Leverhulme Doctoral Scholarships Programme for Interdisciplinary Resilience Studies (PIRS)
University of Southampton

RECRUITMENT CYCLE for studentships starting: October 2025 (Cohort 2)

SUPERVISORY TEAM

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STUDENTSHIP PROJECT TITLE

Sand flows in growing river cities in the global south: Developing a coupled model of urban growth, river sand mining, and system resilience

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OVERVIEW

Rapid urban growth is fuelling demand for river sand, but sand mining poses risks to riverside communities. This project addresses critical questions regarding the resilience of river cities: How much sand flows from rivers to cities? How do these flows impact river environments? How do these changes affect river-related risks?

SUMMARY

By 2050, over two thirds of the world's population will live in cities. Urban growth is fuelling huge demand for sand, a vital construction material, much of which is mined from rivers. However, sand mining poses numerous environmental risks. Deepened channels transmit flood waves to downstream reaches more rapidly. The increased height of riverbanks triggers landslides. Meanwhile, urbanisation often involves

communities encroaching onto floodplains. Consequently, material flows of sand between rivers and cities are a critical component of coupled river-city systems, shaping the ways in which populations' exposure and resilience to environmental risks change as cities grow.

Yet, insight into the nature of sand flows across different cities is entirely absent. Employing a complex systems framework, and using new geospatial methods and datasets, this project will address critical research questions: What are the flows of sand from rivers to cities? Can these flows be linked to different patterns of urban development? What is the impact on river environments and how does this change exposure to river-related risks? The intention is to address these questions across a range of African and Asian cities on different urban growth trajectories, with the insights gained helping to shape debates about how urban planning can promote enhanced resilience. You will be supervised by experts in urban geographies and fluvial systems, drawn from the Landscape Dynamics and Ecology and Economy Society and Governance research groups at Southampton's School of Geography and Environmental Sciences and interacting with Southampton's world-leading WorldPop group and Sustainability and Resilience Institute.

PROJECT CONCEPT

Rationale

The world is rapidly urbanising such that, by 2050, over two thirds of the global population will be living in cities. The bulk of this urban transition will take place in Asia and Africa, where the scale of urban growth – the increase in the absolute number of people living in urban areas – is without historical parallel (Fox and Goodfellow, 2022; Randolph and Storper, 2023). To accommodate billions of new urban residents, cities will need to grow up and out, leading to the emergence of new, densely populated urban areas (Menashe-Oren and Bocquier, 2021; Dorward et al., 2024). Many cities are located close to major river courses, providing a convenient source for the construction grade sand that is needed to form the built fabric of the urban environment (Dujardin et al., 2024). As a result, urbanisation is generating an unprecedented level of sand mining from the rivers that flow through or close to cities: sand is now the most exploited natural resource after water.

However, riverine sand mining poses environmental challenges (Rentier and Cammeraat, 2022), generating adverse consequences that affect riverside communities. For example, as well as the damage to ecosystems caused by removing substrate, the substantial deepening of the channel caused by mining affects the transmission of floods (or of the tidal wave in reaches near the coast; Vasilopoulos et al., 2021). Increases in riverbank heights also trigger large-scale bank erosion (Hackney et al., 2020), damaging property and displacing people inland. Beyond these immediate consequences, urban growth may also involve encroachment onto floodplains, exposing growing populations to flooding. Consequently, material flows of sand between rivers and cities may be viewed as a critical component of coupled river-city systems, shaping the ways in which populations' exposure and resilience to environmental risks change as cities grow.

Within this context, critical questions remain unanswered: What are the flows of sand from rivers to cities? Can these flows be linked to different patterns of urban development? What is the impact on river environments and how does this change exposure to river-related risks?

Uncertainties are compounded because much sand mining is illicit, making it difficult to assess its true scale and likely impacts. This leaves a major research gap around the social-environmental impacts of the river sand trade. This project adopts the interdisciplinary approach needed to answer these questions and thereby provide the whole-system understanding of the costs, benefits and trade-offs involved that is necessary to build more resilient river-city sand systems.

Research aims and objectives

The aim of this project is to develop an understanding of the links between urban growth, riverine sand mining, and associated environmental risks. Using a sample of cities from Asian and African countries, the specific objectives are to:

1. Employ remotely-sensed imagery to (a) quantify locations and extents of sand mining in rivers surrounding each urban area and (b) quantify volumes of sand (i.e., determine demand-side sand flows) employed in buildings, infrastructure, land reclamation.
2. Using the data from (1), alongside population growth data, derive an empirical model linking urban growth and volumes of sand extracted from connected river systems. This will enable comparison of how distinct patterns of urban growth – i.e., densification/sprawl/rural incorporation – place varying demands on riverine sand.
3. Quantify how these sand flows from rivers impact exposure to environmental risks (e.g., flooding and bank erosion).
4. Assess the resilience of, and complex feedback loops between, river systems and communities to sand exploitation.

Methods

Initially, a range of river cities in Asia and Africa, representing a range of different urban forms and different growth trajectories (the latter evaluated using analysis of population datasets such as World Pop) will be identified. Subsequently it is envisioned (naturally, the selected PhD scholar will refine the details):

- For Objective 1, the locations and extent of sand mining in rivers and on floodplains close to each city will be mapped (following Dujardin et al., 2024). These data, in concert with automated sand mining vessel tracking using high-resolution satellite imagery (e.g., following Smigaj et al., 2023), will be used to estimate volumes of sand extraction and hence channel incision rates. These 'supply side' estimates of sand flux will be constrained with estimates of sand used in the urbanisation process (e.g. by mapping land reclamation and sand in buildings using EC-JRC - building volume data).

- For Objective 2, sand flows data from O1 will be used, together with population growth data and maps of changing urban areas (e.g., EC-JRC - Urban Centres Database) to build an empirical model linking urban growth to sand demand across different densities of urbanisation (Dorward et al., 2023)
- For Objective 3, environmental impacts (as a function of sand demand) will be estimated using indicators such as (i) increasing exposure of populations to flood zones; (ii) depth of mining-driven incision as a proxy for bank erosion hazard, etc.
- For Objective 4, the student will seek to integrate the empirical findings (O1, O2, O3) by potentially developing a simple Systems Dynamics Model (SDM) to link stocks and flows of sand, the emergent environmental risks, and the patterns of urban growth.

Wider implications

The project has significant implications. Successfully integrating models of urban and demographic change with riverine sand mining will enable the estimation of future demands on river systems at different locations, which would aid assessments of future impacts of sand mining. This has implications for understanding the risks that sand mining poses for river systems and riverine communities – both rural and urban.

More broadly, this process is taking place in a historical context where many look to the cities of the ‘Global South’ to be at the forefront of climate mitigation and adaptation (Fox and Goodfellow, 2022). Setting aside the ethics of mining, understanding the structural relationships between urban form and sand demand will support planners in their efforts to build cities in ways that minimise their ecological footprints. Furthermore, understanding the relationships between urban form, exposure, and vulnerability will be central to fostering urban resilience. Project outputs therefore have clear relevance to SDG11 ‘Sustainable Cities and Communities’.

Contribution to interdisciplinary resilience studies:

The world is urbanizing rapidly, especially in Asia and sub-Saharan Africa, but the growth of these cities and their infrastructure is driving a huge demand for sand as an essential commodity in construction. Consequently, sand mining from the world's rivers now occurs on a vast scale, but the sector is poorly regulated, and the sand trade conceals hidden costs. Environmental costs in particular are very high, for example by generating major changes in flood processes and in triggering the onset of large-scale riverbank collapses that represent major hazards to river-side communities. These impacts have been ruinous for many communities, yet the associated socioenvironmental and political costs have been almost entirely externalised.

This leaves a major research gap around the social-environmental impacts of the river sand trade. Despite its importance, end-to-end oversight of the material flows of sand from the river to city remains poorly understood, but is necessary to better understand how urban growth drives demand for sand and associated impacts on river systems. An interdisciplinary approach is required to provide the whole-system understanding of the costs, benefits and trade-offs involved that is necessary to build more resilient river-city sand systems. For example, the integrated model of river sand extraction and urban growth proposed here would enable estimates of demand and impacts to be made. There are clear policy impacts for urban growth planning (e.g., does growing up or out demand more sand?) and how that relates to urban resilience as well as supporting the resilience of affected riverside communities.

Please list and describe any specific/additional technical training or support to undertake and successfully deliver this project. *Note that students recruited into this programme will undertake a bespoke training curriculum. Students and their supervisory teams will also identify generic skills gaps to address through training courses offered by the University's Doctoral College.*

- The student will need to develop expertise in the application (and potentially the further development) of existing algorithms (developed in prior work by Darby and colleagues) for **analysis of remote sensing imagery to detect sand mining vessels and hence estimate sand extraction volumes** (see Smigaj et al., 2023. Monitoring riverine traffic from space: The untapped potential of remote sensing for measuring human footprint on inland waterways. Science of the Total Environment, 860, 160363. DOI: 10.1016/j.scitotenv.2022.160363). Methods of **mapping mining sites based on remotely sensed imagery** will also be considered (see Dujardin et al., 2024. Mapping and modelling riverine sand and gravel mining at the sub-continental scale. Science of the Total Environment, 912, 169200. DOI: 10.1016/j.scitotenv.2023.169200).
- Similarly, the student will need to develop expertise in the application (and possibly further development) of existing approaches and algorithms to **detect and model changes in human settlement patterns and urban growth** (see Dorward et al., 2023. A spatial-demographic analysis of Africa's emerging urban geography. Environment & Urbanization, 35(2), pp.310-327. doi.org/10.1177/09562478231190735).
- The student may need to develop some capability in **Machine Learning techniques** in order to develop quantitative relationships between different elements of urban form, river sand demand, and river impacts on human populations. An alternative approach might be to employ **Systems Dynamics Modelling** to quantify these linkages (e.g. Chapman and Darby, 2016. Evaluating sustainable adaptation strategies for vulnerable mega-deltas using system dynamics modelling: rice agriculture in the Mekong Delta's An Giang Province, Vietnam. *Science of the Total Environment*, 1-32. (doi:10.1016/j.scitotenv.2016.02.162).
- Finally, there may also be the opportunity for the selected student to develop their fieldwork skills by undertaking fieldwork in a limited number of case study cities,

for example to provide an element of ‘ground truthing’ and/or to engage with academics, experts, and stakeholders (where appropriate). In particular, the research team have strong networks in Cambodia (Phnom Penh) and Nigeria (Lagos) which can support student research.