Exploring the Relation of Livability Mapping and Flood Exposure Analysis by Combining Remote Sensing and Citizen Science

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Abstract

Environmental hazards are key determinants of urban liveability, shaping the safety, health, and resilience of residents. This study investigates the intersection of urban livability and flood exposure by integrating remote sensing, citizen science, and AI-driven analysis across three African countries: Ghana, Kenya, and Mozambique. Using Sentinel-1 satellite imagery, open geospatial datasets, and advanced deep learning techniques, a citizen-derived perceived livability index was created which was then combined with rapid flood exposure modelling through FastFlood. The results reveal that areas with the lowest livability scores -characterized by poor housing conditions, limited service access, and minimal green spaces- are also consistently the most exposed to frequent and severe flooding. In Nairobi, for instance, approximately 35% of built-up areas are flood-prone, with informal settlements like Kibera and Mathare facing disproportionate risks. Citizen science efforts validated the flood models, underscoring the critical role of local knowledge in capturing fine-scale flood dynamics invisible to remote sensing alone. The project demonstrates that liveability and environmental risk are deeply interrelated, and contribute to worsening urban vulnerability. By combining community mapping with scalable Earth Observation methods, this work delivers actionable methods for urban planners, humanitarian organizations, and local policymakers. Our results stress the importance of planning strategies that prioritize investments in flood mitigation, nature-based solutions, and resilient infrastructure for the most at-risk communities. Such communities are often omitted in official data. The needs and views of such vulnerable communities need to be included in supporting sustainable and inclusive urban development under increasing climate pressures.

1. Introduction

The rapid urbanization in many African cities has brought significant challenges in managing urban growth, with approximately 60% of the urban population living in informal settlements (United Nations, 2022). Such settlements are commonly deprived of key aspects of infrastructure, services, and environmental and housing conditions, as outlined by the IDEAMAPS domains of deprivation framework (Abascal et al., 2022). These areas, besides suffering from deprived housing conditions and socio-economic disparities (Ramiaramanana et al., 2025), often face multiple hazard risks (Kabiru et al., 2023; Kamruzzaman et al., 2021). However, the severity and frequency of hazards and their impacts on lives, properties and livelihoods are not well-documented (Kuffer et al., 2021). A common hazard with severe impacts is floods that are exacerbated by climate change (Kuffer et al., 2023). The "Space4All" project addresses such urgent urban challenges by integrating cutting-edge geospatial technologies with participatory methodologies to promote sustainable, inclusive, and climate-resilient urban development (Space4All, 2025). More specifically, this research focuses on combining livability mapping as perceived by citizens (Abascal et al., 2024b) and flood exposure analysis for vulnerable urban areas in Ghana, Kenya, and Mozambique, leveraging open-access datasets such as Sentinel-1 imagery, land use datasets, and advanced modelling frameworks like the FastFlood Simulation model (Van den Bout et al., 2023).

We combine livability mapping, which is a bottom-up mapping approach building on citizens' perception in contrast to a top-down modelling Earth Observation approach of slum or informal settlement delineations, with mapping urban floods with a focus on flash floods that are commonly omitted in available flood datasets. With projections from the IPCC indicating a staggering 2600% increase in high-frequency flood events in Sub-Saharan Africa by 2030, the need for spatial evidence to anticipate and manage flood risk, in particular in areas most vulnerable, is more critical than ever (Trisos et al., 2022; UNICEF, 2019). Rapid urbanization, combined with inadequate infrastructure and the growth of deprived urban areas (DUAs), places millions at extreme risk, living areas that are chronically omitted in official data. However, conventional flood risk assessments often lack the granularity, speed, complexity of urban environments, and community focus required for effective urban resilience planning (Pourghasemi et al., 2020). Space4All responds to this gap by combining fast simulation models, participatory approaches, and citizen-generated data to deliver locally relevant flood hazard information, with a specific focus on comparing deprived and non-deprived urban areas.

Global flood models commonly omit the extent of urban floods, in particular flash floods, while common hydraulic models (e.g., HEC-RAS (Johnson, 2014)) are computation-intensive. and require massive data for calibration. Therefore, we test and calibrate a less computational-intensive model, i.e., the FastFlood model (Van den Bout et al., 2023). FastFlood is a lightweight, open-source and web-based flood simulation tool suited for data-poor environments and complex urban environments (Figure 1), such as Nairobi (Kenya) and Accra (Ghana), where the increasing impacts of urban floods are already deeply felt. For example, a recent flood event in Nairobi first led to the massive destruction of houses and assets and the loss of lives and second to a massive forced eviction of an estimated 180,000 inhabitants (Kuffer et al., 2025; Kuffer, 2024).

Figure 1. Densely built-up living environment of the majority of the urban population in African cities.

Figure 2. Citizens inspecting the areas that are frequently flooded but are omitted in global flood datasets.

Therefore, Space4All uses several Sub-Saharan African case studies, e.g., Nairobi. In Nairobi alone, where approximately 60% of the population lives in informal, flood-prone settlements (Figure 2), Space4All is pioneering innovative engagement strategies. Even so, Nairobi belongs to the well-mapped cities, and actionable information on floods in DUAs is absent from the local government and Community-Based Organizations (CBOs). Even more, the absence of data is hindering progress on local mitigation and adaptation measures in secondary cities (e.g., Kisumu, Chimoio, Tema). Furthermore, the intersection between a bottom-up understanding of livability and flood hazards and vulnerabilities is not well understood (Figure 3).

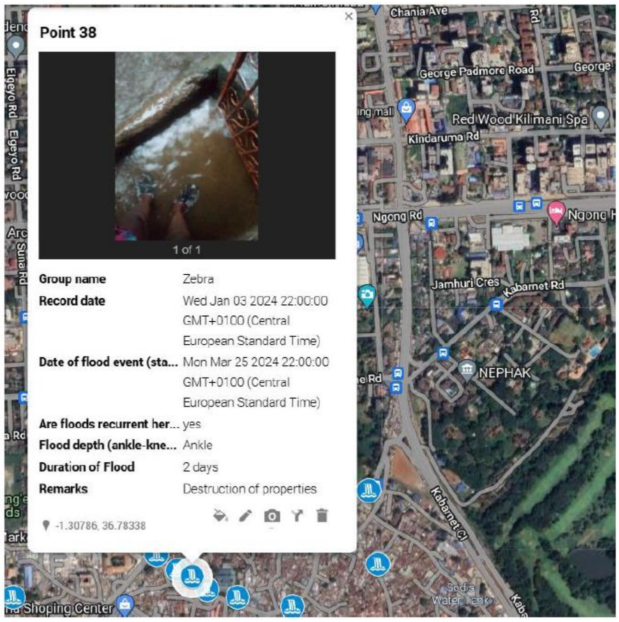

Figure 3. Flood impacts in densely built-up living environments in African cities, mapped by citizens with a simple web-based mapping app.

By bridging global data infrastructures with local realities, Space4All aims to create actionable spatial evidence that can guide urban planning, disaster risk reduction, and climate adaptation policies. Ultimately, this integrated approach seeks to empower communities, inform planners, and strengthen resilience in some of Africa's most rapidly transforming urban environments.

2. Methodology

To analyse the exposure to flood in deprived urban areas, we combine livability and flood exposure modelling in 6 Sub-Saharan African cities, Nairobi, Kisumu (Kenya), Accra and Tema (Ghana) and Beira and Chimoio (Mozambique). The models have been developed in Nairobi, as we have a large network and available reference data, and transferred to the other cities.

Space4All uses Sentinel satellite imagery to assess urban liveability, utilizing a recently developed method that integrates environmental, infrastructural, and social indicators to identify the most deprived areas (Abascal et al., 2024a). This method quantifies livability by evaluating critical dimensions such as green space availability, housing quality, infrastructure access, and socio-economic conditions by combining citizen-generated data (employing a developed app for generating massive labelled data) with deep learning methods.

Liveability mapping builds on the views of citizens and their preferences for urban environments. This is done within workshops where citizens compare image pairs with the main question, "What is the better place to live?". This massive data (e.g., around 0.5 Million votes in Nairobi) is fed into an SoA deep-learning model to produce city-level livability maps (Figure 4). The method (Abascal et al., 2024a) was developed with Very-High-Resolution (VHR) imagery (WorldView-3 images), limiting its scalability due to the high data costs. Experiments with Sentinel-1 and Sentinel-2 imagery showed the advantage of

Sentinel-1 images to have frequent updates with robust accuracy, particularly in frequently cloud-covered tropical cities (Filho et al., 2024).

By processing and analyzing Sentinel-1 data, we generate high-resolution livability indices that highlight spatial disparities across urban landscapes. More specifically, an AI-voter was developed, where the model is given two Sentinel-1 images (one left and one right image), and the AI-voter decides, based on the citizen's input, which is the better place to live. The resulting maps show the variations of the livability score.

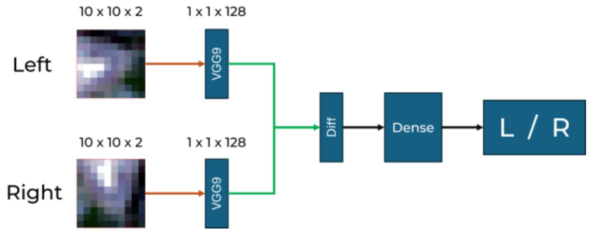

Figure 4. AI-voter using Sentinel images to decide which is the better place to live.

Building on this analysis, we incorporate flood exposure information derived from local knowledge created in workshops in informal settlements with satellite-based hydrological models and historical flood event data using FastFlood (Figure 5).

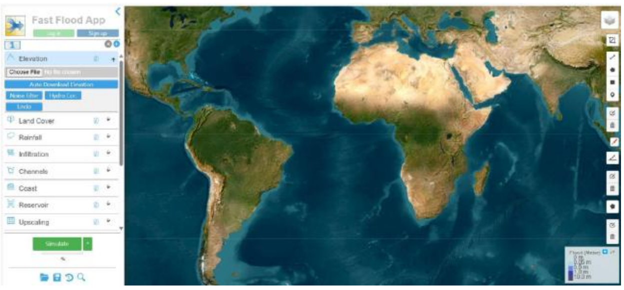

Figure 5. The web-based interface of FastFlood (Van den Bout et al., 2023).

The integration of these two datasets, livability indices and flood exposure, provides a comprehensive framework to evaluate the compounded risks faced by urban populations, particularly in informal areas. Working directly with community-based organizations, residents from neighbourhoods in Nairobi such as Kibera, Mathare, Mukuru, and Kariobangi have been trained to collect flood observations using accessible digital tools like Google My Maps (Figure 3). Through fieldwork, transect walks, and participatory mapping workshops, the project has gathered a large amount of local data, while simultaneously community awareness and ownership of flood risk knowledge.

3. Results

Urban floods are one of the dominant hazards in many Sub-Saharan African cities. Regarding flood exposure, our case studies show the following:

1. Ghana: In Accra and surrounding secondary cities, rapid urbanization combined with inadequate drainage systems, is leaving densely populated low-income areas particularly susceptible to floods. Livability mapping indicates hotspots of deprivation, while flood models show the most exposed locations. Combining these two analyses we highlight areas where targeted interventions can significantly enhance resilience. Such areas are often neglected in urban plans.

2. Kenya: Nairobi's informal settlements, housing around 60% of the population in around 4% of the built-up area, often experience the dual challenges of poor livability and high flood exposure. Similar results were found for Kisumu, a secondary city. Sentinel-2 data reveal spatial patterns of deprivation, such as lack of infrastructure, services, and poor housing conditions. Informal settlements are frequently exposed to flash floods. Working together with city planners, disaster management, and NGOs, this integrated analysis supports local stakeholders in prioritizing flood mitigation projects and community-based initiatives.

3. Mozambique: In Beira to Chimoio, recurring floods disproportionately affect the city's informal communities. The livability mapping identifies regions with inadequate infrastructure, compounded by high flood exposure. The insights provide critical inputs for designing urban development policies that address both socioeconomic disparities and disaster preparedness.

More specifically, our results show that the integration of citizen-based livability mapping and flood exposure analysis provides a bottom-up assessment of urban resilience. Initial results indicate that the least liveable areas, as identified by the livability index, are disproportionately exposed to flood risks. For example, across cities, areas with low livability scores are highly impacted by frequent floods. This impact is often overlooked by flood models that do not incorporate the complex urban environment, e.g., the blockages of drainages caused by waste. Across all three study cities, i.e., Accra, Nairobi, and Maputo, areas with low livability scores consistently align with zones of frequent and severe flooding. This pattern highlights how socio-economic disadvantages and environmental threats are deeply intertwined, reinforcing cycles of vulnerability and marginalization.

Figure 6. Example of FastFlood outputs showing the flood hazards in densely built-up urban environments.

Particularly, the use of lightweight flood models like FastFlood allowed for rapid simulation of flood scenarios, facilitating decision-making processes even in data-scarce environments.

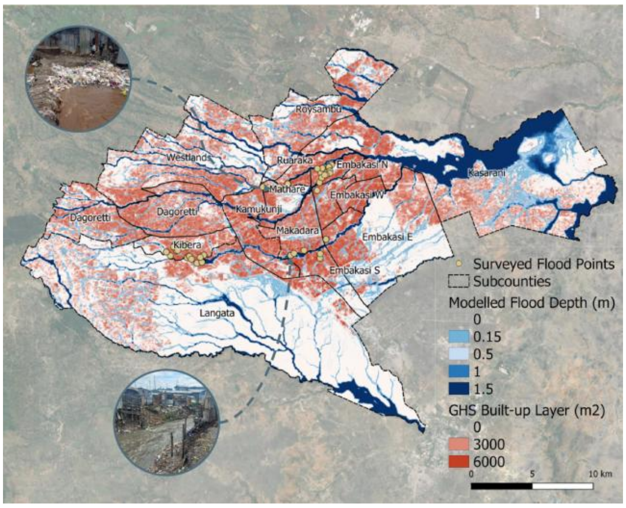

Figure 7. Flood model using community knowledge, Nairobi, Kenya.

In Nairobi, detailed flood exposure mapping revealed that approximately 35% of built-up areas are exposed to flooding, with 99% of exposed areas in informal settlements being densely built-up (Figure 6 and 7). Livability assessments based on urban form, services access, and green space availability further emphasized the heightened risks in slum communities such as Kibera, Mathare, Mukuru, and Korogocho. Local participatory mapping efforts confirmed that many critical community facilities, including schools and health centers, are located in high-risk zones without access to adequate evacuation infrastructure.

Moreover, the combination of citizen knowledge, Sentinel imagery, open-source urban datasets, and advanced AI-based methods (AI-voter) for livability classification, demonstrated the potential of remote sensing and machine learning to deliver scalable, reproducible, and context-sensitive assessments (Figure 8). Evaluation of the robust performance of the AI-voter is shown (Figure 9). Uncertainties exist in image pairs that are very similar to each other. For areas where the images were very different from each other, the results of the AI-voter show a high level of certainty.

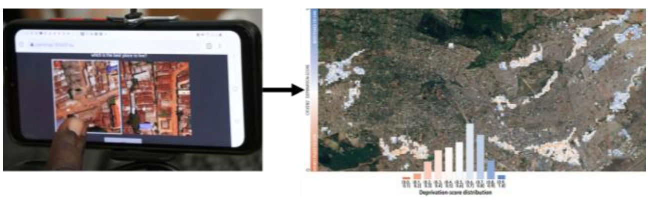

Figure 8. Creating livability scores with local knowledge, employing the Partimap Citizen Science App.

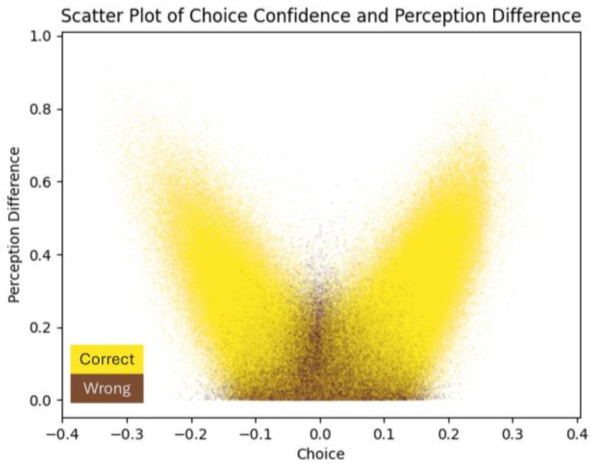

Figure 9. Evaluating how certain the AI-voter selects (left or right), its correctness when compared to its citizen counterpart, and how the difference between pairs of images impacts its selection.

Overall, the lowest livability scores are consistently found in areas that have high flood exposure. Such areas are often along drainage systems, on slopes and in sinks. Housing materials are often very lightweight (e.g., iron sheets or wood) and soil floors, without any prevention that hinders the water from running into houses. As a consequence, even with low flood heights, massive impacts are caused, e.g., destruction of assets and long-lasting health impacts caused by very polluted flood waters. For example, as a result, inhabitants, in particular the most vulnerable population groups, have flood-related bacterial infections.

4. Discussion

A large part of the urban population in Sub-Saharan Africa is not accounted for (Kuffer et al., 2022; Thomson et al., 2021), nor their presence, needs, exposure or vulnerabilities. To provide data on these often invisible spaces, the combination of citizen science, remote sensing, and fast, scalable modelling not only improves the spatial accuracy of flood maps but also addresses historical issues of exclusion in urban decision-making processes. Validation exercises revealed that local knowledge was essential for improving the accuracy of model outputs, particularly in capturing complex, small-scale flood dynamics that are often invisible to remote sensing alone.

The findings of this study provide actionable insights and tools for urban planners, policymakers, and humanitarian organizations. As part of the project, we invest a substantial team into local workshops and capacity building for local governments and NGOs. By identifying and prioritizing the most exposed areas, this research aims to call for targeted investments in infrastructure and flood mitigation projects using participatory and community-based approaches. The combination of Sentinel-1 data and advanced AI methods shows the potential of remote sensing to deliver scalable, data-driven solutions for urban resilience challenges. This impact is often overlooked by flood models that do not incorporate the complex urban environment, e.g., the blockages of drainages caused by waste. This stresses the urgent need for integrated urban planning approaches that consider both socio-economic vulnerabilities and environmental risks (Boanada-Fuchs et al., 2024; Owusu et al., 2024; Tareke et al., 2024).

Taken together, the results stress the urgent need for integrated urban planning approaches that address socio-economic vulnerabilities and environmental hazards. By identifying and prioritizing the most at-risk urban areas, this research calls for targeted investments in infrastructure improvements, nature-based solutions, and inclusive flood risk mitigation strategies rooted in community engagement and participatory governance.

Future work will extend the livability mapping to the city scale for the entire city, in contrast to only the mapping of slums or informal settlements as "islands" or "outliers" of the city. This urges a rethinking of how we see the phenomenon of urban deprivation as well as the terminology used. For example, slums, informal settlements, or DUAs are not homogeneous areas. Thus, we need to acknowledge the diversity of urban spaces and understand both their problems as well as their opportunities (assets). Furthermore, it is important to understand the production of data as a means (Thomson et al., 2020; Wanjiru, 2021) of bringing urban stakeholders into a discussion space to define future developments together.

5. Conclusions

This study successfully developed insights into urban flood exposure using a fast simulation model (FastFlood) combined with citizens' knowledge and open geospatial data. Findings show a clear pattern of higher exposure in the least livable areas (commonly referred to as informal settlements and slums). By integrating community-based data collection with advanced remote sensing and modelling techniques, we were able to capture the fine-scale spatial insights of flood risk across diverse urban environments in Ghana, Kenya, and Mozambique.

The findings are built on a bottom-up model and SoA deep-learning models of livability, revealing that deprivation and flood exposure are deeply interconnected. Areas characterized by low access to services and infrastructure, poor housing conditions, and lack of green spaces, which are key indicators of low livability, are consistently the most impacted by frequent and severe flooding events. This intersection emphasises that environmental risk cannot be separated from socioeconomic vulnerability in rapidly urbanizing regions of low- and low-middle-income countries (LMICs), particularly in Sub-Saharan Africa.

Furthermore, the participatory approach of the Space4All project highlights the importance of local knowledge in providing local data on urban deprivation and relevant flood data. Such data have the potential, when developed together with local stakeholders, to shape resilient urban solutions. The combination of citizen-generated flood observations, Sentinel satellite imagery, and open-source modelling provides a scalable and inclusive framework for flood risk assessment and urban planning.

Ultimately, the study calls for the development of effective resilience strategies that must be built upon both spatial evidence and social equity. Investments in flood mitigation and adaptation, early warning systems, and nature-based solutions must prioritize the most vulnerable communities. This is, in particular, relevant to developing strategies to achieve sustainable and inclusive development under increasing climate pressures.

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