Geomorphology 196 (2013) 267–279

Contents lists available at SciVerse ScienceDirect

Geomorphology

journal homepage: www.elsevier.com/locate/geomorph

Analysis of geomorphic systems' response to natural and human drivers in northern Spain: Implications for global geomorphic change

V.M. Bruschi [a,*], J. Bonachea [b], J. Remondo [a], J. Gómez-Arozamena [c], V. Rivas [d], G. Méndez [e], J.M. Naredo [f], A. Cendrero [a]

[a] Departamento de Ciencias de la Tierra y Física de la Materia Condensada, Universidad de Cantabria, Santander, Spain
[b] Departamento de Ciencias de la Tierra, Universidad de Zaragoza, Zaragoza, Spain
[c] Departamento de Ciencias Médicas y Quirurgicas, Universidad de Cantabria, Santander, Spain
[d] Departamento de Geografía, Urbanismo y Ordenación del Territorio, Universidad de Cantabria, Santander, Spain
[e] Departamento de Geociencias Marinas y Ordenación del Territorio, Universidad de Vigo, Vigo, Spain
[f] Escuela de Arquitectura, Universidad Politécnica de Madrid, Madrid, Spain

ARTICLE INFO

Article history:
Received 16 November 2011
Received in revised form 20 March 2012
Accepted 20 March 2012
Available online 28 March 2012

Keywords:
Global geomorphic change
Sedimentation rates
Anthropocene
Northern Spain

ABSTRACT

An analysis of changes experienced during the last century by certain indicators of the intensity of geomorphic processes in northern Spain is presented, in order to test a previously formulated hypothesis. The hypothesis, already tested in the Rio de la Plata Basin, is that there is a *global geomorphic change* which implies an acceleration of geomorphic processes in general, and that such acceleration is mainly due to the transformation of land surface by human activities, not to climate factors. Sedimentation rates obtained in eight estuaries in northern Spain, through Pb-210 and Cs-137 dating of sediment cores, show a general increase since the beginning of last century, and particularly after the 1950s. Similar increases in landslide frequency have been formerly observed in some areas of the same region. Trends of change in sedimentation rates have been compared with those of potential natural (rainfall) and human (indicators of the intensity of human activities that can contribute to land-surface transformation) drivers. There seems to be no relationship between rainfall and sedimentation rate trends but the magnitude and trends of several indicators of human activity are similar to those of the latter. Data on landslide frequency obtained in a small study area also show a possible relationship with land-use change and infrastructure development, but not with rainfall. The results described are coherent with the hypothesis and suggest that the process described could have a global character. If this is so, the worldwide observed increase in flood and landslide disasters might be a characteristic of the Anthropocene and due to human-induced geomorphic change, rather than climate change (also human-induced), as often assumed.

1. Introduction

Work in certain areas of northern Spain has shown significant increases of landslide frequency in different areas and periods, such as Mid-Holocene and late 18th century (González-Díez et al., 1996, 1999), and second half of last century (Remondo, 2001; Cendrero, 2003; Remondo et al., 2005; Bonachea, 2006). Those increases could not be explained by changes in rainfall or other natural drivers but there was an apparent relationship between landslide frequency and human activities. In particular, there seemed to be a correspondence between GDP (an indicator of the intensity of human activities, including those that produce terrain alterations) and landslide rates during the last few decades (Remondo et al., 2005; Cendrero et al., 2006). The former authors speculated that as the extent and intensity of human activities which affect the land surface is growing throughout the world such relationships could have a global character and represent a significant "global geomorphic change". Data on flood and landslide frequency, as well as rainfall and GDP data at national (Guzzetti and Tonelli, 2004; Cendrero et al., 2006; Bruschi et al., 2008) and global (Historical Statistics for the World Economy, 2006; Cendrero et al., 2009; Gutiérrez et al., 2010; EM-DAT, 2011) levels suggest this might be the case. It is interesting to point out that indicators of both intensity of geomorphic processes (landslides, floods, sedimentation rates) and human activities showed a marked increase after World War II (Cendrero et al., 2006, 2009). This phenomenon has also been pointed out by Steffen et al. (2007, 2011), who named it "the Great Acceleration", referring to different manifestations of human activity and their effects on natural processes.

On the basis of the former facts a conceptual model was proposed (Cendrero et al., 2006, 2009) to express the possible relationship between human activity and geomorphic processes. It considers that there could be a cause-effect sequence of relationships such as: *drivers (population, technology, wealth) – pressures on geomorphic systems (increased human activity and intervention on the territory) – impacts (land-use changes,*

* Corresponding author.
E-mail address: bruschiv@unican.es (V.M. Bruschi).

0169-555X/$ – see front matter © 2012 Elsevier B.V. All rights reserved.
doi:10.1016/j.geomorph.2012.03.017

reduced resilience of surface layer, behaviour of processes) – response of geomorphic systems (increased rates of geomorphic processes, landslides, denudation, sedimentation, and related hazards/disasters). Of course, natural drivers, mainly rainfall, also play a role in geomorphic processes and their changes ought to be considered. Therefore, to test the model possible contributions of human as well as climate-related drivers ought to be analysed. 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, to a certain extent, present climate variations depend on the former. The final dependent variable whose changes could be compared to changes in drivers is sedimentation rate (itself dependent on runoff, slope movements or channel flow, in turn influenced by both human and natural drivers).

The model was tested through an analysis carried out in the Rio de la Plata basin (Bonachea et al., 2010). The results obtained showed that variations experienced by indicators of the intensity of geomorphic processes (sedimentation rate, river discharge) in that basin during the second half of last century could not be explained by the minor changes in rainfall that occurred during the same period, and that there was a much greater similarity between changes in the former and those of different indicators of the intensity of human intervention on the land surface.

Additional analyses carried out in several small areas in northern Spain (Bruschi et al., 2011) also showed that changes in landslide frequency or sedimentation rates that occurred in recent times bear only a limited relationship with rainfall changes, and that land-use changes as well as road network influence seem to have a much more determining role.

As pointed out by Syvitski et al. (2005) and Syvitski and Kettner (2011), human influence on fluvial sediment transport worldwide has grown considerably, particularly after World War II (Walling and Fang, 2003). It appears that one of the characteristics of the modern Anthropocene world is the growing human role on sediment generation, transport and deposition (Syvitski et al., 2005; Wilkinson and McElroy, 2007), through different types of changes produced on the land surface. Human influence on geomorphic characteristics and processes in general is increasing (Slaymaker et al., 2009) and, consequently, also on geomorphic hazards and risks (Bruschi et al., 2011).

The aim of the present work is to further assess (Bonachea et al., 2010) the hypothesis formulated on the basis of the former model, through the analysis of additional data on sedimentation rates from several estuaries in northern Spain, as well as data on potential natural and human drivers.

2. Methodological approach

The methodological approach has been described previously (Bonachea et al., 2010) and was directly derived from the working hypothesis proposed. Sedimentation rates (indicative of the intensity of geomorphic response) during the last century were obtained from different estuaries along the coast and were compared with changes in human and natural drivers to determine to what extent process behaviour conforms to the expected pattern. Some of those rates were determined in former studies – with different objectives – by some of the authors and others correspond to new determinations for the present work (in these cases error bars are represented), as specified in Section 4.

Sediment cores were extracted using hand-driven PVC tubes. Cores were cut into 1 cm thick slices and dated using the Pb-210 and Cs-137 methods (Koide et al., 1973; Appleby and Oldfield, 1978, 1983; Appleby et al., 1988; Shukla and Joshi, 1989; Bolívar et al., 1994; Appleby, 1998; Fuller et al., 1999; Sánchez-Cabeza et al., 2000; San Miguel et al., 2004). The analytical procedures used have been described in detail by some of the authors in former contributions (Gelen et al., 2004; Ródenas et al., 2004; Soto et al., 2006; Cearreta et al., 2008; Irabien et al., 2008a,b).

Drivers considered were rainfall and several indicators of the intensity of human activity, such as population, construction of new houses, GDP, energy or cement consumption (Table 1). The latter reflect human potential to act upon and transform the land surface through all kinds of activities. In particular, cement consumption or new house construction, are directly related to activities that imply excavation or modification of land surface (extraction of construction materials, expansion of urban-industrial areas and related infrastructure, intensive agriculture). Certainly, none of those indicators is univocally and exclusively linked to the alteration of the land surface and related intensification of processes such as landslides, surface runoff, denudation, and sediment generation, although generally speaking the greater GDP value, cement consumption or number of new houses built the more extensive the land modification.

Apart from sedimentation rates possible indicators of the intensity of geomorphic response include, for instance, frequency of slope movements, occurrence of erosion landforms, erosion rates, river discharge, sediment load or frequency of flood events. The model proposed assumes that alteration of land surface by human activity increases the sensitivity – or reduces the resilience – of the surface layer (Cendrero et al., 2006) and increases runoff. This should produce more slope movements and erosion, as well as greater river discharge.

Table 1
Main characteristics of data used in the analysis.

Data	Level	Type	Period	Source	Indicators
Rainfall	Daily	Meteorological stations	Bilbao airport: 1948–2007 Santander: 1924–1996 Mirones: 1968–2006 Molledo: 1958–2001 Pontevedra: 1921–1949; 1964–2010	AEMET, 2010	Total Annual rainfall and $>P_{95}$; (10 years moving average)
River discharge	Yearly mean	Gauging stations	1970–2003	Confederación Hidrográfica del Cantábrico, 2010	Average yearly flow
Population	Local-national	Census data	1900–2009	INE, 2010	Nº Inhabitants
GDP	Provincial and National	Current prices Const. pesetas 1995	1930–2000	Inchausti, 2003	Total, Pesetas/year
Houses	Local	Construction permits	1900–2001	MF/MV, 2010 (Vizcaya and Pontevedra) ICANE, 2010 (Cantabria)	No. of new houses/decade
Cement use	National	Total consumption	1940–2010	OFICEMEN, 2010	Tons/year

AEMET: Agencia Estatal de Meteorología
INE: Instituto Nacional de Estadística.
MF/MV: Dirección General de Programación Económica del Ministerio de Fomento.
ICANE: Instituto Cántabro de Estadística.
OFICEMEN: Agrupación de Fabricantes de Cemento de España.