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# A GIS-BASED ASSESSMENT OF LANDSLIDING IN THE DAUNIA APENNINES, SOUTHERN ITALY

Stefania MOSSA[1], Domenico CAPOLONGO[1], Luigi PENNETTA[1], Janusz WASOWSKI[2]

**Abstract**. We have used a Geographic Information System (GIS) tool to examine the spatial patterns and factors of slope instability in the northwestern part of the Apulia Region (Southern Italy). The area studied belongs to the Daunia Apennines, covers 132 km$^2$, and includes several small municipalities. For the analysis, we have first compiled a geomorphologic landslide inventory map obtained through the systematic interpretation of aerial photographs. Then, a detailed Digital Elevation Model (DEM) was generated from 1:5,000 scale topographic maps. The controls of geology and other variables on slope stability were approximated via landslide frequency statistics.

The main findings of the study can be summarised as follows:

1. The landslide frequency is very high (about 29.5% of the overall area); this confirms the high susceptibility of the area to slope failure.

2. The translational slides predominate (54%, in terms of area frequency), followed by complex failures, i.e. slides evolving into earth flows (35.5%), and earth flows (10.5%).

3. The Early Miocene chaotic, scaly clay-shales are most prone to landsliding, followed by the Middle Miocene limestone–marlstone–mudstone succession, and the Pliocene–Pleistocene clays and sands.

4. The landslide frequency is the highest in 10–15° slope class, followed by 5–10° and 15–20° slope classes. This indicates a very low (≈ residual) strength of the geological materials and is consistent with the fact that most failures represent reactivations of pre-existing landslides.

5. The landslide frequency is the lowest on slopes exposed toward the south, which suggests a possible influence of solar radiation.

6. The landslide distribution is closely linked to the local drainage systems. This implies that drainage improvement works should represent a cost-effective effort of the landslide hazard reduction.

We have also quantified the landslides impact on the road network in the study area, keeping in mind the slope inclinations. The results proved that the road density was highest on slopes ranging from 5 to 15°, and that within these classes about 14% of the road network was affected by landslides (both active and inactive).

**Key words**: landslide distribution, area frequency statistics, landslide susceptibility factors, GIS, Daunia, Italy.

**Abstrakt**. Do badania układu przestrzennego oraz czynników niestabilności zboczy w północno-zachodniej części regionu Apulii (południowe Włochy) wykorzystano system informacji geograficznej (GIS). Badany obszar należy do Apeninów Daunia, ma powierzchnię 132 km$^2$ i obejmuje kilka niedużych miejscowości. W trakcie badań zestawiono przede wszystkim zbiorczą geomorfologiczną mapę osuwisk, na podstawie systematycznej interpretacji fotografii lotniczych. Następnie opracowano cyfrowy model wysokościowy na podstawie map topograficznych w skali 1:5000. Wpływ budowy geologicznej oraz innych czynników na stabilność zboczy oszacowano na podstawie statystyki częstotliwości występowania osuwisk.

Omawiane badania dały następujące wyniki:

1. Częstotliwość występowania osuwisk jest bardzo wysoka: obejmuje około 29,5% badanej powierzchni, co potwierdza wielką podatność zboczy na tego typu zniszczenia.

[1] Dipartimento di Geologia e Geofisica Università degli Studi di Bari, Campo Universitano, 70126 Bari, Italy; e-mails: capolongo@geo.uniba.it, epennetta@geo.uniba.it
[2] CNR-IRPI, Via Amendola 122I, 70126 Bari, Italy; e-mail: j.wasowski@ba.irpi.cnr.it

2. Dominują ślizgi przesuwcze (54% częstotliwości), a następnie bardziej kompleksowe odkształcenia, tzn. zsuwy przechodzące w spływy ziemne (35,5%) oraz spływy ziemne (10,5%).

3. Najbardziej podatne na odkształcenia osuwiskowe są wczesnomioceńskie, nieregularne łupki ilaste, a następnie środkowomioceńskie pakiety wapieni, margli i mułowców oraz plioceńsko-plejstoceńskie iły i piaski.

4. Częstotliwość powstawania osuwisk jest największa na stokach o nachyleniu 10–15°, nieco mniejsza na zboczach o nachyleniu 5–10° i na końcu — 15–20°. Wskazuje to na bardzo niską (szczątkową) wytrzymałość materiału geologicznego, co potwierdza fakt, iż większość odkształceń stanowi odnowienie wcześniejszych osuwisk.

5. Częstotliwość osuwisk jest najmniejsza na zboczach o ekspozycji południowej, co sugeruje pozytywny wpływ napromieniowywania słonecznego.

6. Rozmieszczenie osuwisk jest również ściśle powiązane z lokalnymi systemami drenażowymi. Wskazuje to na możliwość stosunkowo taniego zmniejszenia zagrożenia osuwiskami poprzez poprawę systemów drenażowych.

Oceniono również wpływ osuwisk na sieć dróg na badanym terenie, z uwzględnieniem nachylenia stoków. Wyniki badań wskazują, że największe zagęszczenie dróg występuje na stokach o nachyleniu od 5 do 15° i że na omawianym obszarze około 14% dróg było pod wpływem osuwisk, aktywnych obecnie bądź w przeszłości.

**Słowa kluczowe**: rozmieszczenie osuwisk, statystyka obszarowej częstotliwości osuwisk, czynniki podatności na osuwiska, GIS, Daunia, Włochy.

## INTRODUCTION

In this work, we have used Geographic Information System (GIS) to assess landsliding in an area of the Apulia region, Southern Italy (Fig. 1). In particular, GIS was applied in an attempt to identify the lithological and geomorphic variables responsible for the occurrence of slope failures. The area selected for the study covers 132 km$^2$, includes several small municipalities and is considered a representative portion of the Daunia Mountains (Southern Apennines).

Despite the moderate elevation (from 250 to about 1000 m) and relatively modest amount of total annual precipitation (about 700 mm; Servizio Idrografico Italiano, 1921/1990), the Daunia Mts. are known for their susceptibility to landsliding (e.g. Cotecchia, 1963). Rainfall events and unwise man activity represent the main triggering/causative factors.

There were, however, rather few published papers on the landslides causes in Daunia. Furthermore, most of them were focused on the local and of the limited area, slope stability problems (e.g. Iovine *et al*., 1996; Parise, Wasowski, 2000, 2002). The paper of Zezza *et al*. (1994) was the only one, which provided a preliminary regional scale inventory of landslide activity. Although the distribution of landslides was not quantified, they appeared widespread throughout the entire region.

The following reasons motivated our work:

1. During the last years, there has been an apparent increase in landslide activity in several municipal territories of the Daunia Mts., as indicated by the recent inspections conducted by one of the co-authors (JW) on behalf of the Italian Civil Protection Department.
2. The local roads network in Daunia appeared to be particularly vulnerable (Fig. 1), and each year landslide activity causes there considerable economic damage.
3. To our knowledge, this study represents a first conducted on larger scale attempt of a GIS-based assessment of the landsliding in Daunia.

Throughout this paper, we use the landslide terminology of Cruden and Varnes (1996). The presented GIS analysis follows the approaches used by other workers for landslide hazard evaluation (e.g. Carrara *et al*., 1991; Soeters, Van Westen, 1996). Our main objective was to provide quantitative insights on the spatial distribution of the landslides and their causes.

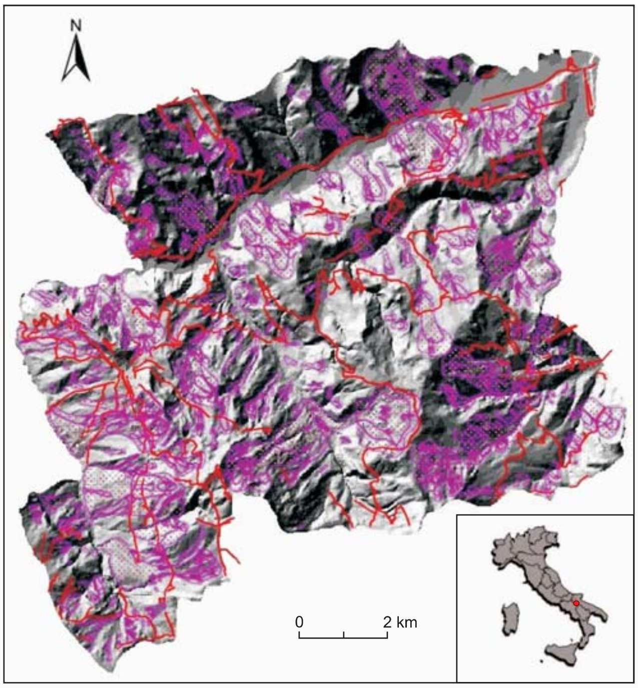


**Fig. 1. Landslides distribution (in violet) and roads network (red) superimposed over a shaded digital elevation model (DEM)**

An inset shows Italy and the location of the study area in the Apulia region

## LANDSLIDES ANALYSES

### GIS DATABASE

To carry the analyses of the landslides distribution, the following data sets were included into the digital spatial database:

1. Contour information from 1:5,000 topographic maps was used to generate a digital elevation model (DEM) of the study area. The TOPOGRID routine of the ARC/INFO was applied to process the topographic data. Taking into account the scale of the original input data, the 5×5 m grid spacing was selected.
2. The lithological information obtained from literature (Dazzaro *et al.*, 1988 and references therein) was integrated with the authors' field data and converted into a digital format.
3. The locations and types of landslides were obtained through the systematic interpretation of two sets of black and white aerial photographs, taken at a scale of 1:33,000 in 1954 and in 1990–1991. Two geomorphologists compiled the landslide inventory to guarantee cross check of the photographs' interpretation and thus obtain results that are more reliable. The positions of many slope failures were also checked in the field.

The final products of the GIS operations used in the subsequent analyses were the DEM of the study area, landslide inventory and lithological maps (Figs. 1, 2).

### LANDSLIDES CHARACTERISTICS

The landslide inventory map (Fig. 1) clearly shows that a significant portion of the study area is affected by slope failures. Using a GIS tool, the data could be readily quantified and provided in terms of the area frequency statistics (Table 1).

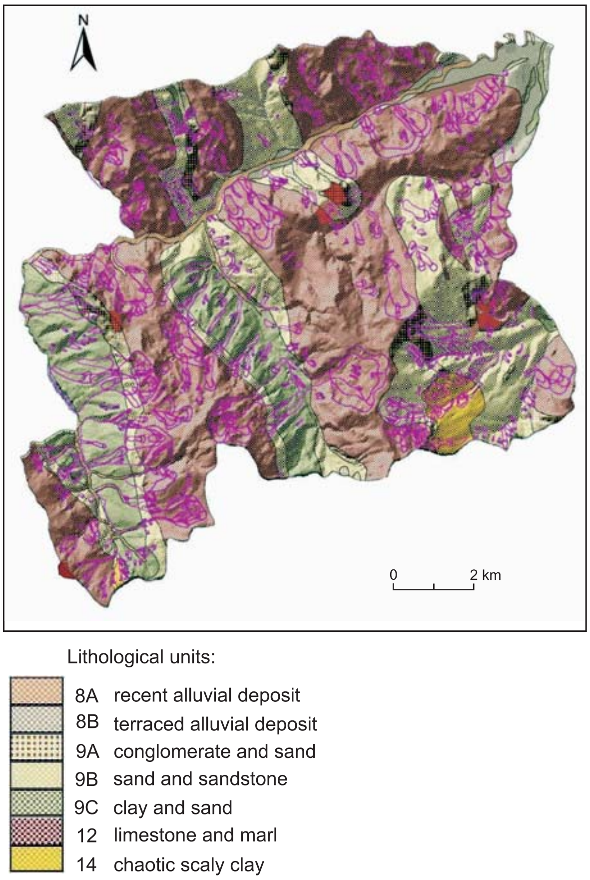


**Fig. 2. Simplified lithological map with superimposed landslide inventory, lapped over a shaded digital elevation model (DEM)**

Table 1

**Type, state of activity and extent of landslides area from 1954 and 1990–1991 aerial photos**

| | Landslides | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | active | | dormant | | old | | total | |
| | km$^2$ | %$^{(*)}$ | km$^2$ | %$^{(*)}$ | km$^2$ | %$^{(*)}$ | km$^2$ | %$^{(*)}$ |
| Landslides detected in 1954 aerial photos | | | | | | | | |
| Earth flows | 0.74 | 0.56 | 3.36 | 2.54 | 0.00 | 0.00 | 4.10 | 3.11 |
| Earth slides | 0.10 | 0.07 | 11.20 | 8.48 | 9.70 | 7.35 | 21.00 | 15.91 |
| Earth slide–earth flows | 0.09 | 0.07 | 7.58 | 5.74 | 6.33 | 4.79 | 14.00 | 10.61 |
| Total | 0.93 | 0.70 | 22.14 | 16.77 | 16.03 | 12.14 | 39.00 | 29.63 |
| Additional landslides detected in 1990–1991 aerial photos | | | | | | | | |
| Earth flows | 0.22 | 0.16 | 0.34 | 0.26 | 0.00 | 0.00 | 0.56 | 0.42 |
| Earth slides | 0.01 | 0.01 | 0.19 | 0.14 | 0.00 | 0.00 | 0.20 | 0.15 |
| Earth slide–earth flows | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Total | 0.23 | 0.17 | 0.53 | 0.40 | 0.00 | 0.00 | 0.76 | 0.57 |

(*) Percentages are referred to the extension of the test area (132 km$^2$); landslide terminology follows that of Cruden and Varnes (1996)

This way of presenting data is useful for comparisons with other areas affected by landsliding. The results show that landslides occupy nearly 30% of the study area (39/132 $km^2$), which demonstrates its very high susceptibility to slope failure. Table 1 contains also information on the frequency of the main types of landslides in the area, and state of their activity. In particular, the earth slides were a predominant type of movement, followed by "complex" earth slides — earth flows and by earth flows. The complex landslides involved two types of movement: rotational slides (slumps) that evolved to flows.

Finally, Table 1 indicates the state of the landslides activity distinguished on air photos on the base of freshness degree of the geomorphic features associated with the slopes failures (cf. Wieczorek *et al.*, 1984; WP/WPLI, 1993). The earth slides generally seem to be old and dormant, while earth flows appear to be more active. Air photo interpretation and field inspections indicated that in many cases the old and dormant slide category was represented by rather large and deep slope failures.

## LANDSLIDES AREA FREQUENCY STATISTICS OF LITHOLOGY

The geological units cropping out in the area include (Dazzaro *et al.*, 1988): recent and old (terraced) alluvial deposits; locally cemented marine gravels and sands (Pliocene–Pleistocene); marine clays with interbeds of gravels and sands (Pleistocene); limestone–marlstone–mudstone successions of the di Faeto Flysch Formation (Middle Miocene); and chaotic, scaly clay-shales of the Argille Varicolori Formation (Early Miocene). The pre-Pliocene units' chain is arranged in thrust sheets and is highly deformed.

For the purpose of this study, the geological units were divided into the following seven lithological categories (Fig. 2): recent alluvial deposits, terraced alluvial deposits, conglomerate and sand, sand and sandstone, clay and sand, limestone and marl and chaotic scaly clay. It is assumed that these categories are characterised by more or less distinctive geotechnical parameters.

Figure 2 illustrates that there is certain relationship between landslide distribution and the lithological units. Again, the map data can be readily quantified and provided in terms of area frequency statistics. As shown on Figure 3, the chaotic scaly clay-shales are most prone to the landsliding, followed by the limestone-marlstone category, and the clays and sands. Alluvial deposits are the least affected by slope failures, but this is likely caused by generally very low slope inclinations in the areas covered by alluvia.

## LANDSLIDES AREA FREQUENCY STATISTICS FOR SLOPE ANGLE AND SLOPE FACTOR

In order to examine further factors of the slope instability, we have investigated the influence of slope angle and slope characteristics on landslides distribution. The slope angle and characteristics data were obtained from the 5 m per 5 m DEM. In an attempt to make the results more meaningful, we have distinguished the overall (total) landslides area and the relevant source area. The slope of each landslide source was approximated by an average slope of the pixels occupying the main scarp-crown area, or by an average slope of the pixels falling within the upper one third (topographically) of the overall landslide area. The latter solution was used in the cases where the main scarp areas were difficult to determine.

Figure 4 demonstrates that landslides frequency is highest in the 10–15° slopes class, followed by 5–10° and 15–20° slopes classes. This suggests a generally very low (≈ residual)

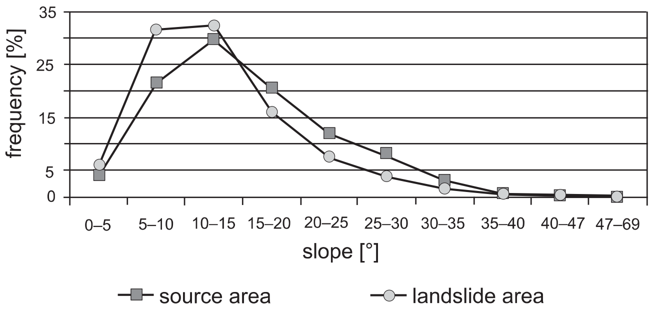


**Fig. 4. Area frequency of landslides source area (red curve) and landslides total area (violet curve) for slopes angle**

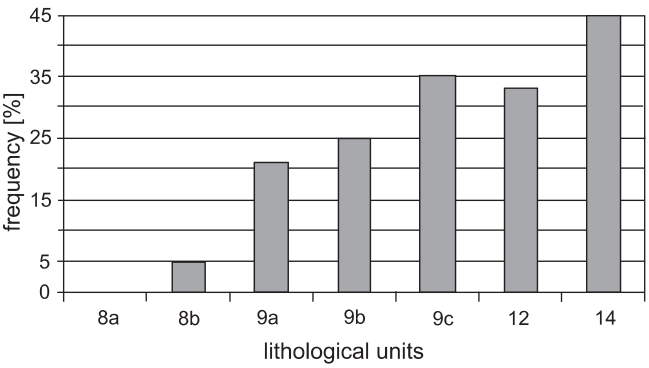


**Fig. 3. Area frequency statistics of landsliding for different lithological units**

For explanations of lithological units see Figure 2

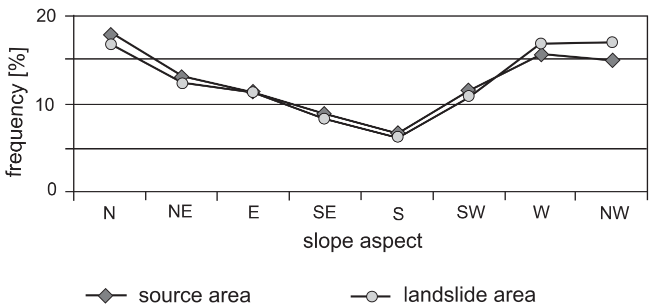


**Fig. 5. Area frequency statistics for landslides distribution (source area and total area) caused by slope factor**

strength of the geological materials and is consistent with the fact that most failures represent reactivations of the pre-existing landslides. As expected, the total landslides area frequencies were higher than source areas for lower slopes inclinations were. The opposite trend was observed for slopes exceeding 15°.

Slopes factor represents another geomorphic attribute of interest in landslides hazard assessments (e.g. Carrara *et al.*, 1991). Indeed, Figure 5 demonstrates that the landslides frequency is the lowest on slopes exposed toward the south. Intuitively, this suggests a possible role of the solar radiation, i.e. slopes with longer exposure to the sun heat should be characterised by higher evaporation values and hence decreased surface water input. However, some other factors can also be important and need to be further examined (e.g. predominant structure pattern, land use, etc.).

## LANDSLIDE DISTRIBUTION AND SURFACE DRAINAGE

The area photo interpretation indicated that landslides and local watercourses tended to show a close spatial relation. In addition, field inspections proved that slope failures indeed appeared abundant in the areas of concentrated surface drainage. To investigate further this problem, we have first reconstructed the pattern of local drainage for the entire study area. Then, this information layer and the landslide inventory data were superimposed together on the DEM (Fig. 6). This data visualisation demonstrated rather clearly that landsliding and surface drainage were intimately linked. However, some quantitative analyses are warranted to provide information that would be more objective.

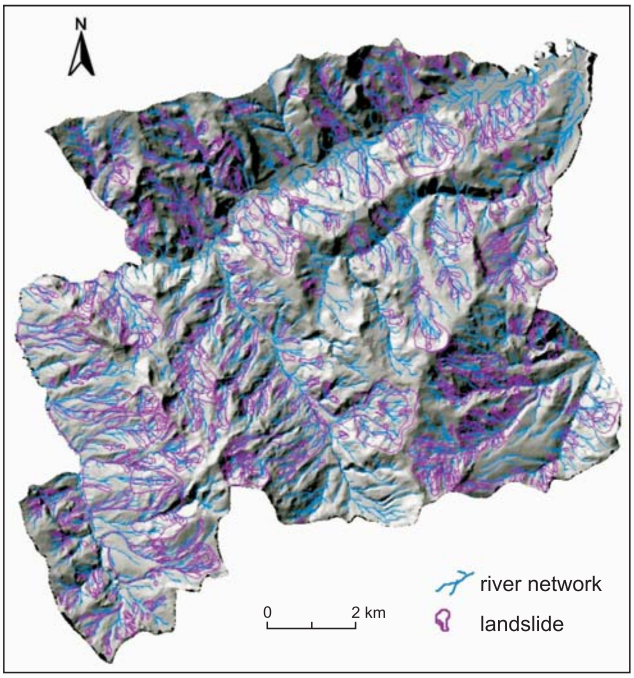


**Fig. 6. Landslides distribution and watercourse network data superimposed on a shaded digital elevation model**

## LANDSLIDES IMPACT ON THE ROAD NETWORK

Although a great majority of landslides in Daunia are characterised by very low velocities, their frequent occurrence produces considerable socio-economic loss. In particular, each year slopes failures cause significant damage to the local road network. In an attempt to quantify the severity of the problem, we have compiled the data on the total area covered by roads (in $m^2$), and on the extent to which roads have been affected by landslides. In this preliminary investigation no distinction was made between different types of roads, but we simply have estimated the area (polygonal) covered by each road, assuming that each road was 10 m wide.

We have measured a road area affected by landsliding by considering separately the landslide source areas and total landslide areas. Given the influence of slopes inclinations on the landslides distribution, the data presented in Figure 7 were plotted against slopes (degrees). The results show that most roads occupy slopes that range from 5 to 15°. Out of these roads, about 1/7 part of the investigated area (100,000 $m^2$) has been or is affected by landslides, if the total landslides areas are considered. For the source areas alone, the number drops to 50,000 $m^2$.

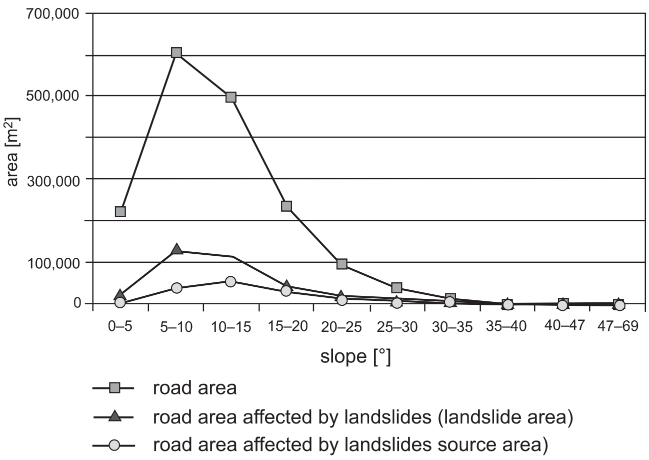


**Fig. 7. Extent of roads area affected by landslides source areas (circles) and by landslides total areas (triangles), versus slopes angle. Total extent of roads area versus slopes angle (squares) is also shown**

## CONCLUSIONS

The data stored digitally in a GIS demonstrate clearly a very high landslides frequency in the Daunia study area. Indeed, old and recent slope failures have affected about 29.5% of the overall area. This percentage is strikingly similar to that of some portions of the Polish Flysch Carpathians, and in particular of Beskid Niski (e.g. Poprawa, Raczkowski, 2003; Mrozek *et al*., 2004). The exact reasons for this are not known, but the apparent similarities in the lithological setting (clay rich flysch sequences), relative relief (moderate slopes) and land use (mainly agricultural), as well as comparable total annual rainfall, are perhaps important there. It may also be possible that such high area frequencies are simply close to the maximum extent of landsliding that can occur (and be preserved) in the similar settings of the slopes.

The GIS-based assessment of slope failures provided also some practical indications for landslides hazard reduction. In particular, we demonstrated which lithology and hill slopes settings (slopes inclination/aspect) are most prone to failure. Furthermore, it was shown that landslides distribution was closely linked to the local drainage systems. This implied that drainage improvement works should become a cost-effective effort of landslides prevention and damages repair.

We have also used GIS to quantify the landslides impact on the road network. The results showed that the roads density was the highest on slopes ranging from 5 to 15°, and that within these classes about 14% of the road network was affected by landslides (both active and inactive).

Finally, it should also be noted that GIS is a convenient tool for breaking down the landslides assessments to a single municipality level. The comparative analyses of landslides area frequency statistics represent a rather simple way of quantifying the slopes failure impact on each municipality, and thereby offer an objective input for a rational allocation of landslides mitigation funds by regional or national authorities.

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