Modelling the climate change impact on the SPM transfers of the Rhône river

Modélisation de l'impact du changement climatique sur les transferts de MES du Rhône

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RÉSUMÉ

Les projections climatiques du GIEC prévoient une hausse de 1.5 à 6°c des températures annuelles sur le bassin versant du Rhône associée à une exacerbation des contrastes saisonniers des précipitations. Ces changements affecteront durablement la dynamique du transport solide du fleuve et de ses affluents via l'ajustement des vitesses d'érosion des versants et la modification du régime hydrologique des cours d'eau. Afin d'anticiper ces changements, l'observatoire des sédiments du Rhône (OSR) a développé un modèle de transferts de Matières en suspension (MES) à l'échelle de tout le bassin versant permettant d'intégrer des scénarios prospectifs du climat à horizon 2100. Il apparait globalement que les transferts sédimentaires tendraient à se réduire de 5% à 20% à l'exutoire du Rhône suivant les modèles climatiques sélectionnés. L'ensemble des simulations convergent notamment vers une diminution de la fourniture sédimentaire des régions alpines, alors que la tendance reste plus incertaine pour le reste du bassin versant (Saône notamment).

ABSTRACT

In accordance with the IPCC climate projections, the annual air temperatures in the Rhône watershed are anticipated to increase by a range of 1.5 to 6°C, while the contrasts in seasonal precipitation are expected to become more pronounced. These changes will impact the solid transport dynamics of the river and its tributaries, influencing hillslope erosion rates and modifying the hydrological regime of the watercourses. In order to anticipate these changes, the Rhône Sediment Observatory (OSR) has developed a model of the suspended particulate matter (SPM) transfers at the scale of the Rhône watershed and its main tributaries, which allows for the integration of prospective climate scenarios to 2100. In general, sediment transfers are projected to decline by between 5% and 20% at the Rhône outlet, depending on the climate models selected. All simulations indicate a reduction in sediment supply from the Alpine regions, while the trend remains more uncertain for the remainder of the watershed, particularly in the case of the Saône river.

KEYWORDS

Suspended particulate matter (SPM), climate change, modelling, Rhône river, sediment connectivity

Matières en suspension (MES), changement climatique, modélisation, Fleuve Rhône, connectivité sédimentaire

1 CONTEXT AND OBJECTIVES

In the context of climate change, the SPM dynamics of the Rhône river are anticipated to evolve as a consequence of the combined impact of hillslope erosion adjustment and the response of water discharge to fluctuations in precipitation and temperature. In this context, it is of paramount importance to anticipate the potential consequences of climate change on SPM fluxes at the catchment scale, for management purposes (e.g., ecological restoration, reservoir management or particle-bound contaminant fluxes). It is therefore important to develop modelling tools that will allow the simulation of sediment transfer at a large scale and that will be able to integrate climate change scenarios. In the period between 2020 and 2024, a model was created as part of the Rhône Sediments Observatory (OSR).

2 METHODS

The model was developed using three distinct elementary models that integrate data on hillslope erosion rates (InVEST-SDR), water discharge (J-2000), and channel reaches sediment connectivity (CASCADE). In order to assess the potential evolution of fluxes up to the year 2100, five climate projection models were implemented to provide climate change scenarios for the period under consideration. (Figure 1).

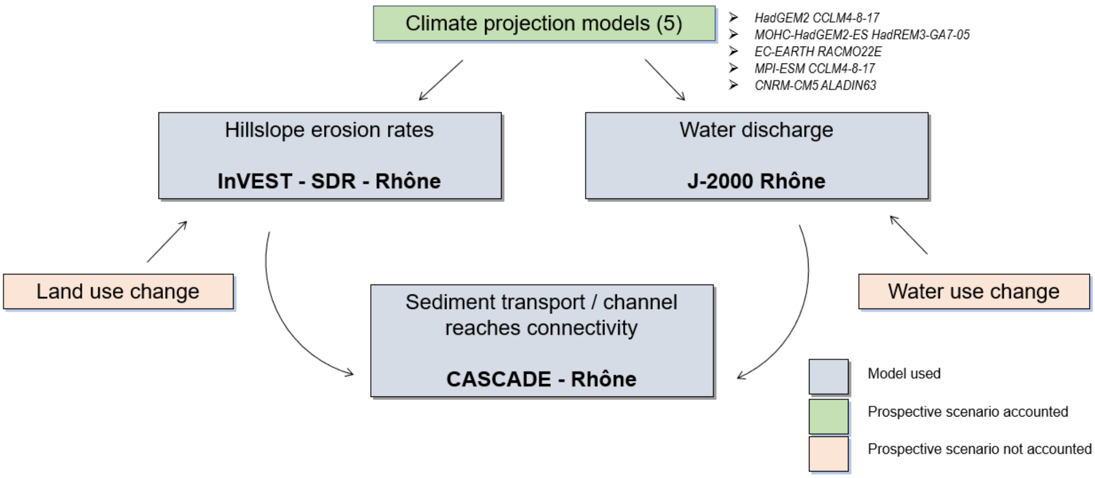

Figure 1 : General framework of the methodology used

2.1 Sediment sources : InVEST-SDR Rhône

The InVEST-SDR model enables the mapping of hillslope to channel sediment transfers induced by runoff through the combination of the RUSLE equations with a normalization of the Index of connectivity (Borselli et al., 2008; Hamel et al., 2017). A set of 245 rainfall gauging stations, with a 6-minute timestep, were combined with the daily gridded precipitation model of Météo-France (SAFRAN) in order to map rainfall erosivity. Seventeen departmental soil maps were aggregated and mined in order to map soil erodibility. Furthermore, the national French digital elevation model (BDAlti® at a 25m resolution) and the Theia-Land national land use map were used in order to compute the LS-factor and the C-factor of the RUSLE equation, as well as the index of connectivity (Fressard et al., 2024).

2.2 Hydrological model : J-2000 Rhône

J-2000 is a catchment scale hydrological model that provides daily water discharge at the reach scale for the Rhône river and its tributaries from 1987 to the present (Branger et al., 2016). Branger et al. (2023) employed J-2000 Rhône to develop scenarios of the evolution of water discharge for six climate projection models. These data were incorporated directly into our modeling framework.

2.3 Channel sediment connectivity : CASCADE Rhône

The CASCADE (CAtchment Sediment Connectivity And Delivery) model describes the connectivity of sediment within river networks, combining approaches based on graph theory and solid transport modelling (Schmitt et al., 2016; Tangy et al., 2019). The main advantage of CASCADE is the quantification of sediment transfers via a "source-to-sink" approach, thereby facilitating spatial analysis of sediment trajectories. Hydromorphological attributes linked to solid transport are associated with each river reach, including slope, length, drained surface, flow, active channel width, grain size distribution, and Manning's roughness coefficient. These attributes are employed in the calculation of the transport capacity of each reach. Subsequently, the local transport capacity is linked with the available sediment sources (i.e., the InVEST-SDR model outputs) in order to route sediments throughout the network. All reach attributes were mapped over the Rhône network (and tributaries) based on the data available from the OSR since 2009 and various bibliographic references. A model validation is proposed by comparing the mean interannual modeled SPM fluxes with a set of 25 SPM gauging stations regularly distributed over the Rhône catchment and its tributaries (Fabre et al., 2024).

2.4 Selection and implementation of climate projection models

We used projections derived exclusively from the RCP 8.5 scenario. This is the most pessimistic scenario that represents the upper limit of potential change. Five climate projection models were selected. We have selected pairs that are representative of the dispersion of existing models (Branger et al., 2023). The climate projection models are integrated into two components of the SPM model: (1) variations in rainfall erosivity, (2) variations in water discharge.

3 RESULTS AND DISCUSSION

In general, the model calibration demonstrates a satisfactory fitting with the field measurements (i.e., 25 SPM gauging stations) for the current period: the R^2 coefficient between the observed and modeled values is 0.87. The main SPM transport map is shown in Figure 2. In addition to this regional scale map, all data are provided in GIS format, allowing detailed attribute queries of all reaches. The mean interannual SPM transfer value at the watershed outlet (Beaucaire station) is 5.15 Mt.yr-1. 75% of the sediment input comes from Alpine tributaries (Isère, Durance, Upper Rhône and Drôme).

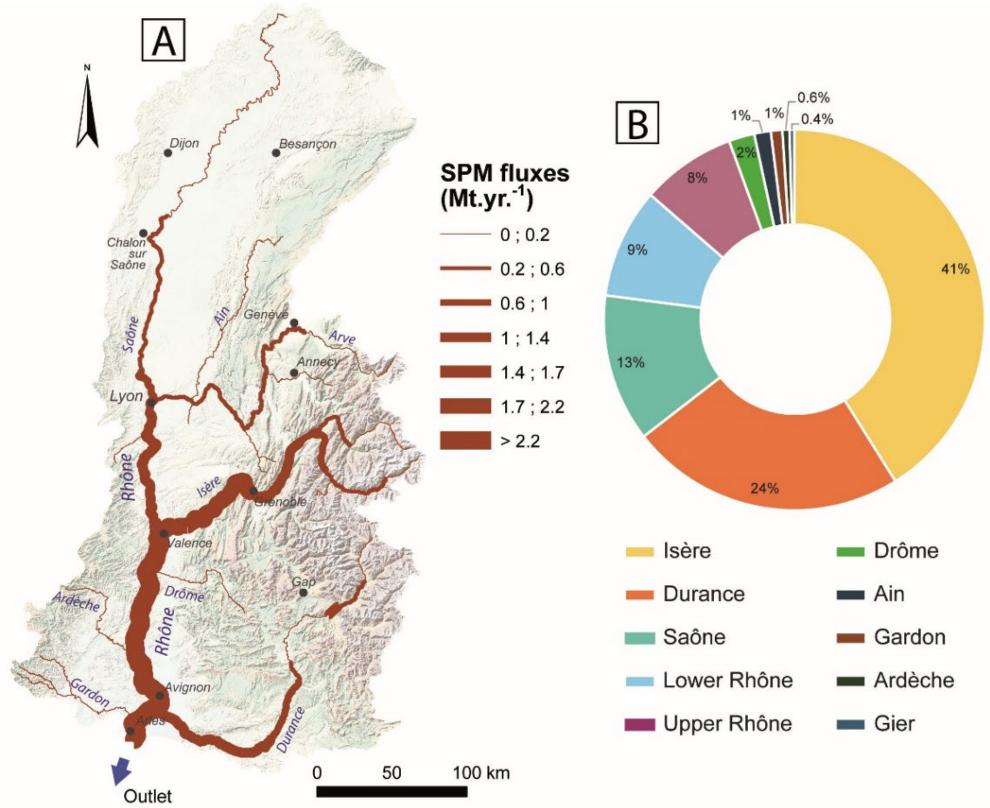

Figure 2 : Present day model outputs. (A) Map of the average inter-annual SPM fluxes and (B) relative contribution of each tributary to total SPM load

The climate projection models collectively indicate a general decline in Alpine sediment supply, particularly along the three main river systems : The Isère, Durance, and Drôme rivers (Figure 3). All projections indicate a notable decline, with the greatest reduction observed in the Isère basin, where the HadGEM2 model predicts a maximum decrease of -25%. In contrast, the Drôme with CNRM-CM5 models only suggest a slight decline of -5%. This trajectory appears to be primarily linked to the reduction of precipitations during the summer and autumn months in these mountainous regions, that lead to a significant reduction of rainfall erosivity. The observed increase in winter flows, attributable to a reduction in the number of days with frost and lower snow precipitation, does not offset this decline. The plain and hilly tributaries of the Rhône watershed (north and west) exhibit less pronounced declines, with some scenarios indicating an increase in transfers (Saône, Ain, Ardèche, Gier, and Gardon). This situation can be partially attributed to the persistence of rainfall erosivity at the local level (or even an increase in some cases), coupled with a notable rise in the frequency of the highest flows (Quantile 10%, see Branger et al., 2023), which facilitate the transport of eroded particles.

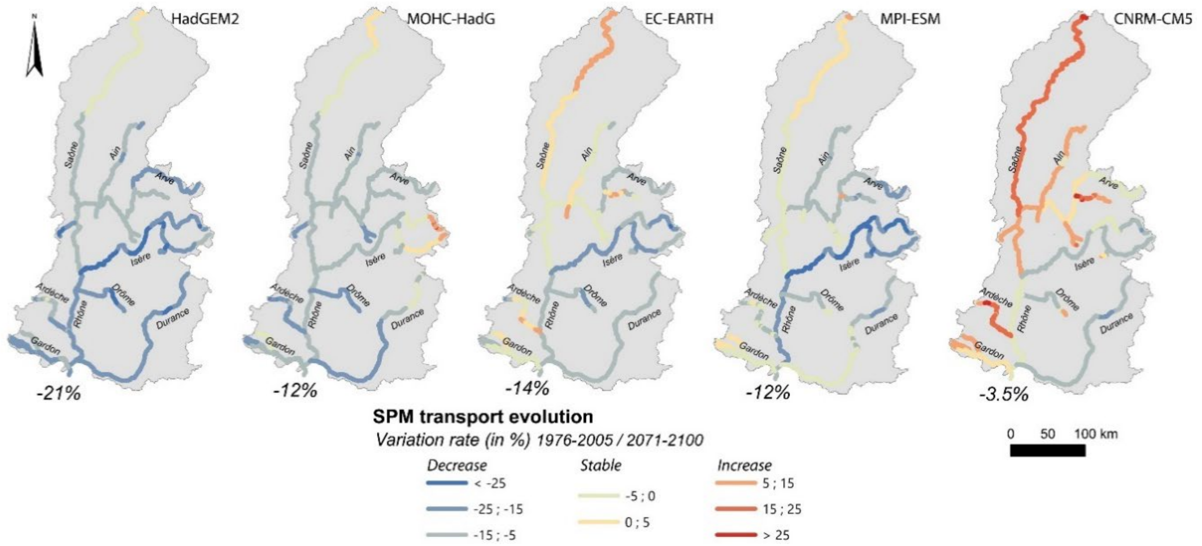

Figure 3 : Maps showing the evolution of SPM transfer in the Rhône watershed between 1976-2005 and 2071-2100 (in %) according to the 5 climate projections models used

At the watershed outlet, all climate projections indicate a reduction in the SPM transfer to the sea. The most pessimistic projection (HadGEM2) indicates a decrease of -21%, while the most optimistic (CNRM-CM5) suggests a decrease of -3.5%. In the latter case (CNRM-CM5), it appears that the decline in flows from the Alps may be partially compensated for by an increase in flows from other tributaries (Saône, Ardèche, Ain, etc.). The remaining projections are of an intermediate order of magnitude, with EC-EARTH showing a decline of -14%, HadREM2 a decline of -12%, and MPI-ESM a decline of -13%.

4 CONCLUSIONS AND PROSPECTS

This project provides a spatially explicit model that predicts annual average sediment yields and allows for the assessment of sediment connectivity over the Rhône catchment. The implementation of climatic projections based on five different models demonstrates an overall decrease in sediment yield at the outlet, with a notable contrast between the Alps and the other parts of the catchment. Following the initial development of the model on the SPM, several additional developments will be conducted over the course of the project's subsequent years, particularly with regard to the integration of coarse sediments (sand and pebbles) and a more explicit incorporation of snow melting processes.

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