Natural Hazards and Disaster Risk Reduction Policies

Loredana Antronico - Fausto Marincioni
Editors

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Cover: A woman shovels mud from her driveway in the aftermath of the October 2010 debris flow that affected the Province of Vibo Valentia (Calabria, southern Italy).

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13. Traditional flood mitigation measures in Mallorca

Miquel Grimalt[1], *Joan Rossello*[2]

Abstract

The drainage system of Mallorca is constituted by ephemeral rivers, known as *torrents*, which are not usually running. The rainfall in the island features high-intensity episodes (of more than 100 millimeters in 24 hours), which occasionally cause *torrents* to overflow and as a consequence causes severe flooding.

The island been historically affected by flood events. Since the 15th century, 223 events have been recorded. Up to the 20th century, floods in the island affected plains with a high agricultural production. In order to reduce the vulnerability of those areas, islanders adopted a wide range of measures based on traditional engineering.

The research is intended to describe the main measures adopted by local population in order to control surface runoff. Among them, the channelization of a large part of the streambeds, the deviation of the streams and the use of *parats*, a complex system of stone walls built within river beds that diverts the flow and to avoid the flooding of the adjacent fields. In limestone areas of Mallorca, another traditional system is the *albellons*, which are artificial runoff channels that run under the soil, build with stones, which help to avoid the flooding of the fertile lands of the area. Finally, in the mountainous areas, other dry-stone structures, called *marges*, are used to create land to farm in the mountain slopes. *Marges* avoid erosion, as they have channels on the sides, where water is deviated and driven to reservoirs where it can be kept to be used later.

The research is focused on that man-made systems, how they work, where are located in the island and their evolution. These systems are currently in ways of abandonment, given the change in the economical framework from the island, which has evolved from the traditional agricultural society to a tourism-based economy. The current situation has not only meant a higher degree of urbanization but also an increase of

[1] Departament de Geografia. Universitat de les Illes Balears, e-mail: miquel.grimalt@uib.cat.

[2] *Corresponding author*. Grup de Climatologia, Hidrologia, Riscs Naturals i Paisatge. Universitat de les Illes Balears, e-mail: joan.rossellogeli@uib.es.

human presence in flood-prone areas. The lack of maintenance of traditional dry-stone structures has a direct effect on the increase of risk of flooding.

Keywords: Mallorca, ephemeral streams, flooding, mitigation, dry-stone.

1. Introduction

The Mediterranean basin has been heavily inhabited since early historical times. The need of farmlands and the protection against natural hazards led to an intense action that modified the original landscapes. The resulting space has been described as “cultural landscapes” (Aplin, 2007; Álvarez, 2011; Minca, 2013), some recognized by the UNESCO (Unesco, 2014).

Around the Mediterranean, the use of dry-stone techniques was usual for a wide range of human activities, building and farming being the most common. The Balearic Islands constitute a unique example of a dry-stone landscape within the Mediterranean due to the extension, variety and complexity of such constructions.

The value of dry-stone techniques for flood mitigation measures is related to the importance of farming and building adjacent to flood zones. The need to gain surfaces to cultivate and to protect the crops from meteorological and hydrological events which may cause severe damages was solved with the use of stones, which were of common in areas with geological and lithological characteristics.

The need of these mitigation measures arises from the fact that the Mediterranean basin has been prone to flooding events for centuries (Barredo, 2007; Barreda-Escoda and Llasat, 2015; Barriendos and Rodrigo, 2006). While the flood causes have been extensively investigated (Gaume *et al.*, 2016; Marchi *et al.*, 2010; Tarolli *et al.*, 2012), the effects of flooding in terms of societal and economical impacts are less known (Barnolas and Llasat, 2007; Barredo, 2009; Glaser *et al.*, 2010).

In this article, man-made structures for flood mitigation purposes will be presented. Their main shared feature is the use of the dry-stone system, common in the whole Mediterranean area but adapted to the specificities of Mallorca in physical, societal and economical terms.

2. Research area

The Balearic Islands archipelago (Fig. 1) is situated off the eastern coast of Spain. It is made up of five islands (Mallorca, Menorca, Eivissa, Formentera and Cabrera) with adjacent islets. The islands' total surface area is around 5,014 km^2 and its population in 2017 was just over 1 million (IBESTAT, 2017). The islands are a well-known summer destination throughout Europe, with millions of yearly visitors. Before the expansion of touristic activities, the islands were isolated from the mainland and produced what was needed in an autarchic way of life.

In spite of the commercial development during the Late Middle Ages, agricultural activities became, from the 17^{th} century until the second half of the 20^{th} century, the foundation of the archipelago's economy, thus leading to an intensive use of the territory. Therefore there developed a need to control surface runoff through man-made techniques.

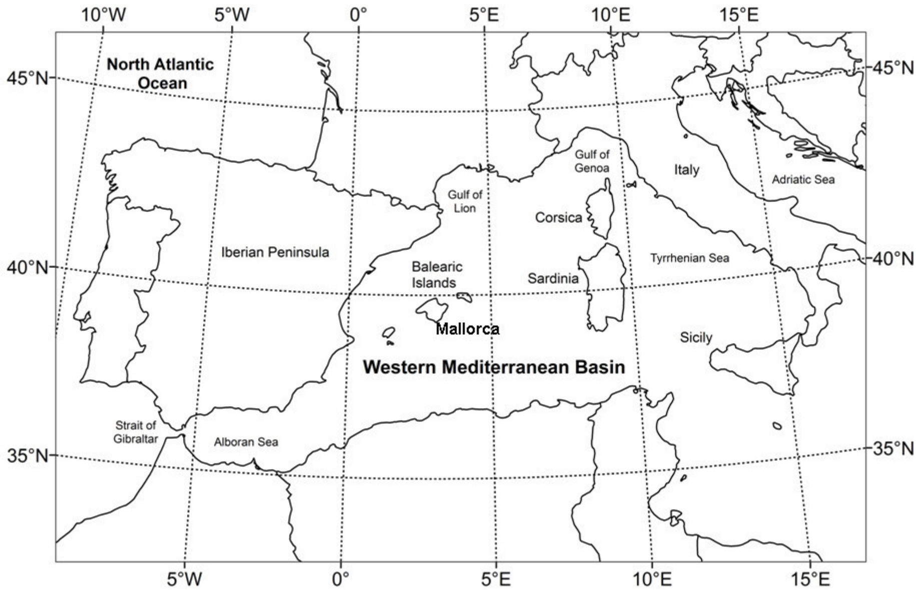

Figure 1 - *Location of the Balearic Islands in the Mediterranean basin. Source: Grimalt et al, 2013.*

The main island of the archipelago is Mallorca, with a surface of 3626 km^2. It is a relatively flat landscape, with a low land in the middle of the island (Es Pla), lying between two main mountainous areas, the Serra de Tramuntana in the north west (1445 m.a.s.l at the highest peak) and the Serres de Llevant in the southeast, with altitudes reaching 500 meters on average. The island features are completed with small hilly areas, included in Es Pla, several alluvial plains (Palma, Inca, Sa Pobla and Campos) and a carbonate Miocene platform in the southeast (Fig. 2).

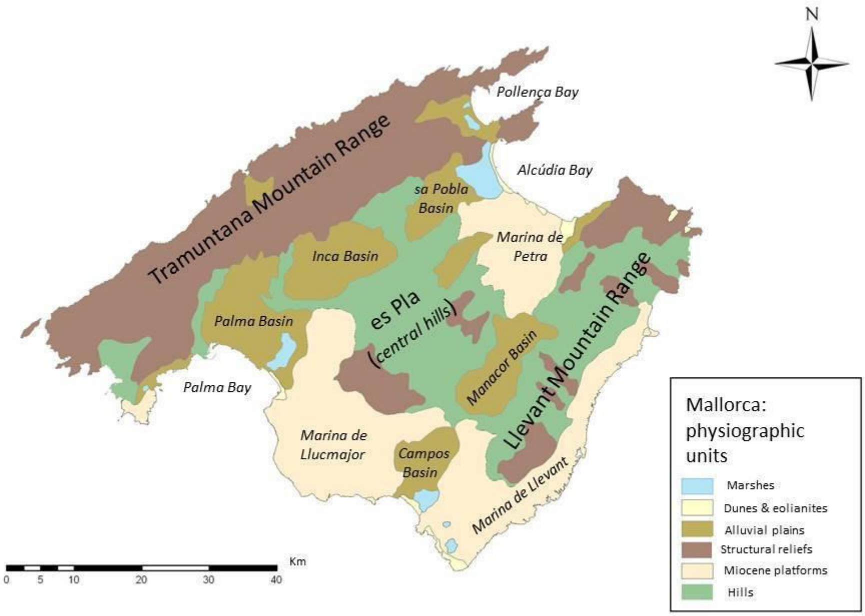

Figure 2 - *Physical features of Mallorca. Source: Author's research.*

Regarding rainfall, Mallorca is affected by intense precipitation events, linked to cyclogenic Mediterranean conditions and the geographical layout of the island. Average yearly rainfall is around 600 millimeters but with a high variability in terms of spatial and temporal distribution (Grimalt *et al.*, 2006). The northern mountains can reach averages of 1400 millimeters per year while the southern zones barely reach 400 millimeters per year. Seasonal distribution shows an autumn maximum and a summer minimum, with July being the driest month, usually without rainfall.

In Mallorca the rainfall regime is highly variable and irregular and dry years alternate with profusely wet ones. Heavy rainstorms, that can occasionally reach 400 millimeters in 24 hours, are frequent and affect mainly the mountainous area in the north of the island, as well as on the east coast.

Severe floods are characterized by extreme peaks that exceed the capacity of *torrent* channels (Grimalt *et al.,* 1990). This overflow affects mainly alluvial plains and coastal areas, both of which register high human occupation since they host crowded touristic venues and facilities as well as the most fertile lands for farming activities.

Mallorca has a population of 861.430 inhabitants as of 2016 (IBESTAT, 2017), distributed unequally between 53 municipalities. Palma, the capital and main city of the island, hosts almost half of the inhabitants of the island (46, 77%). The economy, following the trend of the archipelago, shows an important tertiarization of the active population related to the tourism industry, with an industrial sector, mostly linked to building, and an agricultural sector that is statistically unimportant.

Historically, agriculture shaped the society and the traditional habitat of the island, changing the physical features of the land, thus creating a cultural landscape. The farming activities needed an adaptation of the land with men-made structures, to protect farmlands, obtain hydrological resources and protect the territory from meteorologically or hydrologically adverse conditions. Nowadays, the societal and economical structure and the territorial modeling are the result of the tourism growth since the second half of the 20th century (Salvà, 2008). The increase of urban population, the uncontrolled building in coastal areas and the development of new infrastructures (highways, roads, etc.,) led to an abandonment of agricultural practices and the change of the land use to residential activities in a large area of the former agricultural lands (Salvà, 1995; Binimelis and Ordinas, 2012).

3. Human measures to prevent flooding: *parets, albellons, parats, avencs and marges.*

The control of the surface runoff is accomplished by using dry-stone traditional structures. The main purpose of these structures is to avoid soil loss due to erosion, as a result of the intense precipitation. To accomplish this, the idea is to prevent surface runoff or, at least, regulate the intensity of runoff flow. The constructions can be divided between those which only have hydrological functions and those that also have farming purposes.

3.1. Walls

The simplest structure is the *paret*, a wall which forms boundaries between properties. *Parets* are built with calcareous rocks which have a plain face, the one looking to the external side of the wall, while the internal one has irregular shapes. The rocks are held without concrete and a filling with rubble (Fig. 3). This kind of construction means that water can flow through the rock holes while sediments are retained at the wall. This kind of walling allows fields with small slopes to not overflow thus avoiding the formation of gullies and badlands.

Zoning walls can be found all over the island but they are very common in the carbonate Miocene platforms of Migjorn, Llevant and Marineta de Petra. The landscape in these regions is made by shallow soils and a karstic environment that forms a fluvial system of steep torrential canyons.

A problem with the walls is that when intense rainfall affects the area, plots are flooded and high-water levels pressure the rocks. This can lead to the collapse and the formation of flood peaks with catastrophic effects downstream. To avoid it, in places where the landscape shape allows the concentration of runoff, the walls have openings in their base, called "clavagueres", which allow water flow through.

Figure 3 - *Wall with holes, allowing the water flow through the stones. Campos Basin, January 2017. Source: Author's research.*

3.2. Parats

Parats are man-made structures for hydrological purposes but can be used for land cultivation. The system is made by stone walls laid out transversally in the streambed (Fig. 4). Their main purpose is to avoid runoff formation so the walls are designed to resist water pressure using big rocks at the base and rear parts. Even though they are usually of linear form, some of them can follow parabolic contours, thus offering more resistance to the flood waters (Grimalt *et al.*, 1998).

Parats appear thorough Mallorca but are common in the mid mountain areas of the eastern and western sides of the island as well as the Miocene platforms above mentioned.

Figure 4 - *Parats in Lluc (Tramuntana mountain range) during a flood event (April 2018). Source: Author's research.*

3.3. Albellons

Another technique devised to avoid flooding is to lay drains in the soil. Called *albellons*, these drains are ditches in the cultivated plots which are covered with layers of stones (Fig. 5). The stones allow the drainage of water, thus avoiding the stagnation of flood waters after heavy precipitation episodes. The drains run to a grid of channels (above or underground), located within the plots, which divert the flow to the streams.

The *albellons* are located in two areas of Mallorca. One of them is in the clay-limestone lands at the centre of the island, which has land with low permeability and flat surfaces, where the system avoids the flooding and promotes the growth of cereals. The other one is in mountainous regions where *albellons* are used to drain water from the top of the agricultural terraces to the underground reservoirs.

Figure 5 - *Plain land flooded in Camp den Torrella (Marina de Llevant) after an extreme precipitation event (December 2016). On the right side of the road the "albelló" is draining the flooded plot. Source: Author's research.*

Finally, there are some complex drainage systems linked to regularisations of the main streams. In this particular case, the streams are found between sidewalls (levees) and the drains to allow the exit of flood waters from adjacent fields. Water runs underground into the *albellons* (also known as *eixugadors*), which run parallel to the stream, until reaching a level that allows it to flow into the main bed. An example of this system is found in the Sóller valley, in the Tramuntana mountain range.

3.4. Avencs

A characteristic of the southernmost part of Mallorca is the use of holes, dug from Miocene calcarenite soils, which present an intense karstification close to the ground. Those holes connect the surface with the karstic area and divert the runoff to underground water circulation (Fig. 6). The main purpose of the system is to avoid soil erosion or damages in cultivation due to surface runoff after heavy precipitation events.

Those *avencs* are commonly linked to an *albellons* system, which drain the water to the artificial cavities, thus performing the same function that the natural ones (Barceló *et al.*, 2012).

This technique is found mainly in the Marina de Llevant and Marina de Llucmajor, as well as in the Campos basin. The progressive abandonment and the lack of their maintenance have led to an increase in episodes of flood with damaging effects, especially from the start of the 21st century.

Figure 6 - *Avenc de Son Muletó (Marina de Llucmajor). An example of dig to force the runoff infiltration to the underground. Source: Author's research.*

3.5. Marjades

Along the steep sides of the Tramuntana mountain range, men build dry-stone systems which allowed the cultivation of the land. The terrace walls, known in the islands as *marjades*, is a system that uses stone walls to hold the land and allow the use of plots for agricultural purposes, mainly olive trees, carob trees, citrus and other fruit trees (Fig. 7). Their origin is related to the Catalan conquest during the Middle Ages, between the 13th and 14th centuries (Mas, 2017).

Aside from hosting crops and expanding farming areas, terraced walls are also aimed at regulating the water surface flow, allowing infiltration and avoiding erosion as the water flows through the stone walls to evacuation channels.

The terraces are a complex system, which combines buildings and other structures in order to upgrade their functionality (Fig. 8). For instance, the communication between terraces was provided by different kinds of paths, ladders and even mounting blocks integrated in the walls. Hydrologically speaking, a complex structure of transversal drainage channels (*relles)*, combined with underground drains and stream bed diversions using stone walls, is found in these terrace structure systems. The objective is to avoid an excess of water in the plots and divert the subsurface waters to underground reservoirs.

Figure 7 - *Terraced land in Son Bunyola, Banyalbufar, Tramuntana mountain range. Source: Author's research.*

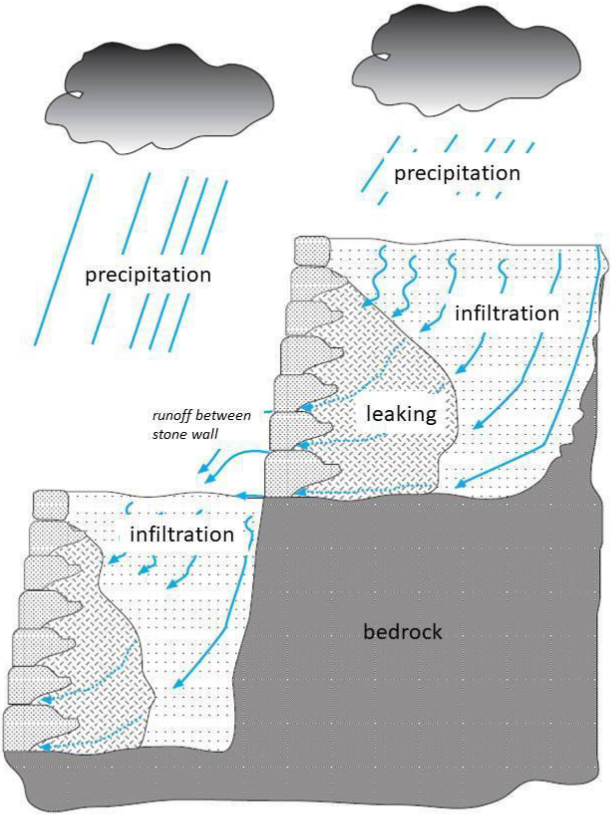

Figure 8. Simplified scheme of the runoff behaviour in a terraced wall system. Source: Author's research.

The terrace walls were built by a professional union (*margers*), who passed the knowledge from fathers to sons. There is a current promotion of this trade, with an official school funded by the *Consell Insular*, the island regional government, with the goal to train people for restoration, maintenance and construction of dry-stone structures.

The building of *marges* during centuries resulted in an extended walled surface, around 200 kilometers, which is located within altitudes ranging from 200 and 600 meters above sea level. The walls have a notable height (2 meters on average) and can be found in plots that reach up to 20% or more of the embankment. It has been calculated that the longitudinal development of the terrace system equals to 10,000 kilometers if laid out in a straight line (Rosselló, 1997).

Another important fact about the walls is that they are used as a protection against landslides in the Tramuntana mountain range. Due to the high precipitation rates and geological trends, it is a landslide-prone area (Mateos and Azañon, 2005; Coste *et al.*, 2017) and the terraces contribute to diminish this risk.

4. Current situation

The whole extension of Mallorca is occupied by the man-made structures, which have been described previously. The extent and functionality of the systems varies in each of the natural districts of the island, and basically depends on the features of the physical environment.

The methodology used to collect data and identify the location and current situation of these structures was (1) the research of archives and historical information about the structures (2) field research in locations where such systems were identified (3) the observation of aerial photography to locate the structures and their current situations and (4) oral interviews with former builders or farmers, who have worked in the building of these runoff mitigation structures.

In Table 1, a description of the presence and the regulation capability of each system in the natural landscapes of Mallorca is included. Regarding the presence, the key is as follows: 0-absent, 1-rare, 2-barely, 3-abundant, 4-highly abundant, while for its flood prevention function, the key is: A-predominant, B-important, C-accessory, D-insignificant.

Table 1 - *Presence and functionality of traditional systems. Source: Author's research.*

Natural area	*Murs*	*Parats*	*Marjades*	*Albellons*	*Avencs*
Mountain	1C	2C	4A	2C	1C
Hills	2C	3B	2C	2C	1C
Planes	1C	1D	0	4A	1C
Miocene platform	4A	3C	1D	2C	3B

For example, in the mountainous areas, the terraces are the main element of hydrological regulation, as the table shows their presence (highly abundant) and function ability (predominant). Even so, *marjades* are usually combined with *albellons* and, sometimes, the streams are diverted using *parats*. On the other side, *murs* and *avencs* only appear sparingly and are accessories, if not insignificant in terms of use.

To date, man-made dry-stone structures suffer an abandonment process, which facilitates their degradation, as they are systems requiring periodical maintenance. The failure of that maintenance leads to the destruction of the system or its disablement as a protection tool. Abandonment is not equal over the island and depends on the type and the main use of the structures as well as their spatial locations.

The following chart shows the presence and conservation of each kind of dry-stone structures in relation to territorial uses.

Table 2 - *Current situation of the traditional systems. Source: Author's research.*

Structure	*Murs*	*Parats*	*Marjades*	*Albellons*	*Avencs*
Harmful practices					
Agricultural	3D	2D	3A	4A	1A
Public works	3C	2C	2B	3C	2C
Urbanization	3C	1C	2A	2C	1C
Abandon	3A	4A	4A	3A	3A
Preservation practices					
Maintenance	3	2	4	2	1
Restoration	3	1	4	1	1

The key is explained as follows, for the frequency of use: 1-rare, 2-barely, 3-common, 4-important, while for the effects of the use: A-degradation (loss of function), B-nullification, C-destruction, D-no effects, E-effective use.

Besides abandonment, other degradation effects are the result of the arrival of new cultivation tools, such as heavy machinery that ploughs deeper than ancient machinery, destroying systems such as *albellons* or *marjades*. Public works are another element of impact, particularly the construction of new roads or the widening of old ones. Both instances also contribute to the damage or destruction of draining systems. Another important fact is the loss of the building culture, which leads to the use of modern restoration techniques that are not as efficient as the traditional ones (Fig. 9).

Finally, the increase of urbanization, which is related to the tourism industry in Mallorca, in coastal areas and in the outskirts of towns, has led to an occupation of former agricultural land and the destruction of protection systems, which were not useful for the new urban activities.

Figure 9 - *Collapsed dry-stone wall as a result of a lack of maintenance. Source: Author's research.*

The consequence of the degradation and abandonment process is the lack of protective measures in the event of severe rainfall. Some examples stand out in the past decades. Flooded lands in the plains are common after heavy rainfall episodes, such as the ones in December 2016 and January 2017. In both cases, the failure of the *albellons* system led to plots that remained flooded for weeks, with the waste of crops and the closure of roads as a result. Another effect of those episodes was the flooding of the urban area of Campos as the destruction of the *avencs* system did not prevent the arrival of surface runoff into the city center.

The dry-stone walls of the Tramuntana mountain range suffered from collapses after rainfall events of high intensity, such as the March 1974 or October 1978 episodes, when kilometers of terraces were destroyed (Grimalt, 1992).

Nevertheless, when the systems were in full use and with correct maintenance, intense storms were able to collapse the system, because they were unable to cope with the amounts of falling rain and the resulting floodwaters. Impact from high water peaks, dragged materials and high erosion rates resulted in the destruction of the traditional engineering system of the affected area. One case was the 1885 event in Sóller (Tramuntana mountain range) with relevant losses of crops and land.

Another example of such catastrophic events is the September 6th 1989 storm, which affected the southern and eastern areas of Mallorca. After a fall raining event (more than 200 millimeter/24 hours records), flooded streams carried peaks of over 500 m^3/s, which destroyed walls, *parats* and filled up *avencs* with sediments. It resulted in collapsed bridges, washed away roads, public and private buildings destroyed, heavy losses in agriculture and livestock farming and fatalities (Grimalt *et al.*, 1990).

5. Conclusions

This research presents a complete study of the traditional flood mitigation measures in the island of Mallorca. The dry-stone structures are related to the Middle Ages, when they were used to develop agricultural plots thorough the island. They allowed the expansion of farming activities while protecting land and people from hydrological extremes, such as intense rainfall events, which are very common in Mallorca.

The abandonment of farming and the increase of tertiary activities in rural areas, especially since the second half of the 20th century, led to a failure to maintain those systems, which now cannot fulfill their function, as has been discussed.

Regarding the current risk reduction situation, the abandonment of the systems in the island has become an added hazard for its inhabitants. The effects to reduce disaster risks have been handed to local or regional authorities because society believes that such actions must be lead by policy-makers. In a sense, disaster risk management has forgotten those man-made structures, which sometimes are seen as remains of the past.

Obviously, if authorities do not engage in a policy to recover or develop traditional systems, the changes in the societal structure will not help to improve the situation. The abandon of the agriculture and the loss of farming tradition mean that the knowledge related to the building and maintenance of those structures is vanishing on the island of Mallorca.

The future, in terms of the flood mitigation, appears to be problematic. The probable increase of events of low or medium intensity, related to global climate change, will have an effect of an increase in flooding events, as the system is not fully working in large parts of the island. In extreme events, the presence of the man-made structures, which in the past could not cope with the impact of such episodes, will not change the outcome but, if they were preserved, they could, at least, reduce the damaging effects.

Environmental and cultural policies have recognized the important heritage of these systems. The ethnological value of the structures, seen as the result of the interaction between men and environment, has to led to a recovery of the trade and protection of the remaining structures in order to allow future generations to inherit a historical legacy, as a means and technique to protect the inhabitants of the Balearics and their lands from the dangers of flooding.

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Natural Hazards and Disaster Risk Reduction Policies collects 14 original essays, of authors from all around the World, exploring strategies and ability of local communities to adjust to natural hazard and disasters. The volume, fostering the current scientific debate on disaster ecology, muses about the need for Homo sapiens to define its rights and responsibilities in environmental dynamics, including extreme events and disasters. In the end, the reflections about how to deal with hazard, vulnerability and disasters, highlights the ethical nature of disaster risk reduction; control of nature or adaptation to its cycles?

Loredana Antronico is a Researcher of the Research Institute for Geo-Hydrological Protection of the Italian National Research Council (CNR). She is author or coauthor of several papers published in international journals or presented at international conferences and workshops in the following issues: soil erosion, debris flow and flood hazard on alluvial fans, landslide incidence, landslide susceptibility and hazard assessment, landslide monitoring, and recently, geo-hydrological risk perception. Loredana Antronico is coordinator of research projects, on some of the cited issues, funded by National and Regional Administrations.

Fausto Marincioni is an Associate Professor at the Università Politecnica delle Marche at Ancona (Italy), where he teaches and carries out research on disaster risk reduction. He holds a Ph.D. in geography from the University of Massachusetts (USA) and is an editor of the International Journal of Disaster Risk Reduction. Previous to the Università Politecnica delle Marche Marincioni has worked with the US Geological Survey, in Woods Hole, Massachusetts, and taught human and environmental geography at Long Island University (LIU Post) in New York.

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