3 Making infrastructure resilient to natural disasters: Learning from concrete projects in Africa, Asia, Latin America and the OECD

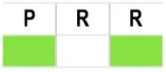
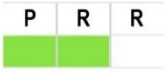
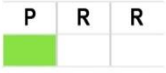
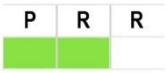
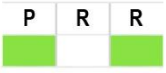
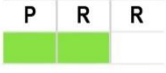
This chapter examines seven concrete infrastructure projects from Colombia, Ghana, India, Indonesia, Japan, Mozambique and the United States, each offering valuable insights into effective strategies and practices to enhance prevention, reaction and rebuilding efforts for resilience to natural disasters. It discusses the restoration of a degraded ecosystem and the upgrading fluvial transport systems in Colombia; the construction a power station in a flood-prone area in Ghana; the use of risk assessment to enhance prevention capacities in Mozambique; the adaptation of assets design and increasing user awareness in urban public transport in Indonesia; the integration of environmental preservation criteria in highway construction in India; the incentives and regulations for aligning interests and achieving cost-sharing in a flood-diversion project in the United States; and the use of strategic preventive maintenance and digital technology for infrastructure resilience in Japan. Through step-by-step analysis of these infrastructure projects this chapter provides valuable in-depth lessons for governments, the private sector, and civil society on how to effectively prevent, react and re-build to ensure infrastructure resilience to natural disasters.

Introduction

Determining resilient designs suitable for a specific country or community, addressing the affordability of infrastructure in developing nations, and prioritising infrastructure projects pose significant challenges. To address these complexities, concrete case studies from seven countries – Colombia, Ghana, India, Indonesia, Japan, Mozambique and the United States – are examined within the framework of the three pillars of prevention, reaction and rebuilding.

Chapter 3 delves into detailed descriptions of these case studies, covering a wide range of infrastructure projects and national policies. The cases span various categories such as transportation, energy, canal and flood diversion, and maintenance efforts, offering a comprehensive analysis of infrastructure resilience from diverse geographical perspectives in Africa, Asia, Latin America and the OECD.

Table 3.1. Overview of the infrastructure projects discussed in this Compendium, selected countries, 2024

Countries		Case studies		
	**Colombia**	Restoring a degraded ecosystem and preventing flooding in the Dique Canal to ensure community well-being and productivity		
	**Ghana**	Reacting to an emergency and increasing preparedness by building a power-station in the capital district during a flood		
	**India**	Reducing vulnerabilities through quality controls and technology to ensure road transport network stability		
	**Indonesia**	Reducing vulnerabilities and increasing preparedness by detailed analysis and facility design improvement of the urban transport		
	**Japan**	Reducing vulnerabilities and increasing preparedness through strategic preventive maintenance and use of cutting-edge technology in transport infrastructure		
	**Mozambique**	The use of data to map hazard zones to minimise the disruption of flood and cyclones on road networks through pre-emptive preparation		
	**United States**	Reducing vulnerabilities and increasing preparedness to ensure road transport network stability through reducing peak flooding		

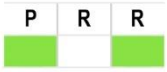
Note: PRR (Prevent, React, Rebuild) are the three key areas that are linked to making infrastructure resilient to natural disasters. Prevent area is linked to actions, tools and physical characteristics of the infrastructure that enable damage prevention and/or minimisation, including strategic preventive maintenance. React area is linked to the actions taken and tools used in response to a natural disaster to restore operational capacity and mitigate service provision disruption, such as by providing alternative infrastructure options in the short term. Rebuild area is linked to actions, tools and plans, including changes in the physical characteristics of the infrastructure, that shape how the disrupted infrastructure is rebuilt with the aim of looking forward. In the case of developing countries, damaged infrastructure in the aftermath of a natural disaster can often be rebuilt different to its original construction, shifting process, materials and even purpose of the infrastructure to consider shifting economic, environmental, and social demands, allowing it to promote transformative economic growth whilst becoming more environmentally sustainable socially inclusive.
Source: Authors' elaboration based on the case studies presented in this chapter.

By analysing these cases, this chapter aims to provide practical insights into how different countries have approached infrastructure resilience challenges. Through step-by-step analyses of each case, valuable lessons emerge, shedding light on effective strategies and practices that can be applied across different contexts. Ultimately, this discussion contributes to a deeper understanding of the complexities involved in enhancing infrastructure resilience worldwide.

The following seven sections present the seven case studies. Each case study is presented following a similar structure: the context and the challenges to be addressed, the innovative solutions implemented and the achieved results.

Restoring a degraded ecosystem and preventing flooding in the Dique Canal in Colombia to support economic and social development

The restoration of the Dique Canal represents a multifaceted endeavor aimed at revitalising a historically significant waterway while addressing contemporary challenges, restoring a degraded ecosystem and preventing flooding. By leveraging innovative solutions and collaborative partnerships, the restoration project has the potential to deliver lasting benefits in terms of transportation efficiency, environmental conservation and regional development.



An historical infrastructure which remains pivotal for regional economic development today

The Dique Canal, a 117 km inland waterway connecting the Magdalena River and the bay of Cartagena, was originally constructed in 1582 and later rebuilt in 1650 due to inadequate maintenance. Historically, it has held significant geopolitical and economic importance as a vital artery for shipping transportation. The canal played a pivotal role in fostering the growth of Cartagena as a thriving trading port city. However, over time, sedimentation issues hampered its usability, and the emergence of land transport alternatives diminished its relevance.

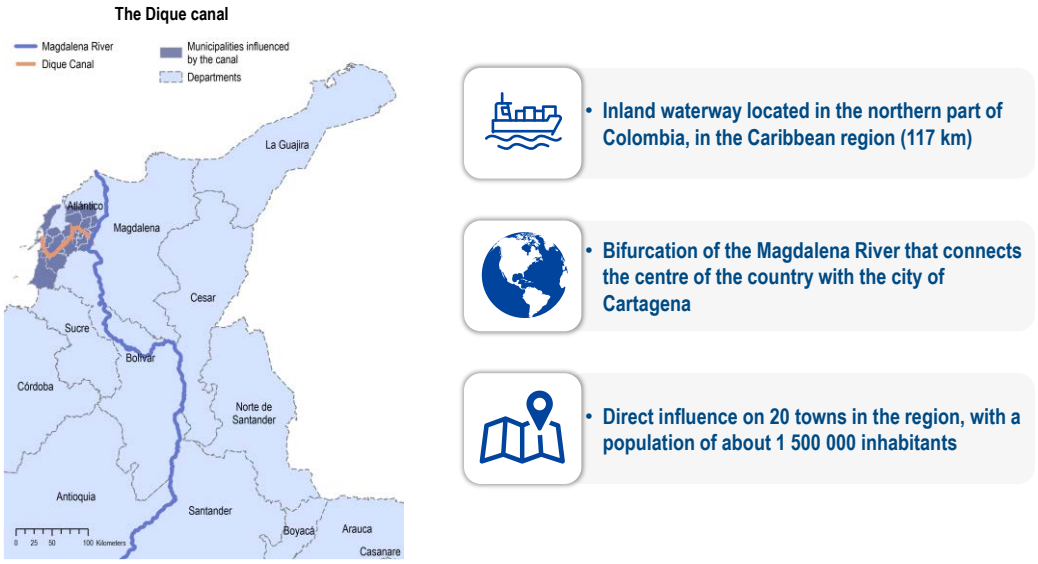
Neglected maintenance and poor management further exacerbated the canal's decline, rendering it inactive for an extended period. Nevertheless, recognising its potential benefits in flood control, water utilisation, transportation and environmental conservation, the National Planning Department of Colombia as part of the National Development Plan and in collaboration with Unit for Disaster Risk Management is responsible for the planning of the restoration of the canal, while the implementation is headed by the National Infrastructure Agency with collaboration from multiple stakeholders.

The restoration plan encompasses various measures, including regulating water inflow, managing sediment transit, ensuring navigational conditions, enhancing marshes and river connectivity, and rehabilitating the degraded ecosystem.

The restoration of the Dique Canal holds promise for revitalising its role as a crucial transportation artery and bolstering regional development (Figure 3.1). By addressing sedimentation challenges and implementing sustainable management practices, the canal is expected to facilitate efficient waterborne transportation, promoting trade and economic activity in the region. Furthermore, the restoration efforts are poised to yield significant environmental benefits, including improved flood control measures, optimised water resource utilisation, and the restoration of degraded ecosystems along the canal's route.

The revitalisation of the Dique Canal aligns with broader efforts to enhance regional connectivity and infrastructure resilience (OECD, 2022[1]). As part of a comprehensive national development strategy, the restoration project contributes to strengthening the region's transportation network and bolstering its resilience to natural disasters and climate change impacts. By integrating flood control measures and ecosystem restoration initiatives, the project demonstrates a holistic approach to infrastructure development that prioritises environmental sustainability and community resilience.

Figure 3.1. Location and background of the Dique Canal project, Colombia



Source: Authors' elaboration based on "Restoration of the Degraded Ecosystems of the "Canal del Dique", presentation by Miguel Gallego, Deputy Director for prospective studies and national development, National Planning Department (DNP), Colombia at the 2nd preparatory meeting for the Compendium of Good Practices on Quality Infrastructure - Thematic Focus: Planning, Financing, and Building Infrastructure Resilient to Natural Disasters that took place on 7 September 2023.

Due to inadequate maintenance of the Dique Canal, the surrounding area has experienced numerous challenges, including the loss of hydraulic connectivity and the inability to regulate floodwaters effectively This deficiency led to a significant flood event in 2010/11, resulting from a breach of the levee system, which adversely affected over 700 000 residents. Additionally, the canal has faced issues related to uncontrolled sediment inflow from the Magdalena River, exacerbating flood risks and causing damage to the coral system in Cartagena Bay.

The Dique Canal holds critical importance beyond flood control, serving as an essential inland waterway for transportation and a livelihood for local fishermen; it also serves as a vital source of fresh water for the city of Cartagena.

Considering these challenges and the canal's essential role in the region, addressing the maintenance and management of the Dique Canal is imperative. Implementing comprehensive restoration measures, including sediment control, hydraulic infrastructure upgrades, and ecosystem conservation initiatives, is essential to mitigate flood risks, preserve ecological integrity and sustainably manage water resources in the area. Additionally, ensuring adequate maintenance of the canal's infrastructure is crucial to safeguarding its functionality and resilience in the face of future hydrological challenges and climate-related hazards.

A comprehensive prevention action to mitigate the impact of climate change and natural disasters and foster regional economic development

By revitalising the canal and implementing comprehensive flood prevention measures, the project aims to safeguard communities, infrastructure and ecosystems from the devastating consequences of inundation events. The project started in June 2023 with the signing of the public-private partnership (PPP) agreement between the National Infrastructure Agency of Colombia and the Ecosistemas del Dique consortium, and is expected to be completed in 180 months. The restoration of the Dique Canal is undertaken as a strategic project in the framework of CONPES 4060 of 2021, which aims to establish a management model for the development of concessions based on the principles of intermodality, and institutional, financial, social and environmental sustainability.

One of the primary ways the restoration project contributes to flood prevention is by enhancing the canal's capacity to regulate water inflow. Through the construction of modernised facilities, such as water gates, sluice gates and spillways, the project enables effective control over the volume and flow of water entering the canal. By regulating water inflow, authorities can manage water levels within the canal system, minimising the risk of overflow and subsequent flooding during periods of heavy rainfall or river discharge.

Additionally, flood prevention works are integral to the restoration project, encompassing a range of engineering and infrastructure interventions designed to mitigate flood risks along the canal's route. These measures may include the construction of levees, embankments and floodwalls to contain floodwaters and prevent inundation of adjacent lands. Furthermore, dredging activities may be undertaken to deepen and widen the canal, improving its capacity to accommodate excess water and reduce the likelihood of flooding in downstream areas. In addition to the construction of locks, the restoration project will include the implementation of a gate system designed to regulate sediment flow, as well as comprehensive flood and erosion prevention measures. These measures will encompass the construction of dikes and hydraulic gates, facilitating connectivity between marshes and the river system. To address flood prevention, the project sets a return period of 100 years, considering potential sea and river water rise resulting from climate change.

The restoration project incorporates nature-based solutions for flood prevention, such as wetland restoration and riparian zone management. By restoring and enhancing natural habitats along the canal's banks, including marshes, mangroves and riparian forests, the project promotes natural flood attenuation processes. These habitats act as natural buffers, absorbing excess water, reducing peak flows, and providing valuable ecological functions that help mitigate flood risks while enhancing biodiversity and ecosystem resilience. Furthermore, restoration efforts will focus on reestablishing connections between marshes and the river, undertaking cleaning operations within the canal, and rehabilitating mangrove ecosystems. Additionally, the construction of fish passages will be implemented to enhance natural ecosystems and promote biodiversity. These interventions are integral to the restoration project's goal of improving ecological resilience and fostering the recovery of degraded habitats.

Overall, the combination of infrastructure development, flood prevention measures and ecosystem restoration initiatives underscores the comprehensive nature of the restoration project. By integrating engineering solutions with ecological restoration efforts, the project aims to enhance the resilience of the Dique Canal ecosystem while mitigating the impact of natural disasters and promoting sustainable management practices.

Collaboration and the smart use of data stand out as good practices

A distinctive feature of this project is that it is multipurpose. The project is conceived in a holistic way and actions aimed at increasing resilience to natural disasters contribute and are compounded by actions aimed at fostering regional economic development. Each purpose plays a crucial role in achieving the project's overarching goals of improving water management, preserving ecological integrity, and increasing infrastructure resilience to natural disasters. The multiple actions foreseen in the project make it act,

ultimately, as a key driver to increase the socio-economic well-being of local communities. In particular, the project addresses the following objectives:

- **Resilience to natural disasters**. Minimising the impact of flooding is indeed a crucial objective of the restoration project. By controlling water inflow into the system through the construction of locks, the project aims to enhance the canal's resilience to natural disasters, particularly floods. This measure helps regulate water levels, mitigate flood risks, and protect surrounding communities and infrastructure from inundation events.
- **Sustainable water management and security**. It controls sediment transit. Sedimentation is a significant issue affecting the environment of the canal and Cartagena Bay. The restoration project includes measures to control sediment transit, such as dredging activities and sediment management strategies. By addressing sedimentation, the project aims to improve water quality, preserve ecological integrity, and maintain navigability within the canal and its adjacent water bodies. It also restricts salt intrusion. Saltwater intrusion poses challenges to freshwater resources and ecosystems in coastal areas. The restoration project seeks to restrict salt intrusion into the canal system, thereby safeguarding freshwater supplies and protecting sensitive habitats from salinisation. This objective contributes to ensuring water security and ecological sustainability in the region. The project also aims at securing fresh water supply. The Dique Canal serves as a vital source of freshwater supply to the region, including the city of Cartagena. Securing and optimising freshwater supply is a fundamental purpose of the restoration project, ensuring reliable access to clean water for domestic, agricultural and industrial purposes, thereby supporting socio-economic development and public health.
- **Promotion of fishery productivity**. The restoration project aims to enhance fishery productivity within the canal and its surrounding waters. By improving water quality, preserving habitats, and implementing sustainable fishery management practices, the project seeks to promote the growth of fish populations and support the livelihoods of local fishermen, contributing to food security and economic development in the region.
- **Optimisation of navigability**. Ensuring navigability within the Dique Canal is essential for supporting transportation and commerce along its route. The restoration project includes measures to optimise navigational conditions, such as dredging, maintenance of navigation channels and infrastructure upgrades. These efforts facilitate safe and efficient navigation for commercial vessels, promoting trade and economic activity in the area.
- **Restoration of natural environment and ecosystems**. Restoring the natural environment and ecosystems along the canal corridor is a key objective of the project. This includes habitat restoration, reforestation and conservation initiatives aimed at enhancing biodiversity, preserving ecological functions and promoting the resilience of natural ecosystems. By restoring degraded habitats and protecting valuable natural assets, the project contributes to ecological sustainability and environmental resilience in the region.

In addition to the holistic approach, the international peer dialogue activities carried out in the framework of the preparatory work for this compendium have identified that this project stands out in the following good practice areas:

- **Risk and impact assessment.** The comprehensive risk and impact assessment and the understanding of the negative impacts of climate change and natural disasters, notably the significant flood in 2010/11 of the area surrounding the Dique Canal, lay a solid foundation for the project. A multitude of data and information from various sources have been meticulously analysed in this broad assessment, contributing to a nuanced understanding of the challenges and opportunities associated with the project.
- **Collaboration.** The success of the project is inherently tied to the active collaboration fostered throughout its life cycle. During the project's conceptualisation, community participation was

prioritised, ensuring that local perspectives and concerns were integral to the planning process. As implementation commenced, continuous engagement with local stakeholders became a cornerstone. Despite the project's national scope, the signing of ten agreements with local governments exemplifies a commitment to co-ordinated efforts and future infrastructure sustainability. Recognising fishermen as vital stakeholders further underscores the inclusive approach, ensuring the project aligns with the needs of those directly affected. The incorporation of local stakeholders into the monitoring plan emphasises a commitment to inclusivity and transparency. By actively involving those impacted in the monitoring process, the project ensures a comprehensive evaluation of its progress and impact. This collaborative approach to measurement systems is instrumental in maintaining accountability and fostering a sense of shared responsibility for the project's success.

The ultimate effectiveness of the project will also depend on actions which go beyond the engineering activities involved in the implementation and will require the implementation of integrated flood management strategies, including early warning systems, community-based flood preparedness initiatives, and land use planning measures. These strategies aim to improve resilience and adaptive capacity at the local level, empowering communities to effectively respond to flood events and minimise the impact on lives and livelihoods. By integrating these measures with engineering interventions and ecosystem restoration efforts, the project adopts a holistic approach to flood prevention that addresses both structural and non-structural aspects of flood risk management.

Technical overview information on the project

The "Restoration of the Degraded Ecosystems of the Dique Canal" is an inland waterway infrastructure project located between the cities of "Calamar" and "Cartagena" in the Caribbean of Colombia, with a total length of 115.5 km. It consists of the construction of a pair of locks and a gates system to prevent the entry of an uncontrolled number of sediments, and also includes the restoration of the connections between the marshes and the river, and the optimisation of navigability. The project therefore serves to restore the natural ecosystems that have provided coastal populations with a means of subsistence, as well as controlling effects of floods.

The project was structured by several national entities such as the National Infrastructure Agency, the Fondo Adaptación (the entity in charge of executing all the projects to address the rainy season emergency that occurred in Colombia in 2010-11) and Cormagdalena (the organisation in charge of the Magdalena River), through the development of agreements to combine technical, administrative, social, environmental, legal, financial and risk-assessment efforts. It is a central government project headed by the National Infrastructure Agency, which is the organisation in charge of planning, co-ordinating, structuring, contracting, executing, managing and evaluating concession projects and other forms of Public-Private Partnerships (PPP) in Colombia. The project was structured from a participatory process with community leaders through more than 97 spaces for dialogue, with the support of local governments.

Project scope

- active regulation of the water inflow to the system
- sediment transit control between Cartagena's and Barbacoa's Bays with the Canal
- flood and water level control in the Canal
- control of salt intrusion
- scenarios for adaptation to climate change
- improvement of the connections between marshes and the river
- restoration of degraded ecosystems of the National Natural Parks in the area

- restoration of adjacent areas to marshes and river
- securing the water resource for drinking water, irrigation, livestock, fishing and other services
- Navigability optimisation for the Canal.

Project time frame and budget

Start date: 1 June 2023.

Estimated duration: 180 months.

Budget: approx. USD 783 million (Capital expenditure of USD 530 and operation expenses of USD 253 million).

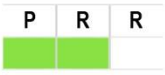
Activities and funding mechanism

This project is developed under a PPP scheme with a solicited proposal. It is financed with contributions from the private party (equity and debt) that are paid back through public resources in accordance with the construction of the functional units and the fulfilment of indicators related to operation and maintenance established in the contract. It includes fourteen functional units (UF):

- **UF0:** Road access to the Calamar complex and road and dredging maintenance.
- **UF1:** River diversion for the lock construction in Calamar.
- **UF2:** Sheet pile installation in Calamar.
- **UF3:** Construction of Calamar set of locks.
- **UF4:** Calamar operation building complex, administration building and store.
- **UF5:** Flow control gate and fish passage of Calamar complex.
- **UF6:** River diversion for the Puerto Badel lock construction and road access to the Puerto Badel complex.
- **UF7:** Sheet pile installation in Puerto Badel.
- **UF8:** Construction of Puerto Badel set of locks, Puerto Badel complex control building, administration building and store.
- **UF9:** Complex F. Restoration of water bodies and construction of dikes.
- **UF10:** Complex G. Restoration of water bodies, fresh water supply to populations, protection dike and interceptor waterway construction, along with securing the area to avoid floods. New connection between Bays.
- **UF11:** Complex D. Construction of dikes, landfills, dams, waterways, new connection between marshes and road.
- **UF12:** Complex A, B and E. Construction of dikes, landfills and waterways and inlet and outlet connection of marshes.
- **UF13:** Protection of the Calamar population, flood protection wall and levee in the municipality of Calamar.
- **UF14:** Shoreline protection at critical points and shoreline scour protection structures.

Building a bulk supply point in a flood-prone area in Accra, Ghana

The building of a bulk supply point in a flood-prone area in the central business district of Accra (Ghana) is a success case of **reacting** to an emergency and increasing **preparedness.** It has increased energy supply and strengthened energy infrastructure resilience to flooding, achieved through international co-operation, technology adoption and capacity building.



Location and background information

Flooding stands out as one of the most common natural disasters in Ghana, mainly due to the country's relatively flat terrain. This topographical characteristic facilitates the accumulation of water, particularly during heavy rainfall events. Accra is particularly susceptible to flooding, given its low-lying nature and inadequate drainage infrastructure.

Accra Central, the bustling business district and capital of Ghana, is the primary load centre for the city. However, it has encountered several challenges with its electricity supply infrastructure, from high losses and inefficiencies to overload, and limited land for additional infrastructure. Frequent flooding has exacerbated these issues and highlighted the need for building a secure and natural disaster resilient power supply. As a result, the Ghana Grid Company (GRIDCo) proceeded to construct a Bulk Supply Point (BSP), completed in 2018 and financed by JICA (Japan International Cooperation Agency), which was designed in such a way as to both continue operations during flooding and enhance the quality and quantity of power supply to consumers across Ghana.

Main challenges to be addressed

In Ghana, the demand for electricity has been rising steadily following strong economic growth. However, this surge in demand has led to electricity shortages, particularly in urban areas like the metropolitan area and major cities. In Accra, the capital city, there has been a delay in expanding the electricity transmission and distribution network to keep pace with the rapidly growing demand. Addressing power losses in transmission and distribution has become urgent, especially as these losses increase with the expansion of electricity supply.

Accra's Central Business District (CBD) stands out as the primary hub for electricity demand in the region. However, the area has faced various power supply challenges. Poor bus voltage has resulted in low-quality electricity supply, while high losses during transmission and distribution have been observed. Frequent power outages, exacerbated by nationwide shortages, have further strained the electricity supply in the CBD. Additionally, the transmission transfer capacity has been insufficient, with transformers operating at 120% of their capacity during peak periods.

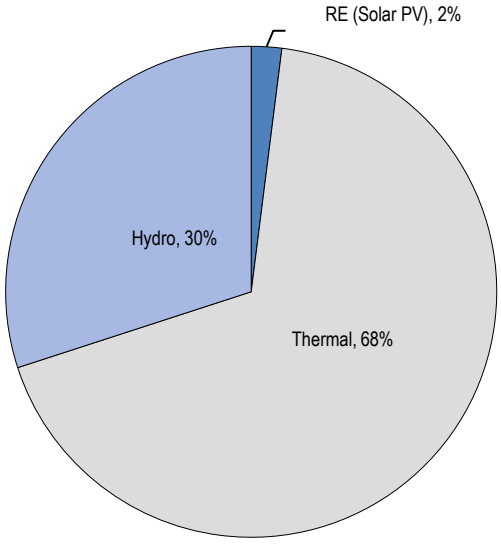
Moreover, Accra's densely developed urban landscape presents limitations in finding suitable locations for new electricity facilities. The available land for such infrastructure is relatively small, and the only viable option lies in a flood-prone area of the city. This presents a significant obstacle to expanding and improving the electricity infrastructure in Accra, as construction in flood-prone areas carries heightened risks and challenges.

Compounding these challenges is the district's susceptibility to flooding, as it lies in a flood-prone area of Accra, necessitating resilient infrastructure solutions to mitigate potential risks and ensure uninterrupted power supply to this critical economic hub.

Project description and assessment

In Ghana, the Grid Company, also known as GRIDCo, plays a crucial role in country's power system. As the system operator, GRIDCo is responsible for making critical decisions regarding which generators should contribute to the national grid and how power should be allocated among various loads. GRIDCo operations span across four voltage levels, including 69 kV, 161 kV, 225 kV, and 330 kV, catering to the diverse energy needs of the nation. The system peak demand stands at 3 558 megawatts (as of April 2023), with an installed generation capacity of 5 366 megawatts, with renewables such as hydro accounting for 30%, and solar 2%, and thermal fuel, primarily natural gas, making up the remaining 68% (Figure.3.2).

Figure.3.2. Mix of installed capacity for power generation by typology (% over total), Ghana, 2021



Note: RE = renewable energies (solar Photovoltaic)
Source: Authors' elaboration based on "Building Power Transmission Projects that are Resilient to Natural Disasters, Accra Central Bulk Supply Point as a Resilient Infrastructure", presentation by Kassim Abubakar, Principal Power System Planning Engineer, Ghana Grid Company Limited (GRIDCo) at the 1st preparatory meeting for the Compendium of Good Practices on Quality Infrastructure - Thematic Focus: Increasing Infrastructure Resilience to Natural Disasters that took place on 18-19 April 2023. Based on IRENA statistics.

Despite the efforts to meet the growing electricity demands, the country encountered significant challenges in supplying power to the central business district of the capital city. This area, serving as a vital load centre, hosts numerous businesses, commercial establishments, light industries and administrative buildings. The issues faced included poor voltage quality, resulting in subpar power supply to consumers, as well as high distribution losses, frequent outages, and limited transmission and distribution capacity to ensure reliable electricity supply.

To address these challenges, GRIDCo identified the need to implement a new transmission facility to enhance the quality of power supply to consumers in the central business district. However, this presented several obstacles. First, the area was densely populated with limited available land for constructing large-scale infrastructure. Additionally, the geographical terrain posed challenges, as the neighbourhood was situated in a flat, flood-prone area.

The Accra Central Substation, designated to serve this area, was intended to act as a receptacle for stormwater during heavy rains, gradually receding into the nearby lagoon and eventually flowing into the sea. To address the electricity supply challenges in Accra, a Bulk Supply Point (BSP) construction project was initiated. The project's design and bidding phases commenced in 2015, followed by construction

starting in 2016 and completion in 2018. The Accra Central BSP was conceptualised as a Gas Insulated Switchgear (GIS) station with a capacity of 375 MVA and operating at 161/34.5 kV, with provisions for expansion up to 500 MVA. Its primary objective was to bolster the power supply to the Central Business District (CBD) of Accra. To address the escalating demand in the CBD, the BSP aimed to minimise transmission losses and enhance the reliability of electricity supply by reducing outages and enhancing operational flexibility.

The site that was identified for the BSP was in a flood-prone area and was selected due to its availability and cost-effectiveness. Consequently, a crucial aspect of the project was to meticulously plan and design a facility that could withstand flooding, ensuring resilience against natural disasters. However, haphazard developments and inadequate drainage systems in a densely populated area led to blockages and the inefficient utilisation of existing infrastructure. Consequently, significant flooding in the neighbourhood often exacerbated the challenges faced by the transmission facility.

The design of the substation incorporated automatic submersible pumps to mitigate the impact of flooding. This feature activates whenever the nearby river floods, ensuring continuous power supply even during flood events. The effectiveness of this design was demonstrated during two major flooding incidents in 2020 and 2022, where the submersible pumps successfully maintained power supply without any interruptions despite the flooding.

In terms of construction methodology, special techniques were employed to minimise disruptions to economic activities in the busy business district of Accra where the substation was located. Specifically, a method involving drilling under roads and buildings was utilised to bury cables and extend high-voltage lines to the substation. This approach allowed for the completion of construction without significant disruption to commercial and business activities in the neighbourhood.

Overall, the incorporation of innovative design features and construction methodologies ensured the resilience and operational efficiency of the substation, even in challenging environmental conditions such as flooding. These measures enabled uninterrupted power supply to the central business district of Accra, contributing to the continued functioning of businesses and commercial activities in the area.

The duration of power outages has been notably reduced by approximately 45% compared to figures recorded in 2013. This improvement in outage duration demonstrates the enhanced reliability and stability of the power supply system. Furthermore, significant progress has been made in terms of transmission capacity, with the commissioning of a station capable of providing an additional 375 MVA of capacity. This increase in transmission capacity has contributed to meeting the growing electricity demand more effectively.

Table 3.2. Overview of project objectives and impact, building of a bulk-power station in a flood-prone area, Accra, Ghana, 2024

Project objectives	Impact
Improve quality of power supply and increase reliability of supply (reduce outages) Increase industrialisation and welfare of citizens.	The quality of power supply has improved significantly. Bus voltages at Accra Central are within ±5 of 34.5 kV nominal distribution bus voltage. The stability of power supply to CBD has been achieved (outage hours reduce by 95% compared to 2013 figures)
Increase transmission and distribution transfer capacity.	The transmission and distribution capacity has increased by 375 MVA, this is helping meet existing and future demand requirements.
Reduce transmission and distribution losses.	Technical losses in the transmission and distribution losses have reduced significantly.
Reduce Network Congestion (overloading)	Overloading on Achimota, Mallam BSP Transformers has been eliminated, transformers loaded around 60% of capacity now.

Source: "Building Power Transmission Projects that are Resilient to Natural Disasters, Accra Central Bulk Supply Point as a Resilient Infrastructure", presentation by Kassim Abubakar, Principal Power System Planning Engineer, Ghana Grid Company Limited (GRIDCo) at the 1st preparatory meeting for the Compendium of Good Practices on Quality Infrastructure - Thematic Focus: Increasing Infrastructure Resilience to Natural Disasters that took place 18-19 April 2023.

Moreover, there has been a substantial reduction in technical losses within the power distribution system. Previously, technical losses were exacerbated by overloaded transmission and medium voltage distribution lines, leading to inefficiencies in power transmission. By addressing these issues and optimising the distribution network, technical losses have been significantly mitigated. For instance, the substation serving the neighbourhood, previously operating at an overloaded capacity of 120%, now maintains an average loading of 60% during peak periods.

Good practices and success factors

The project increased power supply capacity while the impact of flooding was minimal. The application of appropriate technology made it possible to scale-up electricity supply capacity and a new BSP construction within the available site remained operational in conditions of severe flooding. In particular:

- The quality of power supply has improved significantly. Bus voltages at Accra Central are within ±5 of 34.5kV as planned.
- The stability of power supply has been achieved with annual outage hours decreased significantly by 95% compared to 2013.
- The transmission and distribution capacity has increased by 375 MVA, which meets current and future demand. Technical losses in the transmission and distribution have reduced significantly, and overloading of other BSP transformers has been eliminated.
- Two major floods occurred (2020 and 2022) since the construction completed, neither of which resulted in any disruption to the facility and there was no interruption in power supply.

Several factors contributed to the successful implementation of this project, chief among them:

- **International collaboration, technology transfer and financial support.** The project was implemented by JICA under a grant agreement between JICA and the government of Ghana, with strong collaboration among GRIDco, the Electricity Company of Ghana and other stakeholders. The funding from the Japanese government, amounting to a grant aid of JPY 4.2 billion (approx. USD 38.5 million) facilitated through JICA, was instrumental in the project execution.
- Aligned with Ghana's national development policies and the long-term plan to increase electricity supply capacity, the government provided crucial support for the project, facilitating its smooth implementation through political decisions, certification, and granting of permits and land.
- Technology transfer was integral to the project's success, alongside well-planned operation and maintenance strategies executed by a team of well-trained and skilled staff. Thorough understanding of flood risks and meticulous project planning were pivotal to ensure effective mitigation strategies. The construction of the facility was carried out by a joint venture consisting of Mitsubishi Corporation, a Japanese trading house, Hitachi Plant Construction, a Japanese plant construction company, Yurtec, a Japanese electricity facility and engineering company and Yachiyo, an engineering company acting as the supervising consultant. Leveraging on their superior technology, diverse experience and project management capabilities, these companies played a pivotal role in the successful execution of the project. The collaboration among private providers and the construction company involved also contributed to the success of the project implementation. The project was implemented with significant support from the Ghanaian government through various agencies including the Ministry of Energy, the Ministry of Finance, the Energy Commission, the Electricity Company of Ghana, Ghana Railway, Ghana Water, Accra Metropolitan Assembly, and the Department of Urban Roads. With their collaboration, the project commenced and the construction of the substation was completed on time.
- **Innovative technologies and equipment**. Cutting-edge technology was employed for advanced monitoring, real-time data analytics and predictive capabilities, ensuring efficient operation and

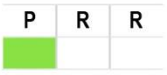
maintenance. Advanced technologies were also integrated to enable operations with minimal disruption during maintenance activities. Notable technologies and equipment utilised include:

- Six automated submersible pumps, which were installed to drain water during rains, mitigating the risk of flooding in the area.
- Cables from the terminal tower were brought into the substation via underground cables using thrust boring techniques under drains and roads, minimising disruptions to vehicular traffic and water flow.
- A concrete fire-resistant wall was incorporated into the BSP to prevent the spread of fire into or from the substation and its surroundings.
- The Accra Central BSP features transformers equipped with acoustic noise abatement systems, effectively mitigating noise pollution in the neighbouring areas.
- Innovative approaches such as the use of submersible pumps in cable culverts, GIS, and control buildings ensured construction continuity during flooding. Sheet piling techniques were also employed to prevent soil collapse in areas with high water content, facilitating timely construction completion without major delays.

- **Maintenance and capacity building.**
  - The operation and maintenance phase is managed by a team of well-trained and skilled staff, ensuring the facility's efficient and reliable operation.
  - Regular quality and safety compliance meetings were held during project implementation to ensure quality and zero accidents during construction (no accidents occurred during the implementation of this project).
  - Regular joint safety meetings between ECG and GRIDCo continue to enhance operational safety and efficiency, fostering a culture of co-operation and continuous improvement.

Increasing connectivity and preserving the environment through sustainable highways in India

The cases of the Delhi Mumbai Expressway, Raipur Visakhapatnam Expressway and the Bangalore Kadapa Vijayawada Expressway exemplify India's approach to infrastructure development. India follows a holistic approach which considers the overall socio-economic impact of infrastructure projects. India prioritises environmental preservation and innovation to increase connectivity. By developing and adopting broad national principles for infrastructure development, India has managed to innovate in infrastructure development while prioritising environmental sustainability and efficiency.



Location and background information

India is prone to severe natural disasters, including earthquakes, floods and various other hazards. The country's susceptibility to earthquakes is particularly noteworthy, with its land divided into different Seismic Zones ranging from Zone-II to Zone-V based on the severity of ground shaking. Zones IV and V, classified as the most severe, cover significant portions of the country, accounting for 14.4% and 11.3% of the land area, respectively. Measures to enhance infrastructure resilience to natural disasters are a top priority for India.

Given India's vast land area, growing megacities and increasing road traffic, the nationwide construction of a highway network is a crucial component of the country's development agenda. This endeavor is

challenged by the high risk of earthquakes and other natural disasters, underscoring the urgent need to ensure the resilience of infrastructure to such hazards.

Main challenges to be addressed

India's massive effort of building a nationwide highway requires addressing multiple challenges in the various stages of the infrastructure project, spanning planning, construction and operation and maintenance phases, each demanding meticulous attention and strategic decisions.

During the planning phase, a comprehensive study of the area's geology, topography and hydrology is imperative to identify potential hazards and vulnerabilities. This entails assessing risks associated with landslides, flooding or earthquakes and strategically avoiding areas prone to such natural phenomena. By conducting detailed assessments, project planners can make informed decisions to mitigate risks and ensure the long-term resilience of infrastructure projects.

In the construction phase, selecting appropriate technologies is a critical challenge. It involves identifying and implementing technologies that not only meet project requirements but also address specific challenges posed by the project's location and environmental conditions. This necessitates thorough research and evaluation to determine the most suitable technological solutions that enhance the durability, safety and efficiency of infrastructure construction.

During the operation and maintenance phase, ensuring continuous operation under severe conditions and facilitating swift disaster response are paramount challenges. Infrastructure must withstand various environmental stresses and unforeseen events while maintaining optimal functionality. Establishing robust maintenance protocols and response mechanisms is essential to address potential disruptions promptly and effectively, minimising downtime and ensuring the reliability of critical infrastructure systems.

Overall, addressing challenges at each stage of infrastructure projects requires a multidisciplinary approach, incorporating thorough planning, innovative technology integration and proactive maintenance strategies. By strategically managing risks and implementing resilient solutions, infrastructure stakeholders can enhance project resilience and mitigate the impact of natural hazards on infrastructure performance and longevity.

Project description and assessment

The Government of India recognises transport roads and highways as crucial assets for the nation's development, emphasising the necessity for their construction, preservation and adequate maintenance. The Ministry of Road Transport and Highways of India is in charge of the national transportation policy which clarifies the overarching principles aimed at enhancing the life cycle of highways, thereby ensuring a comprehensive approach across all stages, from conceptualisation to maintenance.

These principles encompass various aspects such as design, engineering, construction, and maintenance, with the aim of fostering an end-to-end strategy for the development and upkeep of transport roads and highways. The Ministry of Road Transport and Highways mandates that these principles be applied uniformly across all interventions in transport road and highway projects, taking into account their unique characteristics and requirements.

In the planning phase, the key principles followed by India include:

- Conducting detailed studies on topology, geography and hydrology is essential to identify potential hazards and vulnerabilities in the area.
- It is imperative to avoid areas prone to landslides, flooding or earthquakes during the planning phase.

- Utilising advanced technologies for collecting site data is crucial in the project planning phase. This includes Topographical Surveys, Sub-surface Mapping, Traffic Monitoring and Verification of Land Condition.
- Components and engineering techniques are incorporated to minimise the impact of earthquakes and landslides. This involves adopting measures such as embankments, structure foundations and reinforced earth walls designed with seismic considerations.
- Structures with a design life of 100 years are designed for the Design Basis Earthquake (DBE), which accounts for moderate earthquakes that may occur more frequently. For example, bridges should be able to withstand minor structural damage.
- Structures with a design life of more than 100 years are also designed for the DBE and are checked for the Maximum Considered Earthquake (MCE), which accounts for a large earthquake that may occur once. Bridges may sustain significant structural damage but should not collapse, with bridge components expected to remain elastic.
- Various measures such as subsurface/surface drainage, retaining walls, slope flattening, buttresses, rockfall fencing/netting, and soil nailing/rock bolting are implemented to protect slopes.

In the disaster management plan and in the operation and maintenance phase, the following principles are adopted:

- Establishing a disaster management plan is crucial during the operation and maintenance phase. This plan outlines action plans, including emergency response measures such as evacuation routes and procedures, as well as communication strategies and guidelines.
- The implementation of an Automatic Traffic Management System (ATMS), including variable message signs, helps inform users about facilities along highways and ensures a quick response during emergencies.

In addition, India's road development policy clearly mandates that each action should be conducive to achieving the Sustainable Development Goals (SDGs); in particular, it includes the following principles:

- Implementing measures such as animal underpasses, overpasses and other devices helps mitigate the impact on wildlife.
- Planting trees along highways contributes to making them environmentally friendly.
- Considering the connectivity of highways between economically important cities and tribal and aspirational districts is essential to ensure holistic development and contribute to the Sustainable Development Goals (SDGs).

Good practices and success factors

During the preparatory work for the 2024 edition of this *Compendium of Good Practices on Quality Infrastructure*, India presented three case studies:

- Delhi Mumbai Expressway
- Raipur Visakhapatnam Expressway
- Bangalore Kadapa Vijayawada

The three cases exemplify India's approach to competitiveness-related infrastructure development, which aims at balancing efficiency with environmental preservation. In particular, the three cases are guided by the following objectives:

- **Strategic life cycle approach.** Adopting a life cycle approach strategy from the outset to ensure infrastructure resilience throughout its lifespan.

- **Detailed studies at the planning stage.** Conducting comprehensive studies at the planning stage to enhance resilience to natural disasters, enabling proactive measures to be integrated into project design.
- **Deployment of appropriate technologies.** Utilising appropriate technologies to construct structures capable of withstanding external forces during disaster scenarios, thereby enhancing overall resilience.
- **Prioritising resilience and capturing positive spillover effects.** The projects take a holistic approach and recognise the role of improved infrastructure resilience on broader socio-economic development opportunities.
- **Strong support from government leadership** for the adoption of innovative principles in project implementation. This is provided through direct orientation and guidance to ensure the application of the principles and their effective integration into project planning and execution processes.

The three projects share as a common feature the introduction of innovative approaches, often pioneering the implementation of these solutions in emerging economies in Asia, notably in the following areas:

- **Introduction of innovative solutions** on three highways, marking the first use of such approaches in Asia. These highways are intended to serve as pioneers, setting a precedent for future infrastructure projects in the region.
- **Implementation of innovative contracts** for engineering and management specifically designed to address challenges posed by earthquakes, floods and other natural disasters while ensuring adherence to project completion timelines. These contracts will incorporate unique provisions and strategies tailored to effectively manage and mitigate the risks associated with natural disasters, ensuring the timely completion of the projects despite potential disruptions.
- **Focus on territorial inclusion**, through the establishment of vital connections between large cities and communities, enhancing accessibility and promoting socio-economic development. The highways will play a crucial role in fostering connectivity and facilitating the movement of goods and people between urban centres and surrounding communities, thereby stimulating economic growth and regional development.
- **Focus on user convenience**, ensuring that the highways are designed and operated with the needs and preferences of users in mind. Attention will be given to user-centric design elements and operational practices aimed at enhancing safety, comfort and overall satisfaction for motorists and other road users.
- **Focus on environmental sustainability and implementation of measures to protect wildlife** along the highways, minimising the impact of infrastructure development on local ecosystems. Specialised measures and mitigation strategies will be employed to mitigate the environmental impact of the highways, including wildlife crossings, habitat restoration initiatives, and ecological monitoring programmes.

The following paragraphs describe in more detail the application of the abovementioned principles to each of the three specific projects.

- **The Delhi Mumbai Expressway** (Length: 1 386 km and Capital Cost: INR 101 420 Cr) is an example of India's commitment to bridge infrastructure gaps prioritising environmental sustainability, user convenience and innovative engineering solutions. It serves as the main 8-lane access-controlled greenfield expressway, linking India's national capital of Delhi with the financial capital of Mumbai. Notably, the operational section from Delhi to Dausa to Lalsot spanning 247 km commenced operations in February 2023, with a targeted completion date set for 2025. The application of the principles mentioned above has resulted in the following outcomes:
  - **Reduced construction time**. The project is on track to achieve completion within an unprecedented timeframe of 6 years from conceptualisation to execution, setting a new

benchmark for efficiency in large-scale highway projects. This timeframe significantly outpaces similar projects undertaken in other countries, demonstrating India's capability for rapid infrastructure development.

- **Reduced travel distance and time**. Upon completion, the Delhi Mumbai Expressway is expected to reduce the distance between Delhi and Mumbai by 12%, resulting in a substantial reduction in travel time from the current 24 hours to just 12 hours. This enhancement in connectivity will greatly facilitate trade, commerce and passenger travel between the two major cities.
- **Enhanced user convenience**. The project incorporates modern technology and infrastructure design to enhance user convenience and safety. Facilities for travellers have been planned with a view to increasing user experience. Additionally, real-time monitoring systems have been deployed to improve safety and efficiency, further enhancing the overall user experience.
- **Innovative wildlife features**. The Delhi Mumbai Expressway introduces innovative features aimed at minimising its impact on wildlife. Notably, the project includes the conceptualisation and construction of animal underpasses and overpasses, a pioneering initiative in Asia and the second of its kind globally. Furthermore, the project boasts four iconic 8-lane tunnels, each exceeding 4 km in length, designed to reduce the impact on wildlife habitats and migration patterns.

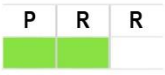
- **The Raipur Visakhapatnam Expressway** (Length: 465 km and Capital Cost: INR 16513 Cr) serves as a 6-lane access-controlled greenfield corridor, connecting the capital of Chhattisgarh, Raipur, with the port city of Visakhapatnam. This project integrates innovative engineering solutions and wildlife-friendly infrastructure designs and sets a precedent for future infrastructure initiatives, aimed at balancing development with ecological preservation. This vital infrastructure project is slated for completion between 2024 and 2025, and the application of the principles mentioned above has led to:
  - **Pioneering highway configuration.** This expressway marks India's first highway traversing hilly terrain with a 6-lane configuration and a design speed of 100 kmph, showcasing innovative engineering solutions tailored to challenging topographical conditions.
  - **Enhanced connectivity.** By linking industrial cities with a major port city, the Raipur Visakhapatnam Expressway is poised to significantly reduce travel time between Raipur and Visakhapatnam from 14 hours to just 6 hours. This improved connectivity is expected to bolster trade, commerce and regional development.
  - **Innovative wildlife conservation measures.** The expressway incorporates innovative features aimed at mitigating its impact on wildlife and preserving natural habitats. Notably, the project includes the construction of six-lane tunnels, and animal underpasses and overpasses across the Sitanadi Sanctuary and other eco-sensitive areas. Specifically, the project features 13 elephant underpasses, 31 animal passes, and 31 monkey canopies dedicated to facilitating unencumbered wildlife movement. Additionally, the installation of smart cameras for wildlife monitoring enables the project team to closely track wildlife movement patterns and assess the project's impact on local ecosystems.
- **The Bangalore Kadapa Vijayawada Expressway** (Length: 342 km and Capital Costs: INR 13559 Cr) serves as a pivotal 6-lane access-controlled greenfield corridor, connecting Karnataka's state capital of Bangalore with the industrial areas of Andhra Pradesh, traversing through hinterland and underdeveloped regions. With a targeted completion date set between 2025 and 2026, the project prioritises environmental sustainability, longevity and efficient connectivity. The key principles mentioned above and applied in the project have led to:
  - **Longevity-focused design**. The project prioritises longevity by incorporating design elements that ensure resilience against natural elements. The finished road level is based on the

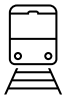
100-year high flood level (HFL) of nearby rivers, enhancing the infrastructure's ability to withstand flooding events. Additionally, the use of flexible pavement is adopted to provide a smoother ride experience and prolong the embankment's life span, contributing to the expressway's long-term durability.

- **Enhanced connectivity**. By linking IT clusters with industrial areas, the expressway is poised to significantly reduce travel time from 13 hours to just 7 hours, facilitating efficient movement of goods and commuters between key economic hubs in the region. This improved connectivity is expected to stimulate economic growth and enhance regional development.
- **Environmental conservation**: The alignment of the expressway is strategically planned to avoid wildlife sanctuaries, minimising disruption to local ecosystems and wildlife habitats. Furthermore, the project incorporates improved road geometry through viaducts connecting hilltops in the rolling terrain, mitigating environmental impact while ensuring efficient and safe transportation infrastructure.

Integrating resilience to natural disasters through the life cycle in the Mass Rapid Transport (MRT) Jakarta in Indonesia

The MRT Jakarta project aims at improving urban transport infrastructure in a highly densely populated area, that is vulnerable to natural disasters. The introduction of the MRT Jakarta system represents a significant step towards alleviating congestion and enhancing mobility within the metropolitan area. By providing a modern and efficient mass transit option, the MRT Jakarta aims to reduce reliance on private vehicles, alleviate traffic congestion and improve overall transportation efficiency. The project involves effective co-ordination and distribution of responsibilities between different stakeholders and relies on a comprehensive policy for resilience to natural disasters relying on smart use of data, technology and innovative design in facilities building and effective knowledge management.





Indonesia, and its capital city Jakarta, require heightened risk prevention measures

Indonesia, with its vast archipelago spanning across the equator, is highly vulnerable to a wide range of natural disasters due to its geographical location and geological characteristics. The country experiences frequent seismic activity, making it prone to earthquakes and subsequent tsunamis. Additionally, Indonesia lies within the Pacific Ring of Fire, a region known for its high volcanic activity, posing risks of volcanic eruptions that can result in widespread devastation.

Indonesia's climate vulnerability is exacerbated by the current climate crisis, which is increasing the frequency and impact of extreme weather events such as heavy rainfall, cyclones and floods. The combination of these factors amplifies the country's vulnerability to natural disasters, leading to significant socio-economic impacts and loss of life.

The densely populated urban areas, particularly in coastal regions, are at heightened risk, exacerbating the challenges of disaster preparedness and response. In addition to geological and hydro-meteorological hazards, Indonesia also grapples with environmental degradation and climate change impacts, further compounding its vulnerability to natural disasters.

Rising sea levels threaten coastal communities, while deforestation and land degradation exacerbate the risk of floods and landslides, particularly in mountainous regions. In the last two decades, Indonesia has faced several devastating natural disasters that have underscored the urgent need for enhanced natural

disasters resilience measures. The 2004 Indian Ocean earthquake and tsunami, which originated off the coast of Sumatra, resulted in unprecedented destruction and claimed hundreds of thousands of lives. The 2018 Sulawesi earthquake and tsunami, followed by the 2018 Lombok earthquakes, highlighted the country's susceptibility to seismic events and the importance of effective disaster management strategies.

Addressing Indonesia's vulnerability to natural disasters requires a multi-faceted approach that encompasses robust disaster preparedness, early warning systems, infrastructure resilience and community engagement. Enhancing the resilience of infrastructure is imperative to support Indonesia's development efforts. Strengthening building codes, implementing land-use planning measures, and investing in resilient infrastructure are critical steps toward mitigating the impacts of disasters. Furthermore, enhancing public awareness and community resilience through education and capacity-building initiatives plays a crucial role in fostering a culture of preparedness and response at the grassroots level.

In Indonesia, the Jakarta metropolitan area deserves special attention. As Indonesia's capital and one of the most populous urban centres in Southeast Asia, it faces unique challenges and vulnerabilities to natural disasters. Situated on the northwest coast of Java Island, Jakarta is particularly susceptible to a combination of geological, hydro-meteorological and environmental hazards.

Improving urban transport and ensuring its resilience

The Jakarta metropolitan area faces multiple transportation related challenges. Chief among them are:

- **Chronic traffic congestion.** Viability is a significant challenge in the Jakarta metropolitan area. Persistent traffic congestion has long been a pressing issue, adversely impacting the region's economic productivity, environmental sustainability and overall quality of life. With the rapid urbanisation and population growth experienced in Jakarta, the demand for efficient and reliable transportation solutions has become increasingly urgent.
- **Overreliance on private vehicles.** Jakarta has long been characterised by high levels of car ownership and a culture of reliance on private vehicles for transportation. This overreliance on cars contributes to traffic congestion, air pollution and environmental degradation.
- **Limited public transportation options.** Prior to the introduction of the MRT Jakarta, the city's public transportation network consisted primarily of buses, which often operated in congested traffic conditions and were subject to delays.
- **Urban sprawl and population growth**. Jakarta's rapid urbanisation and population growth have led to increased demands on its transportation infrastructure. As the city continues to expand outward and its population grows, the need for reliable and efficient public transportation becomes more pressing.
- **Environmental sustainability**. Jakarta faces environmental challenges such as air pollution and greenhouse gas emissions, largely driven by the high volume of vehicles on its roads.

In the Jakarta metropolitan area, the risk of natural disasters, including heavy rainfall, floods, earthquakes, land subsidence and sea-level rise, is significant and has been growing. In particular, the main challenges to be addressed when it comes to improving urban transport, and that are taken into account in the MRT Jakarta project are:

- **Growing flooding risks.** One significant vulnerability of the Jakarta metropolitan area is its exposure to flooding, exacerbated by rapid urbanisation, land subsidence and inadequate drainage systems. The city is crisscrossed by 13 rivers and numerous canals, making it highly susceptible to inundation during periods of heavy rainfall. Additionally, Jakarta experiences tidal flooding due to its low-lying coastal location, with sea-level rise further exacerbating the risk of inundation.
- **Increasing seismic risks.** Jakarta's geology, characterised by soft soil, renders the city vulnerable to relatively high earthquake acceleration, hazard and risk during seismic events. Certain areas with

thick, loose to very loose sand deposit are highly susceptible to liquefaction under high earthquake acceleration. The presence of active fault lines near the city, including the notorious Sunda Megathrust Fault, poses significant threats to urban infrastructure and densely populated areas.

- **Growing environmental degradation.** In recent years, the Jakarta metropolitan area has also grappled with air pollution and environmental degradation, further exacerbating its vulnerability to natural disasters. Deforestation in surrounding areas has led to increased surface runoff and soil erosion, contributing to flooding and landslides, particularly during the rainy season.
- **Socio-economic inequalities and heightened risks for vulnerable communities.** Moreover, the socio-economic disparities within the Jakarta metropolitan area amplify the impacts of natural disasters on vulnerable communities, including illegal settlements and low-income neighbourhoods. These communities often lack access to adequate housing, infrastructure and disaster preparedness resources, increasing their susceptibility to displacement and socio-economic impacts during disaster events.

The Jakarta metropolitan area's vulnerability to natural disasters underscores the urgent need for comprehensive disaster risk reduction measures, including resilient urban planning, infrastructure upgrades, early warning systems and community engagement initiatives, to mitigate the impacts of future disasters and enhance the city's resilience.

The Mass Rapid Transit (MRT) Jakarta is a key component of Indonesia's efforts to improve urban transport

The Mass Rapid Transit (MRT) Jakarta, is a track-based urban transportation system designed to provide efficient and reliable mass transit services in the Jakarta metropolitan area. Current aspects of the MRT Jakarta project include the development of two primary lines: the North-South Line and the East-West Line. The North-South Phase 1, which spans from the city's northern suburbs to the central business district, was the first phase of the project to become operational. The commencement of operations on the North-South Line in March 2019 marked a significant milestone in Jakarta's efforts to improve its urban transportation infrastructure.

Recognising the critical need to address traffic congestion and enhance urban mobility, the implementation of the MRT Jakarta system represents a strategic investment in the region's transportation infrastructure. The MRT Jakarta project is designed to offer a viable alternative to traditional modes of transportation, such as cars and motorcycles, by providing a safe, reliable and efficient public transit option for residents and commuters.

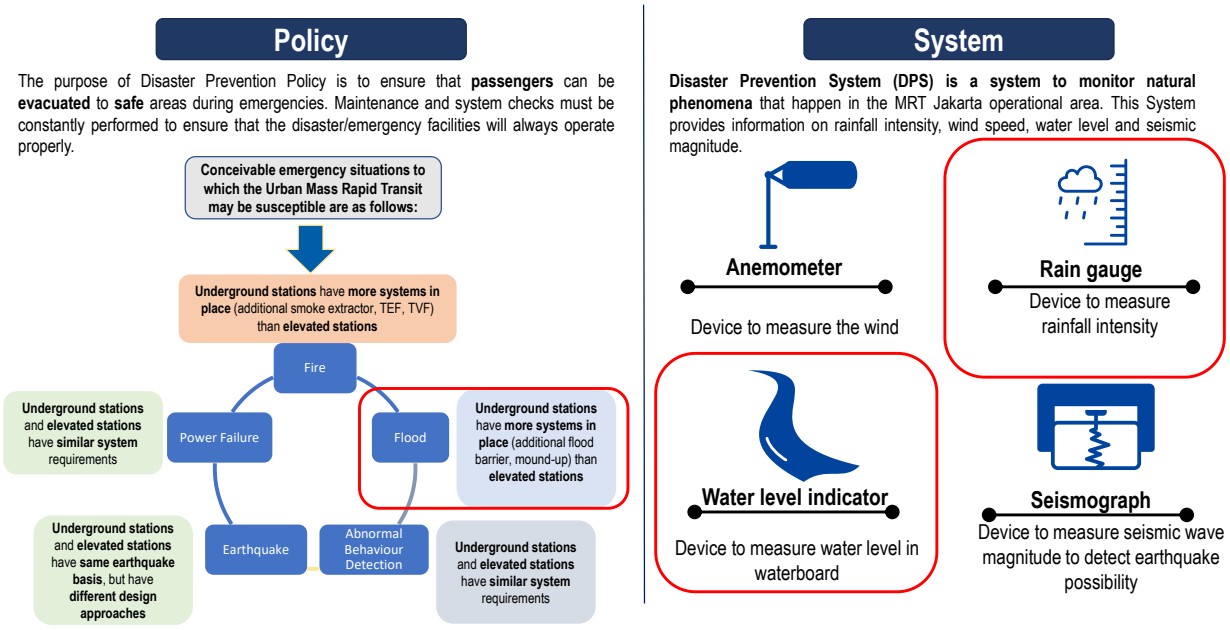
The project addresses multiple objectives, recognises the growing vulnerability to natural disasters and incorporates resilience as a guiding principle in all project phases from conception to building and implementation.

The MRT Jakarta project is aimed at:

- **Addressing the chronic traffic congestion** in the area; it is planned to accommodate the transportation needs of a growing urban population by reducing travel times and enhancing connectivity between key residential and commercial areas in the city.
- **Fostering environmental sustainability** by reducing reliance on fossil fuel-powered vehicles and encouraging the use of cleaner modes of transportation, improving air quality, and reducing carbon emissions in the city.
- **Minimising natural disasters' impact** through enhanced prevention capacities. It implements plans and facility designs aimed at minimising the anticipated impact of disasters in advance.
- **Ensuring effective reaction capacities** in the aftermath of a natural disasters. The project incorporates measures to ensure a seamless response and continuity of service provision in the event of a disaster.

The project counts with a disaster prevention policy and a disaster prevention system (DPS) (Figure 3.3).

Figure 3.3. MRT Jakarta's disaster prevention policy and system, Indonesia



Source: Authors' elaboration based on "Increasing MRT Jakarta Resiliency to Climate Disaster", presentation by PT MRT Jakarta, Indonesia at the 2nd preparatory meeting for the Compendium of Good Practices on Quality Infrastructure - Thematic Focus: Planning, Financing, and Building Infrastructure Resilient to Natural Disasters that took place on 7 September 2023.

Responsibility for the MRT Jakarta project is distributed among several key institutions, each playing a distinct role in its planning, implementation and operation. The central Government of Indonesia, holds overarching responsibility for setting policies, determines project funding schemes and ensures the project's alignment with national development objectives. Within the government, the Ministry of Transportation is a central player, overseeing the planning and development of urban transportation infrastructure projects, including the MRT Jakarta.

- A critical partner in the MRT Jakarta project is PT MRT Jakarta (Perseroda), a state-owned enterprise tasked with the construction, operation, maintenance and commercialisation of the MRT system and its TOD (Transit Oriented Development) operator. The government of Jakarta has delegated PT MRT Jakarta to serve as the sub-implementing agency for construction and be responsible for managing all aspects of the project's execution, from overseeing construction activities and co-ordinating with various construction-related stakeholders, to ensuring the system's safe and efficient operation. As the project's operator, PT MRT Jakarta also plays a vital role in managing day-to-day operations, including fare collection, maintenance of facilities and passenger services.
- The Government of Jakarta, specifically the Provincial Government of the Special Capital Region of Jakarta (DKI Jakarta), is another key stakeholder in the MRT Jakarta project, as the implementing agency. The DKI Jakarta provincial government develops the city master plan and collaborates with relevant stakeholders to address the city's needs and concerns. It is also accountable for the project's execution, such as land acquisition and resettlement, and for the supervision of MRT Jakarta. The national government, in particular the Directorate General of Railways at the Ministry of Transportation, as the executing agency and regulator of railway administrator, provides overall guidance, support, permits and approvals for implementing and operating the project. The close

collaboration between the national and provincial governments is essential for ensuring seamless co-ordination and alignment of priorities throughout the project life cycle.

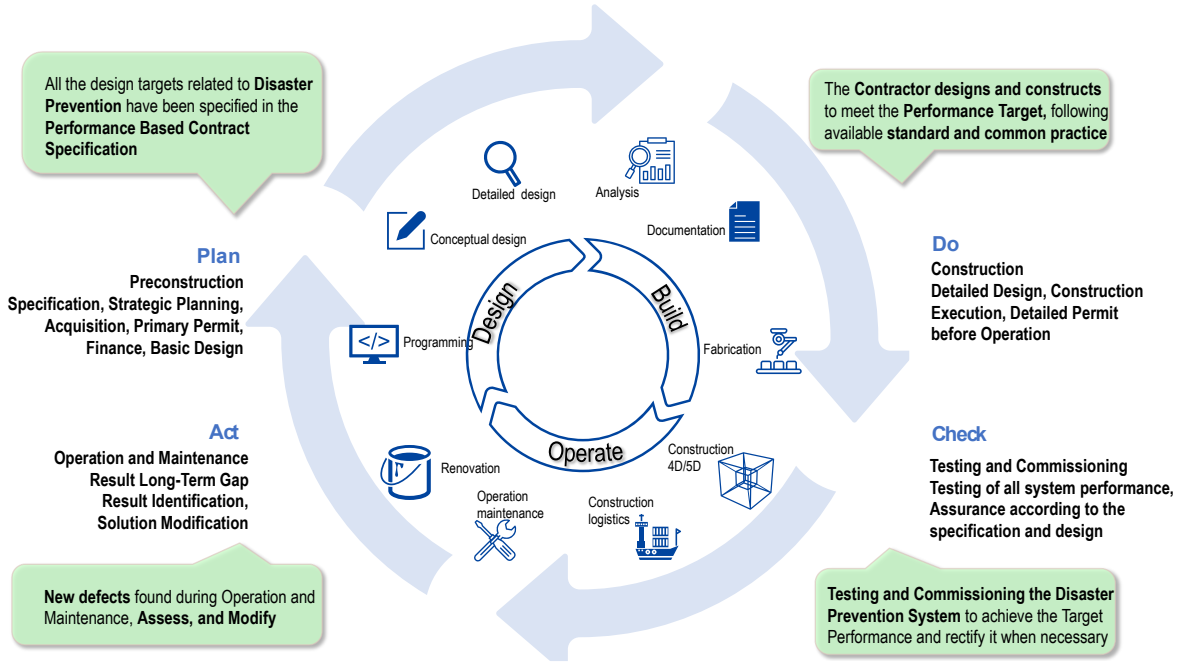
- Beyond government entities, the MRT Jakarta project also involves collaboration with various private sector partners, including engineering firms, construction contractors (including detail design consultants, sub-contractors and technology suppliers) and partnerships with other stakeholders. These private sector entities contribute specialised expertise, technical know-how and resources to the project, playing a crucial role in the successful delivery of key project milestones. Together, these diverse stakeholders form a collaborative ecosystem dedicated to realising the vision of a modern, efficient and sustainable urban transportation system for Jakarta.

Collaboration, smart use of data for risk assessment and technology stand out as key success factors of the MRT Jakarta

Several good practices can be identified in the MRT Jakarta project. In particular, they can be classified in six areas (spanning from design, targeted disasters' response mechanisms, risk assessment, reliance on digital technologies, collaboration and knowledge management):

- **Innovative and resilient facility design**
  - The initial phase of the MRT Jakarta project comprises both elevated and underground sections, each facing distinct challenges in terms of exposure to natural elements. While the elevated section is susceptible to heavy rainfall, the underground section faces flood risks. To address these challenges, specific improvements in facility design were implemented to mitigate associated risks.
  - For the elevated stations, rain screens were installed as part of an enhanced design strategy to minimise the impact of heavy rainfall on passengers waiting at the stations. These rain screens represent an upgrade from the original design, aimed at providing increased protection and comfort for passengers during adverse weather conditions.
  - In the underground stations, measures were taken to prevent floodwater from infiltrating the station premises. Mound up entrances, along with the installation of flood panels, were introduced to effectively mitigate the risk of flooding in underground stations. These countermeasures not only address flood risks but also offer protection against ground subsidence and potential sea level rise, ensuring the resilience of the underground infrastructure.
- **Passenger safety and disaster response mechanisms**
  - Central to the concept of disaster prevention is the assurance of passenger safety and the implementation of effective emergency response measures. Continuous maintenance and regular system checks are essential to ensure that all facilities operate optimally and can facilitate prompt evacuation procedures during emergencies.
  - The Disaster Prevention System (DPS) plays a crucial role in monitoring natural phenomena that could pose risks to the MRT Jakarta's operational areas (Figure 3.4). This system monitors various parameters such as rainfall intensity, wind speed, water levels and seismic activity. By continuously monitoring these factors, the DPS enables timely detection of potential hazards, allowing for proactive measures to be taken to safeguard passenger safety and ensure the smooth operation of the MRT system, even during adverse conditions.

Figure 3.4. Project life cycle for Disaster Prevention System: The MRT approach, Jakarta, Indonesia



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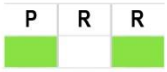
- **Risk and impact assessment**. Continuous risk and impact assessment was conducted, identifying potential major disasters such as the potential increase in flood levels (heavy rainfall due to climate change, sea level rise and land subsidence), earthquakes, fire, terrorism and power failure. Recent trends and long-term predictions were analysed to inform decision making for improvement in disaster-resilient design. Precise data necessary for assessment was collaboratively obtained from relevant institutions, and digital technologies were used for the risk and impact assessment analysis.
- **Effective use of technology.** The selection and application of appropriate technologies were prioritised to effectively address disaster risks.
  - Disaster prevention targets were integrated into the performance-based contract specifications.
  - Initial designs of station facilities, such as rain screens, flood panels and mound-up entrances, were enhanced to improve resilience.
  - Waterways were modified by enlarging channels, creating absorption wells, and installing submersible slurry pumps to enhance drainage capabilities.
- **Collaboration.** Continuous collaboration with these institutions ensured a co-ordinated and comprehensive approach to disaster prevention.
  - Effective co-ordination with the Meteorology, Climatology and Geophysics Agency (BMKG) facilitated access to essential climate, meteorological, hydrological and seismic data. The installation of flood panels was based on hydrological and disaster studies against predicted flood levels under a 200-year rainfall return period. Updates in the hydrological study were based on additional considerations of heavy rainfalls due to climate change, sea level rises and land subsidence, conducted and co-ordinated with the Provincial Government of the Special Capital Region of Jakarta and other relevant organisations.

- MRT Jakarta (MRTJ) has played a pivotal role in co-ordinating with various governmental bodies and agencies to ensure the successful implementation of recommendations stemming from comprehensive hydrological and disaster studies. This co-ordination has involved close collaboration with the DKI Provincial Government and the Water Resources Agency (SDA).
- The DKI Provincial Government, as the local governing authority, has been instrumental in providing support and facilitating the integration of the MRT Jakarta project within the broader urban development framework of Jakarta. Their involvement has included land acquisition support, regulatory approvals and co-ordination with local communities to address any arising issues or concerns.
- The DKI Provincial Government has served as a key intermediary between MRTJ and the relevant government agencies, ensuring effective communication and alignment of priorities. Its role has been critical in facilitating inter-agency collaboration and streamlining administrative processes to expedite project implementation.
- Additionally, the Water Resources Agency (SDA) has played a vital role in providing expertise and guidance related to water management strategies and flood mitigation measures. Their input has been crucial in developing solutions to address flood risks and ensure the resilience of MRT Jakarta's infrastructure against natural disasters such as heavy rainfall and flooding.
- By working closely with these governmental bodies and agencies, MRTJ has been able to leverage their collective expertise and resources to implement comprehensive disaster prevention measures and enhance the overall resilience of the MRT Jakarta system. This collaborative approach underscores the importance of inter-agency co-ordination in addressing complex urban challenges and ensuring the long-term sustainability and natural disasters resilience of critical infrastructure projects.

- **Knowledge management.** MRT Jakarta implemented robust knowledge management practices to capture, disseminate and utilise lessons learned from firsthand experiences, particularly regarding resilience to natural disasters. Continuous knowledge management activities serve as a foundation for applying advanced technologies and building critical human resources and organisational knowledge to plan and manage resilient infrastructure projects and share knowledge with the community. Examples of effective knowledge management activities implemented in this project include:
  - Post-event retrospectives were conducted to discuss phase 1 project outcomes and lessons learned were compiled at the Internal Knowledge, Information, Education Center (KINETIC), as a basis for improvement on the following line project implementation.
  - Learning series books focusing on construction, and operation and maintenance were published to share experiences, insights and best practices.
  - MRT Jakarta also contributed to a study on flood management conducted by the Community of Metros Benchmarking Group (COMET) which compares and benchmarks practices among metros and shares learnings and best practices from various contexts and environments.

Investing in cutting edge technology and strategic preventive maintenance to build resilience in a cost-effective way in Japan

Japan has prioritised a focus on reducing vulnerabilities to natural disasters in a cost-effective way by increasing preparedness, for instance, through strategic preventive maintenance and the use of cutting-edge technology. The country has an integrated approach which levers on the regulatory framework to provide incentives for innovation and prevention measures as well as to clarify responsibilities for actions to be implemented to ensure prevention and reaction capacities operate in an effective and cost-saving way.



Location and background information

Japan's geographical location places it at significant risk of natural disasters, making it highly exposed to various catastrophic events.

Situated in the Circum-Pacific Mobile Belt, Japan experiences frequent seismic and volcanic activities, as the region is known for its tectonic instability. This geological setting contributes to the country's susceptibility to earthquakes, with Japan being one of the most seismically active areas in the world. Approximately 18.5% of the world's earthquakes of magnitude 6 or greater occurred in Japan between 2004 and 2013, often accompanied by high-risk tsunamis (Cabinet Office Government of Japan, 2015[2]). Additionally, the presence of numerous active volcanoes further amplifies the risk of volcanic eruptions, adding to the nation's vulnerability to natural disasters.

The country's extensive coastline and mountainous terrain exacerbate its exposure to natural hazards. Japan's coastline stretches over thousands of kilometers, making it susceptible to typhoons, heavy rains and storm surges originating from the Pacific Ocean. These weather phenomena, exacerbated by climate change, can cause widespread flooding, landslides and infrastructure damage, particularly in densely populated coastal areas. Moreover, the mountainous landscape increases the risk of landslides and flash floods, especially during heavy rainfall and monsoon seasons, posing additional threats to communities residing in mountainous regions.

Furthermore, Japan's densely populated urban areas, coupled with its highly developed infrastructure network, heighten the impact of natural disasters (Cabinet Office Government of Japan, 2015[2]). The country's robust economy and advanced technological capabilities have led to extensive urbanisation and the construction of critical infrastructure, including transportation networks, buildings and industrial facilities. While this development has contributed to Japan's prosperity, it also means that any disruption caused by natural disasters can have far-reaching consequences, resulting in significant economic losses, human casualties and disruptions to essential services.

Overall, Japan's unique combination of geological, geographical and socio-economic factors renders it highly susceptible to a wide range of natural disasters, including earthquakes, volcanic eruptions, typhoons and landslides. In 2019 alone, the estimated damages caused by floods and landslides amounted to USD 16.2 billion, underscoring the substantial impact of these disasters on Japan's infrastructure and economy (MLIT, 2021[3]). The country's ongoing efforts to enhance disaster preparedness, early warning systems and infrastructure resilience are crucial in mitigating the impact of these hazards and ensuring the safety and resilience of its population and economy.

Main challenges to be addressed

Given Japan's unique geographical, topographical and meteorological conditions, it is essential to construct infrastructure with disaster prevention features, particularly to enhance seismic and water related natural disasters resilience. This involves implementing technical and design measures, such as those to address soft ground challenges, and conducting regular maintenance.

In the case of Japan, a significant concern is the ageing infrastructure that was originally developed during the high economic growth period in the 1960s. In 2021, around 32% of bridges in Japan were over 50 years old, and this is projected to increase to 57% by the year 2031 (MLIT, 2021[4]). Addressing these challenges is critical to ensuring the long-term durability, safety and effectiveness of the country's infrastructure.

Project description and assessment

Japan has a strategic and holistic approach to infrastructure planning, combined with high investments, which integrates resilience to natural disasters and growing climate risks, not only at the outset of the planning, but also throughout its life cycle, including during the development and management of project infrastructure.

A key emphasis is placed on strategic preventive maintenance. This involves prevention measures aimed at improving and maintaining infrastructure assets before deterioration leads to failure. This proactive approach aims to avoid or delay the extensive resources and machinery involved in costly reconstruction efforts (OECD, 2022[1]). By formulating a systematic repair plan, carrying out necessary repairs and assessing them regularly, infrastructure integrity is preserved, enhancing its resilience against disaster events and minimising economic disruptions. Timely maintenance reduces life-cycle costs by mitigating future maintenance and repair/update expenses. It requires the estimation and integration of necessary maintenance budgets into overall infrastructure planning.

The effective utilisation of advanced technology is critical to enabling and simplifying construction, inspection and maintenance work in challenging topographical conditions. This facilitates the maintenance of infrastructure and reduces overall life-cycle costs by circumventing the need for costly extensive reconstruction efforts. According to estimates by the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) of Japan, the adoption of preventive maintenance measures could lead to savings of approximately 32% in infrastructure maintenance and upgrade costs over the next 30 years, as compared to reactive maintenance approaches (MLIT, 2018[5]). Beyond the broader socio-economic benefits of resilient infrastructure, these savings directly benefit the government and investors, providing additional fiscal space for the enhancement of existing infrastructure or the construction of new infrastructure in other areas.

In Japan, when it comes to monitoring for strategic preventive maintenance, emerging technologies are proactively used with a view to increase efficiency, effectiveness and safety. For example, the Mobile Mapping System (MMS) utilises high-density laser scanning and infrared cameras to detect damages and cracks down to the millimeter level. By creating detailed 3D models of road surfaces and tunnel walls, MMS enables accurate assessment of current conditions and prioritisation of maintenance tasks, contributing to efficient inspection and monitoring and prolonging infrastructure lifetime (OECD, 2022[1]; MLIT, 2023[6]).

Approximately 30% of Japan's land area is characterised by steep lands in mountainous regions, rendering it uninhabitable and leading to the development of densely built urban areas. These areas are prone to frequent floods and landslides triggered by heavy rainfall, exacerbated by the presence of steep and short rivers (Cabinet Office Government of Japan, 2015[2]). These topographical challenges pose safety risks in the inspection and maintenance of infrastructure. To mitigate these risks, Japan leverages advanced technologies for monitoring and early detection of failures.

For example, Tokyo Gate Bridge utilises approximately 50 fiber-optic sensors resilient against dust and thunderbolt to generate about 2 800 data points per second. This system enables continuous monitoring of the bridge's condition and early detection of potential failures. The data obtained inform maintenance

teams of the precise nature of damages, facilitating prompt and effective responses. This approach has enhanced monitoring efficiency and reduced costs (MLIT, n.d.[7]).

The central government of Japan further promotes preventive maintenance through targeted subsidies, as outlined in the national land resilience policy. For example, the "Five-year Acceleration Measures for Disaster Prevention and Mitigation and National Land Resilience" initiative includes measures aimed at addressing severe wind and flood damage and large-scale earthquakes. This includes the development of disaster prevention infrastructure and projects focused on addressing ageing infrastructure through preventive maintenance shifts. The budget allocation covers both national and local infrastructure, with the central government providing inspection manuals and training programmes to support local governments in their maintenance efforts (Cabinet Office Government of Japan, 2015[2]).

The planning and integration of strategic preventive maintenance into overall planning processes and budgets is instrumental in ensuring operational continuity with consistently high operational standards. Japan proactively incorporates advanced technology for monitoring purposes, facilitating timely data acquisition necessary for emergency evacuation processes and the design and operation of disaster-resilient infrastructure. This not only enhances the resilience of individual infrastructure assets but also ensures the resilience of regions and surrounding industries through improved operational continuity. For instance, the utilisation of optical fiber sensors for bridges enables the detection of bridge mutations and distortions before and after earthquakes, facilitating swift responses to abnormalities and the rapid restoration of transport operations.

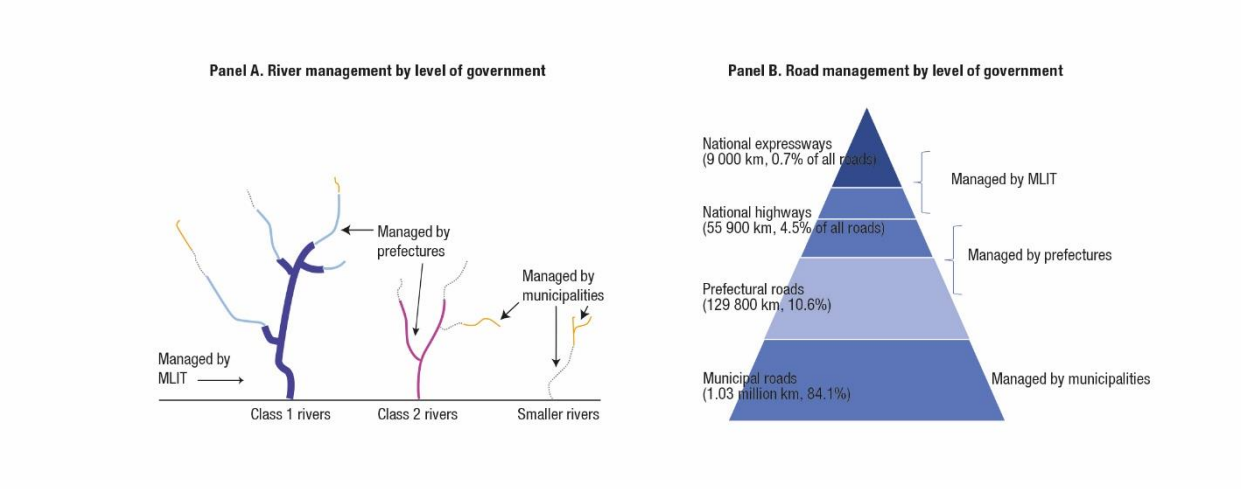
Japan actively promotes the deployment of cutting-edge technologies in other countries through initiatives like the Road Asset Management Platform (RAMP) established by the Japan International Cooperation Agency (JICA) in 2017. RAMP supports effective road asset management and offers capacity-building programmes on advanced technologies to developing countries. These programmes cover various areas such as bridge inspection using drones, AI (artificial intelligence)-based detection of damaged components, dynamic response intelligent monitoring systems, and slope measuring devices. RAMP collaborates with Japan's Cabinet Office-organized Infrastructure Maintenance, Renovation, and Management of Cross-ministerial Strategic Innovation Promotion Program to disseminate advanced technologies globally (JICA, n.d.[8]).

Good practices and success factors

Japan stands out as one of the leading promoters of quality infrastructure worldwide. It has promoted the G20 Quality Infrastructure Investment principles and it embeds resilience to natural disasters in its infrastructure investment policy. The use of strategic preventive maintenance and the capacity to innovate and utilise cutting edge technologies, including advanced and fast evolving digital solutions are distinctive features of the Japanese approach. In particular, the three following elements stand out as good practices:

- **A clear legal framework for strategic preventive maintenance**. Japan's national land resilience policy emphasises strategic preventive maintenance and outlines clear responsibilities among different levels of government, including the prefectures and municipalities (Figure 3.5). This ensures effective co-ordination and accountability in infrastructure resilience efforts.

Figure 3.5. Responsibilities for rivers and road management by level of government



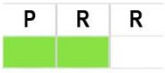
Source: Authors' elaboration based on "Japanese method of enhancing resilience to natural disasters", presentation by Masahiko Murase, Director, International Cooperation and Engineering for Infrastructure, Ministry of Land, Infrastructure, Transport and Tourism, MLIT, Japan at the 1st preparatory meeting for the Compendium of Good Practices on Quality Infrastructure - Thematic Focus: Increasing Infrastructure Resilience to Natural Disasters that took place on 18-19 April 2023.

- **A legal framework with clear provisions to invest and incentivise innovation and the use of advanced technology for prevention and re-building**. The development and deployment of cutting-edge technology plays a crucial role in enhancing the capacity to build infrastructure resilience and minimising damage costs. For instance, automatic evaluation and non-destructive inspection using Information and Communication Technology (ICT) significantly reduce costs and the need for skilled human resources. According to the New Technology Information System (NETIS), a database developed by MLIT to promote the deployment of new technologies in the private sector, 35 registered new technologies have, on average, reduced maintenance costs by 15% and time by 32% compared to conventional maintenance practices (MLIT, 2022[9]). These advancements not only contribute to more efficient maintenance operations but also bolster the overall resilience of infrastructure systems, ultimately enhancing their capacity to withstand and recover from adverse events.

  MLIT employs a comprehensive bidding system that evaluates positively construction companies incorporating advanced technology into their projects, compared to those who do not. Through direct financial support and tax incentives Japan incentivises innovation and encourages the deployment of cutting-edge technologies in infrastructure development to achieve resilience to natural disasters and climate-related risks (Nikkei XTECH, 2021[10]).
- **An emphasis on collaborative approaches in the areas of research and development, and innovation**. Collaborative efforts between government agencies, the private sector, academia and other stakeholders play a crucial role in advancing infrastructure resilience. In Japan, MLIT has established the Advanced Construction Technology Centre to facilitate research, development, and assessment of new technologies. This centre serves as a platform for disseminating knowledge and fostering collaboration among stakeholders, thereby driving innovation in infrastructure construction.

Increasing road network resilience through adapted standards and effective use of data in Mozambique

Mozambique has implemented a comprehensive national strategy to mitigate the impact of climate change and natural disasters on its transport network. The country has improved road standards, incorporating climate resilience considerations, and it has improved its early warning system and monitoring process through digital technologies.



The road network is highly vulnerable to natural disasters

Mozambique is among the world's most exposed countries to natural disasters and mounting risks associated to climate change. It faces significant challenges stemming from recurrent floods, droughts and cyclones, primarily due to its geographical features and hydrological characteristics. Sharing 9 of the 15 hydrographic basins in the South African Development Community (SADC) region and being downstream of 8 basins, Mozambique is particularly susceptible to flood risks. This hydrological connectivity exposes the country to the impacts of upstream activities, such as deforestation and land use changes, which can exacerbate flooding downstream.

Mozambique's hypsometric attributes, characterised by a significant portion of low-altitude terrain, contribute greatly to its flood vulnerability. Much of the country's landscape consists of plains formed over thousands of years by the floods of rivers and the deposition of alluvial material. Approximately 40% of Mozambique's total land area lies below an altitude of 200 meters, making it prone to inundation during periods of heavy rainfall or cyclonic activity. The catastrophic floods that struck Mozambique in January 2013 exemplify the profound impact of natural disasters on the country. These floods, which primarily affected the lower Limpopo valley and other southern regions, were the worst disaster since the floods of 2000. The devastating aftermath included 113 fatalities, the evacuation of approximately 172 600 people, and the destruction of nearly 89 000 hectares of cultivated land. The economic toll of the floods was also significant, with the Mozambique government estimating a substantial negative impact on economic growth.

Over the past two decades, the country has also been severely affected by cyclones, with 23 occurrences recorded since 2000. Recent years have witnessed a notable increase in cyclone activity, with significant events such as Cyclones Desmond, Idai and Kenneth in 2019, followed by Cyclones Ana, Dumaku and Gombe in 2022. The impact of these cyclones on Mozambique's infrastructure and communities underscores the urgent need for resilient measures to mitigate the devastating effects of such disasters.

Natural disasters are deeply affecting the functioning of the road transportation network in Mozambique, posing major economic challenges to the country and the overall region, as Mozambique serves as a gateway for several land-locked countries in the region.

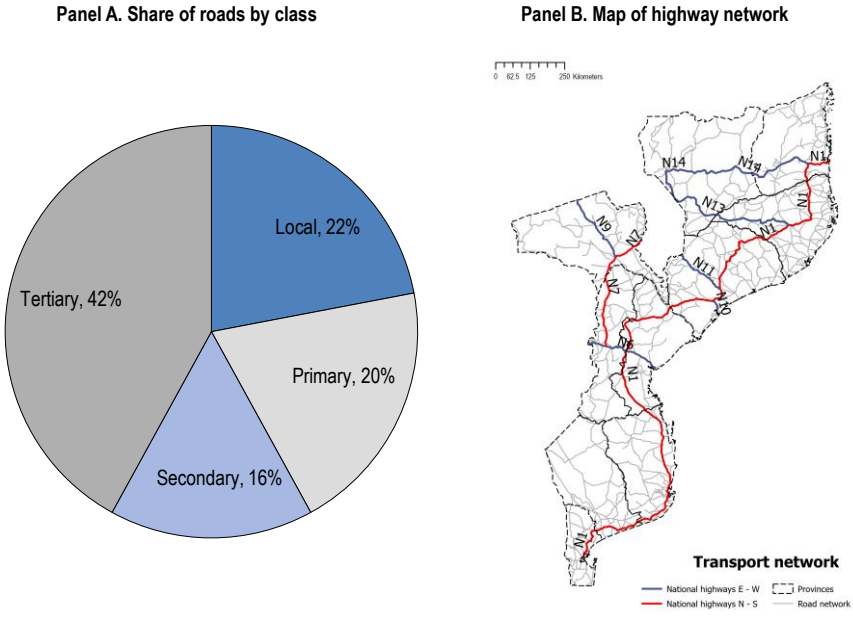
Mozambique needs to address its transportation infrastructure vulnerability under a tight budget

Mozambique relies heavily on road infrastructure for the transportation of goods, particularly to ports, due to being a coastal country with landlocked neighbours.

The country suffers from multiple vulnerabilities:

- **Climate change vulnerability and heightened risk of natural disasters**. The country faces various challenges such as floods, cyclones and varying rainfall patterns, leading to exposure and vulnerability of road networks, especially in coastal areas. Climate change is also introducing significant uncertainty. Road assets generally have service lives of several decades, therefore design parameters or the choice of materials need to be chosen in a way that can withstand future conditions.
- **Infrastructure vulnerability**. The vulnerability of Mozambique's road networks is exacerbated by various natural hazards, including floods and cyclones, as well as the country's exposure to fluctuating rainfall patterns. With few redundancies and prone to disruptions, the road network, especially the north-south links, is prone to disruptions caused by river floods and cyclones. These environmental factors pose significant risks to the stability and functionality of the road infrastructure, particularly in coastal regions, highlighting the urgent need for resilient planning and infrastructure management strategies. Furthermore, the ageing infrastructure presents challenges in adapting to the impacts of climate change, necessitating comprehensive assessments and interventions to enhance resilience and sustainability (Figure 3.6).
- **Budgetary constraints**. While efforts are underway to implement resilient measures, budgetary constraints pose challenges to the comprehensive enhancement of Mozambique's road infrastructure. Implementing resilient measures raises questions about economic feasibility, especially considering the extensive network of mostly unpaved roads which require preventive, reacting and rebuilding responses.

Figure 3.6. Classification of roads in Mozambique, 2023



Source: Authors' elaboration based on "Increasing Infrastructure Resilience to Natural Disasters". Presentation by Cecilio Maria da Grachane, Engineer, Road Fund, Ministry of Public Works, Housing and Water, at the 1st preparatory meeting for the Compendium of Good Practices on Quality Infrastructure - Thematic Focus: Increasing Infrastructure Resilience to Natural Disasters that took place on 18-19 April 2023.

To ensure resilience to natural disasters, the road network in Mozambique, aged between 50 and 60 years, relies heavily on traditional preventive measures such as building embankments. However, the onset of climate change is resulting in more intense rainfall and shifting weather patterns, rendering these measures increasingly inadequate. Particularly in the Limpopo lower basin, where most roads are constructed on embankments functioning as dikes, the impact of floods has been severe. At least 18 stretches of paved roads and bridges, including three sections of the main national highway, were damaged during recent

flood events. Numerous villages were inundated, with some completely cut off and others accessible only by boat. The province's road network sustained extensive damage, with approximately 70% affected, equating to 2 200 kilometers of roads, 30 bridges and culverts, and 62 aqueducts.

To address the challenges posed by climate change and ensure the sustainability and resilience of the country's road network, Mozambique is pursuing a multifaceted approach:

- First, emphasis is placed on proper maintenance of existing infrastructure based on their anticipated risks, ensuring proactive measures are in place to mitigate potential damage.
- Second, efforts are directed towards enhancing connectivity options to accommodate natural disaster occurrences, providing alternative routes or transport modes during emergencies.
- Third, the country is proactively integrating climate adaptation strategies into ongoing infrastructure projects, layering resilience measures over existing work. In the context of climate change, provision of reliable accessibility depends upon effective planning for potential impacts of extreme events and building resilience in the road network accordingly.

Mozambique has strengthened its prevention and reaction capacity through the smart use of data, technology and infrastructure design

To address infrastructure vulnerabilities, Mozambique is implementing technical solutions such as adjusting road design standards and incorporating innovative engineering practices. These measures include modifying slopes and enhancing structural elements in bridges to withstand the effects of extreme weather events and ensure the long-term functionality and safety of the road network. In particular, Mozambique has:

- Introduced new national design and build specifications aimed at enhancing infrastructure resilience to extreme weather events. The new design standards for the National Road Network have been developed and implemented since 2019, incorporating climate resilience considerations.
- Conducted vulnerability assessments of existing roads through pilot projects, prioritising retrofitting and resilience enhancements.
- Introduced the testing of new technical solutions through pilot projects, exploring innovative approaches to strengthen infrastructure resilience in the face of climate change impacts.
- Strengthened its early warning system and the institutions which ensure its effective functioning. Among them it is worth noticing:
    - The National Meteorology Institute (INAM), which utilises satellite imagery, radar data and observations from a network of monitoring stations to produce meteorological warnings.
    - The Institute of Social Communication, which plays a crucial role in disseminating these alerts through its network of 70 community radios. Additionally, trained community brigades are mobilised to warn at-risk communities, guiding them to safety before the occurrence of extreme weather events.

Acknowledging the inherent uncertainties associated with climate change, Mozambique emphasises the importance of adaptive learning and continuous improvement in infrastructure planning and management. By monitoring and evaluating the effectiveness of resilience strategies over time, authorities can better understand evolving risks and refine response measures to ensure the long-term sustainability and functionality of the road network amidst changing environmental conditions.

Redundancy in road network and early warning systems are key pillars of the national resilience strategy

Mozambique has strengthened its capacity to monitor and measure the resilience of infrastructure to natural disasters. The integration of advanced technology, community engagement and effective data tracking systems enhances the country's ability to anticipate hazards, issue timely warnings, and implement proactive measures to safeguard critical road networks and protect the lives and livelihoods of its citizens. In particular, it is worth noting the actions implemented in the following fields:

- **Data Tracking System for Hazard Events and Impacts.** Mozambique employs a robust data tracking system that includes recording hazard events, localisation and impacts, allowing for the classification of road networks based on identified risks and impacts. This system enables authorities to categorise roads according to their vulnerability and define specific risk factors associated with each segment. Examples of road network classification include identifying roads with exposure to permanent exceptional risk, roads prone to flooding and damage due to insufficient drainage capacity, roads with high volumes of runoff leading to overtopping and road cutting, and roads experiencing erosion and poor excavation at bridge abutments. This information enables authorities to strategically allocate resources and deploy timely interventions to minimise disruptions and enhance the resilience of critical infrastructure.
- **Early Warning System.** Mozambique has implemented an early warning system that enables the country to track potential hazards, issue timely alerts and take proactive measures to minimise the impacts on people's lives and property. This system integrates new technology, infrastructure and community action to ensure effective communication and response. Key institutions in charge of ensuring the effective functioning of the national early warning system are:
- **Redundancy and resilience.** Mozambique recognises the importance of creating redundancy within its road network to ensure continuous connectivity and minimise disruptions in the event of infrastructure failures or natural disasters. By strategically planning alternative routes and improving interconnectivity, authorities aim to enhance the resilience of the road network and mitigate the socio-economic impacts of disruptions on local communities and regional trade.

In the context of Mozambique's interconnected hydrographic basins, it is imperative to consider **cross-border issues when developing infrastructure resilience to natural disasters**. The interconnected nature of hydrographic basins means that activities upstream can have significant downstream impacts, including the potential for increased flood risks and changes in water flow patterns. Therefore, effective co-ordination and collaboration with neighbouring countries is essential to address shared challenges and mitigate the transboundary impacts of natural disasters.

One key aspect of addressing cross-border issues is the need for information sharing and early warning systems that encompass multiple countries within the region. This includes sharing data on rainfall patterns, water levels and potential flood risks, as well as co-ordinating response efforts in the event of a natural disaster. By establishing collaborative mechanisms for information exchange, countries can better anticipate and prepare for disasters, reducing the potential for adverse impacts on infrastructure and communities across borders.

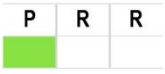
Furthermore, infrastructure resilience planning should take into account the interconnectedness of transport networks and trade routes between countries. Roads, bridges and other critical infrastructure often serve as lifelines for cross-border trade and transportation, making them particularly vulnerable to natural disasters. Therefore, efforts to enhance infrastructure resilience should consider not only the local impacts of disasters but also their potential effects on regional trade and connectivity.

In addition to physical infrastructure, cross-border collaboration is essential for addressing broader challenges related to disaster response and recovery. This includes co-ordinating efforts to provide humanitarian assistance, support affected populations and rebuild damaged infrastructure. By working

together across borders, countries can leverage collective resources and expertise to enhance resilience and build back better in the aftermath of natural disasters. Overall, prioritising cross-border co-operation and co-ordination is essential for effectively addressing the interconnected challenges of infrastructure resilience in the context of Mozambique's interconnected hydrographic basins and shared borders with neighbouring countries.

United States: Fargo-Moorhead Flood Diversion Project

The implementation of the Fargo-Moorhead flood diversion project was driven by the urgent need to address the significant and recurring threat posed by flooding in the region. It represents a critical investment in the region's long-term resilience to flooding, aiming to safeguard lives, protect property and critical infrastructure, and promote sustainable development and economic prosperity in the area and its surrounding communities. By pooling together resources and expertise from multiple stakeholders (federal, state, local and private sector), the project was able to overcome financial and technical challenges and began construction in 2022. The project is the first flood management project in North America to use a PPP model and is expected to be operational by early 2027.



The Fargo-Moorehead metropolitan area is one of the most flood-prone regions in the United States

The United States is highly exposed to natural disaster risks due to its diverse geographical and climatic conditions:

- The country is susceptible to hurricanes along its Atlantic and Gulf coasts, with states like Florida, Louisiana and Texas particularly vulnerable. These powerful storms bring strong winds, heavy rainfall, storm surges and flooding, causing widespread damage to infrastructure, businesses and communities.
- The United States is prone to earthquakes, with seismic activity concentrated along the Pacific Coast, notably in California. Earthquakes can result in structural damage, landslides and tsunamis, posing significant risks to populated areas.
- The country experiences tornadoes, especially in the central region known as "Tornado Alley" where states like Oklahoma and Kansas face frequent tornado activity. These violent storms can devastate communities and cause loss of life, infrastructure disruption and property damage.

Within the United States, the Fargo-Moorhead metro area stands out due to its susceptibility to flooding and extreme weather events. The Fargo-Moorhead metro area comprises Cass County, North Dakota and Clay County, Minnesota, which includes the cities of Dilworth, Minnesota, West Fargo, North Dakota and numerous other towns and developments from which residents travel daily for work, education and regular activities. Situated in the northern section of the Red River the metro area is prone to flooding, particularly during the spring thaw and periods of heavy rainfall (North Dakota State University, 2009[11]).

Its vulnerability stems from a combination of factors, including its location in the northern section of the Red River, the flat topography of the surrounding area and the river's low gradient. Additionally, ice melting from southern regions contributes to ice jams along the river, exacerbating flood risks. Moreover, the region frequently experiences extreme precipitation events, a trend that has been intensifying since 1990. The Red River has exceeded the National Weather Service flood stage of 18 feet in 60 of the past 124 years (1902 through 2023), with seven of the top ten floods occurring in the last 30 years. A 500-year event would flood nearly the entire city of Fargo, a large portion of the city of Moorhead and several smaller communities in the area. Flooding occurs not only from the rivers but also from large rainfall events that

overwhelm storm drainage systems. Average annual flood damages are estimated at approximately USD 238 million. Although emergency flood fights have been very successful, the area has a significant risk of catastrophic flooding (USACE, 2023[12]).

The Fargo-Moorhead flood diversion project aims at increasing preventive capacities and reducing flood vulnerability in the metro area

The project's key objectives are:

- **To limit damage to homes, businesses and the regional transportation network.** The flood events in the area require emergency measures such as constructing levees along large portions of the Red River in the effort to retain floodwaters to prevent widespread damage to properties and transportation infrastructure. Businesses, residents, Federal agencies, and local and state governments each contribute to the flood fight, rescue and clean-up efforts which take significant financial and human resources. By managing spring snow melt and summer stormwater, the project is expected to protect 245 000 residents from excess stormwater flows.
- **To establish permanent flood protection for the region and reduce the risk of catastrophic events.** The project aims at reducing the risk of catastrophic flooding in the Fargo-Moorhead metro area, protecting critical infrastructure and assets, and safeguarding the lives and property of residents and businesses in the region. By constructing a comprehensive flood diversion system, the project aims at redirecting floodwaters away from populated areas and channelling them safely downstream, thereby minimising the risk of damage and disruption caused by flooding.

The recurrent flooding poses significant challenges to local communities, leading to disruptions in daily life, damage to homes and businesses, and substantial economic losses. Additionally, the reliance on emergency measures to combat flooding underscores the vulnerability of the area and the necessity for long-term, sustainable flood management solutions. These issues highlight the urgent need for effective flood mitigation measures to protect lives, properties and critical infrastructure in the Fargo-Moorhead metropolitan area.

The project is a large-scale flood reduction and mitigation initiative

The Fargo-Moorhead flood diversion project is a large-scale flood mitigation and management initiative with a total cost of about USD 3 billion.

The project involves the construction of a comprehensive flood diversion system designed to protect the region from the recurring threat of catastrophic flooding along the Red River and its surrounding tributaries. The project components include:

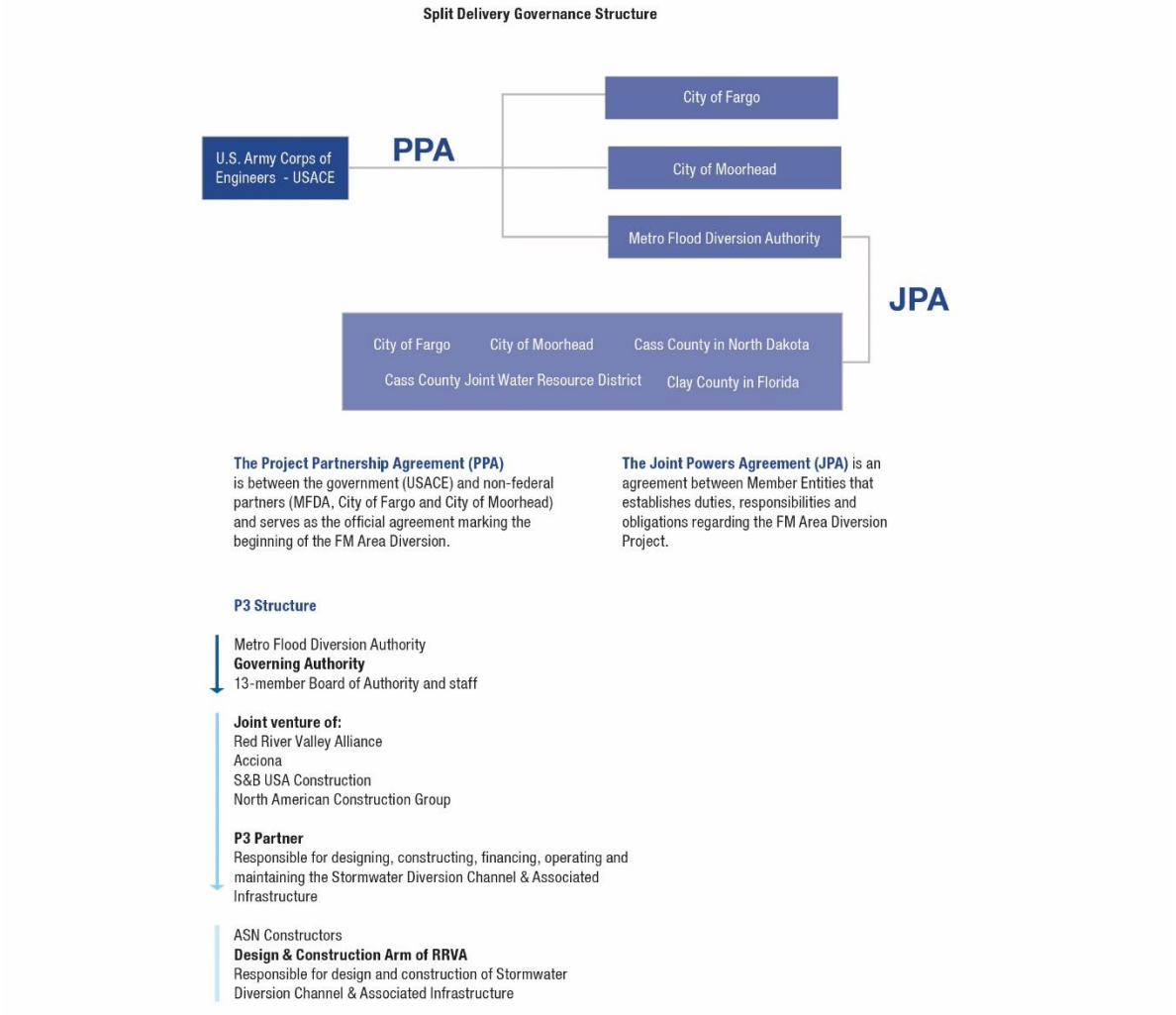
- **The diversion channel and transportation infrastructure** delivered through a public-private partnership (PPP). The primary component of the project is the construction of a 30-mile-long flood diversion channel along the Red River, which will serve to redirect floodwaters away from populated areas during periods of heightened flood risk. This diversion channel will be equipped with various control structures, such as gates and levees, to regulate the flow of water and minimise the risk of inundation in downstream communities.

  Since the construction of the diversion channel will disrupt the local road and rail network located along its 30-mile path, the project includes construction of new transportation elements including two pairs of interstate bridges, 12 county road bridges or crossings, 3 railroad bridges and a number of mixed-use trails along the channel that will be available for hiking after the project is completed.
- **Southern embankment with upstream water staging and storage** constructed by the United States Army Corps of Engineers (USACE). USACE is designing and constructing the 22-mile Southern Embankment and three large, gated control structures (USACE, 2023[12]).

- **In-town flood mitigation and stormwater management facilities** encompassing levees, floodwalls, stormwater lift stations, road enhancements, and grade raises in the cities of Fargo and Moorhead. These additional components of the project are strategically located to provide comprehensive flood protection to vulnerable areas within the Fargo-Moorhead metropolitan area and its surrounding environs.

The Fargo-Moorhead diversion project is a collaborative effort involving multiple stakeholders, including local, state and federal government agencies, as well as private sector partners and community organisations (Figure 3.7). USACE, as the lead agency responsible for the development of large flood management facilities in the United States, entered into a Project Partnership Agreement (PPA) with the local governments and the Fargo-Moorhead Metro Flood Diversion Authority (MFDA) to implement the project. MFDA contracted a private sector partner to implement the diversion channel and associated infrastructure. The project's development and implementation have been guided by extensive planning, engineering and environmental assessments to ensure its effectiveness, sustainability and compliance with regulatory requirements.

Figure 3.7. Project stakeholders and governance structure, Fargo-Moorhead project, United States



Note: PPA: Project Partnership Agreement. JPA: Joint Powers Agreement
Source: Authors' elaboration based on Fargo-Moorhead Metro Flood Diversion Authority (n.d.), FM Area Diversion Delivery Structure https://fmdiversion.gov/about/delivery/

Overall, the Fargo-Moorhead diversion project represents a critical investment in the region's long-term resilience to flooding, aiming to safeguard lives, protect property and critical infrastructure, and promote sustainable development and economic prosperity in the area and its surrounding communities.

Collaboration and co-ordination have been key to ensure project implementation and effectiveness

Among the several good practices of this project, the following two stand out: the effective collaboration and co-ordination across multiple stakeholders, which resulted in an effective project delivery strategy; and the community buy-in as reflected by the diverse funding and financing sources, with contributions of funding from federal, state, local, and capital markets for this capital-intensive project.

An innovative project delivery model was used that allowed the delivery of a large component of the project (the diversion channel and transportation infrastructure) to be outsourced to the private sector. The establishment of the MFDA by the local communities with its dedicated source of funding for flood management projects allowed MFDA to leverage its annual tax receipts and receive a loan that funded construction milestone payments to a private sector partner responsible for delivery of the diversion channel and the transportation infrastructure.

- **Stakeholder collaboration and co-ordination enabled by public-public and public-private partnerships**.
  - The communities of Fargo, ND and Moorhead, MN along with Cass County, ND, Clay County, MN, and the Cass County Joint Water Resources District established the Metro Flood Diversion Authority (MFDA) with the goal of reducing flood risk and damages for the stakeholder communities and counties by building and operating a flood diversion channel along the Red River.
  - MFDA and its members worked with USACE to develop the Fargo-Moorhead Metro Flood Risk Management Feasibility Study for the flood diversion channel project.
  - USACE and MFDA agreed to deliver the project as a "split delivery model" where USACE would retain the responsibility for the delivery of the Southern Embankment and associated infrastructure, MFDA would procure construction of the diversion channel as a PPP project and the cities of Fargo and Moorhead and local communities would spearhead the development and upgrade of the in-town flood mitigation infrastructure. MFDA selected the Red River Valley Alliance (RRVA), a PPP consortium to build the diversion channel and the associated infrastructure, including the transportation elements, under a long-term PPP contract. Under this contract RRVA will also operate the channel.
  - The project has been a high priority for local communities and organisations, cities and governments of the States of North Dakota and Minnesota as well as for USACE. Over time, the project expanded to encompass a network of over 50 organisations from both the public and private sectors. This diverse coalition included 20 utility companies and 30 federal, state, and local agencies, necessitating extensive co-ordination efforts.
  - To facilitate the project's implementation, 14 new pieces of legislation were enacted, along with the issuance of 200 permits containing over 2 000 conditions for monitoring purposes. Additionally, 70 memoranda of understanding/agreements were established among the participating entities (Build America Bureau, US Department of Transportation, 2023[13]).
  - The project's innovative approach allowed different components to be executed by distinct groups of partners, resulting in accelerated project delivery compared to traditional funding and financing methods (Metro Flood Diversion Authority, 2023[14]).
  - Collaboration between engineering and contracting teams has resulted in streamlined construction processes and the implementation of cutting-edge technologies, further reducing

costs. Overall, the mobilisation of the private sector fostered efficiency, innovation and cost reduction.

- Two federal agencies – the Environmental Protection Agency (EPA) and the US Department of Transportation's Build America Bureau played a pivotal role in providing low-cost and long-term financing to the project (Box 3.1). Federal government agencies' involvement in the project has been key in advancing the project implementation and overcoming key challenges related to project funding and financing.

Box 3.1. Federal long-term and low-cost project financing sources

Build America Bureau: DOT's lender for transportation projects

The Build America Bureau (the Bureau) was established in 2016 as part of the US Department of Transportation (USDOT) with the primary goal of facilitating transportation infrastructure investment in the United States. The Bureau was created to serve as a centralised hub for project finance in the US transportation sector. Its mandate encompasses a wide range of responsibilities including providing low-cost, long-term financing with flexible repayment terms to eligible projects, promoting innovative financing solutions, fostering public-private partnerships (PPPs), and accelerating the delivery of infrastructure projects across the country.

The Bureau also provides grants and technical assistance and financial expertise to federal, state and local government agencies, as well as private sector entities, seeking to develop infrastructure projects. The Bureau plays a crucial role in promoting best practices and knowledge sharing in infrastructure development. By disseminating information on successful projects, financing mechanisms and policy frameworks, the Bureau helps build capacity and foster collaboration among stakeholders, driving innovation and excellence in infrastructure development nationwide.

The Bureau provides project finance assistance via its three key programmes:

- **Transportation Infrastructure Finance and Innovation Act (TIFIA)**: this programme provides loans for surface transportation and public infrastructure.
- **Railroad rehabilitation and improvement financing (RRIF):** this programme provides loans for passenger, freight, and commuter rail and transit-oriented development.
- **Private activity bonds**: this programme provides allocations of private activity bond (PAB) authority to qualified surface transportation and transfer facilities that allow public-private partnership (PPP) projects to access lower cost ("tax-exempt") financing than the cost of a taxable bond.

Water Infrastructure Finance and Innovation Act (WIFIA) programme: EPA's lender for water projects

The WIFIA programme is a federal credit programme administered by EPA for eligible water and wastewater infrastructure projects. The WIFIA programme was modelled after the successful TIFIA programme administered by the Build America Bureau. The WIFIA programme's mission is to accelerate investment in the US water and wastewater infrastructure by providing long-term, low-cost financing with flexible repayment terms to creditworthy water and wastewater projects of national and regional significance.

The US Federal Government's lending through the TIFIA, RRIF and WIFIA programmes allows critical infrastructure projects to access long-term financing at affordable interest rates comparable to the US Treasury securities rates. The state and local governments can pledge their annual tax revenues as a repayment source for the loans, thus accelerating delivery of their infrastructure projects. US DOT also recognises the important role of the private sector in transportation infrastructure delivery. Both the

TIFIA and the Private Activity Bonds programmes, administered by the Build America Bureau, have also made a significant contribution to the development of the US PPP market by providing long-term financing at affordable rates for construction of large capital-intensive transportation projects.

Through its comprehensive approach to infrastructure investment, the Bureau has become a key driver of economic growth and prosperity, supporting job creation, enhancing connectivity and improving the overall resilience of the nation's infrastructure.

Table 3.3. The Build America Bureau in a nutshell

What does the Build America Bureau do?	
Financial assistance	**Technical assistance**
Flexible, low-cost, long-term credit assistance (loans, loan guarantees, and lines of credit) – USD 100 billion available for a wide range of projects; and tax-exempt bonds – USD 15 billion available for public-private partnerships.	Grants for project planning and development, community solutions and advisory services; and opportunities for training and education on the use of innovative project planning, financing and delivery techniques.
Major Build America Bureau programmes	
Name	**Details**
Transportation Infrastructure Finance and Innovation Act (TFIA) of 1998	Surface transportation and public infrastructure Airports can finance up to 33% of eligible project costs
Railroad rehabilitation and improvement financing (RRIF)	Passenger, freight, and commuter rail and transit-oriented development Finance up to 100% of eligible project costs
Private activity bonds	State/local governments issue tax-exempt bonds Private equity responsible for debt services Can be used alone or in combination with TFIA and RRIF
Key features of the Bureau's major programmes	
Highly customisable to meet borrower needs Borrowing of up to 33% of eligible project costs and up to 49% for rural, transit and TOD projects Long-term repayment period – up to 35 years Accrues interest when funds drawn Optional five-year deferral after completion No pre-payment penalty Also offer loan guarantees and lines of credit Low interest rate of 3.77% for 35-year loan as of 17/4/23	

Source: Authors' elaboration based on the presentation by Morteza Farajian, Executive Director, Build America Bureau, US Department of Transport at the 1st preparatory meeting for the Compendium of Good Practices on Quality Infrastructure - Thematic Focus: Increasing Infrastructure Resilience to Natural Disasters that took place on 18-19 April 2023.

- **Community buy-in and diversification of funding and financing sources**
  - Diversifying funding and financing sources was imperative due to the substantial cost of the project, totaling approximately USD 3 billion, which exceeded the capacity of local public stakeholders to raise independently.
  - A sound assessment of the cost of inaction – for instance, the estimated damages caused by the floods in 1997 alone amounted to USD 3.5 billion – provided a clear basis for different stakeholders' buy-in in joining forces to support the project. There was a clear economic imperative to act, and consensus among stakeholders was achieved regarding the necessity of investing in the project to avert even greater damages in the future. Transparent estimation of the cost of inaction, highlighting the urgency of the issues and underscoring the project's

significance was effectively shared among stakeholders, serving to mobilise a wide range of participants and facilitating consensus building.

- Effective collaboration and co-ordination among a diverse array of private and public stakeholders, as outlined previously, proved instrumental in mobilising the expertise needed to enhance the project's effectiveness and in diversifying the funding and financing sources to implement the project (Table 3.4)

Table 3.4. Collaboration has been key in diversifying and accessing funding and financing for the implementation of the Fargo-Moorhead flood diversion project, United States

Funding sources	Financing sources
Federal appropriations USD 750 million, USD 437 million of which was allocated by the Infrastructure Investment and Jobs Act of January 2022 State grants: North Dakota: USD 850 million Minnesota: USD 86 million **Local revenues** USD 1 514 billion. Local residents approved multiple sales tax initiatives to fund the project, including payments during construction, debt payments and availability payments to the PPP developer for the annual operations and maintenance of the project	In addition to the funding, the project benefits from financing, such as loans, that will be repaid over time using the sales tax revenues: – The US Environmental Protection Agency issued a USD 569 million Water Infrastructure Finance and Innovation Act Loan. The low 2.08% interest rate on the loan will save area taxpayers about USD 438 million over the life of the loan. – The North Dakota Public Finance Agency issued about USD 55 million in State Revolving Fund Loans. – The US Department of Transportation's Private Activity Bonds (PABs) allocation allowed project sponsors to issue USD 273 million in green bonds for the transportation elements of the project.

Source: Adapted from the presentation by Morteza Farajian, Executive Director, Build America Bureau, US Department of Transport at the 1st preparatory meeting for the Compendium of Good Practices on Quality Infrastructure - Thematic Focus: Increasing Infrastructure Resilience to Natural Disasters that took place on 18-19 April 2023.

- Time and cost savings achieved through a public-private partnership (PPP) have been significant. This groundbreaking flood management project, the first of its kind in North America, is expected to save approximately USD 330 million in construction costs and expedite project completion by a remarkable 10 years, reducing the timeline from 16 years to just 6 years. These substantial savings in both time and cost can be attributed to several key factors:
  - The Red River Valley Alliance (RRVA), the PPP consortium responsible for delivery of the diversion channel and transportation infrastructure elements have contributed innovative technical solutions that align with the requirements set forth by the Metro Flood Diversion Authority (MFDA).
  - The MFDA has secured a fixed-price bid from the RRVA, effectively transferring the risks associated with delays and cost escalations to the private sector.
  - Private equity investors, holding debt in the project, are incentivised to ensure timely and efficient project delivery in order to receive payment, thereby aligning their interests with the successful completion of the project.

- **Cost reduction and increased effectiveness through public-private partnerships.** In particular, PPPs entail the following benefits for this project:
  - MFDA retains ownership and control over operating standards and other requirements.
  - RRVA, as the private sector partner, delivers innovative technical solutions following MFDA standards and requirements.

- Engineers and contractors work collaboratively to lower construction costs and deploy new technology.
- MFDA receives a fix-price bid and RRVA assumes the risks of delay, cost escalation and other costs related to uncertainty.
- The private entity holds the debt responsible for repayment on the private activity bonds and it is incentivised to deliver the project in order to get repaid for its investment.

Conclusions

The seven concrete infrastructure projects discussed in this chapter exemplify different ways to address infrastructure resilience by implementing specific prevention, reaction and rebuilding efforts.

The seven case studies present elements of prevention efforts and showcase the importance of preventive measures. Three of the case studies – the building of a bulk power station in a flood prone area in Accra, Ghana, the life-cycle approach in the Metro Rapid Transport (MRT) project in Jakarta, Indonesia and the use of data and the update of standards to increase road network resilience in Mozambique – present good practices in reaction efforts, showing that effective reaction efforts in the aftermath of extreme weather events and/or natural disasters result also in augmented prevention capacities. Two case studies – the restoration of a degraded ecosystem for preventing flooding and preserving social and economic stability and development in Colombia and the use of digital technologies and strategic preventive maintenance in Japan – present good practices in rebuilding efforts in a forward-looking and comprehensive way. Two case studies exemplify the importance of preventive measures for road network stability in India and the United States, showing how data, technology and collaboration ensure effective actions.

Chapter 2 of this Compendium summarises the lessons learned from these case studies into seven actionable good practices and clarifies enabling conditions in developing countries. The seven good practices for building infrastructure resilience to natural disasters are:

- Adopting a life cycle approach
- Ensuring interests' alignment through effective collaboration
- Conducting risk assessment
- Monitoring and measuring impacts
- Investing in capacity building and knowledge management
- Carrying out strategic preventive maintenance
- Deploying cutting-edge technology and fostering new design and innovation

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