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Natural and human forcing in recent geomorphic change; case studies in the Rio de la Plata basin

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ABSTRACT

An analysis of geomorphic system's response to change in human and natural drivers in some areas within the Río de la Plata basin is presented. The aim is to determine whether an acceleration of geomorphic processes has taken place in recent years and, if so, to what extent it is due to natural (climate) or human (land-use) drivers. Study areas of different size, socio-economic and geomorphic conditions have been selected: the Río de la Plata estuary and three sub-basins within its watershed. Sediment cores were extracted and dated (^{210}Pb) to determine sedimentation rates since the end of the 19th century. Rates were compared with time series on rainfall as well as human drivers such as population, GDP, livestock load, crop area, energy consumption or cement consumption, all of them related to human capacity to disturb land surface. Data on river discharge were also gathered. Results obtained indicate that sedimentation rates during the last century have remained essentially constant in a remote Andean basin, whereas they show important increases in the other two, particularly one located by the São Paulo metropolitan area. Rates in the estuary are somewhere in between. It appears that there is an intensification of denudation/sedimentation processes within the basin.

Rainfall remained stable or varied very slightly during the period analysed and does not seem to explain increases of sedimentation rates observed. Human drivers, particularly those more directly related to capacity to disturb land surface (GDP, energy or cement consumption) show variations that suggest human forcing is a more likely explanation for the observed change in geomorphic processes. It appears that a marked increase in denudation, of a "technological" nature, is taking place in this basin and leading to an acceleration of sediment supply. This is coherent with similar increases observed in other regions.

1. Introduction

Since the 19th century, many authors have pointed out the growing role of humans in changes experienced by the planet; biosphere, hydrosphere, atmosphere/climate or processes affecting the surface of the lithosphere (Marsh, 1877; Thomas, 1956; Wolman and Schick, 1967; Costa, 1975; Dunne and Leopold, 1978; Goudie, 1993, 1995; WCED, 1987; Turner et al., 1990; Walling, 1996; Rawat et al., 2000; Turner, 2006; Slaymaker, 2000; UNEP, 2005, Naredo and Gutiérrez, 2005; Lu, 2005; IPCC, 2001, 2007; Bakker et al., 2008; Liverman and Roman-Cuesta, 2008; Slaymaker et al., 2009).

The important role played by "technological denudation" as well as human contribution to sediment generation was pointed out by several authors (Brown, 1956; Judson, 1983; Douglas, 1990; Hooke, 1994; Goudie, 1995; Phippen and Wohl, 2003; Gellis et al., 2004; Ruiz-Fernández et al., 2005; Syvitski et al., 2005; Cendrero et al., 2005; Rivas et al., 2006). The latter authors indicate that human mobilisation of rocks and unconsolidated materials could be one or two orders of magnitude greater than denudation/transport by natural processes. Also, that areas disturbed by excavation/accumulation, although relatively small, are significant contributors to sediment generation, perhaps the main one. According to Syvitski et al. (2005), human activities have increased global sediment transport by rivers by 2.3 +/− 0.6 Gt a^{-1} and at the

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same time reduced flux to the oceans by 1.4 Gt a^{-1}, through retention in reservoirs.

The existence of a "geomorphic dimension of global change" was mentioned by Cendrero and Douglas (1996), to refer to the direct and indirect effect of human activities on earth surface processes. Remondo et al. (2005b) suggested a possible "global geomorphic change", initially on the basis of data from northern Spain that showed considerable increases of landslide activity during Holocene–present, not explained by changes in rainfall regimes, but coinciding with expansion of human activity.

A conceptual model was then proposed to express the possible relationship between human activity and geomorphic processes. It considers that a possible explanation of the data obtained could be a cause–effect sequence of relationships such as: drivers (population, technology, and wealth) — pressures on geomorphic systems (increased human activity and intervention on the territory) — impacts (land-use changes, resilience of surface layer, and behaviour of processes) — response of geomorphic systems (increased rates of geomorphic processes, landslides, denudation, and sedimentation). Of course, natural drivers, mainly rainfall, also play a role in geomorphic processes and their changes ought to be considered. Therefore, testing of the model includes assessing possible contributions of climate-related drivers. In this conceptual model drivers (human and natural) can be considered as independent variables, although strictly speaking only population and wealth are really independent (and not completely). Other human drivers and present climate variations depend on the former. The final dependent variable whose changes are being compared to drivers is sedimentation rate (itself dependent on runoff, slope movements, channel flow, all of which are influenced by both human and natural drivers).

The model assumes that human capability to affect land surface is determined by the number of people in a region and their economic and technological capacities. GDP (Gross Domestic Product) is an expression of such capability. Greater capability implies more intervention on, and modification of the surface layer. This could trigger a geomorphic response in the form of increased runoff, slope movements, denudation in general and, consequently, sedimentation. Sedimentation rate increase was indeed found in estuaries of northern Spain, with trends and magnitudes "grosso modo" comparable to those shown by landslides (Cendrero, 2003; Remondo et al., 2005b, Ródenas et al., 2004; Gelen et al., 2004; Pérez-Arlucea et al., 2005; Soto et al., 2006; Soto-Torres et al., 2007; Viguri et al., 2007; Irabien et al., 2008a, b; Cearreta et al., 2008; Bruschi et al., 2008).

Data on the frequency of geomorphic events at other scales (Fig. 1) and in other regions (Munich Re, 2005; Guzzetti and Tonelli, 2004; EM-DAT, 2005) are also consistent with the conceptual model. Disasters labelled by EM-DAT (www.em-dat.net) as "geologic" (earthquakes, tsunamis and volcanic eruptions) show an increase which we think could be more apparent than real and probably due to two factors: a) more complete compilation of data on disaster events in recent times; b) an increase in human exposure (more population and material elements) so that recent events would more likely produce damages and therefore be considered as "disasters". We assume that the increase in these disasters, which has been practically the same as that of GDP during the same period, could be due mainly to the latter factor. Strictly climatic disasters, such as droughts or windstorms, show a greater increase. This could be due to the factors commented as well as the effects of climate change. Finally that in the EM-DAT (www.em-dat.net) graph are named as "floods and related" (floods and wet mass movements) increase much more markedly. Our assumption is that this is probably reflecting the same factors as above plus the effects of geomorphic change.

According to Brierley and Stankoviansky (2003) «whether land-use change or climate change is the main trigger of accelerated erosion-accumulation processes in long term landscape evolution remains uncertain… however…it is clear that…land-use changes

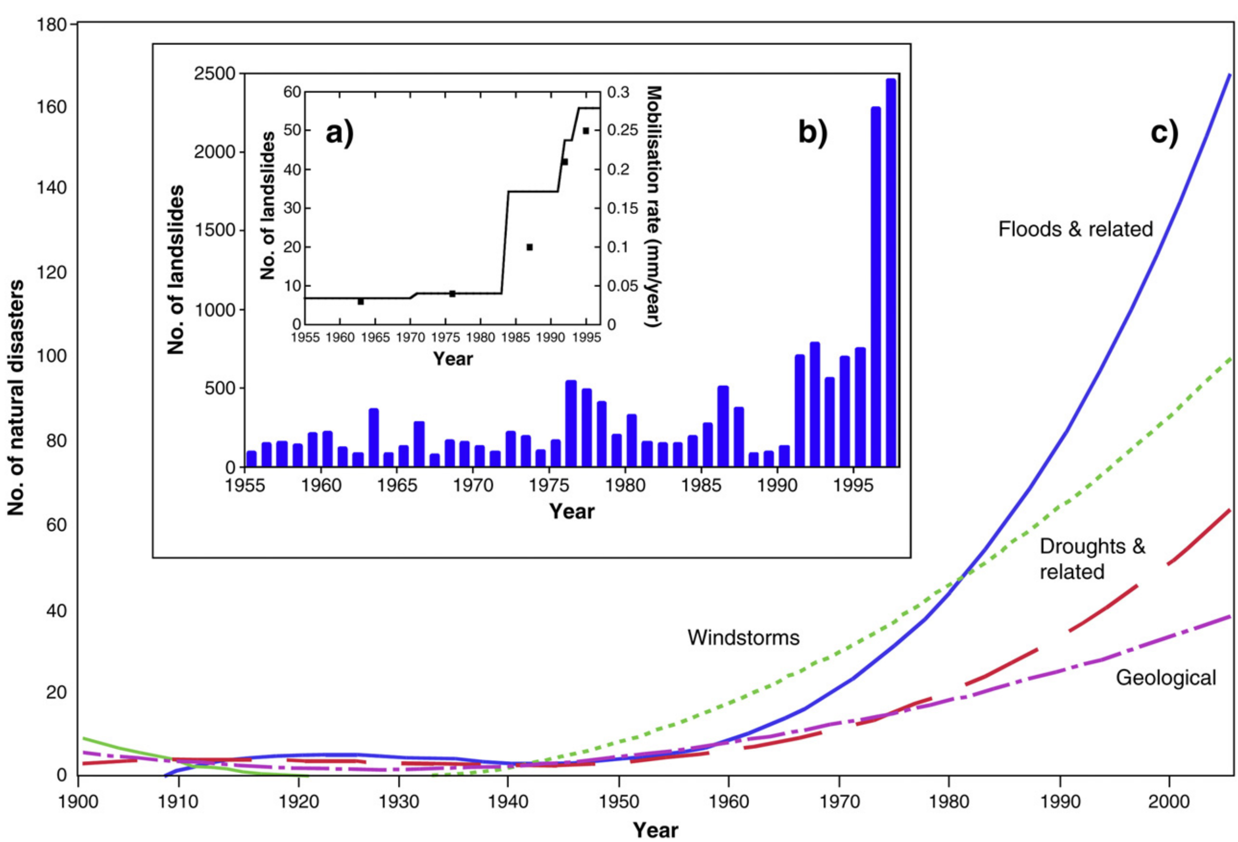

Fig. 1. Landslide frequency in the Deva valley, Spain (a) and in Italy (b). Frequency of natural disasters in the world (c). After Cendrero et al. (2006), with data from Guzzetti and Tonelli (2004), EM-DAT (2005) and Remondo et al. (2003).