Sustainable and Resilient Infrastructure

ISSN: 2378-9689 (Print) 2378-9697 (Online) Journal homepage: www.tandfonline.com/journals/tsri20

Coalition for Disaster Resilient Infrastructure (CDRI) 2022 Conference Proceedings

To cite this article: (2023) Coalition for Disaster Resilient Infrastructure (CDRI) 2022 Conference Proceedings, Sustainable and Resilient Infrastructure, 8:sup2, 1-143, DOI: 10.1080/23789689.2023.2181552

To link to this article: https://doi.org/10.1080/23789689.2023.2181552

Published online: 13 Jun 2023.

CDRI
Coalition for Disaster Resilient Infrastructure

Taylor & Francis
Taylor & Francis Group

Proceedings

DRI Technical Conference

12-13 October 2022 | New Delhi | India

Adaptive Pathways for Resilient Infrastructure

Volume 8 Number S2
May 2023

Conference Organized by

Coalition for Disaster Resilient Infrastructure (CDRI)

CDRI Secretariat, 4-5 Floor, Bhartiya Kala Kendra 1, Copernicus Marg, New Delhi, 110001, India.

The Coalition for Disaster Resilient Infrastructure (CDRI) is a partnership of national governments, UN agencies and programmes, multilateral development banks and financing mechanisms, the private sector, and knowledge institutions that aims to promote the resilience of new and existing infrastructure systems to climate and disaster risks in support of sustainable development. CDRI promotes rapid development of resilient infrastructure to respond to the Sustainable Development Goals' imperatives of expanding universal access to basic services, enabling prosperity and decent work.

Contact Details

Website: www.cdri.world

Tel: +91-11-4044-5999

Twitter: cdri_world

Linkedin: coalition-for-disaster-resilient-infrastructure

Email: Publications@cdri.world

Editor: Ratnesh Kumar (PhD), Lead Specialist – Knowledge Management, CDRI

Proceedings

DRI Technical Conference

12-13 October 2022 | New Delhi | India

Adaptive Pathways for Resilient Infrastructure

Proceedings Editor
Ratnesh Kumar, PhD
Lead Specialist – Knowledge Management, CDRI

Conference Organizers

Concept

Kamal Kishore, Executive Committee Co-Chair, CDRI

Guidance

Amit Prothi, Director General, CDRI

International Steering Committee

Marjorie Greene, Earthquake Engineering Research Institute (EERI), USA
Ila Patnaik, Professor & Chief Economist, Aditya Birla Group, India
Ravi Sinha, Professor, Indian Institute of Technology Bombay, India
Satoru Nishikawa, Professor, Nagoya University, Japan

Conference Team

Mona Chhabra Anand, Director – Research & Knowledge Management
Ratnesh Kumar, Senior Specialist – Research
Geetika Singh, Senior Specialist – Publication

Organizational Support

Anand Kumar, Deputy Director – Admin & HR
Aishwarya Pillai, Lead Specialist – Publications
Alpana Saha, Lead Specialist – Partnerships & External Relations
Amarnath Shukla, Senior Specialist – IT
Aparajita Suman, Expert – Knowledge Management
Avinash Venkata Adavikolanu, Analyst – Knowledge Management
Deepak Rawat, Manager – Procurement
Jessica Mossahari, Senior Specialist – Advocacy
Mallika Srinivasan, Lead Specialist – Communications
Neha Bhatia, Senior Specialist – Knowledge Management
Payal Bhatnagar, Analyst – Communication
Ravi Krishnani, Specialist – Communication
Renu Bhardwaj, Executive Assistant – Administration
Sumit Raghav, Executive Assistant – Procurement
Wasi Md. Alam, Senior Specialist – Capacity Building

Event & Publication Partners

Informa Markets
Taylor & Francis UK

Sustainable and Resilient Infrastructure
Volume 8 Supplement 2 May 2023

CONTENTS

Proceedings: DRI Technical Conference - 12-13th October 2022 (New Delhi, India)

SUSTAINABLE AND RESILIENT INFRASTRUCTURE
2023, VOL. 8, NO. S2, 12–19
https://doi.org/10.1080/23789689.2023.2181552

Systemic assessment of climate risks and adaptation options for transport networks in East Africa

Raghav Pant, Diana Jaramillo and Jim W. Hall

Oxford Programme for Sustainable Infrastructure Systems (OPSIS), Environmental Change Institute, University of Oxford, Oxford, UK

ABSTRACT
Transportation networks are lifeline systems fundamental to economic and social prosperity. Disruptions to these networks can be detrimental to long-term growth plans. This is particularly important in the context of growing climate hazards such as flooding, where long-term sustainable development, social wellbeing and economic stability are at risk from widespread failures of transport networks. In view of these threats, there is a need to create evidence of the impacts of current and future climatic risks to transport networks. To address this problem, the authors have developed and implemented a multi-regional transport infrastructure climate risk and adaptation assessment framework. This framework seeks to understand the extent and location of extreme hazard exposures, direct damage and economic flow losses, risks and adaption investment needs for strategic transport networks. It aims to inform decision-makers to help: (i) improve network resilience by identifying and strengthening the locations of highest vulnerabilities; and (ii) understand the benefits of investing in climate resilience in terms of avoided losses from climate risks. The authors apply their climate risk and adaptation assessment tool for the case study region covering Kenya, Tanzania, Uganda and Zambia, where they investigate the risks due to river and coastal flooding over current and future climate change driven scenarios. Their analysis shows that there are large benefits to investing in climate adaptation of major roads and rail network links in those countries that are exposed to flooding in the present and future. They estimate that investing in climate adaptation from the present (2019) until 2080 to strengthen resilience of the 20 most flood risk incurring roads and railways lines in the region would amount to about US$9 million and US$92 million in adaption investments, but would avoid risks as high as US$875 million and US$234 million across future climate scenarios.

KEYWORDS
climate risks and hazards; resilience assessment; climate adaptation; economic risks; economic risks

1. Introduction

Transport networks of roads and railways are lifelines that provide mobility and access to sustain delivery of essential commodities around the world (Hallegatte, Rentschler & Rozenberg, 2019). Such large-scale networks face risks from natural hazards, which are predicted to intensify in the future under adverse climate change (Wang et al., 2017). This will have an impact on planned transport investments, predicted to take place at record high levels of US$40 trillion or 1.8% of global gross domestic product (GDP) from 2016–2040 (Global Infrastructure Hub, 2017).

The case study countries for this paper – Kenya, Tanzania, Uganda and Zambia – are witnessing significant large-scale infrastructure investments, driven by the prospects of strong economic growth and prospects of enabling these countries to be gateways to growing domestic markets in Africa (Horvat et al., 2021). But there is a danger that climate change driven natural hazards such as flooding might be detrimental to their growth and development plans. Estimates suggest that most of Kenya experienced flooding in 2020 (Makena et al., 2021), that in Tanzania the climate hazards costs in recent years have amounted to about 1% of national GDP (Erman et al., 2019), and that in Uganda rising water levels in Lake Victoria displaced thousands of people, flooding homes and businesses, damaging infrastructure and destroying roads (Brown, 2020). Evidence also suggests that repair and recovery of damaged transport assets in these countries is either very slow or does not take place over many years. In Kenya, a survey of infrastructure flood damage in 27 out of 47 counties showed that transport assets took much longer to repair than other infrastructure (electricity and piped water); only about 6% of damaged roads and bridges were repaired within one month and 57% were never repaired (Njogu, 2021). As climate change increases the magnitudes and frequencies of catastrophic natural hazard events, incidents of transport failures resulting in socio-economic losses are likely to become more common (Schaller et al., 2016).

There is a need to create evidence of the impacts of current and future climatic hazards on transport networks. Presently, the identification of systemic risks to

CONTACT Raghav Pant raghav.pant@ouce.ox.ac.uk

transport networks remain poorly understood. Responding and adapting to the threat of climate change requires a research approach that: (i) maps out where climate hazards are greatest; (ii) identifies the transport network locations exposed and vulnerable to climate hazards; (iii) assesses direct physical damage costs and indirect economic flow losses to quantify climate risks; (iv) assesses the costs and benefits (in terms of risk reduction) of adaptation options under different future development, growth and climate scenarios; and (v) prioritizes adaptation options, so that limited budgets can be used to climate-proof networks as efficiently as possible.

This paper presents research that addresses the above issues, and in doing so delivers analysis on quantifying systemic risks due to failures of key locations in the transport networks of low-income countries (LIC). We present a detailed methodology supported by novel analysis of climate change driven flooding risks and adaptation assessment of transport networks in Kenya, Tanzania, Uganda and Zambia. This research has been undertaken in the High-Volume Transport (HVT) project, 'Decision Support Systems for Resilient Strategic Transport Networks in Low Income Countries' (Hickford et al., 2023), which aims to support investment decisions and option selection for long-distance strategic land transport networks exposed to climate risks by creating the first multi-state transport infrastructure decision support system in a LIC context.

In the next sections we describe the methodology, case study country data and implementation, the main results and the conclusions from our study.

2. Methodology

To quantify climate change driven flooding risks to transport networks on the large scale, we have developed a system-of-systems framework for transport risk and adaptation analysis. Figure 1 provides a graphical overview of this system-of-systems framework implemented for our case-study countries, which is consistent with spatial systems modelling approaches previously applied to Tanzania

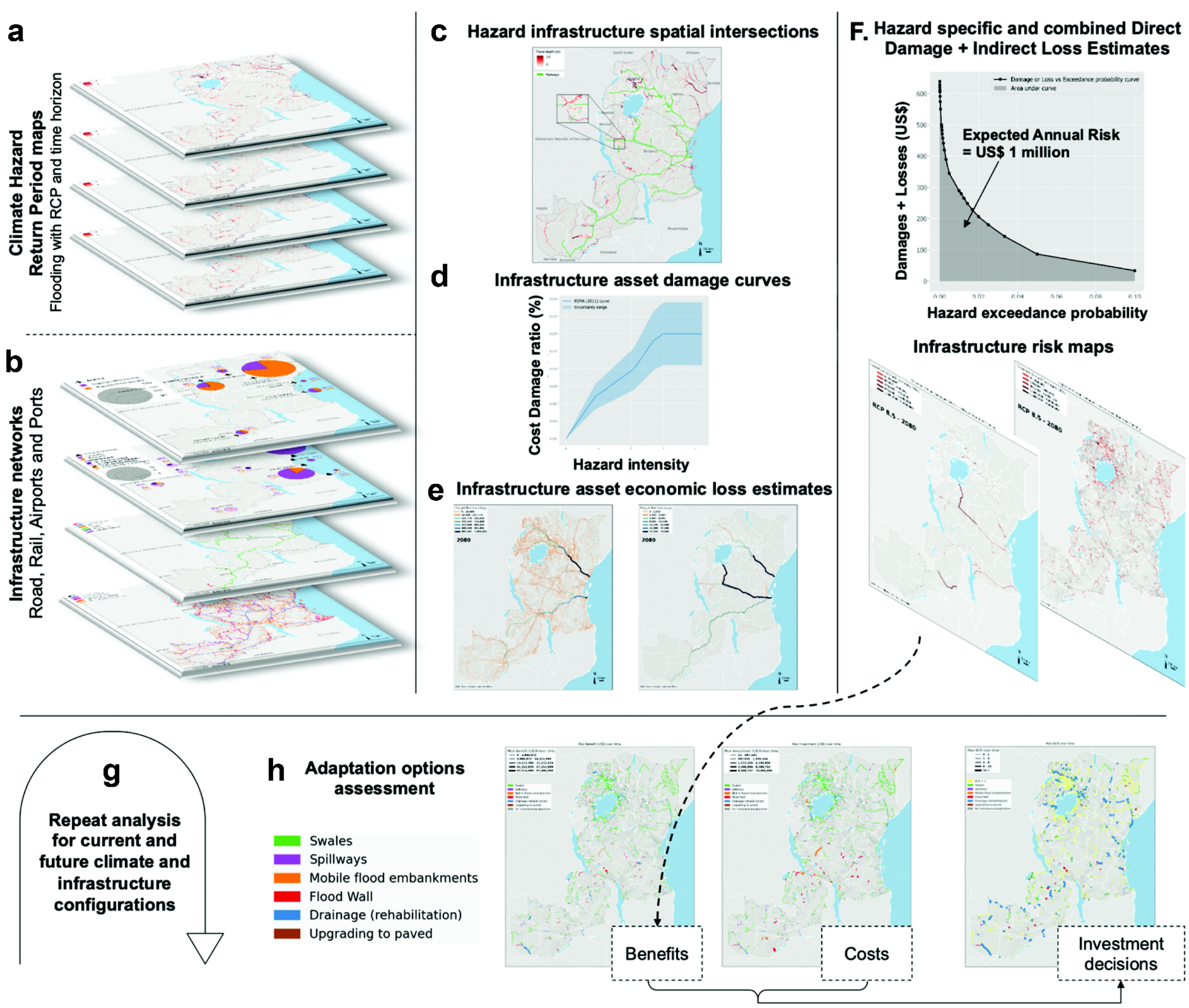


Figure 1. Graphical representation of transport system-of-systems risk and adaptation assessment framework.

(Pant et al., 2018a), Vietnam (Oh et al., 2019) Argentina (Kesete et al., 2021) and the United Kingdom (Pant et al., 2018b). Briefly, the framework components (described as steps A–H) are discussed below.

2.1. Hazard assembly

We assemble flood hazard maps of various flood severities across climate scenarios and futures to initiate failure in transport systems (see, Table 2).

2.2. Multi-modal transport network assembly

We create a transport system-of-systems model by: collecting geospatial data and creating connected network models from such data; identifying network locations with attributes (e.g., road pavement type, type of rail station and so on); identifying locations for freight transport (e.g., key ports, rail stations, road connections to ports and rail); collecting freight trade data in tons/day (or US$/day) in our study region and integrating it with network locations; assigning freight flows in tons/day (or US$/day) on the specific network locations based on a least generalized cost criteria to create flow estimates. Details of these models are provided in Pant et al. (2018a) and Hickford et al. (2023).

2.3. Exposure analysis

We overlay each hazard map with each network location and estimate flood depth and lengths of each asset (road or rail link) inundated. This tells us how many roads and rail lines potentially face flood risks across all flood return periods, climate scenarios and time epochs.

2.4. Direct damage estimation

We estimate *direct damage costs* by: selecting a flood depth that might cause physical damage to assets; looking up vulnerability curves, which quantify the percentage (or fraction) of length of damage sustained by an asset for a given flood depth (Koks et al., 2019); and multiplying the rehabilitation costs in US$/km of each asset by its flood damage length.

2.5. Indirect economic loss estimation

For damaged assets we estimate *indirect economic losses* from import–export trade flow disruptions in US$/day by: finding all existing freight trade routes (mapped in Step B) which are disrupted; finding rerouting options and redirecting flows towards alternative routes to estimate losses as the increase in transport costs; and estimating flow disruptions in terms of freight tonnage lost when there are no rerouting options.

2.6. Direct and indirect risk metrics

In this study we estimate two risk metrics: expected annual damage (EAD) and expected annual economic loss (EAEL), which are respectively the measures of average damage cost (US$) and average economic loss (in US$/day) incurred for an asset in any given year due to a given hazard type for a given time epoch and climate scenario. EAD (or EAEL) is estimated as the area under the direct damage (or economic loss) versus the exceedance probability curve (1/return period; Koks et al., 2019). From the estimate of EAD and EAEL we get the asset level *total risk* = EAD + (duration of disruption) × EAEL/day.

2.7. Multiple failure and scenario estimations

We implement steps A–F for future climate hazard and transport scenarios.

2.8. Adaptation options assessment

After spatial risk assessment across climate scenarios and time epochs, we conduct an adaptation assessment for a set of adaptation options for building resilience to flood shocks. The effectiveness of any adaptation option is evaluated and compared through a cost–benefit analysis (CBA), where the present value (PV) of investments into an adaptation option are compared with the PV of benefits due to avoided risks over an implementation timeline of several years (Pearce, Atkinson & Mourato, 2006). The CBA analysis helps identify priority assets and locations where benefit–cost ratio $\left(\mathrm{BCR} = \frac{\text{PV of benefits}}{\text{PV of adaptation investment}}\right) \geq 1$ or only target the few assets with the highest BCR. We can use this analysis to estimate the total budget needed for investing in climate adaptation for assets with BCR≥1. The next section describes the specific types of adaptation options for flooding considered in this study.

3. Case study data assembly and implementation

We implement the methodological framework, through open datasets of hazards, infrastructure networks, rehabilitation costs and trade flows, which is summarized in Table 1. Here we provide some main data highlights, while all data are described in detail in Hickford et al. (2023).

Table 1. Summary of relevant data sources and details. More information is provided in Hickford et al. (2023).

Category	Data	Source	Details
Hazards	River flooding Coastal flooding	Aqueduct flood product datasets (World Resources Institute, 2020)	• Flood depths in metres over grid squares (~900 m^2 at the Equator) • 1/2, 1/5, 1/10, 1/25, 1/50, 1/100, 1/250, 1/500 and 1/1000 (1/return period) • 5 Future climate models • RCP 4.5 & 8.5 emission scenarios • Epoch: Baseline (2019) + 2030, 2050 and 2080 **For coastal only**: • With and without subsidence • 5th, 50th and 95th percentile sea level rise scenario confidence
Transport networks	Roads	OpenStreetMap (OSM)	• 179,000 km of motorways and trunk roads, primary roads, secondary roads and tertiary roads • Assigned or assumed road properties (road pavement type, construction material, width, lanes)
	Rails	OpenStreetMap (OSM)	• 423 key stations, stops and halts and 10,500 km of lines identified as: currently open; under rehabilitation; construction; proposed for the future
	Ports	Various statistics from the port authorities of Kenya and Tanzania	• Two main maritime ports: Kenya's Port of Mombasa and Tanzania's port of Dar es Salaam, with two more maritime ports in Tanzania • 15 inland ports on Lake Victoria and Lake Tanganyika
	Airports	Country specific reports for aviation authorities in Kenya, Uganda, Tanzania and Zambia	• Six of the largest airports with known freight carrying capacity identified in Kenya (3), Uganda (1), Tanzania (1), Zambia (1)
Direct damages	Fragility curves	Direct damage (fragility) curves for paved roads, unpaved roads and railway lines (Koks et al., 2019)	• Percentage of damage an asset vs flood depth • We assume that damages happen only when flood depth > 50 cm
	Rehabilitation costs	Database of 172 projects (AfDB [African Development Bank], 2014) The World Bank's Road Costs Knowledge System (ROCKS) database (World Bank, 2018)	• Generalized estimated of rehabilitation costs in US$/km for different types of paved and unpaved roads and railway lines • All costs converted to 2019 US$ values
Network flows	Global import–export trade flows between countries	UN Conference on Trade and Development (UNCTAD) and World Bank (unctadSTAT website)	• Flows in tons/day and US$/day mapped to specific ports, airports, road and rail border crossings in four countries • Flows allocated along roads and rail lines connected to ports and airports, to locations of economic activity and population concentration • Assumed 4% annual growth in freight until 2080, with future rail lines also used

Table 2. Description of adaptation options considered with costs, relevant asset types and impacts on damage curves and return period cut-offs.

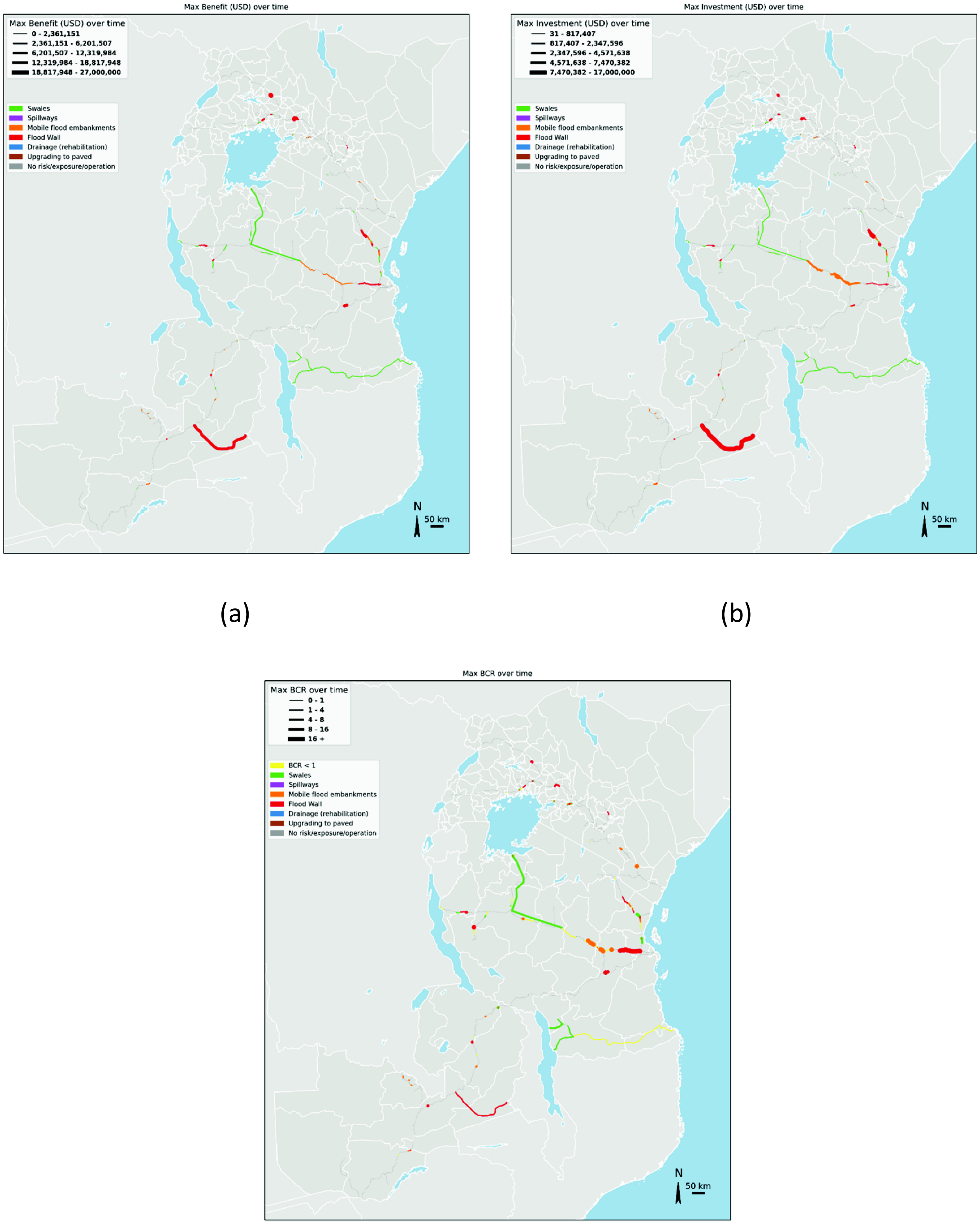
Option	Description	Initial Investment Cost	Assets	Damage Curve Modification *f(x) = ax + b*		High Return Period Cut-offs (years)
				a	b	
Swales	Detention swales, also referred to as 'bioswales', are broad shallow channels topped with vegetation. They are designed to attenuate and infiltrate run-off volume from adjacent impervious surfaces.	13,430 US$/km	Roads, railways	0.965	0.00	10
Spillways	To discharge flows that cannot either be used immediately or stored in a reservoir for future use.	176,193 US$/km	Roads, railways	0.900	0.00	10
Mobile flood embankments	Inflatable tube (hose) segments that are used to insulate/dam flood water.	573,068 US$/km	Roads, railways	1.000	−0.20	0
Flood wall	Freestanding, permanent, engineered structure designed to prevent encroachment of floodwaters.	1,230,000 US$/km	Roads, railways	1.000	0.00	50
Drainage rehabilitation	Dredging by removal of accumulated material from watercourses, canals or drainage systems.	46,843 US$/km	Roads *paved only*	0.780	−0.10	50
Upgrading to paved road	Upgrading to more climate-resilient paved roads.	247,159 US$/ lane-km	Roads*unpaved only*	Assign paved damage curve		0

Important observations from Table 1 are that we have: (i) used several flood maps capturing current and future climate change scenarios at a reasonably high spatial resolution; (ii) derived network data from open-source OSM in which the road and rail network location information is very accurate when compared to satellite

Figure 2. Results of maximum (a) PV of benefits PVs; (b) PV of adaptation investments; and (c) BCR for adaptation options for roads at risk due to river and coastal flooding under climate change.

imagery; (iii) considered and spatially mapped future new rail lines which are being developed in the region; (iv) included all major ports and airports that are used for large-scale freight transport in the region; (v) derived damage costs estimated from known rehabilitation project costs in the region; and (vi) mapped trade flows from a well-documented database and also built scenarios of future trade growth based on regional forecasts.

Table 2 describes the details of adaptation options and their costs derived from different sources (Hickford et al., 2023). The effectiveness of adaptation options in reducing risks are measured in terms of how they reduce the flood vulnerability of assets (damage curves) and how they provide protection up to a given return period. From Table 2 the $f(x) = ax + b$ values show how the damage curves are linearly



(c)

Figure 3. Results of maximum (a) PV of benefits; (b) PV of adaptation investments; and (c) BCR for adaptation options for railways.

scaled down by each option and the right-most column shows the return periods until which the flood has no effect.

4. Results

We present selective results of the adaptation assessment for roads and railway lines in our case study region. Here we evaluate the effectiveness of the adaptation options in respect of the maximum benefits they provide. At each asset level we assume that the duration of disruptions is 15 days, which means the total risk = EAD + 15 × EAEL/day. We estimate these risks at the baseline year 2019 and the three future years 2030, 2050, 2080 under climate scenarios, and linearly interpolate risks between these years. We assume that a climate adaptation option is planned in 2019 and has a timeline of investment until 2080. We perform the CBA analysis for each option selected for each asset type that is at risk, with the adaptation options' initial investment in 2019 and maintenance costs assumed to be 20% of initial investment costs every five years and 1% every year until 2080, with a 10% discounting rate (Hickford et al., 2023).

For a given asset we find that there could be multiple options that provide a BCR ≥ 1 estimate, which means for all these options the PV of benefits (avoided risks) outweigh the PV of adaptation investments. However, if we were to select one preferred option, then we look at the one with the highest avoided risks because it would be the most effective in reducing risks while providing a BCR ≥ 1. We apply this principle to all our assets and their adaptation options to find the most risk reducing option for assets with BCR ≥ 1, whereas for assets with BCR < 1 we select the highest BCR options.

The results of our analysis with the best options for road assets with their (a) PV of benefits, (b) PV of adaptation investments and (c) BCR estimates are shown in Figure 2. These results show at several locations options such as drainage rehabilitation are most effective, while installing flood walls and swales are also effective options in many cases. We have also highlighted the assets for which BCR < 1, which shows that none of our chosen options might be useful for such assets. From these results we estimate that investing in adaptation of the top 20 most benefit incurring road investments would amount to about US$9 million in PV of adaption investments against of PV of benefits of about US$875 million in avoided risks.

Results from Figure 2 for railways show that options such as swales, flood walls and mobile flood embankments are the most effective adaptation options. We suggest that several of these options should be applied to new railway lines such as the new SGR line along the Central Corridor in Tanzania where swales could help avoid potential risks. For rail assets ranking the top 20 most benefit incurring rail investments would amount to about US$92 million PV in adaptation investments and provide US$234 million in PV of benefits (avoided risks).

The adaptation analysis shows that most of the highest benefits and BCR > 1 ranked assets are key linkages that facilitate trade flows across whole networks at present or in the future. Such assets represent very compelling cases for investing in climate adaptation to improve systemic resilience of transport networks. With BCR results we can prioritize the assets and locations for building climate resilience, while estimating the scales of adaptation investment requirements. Results of maximum (a) PV of benefits PVs; (b) PV of adaptation investments; and (c) BCR for adaptation options for roads at risk due to river and coastal flooding under climate change.

5. Conclusion

This paper presents findings from a comprehensive assessment of systemic risks to transport networks due to current and future climate change driven river and coastal flooding hazards. It provides an understanding of magnitudes and locations of extreme hazard exposures, damages, economic losses and risks to strategic road and railway network links, which helps make the case for: (i) improving network resilience by identifying and strengthening the locations of highest vulnerabilities; and (ii) understanding the benefits of investing in climate resilience in terms of avoided physical damages and economic losses from climate risks.

Through the demonstration of a detailed transport network climate risk and adaptation assessment, this study has satisfied its main objective of providing an analytical methodology and tool for prioritizing adaptation decision-making. The quantified direct and indirect risks, adaptation benefits and costs here will help transport planners and stakeholders in Kenya, Tanzania, Uganda and Zambia to understand the scales of climate risks they might face and how they could prioritize adaptation investments along with long-term planning objectives. The methods and tools from this study can be utilized for several other climate hazards and contexts for systemic risk assessment of transport networks on the national and regional scales.

Acknowledgments

This research was funded by UKAID through the UK Foreign, Commonwealth & Development Office under the High-Volume Transport Applied Research Programme, managed by DT Global. The authors wish to gratefully acknowledge the support and funding of FCDO for this project (HVT043). The views expressed in this report do not necessarily reflect the UK government's official policies.

Disclosure statement

The DRI Technical Conference 2022 was sponsored by CDRI, along with editorial work of the Conference Proceedings. However, CDRI did not influence the research, data, findings, and views presented in the research papers.

References

AfDB [African Development Bank]. (2014). *Study on road infrastructure costs: Analysis of unit costs and cost overruns of road infrastructure projects in Africa*.

Brown, V. (2020). *Flooding in East Africa*. C40 Cities Finance Facility.

Erman, A., Tariverdi, M., Obolensky, M., Chen, X., Vincent, R. C., Malgioglio, S., … Yoshida, N. (2019). *Wading out the storm: The role of poverty in exposure, vulnerability and resilience to floods in Dar es Salaam*. World Bank.

Global Infrastructure Hub. (2017). *Global infrastructure outlook*.

Hallegatte, S., Rentschler, J., & Rozenberg, J. (2019). *Lifelines: The resilient infrastructure opportunity*. World Bank.

Horvat, T., Bendix, H., Bobek, V., & Skoko, H. (2021). Impacts of investments in infrastructure projects on emerging markets' growth: the case of East African countries, Economic Research-Ekonomska Istraživanja, 34:1, DOI: 10.1080/1331677X.2020.1860799

Kesete, Y., Raffo, V., Pant, R., Koks, E., Paltan, H., Russell, T., & Hall, J. (2021). *Climate change risk analysis of Argentina's land transport network*. World Bank.

Koks, E. E., Rozenberg, J., Zorn, C., Tariverdi, M., Vousdoukas, M., Fraser, S. A., Hall, J. W., & Hallegatte, S. (2019). A global multi-hazard risk analysis of road and railway infrastructure assets. *Nature Communications*, *10* (1), 2677. https://doi.org/10.1038/s41467-019-10442-3

Makena, B., Osunga, M., Kingori, S., & Abdillahi, H. S. (2021). *An application of flood risk analysis for impact based forecasting in Kenya*. Kenya Red Cross.

Njogu, H. W. (2021). Effects of floods on infrastructure users in Kenya. *Journal of Flood Risk Management*, *14*(4), e12746. https://doi.org/10.1111/jfr3.12746

Oh, J. E., Espinet Alegre, X., Pant, R., Koks, E. E., Russell, T., Schoenmakers, R., & Hall, J. W. (2019). *Addressing climate change in transport, vol. 2, Pathway to resilient transport*. World Bank.

Hickford, A. J., Blainey, S. P., Pant, R., Jaramillo, D., Russell, T., Preston, J., Hall, J. W., Young, M. & Glasgow, G. (2023). Decision Support Systems for Resilient Strategic Transport Networks in Low-Income Countries: Final Report. *High Volume Transport Applied Research Programme*.

Pant, R., Koks, E. E., Russell, T., & Hall, J. W. (2018a). *Transport risks analysis for the United Republic of Tanzania: Systemic vulnerability assessment of multi-modal transport networks*. Oxford Infrastructure Analytics Ltd.

Pant, R., Thacker, S., Hall, J. W., Alderson, D., & Barr, S. (2018b). Critical infrastructure impact assessment due to flood exposure. *Journal of Flood Risk Management*, *11*(1), 22–33. https://doi.org/10.1111/jfr3.12288

Pearce, D., Atkinson, G., & Mourato, S. (2006). *Cost-benefit analysis and the environment: Recent developments*. Organisation for Economic Co-operation and Development.

Schaller, N., Kay, A. L., Lamb, R., Massey, N. R., van Oldenborgh, G. J., Otto, F. E., Sparrow, S. N., Vautard, R., Yiou, P., Ashpole, I., Bowery, A., Crooks, S. M., Haustein, K., Huntingford, C., Ingram, W. J., Jones, R. G., Legg, T., Miller, J., Skeggs, J., … Allen, M. R. (2016). Human influence on climate in the 2014 southern England winter floods and their impacts. *Nature Climate Change*, *6*, 627–634. https://doi.org/10.1038/nclimate2927

Wang, G., Wang, D., Trenberth, K., Erfanian, A., Yu, M., Bosilovich, M., & Parr, D. (2017). The peak structure and future changes of the relationships between extreme precipitation and temperature. *Nature Climate Change*, *7*(4), 268–274. https://doi.org/10.1038/nclimate3239

World Bank. (2018). *Road costs knowledge system (ROCKS): Doing business update*.

World Resources Institute. (2020). *Aqueduct floods hazard maps*: https://www.wri.org/data/aqueduct-floods-hazard-maps