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Slope Processes, Mass Movement and Soil Erosion: A Review

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ABSTRACT

Soil erosion and land degradation are global problems and pose major issues in many countries. Both soil erosion and mass movement are two forms of land degradation and humans play important roles in these geomorphological processes. This paper reviews slope processes associated with mass movement and soil erosion and contributory factors, including physical and human agents. Acting together, these cause diverse geomorphological features. Slope processes are illustrated by reference to case studies from Brazil and UK. The causes and impacts of erosion are discussed, along with appropriate remedial bioengineering methods and the potential of the measures to prevent these types of environmental degradation. Although there are several agents of erosion, water is the most important one. Cultivation can promote soil erosion, due to ploughing and harvesting, which moves soil down slopes. Soil erosion and mass movement data would inform the viability of soil conservation practices. Integrated management of drainage basins offers a promising way forward for effective soil conservation and soil remedial bioengineering in Brazil and UK.

Key Words: geomorphological feature, land degradation, hazards, risks, slope processes, soil recuperation

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INTRODUCTION

The dominant hillslope processes are associated with gravity and running water. Human activities play important roles in hillslope processes, due to land use changes and vegetation clearance, both in rural and urban areas. These processes can be accentuated by climate changes (Varnes, 1978; Trudgill, 1988; Selby, 1993; Goudie, 1995; Cendrero and Dramis, 1996; Cruden and Varnes, 1996; Goudie and Viles, 1997; Favis-Mortlock and Guerra, 1999; Fullen, 2003; Fullen and Catt, 2004; Crozier and Glade, 2005; Van Westen *et al.*, 2008; Kanungo and Sharma, 2014; Shafiq *et al.*, 2014; Arbuckle *et al.*, 2015; Agnihotri and Kumar, 2015). The causes and consequences of both sets of processes and the importance of monitoring these processes have been studied, in order to understand how they occur and can be prevented (Thomas and Allison, 1993; Ellis and Mellor, 1995; Lascelles *et al.*, 2000; Valentin *et al.*, 2005; Bochet *et al.*, 2006; Kitutu *et al.*, 2009; Nadal-Romero *et al.*, 2014; Vanmaercke *et al.*, 2016). In addition, once they do occur, we consider potential recuperation technologies (Fullen *et al.*, 1995; Subedi *et al.*, 2009; Bhattacharyya *et al.*, 2010, 2011; De Baets *et al.*, 2011; Fullen *et al.*, 2011; Subedi *et al.*, 2012; Dhital *et al.*, 2013; Fullen and Catt, 2014; Guerra *et al.*, 2015).

Proactive management of vegetation systems are essential for effective recuperation (Trudgill, 1988; Tiffen *et al.*, 1994; De Baets *et al.*, 2011; Fullen *et al.*, 2011; Bhattacharyya *et al.*, 2012; Dhital *et al.*, 2013; Fullen and Catt, 2004; Guerra *et al.*, 2015). Accelerated erosion is one of the greatest problems of land degradation because it seriously depletes fertile topsoil. The removal of original vegetation for agricultural purposes is one of the main factors causing soil erosion. The general forms of soil erosion by water include sheet, rill and gully erosion.

Geomorphic activity is usually a critical determinant of damage. Each of the two geomorphic processes has specific causal factors, such as vegetation clearance, rainfall intensity, rainfall volume, slope angle, soil properties, land use and land management, which affect soil erosion and mass movement, both in urban

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and rural areas. Depending on the frequency and magnitude of each one of these factors, catastrophic landslides might occur.

The role of mass movement and associated geomorphological processes have been studied, along with the diagnostic parameters to recognize different types of mass movement in the field (Varnes, 1978; Brunsden, 1988; Goudie and Viles, 1997; Crozier and Glade, 2005; Morgan, 2005; Lin *et al.*, 2006; Van Westen *et al.*, 2008; Van Den Eeckhaut *et al.*, 2010; Clague and Robert, 2012; Guzzetti *et al.*, 2012; Kanungo and Sharma, 2014), especially in Brazilian and British (Selby, 1993; Goudie and Viles, 1997; Fullen and Catt, 2004; Coelho Netto *et al.*, 2007; Guerra *et al.*, 2007; Graeff *et al.*, 2012; Petrucci *et al.*, 2013; Guerra and Jorge, 2014).

Selby (1993) outlined that mass movement (or mass wasting) is the movement of soil and/or rock downslope, under the influence of gravity, being a collective material movement, without necessarily being influenced by water or ice. Nevertheless, water or ice may decrease the shear strength of slopes, and thus soils physically behave as plastics or, in very moist conditions, as fluids (Abrahams, 1986; Brunsden, 1988; Selby, 1993; Goudie and Viles, 1997; Clague and Robert, 2012; Kanungo and Sharma, 2014; Guerra and Jorge, 2014). This might, consequently, make mass movement even more catastrophic, causing destruction and even mortalities.

Soil erosion and land degradation are global problems and pose major issues in many countries, including Brazil. The hazards affect both urban and rural areas within the extensive national territory (8 547 403 km^2). In turn, these problems have serious environmental and socio-economic impacts (Guerra *et al.*, 2014). It is important that soils be conserved, for present and future generations. Although erosion is a natural phenomenon, often human activities accelerate erosion processes. Erosion may occur naturally, due to slope angle and rainfall. Some surveys exemplify this, often based on stratigraphical and archaeological evidence within valley floor deposits. For instance, natural soil erosion has been reconstructed in North Germany from the early Holocene, when soil developed under natural woodlands, up to the early Middle Ages, when erosion rates were still very low (Bork, 1989). Furthermore, Dotterweich (2009) and Dreibrodt *et al.* (2010) have discussed soil erosion during the Holocene. During the Neolithic (about 7 500 years BP), many areas of central European soil have been washed downslope by soil erosion and gullies have incised, leading to the development of colluvial and alluvial deposits (Dotterweich, 2009). Soil erosion on US agricultural soils causes the loss of an average of 30 t ha^{-1} $year^{-1}$, some eight times greater than rates of soil formation. A survey by Brazilian Agricultural Research Corporation (EMBRAPA) suggested the situation in Brazil is often worse, reaching 60 t ha^{-1} $year^{-1}$ in southeastern Brazil (Manzatto *et al.*, 2002). According to Goudie and Boardman (2010), it is quite clear that the major areas of intense erosion are associated with both human and natural factors. Boardman (2006) suggested the following countries/regions are global erosion hotspots: the Loess Plateau of China, Ethiopia, Swaziland, Lesotho, the Andes, South and East Asia, the Mediterranean basin, Iceland, Madagascar, the Himalayas, the Sahel of West Africa, the Caribbean and Central America. We propose Brazil is also an erosion hotspot (da Silva *et al.*, 2005; Gurgel *et al.*, 2013; Guerra *et al.*, 2014; Nacinovic *et al.*, 2014).

Although both soil erosion and mass movement are two forms of land degradation and humans play important roles in these geomorphological processes, they present different modes of occurrence and consequently different ways of being identified and monitored and they also present diverse features (Varnes, 1978; Small and Clark, 1982; Abrahams, 1986; Hart, 1986; Brunsden, 1988; Gerrard, 1992; Evans, 1993; Selby, 1993; Guerra, 1994; Goudie and Viles, 1997; Favis-Mortlock and Guerra, 1999; Fullen and Catt, 2004; Crozier and Glade, 2005; Morgan, 2005; Lin *et al.*, 2006; Shukla *et al.*, 2006; Van Beek *et al.*, 2008; Van Westen *et al.*, 2008; Goudie and Boardman, 2010; de Vente *et al.*, 2011; Boardman and Favis-Mortlock, 2014; Kanungo and Sharma, 2014; Orimoogunje, 2014; Sun *et al.*, 2014; Guerra *et al.*, 2015; Monsieurs *et al.*, 2015; Vanmaercke *et al.*, 2016). Nevertheless, the best way to avoid both forms of land degradation is acting preventively, which means to understand the risks of soil erosion and/or mass movement, in order to avoid them. In this respect, Orimoogunje (2014) stated that conservationism emphasizes the need to guarantee a sustainable supply of productive land resource for future generations. Preservationists seek to protect scenery and ecosystems in a state as little affected by humans as possible.

Climate regimes play an important role in both soil erosion and mass movement processes. With regard to rainfall, over a long period, most erosion occurs during events of moderate frequency and magnitude, because catastrophic events are not so frequent so as to cause a great amount of net erosion. This is a short-term perspective: when high magnitude events occur, soil loss is much higher than during moderate rainfalls;