Trajectory of change in the middle Garonne river during the last 150 years: learning of Multiple Factor Analysis (MFA) in the study of historical maps

Trajectoire d'évolution de la moyenne Garonne toulousaine au cours des 150 dernières années : apport de l'Analyse Factorielle Multiple (AFM) à l'étude des cartes historiques

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RÉSUMÉ

Les changements récents observés sur la dynamique fluviale de la moyenne Garonne toulousaine (SO France) sont abordés par le biais d'une analyse diachronique. Une base de données morphométriques a été construite à partir de quatre ensembles de cartes historiques couvrant les 150 dernières années (1868, 1940s, 1970s et 2000s). Ces données ont été traitées par Analyse Factorielle Multiple (AFM) mixte. Les résultats de l'AFM mixte, post-traités par Classification Ascendante Hiérarchique (CAH), mettent en évidence quatre trajectoires d'évolution au sein du linéaire d'étude. Nous discutons du rôle des facteurs de contrôle (climat, activités anthropiques et fonctionnement géomorphologique) dans ces modèles spatio-temporels.

ABSTRACT

Recent changes in the fluvial dynamics of the middle Garonne river (SW France) are approached by a multitemporal analysis. A morphometrical database has been built using a set of four historical maps covering the last 150 years (1868, 1940s, 1970s and 2000s). These data have been processed using mixed Multiple Factor Analysis (MFAmix). The results of the MFAmix, post-processed by Hierarchical Cluster Analysis (HCA), allow to highlight four trajectories of change into the fluvial reach. We discuss the role of controlling factors (climate, human activities and geomorphological functioning) in these spatial patterning and temporal evolutions.

MOTS CLES

Analyse Factorielle Multiple (AFM), Cartes historiques, Dynamique fluviale, Garonne, Trajectoire d'évolution.

INTRODUCTION

Downstream to Toulouse (SW France), the middle Garonne river experiments a decrease in river dynamics for several decades. This change results into three major phenomena : 1) a channel deepening ; 2) a decrease in the lateral riverbed mobility and 3) a loss of riparian environment diversity and extent. These phenomena have been highlighted by several studies, which has focused on the second half of the XXth century. The controlling factors identified are related to human disturbance : in channel gravel quarrying, sediment retention by hydroelectrical dams, riverbank dike and upper catchment reforestation. However, studies on the Garonne river dynamics before the middle of the XXth century are sparse. This limits our understanding of the observed changes and their causes. The aim of this study is to trace back the trajectory of change of the Garonne river downstream to Toulouse during the last 150 years, in order to put into perspective the observed changes and discuss their controlling factors. This kind of study often uses multivarite analyses, especially factor analyses, in order to process morphometrical data (Clement and Piegay, 2003). However, the mixed Multiple Factor Analysis (MFAmix) is rarely used in geosciences. MFAmix is a suitable method to process both quantitative and qualitative data organised by set / date and then to take into account temporal dimension. A lesser goalof this study is to assess the contribution of MFAmix in the establishment of the trajectory of change in the middle Garonne river downstream to Toulouse.

1 TOOLS AND METHODS

1.1 Study area

The Garonne river is the 4th french river in terms of flown length (522 km). The confluence of the Garonne and Dordogne rivers forms the largest European estuary. The middle Garonne river is the median reach of the stream, between the pyrenean mountain and tidal flows influence. This section is characterised by an enlarged floodplain and a high rate in historical channel mobility. Into the middle Garonne river, the reach downstream to Toulouse (63 km until the Tarn tributary) is particularly homogeneous in terms of hydro-geomorphological features.

1.2 Quantitative analysis of historical maps

The analysis of national and departmental archives has allowed to establish a corpus of historical maps of the middle reach of the Garonne river downstream to Toulouse between 1750 and 2000. Into this corpus, three sets of documents have sufficient quality and accuracy to allow a quantitative approach : the anonymous map of 1868 (1:10000) ; the maps drawn by IGN in 1940s (1:5000 – 1:25000) and the maps drawn by IGN in 1970s (1:25000). The reference map (scan25, 1:25000), drawn and georeferenced by IGN in 2000s, completes the set of maps in order to cover the period 1868-2000.

The selected documents have been georeferenced in a GIS environment (ArcGIS) and the river shapes have been digitalized (main channel, secondary channels, bars, vegetalized islands and active belt). The alluvial plaine has been divided into 63 one km length sub-reaches. Ten morphometrical indicators have been computed at each date (1868, 1940s, 1970s and 2000s), firstly at the reach scale and secondly at the sub-reaches scale. Four of these indicators are related to the channel morphology: sinuosity index (SI) ; channel width (CW) ; active belt width (ABW) and number of secondary channels (SC, thereafter converted in qualitative data). The other six parameters characterize islands and bars : vegetalized surface (VS) ; non vegetalized surface (NVS) ; surface (S) ; perimeter (P) ; circularity index of Gravelius (G) and near distance to the bank (ND).

The morphometric indicators computed at the reach scale have been first processed by univariate analysis in order to highlight the general trends. The entire dataset, (ie. 63 individuals and 40 variables organised by date) has been analysed by mixed Multiple Factor Analysis (MFAmix). The MFAmix allowed to highlight correlations between both quantitative and qualitative variables. A Hierarchical Cluster Analysis (HCA) has been performed on the 10 first factor axis of the MFAmix (80% of inertia), in order to pack sets of sub-reaches which have similar features. According to the dendrogramm, data have been agragated into seven classes (Fig. 1).

2 RESULTS AND DISCUSSION

2.1 Changes at the reach scale

The quantitative analysis at the reach scale shows a trend of global simplification and homogenisation of the channel over the last 150 years : the reach loses 330 ha of islands and 260 ha of bars (*i.e.* respectively 90 % and 88 % of the initial surfaces) ; the number of secondary channels decreases (- 24%) and the active belt contracts by 100 m on average (*i.e.* 58 % of the initial surface).

2.2 Fluvial patterns into the river reach

The spatial layout of the AFMmix / HCA results reveals four fluvial patterns into the river reach. Each of these sections is characterized by one or more class(es) (Fig. 1). The controlling factors of these dynamics can be discussed at the light of to the data collected by P. Valette (2002).

The first upper section (S1) is characterized by the class 2. This section is constrained by the Toulouse city . The islands progressively disappear as a result of secondary channels artificial filling, for industry development in the early XXth century and for flood protection after the Second World War.

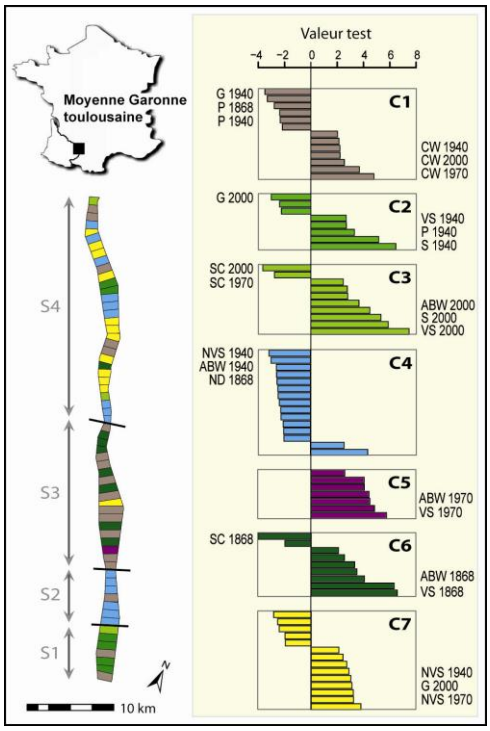

Fig. 1 : Fluvial patterns into the middle Garonne river downstream to Toulouse, according to MFA / HCA results

The second section (S2) is characterized by the class 4. At the beginning of the study period, this section shows a gently meandering pattern (channel mobility and depositional bars on the insides of bends). The channel progressively stabilizes by the spreading of the vegetation on bars and then the disappearing of islands. This trend is consistent with reducing bedload observed as soon as 1930s in this area, as a result of the removing of the fluvial islands in order to make navigation easier.

The median section (S3) is characterized by both classes 1 and 6. Large complexes of islands can be observed only in this section. These islands disappear at the beginning of the period, maybe as a result of previousmanagements carried out to gain ground on the river and / or because of large floods decreasing at the end of the XIXth century according to the end of the Little Ice Age (LIA).

The downstream section (S4) is characterized by high diversity. Almost all classes are present but the class 7 is predominant. This section is clearly meandering during most of the period. The channel only stabilizes in the end of the period, as a result of the campaign of banks management in the Tarn-et-Garonne region between 1960 and 1980.

3 CONCLUSION

This study highlights a channel simplification and a lose of diversity in fluvial patterns in the middle Garonne river downstream to Toulouse, preceding the middle XIXth century at least in the upper and median sections. Human controlling factors, related to river management, could explain this early trend. However, the decrease in runoff under climate control could also be partially recorded. At the same time, this study attests to the involvement of the 1960-80s banks managements in the stabilisation of the downstream section.

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