Approche interdisciplinaire de la détection, de la caractérisation et de la quantification des impacts urbains sur les écosystèmes des plaines d'inondation à l'échelle mondiale, le cluster GloUrb

An interdisciplinary approach to the detection, characterization and quantification of urban impacts on floodplain ecosystems on a global scale, the GloUrb cluster

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RESUME (FR)

Les hydrosystèmes, et notamment les plaines alluviales, jouent un rôle clé en offrant des services écosystémiques essentiels tels que l'approvisionnement en eau, la régulation des crues et le maintien de la biodiversité. Cependant, ces fonctions et services sont de plus en plus fragilisés par une urbanisation croissante à l'échelle globale. Cette grappe de stage de master, qui s'inscrit dans le projet GloUrb, vise à analyser ces impacts à travers une approche interdisciplinaire explorant synoptiquement les enjeux relatifs à la qualité de l'eau et l'extraction de sédiments en lien avec les dynamiques socio-économiques et les cadres réglementaires. L'urbanisation exacerbe la pollution des eaux, appelant à une méthodologie robuste pour identifier les sources des contaminants ainsi que les facteurs facilitant leur transfert et leur influence sur les services écosystémiques. Par ailleurs, l'extraction de sédiments, indispensable pour la construction, affecte l'état écologique des rivières en altérant leur morphologie et la qualité de l'eau. En combinant télédétection et analyse économique, le projet identifie ces pratiques et évalue leurs impacts à l'échelle mondiale. Les disparités régionales, liées au développement économique et aux réglementations environnementales, soulignent la nécessité d'une intégration entre le droit et l'économie environnementale pour une appréhension globale de ces impacts. Ce travail met en lumière l'urgence de solutions globales pour identifier, caractériser, quantifier et apprécier les impacts de l'urbanisation des plaines alluviales sur les hydrosystèmes.

ABSTRACT (ENG)

Hydrosystems, particularly alluvial plains, play a key role in providing essential ecosystem services such as water supply, flood regulation and biodiversity. However, these functions and services are increasingly threatened by growing urbanization on a global scale. This internship cluster, part of the GloUrb project, aims to analyze these impacts through a multidisciplinary approach that integrates water quality, sediment mining, socio-economic dynamics, and regulatory frameworks. Sediment mining, essential for construction, causes ecological degradation by altering river morphology and increasing pollution. By combining remote sensing and economic analysis, the project identifies these practices and assesses their impacts on a global scale. In addition, urbanization is exacerbating water pollution, requiring a robust methodology to identify the sources of pollutants, the factors that facilitate their transfer, and their impact on ecosystem services. Regional disparities associated with economic development and environmental regulation underscore the need to integrate law and environmental economics for a global understanding of these impacts. This work highlights the urgent need for

global solutions to identify, characterize, quantify and assess the impacts of alluvial plain urbanization on hydrosystems.

MOTS CLÉS :

Extraction de sédiments, Plaines alluviales, Qualité de l'eau, Services écosystémiques, Urbanisation

Ecosystems services, Floodplain, Sediment mining, Urbanization, Water quality

1 INTRODUCTION

By 2050, nearly 68% of the world's urban population will live in cities, an increase particularly pronounced in developing countries. 50% of the world's urbanized areas are on floodplains, the latter covering only 3% of the continental surface (ONU, World Urbanization Prospect, 2018). Floodplains provide many ecosystemic services to humans, particularly water supply, biodiversity support, flood regulation, climate change resilience, etc., which are threatened by this growing urbanization (Sofia et al., 2017). At the global level, urbanization follows different patterns and dynamics, leading to various environmental, social, and political issues, and impacts on floodplain ecosystemic functioning and services. Knowledge about these patterns and impacts has been produced locally. However, they and their variability still need to be identified, characterized, quantified, monitored, and prevented globally. The interdisciplinary GloUrb project, funded by the French National Agency for Research, aims to achieve this by focusing on agglomerations with more than 300,000 inhabitants located in alluvial plains around the world and intersecting rivers larger than 30-60 meters.

The present work is part of this larger project. Starting from the 298 GloUrb cities selected according to a set of criteria (climate, physiography, urbanization dynamics, socio-economic development, etc.), to be representative of global cases, this work looks more specifically at the topics of water quality and sediment mining detection and characterization, related to socio-economic drivers, and comparative environmental law. These topics are considered important for studying urban impacts on floodplain socio-ecosystems, as they are significant drivers for the degradation of their functions and services, and hence, will bring a more holistic understanding of urban impacts and patterns.

Which brings us to our main question: How does the urbanization of floodplains affect socio-ecosystem functions and services, in particular through water quality degradation and sediment mining, and how can an interdisciplinary approach involving disciplines such as environmental law, economics, water quality analysis and remote sensing applied to sediment mining, and their specific methods and indicators, be used to identify, characterize, manage, compare and monitor these impacts on a global scale? Several general hypotheses have been formulated to answer this main question, built on the assumption it is possible to establish correlations between the different variables studied and the indicators produced by each of the disciplinary approaches, allowing better detection or characterization of impacts:

- Socio-economic factors in urban areas significantly influence the pressures that cities exert on the ecosystem services of hydrosystems, notably through the intensification of sediment mining practices to meet development demands, and through the increase of contaminants in water bodies.
- Regional differences in the indicators studied are likely to be observed, depending in particular on the level of economic development, legislation in force, and current policies.
- The evolution and enforcement of environmental regulations can help mitigate pressures on the ecosystem services of rivers in urban areas, promoting more sustainable management adapted to urban dynamics, but it is not necessarily respected or present in all countries.

2 METHODOLOGY AND EXPECTED RESULTS

To achieve the objective above, this work is organized around four main topics that are treated by different disciplines while trying to address and respond to the main research question in an interdisciplinary way as part of an interdisciplinary cluster project.

The first topic in the cluster project aims to detect, characterize and monitor sediment mining in floodplains on a global scale, using satellite images and derived datasets.
Sediment or sand mining refers to the mining of alluvial sediment deposits from floodplains and alluvial areas, primarily to provide building materials for the construction industry, with alluvial gravel and sand being used in the manufacture of concrete (Koehnken et al., 2020). As urbanization speed increases, especially in developing countries, the demand for construction materials rises rapidly, and hence, their mining in alluvial deposits, with around 40-50 billion tons of sand, gravel and aggregates used annually worldwide (Koehnken et al., 2020; Vander Velpen et al., 2022). These mining activities impact the dynamics, functions and services of floodplain socio-ecosystems (Koehnken et al., 2020), through direct (e.g., destruction of habitats) or indirect effects (e.g., physical changes that propagate in the hydrosystem due to the alteration of the sediment budget and morphology of the river). As such, identifying, characterizing and monitoring sand mining on a global scale is a major challenge. These observations lead us to the following question: Which indicators can be derived from satellite remote sensing and preexisting satellite datasets to be used to 1. detect, 2. characterize, and 3. monitor sediment mining on a global scale? Which economic variables explain the presence of sediment mining, and its typology? Can we use them to monitor pressure increase worldwide? Which indicators produced can be used as variables for water quality and law topics?
The approach will be global, focusing on several dozen cities within the GloUrb selection where sediment mining is considered to have a major impact, based on bibliographic sources, spectral signatures derived from satellite imagery (Landsat and Sentinel-2), the Global Surface Water dataset, and Open Street Map (OSM) data. In these cities, Maximum Water Extent polygons will be extracted from the GSW dataset and intersected with "quarry" polygons extracted from OSM. The resulting selected polygons, identified as mining pits, will serve as training data for the first model, which will be able to produce shape, size, spectral,... indices that will allow the detection of sediment mining and its characters (density, amount, etc.). Once the mining signature has been accurately identified, it will be possible to develop a monitoring model that triggers alarms when sediment mining occurs in certain areas or when it reaches a certain threshold. The models produced by this topic will allow the production of different variables, such as the presence/absence of sediment mining, its density, the areas affected,... for the 298 cities studied by the cluster and eventually on a global scale. These variables will serve the other topics of this internship cluster by trying to correlate their variables (water quality indicators, environmental regulations and socio-economic factors) with those produced by this topic. If strong correlations with socio-economic factors are found, they could also be implemented in the monitoring model, triggering alerts when a certain level of economic development is reached, for example, increasing the risk of sediment mining. As a result, this internship will produce three methodologies to detect and characterize sediment depletion on a global scale, which has never been done before, with the goal of helping to better manage and conserve floodplain ecosystem functions and services in the future.

The second topic of the cluster project targets water quality. Rivers flowing through urban areas function as receptacles for numerous pollutants originating from both nearby and distant environments, whether discharged intentionally or not. These pollutants, derived from diverse sources and anthropogenic activities, exhibit varying characteristics and behaviors. They exert both positive and negative pressures on river ecosystem functioning (Lalande et al., 2014). Numerous scientific studies have focused on understanding the behavior of pollutants such as organic matter, nutrients, biological pollutants, micropollutants, heavy metals, and persistent elements as well as the interactions between their sources, modes of transfer, and water bodies. However, these studies have often been confined to local or national scales. Defining and presenting water quality in a simple and consolidated manner remains a scientific challenge due to the complexity of the factors influencing water quality and the high variability of parameters available (Sutadian et al., 2016). The aim here is to evaluate water quality in urban rivers on a global scale, considering the pressures of urbanization, sources of contaminants, and their impacts on ecosystem services and functions. Using the DPSIR framework (Driving Forces, Pressures, State, Impacts, Responses), adapted to land use and river ecosystems (DPSIR-LURE) (Lalande et al., 2014), and leveraging international and national databases, this part seeks to explore and characterize 5 pilot cities according to scientific literature. The goal is to identify pollutant origins, impacts, and related environmental conditions. Ultimately, the aim is to develop a generic methodology for designing proxies that capture these characteristics, which can then be applied to other study sites within the GloUrb project, providing a comprehensive understanding of urban pollution dynamics and their effects on rivers.

The economic part of the cluster project aims to identify and quantify the main socio-economic drivers of sediment mining in urban areas based on data collection and statistical modeling. Data used are secondary ones either from satellite imagery (from Google Earth Engine database mainly) or from national and international

institutions. There is a marked difference in data accessibility according to economic development: countries belonging to international organizations (such as the OECD) and more developed countries offer simpler and more comprehensive access, with more local data. All the collected data will be compiled in a panel (multiple observations of the same individual through time) and used as input to explain the dependent variables (sediment mining and water quality) using econometrics models and methods. As a first stage all the available variables will be included to assess if these are relevant for the purpose of the work (e.g. including rural employment and economic activities nearby). It is expected to observe different amount of sediment mining and degradation of water quality depending on the economic development: low development means less mining; in developing countries, we should observe high sediment mining and water quality degradation; for developed countries, the amount of sediment mined is expected to be lower with less pollution. Those initial expectations may not be confirmed because of recent or specific management strategies (e.g. building renovation in developed countries, export of mined material from developing countries). As well, differences can be observed in terms of urban growth due to in-migrant population, the dynamic of the nearby rural areas, the limited accessibility to resources, etc. Finally, the results will be contextualized in terms of existing law regulations and effectiveness. It is expected that those laws are respected in developed countries but aren't in least and in-development ones.

The fourth part focuses on comparative law, by examining the protection and management of floodplains in major South American agglomerations, which face significant challenges related to sediment mining and water quality in the context of rapid urbanization, resource exploitation, and climate change impacts (Amezaga et al., 2023). This topic delves into the regulatory frameworks governing sediment extraction and water quality, evaluating their effectiveness in balancing economic demands with environmental sustainability. It investigates the legal mechanisms designed to address the overexploitation of riverbeds for construction materials, assessing their capacity to regulate mining activities while safeguarding river ecosystems. Furthermore, it explores the interplay between sediment mining regulations and water quality laws, emphasizing their role in mitigating pollution and protecting vital ecosystem services. Special attention is given to the integration of these frameworks into broader zoning and land-use policies, such as urban planning and conservation initiatives. Finally, it critically examines the concept of granting rivers legal personhood, to assess its potential for enhancing legal protections for sediment and water resources.

3 ACKNOWLEDGEMENTS

This work is co-funded by the French National Research Agency (ANR) (GloUrb project ANR-22-CE03-0005), by the EUR H_2O'Lyon (ANR-17-EURE-0018) of Université de Lyon and by the Labex IMU (ANR-10-LABEX-0088).

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