Tracking global floodplain urban growth

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Received: January 5, 2024; Accepted: June 26, 2024; Published Online: July 1, 2024; https://doi.org/10.59717/j.xinn-geo.2024.100086

Citation: Lin P., Yin Z., Zheng K., et al., (2024). Tracking global floodplain urban growth. The Innovation Geoscience 2(3): 100086.

In light of the emergence of geospatial big data, scientists around the world are now able to quantify the floodplain urban growth at the planetary scale. Several recent studies collectively revealed that the spatial divergence of how countries urbanize floodplains can be well differentiated by their development phases. This calls for a better understanding of the socio-economical and geographical constraints to these emerging patterns, and region-specific flood mitigation strategies that jointly consider the tradeoffs among the social, economical, and environmental goals when planning for a sustainable future.

Urbanization is one of the most critical issues the world is facing today. Development inside floodplains has almost always been inevitable because floodplains of large rivers (e.g. the Yellow, Yangtze, Ganges, Euphrates, and Nile) bred some of the most important civilizations. Modern socio-economic growth also favors low-lying areas that are fertile and with easy access to water and transportation. However, this comes with increasing flood risks under climate change.

According to the 2022 Global Natural Disaster Assessment Report, flood hazards accounted for over half of the natural disasters on earth, and in the year of 2022 alone, flood hazards caused 8,049 deaths, 57.53 million affected people, and US$ 44.9 billion socio-economic losses (https://www.preventionweb.net/publication/2022-global-natural-disaster-assessment-report). Record-breaking torrential rain in 2022 submerged district surrounding Dkaha, causing over 200 fatalities (https://edition.cnn.com/2022/06/29/asia/bangladesh-floods-millions-urgent-relief-need-intl-hnk/index.html), while the Ganges flood displaced nearly one million people (https://www.thenationalnews.com/world/asia/2022/08/29/india-floods-10000-families-evacuated-in-varanasi/). In 2023, two devastating floods hit the densely populated areas in China, e.g., the Hai River Basin flood caused by Doksuri (https://www.chinadaily.com.cn/a/202308/13/WS64d86928a31035260b81bcfd.html) and the Pearl River Delta flood brought by Super Typhoon Haikui (http://en.ce.cn/main/latest/202309/09/t20230909_38708254.shtml), resulting in evacuations of 86,484 and 2,516 residents, respectively. These devastating consequences urge scientists to better understand the patterns and trends of floodplain urban growth, which is fundamental to managing flood risks and improving flood resilience.

In the past, floodplain urban growth was often viewed as a regional urban planning issue primarily discussed as context-oriented cases. Over the years, satellite remote sensing and cloud computing enable quantitative analyses of such phenomenon using a unified global framework, which have systematically shifted our understanding of floodplain urban growth as a planetary-scale pattern silently. For example, Tellman et al.[1] obtained flood inundation maps for over 900 flood events worldwide, and found that population exposed to flood hazards has increased by over 20% during 2000 to 2015. This represented an upward correction of existing estimates that are expected to further increase under future climate scenarios. Andreadis et al.[2] leveraged high-resolution flood maps derived from recent global hydrodynamic modeling to quantify global floodplain urban growth. They highlighted that the year 2000 was a turning point, after which the global floodplain urban growth rate has accelerated by 2.1 times. Rajib et al.[3] assessed the land cover change patterns of global floodplains, and concluded that the world has mainly compromised its agricultural land (460,000 km^2) for increased floodplain urban extents (140,000 km^2) during 1992 to 2010. Such results offered insights into the changing phase of global floodplains with potential ramifications to the altered hydrological processes.

In a more recent study, Rentschler et al.[4] further addressed from a different angle how widespread and regionally varied floodplain urban growth is happening. That is, they separated and compared floodplain urban growth patterns not only by high-, medium-, and low-levels of hazard zones, but also by differentiating countries by their income groups. In this way, they were able to focus on examining how the phase of development can explain the diverging floodplain urban growth patterns. Multiple datasets were incorporated, including 30-m Landsat satellite imageries for urban mapping, and 90-m global floodplain maps. Their results revealed that global floodplain urban growth has increased by 587,000 km^2 since 1985, representing an increase of 85% from 1985 to 2015 for all types of floods, i.e., pluvial, fluvial, coastal floods. They also found that people tend to lean towards

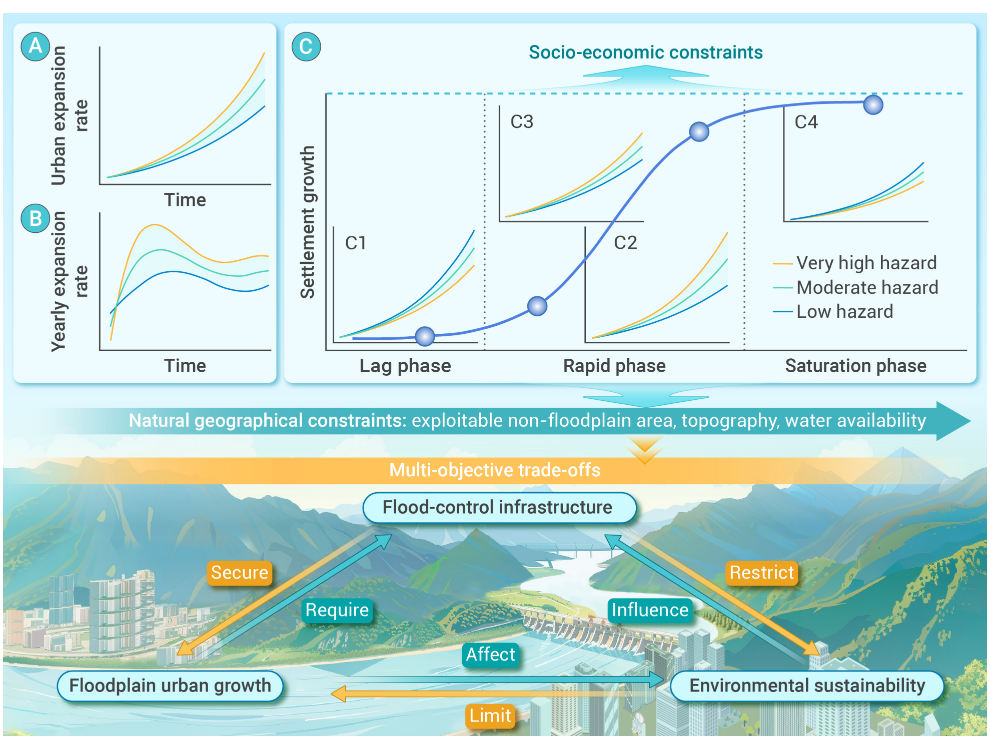

Figure 1. | Global floodplain urban growth patterns and implications for future research (A-C) show a conceptual summary of results derived from Rentschler et al.[4] (A) (B) show the global floodplain urban growth rate and the yearly expansion rate differentiated by hazard level from 1985 to 2015. (C) differentiates the urban growth patterns by the development phase of different countries (i.e., lag-, rapid-, and saturation- phases), where (c1-c4) denote low-income, lower- to upper middle- income, and high-income groups, respectively. The bottom panel shows opportunities for future research, where multi-objective trade-offs among the goals of floodplain urban growth, flood-control infrastructure, and environmental sustainability need to be prioritized.

flood-exposed than flood-safe areas for urban growth, as clearly shown by the outpaced urban growth rate in regions with very high and high hazard levels than those with moderate and low hazard levels (Figure 1A) , reinforcing the findings of Andreadis.[2] The preference of hazard-prone regions is neither temporally nor spatially uniform though. Before 1990, yearly growth rates in less risky zones were in the lead. In the next two decades, urban growth in areas with high levels of hazard surged, while that in relatively safer areas slowed down before rebounding after 2010 (Figure 1B).

Rentschler et al.[4] revealed that the urban growth strategies concerning different hazard levels exhibit clear dependencies on the countries' income groups. For example, lower- to higher-middle income countries tend to occupy regions with high hazard levels more than safer regions (Figure 1C). Low- and high-income countries show opposite patterns, where they are more rational in terms of urbanizing high hazard level areas (see the lower urban growth rates, red lines in Figure 1C). This is most likely because lower- and higher-middle income countries are at their fastest phase of development with strong inner drives for rapid socio-economic growths. For low-income countries, urban growth is lagged (Figure 1C) and thus urbanizing flood-prone zones can be risky and unnecessary. In the cases of high-income countries, the urban growth demand has already exceeded the peak, leading to lower growth rates across all flood hazard levels (comparing Figure 1C), especially for riskier areas that are also more saturated.

Compared with earlier studies, Rentschler et al.[4] went a step further by utilizing the socio-economics lens to reveal that the phase of development is key to explaining the diverging patterns of floodplain urban growth, although it also came with several limitations. For example, the representations of human disturbance in their data and methods are limited. The flood extent data used in their study ignored the constructions of flood-control infrastructure such as dykes, which can lead to inaccurate results for countries with relatively complete flood control measures. Another aspect is related to the over-simplification in using country income levels as the single indicator to explain the observed floodplain urban growth patterns. In fact, natural conditions, urbanization policies and infrastructure distributions might also jointly complicate the patterns, but these was not sufficiently addressed in their study. Findings from recent large-scale studies collectively emphasize floodplain urban growth as an inevitable outcome of the socio-economic growth (demonstrated by development phase). This perspective, compared with previous studies that primarily viewed floodplain urban growth as an element of increased flood risks, can emphasize to researchers and local/national authorities the necessity of region-specific strategies for flood mitigation.

For example, for middle-income countries with predictable strong socio-economic growth momentum for continuous floodplain urban growth, it necessitates prioritizing the safety of floodplain dwellers by adopting flood-control infrastructures, alongside non-structural measures such as early warning systems or flood-resillient housing to mitigate flood losses. The same applies to regions with strong geographical constraints (e.g., reliance on water and riverside flatlands) for floodplain inhabitation, where the financial and technical limits to establishing these measures should be carefully evaluated. For countries with lower economic growth momentum or less geographical constraints, soft-path measures can be prioritized, and ecological restoration might become an overriding requirement. Ding et al.[5] analyzed floodplain urban growth behind levees constructed for the continental U.S, and found that a high-income country like the U.S. has seen a reversal trend of the levee effect. While it offered independent evidence for the more sustainable route that a high-income country has undertaken, the adopted flood mitigation strategies may not be duplicated in countries at other development phases.

It has also become apparent that we need to better understand the interplay among floodplain urban growth, development of flood-control infrastructure, as well as environmental constraints such as changes to river ecology (Figure 1, bottom panel). Currently, it is not clear yet whether a region with rapid floodplain urban growth has been paired up with sufficient flood-control infrastructure to ensure flood security, nor is it clear that if the flood-control infrastructure of a region has already exceeded its environment limit. To achieve the United Nation's Sustainable Development Goals (SDGs), all three aspects of urban growth (SDG 11.5), flood security (SDG 13.1), and environmental sustainability (SDG 15.1) need to be considered. But how to quantify and understand the tradeoffs and synergies among these goals remains to be further explored. To this end, more quantitative and theoretical studies need to be conducted to resolve the tradeoffs among different SDGs as induced by changes in the pattern of floodplain urban growth.

We also urge a revisit and a potentially upward correction to the definition of floodplain boundaries, because historically inactive floodplains can be now active under climate change. Thus, new methods to delineate potential floodplains (e.g., by combining hydrological-hydraulic models with future climate projections obtained from climate models) should be developed. Ultimately, a cross-disciplinary approach integrating the expertise of hydrology, hydraulic engineering, and sustainability science is much warranted to promote a more hazard-resilient and sustainable future, on top of the clearer pictures of global floodplain urban growth patterns revealed recently.

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FUNDING AND ACKNOWLEDGMENTS

This research is funded by the Open Research Program of International Research Center of Big Data for Sustainable Development Goals (CBAS2022ORP05). The funders had no role in study design, data collection and analysis, decision to publish or preparation of the manuscript.

AUTHOR CONTRIBUTIONS

Conceptualization: P.L., Z.Y., K.Z.. Investigation: P.L., Z.Y., K.Y., X.L., Z.Y.. Writing - Initial: P.L., Z.Y., K.Z.. Writing - Review, Editting: X.L., Z.Y.. All authors contributed to and approved the manuscript.

DECLARATION OF INTERESTS

The authors declare no competing interests.