Mapping riverbed conditions at the drainage-network scale in the Perales river basin (Spain)

Cartographie de l'état du lit des rivières à l'échelle du réseau hydrographique dans la rivière Perales (Espagne)

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RÉSUMÉ

Le transport des sédiments et les processus de changement géomorphologique ont des implications pour de nombreuses questions relatives à la gestion des rivières, telles que les risques d'inondation, la restauration des rivières, l'énergie hydroélectrique ou le dimensionnement des infrastructures. Par conséquent, les gestionnaires de cours d'eau ont souvent besoin d'informations sur les conditions géomorphologiques et hydro-sédimentaires des chenaux fluviaux. Dans ce travail, nous proposons une démarche SIG adaptée à la caractérisation de l'état du lit des rivières à l'échelle d'un réseau de drainage, en termes d'incision, d'aggradation ou d'équilibre vertical. Nous avons appliqué cette procédure à la rivière Perales (centre de l'Espagne) et nous avons obtenu une carte des conditions morpho-sédimentaires de 113 segments de cette rivière. Nous pensons que ce type de caractérisation pourrait contribuer à une première évaluation des rivières en termes d'équilibre sédimentaire à l'échelle d'un bassin versant et aider à prioriser les secteurs pour des études plus détaillées et plus approfondies.

ABSTRACT

Sediment transport and geomorphic change processes have implications for many river management issues, such as flood hazards, river restoration, hydropower or infrastructure design. For this reason, river managers often require information on the geomorphic and hydro-sedimentary conditions of river channels. In this work, we propose a GIS workflow adapted to the characterisation the bed condition of channels at a drainage network scale in terms of incision, aggradation or vertical equilibrium. We have applied this procedure to the Perales river (central Spain) and we derived a map of the morpho-sedimentary conditions of 113 river segments of this river. We believe that this type of characterisations could contribute to a first assessment of rivers in terms of sediment balances at a catchment scale and help to prioritise sectors for more detailed, further studies.

KEYWORDS

Sediment transport, bed incision, aggradation, GIS, geomorphic changes

Transport sédimentaire, incision du lit, aggradation, SIG, changements géomorphologiques

1 INTRODUCTION

Sediment transport is a major control on river channel morphology (Church, 2006). At the river reach scale, the balance between sediment inputs and outputs of the reach determines whether the channel is in 'equilibrium' or is experiencing aggradation or erosion. Knowledge of these sediment budgets at the reach scale is of interest for many management issues. For example, bed incision can affect the stability of channel banks and infrastructure such as riverine roads and bridge piers. In addition, aggradation during floods can be a significant source of hazard (Vázquez-Tarrío et al., 2024).

It is not surprising, therefore, that river managers seek catchment-scale characterisations of sediment balances along the different sections of river networks, as this type of information can help them to prioritise those river sections where restoration or other action is required. In this paper, we propose a relatively simple, fast method for producing catchment-based maps of sediment budgets of river channel, based on commonly used Geographical Information System (GIS) tools. To illustrate the method, we will show the results obtained following its application to the Perales basin (Central Spain).

2 STUDY CASE

Perales River basin drains the Sierra de Guadarrama (Spanish Central System, Tagus Basin). It has a catchment area of 528 km^2, draining a substrate dominated by granitic rocks in headwaters and unconsolidated sandstones in the lowland sectors of the basin. Land covered consists mainly in forest, shrubs and crops.

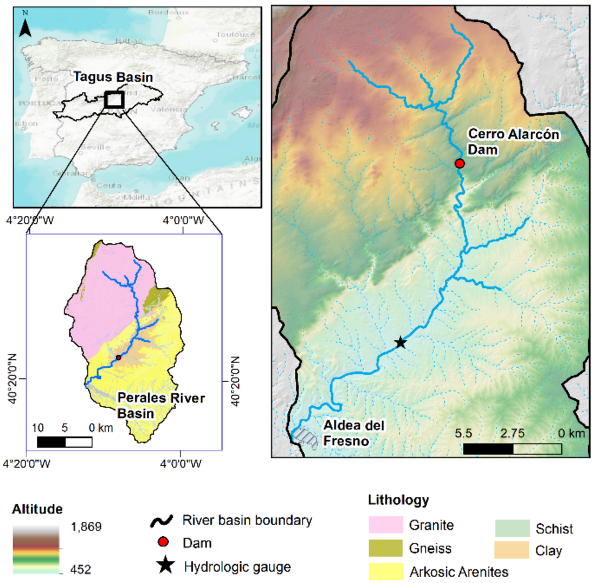

Figure 1. Study site location.

3 METHODOLOGY

3.1 Rationale of the method

The relations between sediment transport and geomorphic changes, at the reach scale, can be described through the 1D sediment continuity equation (Ashmore and Church, 1998):

$$\Delta V = q_{s,i-1} - q_{s,i} \qquad \text{Eq. 1}$$

where ΔV are the volume changes in sediment storages, q_s are the sediment transport rates (in volume), and the subscripts i and $i\text{-}1$ refer to the downstream and upstream boundaries of the considered reach.

When a reach is in 'morphological equilibrium', the amount of sediment exported downstream is equal to the amount of sediment input upstream and ΔV~0. Once there is an imbalance between sediment input and output, the channel will respond by either incising ($\Delta V < 1$) or aggrading ($\Delta V > 1$).

Based on eq.1, it could be defined the following metrics (UPC, 2021):

$$\Delta nV_i = \frac{q_{s,i-1} - q_{s,i}}{min(q_{s,i}, q_{s,i-1})} \quad \text{Eq. 2}$$

which is the volume changes in sediment stocks normalized by the volumes of transported sediment in the reach. Output from eq. 2 will be 0 if the reach is in “equilibrium”, greater than 0 if it is aggrading and less than 0 if it is incising.

If we consider the bankfull discharge as the dominant channel-forming flow, we could combine eq. 2 to Recking’s bedload equation (Recking et al., 2016), the Chezy’s friction equation, the slope-depth product for the bed shear stress and the expression for the Shields parameter to arrive to the following expression:

$$\Delta nV_i = \frac{\left[B^{1.2} A^{3N/5} S^{4.5}\right]_{i-1} - \left[B^{1.2} A^{3N/5} S^{4.5}\right]_i}{min\left(\left[B^{1.2} A^{3N/5} S^{4.5}\right]_i, \left[B^{1.2} A^{3N/5} S^{4.5}\right]_{i-1}\right)} \quad \text{Eq. 3}$$

where *B* is the channel width, *S* is the bed slope and *A* is the catchment area draining the downstream boundary of the reach.

3.2 GIS implementation

The estimation of ΔnV_i using eq. 3 in a Geographical Information System (GIS) environment based on cartographical and geospatial data depends on the availability of four information: i) active channel width; ii) bed slope; iii) catchment area; and iv) the empirical exponent defining how bankfull discharge scales with catchment area.

We then implemented a GIS-based workflow consisting of six main steps to estimate ΔnV_i:

- Step 1: Extracting the drainage network of the study catchment from previous maps. We based on the 1:10,000 topographic map of Spain produced by the Spanish National Geographic Institute (IGN).
- Step 2: Segmenting the drainage network every 500 m. We got 113 reaches.
- Step 3: We mapped the active channel width. To do so, was manually digitised the active channel belt based on the interpretation of the orthophoto of the PNOA project (National Plan of Aerial Ortophotography, IGN), dated 2022 and with a pixel size of 0.25 m. This information was freely downloaded from the CNIG website (CNIG is the Spanish National Centre for Geographic Information, website at https://centrodedescargas.cnig.es/).
- Step 4: estimating the catchment area draining to each reach. We based on a 5-m resolution DEM freely available for the study area on the CNIG website. We used ESRI® ArcGis watershed tools to estimate the area draining the upstream node of each reach.
- Step 5: Estimating the mean channel slope in each reach. This was obtained from the 5-m resolution DEM as the ratio of the height differences between the upstream and downstream nodes of the reach and its length.
- Step 6: Estimating the exponent linking bankfull discharge and drainage area. We based on data available for 59 gauging stations in the Perales River basin, in neighbour catchments and other catchments located in Central Spain.

4 RESULTS

Based on this methodology, we estimated the ΔnV_i for the 113 reaches in which we have segmented the drainage network. Then, according to the values obtained, we classified each segment as potentially aggrading, incising or in equilibrium. The obtained map is shown in Figure 2. The map shows an alternance between aggrading and incising reaches along the entire drainage network.

5 DISCUSSION

The workflow proposed in this work has allowed us to obtain a synoptic characterisation of the morphosedimentary general conditions of the Perales river basin. The method is simple, relatively quick to apply and relies on sources of information available for many basins around the world.

We are aware of all the limitations inherent in attempting to characterise sediment transport relationships with a 'static' picture, such a map, and without detailed field observations. However, we believe that such tools could be of great interest to river managers in terms of: 1) giving them a general idea of the state of sediment fluxes in a given basin; and 2) helping them to prioritise and select sectors to focus on for more detailed studies.

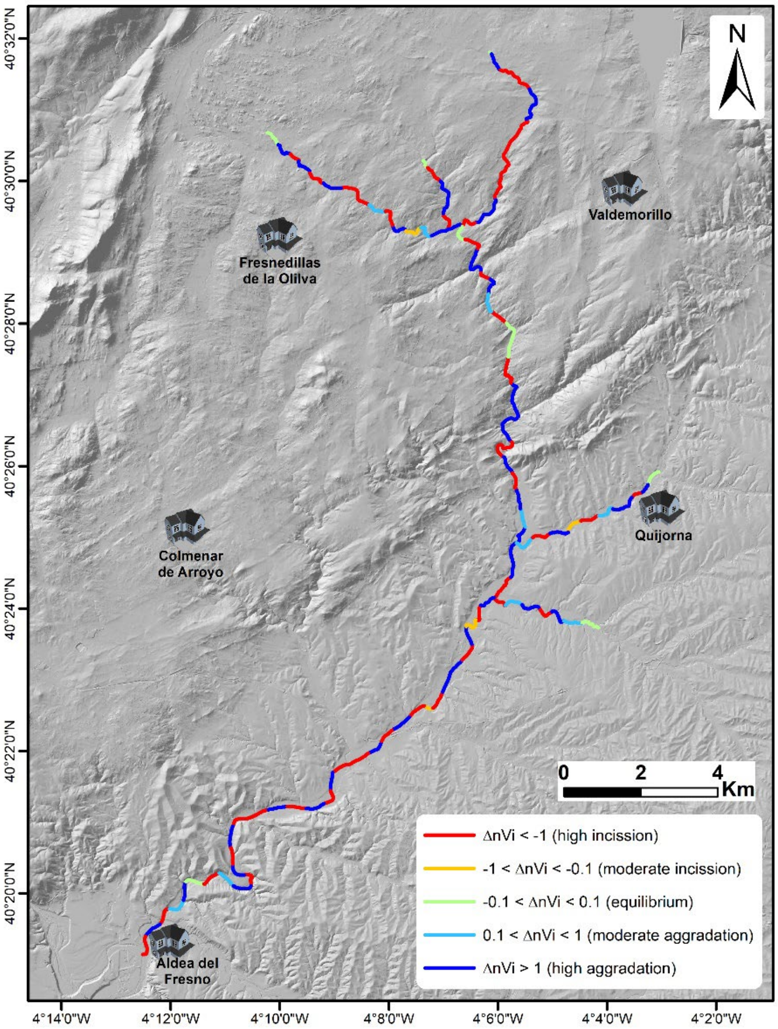

Figure. Map of riverbed conditions along the drainage network of the Perales river.

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