Science of the Total Environment 532 (2015) 208–219

Contents lists available at ScienceDirect

Science of the Total Environment

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

Storminess and geo-hydrological events affecting small coastal basins in a terraced Mediterranean environment

Andrea Cevasco [a,*], Nazzareno Diodato [b,c], Paola Revellino [b], Francesco Fiorillo [b], Gerardo Grelle [b], Francesco M. Guadagno [b]

[a] Department of Earth, Environment and Life Sciences, University of Genova, Corso Europa, 26, 16132 Genova, Italy
[b] Department of Science and Technology, University of Sannio, 82100 Benevento, Italy
[c] Met European Research Observatory, 82100 Benevento, Italy

HIGHLIGHTS

- Changes in storm erosivity was examined over 1954-2012.
- Damaging geo-Hydrological Events evolution was examined over 1954-2012.
- An increasing trend of annual storm erosivity was observed over 1991-2012.
- Storm erosivity is an environmental indicator of many geo-hydrological phenomena.

ARTICLE INFO

Article history:
Received 5 March 2015
Received in revised form 3 June 2015
Accepted 3 June 2015
Available online 10 June 2015

Editor: D. Barcelo

Keywords:
Extreme precipitation events
Rainfall intensity
Storm erosivity
Climate change impacts
Geo-hydrological hazard
Land-use planning

ABSTRACT

This study was prompted by the occurrence of an extreme Damaging geo-Hydrological Event (DHE) which occurred on October 25th 2011 and which affected a wide area of the northern Mediterranean region. After analysing the storm by means of the precipitation time series, the study attempts to relate the October 25th 2011 DHE with a series of other DHEs that occurred in the period 1954–2012, assessed via the use of historical data and classified according to severity, with a Storm Erosivity Indicator (Ra). The annual mean of the Ra value (2582 MJ mm ha^{-1} h^{-1} y^{-1}) confirmed that the study area is one of the European regions with the highest rainfall erosivity level. A shift in storminess during 1991–2012 with respect to 1954–1990 was observed. A return period of 1000 years was calculated for the single storm erosivity of October 25th, which contributed to 84% of the total annual storm erosivity of 2011 A quite good agreement was found comparing DHE distribution and severity with Ra anomalies over time. As a matter of fact, most of the low severity DHEs (62.5%) occurred in years in which the Ra was below the average value. Moreover, almost all DHEs (93%) ranging from medium- to very high-severity occurred in years for which the Ra exceeded the average value. With regard to the occurrence of the most severe DHE classes, a threshold of the Ra and a recurrence time of approximately 3300 MJ mm ha^{-1} h^{-1} y^{-1} and 12 years, respectively, were identified. Finally, some evidences suggest that an increasing frequency of DHEs is expected in the forthcoming years. It is argued that understanding these issues is a major priority for future research in order to improve land and urban planning strategies for preserving people and the environment, leading ultimately to an effective risk reduction.

1. Introduction

In Mediterranean river-torrential landscapes, long phenomena-free periods can be suddenly interrupted by storms from which accelerated erosion, landslides and floods derive (Diodato, 2004). This is particularly evident in landscapes affected by land use conflicts (Pacheco et al., 2014; Valle Junior et al., 2014). Severe weather conditions characterised by intense rainfall causing simultaneous events such as landslides, floods, accelerated erosion and resulting in economic damage and human injury were defined by Petrucci and Polemio (2003) as Damaging geo-Hydrological Events (DHEs). Northern coastal zones of the Mediterranean Sea are particularly exposed to the occurrence of high intensity rainfalls that might cause flash flooding and landslides (Barriendos Vallve and Martin-Vide, 1998; Rusjan et al., 2009; Llasat et al., 2010). As known, climatically-induced mass movements (e.g. debris slides, debris avalanches, debris flows) can damage roads, villages and infrastructures (Revellino et al., 2008, 2010; Fiorillo et al., 2013; Guerriero et al., 2013; D'Amato Avanzi et al., 2013b; Galve et al., 2015; Bordoni et al., 2015) and frequently, together with accelerated erosion,

* Corresponding author.
E-mail address: cevasco@dipteris.unige.it (A. Cevasco).

http://dx.doi.org/10.1016/j.scitotenv.2015.06.017
0048-9697/

they can supply large sources of solid materials to drainage networks. Sediments coming from slopes increase the magnitude and energy of stream flow and, especially in small mountain basins, play a fundamental role in generating flooding phenomena at the basin mouth (Gutierrez et al., 1998; Brandolini et al., 2012). Flash floods are very dangerous, often resulting in the loss of life due to the fact that they can deliver enormous amounts of water and debris in a very short space of time (Gaume et al., 2009; Tarolli et al., 2012). These events, normally, have a special impact in mountain areas, where the effects of extreme precipitations are heightened by slope steepness (Calcaterra et al., 2003; Fiorillo et al., 2001; Lebel et al., 2011; Pereira et al., 2010; Perriello Zampelli et al., 2012). However, coastal environments with mountain-like geomorphological features can also be seriously exposed to accelerated erosion and landslide and flood risks (Guthrie and Evans, 2004; Cevasco et al., 2010; Santo et al., 2012). In such a case, risk conditions are increased by both the high economic value of coastal areas and the large number of tourists that visit these areas (Guadagno et al., 2005; De Vita et al., 2012; McCullough et al., 2013; Revellino et al., 2013; Martino and Mazzanti, 2014).

Several studies have dealt with both the recent changes in rainfall characteristics (Frich et al., 2002; Trenberth, 2011) and their effects on the occurrence of rainfall-induced phenomena, such as landslides and floods. The majority of these studies focused on mountain regions, where rainfall-induced phenomena are more common than in coastal areas (e.g. Jomelli et al., 2004; Pelfini and Santilli, 2008; Floris et al., 2010). On the other hand, many recent studies have focused on storm erosivity, that can be considered as the "power of the rainfall" to produce slope processes (landsliding and erosion) and, therefore, represents an environmental indicator of many geo-hydrological phenomena (e.g. Davison et al., 2005; Diodato, 2006; De Luis et al., 2010; Diodato and Bellocchi, 2010; Xin et al., 2011; Angulo-Martínez and Beguería, 2012; Panagos et al., 2015; Sadeghi and Hazbavi, 2015). Despite this, no study attempting to relate DHEs with storm erosivity changes has been reported in literature.

This study was prompted by the occurrence, on the 25th of October 2011, of a very intense rainfall event which affected a wide area between the eastern Liguria and the northern Tuscany coast (northwestern Italy), causing 13 fatalities and severe damage to villages, cultivations, infrastructures and essential services (Cevasco et al., 2012; D'Amato Avanzi et al., 2013a). Some small coastal basins of the easternmost Ligurian Riviera suffered major damage due to the occurrence of hundreds of shallow landslides, widespread erosional phenomena and flash floods. Starting from an analysis of the October 25th 2011 rainfall event, this paper investigates historical rainfall and the related damaging effects on the abovementioned small coastal basins. In addition to having almost homogeneous geomorphological and climatic features, these basins show similar problems with regard to the occurrence of DHEs. In fact, the local microclimate, which favours high intensity rainfall, and the mountain-like geomorphologic features, make the coastal basins of eastern Liguria prone to shallow landsliding and rapid flooding (Cevasco et al., 2008; Brandolini et al., 2012). With the aim of contributing to a better understanding of the relationships between extreme events, climate change and geomorphic phenomena, and bearing in mind the risks that such phenomena represent both for resident people and tourists, we investigated the response of the environment to severe rainfall over time and the time-scale at which changes on extreme rainfall events occur. In this way, the study analyses changes in storm erosivity and their relationships with the occurrence and severity of DHEs. Additionally, the study discusses the related upcoming trends, also taking into account a more enlarged view on the Mediterranean central area.

2. Study area

The study area is located along the easternmost Ligurian coast, within the border of the La Spezia province (Fig. 1a), and it is formed by the Tyrrhenian basins between the village of Deiva Marina and the city of La Spezia. These basins mainly extend between the coastline and the Cinque Terre/Vara valley watershed, reaching altitudes of approximately 700–800 m a.s.l. The study area includes the famous Cinque Terre, a UNESCO World Natural Heritage Site since 1997 and a national park since 1999.

From a geological point of view, the study area is part of the northern Apennines, a mountain belt formed during the Tertiary by the tectonic superimposition of the Ligurid units onto the Adria plate margin (Alvarez et al., 1974). The area can be divided into three geological sectors (Giammarino et al., 2002): i) ophiolite rocks – relicts of the Jurassic oceanic crust – outcrop between Framura and Levanto; ii) sedimentary rock formations, mainly made up of clay-shales and sandstones (Upper Jurassic-Cretaceous), which are present between Framura and Deiva Marina; and iii) sedimentary rock formations mainly constituted by limestone and sandstone (Upper Trias–Miocene) and clay–shale and limestone (Paleogene) which outcrop between Monterosso and La Spezia. The ophiolitic slopes are usually lacking of soil mantle or it is very thin; conversely, sedimentary rock slopes are covered by 0.5–2.5 m thick eluvial–colluvial soil. The soil covers are characterised by wide heterogeneous grain size, generally consisting in mixtures of gravel and sand with a subordinate fine fraction (Cevasco et al., 2013b, 2014). Often, soils covering slopes do not present the original setting as they have been reworked during the past centuries for agricultural purposes.

The proximity of the Cinque Terre/Vara valley watershed to the coastline does not allow a well-developed hydrographic network typical of coastal areas and, where this happens, the coastal plains have limited extent and only briefly interrupt the continuity of the high rocky coast (Corradi et al., 2013). Coastal basins are usually characterised by narrow and deep-cut valleys, steep slopes and short streams with an ephemeral hydrological regime. The morphological features of the study area strongly controlled the development of urbanization. The most populated villages were built on small coastal plains (Deiva Marina, Bonassola, Levanto) or on the floor of deep-cut valleys (Monterosso, Vernazza, Manarola, Riomaggiore) reducing, over time, natural areas at the mouth of streams. This often resulted in the embanking of the final tracts of the streams or, in some cases, coverage or deviation from their original path. Human activity also affected the steep slopes behind the coast and most of them were terraced in historical times for agricultural purposes. In this area, terracing of slopes can be considered a real geomorphologic value that has few equals of similar magnitude in the world. The abandonment of rural areas following socio-economic changes since the 1950s, which resulted in a general lack of maintenance of dry stone masonries, has led to the loss of many terraced areas with increasing slope instabilities (Terranova et al., 2002). At the same time, given the high environmental, historic and cultural value of the eastern Ligurian Riviera, tourism has significantly increased.

Due to its geographical and morphological features, the study area has a mild Mediterranean climate. Southerly exposition, the vicinity of the sea and mountains acting as a barrier, which protect the coast from continental influxes, are all factors that most contribute to making the climate particularly mild. Moreover, the humidifying action of the sea on the air masses coming from the southern quadrants and the Alpine-Apennine chains effect, which frequently divert Atlantic perturbations towards the Gulf of Genoa, produces relatively abundant rainfalls (Fig. 1b). Along the coast, between Deiva Marina and La Spezia, the mean annual rainfall value ranges between 900 and 1100 mm, with minimum and maximum values towards Portovenere and in the coastal stretch to the west of Cinque Terre, respectively (Pedemonte, 2005). A sudden increase of the mean annual precipitation (MAP) with altitude was observed, with values reaching approximately 1500–1600 mm in the immediate and higher inland Vara/Magra valleys. Precipitation is more abundant in autumn and winter. Very intense rainstorms, which can originate from self-regenerating storm cells or a persistent cyclonic Thyrrenian circulation (Crosta, 1998; Cevasco et al.,