Recent river-floodplain dynamics in a tropical agricultural landscape: a one-way or two-way relation?

Dynamique récente rivière-plaine d'inondation dans un paysage agricole tropical : une relation à sens unique ou à double sens ?

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RÉSUMÉ

Les pratiques agricoles traditionnelles le long des rivières à écoulement libre dans les régions de basses latitudes se sont développées en rapport étroit avec la dynamique des rivières et des plaines alluviales, une relation déjà exprimée par le paradigme de la sociogéomorphologie. Dans le cas de l'agriculture intensive en monoculture, l'ingénierie fluviale est plus invasive que l'agriculture à petite échelle qui contrôle l'érosion des berges et les systèmes d'irrigation qui répondent aux besoins en eus des plantes. Deux tronçons de la rivière Huallaga, dans l'Amazonie péruvienne, ont été analysés afin de comparer la dynamique chenal-lit majeur dans ces différents environnements agricoles : un tronçon de 10 km de long en amont et un tronçon de 45 km de long en aval. Bien que l'utilisation de la plaine alluviale soit agricole dans les deux cas, dans le premier, le système agricole est familial, caractérisé par de petites parcelles et une grande agrodiversité. Sur la rive gauche du second tronçon, en revanche, on trouve une grande parcelle de monoculture (135 km^2 de palmiers à huile). Les trajectoires d'évolution de la rivière des deux cas ont été analysées par une procédure semi-automatique basée sur des images satellites. La comparaison entre les deux tronçons montre des comportements différents dus à la morphodynamique, le facteur environnemental, et à l'utilisation des terres dans le corridor érodable, le facteur anthropique.

ABSTRACT

Traditional agricultural practices along free-flowing rivers in low-latitude regions have developed in close contact with river-floodplain dynamics, often resulting into a co-evolution of the natural and human systems that is well expressed by the sociogeomorphology paradigm. In the case of intensive monoculture agriculture more invasive river engineering is adopted, compared to small scale farming to control bank erosion and irrigation systems to meet the water needs of plants. Two reaches of the Huallaga River in the Peruvian Amazon were analysed to compare river-floodplain dynamics in such different agricultural environments. The upstream reach (9.137 S, 76.041 W) has a wandering morphology and is 10 km long, the downstream reach (8.309 S, 76.379 W), has a meandering morphology and is 45 km long. Although the floodplain use is agricultural in both cases, in the upstream reach the farming system is family-based, characterised by small plots and high agrodiversity. On the left bank of the second reach, in contrast, there is a large monoculture plot (135 km^2 of oil palm). River evolutionary trajectories of the two reaches were evaluated through a semi-automatic procedure based on satellite imageries. Comparison between the two reaches shows different behaviours due to morphodynamics, the environmental driver, and land use within the erodible corridor, the anthropogenic driver.

KEYWORDS

Agriculture, Bank erosion, Low latitude Rivers, Peruvian Amazon, Sociogeomorphology

1 INTRODUCTION

Floodplains and low fluvial terraces have been used for centuries for agricultural purposes because of their proximity to water sources, which are relevant to the water demand of crop species, and because of the nutrient-rich soils, which are favourable due to the predominantly sandy/clayey texture resulting from the deposition of the river fine sediment. At the same time, fluvial disturbance, in terms of both flow regime (water level variation at different time scales) and morphodynamics (floodplain accretion and bank erosion), threatens agricultural practices of riverine communities and of industrial farms. Smallholder agriculture have developed tailored-to-context strategies to fit into these complex adaptive systems (Correa De Silva et al., 2019), including the choice of cropping species with cultivating period suited to flood regime or selecting flood-resistant crop varieties (Serrao et al., 2022), while intensive/mono-cultural agriculture have implemented more impacting interventions aimed to stabilise riverbanks and to limit erosion, at higher implementation and maintenance costs.

Despite smallholder and industrial farms are commonly classified as agricultural land use, they present key differences, in terms of their drainage and water retainment capacity, their sediment load delivery capacity, especially when comparing agro-ecosystems with monocultural fields. Thus, the anthropogenic component of floodplain’s agricultural exploitation might: (i) reduce the river flow, when large volumes are derived through water abstractions, (ii) modify the river-morphology, through riverbank structures and cross-sectional discontinuities, (iii) vary the chemical composition of water, in case of intensive use of pesticides, herbicides or fertilisers that may leach into the water table and eventually discharged into the river, and (iv) affect the natural riparian ecosystem. The present work focuses on the relation between agricultural floodplain use and the variations of the river morphology, comparing the related dynamics in a wandering reach with extensive (traditional) agricultural pattern, highly impacted by river disturbance and slightly influencing river-morphodynamics, with a meandering reach affected by intensive (industrial) agricultural pattern, less impacted by river disturbance but highly affecting river morphodynamics.

The two reaches are part of the Huallaga River (Peru), a tributary of the Marañón river. The upstream meandering Tocache reach (8.309 S, 76.379 W), has intensive floodplain agriculture, and the downstream wandering Shiringal reach (9.137 S, 76.041 W) has extensive floodplain agriculture.

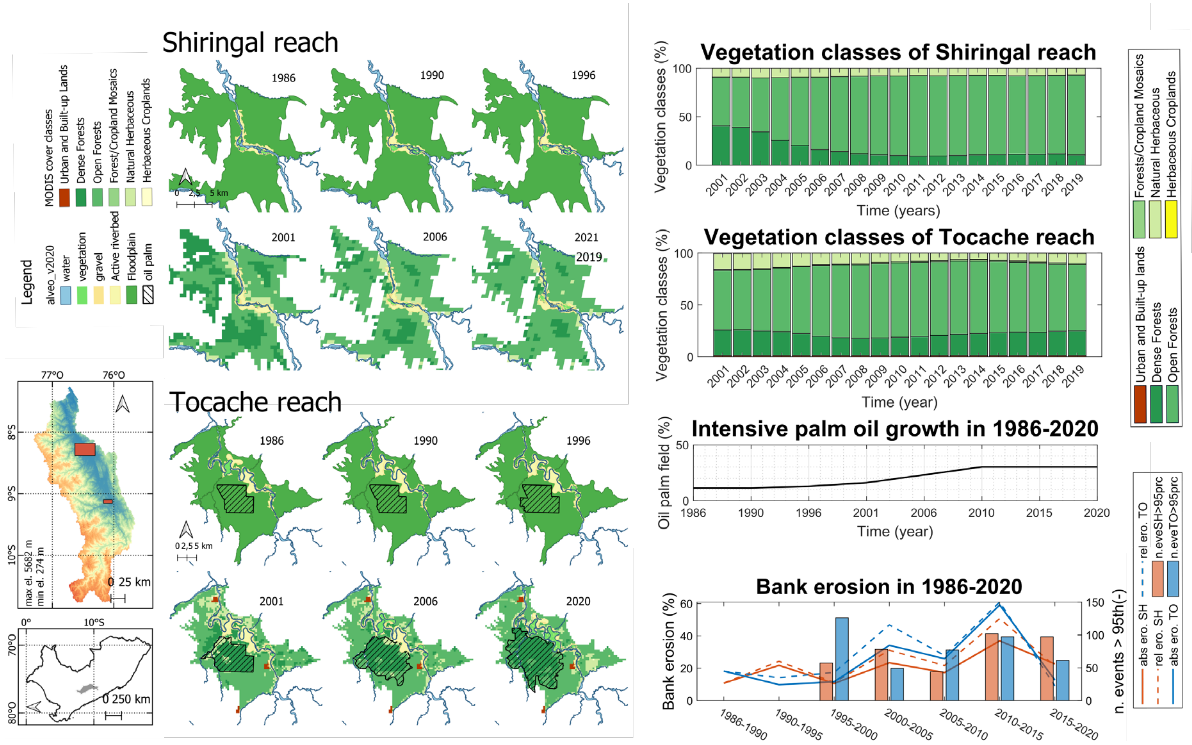
2 METHODS

The semi-automated procedure for remote sensing fluvial analysis developed by Spada et al. (2018) has been used to investigate the river trajectories of the two reaches in 1986-2019 period. Landsat summer scenes with low percentage of cloud cover (<10%) have been analysed with a timestep of about 5 years covering the 1986-2020 period. Summer low flow conditions allow to compare scenes with comparable discharge, highlighting planform changes following flood events. The procedure combines different bands to compute NDVI and NDWI indices, and, through an unsupervised analysis that exploits percentiles of NDVI, VIR and NDWI histograms, can recognise the active riverbed and distinguish the three main land cover classes of erodible river corridors: water, vegetation, and exposed, dry sediment. Floodplain accretion and bank erosion dynamics have been evaluated through the difference of active riverbed masks of two consecutive scenes, Comparison with the first available scene (1986) allowed to obtain the absolute percentage of areal change between classes. The temporal evolution of crop types in the floodplain has been obtained through MODIS images (FAO-Land Cover Classification System 1-LCCS1) referring to the 2001-2020 period for both reaches, while the extension of the oil palm field in Tocache reach have been achieved through a visual identification of Google Earth satellite images in the 1986-2020 period.

In addition to the remote sensing analysis, a water level time series analysis has been conducted for the flow records of Tingo Maria (20 km upstream of Shiringal reach) and Tocache (at the downstream end of the Tocache reach) to detect potential significative trends and to discuss morphological changes. Flood events have been identified as those occurring above a threshold corresponding to the 95th percentile of the water level time series, given the lack of bathymetric information.

3 RESULTS AND DISCUSSION

Preliminary results show that the Huallaga River almost doubled its average active-riverbed width in the two reaches in 1986-2020, regardless of the different morphology in Shiringal and Tocache. The Tocache, meandering reach has considerably decreased its erosion capacity in recent years and, at the same time, has witnessed an increase in intensive agriculture extending up to 50% of its floodplain (classified as *dense forest* by MODIS). The Shiringal, wandering reach, whose floodplain is characterised by extensive agricultural pattern, has continued to show a general increasing trend of erosive capacity and a general loss of *dense forest* class not associated with intensive agricultural field (as in the case of Tocache). The abrupt decrease of bank erosion in Tocache reach (from 60% to 15%) can't be fully explained by the reduced number of above threshold flood events recorded in 2015-2020 period and suggests the need of further investigation on river sensitivity of the two reaches (Fryirs, 2017).



River-floodplain dynamics in 1986-2020. On the left side: maps of vegetation classes evolution in the two reaches. On the right side: vegetation evolution at floodplain scale, growth of the palm oil field in Tocache floodplain and bank erosion vs. over-threshold events of the two case studies.

4 CONCLUSIONS

We investigated the possible hydro-morphological role of different agricultural patterns (intensive vs. extensive) by comparing agricultural land use and morphological changes in a tropical large river. Results suggest that riverside intensive agriculture, besides being likely affected by river flooding, might indirectly affect the river lateral migration because of riverbank structures that are built for protection of the agricultural fields. Floodplains with extensive agriculture are instead dependent on river disturbance (Serrao et al., 2020) without substantially affecting it. Overall, our preliminary findings allow us to formulate the hypothesis that a two-way interaction might characterize river and floodplain intensive agriculture, a one-way interaction being instead dominant when floodplain agriculture is extensive. To fully test such hypothesis, additional morphological parameters, e.g. sinuosity, and a similar analysis on a third reach with complementary properties (wandering morphology and intensive agriculture) are needed. This would allow to better disentangle the relative weight of the possible controlling factors of morphological change, thus allowing a deeper insight into the coevolution of such agro-geomorphic systems.

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