How large can be a braid plain? A worldwide scale comparison

Quelle est la largeur d'une rivière en tresses ? Ue comparaison à l'échelle globale

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RÉSUMÉ

Les rivières en tresses sont des rivières à chenaux multiples caractérisées par de larges bandes actives. Elles se trouvent surtout dans les régions de montagne ou de piémont à travers le monde, là où il existe une connexion active en amont avec les sources sédimentaires. Mais est-ce que les rivières en tresses fonctionnent de la même manière à travers le monde ? L'hypothèse est qu'il existe, à l'échelle globale, une gamme de conditions déterminant le patron de tressage et les largeurs des bandes actives en fonction de la taille du bassin versant et de ses caractéristiques hydroclimatiques, géologiques ou orographiques.

Cette étude est basée sur l'analyse de la relation entre la largeur de la bande active et certaines caractéristiques des bassins versants amont (c'est-à-dire la largeur de la bande active normalisée) de 257 tronçons de rivière en tresses à travers le monde, caractérisés à l'aide d'images satellites disponibles entre septembre 2019 et mai 2020. Nous avons ensuite comparé la gamme de valeurs de largeur de bande active normalisée à certains caractères des bassins (par ex., les conditions climatiques, hydrologiques et de relief). Nos résultats montrent que ces facteurs contrôlent la taille des tresses et qu'il existe ainsi des conditions plus ou moins favorables pour que des systèmes en tresses se développent sur terre.

ABSTRACT

Braiding rivers are multi-channel rivers characterized by large active channel or braid plain areas. They occur in mountain or piedmont regions across the world, most likely where there is an active upstream connection with sediment sources. But do braiding rivers behave the same across the world? The hypothesis is that there is a range of conditions determining braiding pattern and braid plain size across the world according with catchment scale and larger scale drivers.

To demonstrate our hypothesis, this study is based on the analysis of the relationship between the active channel width and the upstream catchment area (i.e. the normalized active channel width) of 257 braiding river reaches across the world, characterized using satellite images at good resolution available between September 2019 and May 2020. We then assessed the range of values assumed by the normalized active channel width against catchment and large scale drivers (e.g. climatic, hydrological and relief conditions). Our results show in some regions these drivers control extremely large and dynamic systems against which to compare the status and behaviour of all the braiding rivers across the world.

KEYWORDS

Active channel width, braid plain, braiding rivers, global scale, hydromorphological functioning

1 BRAID PLAIN RIVERS AND THEIR CHARACTERISATION

Braiding rivers are multi-thread, highly shifting rivers characterized by a wide area of unvegetated gravel corridor, the active braid plain. These rivers often occupy the piedmont valleys of high mountains and are considered hotspots of biodiversity. Because of their dynamics, braiding rivers are expected to be amongst the most sensitive river systems to global environmental changes, including climate change. These rivers underwent significant changes in their intensity and extent as consequence of human disturbances across the globe, notably in France, Italy and New Zealand, amongst others (1).

The intensity of braiding pattern is commonly identified and measured by indices based on bar or channel dimensions or number, which strongly depend on the hydrological conditions when river is observed. Another indicator independent of hydrological conditions at the date of observation is the normalised active channel width (W*), that is the active channel width (water and bare sediment areas, in m) rated by the upstream catchment area ($km^{0.4}$), and whose size is linked to the connectivity to sediment sources, in terms of amount and transport capacity (2). W* is characterized by a high variability. In the French Alps, minimum values are around $10m/km^{0.4}$, below which a network of braided channels is no more observed. Despite some regional references exist (e.g. French Alps, Piedmont region in Italy, new Caledonia (2,3)), it does not yet exist a global overview of braiding river intensity.

2 STUDY AREA AND METHODS

We selected 257 sites displaying a multi-channel braiding-like pattern from visual inspection of Google Earth images of piedmont and mountain areas located in different geographic zones across the world (Figure 1): Albania (n=17), Azerbaïdjan (n=14), Chile (n=17), China (n=44), France (n=53), Georgia (n=14), India (n=37), New Zealand (n=32), United States and Canada (30). Selected catchments are characterised by different climatic conditions and hydrological regime, different catchment conditions and geological context and different human pressures.

The data included in this study are: (i) satellite images available between September 2019 and May 2020 from QGis & ArcMap from DigitalGlobe, GeoEye, Earthstar Geographics, CNE/Airbus imageries; (ii) the HydroSHEDS database including worldwide basins and river networks (https://www.hydrosheds.org/); (iii) elevation data from SRTM DEM at 30 m resolution (https://earthexplorer.usgs.gov/); (iv) data on climate and precipitations for the years 1970-2020 at 30 seconds resolution from WorldClim2.1 (https://worldclim.org/data/bioclim.html).

For the scope of the work we analysed the relationship between the active channel width and the upstream catchment area measured and calculated the normalised active channel width W* as proxy of braiding intensity at reach scale (where a reach is 3 to 5 times the active channel width). We then explained this relationship and the braiding intensity by analysing a series of controlling variables that characterise transport capacity, mainly flood regime (mean annual precipitation and seasonality) and slope (relief ratio and elongation ratio). All GIS measures and processing steps were realized on ArcMap 10.7 and QGis 3.4.9. All analysis were performed on R version 3.6.2.

3 PRELIMINARY RESULTS AND DISCUSSION

The largest active channel are observed in India and New Zealand with mean value of 722.9 and 628.5 m, respectively, whereas narrowest reaches are observed in France with mean values lower than 100 m. For all reaches taken together, the relationship between the active channel width and the upstream catchment area is statistically significant (adjusted r-squared = 0.39; p-value <0.0001), with great variability between geographic zones (Figure 1). Notably the relationship is not significant for reaches in New Zealand, suggesting differences between sub-zones. The existence of three sub-zones for New Zealand is clarified after analysing the residuals to the global model: one sub-zone includes reaches with extremely large active channel widths and highest residuals (>0.5; NZL_G) located in upstream areas close to glaciers in the southern island; a second sub-zone includes reaches with residuals between -0.5 and 0.5 located in piedmont areas in the southern island (NZL_M); a third zone includes reaches with lowest residuals (mainly around zero or negative) located in floodplain areas of the northern and southern islands.

The W* is then calculated for each zone and sub-zone, considering a coefficient 0.36 from a quantile regression model (Q=0.5). Highest W* are observed in India, New Zealand (mainly NZL_G and NZL_M) and USA-Canada, whereas lowest W* are observed in France, Chile, China and Georgia.

Between these two groups, reaches in Albania and Azerbaijan and floodplain reaches in New Zealand display intermediate W* values. The difference between zones and sub-zones is statistically significant in most cases (p-value <0.05), notably between the highest, the lowest and the intermediate W* values mentioned above, but not within these three groups. Interesting and significant (p<0.0001) differences are observed for instance between China and India, which are located northern and southern respectively of the Himalayan chain, suggesting different conditions in terms of sediment production or transport that cause extremely large and potentially active braiding rivers in the Indian side (Figure 1).

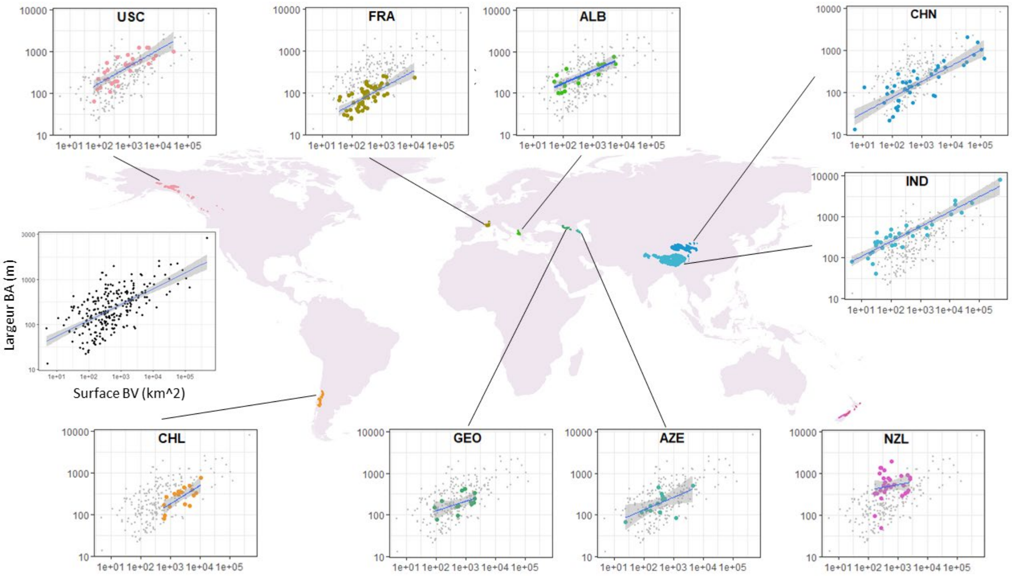

Figure 1. Study area (USC, USA and Canada; FRA, France, ALB, Albania; CHN, China; IND, India; CHL, Chile, GEO, Georgia; AZE, Azerbaijan; NZL, New Zealand) and variability of the relationship between active channel width (m) and the upstream catchment area ($km^{0.4}$).

To explain the observed patterns we related the residuals from the quantile regression, calculated as median values per zone and sub-zone, to potential controlling drivers at catchment scale, namely the precipitation regime over the period 1970-2000, and the relief ratio and elongation ratio. The inter and infra-zones differences in braiding intensity (W*) can be mainly explained in terms of amount of precipitation (p<0.005), notably between China and Indian braiding reaches, but also in terms of precipitation seasonality, such as between France and Albania, or both, such as between sub-zones in New Zealand.

These findings suggest that a range of conditions can determine at global scale the existence of a given planform channel pattern, and as consequence that the expected behaviours (in terms of morphodynamics) might differ, according to the geographic areas related to specific controlling drivers. This has important consequences for braiding river management, for instance in terms of flood risk management or in terms of habitat conservation, braiding rivers being potential sensitive hot-spots at global scale in terms of biodiversity. Further analyses on the temporal trends in W* values from satellite imagery will clarify the braiding river behaviours and potential human pressures affecting them at global scale.

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