Concept Note for Urban Infrastructure Resilience Studies

1. Context

The Coalition for Disaster Resilient Infrastructure (CDRI) as part of its 2021-2022 workplan, will launch a suite of studies on urban infrastructure resilience, exploring global cities. The primary lens of these urban resilience studies will be through examination of the **infrastructure systems** which play a critical role in supporting the city's ability to function and the wellbeing and prosperity of the communities they serve.

These studies will explore major existing and future hazards and threats to urban infrastructure systems, as well as exposure and vulnerability, and interdependencies between urban infrastructure systems. Research will explore resilience measures in place (for each infrastructure sector/system, and with respect to wider systems interdependencies) and consider where the gaps are for selected cities. While infrastructure resilience will be the primary focus of these studies, the scope will extend beyond considerations of infrastructure sectors and sectoral interdependencies, to also consider wider social, economic and environmental dependencies and interdependencies. For example, the cascading socio-economic impacts related to the failure of a city's water service, or the loss of energy provision.

Wider study considerations include the underlying institutional environment that governs and can help or hinder the resilience of infrastructure in case study cities. This includes key infrastructure stakeholders, legislation, regulatory mechanisms, governance frameworks and organisational capacity, amongst other factors. While these studies will focus on natural hazards, it acknowledges the importance of considering wider shocks and stresses through a resilience-based framework and thinking.

This concept note provides technical framing to a series of studies that aim to provide an assessment of the current infrastructure resilience capacity of case study cities and to provide a list of **priority actions for key stakeholders to address gaps and improve the resilience of the city** through improving the resilience of its infrastructure systems. It is also anticipated that these studies will provide **useful infrastructure resilience recommendations for cities of similar typological characteristics** to those identified in the research. Thirdly, these studies will also generate **cross-city learning and findings which will inform the future work of CDRI** and other actors in the fields of urban planning, infrastructure and resilience.

2. Background

Urban areas are already home to 55 per cent of the world's population, and that figure is expected to grow to 68 per cent by 2050.[1] Human wellbeing in cities relies on a complex web of interconnected institutions, infrastructure and information. People are drawn to cities as centres of economic activity, opportunity, and innovation. But cities are also places where stresses accumulate, and/or sudden shocks occur that may result in social breakdown, physical collapse or economic deprivation. That is, unless a city is resilient.

Cities have always faced threats, and many cities that have existed for centuries have demonstrated their resilience in the face of resource shortages, natural hazards, and conflict. In the 21st century, global pressures that play out at a city scale – such as climate change, pandemic diseases, economic fluctuations, and terrorism – pose new challenges. The Lloyd's City Risk Index found that $4.6 trillion of the projected GDP of 301 of the world's leading cities is at risk from 18 threats over the next decade.[1]

Urban risk is increasing due to the number of people living in cities. Risk is also increasingly unpredictable due to the complexity of city systems and the uncertainty associated with many hazards – notably climate change. Risk assessments and measures to reduce specific foreseeable risks will continue to play an important role in urban planning.

By 2030 trillions of dollars will be invested in urban infrastructure, which must be directed towards zero-carbon and resilient development; nearly a billion people will be added to the global urban population, requiring low-carbon, resilient and inclusive places to live; and nearly half of CO2 emissions must be reduced, with cities potentially delivering 58% of the energy-related emission reductions needed to keep the global temperature increase well below 2°C.[2]

At a point when there are multiple agendas or priorities at work simultaneously, cities need to ensure that their development strategies and investment decisions enhance, rather than undermine, the city's resilience. If governments, donors, investors, policymakers, and the private sector are to collectively support and foster more resilient cities, there needs to be a common understanding and emphasis on the opportunity for urban infrastructure to support the overall resilience of the city.

2.1 Climate Change

The COVID-19 pandemic has also highlighted several key vulnerabilities of our societies and economic system. The exposed vulnerabilities are particularly sobering when seen in the light of an even bigger future threat to the global economy: environmental degradation driven by our current economic system. [3]

Climate change is expected to increase the incidence of extreme events, by altering average climatic conditions and inducing greater climate variability, hence increasing extreme weather events like floods and droughts. This also includes the possible occurrence of new threats, such as sea-level rise, where they did not previously exist.[4]

Infrastructure usually involves large investments in assets that are designed to operate over the long term. For example, hydropower dams are large geotechnical structures that are designed to last for up to 100 years.[Error! Bookmark not defined.] The design of these facilities has typically assumed a future scenario that is similar to that of today. However, a changing climate and the resulting more extreme weather events mean those assumptions are becoming outdated, leaving infrastructure operating outside of its tolerance levels. This can present direct threats to the assets as well as significant knock-on effects for dependent systems and ultimately the communities relying on the services those assets deliver.[5]

Infrastructure networks will be affected by the physical impacts of climate variability and change but will also play an essential role in building resilience to those impacts. Extreme events illustrate the extent of this potential exposure. For example, OECD modelling of the potential impacts of a major flood in Paris found that 30% to 55% of the direct flood damages would be suffered by the infrastructure sector, while 35% to 85% of business losses were caused by disruption to the transportation and electricity supply and not by the flood itself. Ensuring that infrastructure is climate resilient will help to reduce direct losses and reduce the indirect costs of disruption.[6]

In 2005, Mumbai experienced unprecedented flooding, causing direct economic damages estimated at almost two billion USD and 500 fatalities. By the 2080s, an 'upper bound' climate scenario could see the likelihood of a 2005-like event more than double. It is estimated that total losses (direct plus indirect) associated with a 1-in-100 year event could triple compared with current situation (to $690–$1,890 million USD), due to climate change alone. Continued rapid urbanisation could further increase the risk level. However, adaptation could significantly reduce future losses; for example, estimates suggest that by improving the drainage system in Mumbai, losses associated with a 1-in-100 year flood event today could be reduced by as much as 70%.[7]

It is also crucial to consider the impact of infrastructure systems on climate risk in addition to the converse. Sustainable infrastructure planning, design, delivery and use can make an important contribution to lower carbon emissions and global and local efforts in climate change mitigation and adaptation. See Annex IV for examples of impacts of climate change on infrastructure types.

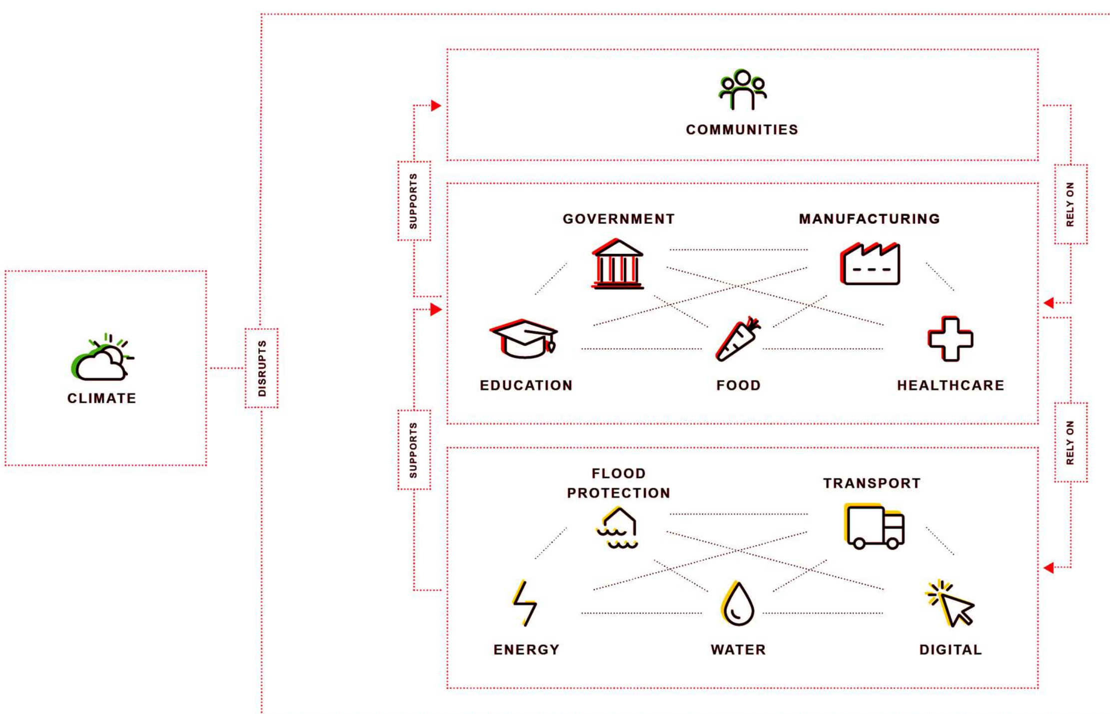


Figure 3: Impact of a changing climate on urban systems © Arup

Since 1992, and the establishment of the United Nations Framework Convention on Climate Change (UNFCCC), the global community has sought to address the above challenges collaboratively, through the lens of sustainable development. In 2015, the UNFCCC adopted the Paris Agreement, with the long-term goal to keep the increase in the global average temperature well below 2 °C. Thus far, the Agreement has been signed by 195 countries and ratified by 55.

In protecting the environment, infrastructure assets play a key role in conserving natural resources and reducing the impact of climate change. Clean energy generation plants, for example, are critical in reducing dependence on fossil fuels. By taking cars off roads, mass transit systems contribute to the reduction in pollution and generation of greenhouse gases. In the US, estimates are that if someone commuting 20 miles a day switches from driving to public transportation, it would lower their carbon footprint by 4,800 pounds annually. [28]

Approximately 70% of global greenhouse gas emissions come from infrastructure construction and operations such as power plants, buildings, and transport. The World Health Organization projects that the number of deaths attributable to the harmful effects of emissions from key infrastructure industries will rise from the current 150,000 per year to 250,000 by 2030[8]. Alongside government commitments, we are now seeing a sea change in societal demands with consumers increasingly choosing companies who share their environmental concerns. This shift is driving an unprecedented level of confidence in the benefits of investing in a cleaner, more sustainable future.

2.2 Additional Infrastructure Resilience Challenges and Opportunities

In the context an ever-increasing demand due to rapid urbanisation as well as during the Covid-19 crisis, there are parts of our critical infrastructure that are lacking, and new opportunities and needs are emerging.

Urbanisation and Population Growth

More than one half of the world population now lives in urban areas, and virtually all countries of the world are becoming increasingly urbanized. This is a global phenomenon that has nonetheless very different expressions across regions and development levels: richer countries and those of Latin America and the Caribbean have already a large proportion of their population residing in urban areas, whereas Africa and Asia, still mostly rural, will urbanize faster than other regions over the coming decades. These trends are changing the landscape of human settlement, with significant implications for living conditions, infrastructure requirements, the environment and development in different parts of the world[9].

Underinvestment

Growth and market demand have outpaced the provision of good quality infrastructure. Although there is widespread consensus among governments and businesses on the importance of infrastructure to a growing economy and evolving society, the world on average continues to underinvest. We also need to layer the growth requirements and the replacement requirements for the future. Worldwide investment in infrastructure is expected to be $79 trillion by 2040.[10] However, the actual global investment need is closer to $97 trillion. To close this $18 trillion gap, average annual global infrastructure investment would need to increase by approximately 23% per year. While public-sector budgets may be insufficient to finance the infrastructure governments need to build, some are finding new ways to tap into the global capital markets and encourage more private sector investment in the sector. For example, using concessional climate finance from sources such as the Green Climate Fund and the Climate Investment Funds, it is possible for governments to assume a first loss position, reducing risk for private investors.[11]

Ageing and stranded assets

Infrastructure in many developed countries was largely built during a post-war, post-colonial or post-Soviet boom. Nearly eight decades on, much of it has deteriorated and needs to be replaced. This provides opportunity to rehabilitate or retrofit infrastructure in a way that enhances the overall resilience of the system and it is sustainable. This is particularly true in developed markets where investment is predominantly required for infrastructure replacement and upgrading purposes. Conversely, in developing countries there is an opportunity to develop sustainable and resilient new infrastructure required to enable economic development and meet basic needs.

Pushed by the loss of demand due to Covid-19 and the pressure of international commitments, there's a drastic increase in stranded assets as well. For example, the International Energy Agency has warned that, if we are to meet Paris' "well below 2°C" target, 1715GW of fossil fuel power generating infrastructure must be shut down before its expected lifetime. There's no better time for stakeholders to rethink their current assets that are not able to meet a viable economic return and which are likely to see their economic life curtailed due to a combination of technology, regulatory and/or market changes.

Automation, digitisation, and other technological innovation

The many opportunities associated with increasing digitisation include increasing efficiency, flexibility and ability to anticipate issues and respond quickly.[Error! Bookmark not defined.] As a result, critical Infrastructure around the world has become almost completely dependent on automated control systems, often referred to as Operational Technology (OT) or Industrial Automation and Control Systems (IACS). The Internet of Things is a reality in many other sectors; sensors and wireless technologies enable equipment and assets to become "intelligent" by connecting them with one another. Examples include power production and distribution, railway signaling, flight control, traffic light control, water management and many more. Some of these systems may be vital to a nation's security. For all, safe and reliable operation is essential.

The advances in Information Technologies (ITs) are providing IACS with a great capacity for interconnection and adaptability. Developing countries have also benefited by being able to leapfrog to smarter, more sustainable systems. Digitisation of infrastructure comes with increasing sophistication and ease of use but also brings an increasing chain of dependencies. The impact of digital technologies on human factors, and vice versa is an important area to understand.[12] Consequently, it is essential to develop methodologies for the identification and subsequent classification of the ICS that intervene in critical infrastructure assets with any level of complexity, scalability and heterogeneity.[13]

International Commitments

Infrastructure is crucial for development. From transport systems to power-generation facilities and water and sanitation networks, it provides the services that enable society to function and economies to thrive. This puts infrastructure at the very heart of efforts to meet the Sustainable

Development Goals (SDGs).[14] The Covid-19 crisis is a wake-up call and an unprecedented opportunity to build back better, with a renewed focus on resilience. Alongside COVID-19, there is a more pressing crisis – the climate emergency. We are now at the stage where we must invest more in building resilience and sustainability into our infrastructure.

The Paris Agreement, the 2030 Agenda for Sustainable Development—which supports the Sustainable Developments Goals (SDGs) developed by UN member states—the New Urban Agenda and the Sendai Framework for Disaster Risk Reduction all require investments that deliver disaster resilient infrastructure that supports sustainable development.

Also in 2015, the Sendai Framework for Disaster Risk Reduction 2015 – 2030 set out to achieve "[t]he substantial reduction of disaster risk and losses in lives, livelihoods and health and in the economic, physical, social, cultural and environmental assets of persons, businesses, communities and countries". The Framework prioritises investing in disaster risk reduction for resilience. In addition, the Framework highlights the enhancement of disaster preparedness to effectively respond and to "Build Back Better" in recovery, rehabilitation, and reconstruction.

Building on all of the previous ambitions, in 2016, the United Nationals Conference on Housing and Sustainable Urban Development (Habitat III), adopted the New Urban Agenda, a declaration on sustainable cities and human settlements for all. It aligns itself with the Sendai Framework by committing to "strengthening the resilience of cities and human settlements, including through the development of quality infrastructure and spatial planning, by adopting and implementing integrated, age- and gender-responsive policies and plans and ecosystem-based approaches" and promoting the development of infrastructure that is both resilient and resource efficient, including through the use of nature-based solutions.

3. Key Concepts

3.1 Resilience

Resilience is defined as:

> ***'the ability of a system or community, exposed to hazards, to resist and absorb the hazard; recover from it or transform if conditions require it to, in a timely and efficient manner, including through the preservation and restoration of its essential basic services and functions.'*** [15]

Resilient infrastructure is essential for the safety, well-being, sustainability, and economic prosperity of cities. (Transformation through infrastructure, World Bank 2012). Goal 9 of the UN Sustainable Development Goals (SDG) is to *'**Build resilient infrastructure**, promote inclusive and sustainable industrialization and foster innovation'*. Resilient infrastructure also links with Goal 11: *Making cities and human settlements inclusive, safe, resilient and sustainable*, as well as being a key aspect which underpins all other SDGs .[16]

Infrastructure resilience embraces three key concepts[17]:

1. Withstand and endure: The capacity of infrastructure systems to continue to perform and provide their intended functions in the face of shocks and stresses.

E.g. A 8.2 magnitude earthquake in Concepcion, Chile in 2014 was the eighth largest in recorded history, but only light damage to property and 7 fatalities– largely to due to the rigorous implementation of building codes which require multiple-storey buildings to be capable of withstanding a 9.0 earthquake. [17]

2. Learn and adapt: The ongoing process of evaluating and adapting performance (systems, processes and assets) to better cope with shocks and stresses. This can also be described as 'adaptive capacity'.

E.g. The city of Ho Chi Minh in Vietnam sits low in the Mekong River delta and boasts a vast series of flood-defence measures including a major dam. However, rapid urbanisation and climate change have exposed the city to new flood vulnerability. Over recent years the city has retrofitted and adapted existing defences, incorporated ecosystem management and undertaken water supply interventions to improve existing water management, rather than build additional dykes. **Error! Bookmark not defined.**

3. Achieve transformational change: Infrastructure functions evolve at system level to meet rapidly changing urban needs and better support city-scale resilience.

E.g. The City of London has adopted a comprehensive transport mode shift strategy to address congestion and manage exponential growth in network demand. A shift towards public and passive transport modes prevented almost two million additional car trips per day during 2012 alone. Cycling is now the fastest growing transport mode in London.[17]

The City Resilience Index[18] research also suggests that **resilient systems also demonstrate certain qualities** – *inclusiveness, integration, reflectiveness, resourcefulness, robustness, redundancy* and *flexibility*. (Annex I). These qualities can be helpful to inform the design of infrastructure and other systems.

These resilience concepts and qualities can be embedded throughout the infrastructure project cycle from infrastructure planning and finance, through to design, construction, operation and ultimate decommission. See section 3.7.

Resilience vs Disaster Risk Reduction/Management (DRR/M)

Traditionally, a DRR/DRM approach seeks to treat and reduce risk (hazard x exposure x vulnerability) of particular assets and/or people, from **specific, known hazards**[19]. DRR/DRM has traditionally focused on natural hazards such as earthquakes, flood etc. but has evolved to also include human-induced hazards like war and pandemics. With resilience the focus is on building underlying **capacity of a system to manage uncertainty**, including a range of hazards, both known and unknown and various combinations of hazards and threats which may include economic (financial crisis, unemployment), social (labour strike, unrest) etc.[20] A resilience approach places additional emphasis on our providing key services that protect us and connect us whatever the future has in store. the **facilitation of adaptation in the face of disruption**.[21 22] DRR/DRM and resilience can be considered complementary approaches to reducing the impact of shocks and stresses.

The resilience concept offers the possibility to include societal aspects by taking into account the ability to absorb external shocks. While these studies will place additional focus on natural hazards, the focus will extend beyond traditional disaster risk reduction which is founded on risk assessments that relate to specific hazards. Instead, such a resilience approach responds to the idea that a wide range of disruptive events – both stresses and shocks – can occur but these are not necessarily predictable in nature or intensity.

Engaging with resilience

People and organisations have struggled to engage with resilience for various reasons. Efforts have always been taken to help address the human suffering in the immediate aftermath of an extreme event, but the scale of these disasters have been long in the making, due to a compendium of social, economic, and environmental challenges, and because strategies that were designed to address crisis and natural shocks were narrow. Resilience as a concept is still new and ill-defined and spans many different disciplines, sectors, and silos. Although the current understanding of the potential risks posed to stakeholders is improving, there has been much less emphasis on understanding how stakeholders can use their influence to promote broader societal resilience to climate-related perils.

3.2 Infrastructure Systems

A City system relies on the operation of a complex web of **infrastructure, institutions, and information *systems*** to perform the essential functions every day. Systems may be **physical** such as energy infrastructure, road and bridges, housing and shelter or ecosystems. They may be **non-physical/social processes/practices or behaviours** such as labour standards and legal rights, building codes & standards, culture, community cohesion or social relationships. It could also be exchanges of material and influence between cities and surrounding landscapes. Infrastructure systems should be understood as being part of **wider complex socio-technical systems**. In a socio-technical system, the social infrastructure elements, technical infrastructure elements and the environment continuously interact with each other and their behaviour cannot be fully understood without acknowledging these interactions.[23]

Urban infrastructure plays a critical role in enabling communities and businesses to survive and flourish in the face of threats**. Critical infrastructure** comprises of those infrastructure elements (facilities, systems, sites, property, information, people, networks and processes), the loss or compromise of which would result in major detrimental impact on the availability, delivery or integrity of essential services, leading to severe economic or social consequences, loss of life or an irreversible change in the nature of the physical environment, including urban climate, hydrology, and soils.

Cities around the world rely on a variety of infrastructure systems that support the wellbeing and growth of cities, their communities and economies.[24] A "systems" view can help to better understand the essential functions that are provided by a combination of manmade assets, natural ecosystems, social resources, finance, regulatory systems (governance), markets (end user) and behaviours. (see Figure 1, below)

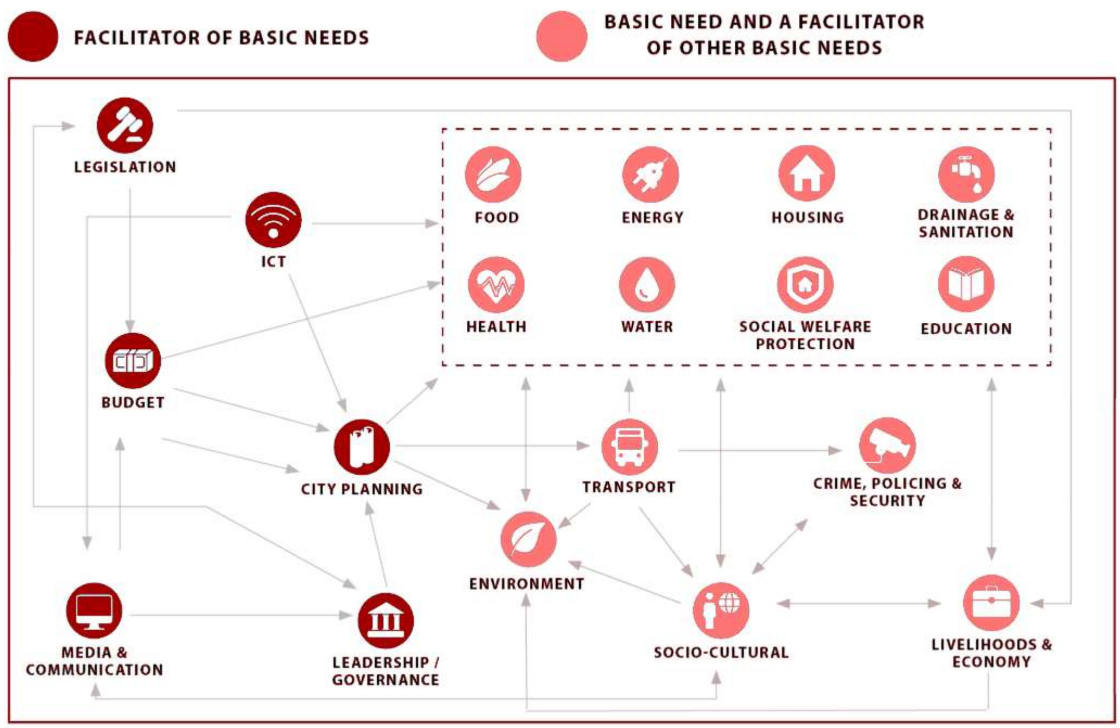


Figure 1. Urban Infrastructure Systems and Interdependencies © Arup [25]

Urban infrastructure systems can be understood across three main functions, according to the type of function they provide[24]:

- **Protect**: Systems such as flood protection, landslide barriers and civil defences protect urban settlements from natural and manmade hazards.
- **Provide**: Systems that provide cities with resources to meet basic human needs, such as water supply, energy networks and public health infrastructure.
- **Connect**: Systems that support movement within and beyond city boundaries, including flows of people, goods and services (transport networks) and information (ICT).

Urban infrastructure plays a critical role in enabling communities and businesses to survive and flourish in the face of threats[26]. Yet, infrastructure systems are themselves subject to increasing levels of risk, driven by a range of critical trends that are shaping cities globally.

Infrastructure system performance can change under different conditions. Shocks and stresses such as natural disasters and terrorism can place additional strain on infrastructure systems due to direct damage, can change the role which an infrastructure system plays within a city, or can trigger demand for new and additional resources to maintain or restore functionality.

3.3 Interdependencies between infrastructure systems

Infrastructure systems can support human wellbeing directly, such as the provision of potable water. However, they can also support other infrastructure systems. For example: energy networks provide power to operate water pumping stations, sewerage treatment plants and hospitals. Any given system will be dependent upon other systems: energy systems depend upon public and private transport infrastructure for fuel supply and access and repair of critical assets. These interactions are commonly referred to as interdependencies. Understanding infrastructure system interdependencies can demonstrate how changes in performance under shock or stress events can have far-reaching impacts beyond a single infrastructure system.[17]

Critical infrastructure is in **constant interaction with its environment**, using and transforming input from the environment to provide outputs to the same environment. It is nearly impossible to adequately analyse or understand the behaviour of a given infrastructure in isolation from the other infrastructures or the environment.[27]

During the Great East Japan Earthquake in 2011, the initial earthquake caused a tsunami which flooded the lower part of the Fukushima Daiichi reactors and led to three nuclear meltdowns, three hydrogen explosions, and the release of radioactive contamination. These incidents show that even well-prepared countries can be caught off guard. The Japanese example also shows that the unexpected effects of cascading disasters on the environment can be felt for many years. Contaminated water and soil management is still a problem in Fukushima today.

Figure 1 illustrates the complex web of connections between key urban systems in which essential services which provide citizens with their basic needs, are in an interdependent relationship with each other and wider social, economic and governance systems.

The interactions between critical infrastructure and its environment can be characterized into three categories:

- **Dependencies on other systems**. The products or services provided to one infrastructure by another external infrastructure that are necessary to support its operations and functions.
- **Internal dependencies.** The interactions among internal operations, functions, and purpose of the infrastructure. Internal dependencies are the internal links among the assets constituting a critical infrastructure (e.g., an electric generating plant that depends on cooling water from its own onsite water well).
- **Impacts on other systems**. The consequences to a critical infrastructure's users or recipients from the degradation of the resources provided by a critical infrastructure.

Increased interconnection between critical infrastructure networks, such as electric power and communications systems, has important implications for infrastructure reliability and security. More recently, technology and automation have enabled better interconnections however, this can also introduce new failure mechanisms: cyber-attacks may reach a larger number of critical components[28] and outages may propagate through the network, increasing the risk of system-wide cascading failures.

3.4 Exposure and vulnerability of infrastructure systems

Cities are socioeconomic hubs[29]. In many countries, it is estimated that 70 to 80 per cent of the gross domestic product (GDP) is produced in urban areas[30]. Indeed, cities are the locations where the capacity of our economic development, the future of societies and the world's ecosystem will play out [29]. The increasing concentration of population in urban areas, together with the high density of assets and the socio-economic and spatial vulnerabilities that characterize many cities, makes urban centres more susceptible to the risk of being severely affected by natural hazards than rural settings[31].

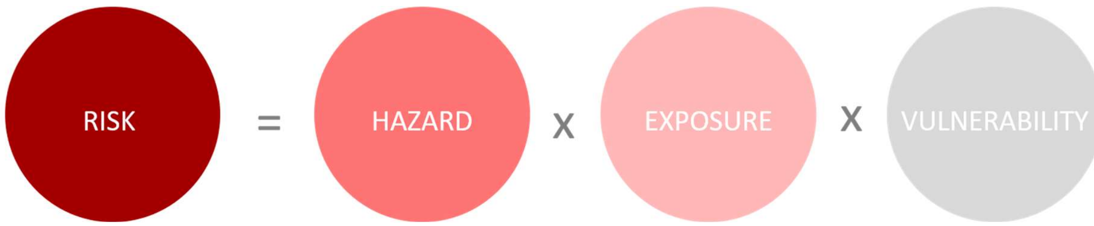


Figure 2. Relationship between Risk, Hazard, Exposure and Vulnerability, UNISDR 2017[32]

According to UNDRR (2017) terminology, the definition of disaster risk reflects the concept of hazardous events and disasters as the outcome of continuously present conditions of risk.

Hazard: A hazard is a process, phenomenon or human activity that may cause loss of life, injury or other health impacts, property damage, social and economic disruption or environmental degradation. Hazards may be natural, anthropogenic or socio-natural in origin.

Exposure: The situation of people, infrastructure, housing, production capacities and other tangible human assets located in hazard-prone areas.

Vulnerability: The characteristics determined by physical, social, economic and environmental factors or processes which increase the susceptibility of an individual, a community, assets or systems to the impacts of hazards.

It is widely acknowledged that risk in cities is distributed unevenly, both socially and spatially. When exploring who is most at risk – to everyday hazards, disasters and climate change impacts – the term vulnerability is widely used because it brings in notions of threat, risk or stress, of insecurity and of lack of power to address these. For example low-income households are often hit hardest by extreme weather because of greater exposure to the hazards (as only on high risk sites can they find accommodation), poor quality housing, lack of hazard-removing infrastructure, less capacity to cope with the impacts, less adaptive capacity (to reduce risks from future events), less state provision and less legal protection or insurance.

Vulnerabilities are especially high where infrastructures are subject to multiple threats and are already stressed (e.g. over capacity, ageing) particularly when they are located in areas already exposed to extreme events resulting sometimes in cascading impacts over several infrastructure systems.

For example, Cyclone Fani was the strongest tropical cyclone to strike the Indian state of Odisha since the 1999 Odisha cyclone. It wrought havoc in the district affecting more than 3 million people. Fani killed at least 89 people in eastern India and Bangladesh and caused about US$8.1 billion in damages in both India and Bangladesh, mostly in Odisha, in India. The storm destroyed several transmission towers and uprooted 156,000 utility poles in the city of Cuttack. Most of the city was cut off as road communication was disrupted due to uprooted trees at many places and power supply was cut off. Consequently, lack of telephone, mobile and internet networks affected communication in the district rendering emergency and essential services paralysed. The combination of high density population and poor construction without effective cyclone resistance made Cuttack highly vulnerable.

The inadequacy of the existing infrastructure in urban areas and poor management and governance has reduced cities' ability to cope and respond quickly to extreme events. Hence it is important for cities to be able to undertake a rapid assessment of their exposure and vulnerability, in order to understand where they need to build their capacity to plan for adaptation, and to develop infrastructure systems which will not lead to cascading failures of other elements or related systems and delivery of key services.

4. Priority Areas for Research

Two complementary agendas exist for building infrastructure resilience.

- Upstream agendas seek to move away from sectoral approaches and create a pipeline of infrastructure investment which delivers resilience to a given location, and the ability to maintain critical service functionality with respect to protect, provide, connect.
- Downstream agendas look at a specific infrastructure sector and consider how to build or enhance resilience in that system, generally and/or to specific shocks and stresses.

An alternative way of considering infrastructure resilience is across the infrastructure lifecycle. Resilience thinking must be embedded in each step of this journey. This can be achieved, for example, by introducing strategies and measures that respond to the three key concepts of infrastructure resilience and qualities of resilient systems presented in Section 3.1.

Planning and Prioritisation

In order for resilience to be effectively integrated into the lifecycle of infrastructure, a facilitating enabling environment must be in place that factors in complexity and uncertainty. Plans and policies must be sufficiently dynamic in order to account for multiplicity of economic, social, spatial, and physical factors, involving a wide range of stakeholders. Hence, to ensure urban resilience, decision-makers must integrate suitable approaches and practices across a multitude of sectors such as transport and land use, public health, and housing[33]. These interventions can mandate specific design and construction regulations, that literally build resilience into physical assets, such as more robust flood defences, embracing the *withstand and endure* concept of infrastructure resilience.

Alternatively, effective policy can steer public behaviour towards more resilient practices, such as in the case of transport, by enabling access to and incentivising the use of public transport and active travel options[34]. Often, decision-makers must combine both physical and non-physical solutions, such as with land use policy, where a community must consider disaster risks and their spatial distribution, to steer more sustainable land development and use, and thereby reduce the vulnerability of poor people who are often settled on degraded sites with significant risks and constraints[35].

Robust risk and vulnerability assessments help to determine the extent to which assets and projects are exposed to and the capacity they have to adapt to shocks and stresses. Such assessment will help planners to prioritise the most vulnerable aspects and focus solutions to elevate, mitigate or adapt to the risks identified, thus enhancing the resilience of the asset efficiently. The prioritisation process is made more robust by involving a set of relevant and diverse stakeholder in the process[36].

Feasibility, Project Preparation and Financing

It is no longer appropriate for infrastructure assets to be considered external from the natural system in which they are situated, given the rapidity with which the boundaries of the natural system are shifting. Infrastructure assets and systems must now be prepared for a changing climate, more frequent and intense severe weather events and denser concentrations of communities living in at-risk areas, such as in coastal region exposed to shocks and stresses, e.g. seismic events, and sea level rise[37]. Resilient preparations must therefore internalise contingencies to account for these changing conditions, to ensure continued coverage in the event of the failure of the primary source.

Adequate budgeting strategies and financial safeguards that acknowledge such risks and vulnerabilities contribute to more resilient resources. Such as in the case of insurance, which can make a significant contribution to resilience in cities, through incentivising robust risk management and providing financial and material support following loss events. In order to achieve these aims, insurers require qualitative and quantitative measures of risk, together with detailed analysis of potential concentrations of risk from extreme events[38].

Resilient Design, Procurement and Construction

Resilient design should, when possible, consider numerous, occasionally competing aspects including robustness, flexibility and redundancy. The actual risks in a given situation may not be a straightforward choice between different infrastructure solutions[39]. For example, re-afforestation upstream or re-planting of mangroves in a coastal delta may be more resilient than 'hard' engineering solutions such as debris flow or flood defence barriers, see Box 1 for more details on nature based solutions. Different physical risks (e.g. sea-level rise and flooding) should also be considered alongside other considerations (e.g. long-term sustainability, livelihoods) so that a fail-safe is built in and resilience is not viewed as something that will affect the detailed design of a piece of infrastructure, but rather sets the context for how overall community/local economic resilience is delivered. Embracing the concept of *learn and adapt* will help to strengthen adaptive capacity in this way.

At the very least, poor construction quality affects the usability and/or aesthetics of a building – but in some cases, it can seriously impact the health and safety of those that live and work in poorly built constructions. We saw the devastating effects of poor design quality when Grenfell Tower caught fire in 2017 in London, which lead to the deaths of 72 people[40].

Additionally, resilience can be integrated into the design and construction of infrastructure, by procuring sustainable materials and sourcing local resources, such as supplies, labour and knowledge where possible and appropriate[41].

Operation, Maintenance and Decommissioning

The dynamic and adaptive monitoring, control and security of critical infrastructure and processes are extremely important aspects to consider in order to avoid the disruption of their normal operation, either due to attacks, natural disasters or component failure, or to ensure that these assets continue to function after an extreme weather event. Alongside fail-safes integrated into the design of an asset, actions must be undertaken to continuously manage and anticipate disruptions to normal operations, in order to respond to shocks and stresses rapidly and effectively as and when they occur. Proactive management strategies can involve collecting data on the condition of assets and taking actions in advance to help withstand or endure shocks and stresses to prevent an impact on infrastructure services[42]. As an example, sector specific business continuity measures that foresee disruption to a transport system linking employees with their place of work might put into place early warning systems, informing workers of possible disruption, mapping and communicating alternative routes to connect workers and businesses, and enabling remote working when alternatives routes are unavailable or, as is the case with the ongoing pandemic, traditional working environments present risks to employees. As with any asset, resilient interlinkages between assets are therefore paramount to ensuring resilient operations. Similarly, when considering the decommissioning of infrastructure assets, broader considerations around the system at large must be taken into account. It is critical that the service that the asset was providing, unless it has become obsolete as the system evolves, must be performed by another asset or a system of other assets, so as to ensure that system resilience is not compromised. This does not necessitate a like-for-like replacement and is more easily achieved in a more integrated, holistically managed system[43].

Wider Systems Resilience Building

As is the case with infrastructure projects, infrastructure systems must abide by the concepts of *withstand and endure*, *learn and adapt* and *achieve transformational change*, in order to fulfil their function to protect, provide and connect. It is therefore important to consider not just how systems interact with each other spatially, but also how those systems can learn, adapt and change over time. Similar to lifecycle considerations at the asset level, temporal consideration of infrastructure systems is a useful tool in assessing the robustness of a system and understanding how risks and vulnerabilities can be addressed to increase its resilience.

System-wide and high-level resilience planning and prioritisation can provide a robust foundation for enhancing resilience throughout a system. As with assets, identifying the most vulnerable aspects of a system through effective planning, can help to set intervention priorities and increase the efficiency with which the system is made more resilient. In addition, a measure of affordability can help to identify solutions that are most suitable when resources or budgets are constrained [44].

To use the COVID-19 pandemic as an example, it has been critical that under prolonged strain, transport, logistics, communication, health care and education, economic and socio-cultural systems have continued to operate at sufficient capacity, so as to minimise the risks of individuals exposed to the virus and to shore-up the system-of-systems, successful responses to the pandemic are ones that *achieved transformational change*.

City Operational Resilience

By embracing the three key infrastructure resilience concepts outlined in Section 3.1 across the entire lifecycle of an infrastructure asset or project and across the system more generally, as discussed above, a city can bolster its operational resilience. What the preceding sections highlight, is that urban infrastructure does not operate within a vacuum, siloed from the assets and resources surrounding it. As a highly complex system-of-systems, a city's resilience, and its ability to ensure business continuity in the wake and aftermath of shocks and stresses, must therefore be addressed by each individual asset, within each system and across their numerous interdependencies.

The immediate response to contain and triage the issue must therefore be rapid, thus ensuring the minimising of damage and avoiding potential cascading failures across system interlinkages[45]. Equally, robust recovery strategies must be in place to get resources back up and running after a disaster has been contained, focussing on the most vulnerable and at-risk elements first. This will ensure that the system-of-systems continues to operate at a sufficient, if reduced, capacity, thereby safeguarding resilience.

In practice, delivering resilience will require coherence with the international agendas as well as effective integration across multiple scales, from local to global. Some approaches to framing or assessing resilience focus either on urban assets or systems, and consider man-made infrastructure, the natural environment, urban management and human behaviour to varying degrees. Asset-based approaches tend to focus on physical assets, rather than considering intangible assets that influence human behaviour, such as culture, social networks and knowledge[33]. They neglect the role that these assets play in city systems, and, therefore, overlook the importance of assets outside the city boundary; for example, a reservoir that may be a critical part of the water supply or flood management system. System-based approaches align more closely with the concept of resilience, and the long-standing notion of cities as 'systems of systems'.[6]

Box 1: Green and Blue-Green Infrastructure

Not all infrastructure resilience measures, and supply solutions need concern hard infrastructure interventions. Oftentimes, solutions that work with, or are inspired by nature can be honed, in order to increase the resilience of the wider system. Nature-based solutions (NbS) for climate change adaptation and disaster risk reduction are actions that work with and enhance nature to restore and protect ecosystems and to help society adapt to the impacts of climate change and slow further warming, while providing multiple additional benefits (environmental, social and economic).[46]

Ecosystems and natural resources form part of the complex web of a larger city system. NbS as an approach to green infrastructure (GI), can help to internalise and strengthens these systems within the wider city 'system-of-system', offering complementary or alternative measures to more traditional grey infrastructure solutions; a more holistic approach thus ensuring that infrastructure is more climate resilient.

NbS provide an ecosystem-based, multi-functional and multi-dimensional approach to societal challenges, such as climate change, disaster risk reduction and food and water security. Their applications are wide-ranging, from the restoration of degraded farmland, to the protection of watersheds in order to secure urban water supplies[47]. Given their holistic approach, often providing cascading benefits and co-benefits over longer temporal scales, the process of evaluating and quantifying their outcomes remains complex, relying on thorough analysis and effective follow-up monitoring. Though often cost-effective, their implementation is hindered by the current policy environment. Proactive and innovative policy making could allow NbS to be integrated into spatial development, strategy development, environmental protection, and low carbon economy planning[48]. Influenced by society's growing awareness of the need to address climate change, the increased willingness to invest in cleaner, more sustainable futures could provide the socio-cultural impetus needed for cities to integrate NbS into their governance strategy, budgets, and planning approaches.

Blue-green infrastructure BGI solutions are most typically associated with managing urban flood risks, such as through re-naturalised rivers and retention and detention ponds[49] and is closely associated with urban greening, as a green infrastructure approach, which presents another climate resilient solution to urban development. BGI and urban greening solutions look to introduce multi-functional blue/green spaces and features, highlighting ecosystem principles[50]. By connecting urban systems to the biosphere, BGI and urban greening promote active travel and supports mental and physical wellbeing, thereby addressing and improving the basic needs of the health and social welfare, which contribute to a more prosperous livelihoods and robust economies within cities. Moreover, increased urban greening can reduce the negative effects of urban heat islands and make cities more resilient to heat waves. Parks, woodlands, and naturalised waterways also act as carbon stores, provide sustainable drainage, and reduce run-off during flooding [51]. These features combine to increase a city's resilience to natural hazards, whilst also strengthening the overall system.

5. Existing studies, tools and guidance for urban and infrastructure resilience

In recent years, research on the resilience of critical infrastructure has increased considerably, resulting in various resilience definitions, approaches, and enhanced strategies. Yet there remain challenges implementing resilience in practice, the result of a complex web of research that spread across numerous fields of study.

Annex III outlines key urban and/or infrastructure resilience assessment tools created in recent years. This is not an exhaustive list but details some key frameworks which might influence the infrastructure resilience assessments of this study. **The tools and frameworks detailed in annex III can largely be summarised as upstream and downstream resilience assessment tools.**

As discussed in section 3.7, the **upstream tools move away from sectoral approaches and examine the infrastructure investment pipeline** (to protect, provide, connect) which depending on how it is developed, may or may not deliver resilience to a given location. For instance, the International Finance Corporation (IFC), the Green Climate Fund (GCF), the World Bank are all advocating for the development of 'resilient pipelines' or programmes. That is pipelines of investments that are generated based on vulnerability assessments for a country, climate resilience goals, critical infrastructure and interdependency analysis and then financed and implemented.

Other tools and frameworks take an even broader, more holistic approach, moving away from an explicit infrastructure focus and instead focusing on wider aspects of urban resilience. These frameworks include the Arup and The Rockefeller Foundation's City Resilience Index, UNDRR's Unbreakable: Resilience Indicator Toolbox, CAT-I, City Resilience Program etc.

Downstream tools and/or frameworks look at a specific infrastructure sector or asset and consider how to build or enhance resilience in that system, generally and/or to specific shocks and stresses. These tools include Power Sector Resilience Planning Guidebook, WASH Climate Resilience, CAESAR, GRRASP, Critical Infrastructure Protection Decision Support System (CIPDSS) etc.

Some tools like the World Bank Resilience Infrastructure Tool may be a useful starting point to conducting an infrastructure resilience assessment in a city. The tool includes detailed Activity Checklists and Activity Forms that support the integration resilience considerations throughout the project lifecycle, usable at any stage of the lifecycle. The tool positions climate-resilience as the starting point for infrastructure design and is both simple and practical in nature, which makes it very relevant for these studies. This can be used as is or developed for further adaptation on notification to the World Bank.

The exact infrastructure resilience priorities/agendas of municipalities will depend on the stage of development of that city with respect to infrastructure and wider institutional factors. There is therefore value in conducting studies in cities across a range of contexts as detailed in Annex II. Some cities will be at the stage of developing a sophisticated infrastructure resilience pipeline, others will be prioritising the integration of fundamental risk reduction and resilience building activities into existing infrastructure systems, while others will be somewhere in between. The Resilience Infrastructure Tool might therefore, in some cases, be complemented by partial integration of a more upstream focused framework.

6. Scope of work

The studies will involve an in-depth assessment of the infrastructure resilience of **20 target cities**. Assessments will involve both desktop research and in-depth primary field study. The underlying sampling process for the selection of cities is detailed in annex II.

With Cuttack as a pilot city, all other studies will preferably be undertaken by one contracted entity who will also produce a synthesis report on the study process and overarching findings.

Traditional infrastructure risk management involves a "predict and prevent" approach to evaluate hazards and take appropriate action to mitigate critical infrastructure asset risk. This approach is increasingly difficult in urban settings due to the diversity of hazards, size of assets, population and GDP at risk, human vulnerability, complexity of urban systems and future uncertainty. A "systems" view helps to better understand infrastructure-performance by looking beyond manmade assets to also consider natural resources, human resources, finances, governance structures and behaviours at the city scale. This has been illustrated in Figure 3.

Figure 4: Nested Systems and Increasing Scale ©Arup

These studies will explore the following aspects and identify any gaps in them:

a) Key urban infrastructure systems, their function and interdependencies
b) Major current/future hazards and threats to urban infrastructure systems, including existing exposure and vulnerability, potential impact of future climate change scenarios, and dependencies on other urban infrastructure systems.
c) Physical and operational resiliency measures in place (for each infrastructure sector/system and with respect to wider systems interdependencies).

d) Wider social, economic and environmental dependencies and interdependencies. E.g. the cascading socio-economic impacts and/or resiliency of a city related to the failure of water service, energy provision etc.
e) City governance, finance and broader institutional arrangements which support or limit the level of resilience within city infrastructure systems (e.g. construction codes, emergency arrangements, coordination mechanisms, revenue streams etc)
f) Analysis of the current status of upstream infrastructure resilience planning and the presence of a pipeline which protect, provide and connect citizens in the face of current and future shocks and stresses.

Steps a-f will be addressed through an infrastructure resilience framework(s). It will likely not be necessary to create an entirely original assessment framework. Instead, the contracted entity is encouraged to review existing urban infrastructure resilience frameworks, including those listed in Annex 3, and **select and or modify an appropriate framework** which robustly captures the above points a-f, and which can be applied across study cities. Section 4 identifies tools Disaster Resilience Scorecard for Cities and Resilience Infrastructure Tool as particularly useful tools to assess upstream and downstream infrastructure resilience, but modification and application will depend on city context including stakeholder engagement and should therefore the assessment framework should be formalised with CDRI during inception.

These studies will produce:

1. **Individual city infrastructure resilience reports** which:
    - Outline the current city infrastructure resilience, addressing points a-f.
    - *Priority physical/operational recommendations* to increase the resilience of specific critical city infrastructure systems. Based on the gap analysis, this step could involve robust financial analysis and an investment pipeline.
    - *Organisational measures* to increase the resilience of specific critical city infrastructure systems could be recommended based on the gap analysis, considering the relationship and processes of key sector/system stakeholders.
    - *Institutional recommendations* which may have broad application across city infrastructure systems but which are grounded in local and national policy context.

2. **An Urban Infrastructure Resilience Toolkit,** which collates recommendations from an analysis by city typology and provides overarching physical, organisational and institutional infrastructure resilience recommendations.

***

Annex I: Resilience Qualities

Reflective systems are accepting of the inherent and ever-increasing uncertainty and change in today's world. They have mechanisms to continuously evolve and will modify standards or norms based on emerging evidence, rather than seeking permanent solutions based on the status quo. As a result, people and institutions examine and systematically learn from their past experiences and leverage this learning to inform future decision-making.

Robust systems include well-conceived, constructed and managed physical assets, so that they can withstand the impacts of hazard events without significant damage or loss of function. Robust design anticipates potential failures in systems, making provision to ensure failure is predictable, safe, and not disproportionate to the cause. Over-reliance on a single asset, cascading failure and design thresholds that might lead to catastrophic collapse if exceeded are actively avoided.

Redundancy refers to spare capacity purposely created within systems so that they can accommodate disruption, extreme pressures or surges in demand. It includes diversity: the presence of multiple ways to achieve a given need or fulfil a particular function. Examples include distributed infrastructure networks and resource reserves. Redundancies should be intentional, cost-effective and prioritised at a city-wide scale, and should not be an externality of inefficient design.

Flexibility implies that systems can change, evolve and adapt in response to changing circumstances. This may favour decentralised and modular approaches to infrastructure or ecosystem management. Flexibility can be achieved through the introduction of new knowledge and technologies, as needed. It also means considering and incorporating indigenous or traditional knowledge and practices in new ways.

Resourcefulness implies that people and institutions are able to rapidly find different ways to achieve their goals or meet their needs during a shock or when under stress. This may include investing in capacity to anticipate future conditions, set priorities, and respond, for example, by mobilising and coordinating wider human, financial and physical resources. Resourcefulness is instrumental to a city's ability to restore functionality of critical systems, potentially under severely constrained conditions.

Inclusion emphasises the need for broad consultation and engagement of communities, including the most vulnerable groups. Addressing the shocks or stresses faced by one sector, location, or community in isolation of others is an anathema to the notion of resilience. An inclusive approach contributes to a sense of shared ownership or a joint vision to build city resilience.

Integration and alignment between city systems promotes consistency in decision-making and ensures that all investments are mutually supportive to a common outcome. Integration is evident within and between resilient systems, and across different scales of their operation. Exchange of information between systems enables them to function collectively and respond rapidly through shorter feedback loops throughout the city.

Annex II: City Sampling Framework

This suite of studies should examine 20 global case study cities. With the criteria below as an example in Figure 5, city typologies may be proposed or developed. One of the most valuable objectives of this suite of studies is to develop a process template / workbank of solutions that can be applicable within these different city types. A sample of location of cities by population size and level of exposure to natural disaster is shown in Figure 6. Further suggestions of metrics to select cities and city typologies are welcome.

The exact cities will be agreed between contracted entity and CDRI at time of inception.

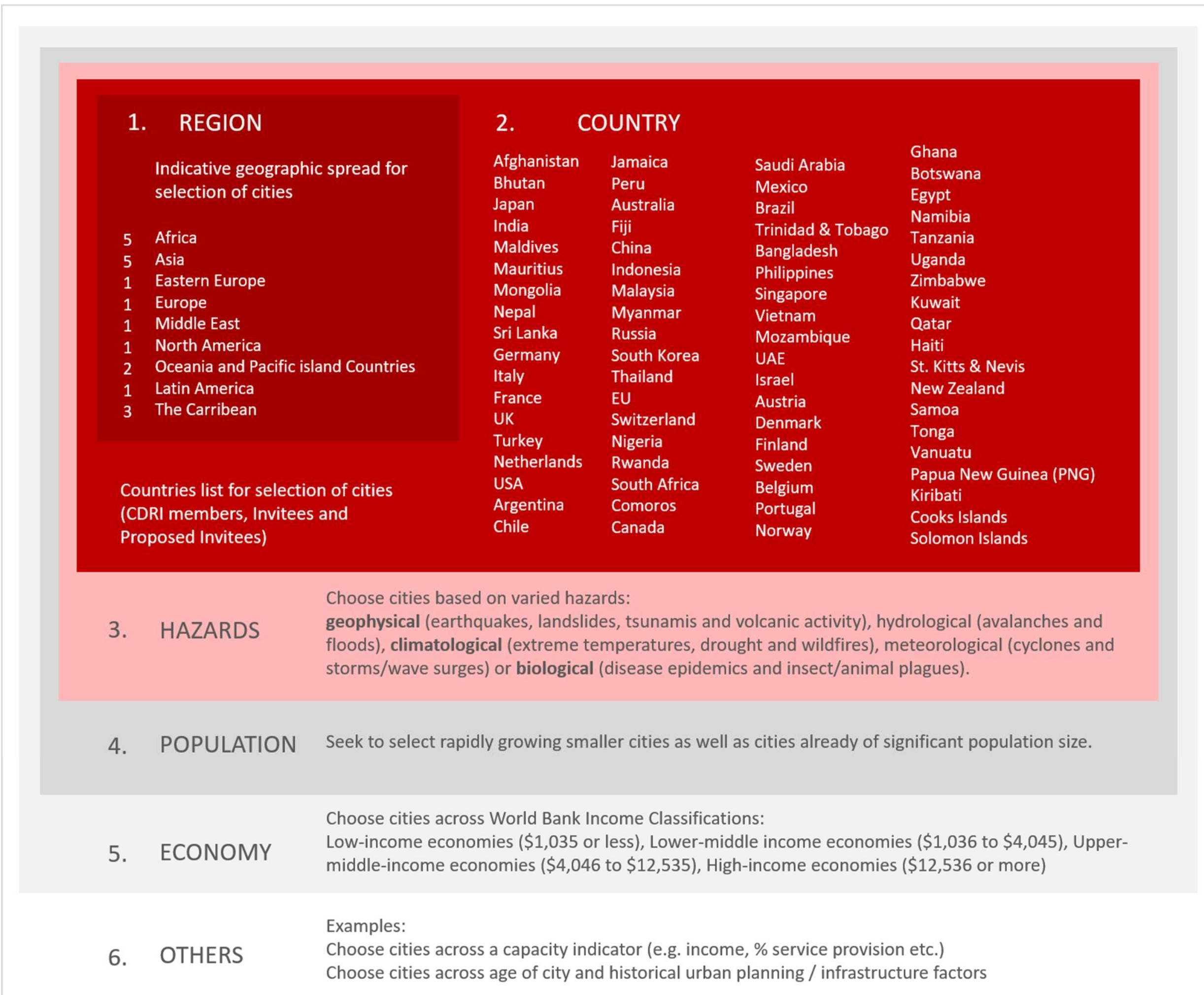


Figure 5: City Sampling Framework

* The recommended framework #18 requires a level of stakeholder/city apetite and buy-in. (It has to be a priority of the city to improve its urban infrastructure resileince. This coukd also be a criteria in ultimate country/city selection.

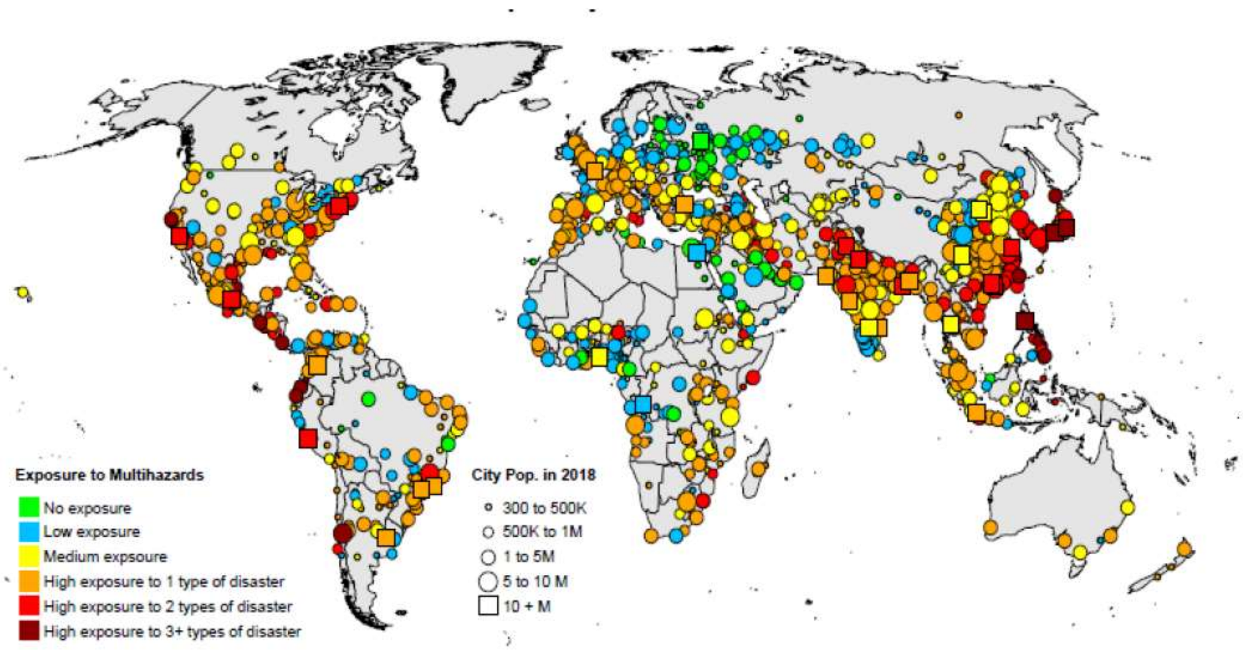


Figure 6: Location of cities by population size and level of exposure to natural disaster Source: World Urbanization Prospects: The 2018 Revision; Dilley et al. (2005)

*Disclaimer***:** The designations employed and the presentation of material on this map do not imply the expression of any opinion whatsoever on the part of CDRI concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries.

Annex III: Examples of existing studies, tools and approaches of infrastructure resilience

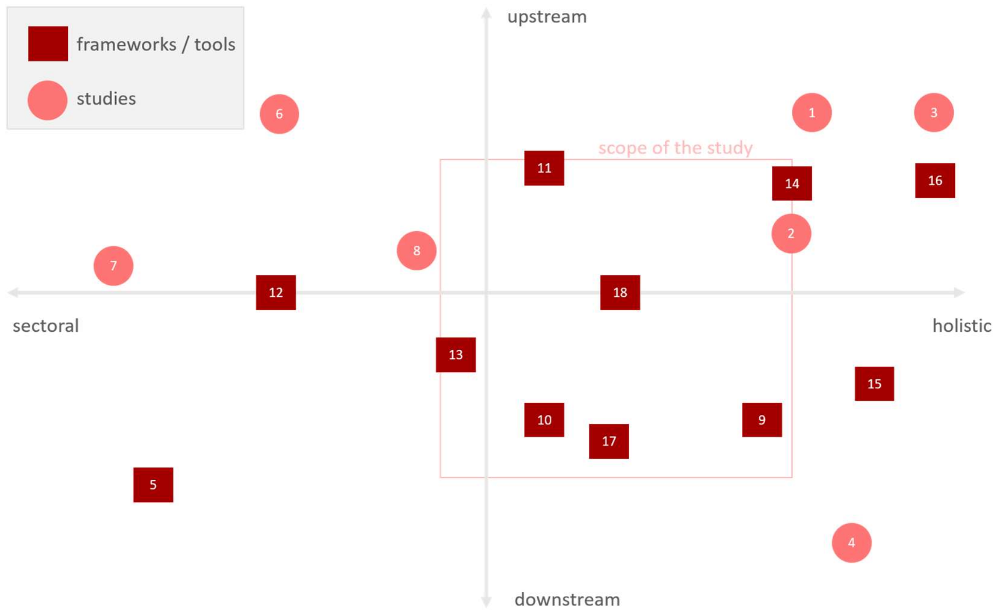


Figure 7: Matrix of selected existing infrastructure resilience studies, tools and approaches.

Holistic Urban Resilience Studies and Frameworks

1. The World Bank Group and the Global Facility for Disaster Reduction and Recovery (GFDRR) City Resilience Program (CRP) empowers cities to pursue investments that build greater resilience to climate and disaster risks, and to provide support to financing necessary to ensure those investments come to fruition. CRP pursues three strategic objectives to move toward this vision:
   a) Cities have **increased access to tools and technical support** to effectively plan for resilience.
   b) Cities have **increased access to multiple sources of financing** to ensure that more investment in resilience come to fruition.
   c) Cities can **leverage global partnerships** to support their resilience objectives.

CRP supports cities across three main thematic areas:

- Planning for Resilience focuses on providing **technical support to ensure that capital investment plans are risk informed**.
- Finance for Resilience zeros in on **capital mobilization** around urban resilience.
- Partnership for Resilience concentrates on **advocacy** and convening global expertise.

Together, these three thematic areas are key to helping cities address the resilience challenges of the future. **This type of study can catalyze a shift toward longer term, more comprehensive multi-disciplinary packages of technical and financial services, building the pipeline for viable projects at the city level that, in turn, build resilience.**

2. Cities Alliance Joint Work Programme on Resilient Cities (JWP) was officially launched at COP 21. The JWP brings together members and partners to promote local resilience strategies

through inclusive, long-term, urban planning processes. In keeping with the niche of Cities Alliance, the JWP focuses specifically on addressing the resilience challenges of informal settlements and the working urban poor. **Member organisations who typically work on resilience from one particular angle – such as the environment, slum upgrading or urban poverty reduction – using this platform, joined forces and knowledge to adopt a more comprehensive approach for stronger results.**

3. 100 Resilient Cities – pioneered by the Rockefeller Foundation (100RC), aimed to enhance city resilience through a programme of activities, including the appointment of a City Resilience Officer (CRO), creation of a Resilience Strategy in each participating city, and the sharing of knowledge and best practice through a global network of cities and service providers. City strategy development was developed through partnership between the city government and an external city partner, funded by 100RC. The holistic, multi-stakeholder strategy development process helps cities to improve the robustness, flexibility and inclusiveness of their systems, and to build resilience capacity across stakeholder groups. **This strategy is designed to articulate solutions that make 100 cities around the world more resilient not only to physical challenges, such as floods and aging infrastructure, but also to social challenges, such as cohesion and urban health, which can be applied here as well. Please see below for The City Resilience Index tool in the Resilience Tools and Frameworks section.**

4. The Making Cities Resilient Campaign (MCRC) - launched in May, 2010 - addresses issues of local governance and urban risk. The Campaign is led by the United Nations Office for Disaster Risk Reduction (UNDRR) but is self-motivating, partnership and city-driven with an aim to raise the profile of resilience and disaster risk reduction among local governments and urban communities worldwide. Since being launched, the Campaign has strengthened local level leadership and increased political will for disaster risk reduction. **Please see below for the Disaster Resilience Scorecard for Cities tool in the Resilience Tools and Frameworks section.**

Box 2: Other studies studies / frameworks currently being developed

Presently, the University of Oxford's Environmental Change Institute has developed a methodology that is testing in Ghana in cooperation with the Global Center on Adaptation (GCA). The publication 'A System-Wide Approach for Infrastructure Resilience: Technical Note' (January 2021) by ADB and GCA presents the approach and existing case-studies. The World Bank publications "Lifelines: The Resilient Infrastructure Opportunity. Sustainable Infrastructure Series" also describes the approach and present methods used to conduct complex interdependency analysis.[1] Vulnerability assessments are based on widely accepted methodology and approaches. ISO standard is preparing ISO 14091:2020 (TBC) "Adaptation to climate change - Vulnerability, impacts and risk assessment" (expected early 2020). This will provide a detailed process for undertaking vulnerability, impact and risk assessment, following the language and principles set out in 14090. The ISO Standard 14090 ISO 14090:2019 "Adaptation to climate change - Principles, requirements and guidelines" was published in June 2019. However, city scale assessments on the impact of climate change on infrastructure, and adaptation required is not covered in this guidance.[1]

Specific Infrastructure Resilience Studies and Guidance

5. USAID and NREL's Power Sector Resilience Planning Guidebook is a reference for power sector resilience planning that introduces policymakers, power sector investors, planners, system operators, and other energy-sector stakeholders to the key concepts and steps involved in power sector resilience planning. Users can then apply this knowledge in the development of strategic, country-specific processes and identify actions that increase power sector resilience. **The resources in the guidebook can facilitate the step-by-step process of identifying threats to the power system and their associated impacts, assessing potential vulnerabilities, evaluating risk, and developing strategies to increase resilience.**

6. Partnering with The Resilience Shift, The Rockefeller Foundation and SIWI, the Arup City Water Resilience Approach (CWRA) responds to a demand for innovative approaches and tools that help cities build water resilience at the urban scale. The CWRA was developed to help cities grow their capacity to provide high quality water resources for all residents, to protect them from water-related hazards, and to connect them through water-based transportation networks ("provide, protect, connect"). **The approach details five steps to guide cities through initial stakeholder engagement and baseline assessment, through action planning, implementation and monitoring of new initiatives that build water resilience**

7. WASH Climate Resilience –The Global Water Partnership (GWP) is a global action network with over 3,000 Partner organisations in 179 countries. This Strategic Framework consists of 4 quadrants which provide guidance on how to ensure resilient WASH services. To support the implementation of the Strategic Framework, a number of Technical Briefs have also been developed. **Applying the Framework will help reduce the impact of climate change on WASH; strengthen the reliability of WASH services; and strengthen the capacities of governments and communities to build resilience over time.**

8. The European Union Joint Research Centre has launched the European Programme for Critical Infrastructure Protection (EPCIP) to reduce the vulnerabilities of critical infrastructures. This is a package of measures aimed at improving the protection of critical infrastructure in Europe, across all EU States and in all relevant sectors of economic activity. **The three workstreams deal with the strategic aspects and the development of measures horizontally applicable to all CIP work, measures implemented at a sectoral level and measures to support Member States in their activities concerning National Critical Infrastructures. This is however not at city scale.**

Resilience tools and frameworks

9. The Tool CAESAR (Cascading Effect Simulation in urban Areas to assess and increase Resilience) addresses the need to better understand the cascading effects of major disasters in connected and interdependent urban infrastructure systems. CAESAR has the capacity to identify the most vulnerable components within individual infrastructure grids and it allows to assess potential damages within the grid as well as within coupled grids.

   The CAESAR software estimates how much primary damage is caused by natural disasters, e.g. a utility pole falling over. The simulation then propagates the damage caused by the entire supply network. Two forms of cascade effects are considered: first, the propagation of a failure within the same network (for instance, if a utility pole falls over, this may lead to a disruption of power supply of a substation) and second, the propagation of a failure beyond the boundaries of that network (for example could the failure of electrical supply lead to a disruption of mobile phone base stations). Physical dependencies between the different infrastructures are displayed as probabilities. By using these dependencies, it is possible to calculate to what extent, for example, power outages influence the functionality of the water and cellular networks within simulations. **CAESAR can determine which parts of the infrastructure contribute to the cascade effect. Based on these identified critical parts, CAESAR then provides possible strategies to increase the robustness against the cascade effects**

10. The Critical Infrastructure Protection Decision Support System (CIPDSS) is a risk-based tool to help decision-makers prioritise infrastructures (seventeen types) to be protected within the overall system. This is done through cross-sectoral impact analysis. The method is flexible as it can be applied across a wide range of infrastructures. **The tool simulates uncertainties at input (event) and output level (impact), which makes it relevant to climate change. It also considers interdependencies. Although it focuses mostly on 'risk' to the infrastructure(s), and not on the resilience of the system which the infrastructure supports.**

11. The Capacity Assessment Tool for Infrastructure (CAT-I) is a tool developed by UNOPS to help countries facilitate better infrastructure development. The tool is designed to help governments identify gaps or challenges in the capacity of their enabling environment to plan, deliver, and manage sustainable, resilient, and inclusive infrastructure systems. **CAT-I can be done to create a baseline and to identify actionable capacity building programmes and projects. The tool can then be used to measure progress based on the outcome of implemented capacity building programmes and projects and to identify continued gaps in capacity. However, it is based on qualitative inputs of about 800 yes/no questions which may not provide an objective picture in some instances.**

12. The World Bank provides Climate and Disaster Risk Screening Tools for self-assessment to provide a systematic, consistent, and transparent way of considering short- and long-term climate and disaster risks in project and national/sector planning processes. The tools target a range of sectors (both national/ policy and project levels): national plans, agricultural, coastal flood protection, energy, health, roads, water, etc. **This self-paced tool can provide high-level screening at an early stage of program and/or project development. It does not provide a detailed risk analysis, nor suggest specific options for increasing the project's resilience. It is intended to help determine the need for further studies, consultation, and/or dialogue in the course of program or project design**

13. The Geospatial Risk and Resilience Assessment Platform (GRRASP) can be used for the analysis of complex networked systems taking into consideration cross-sectoral and cross-border interdependencies. GRRASP is an ensemble of tools that can be used for the analysis of Critical Infrastructure disruptions and cascading effects at regional/state level, as well as at EU level (depending on the type of infrastructure) and to estimate the economic impact of such disruptions at state level. **GRRASP can be used for the structural analysis of critical infrastructure networks (e.g identify the most critical or most vulnerable elements of a network). Its architecture allows end users to use their own datasets for performing**

analyses as well as develop modules that can be plugged in the GRRASP environment. It does have a geographic limitation to Europe at the moment.

14. UNDRR's Unbreakable: Resilience Indicator Toolbox provides an advanced tool to explore the drivers of resilience, and to estimate the benefits of custom interventions. By manipulating the sliders that can quantify specific indicators, a scenario can be created for a country and how these shifts contribute to resilience in that country can be observed. This toolbox moves beyond asset losses and extends risk assessment to estimate how natural disasters affect well-being. Specifically, the analysis considers the different abilities of poor and nonpoor people to cope with asset losses by modelling the effects of asset losses on income (accounting for capital productivity and diversification of income sources) and consumption (accounting for savings, remittances and social protection, and post disaster transfers). Consumption losses are translated into well-being losses, taking into account the different impacts of a $1 loss on poor and nonpoor individuals. **This tool could provide a country level insight into not only how much benefit an intervention or project generates, but also who benefits. The package of resilience-building policies discussed here would deliver benefits that extend beyond the context of natural disasters: financial inclusion, access to health and nonhealth insurance, and stronger social protection shield people against all sort of shocks, facilitate investment and innovation, and promote development and poverty reduction However, it may not support city level impact in its current form.**

15. CityStrength is a rapid diagnostic that aims to help cities enhance their resilience to a variety of shocks and stresses. CityStrength is a qualitative assessment developed with support from the Global Facility for Disaster Reduction and Recovery (GFDRR). The diagnostic takes a holistic and integrated approach and encourages collaboration between sectors to tackle issues and unlock opportunities within the city more efficiently. CityStrength is flexible and can adapt to different needs of clients in terms of depth and breadth and can be implemented in any city or combination of cities within a country regardless of size, institutional capacity, or phase of development. **It can be used either as a diagnostic and/or as a means of engaging with a new stakeholder, which will impact it's focus. The process will need to be followed by an engagement plan, studies and surveys to fill data gaps, feasibility studies for critical infrastructure or programs, scope for technical assistance, and a project concept.**

16. The City Resilience Index developed by Arup with support from The Rockefeller Foundation, is the first comprehensive tool for cities to understand and assess their resilience, enhancing their ability to build sound strategies and plans for a strong future. Through an online platform, it uses a comprehensive, holistic framework that is applicable at the city scale – one that combined the physical aspects of cities with intangible aspects associated with human behaviour which are often relevant in the context of economic, physical and social disruption. The framework is based around 12 Goals and 52 indicators which contribute to urban resilience.

    Goals 1, 3, 7, 8 and 9 specifically concern physical urban infrastructure systems, while the remaining Goals both contribute to the resilience of these infrastructure systems and are influenced by the performance of these infrastructure systems. Goals 7 and 8 are particularly relevant to the work of CDRI, highlighting some key factors which inform infrastructure resilience. **The CRI could potentially provide an initial lens through which to explore urban infrastructure resilience, although this might be complemented by one of the**

below tools, which places a more detailed lens on the resilience within and between specific infrastructure systems.

City Resilience Index Goals and Indicators Arup | Rockefeller (2014)

1 Minimal human vulnerability	**1.1 Safe and affordable housing** **1.2 Adequate affordable energy supply** **1.3 Inclusive access to safe drinking water** **1.4 Effective sanitation** **1.5 Sufficient affordable food supply**
2 Diverse livelihood & employment	2.1 Inclusive **labour policies** 2.2 Relevant **skills & training** 2.3 Local **business development and innovation** 2.4 Supportive **financing mechanisms** 2.5 Diverse **protection of livelihoods** following a shock
3 Effective safeguards to human health & life	3.1 Robust **public health systems** 3.2 Adequate access to **quality healthcare** 3.3 Emergency **medical care** 3.4 Effective **emergency response services**
4 Collective identity & community support	4.1 Local **community support** 4.2 Cohesive **communities** 4.3 Strong **city-wide identity & culture** 4.4 Actively **engaged citizens**
5 Comprehensive security & rule of law	5.1 Effective **systems to deter crime** 5.2 Proactive **corruption prevention** 5.3 Competent **policing** 5.4 Accessible **criminal and civil justice**
6 Sustainable economy	6.1 Well-managed **public finances** 6.2 Comprehensive **business continuity planning** 6.3 Diverse **economic base** 6.4 Attractive **business environment** 6.5 Strong **integration with regional & global economies**
7 Reduced exposure & fragility	7.1 Comprehensive **hazard and exposure mapping** 7.2 Appropriate **codes, standards & enforcement** 7.3 Effectively managed **protective ecosystems** 7.4 Robust **protective infrastructure**
8 Effective provision of critical services	8.1 Effective **stewardship of ecosystems** 8.2 Flexible **infrastructure services** 8.3. Retained **spare capacity** 8.4 Diligent **maintenance & continuity** 8.5 Adequate **continuity for critical assets & services**
9 Reliable mobility & communications	9.1 Diverse and affordable **transport networks** 9.2 Effective **transport operation & maintenance** 9.3 Reliable **communications technology** 9.4 Secure **technology networks**
10 Effective leadership & management	10.1 Appropriate **government decision-making** 10.2 Effective **co-ordination with other government bodies** 10.3 Proactive **multi-stakeholder collaboration** 10.4 Comprehensive **hazard monitoring and risk assessment** 10.5 Comprehensive **government emergency management**
11 Empowered stakeholders	11.1 Adequate **education for all** 11.2 Widespread **community awareness & preparedness** 11.3 Effective **mechanisms for communities to engage with government**
12 Integrated development planning	12.1 Comprehensive **city monitoring & data management** 12.2 Consultative **planning process** 12.3 Appropriate **land use and zoning**

	12.4 Robust **planning approval process**

17. United Nations Office for Disaster Risk Reduction with the support of other partners and cities participating in the Making Cities Resilient Campaign have updated the Disaster Resilience Scorecard for Cities. The Scorecard is structured around the "Ten Essentials for Making Cities Resilient", first developed as part of the Hyogo Framework for Action in 2005, and then updated to support implementation of the Sendai Framework for Disaster Risk Reduction: 2015-2030. The Ten Essentials for Making Cities Resilient offer a broad coverage of the many issues cities need to address to become more disaster resilient:
    - Essentials 1-3 cover governance and financial capacity;
    - Essentials 4-8 cover the many dimensions of planning and disaster preparation;
    - Essentials 9-10 cover the disaster response itself and post-event recovery.

    The Scorecard offers the potential for scoring at two levels:

    - Level 1: Preliminary level , responding to key Sendai Framework targets and indicators, and with some critical sub-questions. This approach is suggested for use in a 1 to 2 day city multi-stakeholder workshop. In total there are 47 questions indicators, each with a 0 – 3 score;
    - Level 2: Detailed assessment. This approach is a multi-stakeholder exercise that may take 1 –4 months and can be a basis for a detailed city resilience action plan.
      The detailed assessment includes 117 indicator criteria, each with a score of 0 – 5.

    While the Scorecard could be a good starting point, and can be used to establish a baseline measurement, increase awareness and understanding and enable dialogue between key stakeholders, it is a qualitative scorecard which may not provide a complete picture unless more in-depth analysis is done.

18. Within the framework of the Ghana Secondary Cities Support Program of the World Bank, Arup developed a Resilience Infrastructure Tool for ensuring that resilience considerations are integrated throughout the lifecycle of the development of projects. This tool has been applied in 25 Ghanaian Municipalities, focussing on solid waste management, urban markets and storm water drainage infrastructure. **The tool has a double audience: one the one hand,** Ghana's **Municipal Assemblies and technical staff to ensure resilience is integrated in the planning and delivery of urban infrastructure investments (storm water drainage, solid waste management and urban markets); and, on the other, to provide the Word Bank (or other funders) an instrument to monitor resilience considerations in the projects supported by the overall Program.**

    The tool is readily applicable and can be applied in other location. Whilst an envisaged method for using it is proposed, users are encouraged to use it in any way that suits their context and objective. The Activity Checklist and Forms are easy to understand, provide rationale and guiding questions for each stage and suggest which technical expertise will be best placed to lead each element. Whilst the tool was designed for the Ghanaian context, its contents and procedures are by no means exclusive to this context. Rather, the tool is a guiding resource that, insofar as an enabling institutional environment is present, can be openly replicated in different circumstances. **Benefits of the tool include its practicality and usability while still incorporating detailed Activity Checklists and Activity Forms that support the integration resilience considerations throughout the**

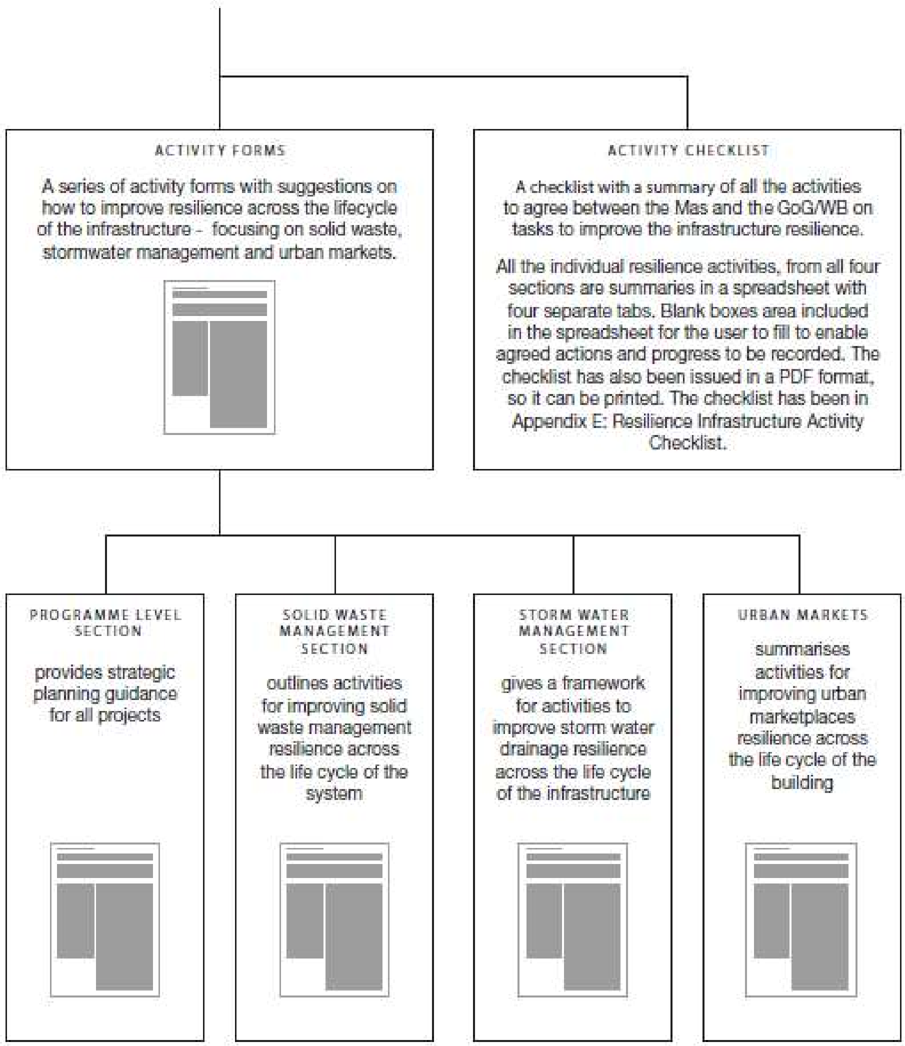
project lifecycle. It can be used at any stage of the infrastructure lifecycle and aligns well with the objectives of this note and of CDRI, putting climate-resilience as an originating point for infrastructure design. This tool might be used as is or developed / further adapted depending on the context and circumstances of the assessment city on notification to the World Bank.

STRATEGIC PLANNING
A. Identify current and future natural hazards relevant to the municipality through hazard mapping
B. Ensure updated municipality land-use plans exist
C. Ensure budget allocation is aligned with available funds
D. Establish a fair and ethical procurement processes
E. Develop an Information Management Strategy
F. Develop public education and strengthen climate resilience awareness

INFRASTRUCTURE PLANNING
Develop or update the multi-hazard risk assessment
Develop or update the infrastructure flood risk assessment
Develop an appropriate emergency preparedness/response plan for the proposed project.
Identify relevant legal and regulatory frameworks and identify gaps
Undertake an infrastructure governance mapping and identify additional coordination needs
Develop a baseline assessment for the existing infrastructure
Develop and establish current and future needs and performance criteria
Identify the skills mix required for the design of the infrastructure and improve knowledge and capacity/skills in the MAs
Identify external technical support required throughout the lifecycle of the proposed infrastructure (Planning, Design, Construction, O&M)
Undertake a site investigation
Design and implement a data collection plan aligned with the information management strategy
Develop a business continuity plan for the proposed infrastructure
Develop or update mobility strategies related to the proposed service.
Develop a public engagement and education plan in relation to the proposed infrastructure
Improve regulation and law enforcement to avoid behaviours that impact the proposed infrastructure
DESIGN
Identify the skills mix required for the design of the infrastructure and develop a plan for meeting the needs of the team and supporting project delivery
Develop relevant environmental and social safeguards instruments (ESIA, ESMP, RAP, ARAP)
Identify and assess infrastructure interdependencies
Review which future needs previously identified have been incorporated in the design
Design an acceptable O&M plan aligned with local skills and materials
Check and obtain necessary approvals to meet the relevant legal and normative frameworks
CONSTRUCTION / IMPLEMENTATION
Ensure that the capacity/skills/qualifications of the construction/implementation team are appropriate
Consider risks identified in the site selection investigation and identify risks associated with design

Ensure site supervision and quality control (of workmanship and materials) is undertaken and check that it has been constructed as per the design
OPERATION & MAINTENANCE
Identify knowledge gaps and improve knowledge and capacity/skills in the MAs for the operation of the infrastructure
Implement the O&M plan
Undertake performance assessments and collect lessons learnt

TOOL CONTENT



Annex IV: Examples of impact of climate change on infrastructure types[lii]

	TRANSPORTATION					WATER			ENERGY					TELECOMS			BUILDINGS		
	Rail	Road	Airports	Pors & maritime transport	Rivers	Portable water	Waste water & sanitation	Flood & coastal erosion management	Thermonuclear power plants	Wind power plants	Solar power plants	Hydroelectric power plants	Transmission, distribution & substations	Wireless infrastructure	Fixed infrastructure	Data centres	School building + education	Health buildings & healtcare	Homes, offices & other buildings
SEA LEVEL RISE																			
Damage of disruption from coastal flooding	○	○	○	○		○	●	○	○	○		○	○		○		○	○	○
Tide locking				○	○		○	○				○							
Saline intrusion					○	○	○												
Coastal erosion	○	○	○	○		○		●											
RAINFALL																			
Damage or disruption from river flooding	●	●	○		●	○	●	○	○	○	●	○	○	○	○	●	●	○	○
Damage or disruption from pluvial flooding	●	●	○	○	●	○	●	○	○	○	●	○	○	○	○	●	○	○	○
Droughts and low precipitation					○	●	○				○	○				○			
Altered capability or efficiency	○	○	○			○											○	○	○
Altered average rainfall					○	○	○	○				○							
Altered biological processes					○	○	○												
Stability of earthworks	○	○	○					○											
TEMPERATURE																			
Severe heat	○	○	○	○		○	○				●		○	○	○	●			
Severe cold, snow, ice	○	○	○	○		○	○	○			○		○						
Altered capacity or efficiency	○	○	○	○		○	○		○		●		○	○	○	●			
Altered average temperatures	○					○	○												
Subsidence and / or desiccation	○	○	○			○	○												
Altered biological processes						○	○	○											
Demand for service	○	○	○			○	○	○					○						
OTHER FACTORS																			
Lighting strike	○	○	○																
Humidity	○	○																	
Solar radiation											○								
Fog			○	○							○								
Wildfire	○	○	○										●				●	○	○
Damage to electricity as a result of water	○		○										○	○	○		○	●	○
Hurricanes, storms and wind damage	○	○	●	●		○	●	○	●	●	○		●	●	●		○	○	○

○ Impact
● High impact

Figure 8: Adapted from Dawson,(2015) as cited in OECD(2017) and Mckinsey(2019). Available at https://www.mckinsey.com/business-functions/sustainability/our-insights/will-infrastructure-bend-or-break-under-climate-stress.

Endnotes

[1] World Cities Report (2020) The value of sustainable urbanization. UNHabitat https://unhabitat.org/sites/default/files/2020/10/wcr_2020_report.pdf

[2] Lloyd's City Risk Index (2018) https://cityriskindex.lloyds.com/

[2] Coalition for Urban Transitions (2021) Seizing the Urban Opportunity https://urbantransitions.global/urban-opportunity/seizing-the-urban-opportunity/

[3] OECD Policy Responses to Coronavirus (Covid-19) https://www.oecd.org/coronavirus/policy-responses/building-back-better-a-sustainable-resilient-recovery-after-covid-19-52b869f5/

[4] IPCC (2012) 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. Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.). Cambridge University Press: Cambridge and New York. See http://ipcc-wg2.gov/SREX/images/uploads/SREXAll_FINAL.pdf

[5] McKinsey institute (2020) Will infrastructure bend or break under climate stress? https://www.mckinsey.com/business-functions/sustainability/our-insights/will-infrastructure-bend-or-break-under-climate-stress

[6] OECD Environment Policy Paper No.14 (2018) Climate-resilient Infrastructure http://www.oecd.org/environment/cc/policy-perspectives-climate-resilient-infrastructure.pdf

[7] Ranger, Nicola, Hallegatte, Stéphane, Bhattacharya, Sumana, Bachu, Murthy, Priya, Satya, Dhore, K., Rafique, Farhat, Mathur, P., Naville, Nicolas, Henriet, Fanny, Herweijer, Celine, Pohit, Sanjib and Corfee-Morlot, Jan (2011) An assessment of the potential impact of climate change on flood risk in Mumbai. Climatic Change, 104 (1). pp. 139-167. ISSN 0165-0009

[8] World Health Organisation Fact sheets – climate change and health (2020) https://www.who.int/en/news-room/fact-sheets/detail/climate-change-and-health

[9] United Nations Population Division (accessed 2021) https://www.un.org/development/desa/pd/themes/urbanization

[10] World Bank (2017) Forecasting Infrastructure Investment Needs https://blogs.worldbank.org/ppps/forecasting-infrastructure-investment-needs-50-countries-7-sectors-through-2040

[11] Meltzer, J, Blending climate funds to finance low-carbon, climate-resilient infrastructure, Brookings, June 2018, https://www.brookings. edu/research/blending-climate-fundsto-finance-low-carbon-climate-resilientinfrastructure/

[12] National Infrastructure Commission (2017) Infrastructure and Digital Systems Resilience https://nic.org.uk/app/uploads/CCCC17A21-Resilience-of-Digitally-Connected-Infrastructure-Systems-20171121.pdf

[13] S.G.González, S.D.Canto, J.S.Moreno Obtaining high preventive and resilience capacities in critical infrastructure by industrial automation cells (2020) International Journal of Critical Infrastructure Protection https://www.sciencedirect.com/science/article/abs/pii/S1874548220300196

[14] The critical role of infrastructure for the Sustainable Development Goals (2019) UNOPS https://unops.economist.com/wp-content/uploads/2019/01/ThecriticalroleofinfrastructurefortheSustainableDevelopmentGoals.pdf

[15] 2009 UNISDR terminology on disaster risk reduction at https://www.preventionweb.net/publications/view/7817

[16] United Nations Department of Economic and Social Affairs Sustainable Development https://sdgs.un.org/goals

[17] Lloyds Future Cities (2017) https://assets.lloyds.com/assets/pdf-arup-lloyds-arup-future-cities-2017/1/pdf-arup-lloyds-arup-future-cities-2017.pdf

[18] Arup in partnership with The Rockefeller Centre 2014a. City Resilience Framework Research Report - Volume 1: Desk Study. [online]. Available at: www.arup.com/~/media/Publications/Files/.../C/CRI_Research_Report_Vol1.ashx

[19] Global Facility for Disaster Reduction and Recovery https://www.gfdrr.org/en/publication/gfdrr-annual-report-2020

[20] Jerry Velasquez, Director, Division of Mitigation and Adaptation, Green Climate Fund, 2015 - https://www.linkedin.com/pulse/disaster-risk-reduction-resilience-jerry-velasquez

[21] Linkov, I., Bridges, T., Creutzig, F., Decker, J., Fox-Lent, C., Kröger, W., ... & Thiel-Clemen, T. (2014). Changing the resilience paradigm. Nature Climate Change, 4(6), 407-409.

[22] Jerry Velasquez, Director, Division of Mitigation and Adaptation, Green Climate Fund, 2015 - https://www.linkedin.com/pulse/disaster-risk-reduction-resilience-jerry-velasquez

23 Source: Chappin, E J. L. and van der Lei, T. 2014. "Adaptation of Interconnected Infrastructures to Climate Change: A Socio-Technical Systems Perspective." Utilities Policy 31:10–17.

[24] Da Silva, J. and Moench, M. 2014. City Resilience Framework [online]. Arup. Available at: https://assets.rockefellerfoundation.org/app/uploads/20140410162455/City-Resilience-Framework-2015.pdf

[25] Birtill. K (2019) Mass Displacement: Host Cities and Urban Systems. Arup. Available at: https://www.alnap.org/help-library/mass-displacement-host-cities-and-urban-systems

[26] Arup. 2014b. City Resilience Framework Research Report - Volume 2: Fieldwork Data Analysis. [online]. Available at: http://www.cityresilienceindex.org/wp-content/uploads/2016/05/Vol2-Fieldwork-Report.pdf

[27] Rinaldi, S.M., J.P. Peerenboom, and T.K. Kelly, 2001, "Complex Networks, Identifying, Understanding, and Analyzing Critical Infrastructure Interdependencies," IEEE Control Systems Magazine, December 2001, pp. 11–25, http://user.it.uu.se/~bc/Art.pdf

[28] Wei, D., Lu, Y., Jafari, M., Skare, P. M. & Rohde, K. Protecting smart grid automation systems against cyberattacks. IEEE Trans . Smart Grid 2, 782–795 (2011).

[29] Brunn, S. D., M. Hays-Mitchell, and D. J. Ziegler (2008). Cities of the World: World Regional Urban Development. Lanhma, MY: Rowman & Littlefield Publishers, Inc.

[30] Weiss, M.A.(2001). Productive cities and metropolitan economic strategy. Paper presented to the United Nations International Forum on Urban Poverty (IFUP). Fourth International Conference, Marrakech, Morocco, 16-19, October, 2001. Available at www.globalurban.org/prod_cities.htm.

[31] Gencer, E.A. (2013). "Natural disasters, urban vulnerability, and risk management: a theoretical overview." Pp.7-43 in The Interplay Between Urban Development, Vulnerability, and Risk Management: A Case Study of the Istanbul Metropolitan Area. edited by E. A. Gencer (ed.) New York: Springer.

[32] Report of the open-ended intergovernmental expert working group on indicators and terminology relating to disaster risk reduction (2017) United Nations General Assembly (UNGA) United Nations Office For Disaster Risk Reduction (UNDRR) https://www.preventionweb.net/publications/view/51748

[33] Vallejo, L. and M. Mullan (2017), "Climate-resilient infrastructure: Getting the policies right", OECD Environment Working Papers, No. 121, OECD Publishing, Paris, https://doi.org/10.1787/02f74d61-en.

[34] Rendall et al. 2011. Quantifying Transport Energy Resilience: Active Mode Accessibility. Transportation research record: Journal of the transportation research board. Volume to 242. Issue 1. Pages 72 - 80. https://doi.org/10.3141/2242-09

[35] World Bank. 2021. Inclusive Resilience: Inclusion Matters for Resilience in South Asia. Washington, DC: World Bank.

[36] NIST. 2020. Community Resilience Guide for Buildings and Infrastructure Systems: A Playbook.

[37] PIANC. 2020. Climate Change Adaptation Planning for Ports and Inland Waterways. The World Association for Waterborne Transport Infrastructure. https://www.pianc.org/publications/envicom/wg178

[38] OECD. 2018. Climate-resilient Infrastructure OECD Environment Policy Paper No. 14. http://www.oecd.org/environment/cc/policy-perspectives-climate-resilient-infrastructure.pdf

[39] United Nations Environment Programme (2021). International Good Practice Principles for Sustainable Infrastructure. Nairobi. https://wedocs.unep.org/bitstream/handle/20.500.11822/34853/GPSI.pdf

[40] Macleod, G. (2018) 'The Grenfell Tower atrocity: exposing urban worlds of inequality, injustice, and an impaired democracy.', City., 22 (4). pp. 460-489. https://doi.org/10.1080/13604813.2018.1507099

[41] ASCE. 2020. Sustainable Procurement for Infrastructure. https://ascelibrary.org/doi/book/10.1061/9780784483107

[42] C40 Cities. 2017. C40 Infrastructure Interdependencies and Climate Risks Report. https://unfccc.int/sites/default/files/report_c40_interdependencies_.pdf

[43] Invernizzi et al. 2020. Developing policies for the end-of-life of energy infrastructure: Coming to terms with the challenges of decommissioning. Energy Policy 144. https://www.sciencedirect.com/science/article/pii/S0301421520304067

[44] ICE. 2020. Enabling Better Infrastructure: 12 guiding principles for prioritising and planning infrastructure.

[45] Ash & Newth. 2007. Optimizing complex networks for resilience against cascading failure. Physica A: Statistical Mechanics and its Applications. Volume 380. Pages 673-683 https://doi.org/10.1016/j.physa.2006.12.058

[46] Nature-based solutions in Europe: Policy, knowledge and practice for climate change adaptation and disaster risk reduction (2021) European Environmental Agency https://www.eea.europa.eu/publications/nature-based-solutions-in-europe/

[47] IUCN (2020). Global Standard for Nature-based Solutions. A user-friendly framework for the verification, design and scaling up of NbS. First edition. Gland, Switzerland: IUCN https://portals.iucn.org/library/sites/library/files/documents/2020-020-En.pdf

[48] Somarakis, G., Stagakis, S., & Chrysoulakis, N. (Eds.). (2019). ThinkNature Nature-Based Solutions Handbook. ThinkNature project funded by the EU Horizon 2020 research and innovation programme under grant agreement No. 730338. doi:10.26225/ jerv-w202 at https://platform.think-nature.eu/system/files/thinknature_handbook_final_print_0.pdf

[49] Lamond & Everett. 2019. Sustainable Blue-Green Infrastructure: A social practice approach to understanding community preferences and stewardship. https://reader.elsevier.com/reader/sd/pii/S0169204618309770?token=7EE3840B7FBF29CF8D257A8EA162BAEA56BFEB995105110F5484BB816C5A6889CDE32987E35DFB7FFD9BEA46D485813C&originRegion=eu-west-1&originCreation=20210414114540

[50] Asian Development Bank (2016) Nature-based solutions for building resilience in towns and cities: Case studies from the Greater Mekong Subregion at https://www.adb.org/sites/default/files/publication/215721/nature-based-solutions.pdf

[51] The Journal of the Town and Country Planning Association ISSN 0040-9960 Published monthly (May 2019) Volume 88 Number 5https://www.tcpa.org.uk/Handlers/Download.ashx?IDMF=a70fd808-eee1-4b50-bb9d-805e5c017d26

[lii] Adapted from Dawson, (2015) as cited in OECD (2017) and Mckinsey (2019). Available at Impactofclimate changeon infrastructure types.Arup 2020.AdaptedfromDawson,(2015)ascited in OECD(2017)and Mckinsey(2019). Available at https://www.mckinsey.com/business-functions/sustainability/our-insights/will-infrastructure-bend-or-break-under-climate-stress.