GIS approximation of how land use/cover changes affect the hydrological system in a mediterranean mountain catchment

Una aproximación SIG de la afección producida por los cambios de uso del suelo en un sistema hidrológico de una cuenca mediterránea de montaña

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Abstract: Land use and land cover patterns are linked to natural and anthropogenic activities. Particularly, in the mediterranean region, the development of agriculture with a long history of cultivation is associated with many significant changes in the original landscape. During recent decades, most changes in Mediterranean agroecosystems are linked to the rapid expansion of crops and on the other side the abandonment of agricultural lands. In Spain land abandonment has particularly increased since the 1960s as a consequence of complex socio-economic factors leading to depopulation of rural areas.

Agriculture intensification in mediterranean agroecosystems and posterior land abandonment and reforestation have significantly affected the hydrological behavior and the connectivity patterns thus information on the spatial distribution of land use/cover is essential for monitoring the runoff response to interpret catchment hydrology. In this study, a medium size catchment (23 km^2) located in the central part of the Ebro Basin in the north-east of Spain, representative of Mediterranean mountain agroecosystems was selected to assess the effect of land use/cover changes during the last decades on the hydrological network in the catchment. The present study evaluates the spatio-temporal changes of land use/cover in the Vandunchil stream catchment over a period of 55 years. To this purpose remote sensing techniques for land use change detection by using aerial photographs are used to understand the landscape dynamic.

Key words: digital techniques, hydrological network, land abandonment, mediterranean agroecosystems, natural revegetation.

Resumen: *Los patrones de la cubierta vegetal y los diferentes usos del suelo se encuentran ligados a las actividades antropogénicas. Particularmente, en la región el desarrollo de la agricultura en la región mediterránea ha producido enormes cambios en el paisaje, y con ello en la conectividad hidráulica y su distribución. Estos ecosistemas fueron sometidos a una gran presión agrícola, la cual a partir de los años sesenta comenzó a abandonarse. Este abandono de los terrenos agrícolas produjo la revegetación natural de los campos de cultivo y la recuperación del bosque mediterráneo. Todo esto unido a los planes de reforestación llevados a cabo en estas áreas ha restaurado gran parte de la conectividad hidráulica natural reduciendo enormemente la escorrentía.*

*En este estudio se ha seleccionado una cuenca de tamaño medio (23Km^2) representativa de los agroecosistemas montañosos mediterráneos situada en la parte central de la cuenca del río Ebro al noreste de España. Esta cuenca fue seleccionada con el objetivo de estudiar y cuantificar la diferencia de la conectividad hidr**áulica** a causa del cambio en los usos del suelo de las últimas décadas. Para el desarrollo de este trabajo, se utilizaron técnicas de teledetección y fotografías aéreas de diferentes épocas. En el presente estudio se evalúan los cambios espacio-temporales producidos por los cambios en la cubierta vegetal de la cuenca del barranco Vandunchil en un periodo de 55 años.*

Palabras clave: *abandono de tierras, revegetación natural, red hidrológica, técnicas digitales, agroecosistemas Mediterráneos.*

INTRODUCTION

Sediment connectivity has an important effect on the development of morphological landform features being one of the greatest conditioning factors on the development of hydrological networks. Sediment connectivity have a great influence on how sediment is moved and relocated, modifying the current landscape and determining the spatial distribution of sources and sinks of water (Puigdefabregas *et al.*, 1999).

Soil erosion and hydrological connectivity is greatly responsive to land use (García-Ruiz, 2010; Kosmas *et al.,* 1997; Mohammad and Adam, 2010; Nunes *et al.,* 2011)and is not only closely related to geoecological factors (lithology, topography, and climatology. Humankind rather than natural forces are the source of most contemporary changes in land-cover (Meyer and Turner, 1994). Agricultural deforestation and changes in land use have generally been considered a local environmental issue, but it is becoming an important global problem (Foley *et al.,* 2005).

The literature has shown an increasing attention to the linkage between areas with different hydrological behavior and land use, with particular focus on the connection between hillslopes and channels (Cavalli *et al.,* 2013) and modelling the different process of hillslope instability (Heckmann and Schwanghart, 2013) geomorphic coupling and (sediment.

The problem of steep slope agriculture has changed connectivity and erosion rates during the last centuries in Mediterranean landscapes. In this investigation we assess an approximation to the variation of connectivity produced by land cover changes during the last 50 years. As a consequence of complex socio-economic and environmental factors such as the depopulation of rural areas and the impossibility of mechanization in steep terrain, land abandonment has occurred since the 1960s (Quijano, 2016). In addition, subsequent reforestation during the 70 and 80's caused a large impact on runoff reduction due to afforestation (Buendia *et al.,* 2016). The aim of this study is to approach how land cover change affects hydrological behavior in a middle size mountain Mediterranean catchment.

STUDY AREA

The study area is located in the Vandunchil stream valley within the central part of the Ebro Basin in the North-east of Spain (Figure 1a). From the geological point of view it is located on the distal part of the Pre-Pyrenean range with characteristically S-SW low bedding between 5 - 8 degrees. The rock outcrops in the study area include two conformable

Oligo - Miocene lithostratigraphic units of the Uncastillo Formation composed by sandstones, claystones and siltstones. The geomorphological setting is clearly conditioned by the low bedding strata.

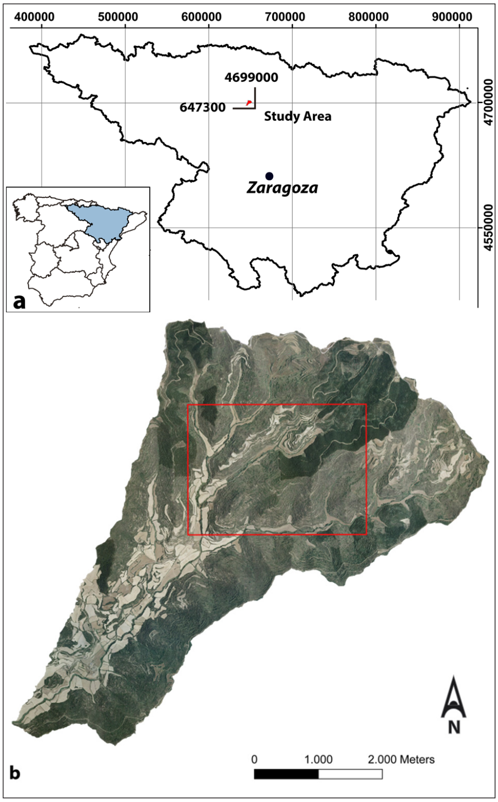

FIGURE 1. *(a) Location of the study catchment in the central part of the Ebro Basin (NE Spain). (b) Detailed orthophoto of Vandunchil Catchment. Red square delimits visualization of Figures 3-4*

MATERIALS AND METHODS

The assessment of sediment connectivity was carried out by applying topography - based index complemented by two land use maps for 1957 and 2012. A first map was created by an orthorectification of the American army aerial photographs 1957 using a supervised classification in ERDAS after a photographic enhancement. The current map was digitalized over 2012 PNOA orthophotography and field work maps.

Sediment connectivity was estimated using a numerical modeling approach to simulate how connectivity changes due to the different land covers. Coupling behavior has a great effect on how the systems respond to disturbance. Hence it is really important to determine how the system connectivity responds to human induced cover changes (Harvey, 2002)based mainly on previously published work. Coupling mechanisms link the components of the fluvial system, controlling sediment transport down the system and the propagation of the effects of base-level change up the system. They can be viewed at several scales: at the local scale involving within-hillslope coupling, hillslope-to-channel coupling, and within-channels, tributary junction and reach-to-reach coupling. At larger scales, coupling can be considered as zonal coupling, between major zones of the system or as regional coupling, relating to complete drainage basins. These trends are illustrated particularly by the examples of hillslope-to-channel coupling in the Howgill Fells, northwest England, badland systems in southeast Spain, alluvial fans in Spain, USA and UAE, and base-level-induced dissection of Neogene sedimentary basins in southeast Spain. As the spatial scales increase, so do the timescales involved. Effective temporal scales relate to magnitude and frequency characteristics, recovery time and propagation time, the relative importance changing with the spatial scale. For downsystem coupling at the local scale, the first two are important, with propagation time increasing in importance in larger systems, especially in those involving upsystem coupling related to base-level change. The effective timescales range from the individual event, with a return period of decades, through decadal to century timescales for downsystem coupling, to tens to hundreds of thousands of years for the basinwide response to base-level change. The effective timescales influence the relative importance of factors controlling landform development.”,”-DOI”:”10.1016/S0169-555X(01. For this reason we used the connectivity index (1) proposed by (Borselli et al., 2008)one (IC using the C-factor from RUSLE as a weight factor (*W*) in the index.

$$IC = log_{10} \frac{D_{up}}{D_{dn}} \quad (1)$$

Where and are the upslope and downslope component defined by:

$$D_{up} = \overline{WS}\sqrt{A} \quad (2)$$

where *W* is the average weighting factor of the upslope contributing area, *S* is the average slope gradient of the upslope contributing area (m/m) and *A* is the upslope contributing area (m^2).

$$D_{dn} = \sum_i \frac{d_i s_i}{w_i} \quad (3)$$

where is the length of the flow path along each *i* cell according to the steepest downslope direction (m), and are the weighting factor and the slope gradient of the *i* cell, respectively.

Borselli *et al.* (2008) one (IC proposed including 0.005 as the minimum slope value to avoid infinitive values in equation (2). Following the methodology applied by Cavalli et al. (2013) we preserved the original values of our 2m DEM to obtain more realistic results. In equations (2) and (3) we used our two land use maps (C-factor) as weighting factor to show the differences between both land uses (1957 and 2012) and how the connectivity index changes over time. To facilitate the visualization we selected the same area as Figure 3 to show how connectivity has changed over 50 years due to land cover modifications.

Results

Steep slope terraces are usual in mountain agroecosystems for rudimentary agriculture. Near-absence tectonic in Vandunchil Catchment determined low dip strata resulting an easy farmable terrain for rudimentary agriculture. Steep slope agriculture not only increases erosion and runoff ratios on the hillslopes but also produces slope instability fostering the probability of mass movements due to the absence of vegetation cover that protects the soil from erosion (Figure 2).

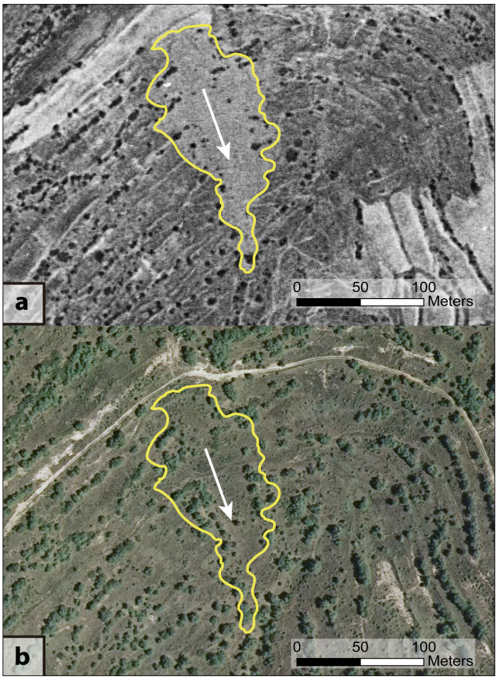

FIGURE 2. *(a) Elongated slide-flow-type slope movement detected on 1957 aerial photography, likely developed during a storm event and favored by the absence of vegetation cover, high slope and the upper dryland crops. (b) Same area, now stabilized by the revegetated cover*

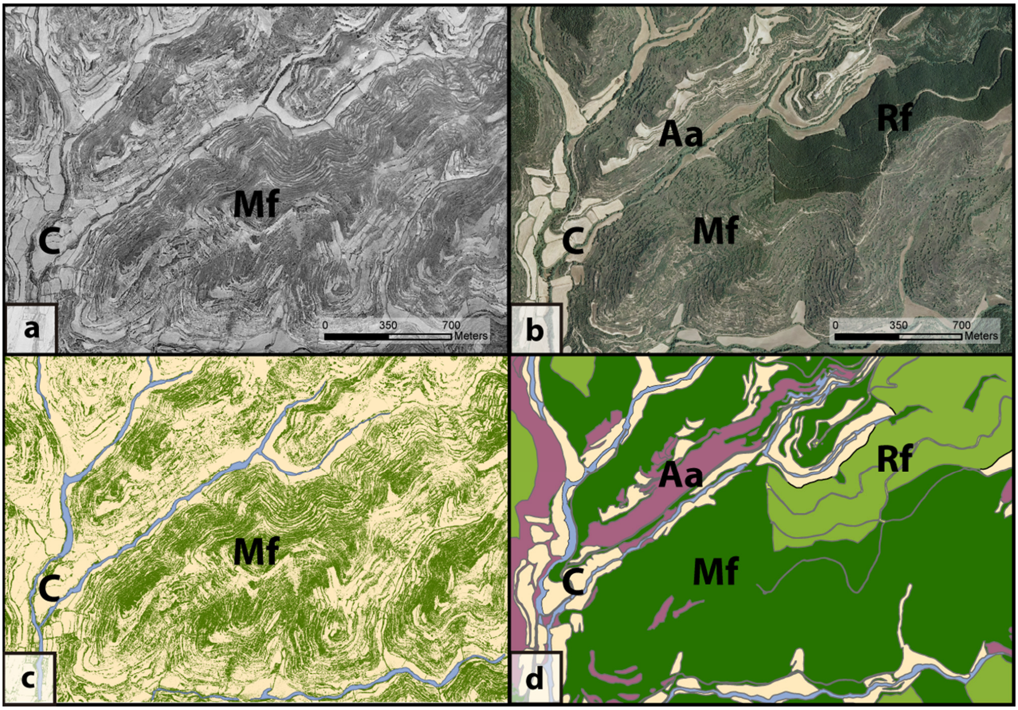

FIGURE 3. *(a) 1957 Aerial photograph. (b) 2012 Orthophotography (c) Land cover map developed using a supervised classification of (a). (d) Land cover map of (b) completed in field work. Cultivated land (C), Mediterranean forest (Mf) Reforestation forest (Rf) Abandoned agriculture (Aa)*

The total crop area percentages in both years are 12.3 km^2 and 3.8 km^2 for 1957 and 2012, respectively being 53% and 16% of the total area (23 km^2) of the Vandunchil catchment.

Figure 3a shows a classic example of steep slope agriculture with almost 70% of the slopes and stream terraces cultivated. Conversely Figure 3b shows an important modification caused by reforestation and the steep slope cover by scrublands. It has been shown that badlands and severely eroded areas have a higher degree of connection than agricultural forest and scrubland (Palazón and Navas, 2014).

Connectivity index with different land covers as a weight factor show an approximation of the effect of human activity over the study area. In Figure 4 it can be easily recognized the decrease on runoff due to new covers as natural revegetation, abandoned fields and the great variation induced by reforestation.

In headwater fluvial catchments the more relevant aspect of coupling is connection between hillslope and channel, i.e. hillslope-channel coupling (Harvey, 2002). Connectivity and slope are essential for coupling development. With the modification in land cover, mostly in reforestation areas, reduction on overland flow might interfere reducing sediment displacement and probably centralizing highest connectivity and erosion areas in streams that remain coupled (yellow-green streams inside afforestation areas in Fig 4).

The treetops minimize the kinetic energy of the raindrops preventing soil detachment (De Luna *et al.*, 2000). Besides, the vegetation cover improves soil quality, by favouring infiltration and preventing runoff. On the contrary, high erosion rates and the low slope resistance could easily produce mass and flow-type slope movements (Figure 3). These fed large volumes of sediment into the stream system.

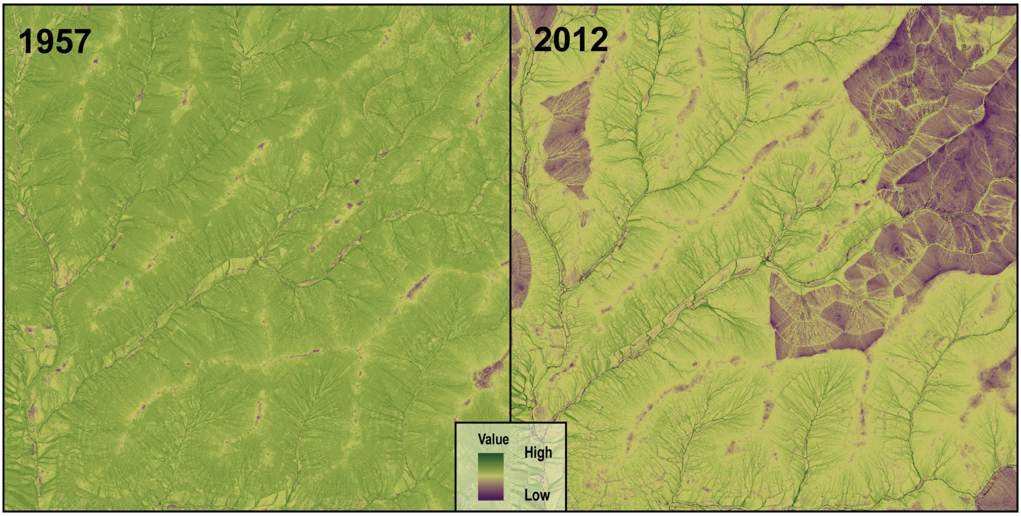

FIGURE 4. *Connectivity index for 1957 and 2012. These figures correspond to the red square on Figure 1 to improve visualization of a representative part of the catchment affected by changes in land cover*

Comparing both IC output map and land cover maps (Figure 4) it can be seen the importance of land cover for preventing runoff and the benefits of landscape restoration. Strong changes in reforestation cover in the IC maps, land abandonment, natural revegetation and especially the reversal to Mediterranean forest have a great effect on the loss of coupling as a consequence on the decrease of runoff.

CONCLUSION

Land use/cover changes by human intervention, have probably increased connectivity and runoff in Vandunchil Catchment, mostly due to tillage and soil loss whilst abandoned arable lands and reforestation areas seems to be very efficient in reducing runoff and connectivity. Besides reforestation works have reduced the connectivity that probably has contributed to limit soil erosion.

Likely human land cover changes were favored by the low dip of the strata, which created natural terraces easily farmable for rudimentary agriculture. Nowadays the loss of steep slope agriculture and the searching for more propitious an easier agriculture lands are reducing runoff in mountain catchments but also producing abandonment of rural communities.

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