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Research article

The land morphology approach to flood risk mapping: An application to Portugal

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ABSTRACT

In the last decades, the increasing vulnerability of floodplains is linked to societal changes such as population density growth, land use changes, water use patterns, among other factors. Land morphology directly influences surface water flow, transport of sediments, soil genesis, local climate and vegetation distribution. Therefore, the land morphology, the land used and management directly influences flood risks genesis. However, attention is not always given to the underlying geomorphological and ecological processes that influence the dynamic of rivers and their floodplains.

Floodplains are considered a part of a larger system called Wet System (WS). The WS includes permanent and temporary streams, water bodies, wetlands and valley bottoms. Valley bottom is a broad concept which comprehends not only floodplains but also flat and concave areas, contiguous to streams, in which slope is less than 5%. This will be addressed through a consistent method based on a land morphology approach that classifies landforms according to their hydrological position in the watershed. This method is based on flat areas (slopes less than 5%), surface curvature and hydrological features.

The comparison between WS and flood risk data from the Portuguese Environmental Agency for the main rivers of mainland Portugal showed that in downstream areas of watersheds, valley bottoms are coincident with floodplains modelled by hydrological methods. Mapping WS has a particular interest in analysing river ecosystems position and function in the landscape, from upstream to downstream areas in the watershed. This morphological approach is less demanding data and time-consuming than hydrological methods and can be used as the preliminary delimitation of floodplains and potential flood risk areas in situations where there is no hydrological data available.

The results were also compared with the land use/cover map at a national level and detailed in Trancão river basin, located in Lisbon metropolitan area, an urbanized basin that suffered heavy flooding in the last decades. This study also contributes to a better understanding of the basin morphology at a local-scale and the effects of soil sealing in downstream flood risks.

This work will contribute to the understanding of the morphology, ecology and land use of watersheds that could be used to reduce runoff and downstream flood risk. This can be accomplished by using natural water retention and infiltration methods or higher-level based planning instead of a reaction to local decisions on flood hazards. This morphological approach to map landforms, including wet system, is a valuable tool to assist policy makers and planners in flood risk and land use management, floodplain restoration, agricultural land management practices, and location of human activities according to ecological suitability.

1. Introduction

Since ancient times, populations have settled near floodplains,

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taking advantage of their valuable geographical and biophysical conditions, e.g. fertile soils with high food productivity, navigable waterways, with access to water supplies for transportation and power development (Balica et al., 2009; Douben, 2006; OAS, 1991). The increasing vulnerability of these areas is linked to changes in population density and land use (Douben, 2006; EEA, 2013; EEA, 2015). In the same way, there is a direct relation between incorrect land use practices and flood risk and frequency (Deasy et al., 2014; Leopold, 1994; Zaharia et al., 2015). The dramatic increase in flood hazard is consequence of several activities that promote soil structure degradation, leading to soil erosion, decrease of water infiltration rates and water storage capacities (Wheater and Evans, 2009), increase of rapid runoff, stream flow and rising flood level (Brauman et al., 2007; Minea, 2013). The soil degradation is a consequence of soil sealing due to incorrect practices, either arable or grazing intensification as upland deforestation, intensive agriculture, or urbanisation and construction of infrastructures (EEA, 2012; Jacinto et al., 2015; Minea, 2013; OAS, 1991; Wheater and Evans, 2009).

A higher-level planning based on land morphology and landforms mapping, including floodplains and flood risk areas, is an essential tool to reduce flooding and associated costs with damages and insurance claims. This approach could help to change the paradigm of urban location, in order to “keep the people away from floods” and should be incorporated into new maintenance strategies focus on “self-regulating nature” as “inclusive River management” (Fliervoet et al., 2013), “Room for River” (De Groot, 2014; Lennon et al., 2014; Rohde et al., 2006). Such measures have been encompassed by the 2000/60/EC Water Framework Directive (EC, 2000) and 2007/60/EC Floods Directive (EC, 2007) which were designed to identify hazard areas, and urban development that promotes soil sealing, especially in floodplains.

Mapping landforms is particularly useful for analysing river ecosystem position and function in the landscape. Land morphology is also a valuable complementary tool to assist policymakers and planners, not only in terms of flood risk, but also in land use management because it can identify ecological suitability areas for societal activities (Magalhães et al., 2007; Magalhães et al., 2011).

For any given scale, landforms can be quantitatively categorised and mapped, according to their hydrological position in the watershed, by using the land morphology concept (LMC) and land morphology mapping (LMM) method (Magalhães, 2001; Magalhães et al., 2007). By classifying landforms according to hydrological position, it also outlines two different systems, the wet and dry (concave-convex surfaces) in the hillslope profile, including valley bottoms, hilltops and hillslope. As a topographic and physical method, it recognises and maps, with sufficient detail, finer landforms characterised by different land surface parameters, relative to surface water flow and accumulation, microclimate, soil erosion and accumulation, and vegetation.

In this paper, the land morphology concept (LMC) approach is used to map Portuguese landforms. The authors thus evaluate how landform mapping, particularly when it comes to the wet system, can support flood risk management. The LMC is applied through the land morphology mapping (LMM) method, using mainland Portugal as the case study. The resulting land morphology map is based on the 25 m resolution DTM, and is derived from the intersecting of flat areas (slopes less than 5%), surface curvature and hydrological features, including streams and ridgelines. The map for is compared and validated, at both the national and local scale, against previous flood risk data obtained from hydrological models for the main river basin. One set of data was taken from 2010 by the former National Water Institute (Instituto Nacional da Água – INAG, 2010) and the other from the 2015 database belonging to the Portuguese Environmental Agency (Agência Portuguesa de Ambiente – APA, 2015) and that of the 2010 land use and cover map from Portuguese Geographic Institute (Instituto Geográfico Português – IGP, 2010).

Given that hydrological modelling requires full documentation of hydrological characteristics and some streams are difficult to model, the LMC/LMM approach is a simplified one that does not affect the quality of the results. It is less demanding in terms of data, it is less time-consuming, and does not require so many complex steps. Consequently its introduction to mainstream flood mapping poses significant value for the Portuguese Government and the European Union, especially where there is no, or limited, available hydrological data for all river basins to map floodplains and flood risk areas.

2. Floodplain and wet system mapping

Floodplains are a vital part of river ecosystems, providing a buffer between the river and human activities on land (Konrad, 2015; Naiman et al., 1993). A broad definition of the term “floodplain” is given by Schmudde (1968). It encompasses three criteria: (i) topographical – flat and adjacent area to a stream (ii) geomorphological – a landform composed primarily of unconsolidated depositional material derived from stream sediments, and (iii) hydrological – a landform subject to periodic flooding by a parent stream. A floodplain may also be defined as a relatively smooth area of land adjacent to a stream or river that naturally flow beyond their banks, every few years during periods of high discharge (Marriott and Alexander, 1999; Goudie, 2004; Junk et al., 1989; Leopold et al., 1964; OAS, 1991).

Since flooding is a naturally recurring event (Bayley, 1995; Leopold et al., 1964) it may also be used to define natural floodplain environments (flood pulse concept) (Junk et al., 1989). Consequently, the demarcation of flood risk/flood-prone areas is based on floodplain delineation. In turn, a flood risk refers to the probability of a flood event causing adverse consequences to human health, heritage or economic activity (Jacinto et al., 2015). It does not conventionally take into account magnitude or severity. Most flood simulation models and administrative decisions rely on hydrological models and a hydrological definition of floodplain, i.e. an area inundated by floods within a particular return period. Therefore, the identification and consequently the mapping of flood prone areas depend on historical records of inundation and discharge, and empirical models of runoff and flood storage.

Floodplain mapping can address a wide-range of physical (e.g. morphological, hydrological), biological, ecological, economic and social problems (Kourgialas and Karatzas, 2011; Lastra et al., 2008; Rohde et al., 2006). The most common way to map a flood is through hydrological modelling. These models characterise terrain through a series of riverbed cross-sections and calculate aspects such as water depth and flow velocity. The models can be either two or three dimensional. Both are used for modelling areas of complex topography such as wider floodplains or broad estuaries but require high quality data and long computation time. Three dimension models consider time as a component (Jha et al., 2012). Hydrological modelling requires several variables, such as maximum monthly and annual discharges, flood-related data, riverbed cross-sections and channel geometry, to calculate runoff and flood storage, stage and duration, flood wave velocity, sedimentation and degradation patterns in the channel and a full documentation of hydrological characteristics, including historical records of inundation and peak discharges (Marriott and Alexander, 1999; Lastra et al., 2008).

Since hydrological models are built using historical, climatic, hydrological and geomorphological variables, they are particularly