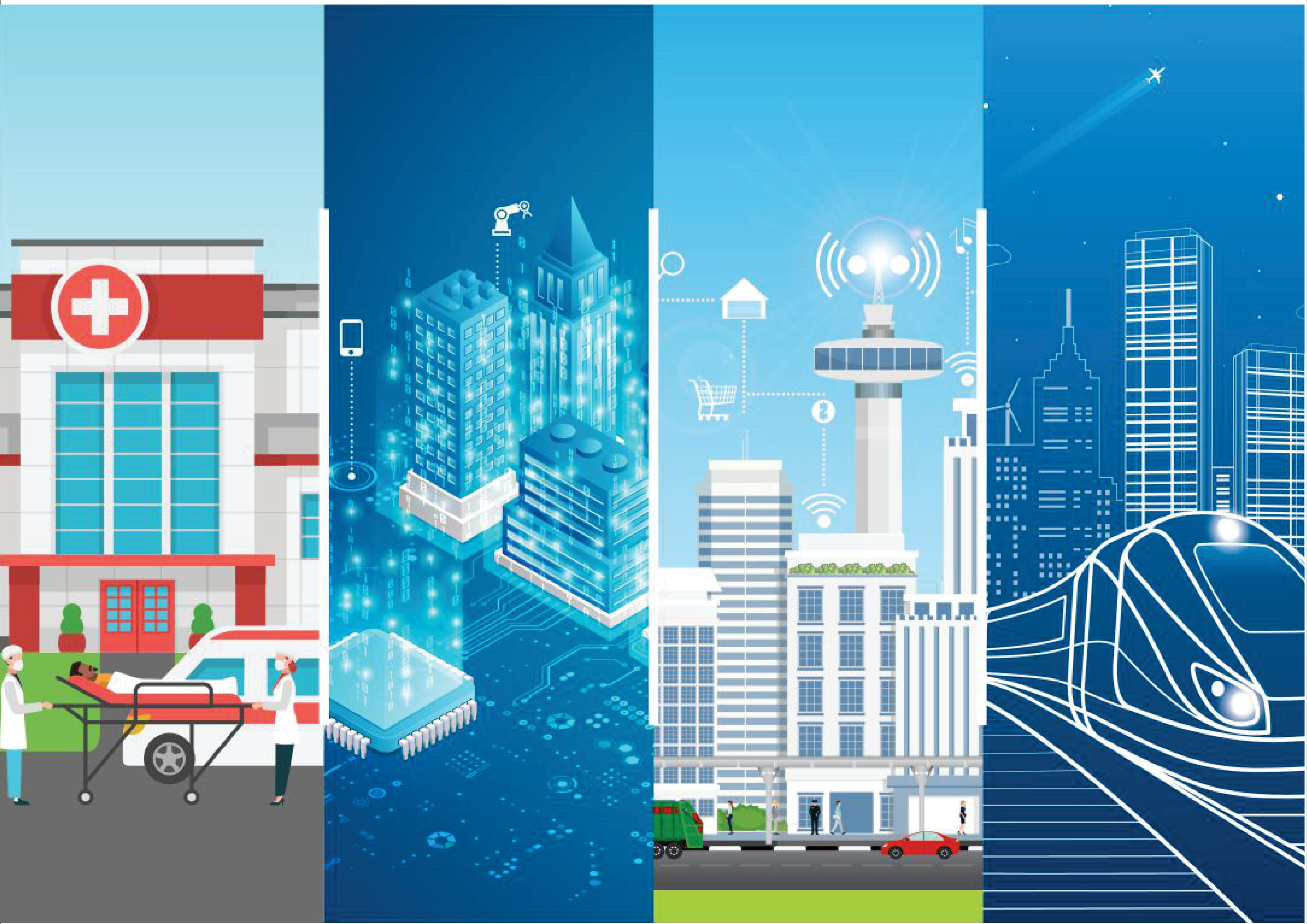
Mainstreaming Climate Adaptation for Creating Resilient Infrastructure

Technical Note

By **Vallary Gupta**
Under CDRI Young Professionals Programme



Coalition for Disaster Resilient Infrastructure

The Coalition for Disaster Resilient Infrastructure (CDRI) is a global multi-stakeholder partnership of national governments, UN agencies, programs, multilateral development banks financing mechanisms, private sector, academic and knowledge institutions. CDRI is committed to working with various stakeholders to promote the resilience of infrastructure globally.

CDRI Young Professionals Programme

CDRI hosts Young Professionals Programme as part of its overall strategy to address the challenges of building resilience into infrastructure systems and associated development globally. Under the guidance of identified mentors, the Young Professionals participate in the implementation of projects by contributing to methodological soundness, rigour, validation, and timely achievement of the goals of CDRI. The Young Professionals Programme is designed as an immersive learning experience to enable young professionals to pick up critical knowledge and skills for taking forward the disaster resilient infrastructure agenda through their professional journeys. Young minds from leading institutions across the globe gain a practical understanding of formulating and implementing initiatives that promote resilient infrastructure through their involvement in CDRI's programmes.

Contents

From the Director General's Desk

The increasing frequency and severity of extreme events and the resultant massive human and economic losses serve as a clarion call for the global community to collectively ensure the resilient growth of infrastructure. The Coalition for Disaster Resilient Infrastructure (CDRI) is a global multi-stakeholder partnership aiming to promote the resilience of new and existing infrastructure systems to climate and disaster risks in support of sustainable development and wellbeing of communities.

At CDRI, our knowledge initiatives are targeted at developing futuristic perspectives, practical strategies, cutting edge research and innovative solutions for promoting resilience of infrastructure. Youth are an important stakeholder in this mission. Towards the inclusion of this important group in the promotion of the disaster resilient infrastructure narrative, CDRI has launched initiatives such as Fellowships, Young Professionals Programme, and Internships to encourage young researchers to develop actionable solutions on disaster resilient infrastructure.

As part of the Young Professionals Programme, brilliant minds from some of the best institutions in the world have been selected to participate in an immersive learning programme. CDRI Young Professionals, under the guidance of their mentors, have been actively engaged in formulation and implementation of projects and programmes within CDRI as well as engaging with the emerging narrative on disaster resilient infrastructure.

I am pleased to present this knowledge product as part of a series of outputs emerging from the CDRI Young Professionals Programme (2021-22).

Sandeep Poundrik
Director General, CDRI

Executive Summary

Critical infrastructure systems underpin essential societal services and provide vital services like energy, water, transport and communications access. A single glitch in these services can result in debilitating impacts on an economy. Infrastructure systems are under increasing pressure from the rising frequency and intensity of disasters linked to climate change. This is further aggravated by the increasingly interdependent nature of infrastructure systems. The inter linkages influence the operational capability and resilience of the overall infrastructure. The need to create resilient infrastructure to withstand and respond to impacts of climate change is imperative.

This technical note seeks to build a case for ensuring infrastructure resilience to disasters by mainstreaming adaptation concerns in the foreseeable future. Since disaster risks in the next few decades will be largely defined by the combination of past actions and current trends, adaptation and mitigation are both needed to reduce risks of disruptions from climate change. The purpose of the note is to consolidate available literature on the significance of adaptation for disaster resilient infrastructure, specifically for climate change effects in terms of slow and rapid onset events. The note underscores the need for adaptation for tackling events here and now, and the importance of both mitigation and adaptation as a set of complementary actions to deal with foreseeable impacts of climate change.

Background

"Along with adequate measures to create the infrastructure that is resilient to climate change and services required to minimize risks and vulnerabilities in urban areas, with most of the world population residing in cities, adaptation can be the easiest and cost-effective option for creating disaster resilient infrastructure in cities" (Satterthwaite D. H., 2007).

Infrastructure is crucial to the functioning of the society and economy. It is an invaluable asset and a driving force for development (WBG, Climate Change Action Plan 2016-2020, 2016). Critical infrastructure services[1] like telecommunications, power, transport, and water and sanitation are central to daily activities. As much of the infrastructure around the world is under severe strain from rapid urbanization or is collapsing, aging, or simply absent, in addition to being under increasing pressure from natural hazards, huge amounts of investments in infrastructure are required to ensure continuity in service delivery.

As per the Global Infrastructure Outlook report, 2017, the cumulative value of global infrastructure investments over the entire forecasted period of 2016 to 2040 is estimated to be US$79 trillion. Climate change has worsened the issues (Filho, 2015) in the form of disasters like frequent storms, earthquakes, floods, and other extreme events (Benson, 2000). Disasters have resulted in huge economic losses globally, causing approximate $2.78 trillion in total damages[2] from 2000 to 2021 as per Emergency Events Database (EM-DAT). Global expected annual damages to road and rail from natural hazards range from $3.1 to 22 billion (E. E. Koks, 2019). The direct economic losses[3] over 2003 to 2012 from disaster situations were estimated to be $627 billion, an increase from $154 billion between 1993 and 2002 (UN, 2015). With these impacts and associated rapid and slow-onset disaster risks becoming a challenge, there is an urgent need for creating resilient infrastructure (WBG, 2019).

Effects of Floods and Storms on Infrastructure

EM-DAT recorded 7,348 disaster events between 2000 and 2019, which claimed a total of 1.2 million lives approximately. There were 367 disaster events each year on average and the majority of these were floods and storms. Floods form the most common type of disaster globally, accounting for 44 percent of total events and $617 million in damages from 2000 to 2020.

[1] *Critical infrastructure refers to essential services and assets that provide essential support for economic and social well-being, for public safety and for the functioning of key government responsibilities.*
[2] *A value of all damages and economic losses directly or indirectly related to the disaster.*
[3] *Direct economic losses include infrastructure losses.*

Storms, the second most common type of disaster events, account for $1.3 billion in total damages from 2000 to 2020 and form 28 percent of all events globally.

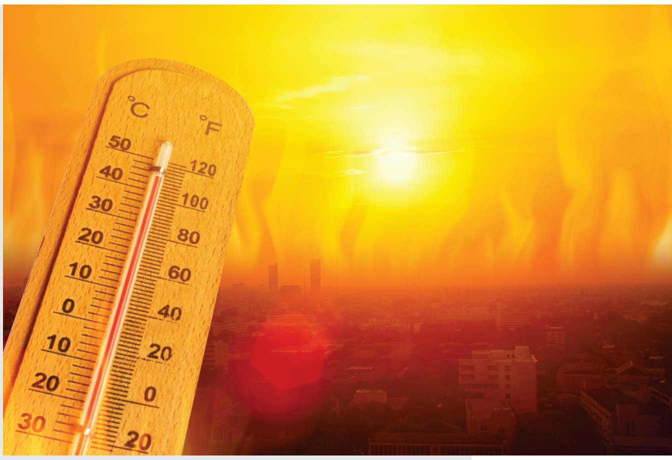
Sea level rise led by anthropogenic climate change combined with warmer ocean temperatures resulted in Hurricane Sandy causing $50 million in total damages. The storm impacted telecommunications services resulting in the loss of all services, high speed internet, and telephone (ITU, 2014). It knocked out roughly 25 percent of cell towers, causing power failures and rendering the backup systems sites inoperable. Telecommunication providers used diesel backup generators, fixed new batteries at cell tower sites and set up makeshift cell towers during the hurricane.

Excessive waters can also disrupt transport functions causing them to shut down. The Metropolitan Transportation Authority (MTA), New York based on its experience with Hurricane Irene, took preparatory actions. Before Hurricane Sandy made landfall on 29 October 2012, traffic was closed at major crossings, and ferry, flight and bus services were suspended. Subway ventilation grates vulnerable to flooding were sandbagged and tarped over (Sarah Kaufman, 2012).

Station entrances and ventilation grates in low-lying areas had been raised following lessons from past events. The storm caused no damage to the rolling stock and buses and some subway services were back in service within a week.

Despite the successes, there were unexpected challenges. Hurricane Sandy exposed the limits of the transportation infrastructure in New York City and nearby region. The storm inundated tunnels, rail yards and bus depots. The Central Transit's Rail Operations Center was engulfed in water, damaging the power backup systems, and the control system (Transit, 2012). In the aftermath of the hurricane, severe crowding on mass transit with limited services forced suspension of services across regions. It underpinned the significance of having multiple modes of transportation for moving people in and out of the city and surrounding region.

Effects of Extreme Temperatures on Infrastructure



Between 2000 and 2019, extreme events caused 13 percent of all disaster deaths across the globe and accounted for $44.6 million in total damages from 2000 to 2016, with the majority (91%) being the consequence of heat waves (UNDRR, Human Cost of Disasters, 2019). Longer and more intensive heat waves will cause an increased pressure on electrical grids, and unless properly managed, could worsen the impacts. It can affect and increase the risk of failure of power generation and transmission systems. This can amplify vulnerability as electricity supply ensures air conditioning and refrigeration – a significant adaptation strategy in developed countries (Sailor and Pavlova, 2003).

In addition to increased demand for electricity with rising temperatures, there is added risk of heat waves pressuring water resources and increasing the risk of droughts. Heat-related extreme events can also magnify infrastructure losses by affecting transport networks, damaging roads, rail tracks and building facades, resulting in rising seas which can threaten ports and coastal airports.

Climate change effects as discussed above can be categorized into slow-onset events (like rising temperatures) and rapid-onset events (like storms and floods). These events considerably impact infrastructure and result in loss and damage. The inter-linkages between infrastructure systems can influence the operational capability and resilience of the overall infrastructure. Even a single glitch in critical infrastructure services can create a ripple effect of indirect but costly impacts on an economy. There is, thus, an urgent need to create resilient infrastructure to withstand and respond to impacts of climate change.

Ensuring infrastructure resilience requires adaptation measures in the foreseeable future along with long-term mitigation actions. As less mitigation implies more climatic change and will subsequently require additional adaptation, climate mitigation cannot be seen as an alternative to adaptation. Mitigation and adaptation are rather a joint set of complementary actions to deal with climate change. Despite the mitigation measures, adaptation will be needed to allow communities and infrastructure to adapt to constantly changing climatic conditions. Average temperatures are likely to exceed the 2°C target of the Paris Agreement, and even if emissions cease today, past emissions will continue to produce climate change impacts for decades to come; the frequency and intensity of disasters will increase (UNDRR, Human Cost of Disasters, 2019), making adaptation to rapid and gradual climate changes inevitable.

As much of the existing stock may fail to withstand the changing climate and associated disasters, and climate change impacts will exacerbate and proceed even after success of mitigation in achieving the goal of stabilization (Thomas V. &., 2015)(Guha-Sapir, 2017), *the Coalition for Disaster Resilient Infrastructure (CDRI) believes that adaptation to climate change is inevitable and the only way forward to create infrastructure that is resilient to disasters.*

This note underscores the significance of adaptation for creating disaster resilient infrastructure and makes the case for investments into resilient infrastructure by referring to global examples. It provides a summary of the current discussions related to the theme of climate adaptation for a more resilient infrastructure. It dwells into the intersections of adaptation and resilience to provide evidence for the need to mainstream climate adaptation for creating resilient infrastructure.

The rest of the note is organized as follows – first, the concepts of resilience and resilient infrastructure are discussed; next, concepts related to adaptation are discussed; and finally, the linkages between resilience and adaptation are made in the context of disaster resilient infrastructure.

Understanding Resilience and Resilient Infrastructure

What is Resilience?

The concept of resilience has several definitions, defined in multiple fields, in different contexts. This note intends to focus on interpretation of resilience in terms of climate change and disasters. The United Nations International Strategy for Disaster (UNISDR) gives a suitable definition of resilience in the context of climate adaptation. It defines resilience as *"the ability of a system exposed to hazards to resist, absorb shocks and stresses (by reducing vulnerability, exposure, and increasing the system's coping and adaptive capacities), accommodate and continue maintaining functionality during an event and recover, learn and adapt in a timely and efficient manner through the preservation and restoration of its essential basic structures and functions."* Resilience can also be referred to as the magnitude of disruption that can be absorbed by a system before it changes its structure. The restoration and preservation can be understood in terms of infrastructure functions and the ability to retain its structure. It can involve both the ability to withstand as a shock and flexibility i.e., the ability to bounce back.

Resilience is also understood as a set of absorptive, adaptive and transformative capacities, giving a nuanced conceptualization in three dimensions – persistence for now, and response for future emergencies in incremental ways (Feng Mao, 2016).

Ratih, Dyah and Kusumastuti (2014) in their framework define resilience as *"the ratio between preparedness and vulnerability"*. It suggests that while higher preparedness will result in higher resilience, higher vulnerability will result in lower resilience. Vulnerability and preparedness are not alike and vary in their actions. For example, storing dry ration before disaster is part of community preparedness, while raising houses on stilts is an example of reducing a community's vulnerability to an anticipated disaster.

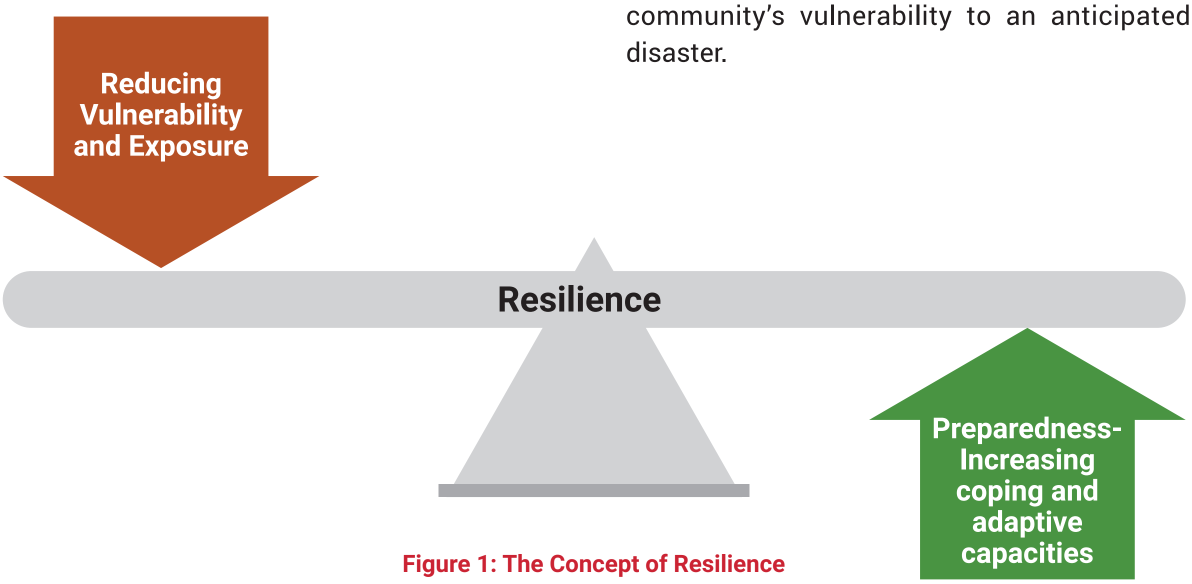


Figure 1: The Concept of Resilience

Source: Author-generated

Therefore, based on the above definitions, it can be said that *actions that reduce the vulnerability of infrastructure to disasters and enhance preparedness together help to create resilience* as shown in Figure 1. Resilience is achieved through a right balance of preparedness and vulnerability reduction.

The concept of resilience brings together both climate and disaster risks. Climate resilience incorporates disaster resilience as well as the capability to cope with longer-term climate changes that cause slow-onset events (DFID, 2013) (UNDP, 2011).

What is Infrastructure Resilience?

Resilience covers both 'physical and societal systems' that can be described through four 'R' principles: *robustness* i.e., inherent strength against external impacts without loss of functionality; *redundancy* i.e., properties that permit alternative choices and replacements under stress; *resourcefulness* i.e., the ability to mobilize desired resources when needed, and *rapidity* i.e., the speed to overcome disruption (Bruneau, 2007). These four principles in addition to others like safe failure, good governance, capacity to learn, information flows, and responsiveness make infrastructure resilient (Raphaelle Moor, 2015).

Infrastructure resilience can, therefore, be defined as "the ability of critical infrastructure systems, networks, and functions to withstand and rapidly recover from damage and disruption and adapt to changing conditions" (NIAC, 2010).

Repeated disasters due to climate change decelerate the development of infrastructure systems and diminish productivity of local economies (WBG, 2019). The 2019 Asia-Pacific Disaster Report (APDR) underscores that 30 percent of transport, 28 percent of energy, and 34 percent of information and communication technology (ICT) infrastructure is subjected to several hazards. Climate change associated disasters have thus highlighted the significance of resilient infrastructure for preventing huge losses as discussed and for protection against climate risks.

Adaptation for Creating Disaster Resilient Infrastructure

What is Adaptation?

The International Panel on Climate Change (IPCC) defines adaptation as an *"adjustment in natural or human systems to a novel or shifting environment or in response to actual or expected stimuli or their effects, which moderates harms or utilizes beneficial opportunities"*. It comprises efforts to reduce vulnerability and augment capacity through modifications and adjustments in systems.

It comprises an understanding of how systems can prepare by coping, adjusting, and transforming to adequately respond to changes in their environment. Adaptation focuses on safeguarding against negative impacts as well as developing resilience and taking advantage of any resulting benefits. It is about targeting disasters- *'here and now'*, dealing with current threats or preparing for a threat that lies in future or is not (yet) perceived as looming. For example: situating new airports on elevated sites, in areas that face major flood risks, is an adaptation measure that can reduce the risk of airport functioning failure (resulting from flooding) and make passenger and cargo mobility resilient to disasters. Unlike adaptation, *mitigation (efforts to reduce emissions and future climate changes) is significant to deal with causes of climate change*. Mitigation targets the root cause of the climate change problem and ensures long-term benefits, helping in reducing damages, and thus the costs of adaptation.

The New Strategy on Adaptation to Climate Change by European Union, 2021 suggests that adaptation and mitigation strategies can affect socio-ecological landscapes' vulnerability to climate change. W*hile mitigation efforts reduce contributions to climate change, adaptation responds to a changing climate by reducing its impacts*. Though both mitigation and adaptation have discernible synergies, they differ in what they mean and how they work (J., 2005) in terms of scale, both spatial and temporal. While mitigation attempts are large scale, propelled typically by national/international initiatives,

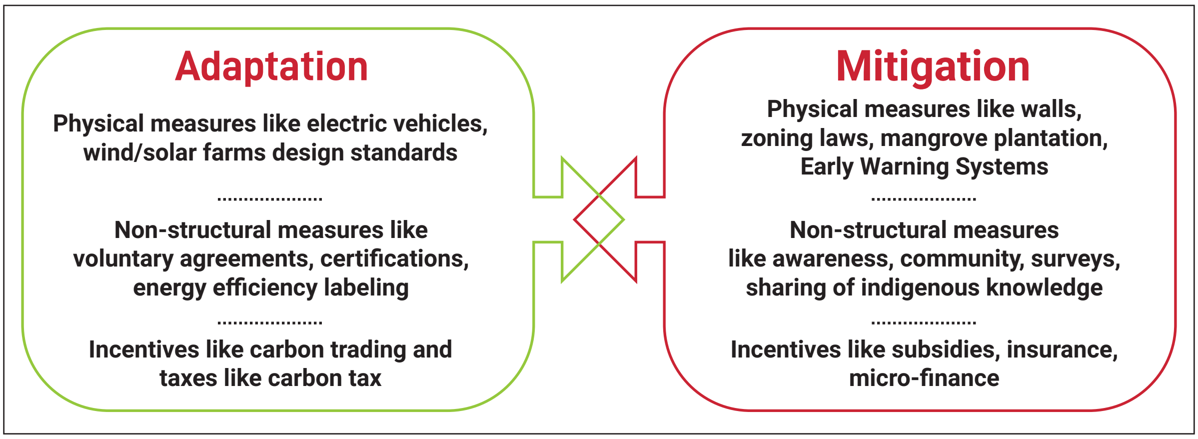


Figure 2: Adaptation and Mitigation for Climate Resilience

Source: Author generated based on (Calgary, 2018) adaptation measures are more local in nature, often in the range of local/regional economies (Mcevoy D., 2006).

Adaptation actions include large-scale infrastructure changes, like building coastal defences, heat insulation, revised standards, improved drainage or behavioural shifts like individuals using less water. Mitigation, on the other hand, aims at reducing the sources of these gases by increasing the share of renewable energies or enhancing sinks like size of forests. Measures can include changes like use of electric vehicles, energy audits, certifications, or economic instruments like carbon tax, congestion charges, subsidized loans etc. Both are important to create societies that are resilient to the threat of climate change and disasters (EU, 2021).

Creating Long-term Resilience - Role of Adaptation and Mitigation

Mitigation refers to efforts aimed at decreasing or eliminating greenhouse gas emissions from the atmosphere. It deals with the causes of climate change and is defined by Intergovernmental Panel on Climate Change (IPCC) as "the anthropogenic intervention to decrease the causes or enhance the sinks of greenhouse gases" (IPCC, 2014). Since mitigation targets the root cause of the climate change problem, it ensures long-term benefits, unlike adaptation which faces uncertainty as it is based on regional climate and impact projections.

Mitigation is essential (as a way to keep climate change moderate rather than extreme, i.e., within determined limits of the Paris Agreement and to not exceed the limits of communities and infrastructure to adapt) to make adaptation workable. Also, dependence on adaptation alone can result in a level of climate change to which effective adaptation may not be possible, or even if feasible, will remain available at high environmental, social, and economic costs (Hamin, 2009).

Mitigation activities can decrease but not eliminate disaster risk. The past consumption of fossil fuels and ensuing emissions are and will continue to amplify the vulnerabilities (UNDP, 2008). It is difficult to foresee how the climate will respond, to assess overall benefits and costs (or effectiveness) of policies, or to predict the socio-economic shifts that will occur. *Suspecting that mitigation measures may not prevent the harmful outcomes, investment in adaptation is inevitable to moderate the outcomes in long term* (Zemel, 2015).

How is Adaptation Related to Resilience?

Adaptation (in terms of coping, adapting, and transforming) is intricately linked to resilience specifically with regards to the capacities of resilience. The Department for International Development's BRACED Programme (Building Resilience and Adaptation to Climate Extremes and Disasters) supported under the United Kingdom's International Climate Fund has provided a framework for understanding diverse types of capacities to become resilient, which includes:

- Anticipatory capacity: The systems' ability to foresee disruptive events and reduce the impacts of climate variability through preparedness (early warning systems to provide timely alerts needed for preparedness or prior modification like raising houses on stilts).
- Absorptive capacity: The ability of systems to absorb, face and cope with the impacts of

climate using available skills and resources without changing function and structure (structures and systems like mangroves and forests conserved for protecting infrastructure).

- Adaptive capacity: The systems' ability to adapt to climate change risks, and to learn, and adjust and improve existing systems after a disaster (new building codes). It denotes the change in absorptivity capacity in response to external changes. It also defines resilience by shifting the tipping point and altering the desired attraction basin to make it wider or deeper. It does not necessarily improve the state of system.

- Transformative capacity: The ways in which capacity to adapt, anticipate and absorb shocks can be newly created, modified, and enhanced or intentionally changed to reduce the causes of risk and vulnerability. It may entail changing the stability landscape or creating a novel system by presenting new components (building dikes to supplement mangroves).

Transitions from Absorptive to Adaptive and Transformative Capacity

In event of any hydrological hazard, the anticipatory capacities will include timely evacuation of communities located near flood plains especially those living in un-serviceable (kutcha) structures. For communities living in serviceable (pukka) houses (which have improved capacity compared to kutcha houses) away from the flood plains, absorptive capacity in terms of structure and location will offer resilience to disaster. The absorptive capacity will support in maintaining the essential structure and function, thus, displaying improved resilience to disasters.

Adaptive capacity for both communities to stay persistent in face of upcoming disasters will include modifications like mangrove plantations or flood dikes, increased frequency of monitoring, retrofitting existing structures etc. It may increase in response to external changes (frequency and intensity of hazard) in an incremental way (planting mangroves- building durable houses following prescribed codes- building flood walls), thus enhancing the level of resilience offered. The final modifications with increasing intensity and frequency of disasters will entail transitions to a stable or to a new state. This can include communities abandoning settlements, moving away from flood plains or relocating to higher elevations.

Human subsystems are not the only factors that determine the resilience of socio-hydrological system. Human-water interactions may also affect it. For example, real-time monitoring of hydrological disasters enhances absorptive capacity. Water governance, as well as environmental knowledge and exchange can reinforce adaptive capacity. Transformative capacity can be enhanced by developing water-usage model or a water-dependent socio-economic structure (Wilson, 2013).

The Oxfam Framework for Resilient Development suggests that these capacities, which are overlapping and mutually reinforcing, are essential and need to be enhanced to achieve resilient development outcomes (Helen Jeans, 2017). It is very unlikely for an action to enhance one capacity in isolation (Helen Jeans, 2017). Alex Cornelius, 2018 suggests that ensuring absorptive capacity to build resilience contributes to fostering the longer-term adaptive and transformational capacity to climate change.

Based on these definitions, adaptations conceptualized as a sub-category of resilience and can be articulated as a combination of all four capacities. While resilience is a broader system property, adaptation is more narrowly focused on the adjustments, specific skills and mechanisms deployed to contribute to resilience.

It can, therefore, be said that adaptation actions decrease vulnerability and augment preparedness of infrastructure systems to cope, adapt and then transform in response to climate change and disasters, and thus enhance resilience. As intensity of shock or stress increases, the level of adaptation measure shifts from coping to adaptive to transformative. In response to the shifts in adaptation actions, the capacities of systems to stay resilient/enhance resilience also move from absorptive to adaptive to transformative as discussed in Figure 3.

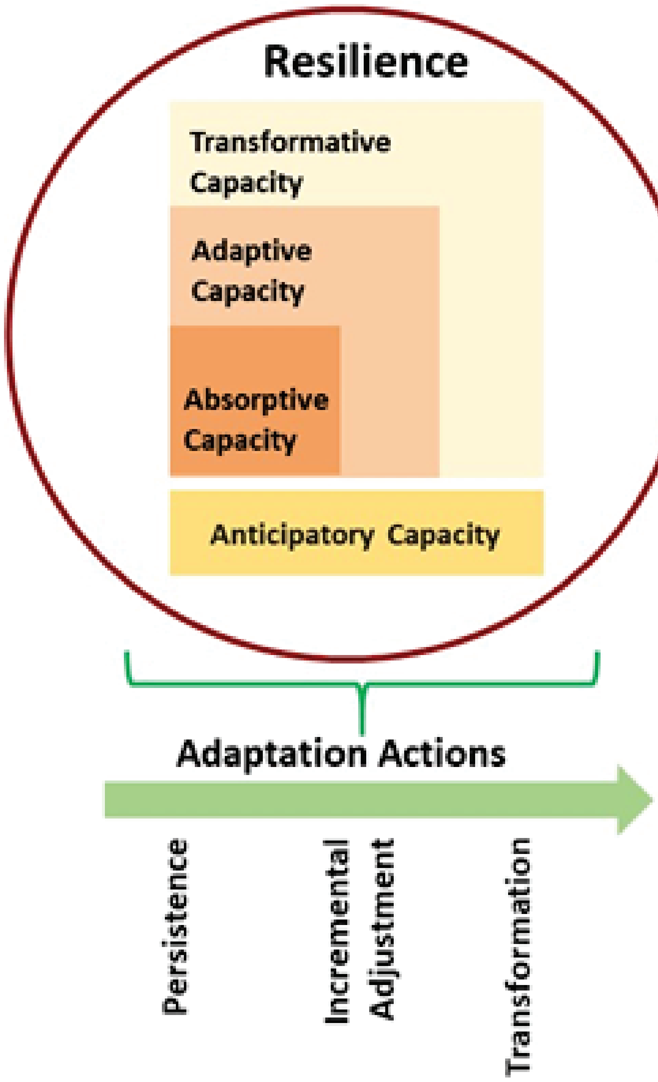


Figure 3: Understanding the Linkages between Adaptation and Resilience

Source: Author generated based on (Alex Cornelius, 2018)and (Ratih Dyah Kusumastuti, 2014)

Why Choose Adaptation for Resilience?

Mainstreaming adaptation across development initiatives stimulates resilient growth, preserves development gains, and helps prevent investments that enhance vulnerability (Summerlin, 2020).

Early and proactive adaptation actions can help promote resilient development by decreasing vulnerability and risks, thus reducing costs related to disaster losses (UN, 2015), and infrastructure repair (WBG, 2019). With the net benefit from climate-proofing existing infrastructure through adaptation being $4 for every $1 invested, these actions with low or no capital investments prove to be cost-effective and easy to implement.

Adaptation Offers Triple Dividend

A recent report of Global Commission on Adaptation (GCA) suggests that adaptation can offer a triple dividend: prevent economic losses, deliver positive gains, and provide added environmental and social advantages. As per GCA, the overall rate of return from investments made in improved resilience offer a benefit-cost ratio ranging between 2:1 and 10:1. An investment of $1.8 trillion globally from 2020 to 2030 can produce $7.1 trillion in total net benefits. Early warning systems reduce losses by saving lives and assets valued 10 times their cost. An advance 24 hours warning of a storm or heat wave can reduce the resulting damage by 30 percent. Mangrove forests can avoid $80 billion losses in a year from coastal flooding, protect communities, and contribute as much as $40–50 billion per year in gains associated with opportunities like eco-tourism, forestry, fisheries, and recreation. The advantages accruing from mangrove preservation and restoration can be up to 10 times its costs (GCA G. C., 2019).

Adaptation measures not only help in creating an economy resilient to the climate change effects but also offer several positive co-benefits. Also, not all adaptation measures involve investment or are costly. Sea walls guard against sea-level rise and protect against tsunamis (Frihy, 2001); improved building insulation helps mitigate energy usage and safeguards against heat (Sartori, 2007); more efficient use of water can yield benefits during times of water scarcity; reduced use of coal-fired power plants and shift to energy-conserving techniques can improve quality of air and lessen the health impacts (Burtraw, 2003).

The co-benefits resulting from adaptation measures over the years have exhibited a surge, surpassing mitigation co-benefits post-2019 (as shown in Figure 4). For the financial year 2018, the adaptation co-benefits were 49 percent of the total climate co-benefits, exhibiting a rising trend in its share of total co-benefits.

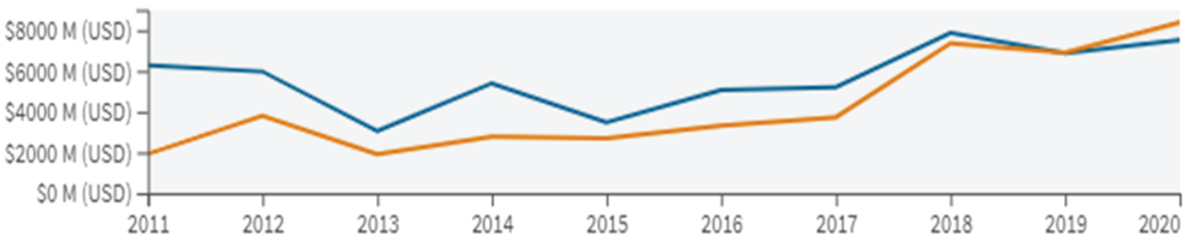


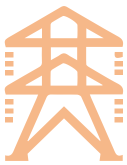
Figure 4: Co-benefits from Adaptation and Mitigation

Source: (WBG, 2020), (WBG, 2019)

Best Practices on Adaptation for Creating Infrastructure Resilience to Rapid-Onset Events

Several countries have looked at mainstreaming adaptation measures to build infrastructure that is resilient to climate change and disasters. Adaptation actions in terms of structural and soft policy measures for rapid-onset events are quite common. Table 1 lists selected examples from around the world to discuss existing adaptation measures for adjusting to rapid-onset events.

Table 1 : Global Best Practices on Mainstreaming Adaptation for Infrastructure Resilience to Rapid-Onset Events

Infrastructure	State/ Country	Adaptation Measures	Key Learnings
Telecommunications 	USA	▪ Replacing copper wire network with water-proof fibre optic cables ▪ Using portable or provisional base stations to provide network continuity and backup power sources ▪ Tailoring continuity of service plans based on the needs of localities ▪ Employing network management techniques for addressing congestion	Building resilient telecommunications networks through adaptation options can prevent disruptions in critical service in cases of power failures caused by disaster events. Adaptation measures can ensure continuity of telecoms which is essential for emergency responses and relief functions.
Transportation-Roads 	USA	Implementing contra flow- a reversible traffic operation that uses one or more travel lanes to move traffic in the opposing direction (TRB, 2017)	Contraflows can boost the directional capacity of a roadway instantly in time of a cyclone without extra time or cost to plan and construct extra lanes.
	Ontario, Canada	Amending existing city bye-laws to prevent the construction of reverse slope driveways (a driveway that leads down from a public street to a garage located below ground level) (Canada G. o., 2019)	Changes in existing standards/ codes/ bye-laws can prevent millions of dollars wasted in asset damages caused by climate change effects like flooding, heat, rains, etc.
Transportation - Railways 	Europe	▪ Repairing infrastructure to the similar specification as earlier or revised ▪ Incorporating climate change projections into drainage design ▪ Surveying track drainage for blockages ▪ Construction of further sub-surface drains in areas with constant flooding issue	Europe's response to flooding events not only permits the transportation network to resume operations after a flooding event but also helps to lessen the risk from future events. Constant and updated retrofitting measures can help enhance

Infrastructure	State/ Country	Adaptation Measures	Key Learnings
Power		▪ In case of reconstructing railway lines, prioritizing long-distance railways followed by local networks, stations, and remaining infrastructure ▪ Warnings to interrupt traffic operations before the event ▪ Flood protection walls or inflatable dams to contain water ▪ Relocating essential infrastructure to higher elevations and lower flood risk areas (David Jaroszweski, 2014)	resilience to similar and unforeseen events. Prioritizing major networks in the post-disaster phase can restore essential supply chains and help in allocating resources to places in urgent need.
	Austria	▪ Protective measures, such as dikes or debris sheds ▪ Railway weather information system - *infra*:*wetter* for monitoring of the network, to give updated forecasts and warnings for planning operations and taking precautions (like speed limits, pre-heating, track closures, etc.), and to schedule track repairs (UBIMET, 2005), (Adapt, 2017) ▪ Provides demand forecasts to users on important railway stations and critical points along tracks	Weather monitoring and early warning system services based on regional meteorology and railway tracks data is an effective solution to reduce risks from hazards like avalanches, torrential floods, and debris flows. It helps to prepare for anticipated shifts in the hazard intensity and frequency. The individualized and route-specific warnings to users and operators can inform decision making, thus enhancing the safety and resilience of infrastructure to disasters.
Power - Nuclear	France	System to review changes in climate (air and water temperatures), their concerns for structures, and components of nuclear power plants every five years (WBSCD, 2014)	Long-term high air temperatures can increase the temperatures of the river water (required for cooling) resulting in reduced power or shutdown of nuclear power plants. Projects to review system components can enable periodic modifications to ensure functioning despite the changing climate.

Infrastructure	State/ Country	Adaptation Measures	Key Learnings
	India	▪ Raising the floor level of buildings which house critical infrastructure ▪ Building flood levees around low-lying parts of the site ▪ Increasing drainage capacity and diverting cooling water pipes to access fresh water in case of saline intrusion (WBSCD, 2014)	Simple adaptation measures can be successful in preventing disruptions to power stations and lines and reduce vulnerability to floods in developing countries like India and Africa.
	South Africa	▪ Increasing elevation of substations and improving foundations ▪ Increasing distance between the coast and the substations/lines	
	USA	A Rapid Recovery Transformer is a modular transformer that reduces recovery time after a transformer has been broken during the event of a disaster. RecX design is a suitable alternative in an emergency for more than 90 percent of the transformers (WBSCD, 2014).	High-voltage transformers, the most susceptible components in a grid, take months to restore/ replace and are too large to transport. Modular transformers are easy to transport and can be up and running in less than a week. Considering infrastructure interdependencies, sustained electric supply can ensure the uninterrupted functioning of critical infrastructure.
Built Infrastructure 	Manitoba, Canada	▪ Structural works like raising buildings onto a raised foundation ▪ Capping wells on abandoned lots to prevent harsh weather effects ▪ Earthworks like constructing an earth dike around buildings, raising roads that could act as flood protection, terracing or raising the land immediately around homes (Manitoba, 2015).	Changes in existing standards/ codes/ bye-laws can prevent millions of dollars wasted in asset damages caused by climate change effects like flooding, heat, rains, etc. Financial assistance to flood-protect buildings through structural changes may not affect the current condition but could prevent further aggravation.

Source: Author's compilation from multiple sources

Nature-based Solutions for Creating Disaster Resilience

In addition to above-mentioned efforts for creating resilience to disasters, adaptation actions to achieve resilient development include nature-based solutions (NbS). The International Union for Conservation of Nature (IUCN) defines NbS as "actions to protect, sustainable manage and restore natural or modified ecosystems, which address societal challenges (e.g., climate change, food and water security or natural disasters) effectively and adaptively, while simultaneously providing human well-being and bio-diversity benefits" (IUCN, 2020). These solutions have emerged as a cost-effective mechanism to enhance long-term resilience. In the face of climate related-uncertainties, NbS can offer the ability to adapt to climate changes unlike permanent grey infrastructure[4] solutions.

Improving Natural Drainage to Increase Resilience to Floods in Mozambique

The coastal city of Beira, Mozambique has witnessed several instances of violent storms and recurrent flooding. The worsening effects of climate change has left assets and communities vulnerable to disasters.

As a part of its Mozambique Cities and Climate Change Project, the city has created urban parks to strengthen its resilience to floods by enhancing and safeguarding the natural drainage capacity of the Chiveve River. The rehabilitated storm water drainage system has reduced flooding risks by 70 percent. Other NbS include construction of a large water retention basin, rehabilitation of the riverbed and plantation of 2,200 mangrove trees in addition to rehabilitation/ construction of drainage canals, and installation of flood control stations.

The second phase will focus on creation of multi-purpose green infrastructure solutions like parks, public spaces, cycling paths, and overall landscape planning along the river.

Source: (SE, 2020)

Adaptation Measures for Slow-Onset Events

There is a lack of clarity regarding adequate adaptation measures to create resilience against slow-onset processes in contrast with extreme weather events (Laura Schäfer, 2021). Slow-onset processes are a predictable phenomenon unlike rapid-onset events which are not foreseeable, due to their frequency and intensity.

Timely adaptation measures can help build resilience against slow-onset processes. Adaptation Tipping Points (ATPs) can be a vital solution as they can help to ascertain the resilience and adaptation capacity of physical systems both under present or future policy regimes. The predictability of the effects from slow-onset events (on infrastructure) can help in determining ATPs (for infrastructure) and inform/re-inform adaptive actions. ATPs for slow-onset events take place over several centuries, giving more time to act and modify actions (Paul D. L. Ritchie, 2021).

[4]Grey infrastructure or hard infrastructure involves engineered assets that provide one or multiple services required by society, such as transportation or wastewater treatment (IISD, 2020).
Green infrastructure is the "strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services, such as water purification, air quality, space for recreation and climate mitigation and adaptation, and management of wet weather impacts that provides many community benefits" (UNISDR, 2017).

Achieving Resilience through Adaptation Tipping Points

United Nations Framework Convention on Climate Change (UNFCCC) defines ATP as “the point at which there is an abrupt change in an ecosystem quality, property, or phenomenon, or where small changes in one or more external conditions produce large and persistent responses in an ecosystem” (UNFCCC, 2012). *ATPs are infrastructure thresholds levels or physical boundary conditions where the acceptable economic, technical and spatial limits are surpassed (due to external changes) and the current infrastructure system fails and requires proactive adaptation actions* (Haasnoot M. H., 2009), (Kwadijk C. M., 2010), (Mastrandrea, 2010). These are the points at which an infrastructure system changes from one state to another. Limits to resilience are encountered when these thresholds are exceeded, creating challenges for adaptation. ATPs can give information about the amount of pressure a system can absorb, the acceptable limit for impacts, and the time/ point at which the limit will be reached (Farhana Ahmed, 2018).

For example, if sea levels increase more than a certain threshold, the coastal barriers will no longer work, and the resulting surge will substantially impact infrastructure systems like transport networks and power supply systems. The moment this shift occurs is known as ATP.

An infrastructure system may surpass a tipping point either due to a slow-moving variable or a sudden extreme event. Since adaptation actions vary as per the system in which they occur, and according to the climatic stimuli (slow or rapid) that stimulates them, the examination of tipping points can inform and re-inform the type of measures to prevent infrastructure losses caused by any climate change effect by either enhancing or restoring the level of resilience.

Adaptation Tipping Points in Practice- Case of the Netherlands

The ATP approach was first established in the Netherlands to evaluate water management strategies in Dutch case studies (Kwadijk J. C., 2010). The Delta Programme was introduced to provide protection from flooding and ensure adequate fresh water supplies in the face of climate change. The approach allowed to alter the adaptation strategy as per the changing knowledge of the climate change effects. It focused on identifying ATPs to identify sectors (like water supply, energy, shipping routes, etc.) that will continue to be effective irrespective of sea-level rise.

Determining these thresholds can help inform decisions and thus prevent cascading impacts (as outputs of one sector can act as a trigger to other sectors) and negative effects of climate change on infrastructure. For instance, the open shipping route might fail with a 90mm sea-level rise whereas the energy supply may hold until the end of the century highlighting the disaster resilience of the latter (Commission, 2010) (Jeuken A. t., 2010).

Conclusion

Climate change is one of the greatest risks facing humanity today, with far-reaching destructive impacts on people, infrastructure systems, environment, and economy. Extreme weather events have already caused nearly $2.78 trillion in economic losses over the last 20 years. The costs of climate change on the economy are clear and the toll on infrastructure is undeniable. *Accelerating the creation of resilient infrastructure is a human, environmental, and economic imperative that can no longer be overlooked and the need for which has now been globally reiterated.*

Since climate change and disaster risks in the next few decades will be largely defined by the combination of past actions and current trends, adaptation and mitigation are both needed to reduce risks of disruptions from climate change. Even if mitigation succeeds in achieving the global goal of stabilization, climate change will proceed. Adaptation is thus imperative to enhance preparedness by adjusting, reducing vulnerability and creating resilient infrastructure. Adaptation is inevitable to address the impacts of climate change and create resilient infrastructure, both in the short and long term. It is significant for preventing the cascading impacts of infrastructure damage/loss on resiliency of other infrastructure systems. However, adaptation efforts will require mitigation. Climate change in an unmitigated world is likely to exceed the financial and adaptive capacities of systems to adapt in long term. Mitigation offers the potential to keep the threats (that yield impacts) at a moderate (adaptable) level. Risks are minimized in the scenario that combines both adaptation and stringent mitigation. Mitigating the threats and adapting to the changes and impacts already in progress to prevent losses to infrastructure systems will together result in success. *More the mitigation, lesser would be the impacts to adjust to, and thus, less the risks to prepare for. However, the greater the degree of adaptation, the less may be the impacts linked to any given degree of climate change.*

A coordinated effort both by developed and developing nations is needed to prioritize and strike a balance between mitigation and adaptation at various levels. Determining ATPs, developing standards, design retrofits, early warning systems etc. can help inform decision-making and provide flexibility to infrastructure operations. To adjust in a mitigated world, determining ATPs will be critical for updating systems and making infrastructure resilient to unforeseen events. Practices from across Europe and the USA highlight how technological innovations, timely warnings and preparedness, and mere modifications in design, standards and operations can make both existing and new infrastructure resilient to climate change effects and disasters.

Planning for resilient infrastructure through adaptation in combination with mitigation should overcome an inadequate infrastructure quality base and costs and technological challenges. Such an approach can create new resilient systems by building improvements/ retrofitting, local and regional governance structures, and protection and strengthening of critical infrastructure. With its immediate synergies with development, socio-economic benefits, scale and context-specific solutions, adaptation is a bankable option for creating disaster resilient infrastructure.

The impacts of climate change that will remain will affect both the developing and developed countries, impacting the least developed countries the hardest. Combined by an insufficient infrastructure and low adaptive capacity, adaptation planning and implementation will be an urgent issue for developing countries requiring international cooperation.

It is vital that guidelines and knowledge base for creating disaster resilient infrastructure be developed and promoted, ensuring that adaptation concerns as complementary to ongoing mitigation strategies are incorporated into infrastructure design. Adaptation and mitigation must go hand in hand to reduce the severity of climate warming and make it easier for communities and systems to adapt. Though not all climate change impacts can be minimized by adaptation and mitigation, not adapting will yield substantially greater losses and make it difficult for systems and communities to sustain.

Way Forward

Climate change is inevitable, and early adaptation efforts are prudent. Adaptation has largely been thought of as an issue of developing countries. However, the growing impacts of climate change are a clarion call for all nations, developing and developed, to collaborate on adapting to climate change and creating disaster resilient infrastructure. Adaptation calls for an evidence cost-benefit evaluation of adaptation measures, policy instruments, funding mechanisms and monitoring of these initiatives.

CDRI, as the global knowledge and solutions hub on disaster resilient infrastructure, can invest energies to explore on-ground implementation of adaptation and mitigation strategies for ensuring infrastructure resilience and practices that enable mainstreaming of climate adaptation. A review of global practices in terms of technological advances can facilitate the process; global examples that offer cases for constant review, monitoring, and maintenance of adaptation plans can be identified to improve the existing implementation processes.

The Coalition can support international efforts to ensure a more sustainable tomorrow. It can promote adaptation for creating resilience by playing an active role in strengthening institutions and human resources working in the domain. CDRI can promote collaborative research and build capacities to help government officials and institutions from its member countries become more conscious and be able to communicate more easily the adaptation measures needed for battling the current and future potential climate-related disasters.

"Adaptation is no longer an alternative to an increased effort to prevent climate change, but an essential complement to it. Failing to act on adaptation will result in a huge economic and human toll, causing widespread increases in poverty and severely undermining long-term global economic prospects"- Global Commission on Adaptation, 2019

Acknowledgements

I take this opportunity to express my profound gratitude and deep regards to my mentor Dr. Hem Dholakia for his support and guidance that helped me build the narrative. Also, I would like to express my sincere gratitude to Dr. Mona Anand for her exemplary monitoring and encouragement throughout the completion of the note. Their immense knowledge on the subject helped me develop an improved understanding of the topic and put the pieces together. I further extend my sincere gratitude to Ms. Aishwarya Pillai and Mr. Rajat Uchil, without whom the note would not have taken shape.

I also take this opportunity to express my sincere thanks to Dr. Parisa Kloss, Dr. Kampanart Silva, Dr. Sai Bhaskar Reddy and Dr. Sparsh Johari for taking the time to review this document and promptly sharing their invaluable inputs.

Getting through the technical note required more than technical support, and I must thank Rikza Imtiyaz and Pranjal Chavanke for their encouraging words and feedback during times of uncertainty. Their words helped me stay confident and persistent.

Vallary Gupta
CDRI Young Professionals Programme
(2021-22)

References

A, A.-H. (2006). Assessment of impacts, adaptation, and vulnerability to climate change in North Africa: food production and water resources. Project no AF 90. *Assessments of Impacts and Adaptations to Climate Change (AIACC).*

Aaheim, A. H. (2009). A Macroeconomic Assessment of Impacts and Adaptation of Climate Change in Europe. *CICERO Report 2009:06, Center for International Climate and Environmental Research.*

Adapt, C. (2017). *Building Railway transport resilience to Alpine hazards Austria.* Climate Adapt.

Ahmed, F. E. (2018). Tipping points in adaptation to urban flooding under climate change and urban growth: the case of the Dhaka megacity.

Akbari, H. M. (2001). Cool surfaces and shade trees to reduce energy use and improve air quality in urban areas. . *Solar Energy, 70(3), 295-310.*

Alex Cornelius, C. B. (2018, November 7). *Is my social protection programme 'shock-responsive' or 'adaptive'?* Retrieved from itad: https://www.itad.com/article/is-my-social-protection-programme-shock-responsive-or-adaptive/

Antonioni, G. S. (2009). Development of a framework for the risk assessment of Na-Tech accidental events. . *Reliability Engineering and System Safety, 1442-1450.*

Arumala, J. (2012). Impact of Large-Scale Disasters on the Built Environment. *Leadership and Management in Engineering.*

Arup. (2014). *City Resilient Framework.* Arup and Rockefeller Foundation.

ASCE. (2019, August). *America's Infrastructure Grades Remain near Failing.* Retrieved from https://www.asceAmerican Society of Civil Engineers: https://www.asceorg/templates/press-release-detail.aspx?id=24013

Baker, I. P. (2012). Local government response to the impacts of climate change: An evaluation of local climate adaptation plans. *Landcape and Urban Planning,* 127-136.

Bank, W. (2005). *Learning Lessons from Disaster Recovery: The Case of Mozambique. Disaster Risk Management Working Paper Series No. 12. Washington,* DC.: World Bank.

Bank, W. (2006). *Ethiopia: Managing Water Resources to Maximize Sustainable Growth. CountryWater ResourcesAssistance Strategy.* Washington, DC,USA: The International Bank for Reconstruction and Development / The World Bank.

Bank, W. (2011). *Disaster Risk Management Programs for Priority Countries.* Washington, DC: Global Facility for Disaster Risk Reduction.

Bank, W. (2012). Turn Down the Heat: *Why a 4° Warmer World must be Avoided.* Washington, DC: A Report for the World Bank by the Potsdam Institute for Climate Impact Research and Climate Analytics.

Bartzokas, A. J. (2010). *The RISKMED project: philosophy methods and products.* 1393-1401: Natural Hazards and Earth System Sciences.

Batrana, M. a. (2014). Climate Change Adaptation: An Overview on Challenges and Risks in Cities, Regions

Affected, Costs and Benefits of Adaptation, and Finance Mechanisms. *Handbook of Climate Change Adaptation*.

Becker, A. S. (2011). Climate change impacts on international seaports: knowledge, perceptions, and planning efforts among port administrators. *Climatic Change, 5-29*.

Benson, C. a. (2000). Developing countries and the economic impacts of natural. *Economics of Natural Disasters: a preliminary investigation*.

Biesbroek, R. &. (2009). The mitigation–adaptation dichotomy and the role of spatial planning. *Habitat International*, 230-237.

Birthal, P. S. (2011). An Economic Assessment of the Potential Benefits of Breeding for Drought Tolerance in Crops: A Case of Groundnut in India. *Research Bulletin No. 25, International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Andhra Pradesh, India, 36*.

Bollin, C. N. (2005). *Disaster Risk Management along the Rio Búzi. Case Study on the Background, Concept and Implementation of Disaster Risk, Management in the Context of the GTZ-Programme for Rural Development (PRODER).* Eschborn, Germany, 26 pp: German Gesellschaft für Technische Zusammenarbei, Governance and Democracy Division.

Bosello, F. C. (2010). Climate Policy and the Optimal Balance between Mitigation, Adaptation and Unavoided Damage. *Climate Change Economics*, 71-92.

Bourrelier, P. B. (2000). IDNDR objectives: French technical sociological contributions. *Natural Hazards Review*, 18-26.

Boyd, R. a. (2009). Extreme climate events and adaptation: an exploratory analysis of drought in Mexico. *Environment and Development Economics*, 371-395.

Bréchet, T. H. (2013). Adaptation and Mitigation in Long-term Climate Policy. *Environmental and Resource Economics*, 217-243.

Broad, K. a. (2000). The Ethiopia food crisis: uses and limits of climate Forecasts. *Science*, 1693-1694.

Bruneau, M. C. (2007). A Framework to Quantitatively Assess and Enhance the Seismic Resilience of Communities. Earthquake Spectra Engineering and Society, National Academy of Engineering. *The Bridge: Linking*, 733–752.

Burtraw, D. A. (2003). Ancillary benefits of reduced air pollution in the US from moderate greenhouse gas mitigation policies in the electricity sector and Management. *Journal of Environmental Economics*, 650-673.

Canada, G. o. (2019). *Emergency Management Strategy for Canada: Toward a Resilient 2030.* Ottawa, ON: Government of Canada. Retrieved from Public Safety Canada: https://www.publicsafety.gc.ca/cnt/rsrcs/pblctns/mrgncy-mngmnt-strtgy/index-en.aspx?wbdisable=true

Canada, H. (2010). *Communicating the Health Risks of Extreme Heat Events: Toolkit for Public Health and Emergency Management Officials.* Ottawa, Canada: Health Canada.

Carlos, J. a. (2014). Integrated assessment of climate impacts and adaptation in the energy sector. *Energy Economics*, 531-538.

Casassa, G. a. (2007). *Assessment of observed changes and responses in natural and managed systems. In: IPCC (ed) Climate change 2007: climate change impacts, adaptation, and vulnerability, chap 1. Cambridge University Press, Cambridge.* Cambridge: Cambridge University Press.

Chang, S. M. (2013). Toward Disaster Resilient Cities: Characterizing Resilience of Infrastructure Systems with Expert Judgments. *Society for Risk Analysis.* doi: https://doi.org/10.1111/risa.12133

Changnon, S. (2005). Economic impacts of climate conditions in the United States: past, present, and future – an editorial essay. *Climatic Change*, 1-9.

Choularton, R. (2007). Contingency planning and humanitarian action: a review of practice.

Humanitarian Practice Network, 59.

Clarke, J. (1972). Some effects of the urban structure on heat mortality. *Environmental Research,* 5 , 93-104.

Commission, D. P. (2010). *Working on the delta. Investing in a safe and attractive Netherlands, now and tomorrow.* . Ministry of Transport, Public Works and Water Management, Ministry of Agriculture, Nature and Food Quality, and Ministry of Housing, Spatial Planning and the Environment.

COWI. (2012). *Skybrudsplan og strategi — Københavns kommune.* Copenhagen: Frederiksberg kommune.

CRED. (2009). E*M-DAT, Emergency Events Database Epidemiology of Disasters (CRED).* Retrieved from Centre for Research on the Epidemiology of Disasters (CRED): www.emdat.be/.

Cruz, A. a. (2013). Vulnerability of the oil and gas sector to climate change and extreme weather events. *Climatic Change*, 41-53.

Da Silva, J. B. (2004). Improving epidemic malaria planning, preparedness and response in Southern Africa. *Malaria Journal,* 37.

David Jaroszweski, A. Q. (2014). *Guidebook for Enhancing Resilience of European Rail Transport in Extreme Weather Events.* MOWE- IT and European Commission.

De. Bruin, K. D. (2009). AD-DICE: an implementation of adaptation in the DICE model. *Climate Change,* 63-81.

DEFRA, D. F. (2006). *The UK Climate Change Programme 2006.* Defra, London, 2006.

DFID. (2013). *Embedding Disaster Resilience Lessons Review, CHASE.* Crown Copyright.

Duan, H. Z. (2019). Integrated benefit-cost analysis of China's optimal adaptation and targeted mitigation. E*cological Economics,* 76-86.

Duana, H. Z. (2019). Integrated benefit-cost analysis of China's optimal adaptation and targeted mitigation. *Ecological Economics,* 76-86.

Dyson, L. a. (2001). The heavy rainfall and floods over the northeastern Interior of South Africa during February 2000. . *South African Journal of Science,* 80-86.

Ebinger, J. a. (2011). *Climate Impacts on Energy Systems: Key Issues for Energy Sector Adaptation.* Washington, DC, USA: The International Bank for Reconstruction and Development /The World Bank and Energy Sector Management Assistance Program (ESMAP), The World Bank.

Edenhofer, O. R.-M. (2011). *IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation.* Cambridge: Cambridge University Press.

EEA, E. E. (2013). *Adaptation in Europe.* Copenhangen: European Union.

EU. (2021). *Forging a climate-resilient Europe - The new EU Strategy on Adaptation to Climate Change.* European Commission.

Evans, C. G. (2020). *Building Resilient Infrastructure Systems.* Economic Effects of Infrastructure Investment and its Financing.

Fawzy, S. O. (2020). Strategies for mitigation of climate change: a review. *Environmental Chemistry Letters,* 2069-2094.

Fieser, E. (2011). Hurricane Irene barrels toward US as Caribbean Islands take stock of damage. *Christian Science Monitor.*

Filho, W. (2015). *Handbook of Climate Change Adaptation. Springer.*

Folke, C., Carpenter, S., Walker, B., Scheffer, M., Chapin, T., & Rockström, J. (2010). Resilience thinking: Integrating resilience, adaptability and transformability. *Ecol. Soc. , 20–28.*

Forzieri, G. B. (2018). Escalating Impacts of Climate Extremes on Critical Infrastructures in Europe. *Global Environmental Change,* 97–107.

Freeman, P. a. (2001). *Vulnerability of Infrastructure to Climate Variability: How Does this Affect Infrastructure Lending Policies?* Washington, DC.: World Bank and ProVention Consortium.

Frihy, O. (2001). The necessity of environmental impact assessment (EIA) in implementing coastal projects: lessons learned from the Egyptian Mediterranean Coast. *Ocean & Coastal Management,* 489-516.

Fussel H-M, K. R. (2006). Climate change vulnerability assessments: an evolution of conceptual thinking. *Climate Change,* 301-329.

Füssel, H. (2007). Adaptation planning for climate change: Concepts, assessment approaches, and key lessons. *Sustainability Science,* 265-275.

Gabrielsen, K. T. (2005). *Climate Change-Lower Electricity Prices and Increasing Demand: An Application to the Nordic Countries*. Kongsvinger, Norway: Discussion Paper No. 430, Statistics Norway, Research Department.

Gallego-Lopez, C. E. (2016). *Introducing Infrastructure Resilience.* Department for International Development, UK.

García, A. R. (2006). *Características e impacto socioeconómico de los huracanes "Stan" y "Wilma" en la República Mexicana. Mexico: Secretaria de Gobernación, Centro Nacional de Prevención de* Desastres.

GCA, E. C. (Global Commission on Adaptation). *Infrastructure background paper for Global Commission on Adaptation.*

GCA, G. C. (2019). *ADAPT NOW: A GLOBAL CALL FOR LEADERSHIP ON CLIMATE RESILIENCE.* Global Centre on Adaptation, World Resources Institute.

GFDRR. (2015). *Bringing Resilience to Scale.* Global Facility for Disaster Risk Reduction.

GoB, G. o. (2008). *Cyclone Sidr in Bangladesh: Damage, Loss and Needs Assessment for Disaster Recovery and Reconstruction.* Dhaka, Bangladesh.: Government of Bangladesh.

GoB, G. o. (2014). *Bangladesh Delta Plan 2100 Formulation Project: Inception Report. Dhaka:* Government of Bangladesh.

Golombek, R. S. (2011). Climate change: impacts on electricity markets in Western Europe. *Climatic Change,* 357-370.

Grey, D. a. (2007). Sink or swim? Water security for growth and development . *Water Policy,* 545-571.

Guha-Sapir, D. H. (2017). *Annual Disaster Statistical Review* . Centre for Research on the Epidemiology of Disasters (CRED).

Haasnoot, M. H. (2009). A method to develop sustainable water management strategies for an uncertain future. *Sustainable Development.*

Haasnoot, M. K. (2012). *Designing adaptive policy pathways for sustainable water management under uncertainty: Lessons learned from two case.* Third international engineering system symposium. CESUN 2012, Delft University of Technology .

Haasnoot, M. M. (2012). Exploring pathways for sustainable water management in river deltas in a changing environment. *Climate Change.*

Habib, A. S. (2012). *The Bangladesh Cyclone Preparedness Program: A Vital Component of the Nation's Multi hazard Early Warning System*. Berlin: Institutional Partnerships in Multi hazard Early Warning Systems.

Haile, M. (2005). Weather patterns, food security and humanitarian response in sub Saharan Africa. . *Philosophical Transactions of the Royal Society* B, 2169-2182.

Hamin, E. &. (2009). Urban form and climate change: Balancing adaptation and mitigation. *Habitat International 33*, 238-245.

Hansen, J. S. (2011). Review of seasonal climate forecasting for agriculture in sub-Saharan Africa. *Experimental Agriculture,* 205-240.

Hegerl, G. a. (2007). *Understanding and attributing climate change.* Cambridge University Press, Cambridge: In: IPCC (ed) Climate change 2007: the physical science basis, chap 9.

Hellmuth, M. A. (2007). Climate Risk Management in Africa: Learning from Practice. *International Research Institute for Climate and Society, Columbia University.*

Hjort, J. K. (2018). Degrading Permafrost Puts Arctic Infrastructure at Risk by Mid-century. *Nature Communications.*

Hope, C. A. (1993). Policy analysis of the greenhouse effect: An application of the PAGE model. *Energy Policy,* 327-338.

Hughes, G. P. (2010). The costs of adaptation to climate change for water infrastructure in OECD countries. *Utilities Policy*, 142-153.

HULME M., *J. G. (2002). Climate Change Scenarios for the 21st Century for the UK (UKCIP02)*. UKCIP, Oxford.

IFRC. (2009). *World Disasters Report 2009 – Focus on Early Warning and Early Action. Geneva,* Switzerland: International Federation of the Red Cross and Red Crescent Societies.

IPCC. (2013). *Climate Change 2013: The Physical Science Basis. Summary for Policymakers.* Working Group I Contribution to the IPCC Fifth Assessment Report.

IPCC. (2014).: *Summary for policymakers. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the IPCC. Cambridge, United Kingdom and New York, NY, USA, pp. 1-32.: Cambridge University Press.*

IPCC. (2014). *Climate Change 2014: Synthesis Report.* Geneva, Switzerland: Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.

IPCC. (2014). *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Geneva, Switzerland.*

J., W. T. (2005). Issues in developing a capacity for integrated analysis of mitigation and adaptation. *Environmental Science and Policy,* 541–547.

Jeuken, A. a. (2011). *Short-term decision making and long-term strategies: how to adapt to uncertain climate change.* Examples from the Thames Estuary and the Dutch Rhine-Meuse Delta, Water Governance 1.

Jeuken, A. t. (2010). *On the use of water scenarios in the Dutch Delta Programme.* Veranstaltungen, Deltares: Bundesanstalt für Gewässerkunde.

K, M. A. (2007). Climate or development: is ODA diverted from its original purpose? *Climatic Change.*

Kabat, P. H. (2003). *Climate Changes the Water Rules: How Water Managers can cope with Today's Climate Variability and Tomorrow's Climate Change. Dialogue on Water and Climate (DWC).* Wageningen, Netherlands: International Secretariat of DWC.

Kelly, S. (2015). Estimating economic loss from cascading infrastructure failure: a perspective on modeling interdependency. *Infrastructure Complexity.*

Kemp, R. a. (2004). Managing the transition to *sustainable mobility. sustainable mobility to sustain ability: theory, evidence and policy,* 137-167.

Kern, F. a. (2008). Restructuring energy systems for sustain ability? Energy transition policy in the Netherlands. *Energy Policy,* 4093-4103.

Kinzig, A. P. (2006). Resilience and regime shifts: assessing cascading effects. *Ecology and Society VOL 11.*

Kirshen, P. K. (2008a). Climate change and coastal flooding in Metro Boston: impacts and adaptation strategies. *Climatic Change,* 453-473.

Kirshen, P. M. (2008b). Interdependencies of urban climate change impacts and adaptation strategies: a case study of Metropolitan Boston USA. *Climatic Change,* 105-122.

Klein, R. J. (2007). Inter-relationships between adaptation and mitigation. Fourth Assessment Report of the Intergovernmental Panel on Climate Change.

Klein, R. M. (2014). Adaptation opportunities, constraints, and limits. Climate change 2014: Impacts, adaptation, and vulnerability. *Contribution to Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change,* 899-943.

Koks, E. R. (2019). A Global Multi-hazard Risk Analysis of Road and Railway Infrastructure Assets. *Nature Communications.*

Kron, W. a. (2007). *Flood disasters and climate change: trends and options a (re-)insurer's view.* Wissenschaftliche Auswertungen, Hamburg, Germany: In: Global Change: Enough Water for All?

Kwadijk, C. M. (2010). Using adaptation tipping points to prepare for climate change and sea level rise: a case study in the Netherlands. *Wiley Interdisciplinary Reviews: Climate Change,* 729-740.

Kwadijk, J. C. (2010). Using adaptation tipping points to prepare for climate change and sea level rise: a case study in the Netherlands. *Wiley Interdisciplinary Review: Climate Change Vol 1*, 729-740.

LA Reis, M. T. (2016). Assessing INDCs in China, India, and developing Asia: An application of the WITCH model. *FEEM and CMCC working paper.*

Larsen, P. S. (2008). Estimating future costs for Alaska public infrastructure at risk from. Climate Change. Global Environmental Change, 442-457.

Laura Schäfer, P. J. (2021). Slow-onset Processes and Resulting Loss and Damage – An introduction. Bonn, Germany: Germanwatch.

Lesnikowski, A. F.-F. (2016). National-level progress on adaptation. *Nature Climate Change*, 261-264.

Lewis, J. a. (1996). *yclone-resistant domestic construction in Bangladesh.* Dhaka: Implementing Proceedings of Hazard-Resistant Housing: Proceedings of the First International Housing and Hazards Workshop to Explore Practical Building for Safety Solutions.

Manitoba, G. o. (2015). *Individual Flood Protection Initiative.* Manitoba, Canada: Government of Manitoba.

Mastrandrea, M. N. (2010). Bridging the gap: linking climate-impacts research with adaptation planning and management. *Climatic Change,* 87-101.

Mcevoy D., H. J. (2006). Climate Change and the Visitor Economy: Challenges and Opportunities for England's Northwest. *Sustainability Northwest, Manchester and UKCIP, Oxford.*

McEvoy, D. L. (n.d.). Adaptation and mitigation in urban areas: synergies and Conflicts.

Meehl, G. a. (2007). *Global climate projections. In: IPCC(ed) Climate change 2007: the physical science basis, chap 10.* Cambridge: Cambridge University Press.

Mike Hulme, H. N. (2009). *Adaptation and Mitigation Strategies. Supporting European Climate Policy. The Final Report from the ADAM Project. Norwich, U: Tyndall Centre for Climate Change Research,* University of East Anglia.

Mogaka, H. S. (2006). *Climate Variability and Water Resources Degradation in Kenya: ImprovingWater Resources Development and Management. World Bank Working Paper No. 69*. Washington, DC, USA: The International Bank for Reconstruction and Development/ The World Bank.

Mogelgaard, K. A. (2018). *Integrating Adaptation into Social and Economic Development: Insights from Some "Early Movers". Rotterdam and Washington:* Global Centre on Adaptation.

MonicaDi Gregorio, D. R. (2017). Climate policy integration in the land use sector: Mitigation, adaptation and sustainable development linkages. *Environmental Science & Policy,* 35-43.

Mozaharul Alam, F. G. (2014). *Adaptation Opportunities, Constraints, and Limits. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Cambridge, United Kingdom and New York, NY, USA:* Cambridge University Press.

Mozambique, R. o. (2006). *Master Plan for Prevention and Mitigation of Natural Disasters.* Maputo: Council of Ministers, Republic of Mozambique.

Mukheibir, P. (2013). Potential consequences of projected climate change impacts on hydroelectricity generation. *Climate Change,* 67-78.

Munich Re, M. R. (2005). *Weather Catastrophes and Climate Change: Is There Still Hope for Us?* Munich: Münchener Rückversicherungs-Gesellschaft.

Murray, V. G. (2012). *Case studies. Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change.* Cambridge: Cambridge University Press.

Nchito, W. S. (2007). Flood risk in unplanned settlements in Lusaka. *Environment and Urbanization Vol 19, No 2,* 539–551.

Nemry, F. a. (2012). *Impacts of Climate Change on Transport: A Focus on Road and Rail Transport Infrastructures.* Luxembourg: JRC Scientific and Policy Reports, European Commission, Joint Research Centre, and Institute for Prospective, Technological Studies, Publications Office of the European Union.

NIAC, N. I. (2009). *Critical Infrastructure Resilience. NIAC.*

NIAC, N. I. (2010). *A Framework for Establishing Critical Infrastructure Resilience Goals.* USA: National Infrastructure Advisory Council.

NRDC. (2017). *Ahmedabad Heat Action Plan 2017: Guide to Extreme Heat Planning in Ahmedabad, India.*

Nursey-Bray, M. a. (2012). Ports and climate change: building skills in climate change adaptation, Australia. . *Climate Change and the Sustainable Use of Water Resources, 273-282.*

OECD. (2014). Resilience to Major Floods. Seine Basin, Île-de-France.

OECD. (2018). *Climate-resilient Infrastructure.* OECD.

Owen, G. (2020). What makes climate change adaptation effective? A systematic review of the literature. *Global Environment Change.*

Parry, M. (2009). Closing the loop between mitigation, impacts and adaptation. *Climate Change, 23-27.*

Parry, M. C. (2007). *Climate change 2007: impacts, adaptation and vulnerability.* Cambridge: Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.

Patt, A. P. (2005). Effects of seasonal climate forecasts and participatory workshops among subsistence farmers in Zimbabwe. *Proceedings of the National Academy of Sciences, 102(35), 12623-12628.*

Paul, B. (2009). Why relatively fewer people died? The case of Bangladesh cyclone Sidr. . Natural Hazards, 289-304.

Peng, R. J. (2010). Toward a quantitative estimate of future heat wave mortality under global climate change. *Environmental Health Perspectives,* 119(5), 701-706.

Peters, G. M. (2013). The challenge to keep global warming below 2 °C. *Nature Climate Change,* 4-6.

Pielke, R. a. (2000). Precipitation and damaging floods: trends in the United States. *Journal of Climate.*

Policy, P. D. (2006). *Climate Change and Natural Disasters: Scientific evidence of a possible relation between recent natural disasters and climate change.* European Parliament.

Raphaelle Moor, *M. B. (2015). Disaster Risk Management in the Transport Sector.* GfDRR, World Bank, US.

Ratih Dyah Kusumastuti, V. Z. (2014). Developing a resilience index towards natural disasters in Indonesia. I*nternational Journal of Disaster Risk Reduction.*

Reason, C. a. (2004). Tropical Cyclone Eline and its unusual penetration and impacts over the Southern African mainland . *Weather and Forecasting,* 789-805.

Reeder, T. a. (2011). Ho*w do you adapt in an uncertain world? Lessons from the Thames Estuary 2100 project.* Washington DC: World Resource Report.

Rossetto, T. (2007). *Construction Design, Building Standards and Site Selection: Tools for Mainstreaming Disaster Risk Reduction.* Geneva: ProVention Consortium.

Russo, S. J. (2012). Neurobiology of resilience. *Nat. Neurosci.,* 1475–1484.

Ruth, M. a. (2007). Understanding and managing the complexity of urban systems under climate change. *Climate Policy,* 317-336.

Sartori, I. a. (2007). Energy use in the life cycle of conventional and energy 30 buildings: a review article. Energy & Buildings, 249-257.

Satterthwaite, D. (2007). *Adaptation Options for Infrastructure In Developing Countries. A report to the UNFCCC Financial and Technical Support Division.* Bonn, Germany: United Nations Framework Convention on Climate Change.

Satterthwaite, D. H. (2007). Adapting to climate change in urban areas: the possibilities and constraints in low- and middle-income nations. *Human settlement s discussion paper series, theme: climate change and cities – 1* (p. 48). International Institute for Environment and Development (IIED),.

Schipper, E. L. (2006). *Conceptual history of adaptation in the UNFCCC process.* Review of European Community & International Environmental Law.

Schreurs, M. A. (2007). Multi-level reinforcement: explaining European Union leadership in climate change mitigation. *Global Environmental Politics.*

Schwirplies, C. (2018). Citizens' Acceptance of Climate Change Adaptation and Mitigation: A Survey in China, Germany, and the U.S. *Ecological Economies, 308-322.*

Shimoda, Y. (2003). Adaptation measures for climate change and the urban heat island in Japan's built environment. *Building Research & Information, 31(3-4), 222-230.*

Sietz, D. M. (2008). *Mainstreaming Climate Adaptation into Development Assistance in Mozambique: Institutional Barriers and Opportunities. Policy Research Working Paper 4711*. Washington, DC.: World Bank.

Silva, H. P. (2010). *Modeling effects of urban heat island mitigation strategies on heat-related morbidity: a case study for Phoenix,*. Arizona, USA. : International Journal of Biometeorology, 54, 13-22.

Smit, B. P. (2001). *Adaptation in the Context of Equity and Sustainable Development.* IPCC Second Assessment Report.

Smithers, J. R. (2001). A hydrological perspectiveof the February 2000 floods: a case study in the Sabie River Catchment. *Water SA, 25-31.*

Sovacool, B. (2011). Hard and soft paths for climate change adaptation. *Climate Policy,* 1752-7457 .

Statistics, N. B. (2008). *Consumer price index expanded in February.* National Bureau of Statistics of the People's Republic of China.

Steeves, P. A. (2014). *Climate Risks Study for Telecommunications and Data Center Services. Riverside Technology, inc.* and Acclimatise.

Suarez, I. (2020, February 10). 5 *Strategies that Achieve Climate Mitigation and Adaptation Simultaneously.* Retrieved from WRI: https://www.wri.org/insights/5-strategies-achieve-climate-mitigation-and-adaptation-simultaneously

Summerlin, T. C. (2020, Sepetmber 15). *INSIDER: Mainstreaming Climate Adaptation into Development: Three Lessons from Kenya . Retrieved from https://www.wri.org/:* file:///C:/Users/HP/Desktop/CDRI/Position%20Paper/Mitigation%20VS%20Adaptation/Resilience/3_disaster_risk_resilience.pdf

Swart, R. J. (2007). Making integration of adaptation and mitigation work: mainstreaming into sustainable development policies? Climate Policy,. *Climate Policy, 288-303.*

Tanner, T. W. (2006). *Overcoming the barriers: Mainstreaming climate change adaptation in developing countries.* Institute of Development Studies.

Tatano, H. a. (2008). A framework for economic loss estimation due to seismic transportation network disruption: a spatial computable general equilibrium approach. *Nat Hazards,* 253–265.

Teodosio, B. (2019). Community Organizers Multiversity.

Thomas, V. &. (2015). *Global Increase in Climate related Disasters.* Asian Development Bank.

Thomas, V. J. (2013). *Climate-Related Disasters in Asia and the Pacific.* ADB.

TRB, T. R. (2017). *Transportation System Resilience.* TR News.

UBIMET. (2005). *Weather Alert System for Railways*. GMBH.

UN. (2015). *Infrastructure and Disaster* . UN World Conference on Disaster Risk Reduction .

UN, W. B. (2010). *Natural Hazards, Unnatural disasters : The Economics of Effective Prevention.* Washington, DC: International Bank for Reconstruction and Development/ World Bank.

UNCTAD. (2009). Multi-Year Expert Meeting on Transport and Trade Facilitation. *Maritime Transport and the Climate Change Challenge (p. 47).* Geneva: United Nations Conference on Trade and Development (UNCTAD).

UNDP. (2011). *Support Resilient Infrastructure in El Salvador.* UNOPs and Ministry of Public Works .

UNDP. (2011). *The economic impacts of climate change on energy demand for space heating and cooling. In: Assessing the Economic Impact of Climate Change* –. New York: National Case Studies. United Nations Development Program (UNDP).

UNDRR. (2019). *Human Cost of Disasters.* CRED, UNDRR.

UNDRR. (2021, May 10). *Definition of basic effects.* Retrieved from DesInventar Sendai: https://www.desinventar.net/effects.html

UNECE, U. a. (2010). Note by the United Nations Economic Commission for Europe (UNECE) and United Nations Conference on Trade and Development (UNCTAD) Secretariats. *Proceedings of Joint Workshop on Climate Change Impacts on International Transport Networks, (p. 14).* Geneva.

UNESCAP. (2019). *Asia-Pacific Disaster Report.* Economic and Social Commission for Asia and the Pacific.

UNESCO. (2000). A*ssistance to Mozambique following the devastating floods: Report of the Secretary-General.* New York, NY,: United Nations General Assembly Economic and Social Council.

UNESCO. (2017). Ethical principles for climate change: adaptation and mitigation report of COMEST. *International Social Science Journal.*

UNISDR. (2006). *Global Survey of Early Warning Systems. Geneva :* UN International Strategy for Disaster Reduction for the United Nations.

UNISDR. (2010). E*arly Warning Practices can Save Many Lives: Good Practices Lessons Learned.* Bonn, Germany, 67 pp.: United Nations Secretariat of the International Strategy for Disaster Reduction, UN International Strategy on Disaster Risk Reduction.

UNISDR. (2012). *Disaster Risk and Resilience.* UNISDR, WMO.

Vallejo, L. a. (2017). *limate-resilient infrastructure: Getting the policies right. OECD Environment Working Papers.* Paris: OECD Publishing.

Walker, B. A. (2009). Resilience, adaptability, and transformability in the Goulburn-Broken Catchment, Australia. . *Ecol. Soc.,* 12–35.

Walker, B. H. (2004). Resilience, adaptability and transformability in social-ecological systems. *Ecol. Soc,* 3438–3447.

Walker, B. H. (2004). Resilience, adaptability and transformability in social–ecological systems. *Ecology and Society.*

Ward, A. (2013). The effect of weather on grid systems and the reliability of electricity supply. *Climatic Change,* 103-113.

Ward, R. C.-W. (2008). The role of insurers in promoting adaptation to the impacts of climate change . *The Geneva Papers,* 133-139.

Watkiss, P. B. (2015). The complementarity and comparability of climate change adaptation and mitigation. *WIRE Climate Change.*

WBG. (2016). *Climate Change Action Plan 2016-2020.* World Bank Group.

WBG. (2019). Action Plan on Climate Change Adaptation and Resilience. The World Bank Group.

WBG. (2019). Document of The World Bank: Mozambique -Roads and Bridges Management and Maintenance Program - Phase II. The World Bank Group.

WBG. (2019). *World Bank Climate Finance 2019*. The World Bank.

WBG. (2020, September 8). *5 Years of Climate Leadership: The World Bank Group's First Climate Action Plan.* Retrieved from The World Bank: https://www.worldbank.org/en/news/immersive-story/2020/09/08/5-years-of-climate-leadership-the-world-bank-groups-first-climate-action-plan

WBG. (2021). *2025 Targets to Step Up Climate Action.* World Bank Group.

WBG, W. B. (2019). *Lifelines: The Resilient Infrastructure Opportunity.* World Bank.

WBSCD. (2014). *Building a Resilient Power Sector.* Geneva: World Business Council for Sustainable Development.

Wei Xie, N. L.-d. (2013). Quantifying cascading effects triggered by disrupted transportation due to the Great 2008 Chinese Ice Storm: implications for disaster risk management. *Natural Hazards,* 337–352.

Werners, S. S. (2012). *Turning Points in Climate Change Adaptation.* Amsterdam, Netherlands: The Governance of Adaptation — An international symposium.

Wilby R.L. and G. L.W. Perry, 2. (2006). Climate change, biodiversity and the urban environment. *Progress in Physical Geography,* 73-98.

WMO. (2011). *Climate Knowledge for Action: A Global Framework for Climate Services – Empowering the Most Vulnerable. The Report of the High-Level Task force for the Global Framework for Climate Services.* Geneva, Switzerland.: World Meteorological Organization.

WMO. (2011a). *Climate Knowledge for Action: A Global Framework for Climate Services – Empowering the Most Vulnerable. The Report of the High-Level Task force for the Global Framework for Climate Services.* Geneva, Switzerland.: World Meteorological Organization.

WN, P. J. (2006). Fair adaptation to climate change. *Ecological Economics,* 594–609.

Wright, L. P.-M. (2012). Estimated effects of climate change on flood vulnerability of U.S. bridges. *Mitigation and Adaptation Strategies for Global Change,* 939-955.

Zemel, A. (2015). Adaptation, mitigation and risk: An analytic approach. *Journal of Economic Dynamics and Control,* 133-147.

Zemel, A. (2015). Adaptation, mitigation and risk: An analytic approach. *Journal of Economic Dynamics & Control 51, 133-147.*

Coalition for Disaster Resilient Infrastructure

4th & 5th Floor, Bharatiya Kala Kendra, 1, Copernicus Marg, New Delhi - 110001, India

www.cdri.world @cdri_world +91 11 4044 5999 info@cdri.world

@coalition-for-disaster-resilient-infrastructure /Coalition-for-Disaster-Resilient-Infrastructure-109999954712859