Le témoignage des archives sédimentaires pour mieux appréhender l'impact environnemental des nouvelles technologies - ANR TRAJECTOIRE (2020-2024)

The memory of riverine sediments used to predict the environmental impact of new technologies - ANR TRAJECTOIRE (2020-2024)

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RÉSUMÉ

Le projet ANR TRAJECTOIRE (ANR-19-CE03-0009, 2020-2024) vise à établir, aux exutoires des grands bassins versants français, les trajectoires des radionucléides, des micro-plastiques et des métaux critiques. Il s'agira d'évaluer comment la société peut être un acteur de la résilience de l'environnement à la suite de perturbations anthropiques résultant de ses choix économiques, ses décisions politiques et de ses actions collectives. Les archives sédimentaires permettent de renseigner sur la capacité des grands fleuves à absorber ou à éliminer les pressions anthropiques. Cette capacité sera évaluée à partir de l'analyse de séries chronologiques : 1) celles sur les niveaux de contamination, reconstruits à partir d'archives sédimentaires, 2) celles sur les pressions exercées sur les environnements, construites à partir d'archives documentaires (frises socio-historiques). Les liens de causalité entre les niveaux de contamination observés dans les archives sédimentaires (données quantitatives) et les pressions anthropiques (données qualitatives et semi-quantitatives) seront évalués à l'aide d'algorithmes d'apprentissage automatisés. En fournissant des retours d'expérience quantitatifs et des modèles prédictifs basés sur des scénarii, TRAJECTOIRE permettra d'informer les parties prenantes des conséquences des décisions passées et futures sur les impacts environnementaux à court, moyen et long terme. Il vise à démontrer que la société peut agir sur la résilience environnementale.

ABSTRACT

TRAJECTOIRE ANR Project (ANR-19-CE03-0009, 2020-2024) aims to establish trajectories of radionuclides, microplastics and critical metals contaminants at the outlets of the major French watersheds. It will be a question of evaluating how society can be an actor of the resilience of the environment following anthropic disturbances from economic choices, political decisions and collective actions. Sedimentary archives are useful tools giving access to the ability of large rivers to absorb or remove anthropogenic pressures. These abilities will be established by reconstructing time-series of 1) contamination levels based on sedimentary records and 2) pressures exerted on environments and responses provided by institution and society, based on analyses of documentary archives. The causal links between the observed contamination levels in sedimentary archives (quantitative data sets) and the anthropic pressures determined from documented archives (qualitative and semi-quantitative data sets) will be assessed using machine learning analyses for time series prediction. Our project aims to give quantitative feedbacks and predictive models based on scenarios in order to inform stakeholders on environmental impacts of their past and future decisions, over short and longer time periods. It aims to demonstrate that society can act on environmental resiliency.

MOTS CLES

Large rivers, contaminants, sediment cores, trajectories, resiliency.

1 OBJECTIVES AND HYPOTHESES

The rapid evolution of environmental concerns, engineering techniques, as well as of political choices that characterized the last industrial era sometimes led to a lack of precise and exhaustive information on the environmental consequences related to industrial development. At the dawn of the 4th industrial revolution, when mankind converges to sustainably escape from the era of intensive exploitation of carbon and nuclear resources, the energy transition cannot exclude questions and awareness related to the potential environmental impacts from the use of new materials and new resources. These future impacts can be anticipated from feedback analysis derived from past environmental impacts of key contaminants that were stored over time in well-preserved sedimentary deposits in river systems. Indeed, sedimentary archives give testimonials on previous contaminations and anthropic pressures because rivers are the final receptacle for many substances and sediments convey and store most of them. Sedimentary deposits at the outlet of watersheds, allow us to trace the history of these substances brought about by human activities in these environments during the technological, industrial and environmental development that punctuated the 20th century. In river systems, while part of pollution is conveyed by waters as dissolved species, solid particles (i.e. sediments) constitute a major carrying phase for the vast majority of pollutants whether they are directly discharged into streams by industries or originate from soil leaching and erosion. Thus, in many cases, sediments are useful environmental matrices to assess the current and historical pollution events in a river and its watershed. Investigation on contamination levels in sedimentary records coupled with qualitative or semi-quantitative data sets acquired from documented archives analyses (socio-chronological friezes for the considered contaminant) can help to establish feedbacks on the ability of large rivers to absorb or remove anthropogenic pressures, whether they have been additive (e.g. industrialization, pollutants releases, consumption and consumption patterns) or remedying (e.g. reducing emission, dismantlement, environmental standards, regulations, evolution of the consumption patterns).

The main objective of the TRAJECTOIRE project is to analyze the causal links between the evolution since the beginning of the last century of (1) the concentrations of key contaminants reconstructed *a posteriori* by using riverine sedimentary archives and (2) the anthropic pressures expressed as qualitative or semi-quantitative data from documented archives analyses in order to establish predictive models describing expected trajectories of contamination in large rivers and hydrosystems resiliencies based on scenarios (Figure 1).

The challenge for the project is to combine environmental science with the political and socio-economic drivers to inform stakeholders about the time-resolved releases of those pollutants into the environment and the economic and environmental concerns over the last 100 years. The TRAJECTOIRE project focuses on establishing their socio-historical trajectories based on the observations of the last decades, reconstructed on the one hand from the documented archives leading to the understanding of the different temporal scales between pressures exerted on the environments and answers provided by society, and secondly from the sedimentary archives testifying environmental footprints. It aims at establishing the socio-historical trajectories of key non-legacy contaminants (Radionuclides, microplastics and their additives (Phuong et al., 2021), and ultra-rare metals) based on the observations of different sources of the last decades.

1.1 Lessons expected from sedimentary archives

Well-preserved sediment deposits in perennial storage areas within river systems such as riverbanks, alluvial margins, floodplains and infrastructures (e.g. dams) may constitute useful chronological archiving compartments for pollutants conveyed by rivers enabling the understanding of historical pollution of large rivers over the last decades (Schäfer et al., 2022). Sedimentary archives from large rivers have been widely explored in recent years, particularly in France, in the Garonne, the Rhone, the Loire and the Seine rivers, mainly for the most common heavy metals (e.g. Zn, Pb, Cd, Cu) and organic micro pollutants (e.g. PCB, HAP). The INTERPOL research project supported by the French Agency for Biodiversity (AFB) and LTSER France network (CNRS-INEE) was structured in 2017 to partially address the challenges of these major legacy contaminants in French Rivers; however, there is a lack of knowledge and an increasing demand from River basin managers for many others such as radionuclides, microplastics and high-technology metals. Sediment cores are being collected at the outlets of the major French watersheds (Rhône, Loire, Seine, Garonne, Rhine, Meuse, Moselle). These sedimentary archives are dated by using multi proxy approaches including the use of ^{137}Cs peaks as chronological markers (Foucher et al., 2021), $^{210}Pb_{xs}$ profiles, and the available data sets from radiological river surveys. In order to answer the challenge of the TRAJECTOIRE project, the sediment cores cover ideally a period of at least ten decades and have high resolution to ensure their suitability. The studied contaminants are analyzed along the sediment cores, in particular in those from the watersheds that are the most documented regarding anthropic pressures (based on social-economic data).

1.2 Lessons expected from documented archives (socio-chronological friezes)

Qqualitative or semi-quantitative data extracted from the documented archives (socio-chronological friezes) lead to an understanding of the different temporal scales between pressures exerted on environments and responses provided by institution and society. The interpretation of the information recorded in the sedimentary archives as a result of anthropic disturbances requires the use of socio-historical trajectories to gain understanding of the evolutionary pressures exerted on the environment. Generally, the tool advocated for such work is that of material flow analysis (Material Flow Analysis, which requires the establishment of matter circulations and fluxes (or metabolism) over a long period. The difficulties of such retrospective exercise, requiring to cross multiple sources of information, are all the greater as the statistical sources concerning contaminants are rare or confidential. However, the resulting lessons are richer than those resulting from a more qualitative approach based only on conventional control factors of population evolution or change in industrial production modes. Additionally, several properties of time series make them inherently challenging to analyze. First, the data are highly dynamic. It is often difficult to tease out the structure that is embedded in time series data. Second, time series data can be nonlinear and contain highly complex autocorrelation structure.

1.3 Neural network analyses

We challenge the links between concentrations from the sedimentary archives (quantitative data sets) and documented archives (qualitative and semi-quantitative data sets) can be assessed by using a mathematical approach based on neural network analyses for time series prediction.

Developing appropriate time series models based on neural network analyses to make accurate forecasts has significance across a myriad of domains. The neural network itself is a framework for many different machine learning algorithms to work together and process complex data inputs. Most generally, these connectionist systems are computing systems based on biological neural networks that compose animal or human brains. Neural networks approach considers known datasets as training examples (e.g., concentration of radioactive substances in sediments of the Rhône River and radioactive releases from nuclear industries in this river; concentration of lead in sediments of the seine River and lead production/use over time in the watershed; others environmental consequences and anthropic pressures datasets), and then develops a system which can learn from those training examples. In other words, it uses the examples to automatically infer rules of recognition. Furthermore, increasing the number of training examples helps the network to improve its accuracy.

By using this mathematical approach, various anthropic pressures can be considered and their consequences on the concentration of contaminants over time will be identified. These causal links between environmental consequences and anthropic pressures constitute rules of operation (rules of recognition) that will be defined and integrated within a neural network as a knowledge base. Time series describing contamination levels in rivers, acquired from sedimentary archive analyses, will be modeled by using mathematical functions aiming at (i) describing the main tendencies over various periods of time (linear equations) and (ii) reducing the gaps between these last functions and the measured concentrations. This will be achieved by using Auto Regressive Integrated Moving Average (ARIMA) and a BackPropagation Neural Network (BPNN).

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