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# Making India's Coastal Infrastructure Climate-Resilient: Challenges and Opportunities


## ABSTRACT

In recent years, India's coastal regions have become more vulnerable to multiple risks related to climate change. Intense and more frequent cyclones such as the recent Fani, Gaja and Hudhud as well as severe floods have caused massive devastation to the country's coastal states. While efficient disaster preparedness in many of these states has helped save many lives, there remain significant challenges in rebuilding damaged infrastructure and returning to normalcy after the disruptions. This paper assesses the vulnerability of India's coastal infrastructure to climate change impacts, examines the obstacles to building the climate resilience of such infrastructure, and recommends entry points at multiple levels of decision-making for fostering climate-resilient development.



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## I. INTRODUCTION

India has been witnessing increasingly intense and frequent climatic events and climate-induced natural disasters in recent times. The country's fragile coasts are particularly vulnerable. Intense cyclones such as the recent Fani, Gaja and Hudhud as well as severe floods have caused massive devastation to its coastal states, Odisha, Andhra Pradesh, Tamil Nadu and Kerala, respectively.[1] Many of these coastal states have upgraded their disaster preparedness and response mechanisms, instituting effective early warning systems and well-planned evacuation strategies. These measures have helped millions of people safely move to disaster shelters, thereby saving the lives of the vulnerable population of the sensitive coastal ecosystem.[2]

However, most of these states are facing significant challenges in rebuilding the critical infrastructure lost and damaged, and in recovering from the consequent disruptions caused by disasters.[3] The August 2018 floods in Kerala, for example, destroyed 280,000 houses, 140,000 hectares of standing crops, and about 70,000 kilometres of road network.[4] The total recovery needs of the State were estimated at INR 310 billion, according to the Post Disaster Needs Assessment (PDNA) conducted by the UN Agencies.[5] Similarly, the April 2019 cyclone Fani damaged 500,000 houses, 6,700 hospital buildings, and 100,880 lakh ha. of agricultural land. Electricity infrastructure was also damaged, bringing the total losses to INR 500 billion.[6] Studies[7] and the damage assessment report indicate that it will take the coastal states about five to 10 years to rebuild and recover.[8]

Scientists warn that the intensity and frequency of extreme weather events will only increase in the coming years. Given the highly climate-sensitive nature of India's coastal infrastructure, the question is

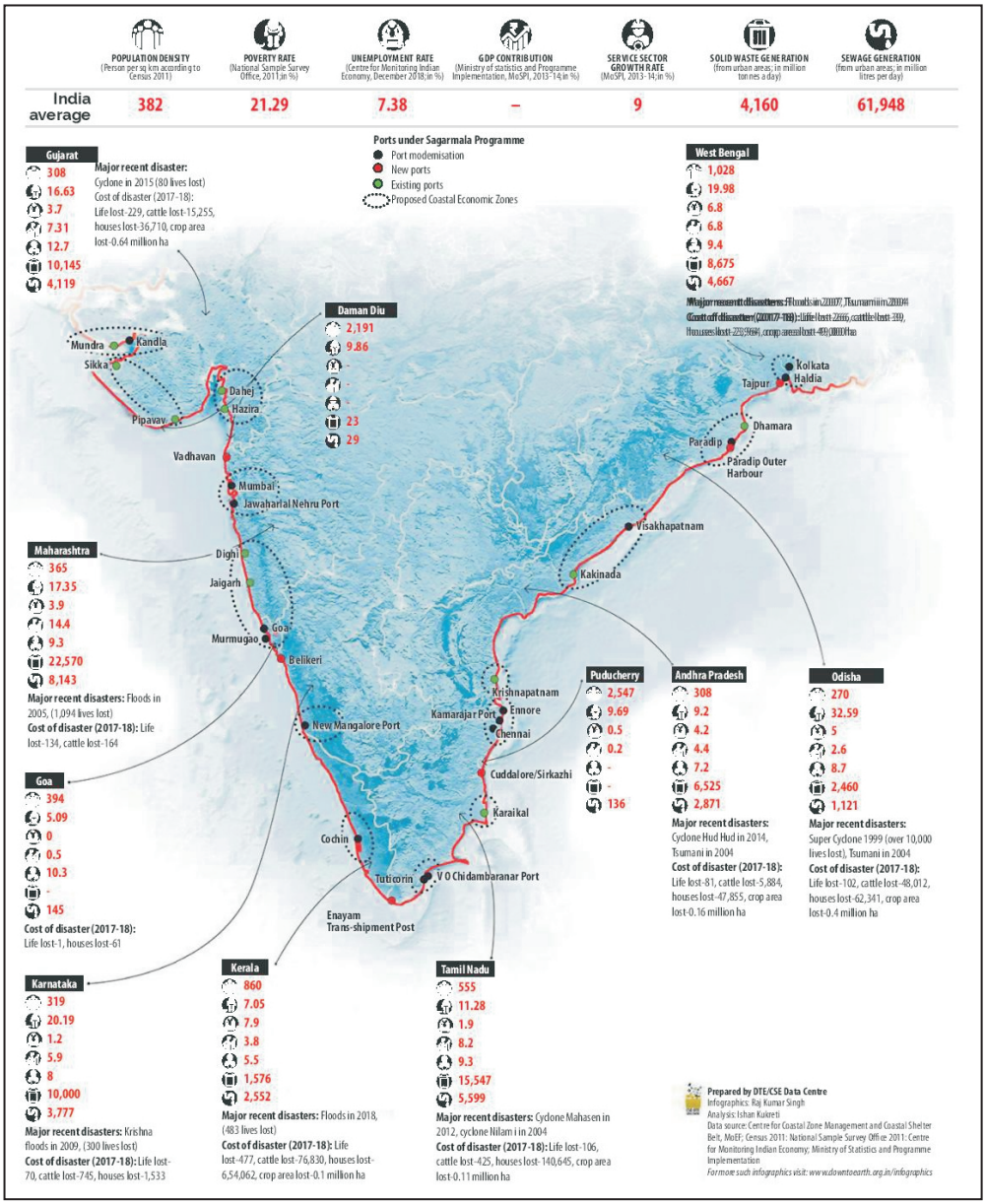
whether or not India's coastal infrastructure are equipped to withstand the impacts of these climate change-induced events. Do the coastal ecosystems have the capacity to cope and recover?

## II. CLIMATE CHANGE AND THE VULNERABILITY OF INDIA'S COASTAL INFRASTRUCTURE: AN OVERVIEW

India is the third worst-affected country due to climate-induced natural disasters.[9] The country's coastal regions, in particular, are highly vulnerable because of rapid urbanisation, high population densities and related economic activities such as agriculture, aquaculture, tourism, industries and trade. The 7,517-km-long coastline is home to 260 million people or one-third of India's population, who live in low-lying areas within 50 km of the sea coast and are perennially exposed to climate variabilities and extreme weather events.[10] (See Figure 1)

The 130 towns and 77 cities within India's 84 coastal districts[11] are of enormous socio- economic importance. Majority of the largest and most dense coastal urban agglomerations such as Mumbai, Kolkata, Chennai, and Vishakhapatnam are hubs of critical infrastructure and assets that contribute to the nation's economy and growth: transport and freight networks, road and rail corridors, industrial zones and parks, maritime and port facilities, petroleum industries, and refineries.[12] The nine coastal states, collectively, receive more than 60 percent of India's FDI (foreign direct investments) inflow.[13] Development gains, however, are being threatened by the impacts of climate change—including sea-level rise, floodings, storm surges and cyclones. An increase in greenhouse gas (GHG) emissions, predominantly from the economic activities, is projected to aggravate the impacts of climate change and the vulnerability of coastal ecosystems.[14]

**Figure 1.**




*Source: Down to Earth, 2019*[15]

Warming oceans leading to sea-level rise provide a source of thermal expansion of sea water, contributing to more intense and frequent

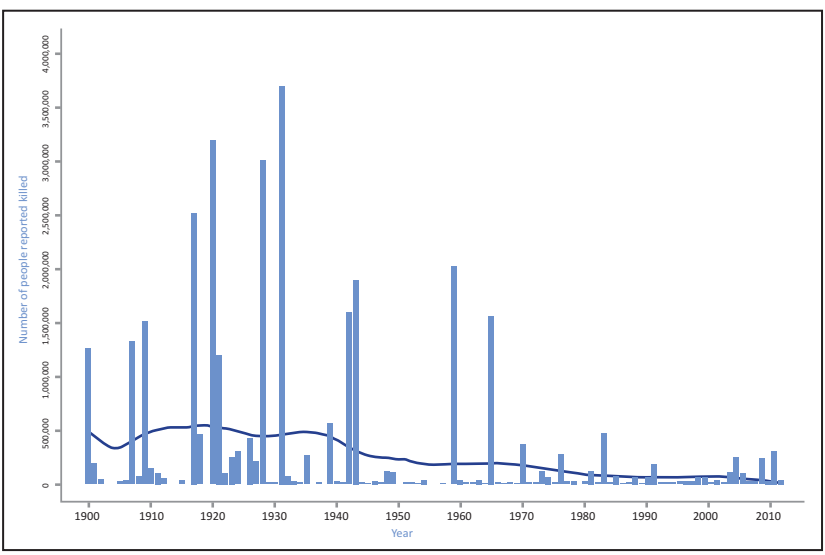
storm surges and cyclones[16] in the coastal regions. Between 1877-2005, a total of 283 cyclones made landfall in India's coastal regions; 106 of them were severe cyclones that occurred in a 50-km-wide strip on the east coast, and 35 were less severe ones on the west coast. In 19 severe cyclonic storms, the combined mortality rate exceeded 10,000.[17] In 1999 a super cyclone wreaked havoc in coastal Odisha, claiming more than 30,000 lives. India today is projected to be at 'very high' risk levels in terms of intensity of cyclones.[18] The mangroves ecosystem along the coastal regions that act as a natural barrier against cyclones and coastal erosion have become severely degraded and face even worse decline due to the cumulative climate change impacts.[19]

This is not to say that the governments in India's coastal states have been completely remiss. Following the devastating trail of extreme weather events such as the super cyclones Bob (1999) and Phalin (2013), these states have significantly upgraded their respective disaster response mechanisms. They established Disaster Management Authority (DMA), built cyclone and flood shelters, invested in early warning systems, created Disaster Rapid Action Force, conducted public awareness campaigns,[20] and created a disaster loss database under the Sendai Framework for Disaster Risk Reduction (SFDRR).[21] Consequently, there has been a dramatic decrease in the casualty count: over 10,000 in 1999; 24 in 2014 because of cyclone Hudhud; and 16 in 2019 due to cyclone Fani.[22]

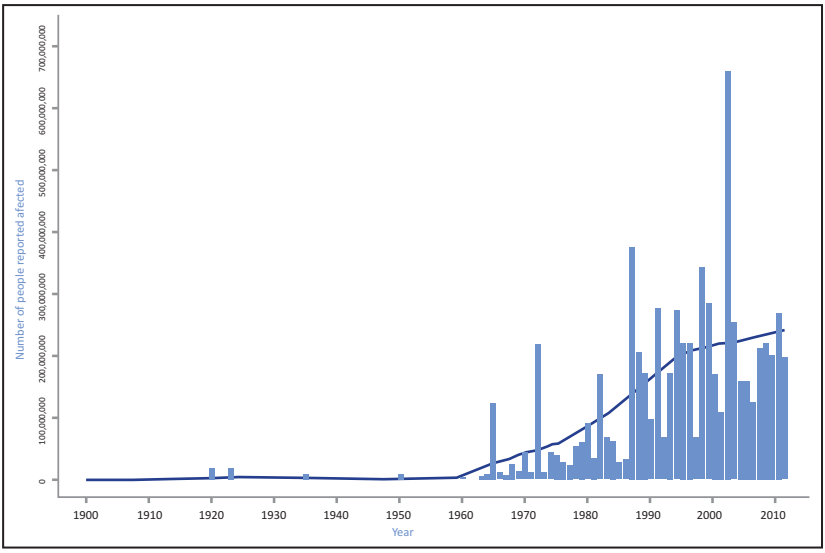
While the upgrade of disaster preparedness mechanisms in many of India's coastal states has led to significant reduction in the mortality rate, the number of people affected and the impacts on physical assets have remained unchanged.[23] (See Graphs 1a and 1b) The greatest impact of the extreme weather events are increasingly being felt in terms of the loss and damage to the critical infrastructure in India's coastal regions.[24]

For instance, the damage assessment figures indicate a total loss of 90,000 crores (approximately US$20 billion) due to the Hudhud cyclone that struck the east coast of India in 2014.[25] In the case of recent cyclone Fani, the first preliminary assessment report of the Odisha government suggests damages to 500,000 houses and 6,700 hospital buildings and 1.88 lakh hectares of agricultural land, while 3.4 million livestock perished. In the district of Puri and parts of Khurda and Bhubaneshwar, the electricity infrastructure has been totally devastated. Total losses have reached at least INR 50,000 crore. The damage to infrastructure has severely affected nearly 1.51 crore people spread over 16,659 villages in Odisha.[26] Reports suggest that it will take the Odisha government five to 10 years to rebuild the state from the loss and damage caused by cyclone Fani alone. Similarly, the 2018 floods in Kerala destroyed 280,000 houses and 140,000 hectares of standing crops, and damaged about 70,000 km of road network.[27] The total recovery needs of the State was estimated at 31,000 crores as per the Post Disaster Needs Assessment (PDNA) conducted by the UN Agencies.[28]

**Graph 1a. Number of People Killed by Natural Disasters, 1900-2011**



**Graph 1b. Number of People Affected by Natural Disasters, 1900-2011**




*Source: NIDM*[29]

Furthermore, India's coastline has already been affected by the sea level rise (SLR) that has been recorded at a rate of 2.5 mm per year since the 1950s. A 15 and 38 cm projected rise in sea level along India's coast by 2050 is likely to affect 5,763 sq km combined area of the coastal states, resulting in the submergence of coastal areas, floodings and an increase in tropical cyclones and storm surges, thereby threatening infrastructure (See Table 1). Gujarat and West Bengal are projected to be the most severely affected, with a loss of 1 metre land area to SLR.[30] The estimated economic costs from the impact of climate change to coastal infrastructure ranges from INR 2287 billion in the case of Mumbai to INR 3.6 billion for Baleshwar district of Odisha.[31] According to data from the Central Water Commission (CWC), the cost of damages from climate-related extreme weather events on infrastructure and housing has been INR 3,65,860 crore, or three percent of India's GDP. Poor or inadequate infrastructure such as drainage capacity of rivers, unplanned regulation and failure of flood control structures to withstand the climate impact, will further add to the vulnerability of coastal regions.[32]

**Table 1: Potential impact of 1metre sea level rise on India's coastal area and population**

| STATE/UNION TERRITORIES | COASTAL AREA (MILLION HECTARES) | | | POPULATION (MILLIONS) | | |
|---|---|---|---|---|---|---|
| | *TOTAL* | *LIKELY TO BE INUNDATED* | *PERCENTAGE* | *TOTAL* | *LIKELY TO BE AFFECTED* | *PERCENTAGE* |
| Andra Pradesh | 27.504 | 0.055 | 0.19 | 66.36 | 0.617 | 0.93 |
| Goa | 0.37 | 0.016 | 4.34 | 1.17 | 0.085 | 7.25 |
| Gujarat | 19.602 | 0.181 | 0.92 | 41.17 | 0.441 | 1.07 |
| Karnataka | 19.179 | 0.029 | 0.15 | 44.81 | 0.25 | 0.56 |
| Kerala | 3.886 | 0.012 | 0.3 | 29.08 | 0.454 | 1.56 |
| Maharashtra | 30.771 | 0.041 | 0.13 | 78.75 | 1.376 | 1.75 |
| Odisha | 15.571 | 0.048 | 0.31 | 31.51 | 0.555 | 1.76 |
| Tamil Nadu | 13.006 | 0.067 | 0.52 | 55.64 | 1.621 | 2.91 |
| West Bengal | 8.875 | 0.122 | 1.38 | 67.98 | 1.6 | 2.35 |
| Andaman and Nicobar Islands | 0.825 | 0.006 | 0.72 | 0 | 0 | 0 |
| India | 139.594 | 0.571 | 0.41 | 416.74 | 7.1 | 1.68 |

*Source: TERI, 1996*

## III. PLANNING CLIMATE-RESILIENT COASTAL INFRASTRUCTURE:[33] OPPORTUNITIES AND BENEFITS

The defining feature of climate-resilient infrastructure is that it is "planned, designed, built and operated in a way that anticipates, prepares for, and adapts to changing climate conditions. It can also withstand, respond to, and recover rapidly from disruptions caused by these climate conditions."[34] As extreme weather events caused by climate change are becoming more frequent and extreme in India's coastal regions, so is the level of disruption that they cause. It is therefore imperative for any coastal development plan to integrate measures towards building climate resilience. As a county still building much of its basic infrastructure, India has the opportunity to make the infrastructure in vulnerable coastal regions climate-resilient from the outset. This will incur no or little additional cost, and avoid costly retrofitting later.

Planning and investing in climate-resilient infrastructure would yield India and its coastal regions multiple benefits. It would help avoid losses during extreme weather events, unlock development potential, and produce economic, social, and environmental co-benefits.

### 3.1 Avoiding loss and damage

The value (in present terms) of risk to the global stock of manageable assets owing to climate change impacts is estimated to rise to upto US$43 trillion by 2105.[35] At the same time, the rapid growth in population and consequent urbanisation has led to an estimated rise in total global exposure to river and coastal flooding—from US$46 trillion in 2010 to US$158 trillion by 2050.[36] India is among the top five countries in the world that was most frequently affected by natural disasters between 2006-2015. According to the World Bank, over eight percent of India's landmass is susceptible to floods; almost 5,700 kilometres of the 7,500-km coastline is prone to cyclones; and 68 percent of the country's total territory is susceptible to drought episodes. India's average losses due to multi-hazard disasters are worth around US$9.8 billion, of which US$7.4 billion is lost due to floods alone.[37] A projected increase of 1-1.5°C in mean annual air temperature in India from 2016 to 2045 is likely to result in floodings, particularly in coastal regions, thereby causing huge damage to infrastructure.[38] India's overall government spending on adaptation to climate change was pegged at US$ 91.8 billion in 2013-14 alone.[39] According to the Asian Development Bank, the economic damage and loss from climate impact in India is projected to be around 1.8 percent of its GDP annually by 2050.[40]

For a middle-income country such as India that faces significant resource constraints, to begin with, incurring huge economic losses due to climatic calamities would significantly set the country back in terms

of development (See Table 2). Making the infrastructure of the most vulnerable coastal regions "climate-proof" would allow the resources to be utilised for constructive welfare projects and economic programmes.

**Table 2: Climate Change Impacts on Different Sectors**

| | Temperature changes | Sea-level rise | Changing patterns of precipitation | Changing patterns of storms |
|---|---|---|---|---|
| **Transport** | - Melting road surfaces and buckling railway lines<br>- Damage to roads due to melting of seasonal ground frost or permafrost<br>- Changing demand for ports as sea routes open due to melting of arctic ice | - Inundation of coastal infrastructure, such as ports, roads or railways | - Disruption of transport due to fooding<br>- Changing water levels disrupt transport on inland waterways | - Damage to assets, such as bridges<br>- Disruption to ports and airports |
| **Energy** | - Reduced efciency of solar panels<br>- Reduced output from thermal plants due to limits on cooling water temperatures<br>- Increased demand for cooling | - Inundation of coastal infrastructure, such as generation, transmission and distribution | - Reduced output from hydropower generation<br>- Disruption of energy supply due to fooding<br>- Insufcient cooling water | - Damage to assets - e.g. wind farms, distribution networks<br>- Economic losses due to power outages |
| **Telecoms** | - Increased cooling required for datacenters | - Inundation of coastal infrastructure, such as telephone exchanges | - Flooding of infrastructure<br>- Damage to infrastructure from subsidence | - Damage to above ground transmission infrastructure, such as radio masts |
| **Urban development** | - Increased cooling demand<br>- Reduced heating demand | - Inundation and increased food risk<br>- Changes in land use due to relocation of people living in exposed areas | - Risk of drought<br>- Flooding | - Damage to buildings<br>- Deaths and injuries |
| **Water** | - Increased need for treatment<br>- Increased evaporation from reservoirs | - Inundation of coastal infrastructure<br>- Salinisation of water supplies<br>- Decreased standard of protection ofered by coastal defences | - Increased need for water storage capacity<br>- Increased risk of river embankments being overtopped | - Damage to assets<br>- Decreased standard of protection ofered by food defences |

*Source: OECD, 2018[41]. For more comprehensive assessment refer to IPCC's Fifth Assessment Report*

## 3.2 Ensuring growth and development

India's coastal regions are of immense economic and strategic significance, as approximately 90 percent of their trade by volume (or 70 percent in terms of value) is carried out by sea.[42] The coastal

infrastructure that supports lives and livelihoods, including houses, hospital buildings, transport networks, ports and shipping industries, are therefore vital to sustaining growth and development.

Indeed, current investments for tomorrow's well-being could be wiped out by a disaster.[43] As a result, sectors refrain from investing in potentially revenue-generating assets nor in long-term planning. The background risk of a disaster causes a rise in risk aversion, in turn preventing higher-return investments. Consequently, innovation is stifled, jobs are not created and development opportunities are lost.[44] Large firms move to locations that offer safer operating environments; this adds to the economic difficulties of the coastal regions.[45]

Reducing the burden of background risk by increasing the resilience of infrastructure would generate benefits that extend across sectors to the macroeconomic level. For instance, protecting coastal regions, towns, business districts, or ports with flood protection infrastructure, will foster economic activity, long-term planning and capital investments. In turn, a boost to entrepreneurship, innovation and productive investments would aid India's overall growth and development.

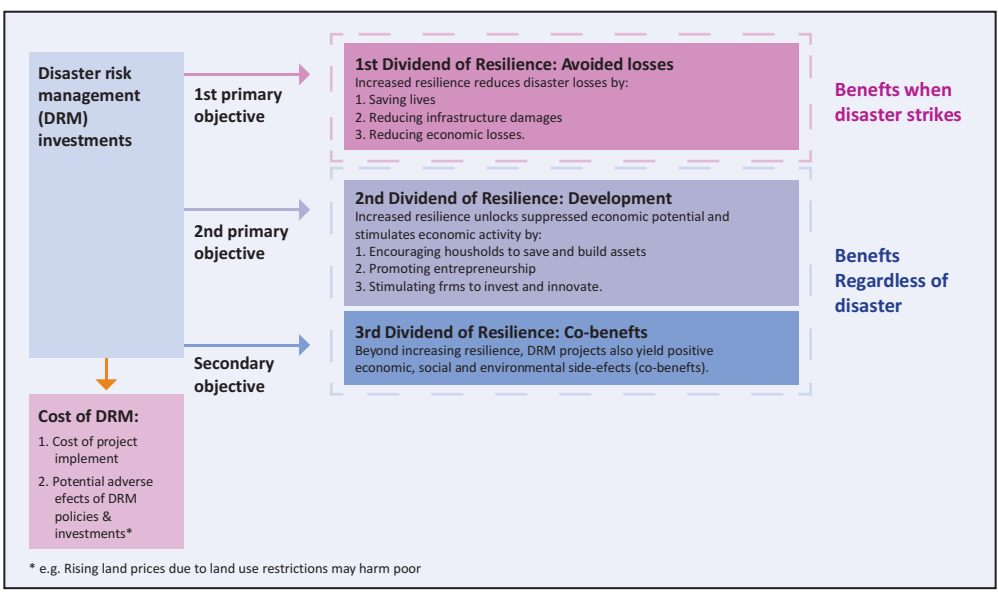
### 3.3 Co-benefits

Aiming for resilient infrastructure in coastal regions will deliver co-benefits that are not related to extreme weather events. For instance, building new resilient infrastructure or retrofitting existing ones would create direct employment opportunities for the coastal communities. Flood protection infrastructure would create provision of reliable water supplies and hydroelectricity. A study of community-based adaptation measures has found, for example, that boats that had been purchased initially for evacuation purposes were then used as fishing vessels;

evacuation shelters were used for community meetings or as schools; and raised water wells provided clean water throughout the year.[46] The installation of dedicated irrigation systems to overcome the impact of droughts has also helped farmers to increase their productivity and output, while also reducing soil erosion and deforestation by optimising previously inefficient farming practices.[47] Other co-benefits may be more indirect: for one, improving the resilience of transport networks for commercial activity may also improve human mobility to access employment.[48]

Similarly, community participation in developing and managing climate-resilient infrastructure may also generate significant social benefits. The local government's reliance on communities for knowledge, communications, vehicles, storage facilities and labour, can strengthen community cohesion, as well as local-state-society relations even during non-emergency situations. Measures to build resilience can therefore contribute significantly to social welfare and inclusiveness.[49]

**Figure 2. Benefits of Climate-Resilient Infrastructure**




*Source: Adapted from Tanner et al., "The Triple Dividends of Resilience," 2015, ODI*

## IV. CHALLENGES IN MAINSTREAMING CLIMATE RESILIENCE IN INFRASTRUCTURE PLANNING AND DEVELOPMENT

The coast of India is confronted with a host of challenges that it must address to make its infrastructure resilient to climate-induced natural hazards. This section examines these crucial obstacles: liberalisation of coastal regulations; lack of scientific data and regulatory frameworks; unplanned cities and urbanisation; inadequate capacities of municipal councils; and lack of funds.

### 4.1 Liberalisation of coastal zone regulations

The Union Cabinet approved the Coastal Regulation Zone Notification, 2018 which, according to official statements, "will lead to enhanced activities in the coastal regions thereby promoting economic growth while also respecting the conservation principles of coastal regions." [50] Environment activists, however, say the notification "dilute(s) India's protection system for the fragile ecology and open(s) it up for large-scale development projects." Since India's coastline is extremely vulnerable to climate change impacts such as erosion, cyclones and floods, allowing for infrastructure development and construction along the shoreline will further heighten the vulnerability. By opening up 6,068 km of mainland coastline for more commercial activities, India's own regulation has put at risk the sensitive ecology and infrastructure that are already vulnerable to extreme weather events and sea level rise.[51]

Since the aftermath of the 2004 tsunami,[#] the primary purpose of India's coastal zone regulation (CRZ) has been to regularise population and commercial pressure near the High Tide Line (HTL) by drawing

# 'A magnitude 9.1 earthquake struck beneath the Indian Ocean near Indonesia, generating a massive tsunami that claimed more than 230,000 lives in fourteen different countries, one of the deadliest natural disasters ever recorded.'

classification depending on land use or sensitivity in order to save the region from significant loss and damage.[52] In reality, however, the CRZ has been more violated than followed. The coastal ecology is becoming extremely volatile, with changing coastline due to climate change impacts. In such a context, allowing denser construction closer to the HTL would expose infrastructure to increased risk of the projected intense extreme weather events, thereby increasing the vulnerability of the coastal populations.

### 4.2 Uncertainties in modelling future climate scenarios

Policy planners at the national and subnational levels in the coastal region would require definite risk assessment and data of time, probability, occurrence, and the degree of potential hazard to different infrastructure, to be able to plan for new infrastructure or retrofit existing ones. These assessments are either not available with the government or are not in a useable format, that could inform public policies and decisions.[53] Moreover, there are inherent uncertainties in modelling how the climate, and other factors affecting infrastructure resilience, will evolve in the future. For example, assessments for sea level rise (SLR) project scenarios for 100 years, whereas development planning is carried out considering a much shorter 10–15-year horizon.[54]

### 4.3 Lack of inventory/database system

To plan for resilient infrastructure, it is imperative for policymakers and planners to have comprehensive information on the infrastructure's design details, age, maximum capacity, and location. However, no Indian state maintains up-to-date records of their current infrastructure. The data on infrastructure and services in India is generally spread across various departments.[55] In the absence of a single

repository where the data is either inventoried or maintained, it would be difficult for the decision-makers to use such data to formulate strategic plans and designs.

### 4.4 Lack of integration of climate concerns in land use planning and project planning

The environment and sustainability concerns have just begun to be mainstreamed in master and land use planning processes in the coastal cities. National government schemes like the Jawaharlal Nehru National Urban Renewal Mission (JNNURM)—since re-introduced as Atal Mission on Rejuvenation and Urban Transformation (AMRUT)—have been channelling financial resources for urban infrastructure development.[56] The JNNURM scheme, with an investment of about US$ 20 billion on urban infrastructure development over a period of seven years, primarily focused on provision of housing and basic urban services.[57] It did not expressly stress on making the newly developed infrastructure in coastal cities climate-resilient. Nor does the AMRUT scheme, which envisions an investment to the tune of about US$ 7 billion for five years—it focuses largely on water supply, sewerage, transport and green spaces.[58] The risks related to climate change and its impact on infrastructure are yet to be integrated in the urban development planning paradigm in coastal India. With exceptions to small-scale implementation of programmes by a few coastal states such as the Heat Action Plan developed by Ahmedabad Municipal Corporation, the early warning system for floods developed by Surat Municipal Corporation, or using rainwater harvesting for recharging borewells in Solapur, the focus of a majority of city planning has remained on infrastructure development for better service delivery. Climate concerns come as secondary benefits.[59]

## 4.5 Potential misalignments and non-compliance with policies

Majority of infrastructure planning in coastal states such as water, sewage, telecommunication and roads, lie with various government departments that have no integration point for multi-sectoral planning.[60] Issues of jurisdiction and overlapping policies and mandates of government agencies often interfere with the effective implementation of resilience-building measures in development plans.

Given the complexity of challenges, the respective governments across the national and subnational levels must work in a systematic manner towards a coordinated policy response, roadmap and action plan. Stringent mandates, mechanisms and institutional arrangements are required to address these barriers. Ensuring collaboration between the public sector, infrastructure owners and operators, professional associations, investors and engineers is critical in planning for new infrastructure and retrofitting the existing ones. Investing in and integrating climate-resilient infrastructure in development and policy plans would yield the country's coastal regions a range of dividends.

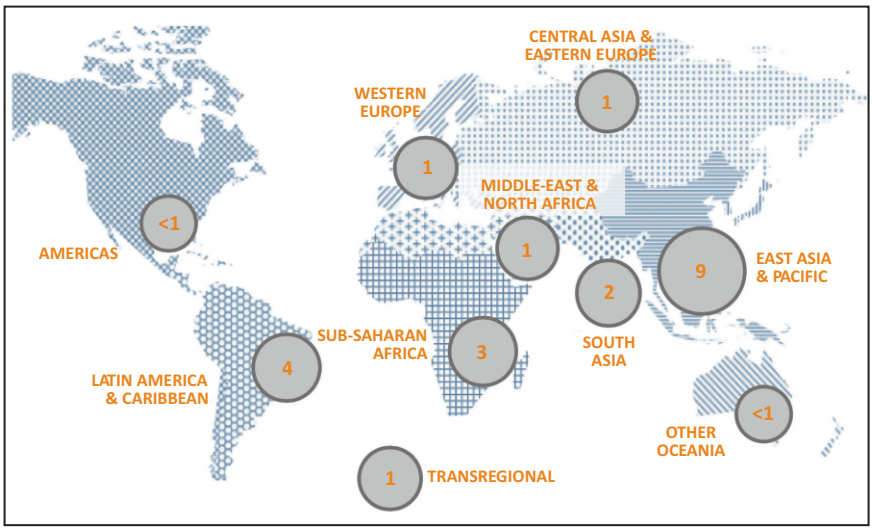
Moreover, one of the major reasons for the vulnerability of India's infrastructure to severe weather events is the non-compliance with national guidelines and lack of adequate by-laws. The *Model Building Bye-laws 2016* of the Ministry of Housing and Urban Affairs provides for risk classification of buildings and climate-resilient construction;[61] however, most of the venerable cities do not adhere to the provisions.

## 4.6 Gaps in financing for resilience

India's economy has suffered a massive US$ 79.5-billion loss due to climate-related disasters in the last 20 years.[62] Ironically, investments in resilience-building is yet to be reflected in the majority of policy and practice by governments, aid agencies, communities or businesses (World

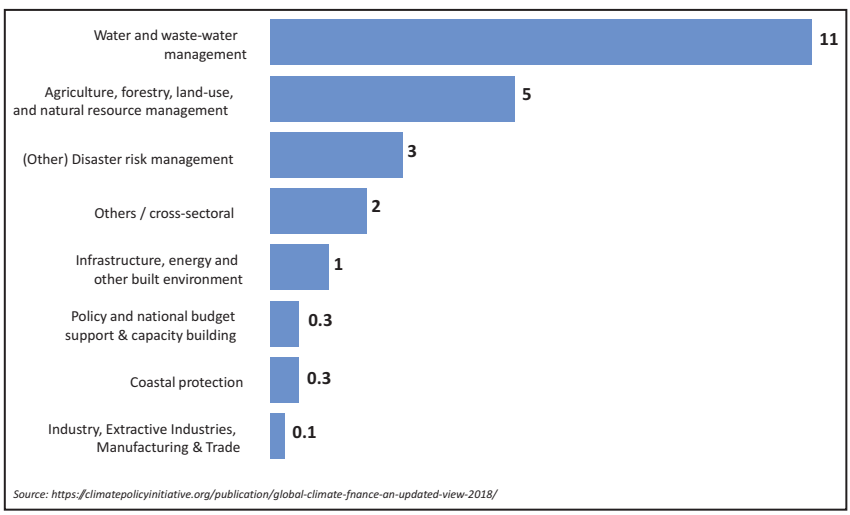
Bank and United Nations, 2010).[63] In terms of disaster management, data indicate that expenditures on disaster response are always higher than those directed at prevention measures such as resilience-building. For every US$7 spent on relief, US$1 is spent on risk reduction.[64]

**Figure 3. Adaptation finance by region (2015-16 average, in USD billion)**




*Source: Climate Policy Initiative, 2018*[65]

**Graph 2: Adaptation finance by sector (2015-16 average, in USD billion)**




*Source: Climate Policy Initiative, 2018*[66]

There is no available data on the investments and expenditure in building climate-resilient infrastructure in India. The Disaster Management Act 2005 mandated the creation of a Disaster Response and Mitigation Funds at the National, States and District levels,[67] clearly reflecting prioritisation of disaster response and mitigation over resilience-building activities. Moreover, the funding needs for disaster management activities are designed to be integrated within the regular budgeting of line ministries, addressed at various administrative scales, and are allocated for both risk reduction and relief-oriented funds.[68] There is no mainstreaming of a dedicated disaster resilience fund. The lack of funds specifically aimed at creating resilient infrastructure is a major roadblock for putting risk-resilience plans into operation, while making it complex for other departments to mainstream concerns about climate resilience.[69]

The impacts of climate change are projected to increase the demand of investment required for development infrastructure such as flood defences, water supply and sanitation.[70] It is estimated that US$1.7 trillion will be required annually to meet demand for new infrastructure in Asia over the next 12 years, including US$200 billion to ensure that new infrastructure is resilient to disasters and climate-related events.[71] The long-lived nature of infrastructure assets means that decisions made now will lock-in vulnerability if they fail to consider these impacts.[72] Therefore, it is critical for developing countries such as India to see the building of climate-resilient infrastructure not as an additional expense but as an opportunity to create shared value for the economy and society. Developing infrastructure plans of the coastal states based on their different climate vulnerability needs would allow policymakers to gain a strategic view and aid in designing investment pathways that address sustainable and resilient development.

# V. RECOMMENDATIONS: ENTRY POINTS FOR CREATING CLIMATE-RESILIENT COASTAL INFRASTRUCTURE

## 5.1 Regulatory Mechanisms

The lack of enabling legislations or the absence of institutional frameworks prevents the implementation of climate-resilient development measures in coastal regions. The governments, both at the centre and states must formulate appropriate zoning regulations, building by-laws and land use restrictions to conserve the coastal ecosystems and protect its critical infrastructure from future climate impacts. Since there are overlaps in the roles of various sector-wise ministries and departments in infrastructure planning,[73] integrating resilience measures in infrastructure would require the growth of multi-stakeholder partnerships and interventions. For instance, under the Asian Cities Climate Change Resilience Network's (ACCCRN) intervention, the coastal city of Surat in the state of Gujarat established the country's pioneering institution, the Urban Health and Climate Resilience Centre (UHCRC) within Surat Municipal Corporation's (SMC) Health Department to make the health systems and infrastructure resilient to projected climate impacts.[74]

Given the frequency and intensity of risk, it is imperative for densely populated coastal regions to encourage decentralised management of supplementary infrastructure through statutory processes. For instance, rising sea levels will lead to increased flooding and erosion of coastal dump sites that are located in low-lying swampy areas, thereby causing further pollution of coastal waters.[75] Decentralised treatment of wastes at the ward/ district level would be an effective way to address the risk and disruptions caused by unmanaged wastes at the time of disaster events. However, it is important that the relevant supporting policies must include appropriate institutional mechanisms for effective

implementation. A government-NGO (non-governmental organisation) partnership can assist vulnerable communities in learning the operation, maintenance, and management of infrastructure.

### 5.2 Increased role of knowledge

Technical assessments through modelling of climate change impacts and vulnerability mapping is an extremely important tool that supports policy decision-making on infrastructure design, planning and locations. Generating analyses on cyclones and storm surges, or flood modelling would help in a holistic evaluation of future risks.[76] For instance, a detailed flood modelling of coastal zones would allow planners to select design features based on future vulnerability scenarios. Major loss and damage faced by India's coastal regions during extreme weather events are due to its impact on critical infrastructure such as damage to equipment, and disruption of transport networks and services such as waste management. Therefore, constant generation and update of knowledge on various kinds of assessments—such as local topography, drainage flow patterns and higher vertical elevation of sites—are critical for the region's resilience building. Uptake of detailed regional climatological studies could identify sector-specific vulnerabilities and guide micro-level design interventions required to build the resilience of infrastructure assets.[77] This could also help analyse the cumulative impact that damage to one infrastructure sector can have on others, state functions and populations.

India already has an excellent institutional framework for predicting disasters. The Indian Space Research Organisation (ISRO) and National Remote Sensing Agency (NRSA) provide satellite eyes capable of high-resolution imaging of weather systems while the India Meteorological Department (IMD) carries out their real-time monitoring. The GSI

maps out the high-risk areas and can effectively predict tsunamis. These institutional climate capabilities should be collectively mobilised to create a comprehensive approach that could guide the design, plan and delivery on resilient infrastructure building. Access to the knowledge of traditional or local practices of resilience building and their dissemination, as well as encouraging adoption of diverse and locally appropriate techniques for vulnerable coastlines would be crucial. Each of the disaster events that the coasts face are opportunities to collect detailed data and carry out simulations and analysis of their impact on major and critical infrastructure.[78] A well-planned collaboration between government, academia and industry to get the best learning out of such events would benefit the state as well as the country.

### 5.3 Innovative Financing

Climate-resilient coastal infrastructure development is a major challenge for India given the enormous funding requirements. The key is in examining the sources and modalities of financing. While low-cost public finance plays a vital role in the initial stages due to associated risks, mobilisation of private capital for investing in resilient infrastructure is extremely important. The funds available with institutional investors such as pension funds, insurance premiums, and sovereign wealth funds, are crucial supplementary sources of funding. However, private investors make decisions based on profitable and higher returns. Coastal regions are projected as 'high risk' zones, thereby making the flow of investments from the private sector extremely difficult.[79]

There is a need therefore for 'out of the box' solutions as well as institutional innovations for bundling risks and returns. To incentivise private investors, institutional capacity to develop financially viable project proposals must be strengthened; incentive structures in

contracts in the form of guarantees against exchange rate volatility need to be devised; and investment-related dispute resolution and proper sequencing of funding plans at phases of the project cycle should be made more efficient. Further, it is important to get the private players to enter into long-term partnerships with the Multilateral Development Banks and Development Financial Institutions to work on various models of innovative financing for resilient and sustainable infrastructure.[80]

Besides attracting large investments, it is also important for the government to initiate policy reforms by incorporating environment and sustainability concerns in every phase of the project cycle as well as the budgeting processes. This would require institutionalisation and implementation of measures including the phasing out of wasteful subsidies such as fossil fuels and introducing 'green taxes' that could boost government revenues.[81]

### 5.4 Innovations in technology, standards and governance

To protect the longevity and performance of India's coastal infrastructure from damage due to SLR and extreme weather, there is a need to adopt innovative measures that involve elevating road embankments, water treatment works, and enhancing design and maintenance standards. Moreover, integrating innovative processes such as improved equipment / materials in construction and operations, environmentally optimised road designs using local and marginal materials, could reduce the cost of lifecycle, increase durability and improve long-term performance of infrastructure.[82]

Incorporating global standards on resilience and sustainability, that could assess environmental, social and governance (ESG) performance and impact of infrastructure projects is crucial to monitor resilience

building. The framework for quality assessment and standardisation could be adopted from SuRe, a multi-stakeholder, inclusive, transparent, accessible and holistic standard for sustainable and resilient infrastructure that is jointly led by Global Infrastructure Basel (GIB) and Natixis; and the World Standards Cooperation — a high-level collaboration between the IEC (International Electro-technical Commission), ISO (International Organization for Standardization) and ITU (International Telecommunication Union). These standards are supported by multilateral organisations and public sector bodies [OECD, European Investment Bank (EIB), ICLEI, CREAM Europe and FOEN], financiers (Erste Bank Group and Mirova), the IDFC Foundation (Infrastructure Development Finance Company Ltd, India's leading integrated infrastructure financier), non-governmental organisations (NGOs) and civil society (WWF and GIP Pacifico) and consultants (BASE, FIDIC, CAPEC and Quantis Switzerland).[83]

While innovations to foster resilient infrastructure is a priority, there is a need for creating standards, codes and manuals to integrate state-of-the-art engineering technologies. There is also the need to promote the use of science and technology applications such as Geographical Information Systems (GIS), geological-geographical and hydrological research capacities that can improve risk and vulnerability assessments.

As communities are the direct and most valuable stakeholders of resilient infrastructure, there is a need to find a sense of local ownership that the infrastructure projects would attract. Sustainable and resilient infrastructure calls for integration of environmental, social and governance factors into the planning of projects. Therefore, stakeholder consultation process is important to assess the needs, identify the opportunities and ensure the inclusion of local communities.

### 5.5 Capacity building and awareness generation

Capacity building at all levels has to be taken up in terms of state and city level decision-makers, community, and key stakeholders in the cities. Sensitisation and awareness generation amongst the citizens is also an integral step for city-level resilience planning. Strong community support and community demand can often lead to building consensus at the level of the decision-makers and planners.

## VI. CONCLUSION

Half of the infrastructure needed in Asia by 2050 is yet to be built. It is estimated that, globally, US$6 trillion needs to be invested in infrastructure every year until 2030 to meet current demands. Given the importance of India's coastal regions to the country's economy and growth, massive investments would be required for building even the most basic of essential infrastructure. This level of investment provides a window of opportunity to ensure that all new infrastructure is made resilient to withstand future shocks, including those brought about by a changing climate.

As climatic variabilities and extreme weather events are becoming the new normal in an increasingly climate-constrained world, it is important for a developing country such as India to invest in making its infrastructure climate-resilient, if it has to protect the development gains it has achieved so far. It is imperative to build climate-resilient infrastructure and services to equip coastal states to withstand the impacts of extreme events such as floods, cyclones, and storm surges. Given the multiple sustainable development challenges that already cost India significant amounts of resources, building climate-resilient infrastructure will aid in the achievement of goals set by the Paris Agreement, as well as the Sendai Framework for Disaster Risk Reduction. ORF

## ENDNOTES


1. "Cyclone Fani: Indians shelter from powerful storm," *BBC News*, May 03 2019. Accessed on June 02, 2019. https://www.bbc.com/news/world-asia-india-48121606

2. Aparna Roy and Biplob Chatterjee, "After a month of cyclone Fani Odisha remains shattered, are we a resilient enough state to face a natural disaster?," *Observer Research Foundation*, June 04, 2019. Accessed June 20, 2019. https://www.orfonline.org/expert-speak/after-a-month-of-cyclone-fani-odisha-remains-shattered-are-we-resilient-enough-state-to-face-a-natural-disaster-51632/

3. Anumita Roychowdhury, "Rebuild to tame cyclones," *Down to Earth*, May 06, 2019. Accessed June 02, 2016. https://www.downtoearth.org.in/blog/natural-disasters/rebuild-to-tame-cyclones-64345

4. Pinarayi Vijayan, "Resilient Rebuilding – Lessons from the Kerala Floods," *The Hindu*, May 15, 2019. Accessed June 04, 2019. https://www.thehindu.com/news/national/kerala/resilient-rebuilding-lessons-from-the-kerala-floods/article27134928.ece

5. United Nations, Asia Development Bank, The World Bank and European Union, "Kerala Post Disaster Needs Assessment Floods and Landslides - August 2018," *United Nations Development Programme*, October 2018. https://www.undp.org/content/undp/en/home/librarypage/crisis-prevention-and-recovery/post-disaster-needs-assessment—kerala.html

6. "Cyclone Fani caused loss of over Rs 9,000 crore in Odisha; 1.6 crore people affected," *Business Today*, June 7, 2019. Accessed June 15, 2019. https://www.businesstoday.in/current/economy-politics/cyclone-fani-news-odisha-fani-cyclone-disaster-total-loss-due-to-cyclone-fani/story/354287.html

7. Tripathi, Prakash. "Flood disaster in India: an analysis of trend and preparedness." *Interdiscip J Contemp Res* 2, no. 4 (2015): 91-98.

8. United Nations, Asia Development Bank, The World Bank and European Union, "Kerala Post Disaster Needs Assessment Floods and

Landslides - August 2018," *United Nations Development Programme*, October 2018. https://www.undp.org/content/dam/undp/library/Climate%20and%20Disaster%20Resilience/PDNA/PDNA_Kerala_India_Executive_Summary.pdf

9. "India third worst-hit country by natural disasters: Antonio Guterres," *The Economic Times*, September 19, 2017. Accessed 04 June 2019. https://economictimes.indiatimes.com/news/politics-and-nation/india-third-worst-hit-country-by-natural-disasters-antonio-guterres/articleshow/60755819.cms

10. Senapati, Sibananda, and Vijaya Gupta, "Climate change and coastal ecosystem in India: Issues in perspectives," *International Journal of Environmental Sciences* 5, no. 3 (2014): 530.

11. Sharma, Divya and Raina Singh "Towards a Policy for Climate Resilient Infrastructure and Services in Coastal Cities," *The Energy and Resources Institute*, Policy Brief (2015).

12. Nair, K. Shadananan. "An Assessment of the Impact of Climate Change on the Megacities of India and of the Current Policies and Strategies to meet Associated Challenges," *In fifth urban research symposium*, pp. 1-10. 2009.

13. Senapati, Sibananda, and Vijaya Gupta. "Climate change and coastal ecosystem in India: Issues in perspectives," *International Journal of Environmental Sciences* 5, no. 3 (2014): 530.

14. Change, IPCC Climate, "Synthesis Report Summary for Policymakers. 2014." URl: https://www. ipcc. ch/pdf/assessment-report/ar5/syr/AR5_SYR_FINAL_SPM. pdf (2014).

15. Ishan Kukreti, "Coastal Regulation Zone Notification: What development are we clearing our coasts for," *Down to Earth*, February 04, 2019. Accessed June 05, 2019. https://www.downtoearth.org.in/coverage/governance/coastal-regulation-zone-notification-what-development-are-we-clearing-our-coasts-for-63061

16. Mimura, Nobuo. "Sea-level rise caused by climate change and its implications for society," *Proceedings of the Japan Academy*, Series B 89, no. 7 (2013): 281-301.

17. Rana, Duni Chand, and Himachal Pradesh Secretariat. "Current Status of Emergency Response System (ERS) in India and Model ERS Based on International Best Practices," Final Research Report, *Asian Disaster Reduction Center (ADRC), Visiting Researcher Program FY2012B*. https://www.adrc.asia/aboutus/vrdata/finalreport/2012B_IND_fr.pdf

18. National Disaster Management Guidelines, Management of Cyclones. *National Disaster Management Authority, Government of India*, 2008. Available at: https://ndma.gov.in/images/guidelines/cyclones.pdf

19. Senapati, Sibananda, and Vijaya Gupta. "Climate change and coastal ecosystem in India: Issues in perspectives." *International Journal of Environmental Sciences* 5, no. 3 (2014): 530

20. United Nations Development Programme, "Preparing for Disaster: Lessons from Phailin Response," *UNDP* (2015) https://reliefweb.int/sites/reliefweb.int/files/resources/UNDP%20-%20Preparing%20for%20Disaster%20-%20Lessons%20from%20Phailin%20Response.pdf

21. Aparna Roy and Biplob Chatterjee, "After a month of cyclone Fani Odisha remains shattered, are we a resilient enough state to face a natural disaster?," *Observer Research Foundation*, June 04, 2019. Accessed June 20, 2019. https://www.orfonline.org/expert-speak/after-a-month-of-cyclone-fani-odisha-remains-shattered-are-we-resilient-enough-state-to-face-a-natural-disaster-51632/

22. Mangroves for the Future (MFF) Small Grant Facility (SGF) project, "Role of coastal ecosystems in enabling resilience of coastal communities post a natural disaster," Implemented by Institute of Economic Growth. December 2014 – January 2016. https://www.mangrovesforthefuture.org/assets/Repository/Documents/IEF-SGF-Final-Technical-Report.pdf

23. Aparna Roy and Biplob Chatterjee, "After a month of cyclone Fani Odisha remains shattered, are we a resilient enough state to face a natural disaster?," *Observer Research Foundation*, *June 04, 2019*. Accessed June 20, 2019. https://www.orfonline.org/expert-

speak/after-a-month-of-cyclone-fani-odisha-remains-shattered-are-we-resilient-enough-state-to-face-a-natural-disaster-51632/

24. National Intelligence Council, United States, "India: The Impact of Climate Change to 2030- A Commissioned Research Report," *Joint Global Change Research Institute and Battelle Memorial Institute, Pacific Northwest Division*, April 2009. https://www.dni.gov/files/documents/climate2030_india.pdf

25. A Rajendra Krishna, "Urban resilience and recovery of hud hud cyclone in Visakhapatnam: A leadership approach," *Centre for Cities Development and Coordination*, 2015. http://www.ccdcindia.in/hud/hudhudbook.pdf

26. "Cyclone Fani caused loss of over Rs 9,000 crore in Odisha; 1.6 crore people affected," *Business Today*, June 7, 2019. Accessed on: June 15, 2019. https://www.businesstoday.in/current/economy-politics/cyclone-fani-news-odisha-fani-cyclone-disaster-total-loss-due-to-cyclone-fani/story/354287.html

27. Official Website of the Chief Minister of Kerala. Address by Pinarayi Vijayan, Hon'ble Chief Minister of Kerala at the Opening Session of World Reconstruction Conference held at Geneva on May 13, 2019. https://www.keralacm.gov.in/2019/07/02/geneva-listened-stubborn-voice-rebuilding-kerala/

28. United Nations, Asia Development Bank, The World Bank and European Union, "Kerala Post Disaster Needs Assessment Floods and Landslides - August 2018," *United Nations Development Programme,* October 2018. https://www.undp.org/content/undp/en/home/librarypage/crisis-prevention-and-recovery/post-disaster-needs-assessment—kerala.html

29. National Institute of Disaster Management (NIDM), Disaster Trends, *Ministry of Home Affairs, Government of India*. https://nidm.gov.in/PDF/Disaster_trends.pdf

30. Senapati, Sibananda, and Vijaya Gupta, "Climate change and coastal ecosystem in India: Issues in perspectives," *International Journal of Environmental Sciences* 5, no. 3 (2014): 530

31. Dinda, Soumyananda, ed., "Handbook of Research on Climate Change Impact on Health and Environmental Sustainability," *IGI Global*, 2015.

32. Akshit Sangomla, "Floods damage 55,000 houses, kill 511 people this monsoon," *Down to Earth*, July 18, 2018. Accessed June 03, 2019. https://www.downtoearth.org.in/news/natural-disasters/floods-damage-55-000-houses-kill-511-people-this-monsoon-61168

33. A comprehensive definition of infrastructure includes both traditional types of infrastructure (everything from energy to public transport, buildings, water supply and sanitation) and, critically, also natural infrastructure (such as forest landscapes, wetlands and watershed protection).

34. Michael Mullan, "Climate-resilient Infrastructure," *OECD Environment Policy Paper* No. 14, 2018.

35. The Economist Intelligence Unit, "The cost of inaction: Recognising the value at risk from climate change," *The Economist*, 2015. https://www.eiuperspectives.economist.com/sites/default/files/The%20cost%20of%20inaction_0.pdf

36. Jongman, Brenden, Philip J. Ward, and Jeroen CJH Aerts. "Global exposure to river and coastal flooding: Long term trends and changes," Global Environmental Change 22, no. 4 (2012): 823-835.

37. "World Bank's India Disaster Risk Management Program, India Brochure," The World Bank and GFDRR. http://siteresources.worldbank.org/INTSOUTHASIA/Resources/2234971378327471830/IndiaBrochureFinalSingles.pdf

38. Aggarwal, Manu, and Kanika Chawla, "Deepening Renewable Energy Markets in South Africa: Lessons for and from the Indian renewable energy market," *Council on Energy, Environment and Water*, 2019. https://www.ceew.in/sites/default/files/CEEW-Deepening-Renewable-Energy-Markets-in-South-africa-17Jul19.pdf

39. Garg, Amit, Vimal Mishra, and Hem H. Dholakia, "Climate change and India: adaptation GAP," *Indian Institute of Management Ahmedabad*, Research and Publication Department, (2015). No. WP2015-11-01.

40. Ministry of Finance, Government of India and Research and Information System (RIS), "AIIB Annual Meeting 2018: Host Country Seminars. Background Papers." http://ris.org.in/sites/default/files/Host%20Country%20Seminar%20Background%20Paper_Report.pdf

41. Michael Mullan, "Climate-resilient Infrastructure," *OECD Environment Policy Papaer* NO. 14, 2018.

42. The growth profile of the shipping sector in India shows that there has been a 53-fold increase in the Gross Registered Tonnage (GRT) since India's independence (1947). See Government of India, Ministry of Shipping, Indian Shipping Statistics (2010), available at http://shipping.nic.in/ writereaddata/l892s/shipstat-12478603.pdf.

43. Tanner, Thomas, and Jun Rentschler, "Unlocking the "Triple Dividend" of Resilience: Why Investing in Disaster Risk Management Pays Off," *Interim Policy Note*. (2015).

44. Hallegatte, Stephane, Colin Green, Robert J. Nicholls, and Jan Corfee-Morlot, "Future flood losses in major coastal cities," *Nature climate change* 3, no. 9 (2013): 802.

45. Pozsar, Zoltan, Tobias Adrian, Adam Ashcraft, and Hayley Boesky, "Shadow banking," *New York* 458, no. 458 (2010): 3-9.

46. Tran, K, "Community based adaptation strategy for the urban poor under a changing climate," *School of Global, Urban and Social Studies, Design and Social Context Portfolio, RMIT University (*2014).

47. Ibid

48. Michael Mullan, "Climate-resilient Infrastructure," *OECD Environment Policy Paper* No. 14, 2018

49. Hallegatte, Stephane, Colin Green, Robert J. Nicholls, and Jan Corfee-Morlot, "Future flood losses in major coastal cities," *Nature climate change* 3, no. 9 (2013): 802.

50. Press Information Bureau, Government of India, Cabinet, "Cabinet approves Coastal Regulation Zone (CRZ) Notification 2018," December 28, 2018. Accessed 05 June 2019. http://pib.nic.in/newsite/PrintRelease.aspx?relid=186875

51. Ishan Kukreti, "Coastal Regulation Zone Notification: What development are we clearing our coasts for," *Down to Earth*, February 04, 2019. Accessed June 05, 2019. https://www.downtoearth.org.in/coverage/governance/coastal-regulation-zone-notification-what-development-are-we-clearing-our-coasts-for-63061

52. Ibid

53. Michael Mullan, "Climate-resilient Infrastructure," *OECD Environment Policy Paper* No. 14, 2018

54. Sharma, Divya and Raina Singh, "Towards a Policy for Climate Resilient Infrastructure and Services in Coastal Cities," *The Energy and Resources Institute*, Policy Brief (2015).

55. Ministry of Statistics and Programme Implementation Website. Strengthening Infrastructure Statistics. http://mospi.nic.in/83-strengthening-infrastructure-statistics

56. Ministry of Housing and Urban Affairs, Government of India, Website. Atal Mission for Rejuvenation and Urban Transformation -AMRUT. http://mohua.gov.in/cms/amrut.php

57. Special issue on JNNURM Vol VII Issue 2 Autumn/Winter 2010, *Journal of the Development and Research Organisation for Nature, Arts and Heritage*. https://www.dronah.org/wp-content/uploads/2017/03/context-12.pdf

58. Ministry of Housing and Urban Affairs, Government of India, Website. Atal Mission for Rejuvenation and Urban Transformation -AMRUT. http://mohua.gov.in/cms/amrut.php

59. Bedoshruti Sadhukhan, "Indian Infrastructure Must Be Climate-Proofed to the Core," ICLEI South Asia. January 28, 2019. Accessed June 05, 2019. http://southasia.iclei.org/es/newsdetails/article/blog-indian-infrastructure-must-be-climate-proofed-to-the-core.html

60. Planning Commission, 9th Five Year Plan (Vol-2), *Human and Social Development*. http://planningcommission.nic.in/plans/planrel/fiveyr/9th/vol2/v2c3-7.htm

61. Ministry of Urban Development, Government of India, 2016. *Model Building Bye-Laws- 2016*. http://www.indiaenvironmentportal.org.in/files/file/MODEL%20BUILDING%20BYE%20LAWS-2016.pdf

62. Wallemacq, Pascaline, "Economic losses, poverty & disasters: 1998-2017," *Centre for Research on the Epidemiology of Disasters*, CRED, 2018.

63. Tanner, Thomas, and Jun Rentschler, "Unlocking the "Triple Dividend" of Resilience: Why Investing in Disaster Risk Management Pays Off," *Interim Policy Note*, (2015).

64. Kellett, Jan, Alice Caravani, and Florence Pichon, "Financing disaster risk reduction," *Overseas Development Institute and Global Facility for Disaster Reduction and Recovery* (2013).

65. Oliver, P., A. Clark, and C. Meattle, "Global Climate Finance: An Updated View 2018," *Climate Policy Initiative*, November (2018).

66. Ibid

67. Bahadur, A., E. Lovell, and F. Pichon, "Strengthening disaster risk management in India: A review of five state disaster management plans," *Climate Development Knowledge Network (CDKN) and the Overseas Development Institute (ODI), UK* (2016).

68. Ibid

69. Ibid

70. Michael Mullan, "Climate-resilient Infrastructure," *OECD Environment Policy Paper* No. 14, 2018

71. Asian Development Bank, Annual Report, *ADB Sustainable infrastructure for future needs 2018*, https://www.adb.org/sites/default/files/institutional-document/411996/adb-annual-report-2017bog.pdf

72. OECD, "Investing in Climate, Investing in Growth," *OECD Publishing*, 2017, Paris https://www.oecd-ilibrary.org/economics/investing-in-climate-investing-in-growth_9789264273528-en

73. Sapatnekar, Sanhita, Ila Patnaik, and Kamal Kishore, "Regulating

infrastructure development in India," *National Institute of Public Finance and Policy, New Delhi* No. 18/230. 2018.

74. Anguelovski, Isabelle, Eric Chu, and JoAnn Carmin, "Variations in approaches to urban climate adaptation: Experiences and experimentation from the global South," *Global Environmental Change* 27 (2014): 156-167.

75. "Responding to Rising Seas. OECD Country Approaches to Tackling Coastal Risks," *OECD*, 2019. http://www.oecd.org/environment/cc/policy-highlights-responding-to-rising-seas.pdf

76. Dube, Shishir K., Tad S. Murty, Jesse C. Feyen, Reggina Cabrera, Bruce A. Harper, Jerad D. Bales, and Saud Amer. "Storm surge modeling and applications in coastal areas." *In Global Perspectives on Tropical Cyclones: From Science to Mitigatio*n, pp. 363-406. 2010.

77. Turnquist, Mark, and Eric Vugrin, "Design for resilience in infrastructure distribution networks," *Environment Systems & Decisions* 33, no. 1 (2013): 104-120.

78. Aparna Roy and Biplob Chatterjee, "After a month of cyclone Fani Odisha remains shattered, are we a resilient enough state to face a natural disaster?," *Observer Research Foundation*, June 04, 2019. Accessed June 20, 2019. https://www.orfonline.org/expert-speak/after-a-month-of-cyclone-fani-odisha-remains-shattered-are-we-resilient-enough-state-to-face-a-natural-disaster-51632/

79. Ministry of Finance, Government of India and Research and Information System (RIS), AIIB Annual Meeting 2018: Host Country Seminars. Background Papers. http://ris.org.in/sites/default/files/Host%20Country%20Seminar%20Background%20Paper_Report.pdf

80. Ibid

81.

82. International Workshop on Disaster Resilient Infrastructure 2018: Workshop Summary, https://ndma.gov.in/iwdri/ppts/15jan/TS-1/2/IWDRI2018_TS1_Kumar_World%20Bank.pdf

83. Basel, Global Infrastructure. "SuRe–the Standard for Sustainable and Resilient Infrastructure." Version 0.3. *Basel* (2016). protection).

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