

FLOODS AND URBAN CONNECTIVITY: A TOOLKIT FOR PRIORITIZING RESILIENCE INVESTMENTS

Demonstration note with case studies from Kinshasa and Kigali

The challenge: floods disrupt urban connectivity and livelihoods

Cities are intricately interconnected socioeconomic systems, with transport networks connecting people to their jobs, health and education facilities, and ensuring the smooth functioning of supply chains. When floods happen, they isolate people and firms from these vital networks, causing cascading disruptions and losses. Such floods are not limited to rare and extreme events. Especially in developing country cities, the lack of resilient infrastructure systems means that even regular rainfall events—for example, during rainy seasons—can cause havoc.

Attention is often biased towards direct asset losses from floods, rather than the wider economic costs of disrupted networks. This is due primarily to the complex dynamics of economic and infrastructure networks. But public transport and road usage data are also often limited, especially when the predominant modes of transport are informal and walking. So how can we identify and

prioritize cost-effective measures for urban resilience? This note describes an analytical approach that can help prioritize investments in urban transport resilience and public transport (figure 1), while also strengthening the economic case for such investments.

An analytical solution, in a nutshell

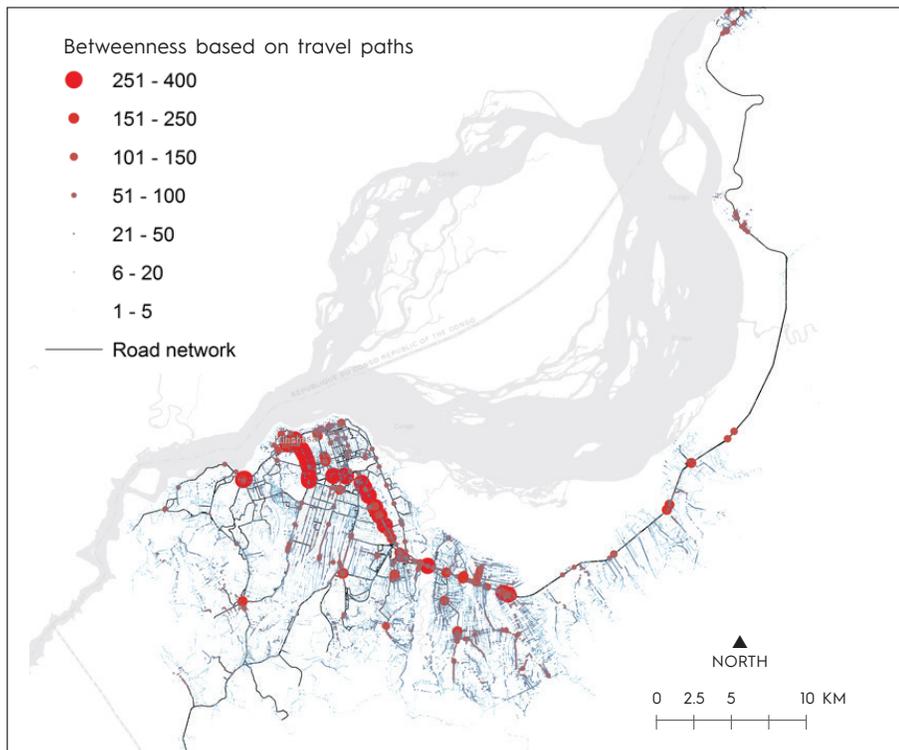
Assessing urban network disruptions and prioritizing investments in urban resilience

We have developed a replicable novel methodology to:

1. Document the impacts of flooding on the performance of collective transport systems¹ in developing country cities

¹ In many African cities, most “public” transport is in fact privately owned and operated. In this paper, we refer to collective transport and public transport, using the latter as an overarching term that includes privately owned collective transport services.

Figure 1. Kinshasa’s most critical transport nodes: candidates for priority resilience upgrades



Note: Betweenness is an indicator of the criticality, i.e. importance, of a road segment to the network’s overall functionality.

2. Measure the consequences of these disruptions on employment and key service accessibility
3. Estimate the economic costs linked to travel delays
4. Guide local decision makers by identifying the most critical links in transport networks that would benefit from climate-proofing, increased maintenance, or resilience upgrades.

Key insights: Illustrations from Kinshasa and Kigali

Public transport performance under flooded conditions

To compare public transport performance, we conducted travel surveys under normal (“dry”) and flooded (“wet”) conditions for Kigali and Kinshasa. These surveys include data on stops, schedules, travel times, and routing related to different public transport services, and they can often include supplementary information such as fares. We conducted the wet survey in the height of the rainy season in both cities, within 48 hours of a heavy rain episode. By comparing General Transit Feed Specification (GTFS)² feeds under normal and flooded conditions, we can document the impact of rain and flooding on three dimensions of public transport performance: trip rerouting, headway (difference in minutes between two departures along a given route)/frequency, and travel speeds.

Figure 2 shows examples of itinerary changes between normal and flooded conditions in Kinshasa, with similar behaviors identified in Kigali. While most itineraries remain identical whatever the conditions, others can change slightly (panels a and d) or substantially (b and c) when heavy rain occurs, as drivers adapt trips to avoid the worst-affected road segments. These sudden changes in itinerary impact on travelers’ ability to reach their jobs and other destinations. Some transport services, such as those provided by Kinshasa’s formal bus company TRANSCO, were suspended under heavy rain conditions.

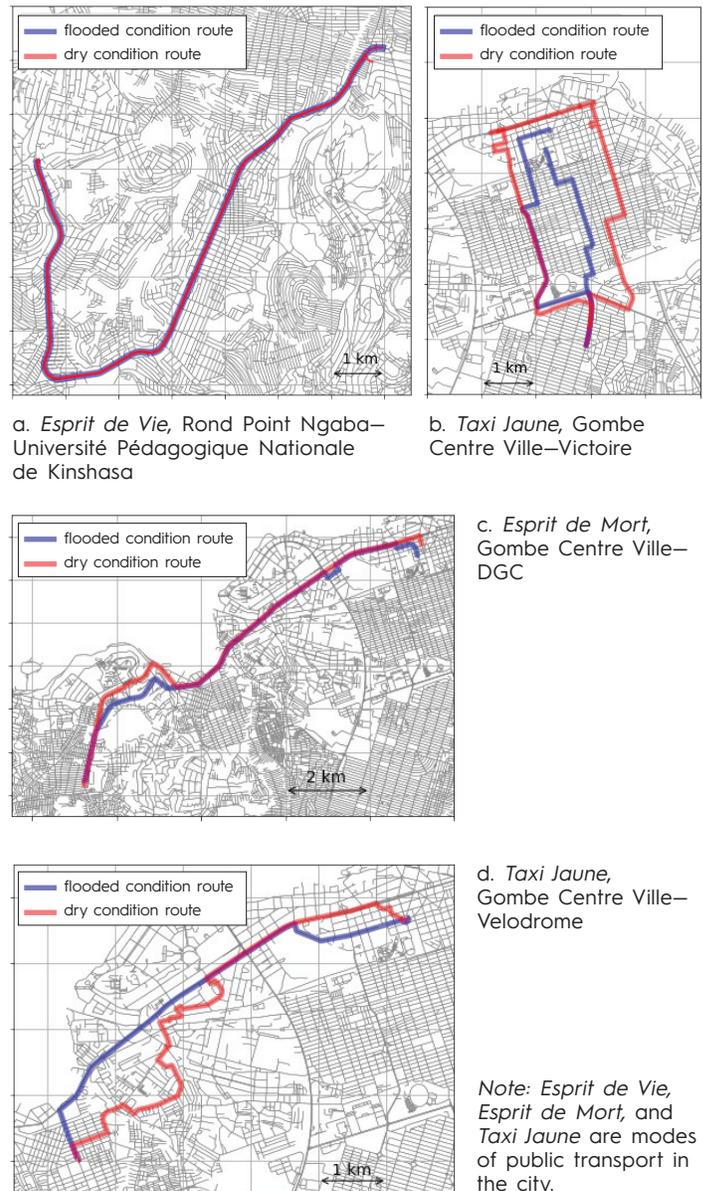
Heavy rain episodes can also reduce travel speeds. In Kigali, speeds were reduced by 1.8 kilometers per hour on average (an 8 percent reduction); in Kinshasa, they were reduced by 1–4 kilometers per hour, depending on service type. Headways also increased in both cities, with the difference in minutes between two departures along a given route rising by approximately 28 percent on average in Kigali, and 30 percent (*Esprit de Vie* vehicles) and 75 percent (*Taxi Jaune* vehicles) in Kinshasa.

Accessibility of employment and other services

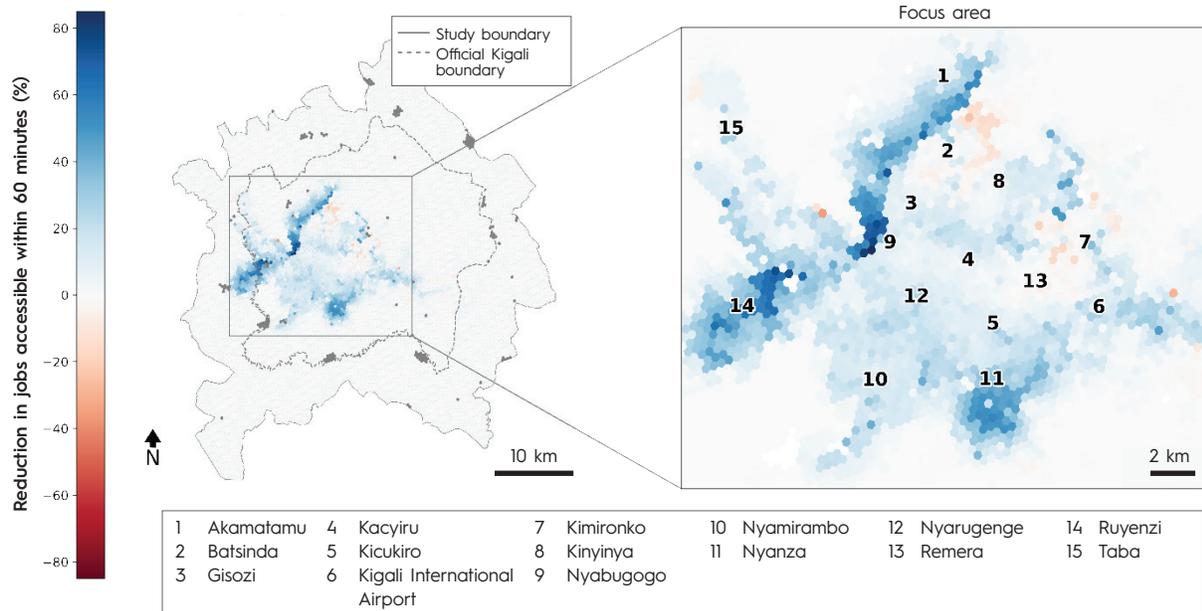
The combination of rerouting, cancelled trips, skipped bus stops, slower travel speeds, and increased headways leads to travel delays for commuters trying to reach different parts of both cities. This in turn results in lower accessibility of employment

This methodology relies on an innovative, dual condition, transit feed data collection campaign (under flooded and normal conditions) combined with global flood maps, commuter or household surveys, and open-source information retrieved from Open Street Map (OSM). The first applications of the methodology focus on Kinshasa, Democratic Republic of Congo and Kigali, Rwanda.

Figure 2. Trip consistency and rerouting in Kinshasa under normal and flooded conditions



² A set of text files that describe particular aspects of transit information: stops, routes, trips, and other schedule data.

Figure 3. Accessibility of jobs: Difference between normal and flooded conditions in Kigali

Note: Blue cells indicate locations where the share of jobs accessible within 60 minutes decreases by up to 80 percent. Red cells indicate locations with increased job accessibility due to flood-induced rerouting.

opportunities from public transport, or the share of jobs that can be reached within 60 minutes. This is a commonly used metric to assess urban labor market physical integration.

In flooded conditions, average accessibility of jobs reachable in 60 minutes falls from 34 to 25 percent in Kigali and from 20 to 15 percent in Kinshasa. This represents a 25 percent decrease in both cities, in flood events typical of 5- and 10-year return periods, respectively. These decreases get larger for less frequent and more intense flood events as more road links are flooded and travel is increasingly impeded. Figure 3 also shows sizeable spatial heterogeneity in accessibility losses.

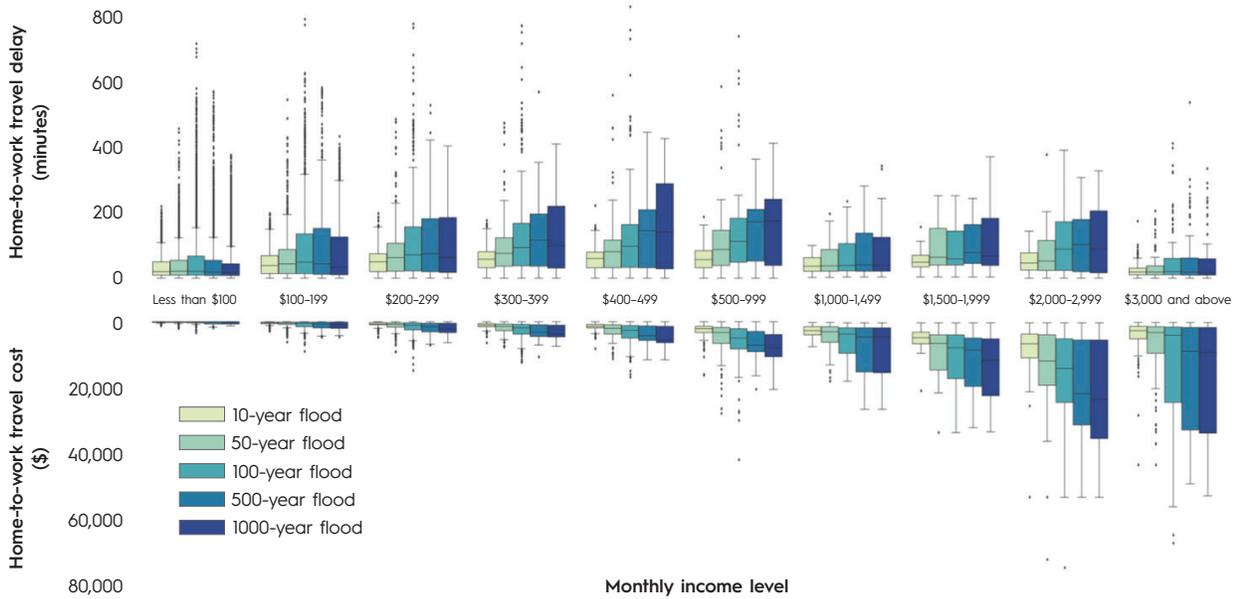
Economic costs and heterogeneous socioeconomic impacts of travel delays

With information about commuters' incomes and their residential and work locations, we can calculate travel delays from flood disruptions and estimate a lower-bound economic cost of floods by calculating their opportunity costs at city scale. We find that in Kinshasa, travel delays alone represent \$5.4 million in opportunity costs per flood day for a typical 10-year event. When

accounting for flood probabilities and aggregating for the 10, 50, 100, 500 and 1000-year flood events, the average opportunity cost per flood day represents \$1.2 million.

The average figures are large. They also hide important spatial and socioeconomic variations that we documented. Figure 4, for instance, shows travel delays and associated opportunity costs broken down by income group in Kinshasa for five return periods. On average, more extreme floods with a longer return period induce longer travel delays and higher economic costs compared with those with a shorter return period. It is clear from figure 4 that commuters with medium income levels (monthly salary of \$100–1,000) experience higher travel delays than those on a low (under \$100) or high (over \$3,000) incomes. It is also clear that higher income groups incur the highest opportunity costs in terms of time, despite their comparatively small travel delays. Note, however that different metrics such as opportunity costs in relation to income would show higher economic impacts for the poorer income groups. Estimated travel delays for the lower income groups are more extreme (over one hour), suggesting the existence of highly disadvantaged commuter groups who are heavily impacted by flood disruptions on road networks.

Figure 4. Histogram of travel delays and estimated economic loss in Kinshasa, by income level, under five flood scenarios



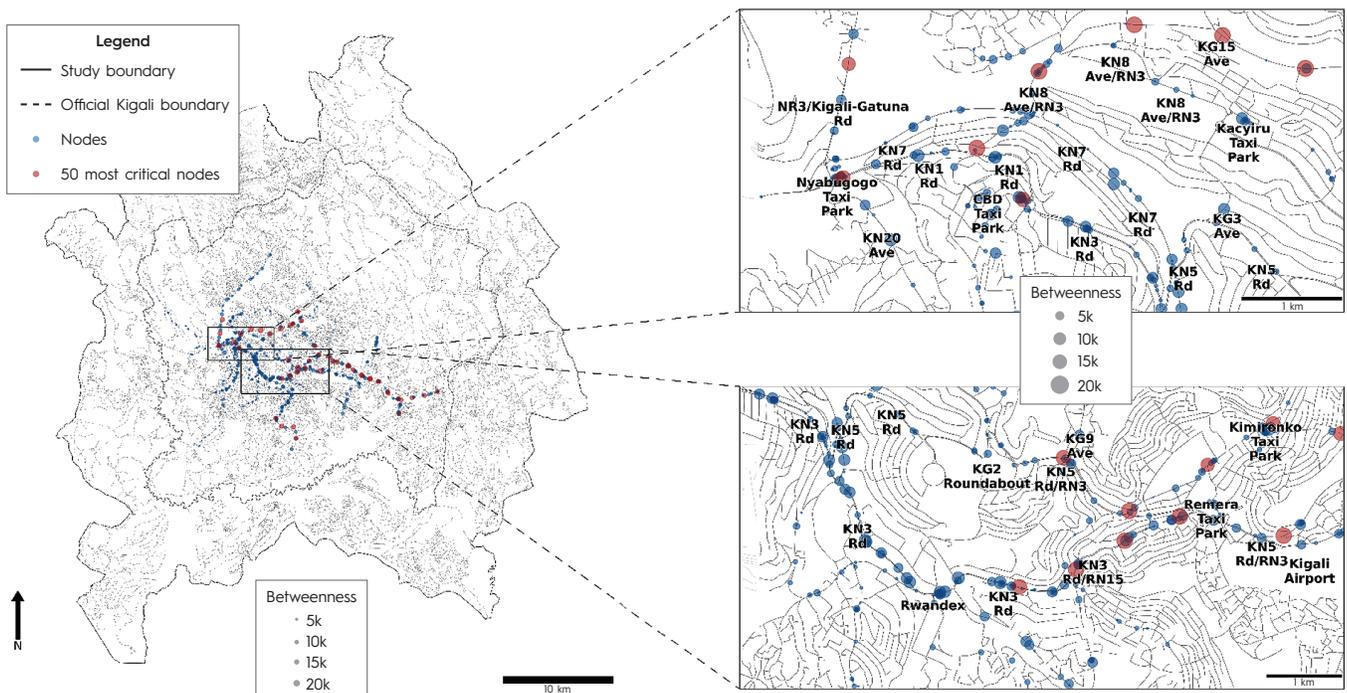
Investment prioritization: starting from the most critical points

Our work does not stop at assessing the physical and economic consequences of floods on transport systems and accessibility; we also consider how to prioritize resilience upgrades to reduce disruptions most effectively. In Kinshasa and Kigali, we identify the most critical transport links that are at risk of flooding and that create the most extensive travel delays for commuters. In other words, we identify the road segments and intersections that are responsible for the highest travel delays, and should therefore be prioritized for upgrade. Targeted investments to increase the

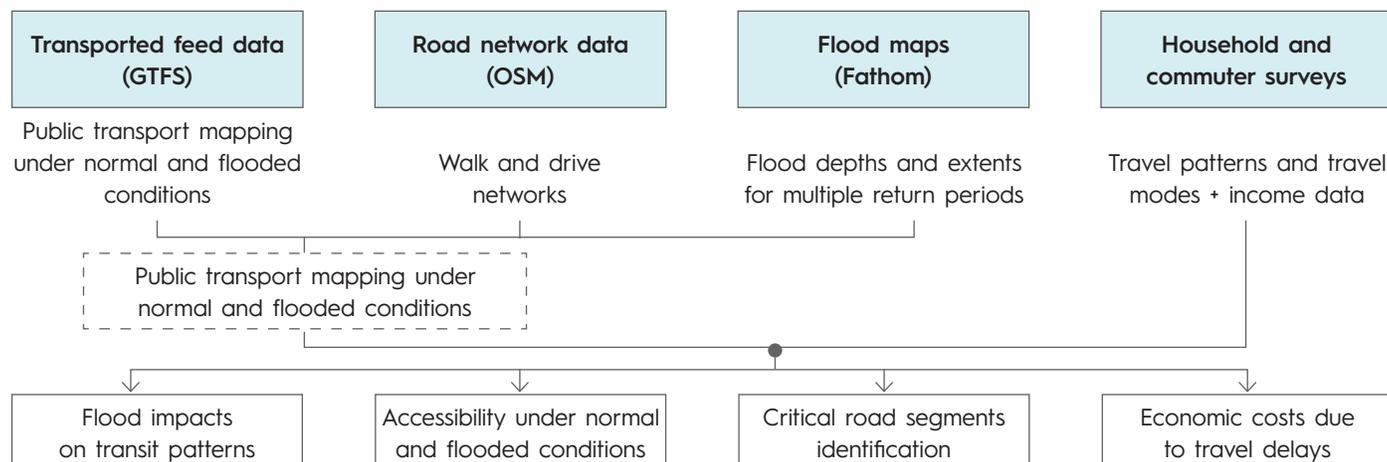
resilience of these points will yield the largest reductions in economic disruption and flood loss.

Figure 5 shows the most critical nodes in Kigali’s public transport system, which would create the largest travel delays if they become impassable due to heavy rains or other exogenous factors. Six of Kigali’s 13 most critical nodes are at risk of flooding. Figure 1 (page 1) highlights Kinshasa’s most critical road segments. Upgrading the most critical nodes should be considered a priority for resilience investments. With additional information about resilience upgrade options, the system costs from flood-induced travel delays could be compared to costs of climate-proofing road segments.

Figure 5. Weighted betweenness centrality for Kigali’s public transport network



Note: KN = Kigali Nyarugenge; KG = Kigali Gasabo; RD = Road; RN and NR = National Road; CBD = Central Business District

Figure 6. Overall project workflow from data collection to processing and analysis

Overall, this information can help local decision makers channel their resources—for example, for public transport investment and road maintenance—to where they will deliver the highest dividends in ensuring smooth urban mobility under normal and flooded conditions.

Methodology and data

In many developing countries, and Africa in particular, collective and informal transport modes—such as *matatus* in Kenya, *tap taps* in Haiti, *tro tro* in Ghana, and *dala dala* in Tanzania—are the most used means of travel besides walking. Recent initiatives (such as Digital Matatus) that survey these transport modes in urban areas in Africa, Latin America, and the Caribbean document how these systems operate and offer crucial information to mainstream accessibility analyses. Yet, coverage is far from universal. And even less is known about how these systems are impacted by disasters.

To overcome such data shortfalls, we combine four key datasets to assess the impact of floods on urban transport in Kinshasa and Kigali:

1. An innovative GTFS dataset collected for these analyses under normal and flooded conditions for collective modes of transport
2. OSM transport network vector data
3. A set of high-resolution global flood maps capturing the extent and depth of pluvial and fluvial floods, which can be supplemented with coastal floods as needed. When local flood maps are available, they should be preferred as they are typically of higher quality and resolution and can account for local conditions, such as drainage capacity.

4. A commuter travel survey with origin-destination information of commuters' trips (and ideally, travelers' socioeconomic attributes)³, or a firm census or business registry

Challenges in replication and available support

The Global Facility for Disaster Reduction and Recovery's (GFDRR) Global Programs on Resilient Infrastructure, Disaster Risk Analytics, and Resilient Health Systems can provide support in implementing network analysis approaches to quantify the wider economic impacts of disasters and identifying investment or policy options to mitigate their costs and harness the dividends or resilience.

The GFDRR team can also advise teams on the procurement process to contract firms for the travel surveys and the GTFS data collection.

Finally, the GFDRR team is available to discuss with teams whether the approach proposed in this short note is the most appropriate for the task at hand and can suggest alternative methods if it is not.

Contacts and additional information

The interested reader is welcome to explore our journal paper on Kinshasa⁴ and our blog post summarizing its findings.⁵

For more information, or if you are interested in applying this methodology to your projects or analyses, please feel free to contact:

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³ Note that a commuter survey with Origin/Destination pairs and socioeconomic information is not mandatory but will considerably enrich analyses by allowing for a more meaningful criticality analysis and the economic evaluation of travel delay costs. In the absence of such surveys, a dataset with information about the spatial distribution of jobs will be enough to measure the impacts of floods on accessibility and a more standard criticality analysis can be performed.

⁴ He, Y, Thies, S, Avner, P and Rentschler, J. 2021. "Flood impacts on urban transit and accessibility—a case study of Kinshasa." *Transportation Research Part D: Transport and Environment*, 96 (102889). <https://doi.org/10.1016/j.trd.2021.102889>

⁵ Avner, P and Rentschler, J, He, Y and Thies, S. 2021. "When floods hit the road – impacts of rainy season flooding on transit and commuting in Kinshasa." World Bank blog, February 8. <https://blogs.worldbank.org/developmenttalk/when-floods-hit-road-impacts-rainy-season-flooding-transit-and-commuting-kinshasa>.