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Hydrogeological hazards and weather events: Triggering and evolution of shallow landslides

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Abstract

Landslides are the most intense and serious manifestations of the degradation of slopes and they are the main causes of geological hazard when they, directly or indirectly, involving towns and infrastructures.

They are a global environment problem; there are several examples that have produced untold damages and loss of human lives in many parts of the world. In 1920 the landslides mobilization, as a result of a strong earthquake in China, in the province of Kansu, killed 200,000 people; in 1938 fast debris flow, triggered by heavy rainfalls in Japan, caused the death of 600 people; in 1963 in Italy the Vajont disaster caused the death of 1,899 people, as a result of a landslide localized in the underlying artificial storage. During the last years there have been many tragedies linked to intense rainfall events which have sparked many shallow landslides: 1996 in Garfagnana, 1998 in Sarno, 2009 in the Ionic side of Messina, 2011 in Liguria. To throw light on this problem, over the past decades, the assessment and mitigation of landslides hazard and the danger related to it, have become goals of paramount importance in territorial planning and, more generally, in its management and with it the safeguard of the historical and cultural heritage within it. The occurrence of events which are considered exceptional thus implies a re-reading in terms of spatial planning to renovate the slopes and river-beds, as well as urban planning, infrastructural and socio-economic organization.

The complex nature of these instability events that affect anthropized areas does not allow specific approaches for the defence of single good, but it finds a more effective solution based on the extensive knowledge of territory, perhaps at the scale of individual or several watersheds.

Key Words: Geo-environmental hazard, Hydrogeological instability, Urban planning

1 Introduction

Most hydrogeological instability phenomena have a recurrent nature: they have already occurred in the past, in the same sites, often with equal or higher intensity. Landslides are a case in point. Predicting landslide hazards requires knowledge of slope lithology, morphology and hydrogeology, as well as a retrospective analysis of prior slope movements and their scale in the investigated area. Moreover, identifying landslide hazards supposes static conditions at a given point in time. Thus, landslide risk assessment should not only define the levels of hazard and vulnerability of a given site, but also and above all anticipate their evolution throughout time, since the extent of geo-environmental risks cannot be projected indefinitely over time.

Risk conditions arising from landslides are directly correlated with their types and rates of evolution. From this standpoint, slope movements may be distinguished into moderately- to slow-moving landslides and fast-moving mud and debris flows.

The latter may be triggered by heavy rainfall, e.g. storms. One of these events recently involved the Ionian side of the Messina area. The disaster occurred in an area at high hydrogeological risk that had already been hit by landslides and floods in 2007. In particular, the origin and effects of the mud and debris flows were similar to those that ravaged the Sarno area in Campania in 1998 (De Vita, 2000; Gullà and Antronico, 2003). Under the

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classification commonly used in the international literature, these gravitational movements are defined as mud flows or debris flows, depending on whether their dominant fraction is fine or coarse (Varnes, 1978). As the definition of mud flows and debris flows often applies to mass transport along streambeds during high-water episodes, these phenomena may be specified as soil slips-mud flows and soil slips-debris flows, depending on their mechanism of initiation (Campbell, 1975; Ellen and Fleming, 1987). In both cases, these translational slides are extremely fast and triggered by very intense rainfall, when slopes reach critical rupture conditions and abruptly collapse.

These movements produce a huge amount of sediment, as well as linear erosion along ephemeral streams and first-order stream channels. As a result, measures should be taken to mitigate slope movements and minimise the erosional capability of channelled waters. Soil bioengineering may address both of these requirements, with functional and ecological advantages: live plant materials have a high anti-erosion potential, increase the shear strength of soil and are environment-friendly in the most diverse settings.

2 Gravitational movements and precipitation events

Intense and protracted precipitation often causes slope movements. The types and kinematics of rainfall-triggered landslides are different, depending on climate and geo-mechanical properties of soils in the sites involved. Climate factors, e.g. rainfall and temperature, affect the hydraulic and mechanical properties of outcropping soils, as well as the water budget of the local hydrographic network, with an impact on subsurface water filtration along slopes. Changes in these conditions in the short-medium term may activate shallow to averagely deep landslides.

From the viewpoint of the rainfall pattern in a given area, scenarios that typically trigger slope instabilities may be summarised as follows (Clarizia et al., 1996):

1) short spells of rain, i.e. very intense bursts preceded by significant cumulated rainfall;
2) short spells of rain, i.e. very intense bursts preceded by moderate cumulated rainfall;
3) hydrological years with high values of total rainfall, preceded by significant rainfall cumulated over multiple years;
4) hydrological years with high values of total rainfall, preceded by moderate rainfall cumulated over multiple years.

On the first assumption, diffuse shallow slope instabilities are very likely. Indeed, one of the most common and, at times, tragic consequences of extreme weather events is the activation of numerous shallow landslides (almost all of small scale) in eluvial-colluvial covers (De Luca et al., 1996; Johnson and Sitar, 1990). On the second assumption, shallow slope instabilities are usually isolated. In the latter two cases, deep to averagely deep slope instabilities may take place (Terranova and Gullà, 2002).

Soil lithology, dip and strike often make slopes prone to instability. Sometimes, extreme weather events are not the only triggers of slope instabilities but add to anthropogenic factors. All too often, lack of knowledge of geological and geomorphological issues has caused the evolution of precarious slope stabilities into overt slope instabilities. Identifying the geomorphological features of landslide bodies and interpreting them in terms of shallow deformations are very useful elements to gain insight into their types and possible evolution in space and time.

Based on the volume of their mobilised material, their kinematics and hazard level, instabilities may be distinguished into three categories, each with distinctive features: large-scale landslides, averagely deep instabilities and instabilities of regolith covers. The following is a description of the mechanisms of evolution of each category and of their causal factors, especially for shallow slope instabilities, whose unique features make them particularly insidious and hazardous in economic and social terms.

2.1 *Large-scale landslides*

The geomorphology of slopes affected by deep landslides, known in the literature as Deep-Seated Gravitational Slope Deformations, has been investigated for decades. Their deformation mechanisms reflect the stratigraphic-structural and tectonic conditions favouring their onset, even on otherwise stable slopes. Thorough debates have led to define these landslides as the deformation of a mass not necessarily implying a well-defined deformation surface (Dramis and Sorriso-Valvo, 1994). Scale factors, which induce changes in the mechanical properties of the material, may have an impact on the deformation mechanism (Sorriso-Valvo and Tansi, 1996).