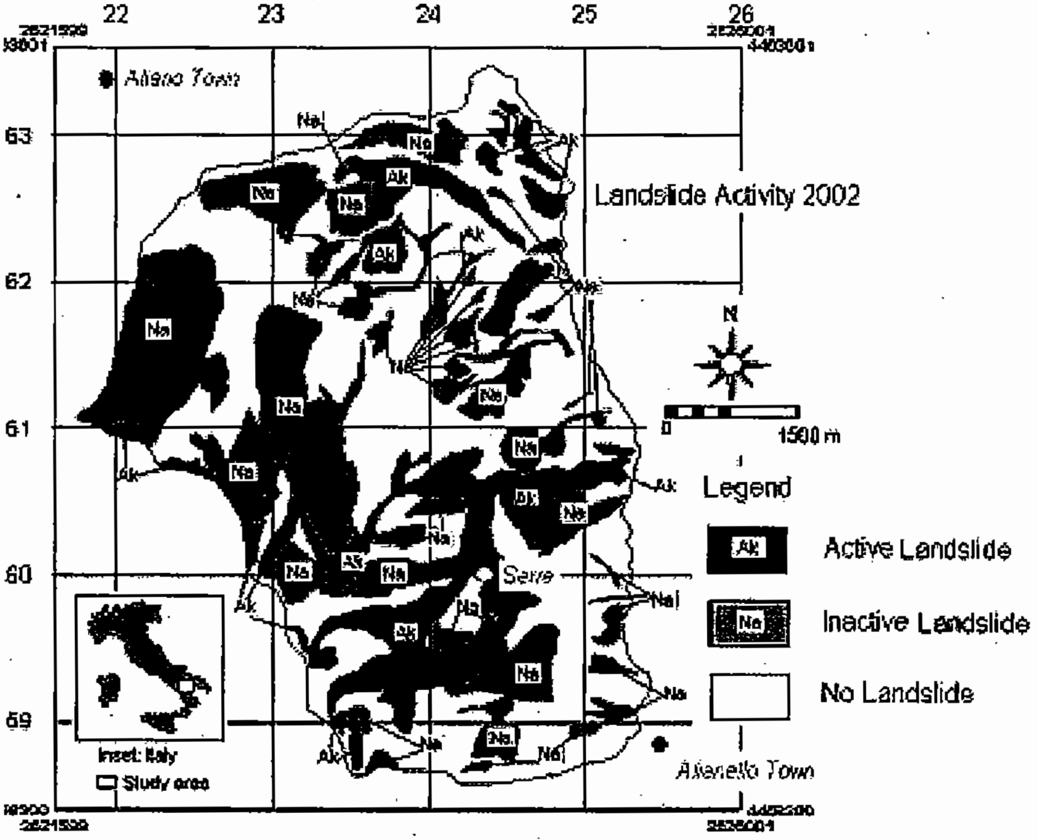

Figure 10. Attribute Map of Landslide Activity 2002

Qualitative analysis of the multitemporal evidence based on the landslide activities 1976 and 2002 has been done in order to generate the expected hazard on the existing landslide. Comparison of the landslide-polygons has been done in GIS operation and level of hazard has been determined as well. Polygons of the active landslide in 1976 and still active or reactive in 2002 are determined as high hazard area. Polygons of the active landslide in 1976 and no longer active or dormant in 2002 as well as polygons of the inactive landslide in 1976 but become active in 2002 are pointed as moderate hazard area. Meanwhile the low hazard area is the landslide area where in 1976 is inactive as well as in 2002. Fig. 11 shows the expected hazard on the existing landslide in the study area.

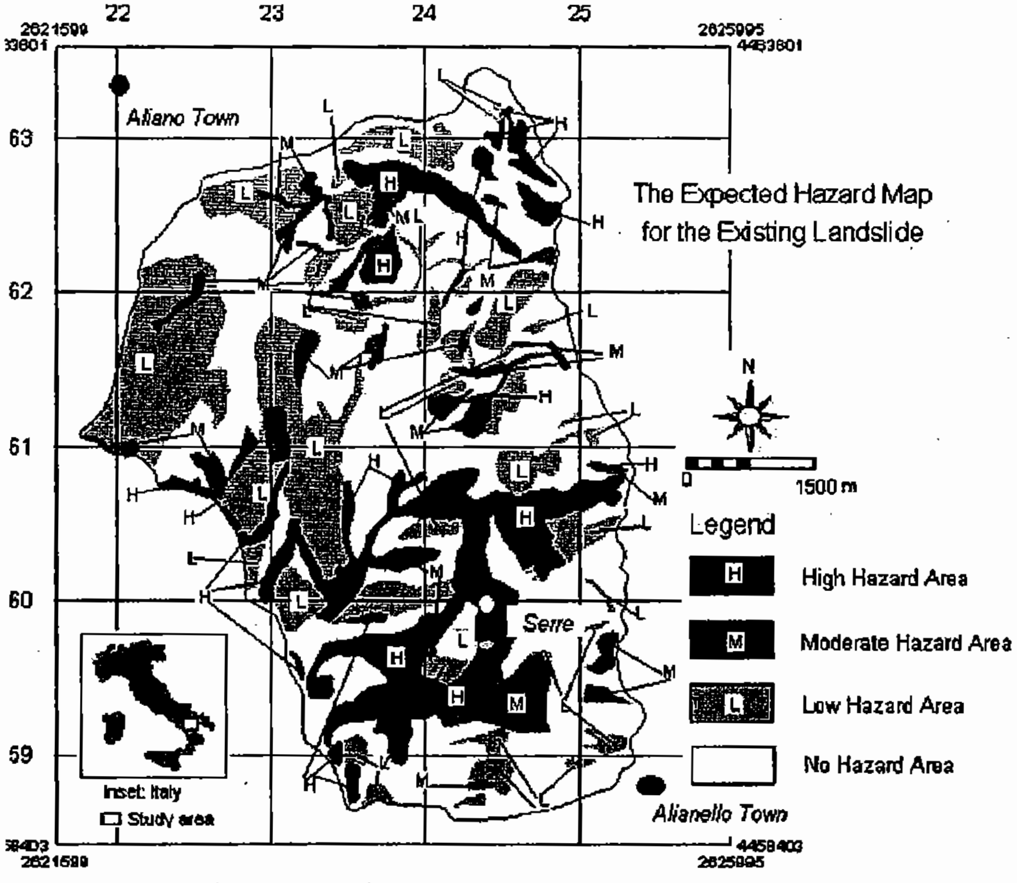

Figure 11. The expected hazard on the existing landslide in the study area

CONCLUSION AND REMARK

Qualitative analysis using multitemporal evidence can be used in order to generate the expected landslide hazard map. On this study the polygons landslide, where generated trough the aerial photograph interpretation and fieldwork, can be individual observed and examined to get the type of landslide activity. This methodology is most direct way for landslide hazard assessment.

Types of landslide on the study area are rockfalls, spread, slide, flow and complex landslide. The last one is the biggest type on the study area. Complex landslide and rockfall are the most active-landslide which appear in 1976 and 2002. Spatially can be analyzed that the active landslide in 1976 mostly situated on the middle part and several in north-east part of the study area. These active landslides were still active in 2002 and even inactive landslide in 1976 becomes reactive in 2002. Therefore in the middle and in the north-east part of the study area determined as high and moderate hazard area.

Map as a static model is always an attempt to forecast reality. However, reality is too complex to be completely modeled especially when dealing with mass wasting process in which regional, local and site conditions have influence. In this study, the maps were derived from aerial photo interpretation and field check. Therefore contain a numbers of uncertainty, which can be also augmented by the different scale of analysis, time, and area to be evaluated.

Although a qualitative analysis by comparison of the landslide-polygons in two or more different times is the most direct way for hazard assessment due to its present and past landslide display, this methodology is applicable just for those areas where landslides have already happened or are acting in the present, but they do not provide information for areas surrounding them or landslide-free.

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