PROMOTING LOW CARBON TRANSPORT IN INDIA

Impact Assessment and Management

Framework for Infrastructure Assets: A Case Study of Konkan Railways

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A Case Study of Konkan Railways

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Preface

Huge investments are being committed in new infrastructure projects in developing countries. Infrastructuresare long-life assets and are designed to withstand normal variability in climate regime. The Konkan Railway Corporation Limited (KRCL), a railway line operating for the past decade on the western coast of India, has met with two major accidents since its inception due to bad weather conditions. This case study presents the uncertainties and risks that such infrastructure assets face due to the changing climate, and suggests possible adaptation strategies. A framework for assessing the likely climate change impacts on long-life assets, using a methodology of reverse matrix for climate change impact analysis, is also suggested. The framework links climate change variables – temperature, rainfall, sea level rise, extreme events, and other secondary variables – and sustainable development variables – technology, institutions, economic, and other policies.

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Abbreviations

ACD	Anti-Collision Device
BFSS	Boulder falling and soil slippage
CCV	Climate change variables
ESCAP	Economic and Social Commission for Asia and the Pacific
GDP	Gross domestic product
GHG	Greenhouse gas(es)
HSBN	High strength boulder net
IITM	Indian Institute of Tropical Meteorology
INCCA	Indian Network for Climate Change Assessment
IPCC	Intergovernmental Panel on Climate Change
IWT	Inland water transport
KRCL	Konkan Railways Corporation Limited
MoEF	Ministry of Environment and Forests
NPCC	New York City Panel on Climate Change
SCV	System condition variables
SD	Standard deviation
SDV	Sustainable development variables
SLR	Sea level rise
USD	United States Dollar
WMO	World Meteorological Organization

Photo credit: Prakriti Naswa

1. Context

1.1 Introduction

Infrastructure development is considered as a prerequisite to achieving economic development. The term infrastructure, in general, refers to the technical structures that support a society and serve as linkages and provision of basic services such as roads, railways, river systems, airways, water supply, sewers, electrical grids and power generation systems, telecommunications, etc. India is on a developmental path and is planning investments of up to 1 trillion USD in infrastructure during 2012–17, the 12th Five-Year Plan of India, half of which is expected to come from private participation (Planning Commission, 2011; Money control, 2013).

Infrastructure is exposed to vagaries of nature and, therefore, faces uncertainties and risks; uncertainty of future weather conditions, and risk of being unable to deliver designed performance as a result. Infrastructures are typically designed based on past weather data, whereas climate change is a future phenomenon. Climate change could not only affect the average conditions, but also the probability of the occurrence of extreme events. Different sectors and assets exhibit different levels of sensitivity to climate change because of varying vulnerability and adaptive capabilities (Garg, *et al.*, 2007). The underlying assumptions considered during the designing of an infrastructural asset may drastically alter in light of the changing climate conditions.

1.2 Scope of the report

The report presents a case study on a prominent railway system in India that is facing challenges from climate change, along with a framework to analyse such situations. The railway system is in a coastal region with hilly terrain, which experiences heavy rainfall during the southwest monsoon period in India. The tree cover along the railway track is also succumbing to increasing population pressures from resettlements after the construction of this railway line. Loose rocks, boulders, and soil slips on the railway track create infringement and unsafe conditions for train operations. Incessant rains are the main cause of such incidents. In general, the rainfall is very high in the region, ranging from 3,500–4,500mm per annum, which under extreme conditions, in the monsoon period, could be about 50–80mm of rainfall per hour (TOI, 2013). The case study looks at the uncertainty of rainfall events that introduce randomness in probability of boulder falling and soil slippage (BFSS) incidents. These incidents lead to risks of accidents, and have economic implications. Railway authorities take preventive actions such as maintenance of track geometry, and cuttings and tunnels to reduce the likelihood of such incidents from occurring. While this reduces risks, it also has financial implications. Furthermore, some risks may remain uncovered as the cost of prevention increases at the margin, and reducing some highly improbable risks may require very high preventive investments. Therefore, policy choices must be made on how much preventive adaptation (or climate proofing in this case) should be done, and how much risk should be left uncovered to chance. Since every action comes with a cost – to prevent an incident, or pay after an incident has occurred – decision-making revolves around identifying the right magnitude of risk coverage. The case study provides some insights into this.

The analysis captures the inter-linkages between climate change variables, developmental variables and system conditions to provide a holistic coverage of associated uncertainties and risks. Relevancy of parameters is established through a reverse impact matrix supported by econometric modeling. Such analysis is data intensive and includes information on past performance of the system and climate, and model-based future projections of relevant climatic parameters.

1.3 Infrastructure development in India

The association of economic growth and infrastructure development is very significant in promoting inclusive growth and sustainable development. The development of infrastructure is essential for sustaining India's economic growth. India's Five-Year Plans have proposed larger outlays for the development of economic, social, and institutional infrastructure. Approximately 45% of the plan outlay for the recently concluded 11th Five-Year Plan (2007–2012) has been on economic infrastructures such as transport, irrigation, communication, power, etc. (Planning Commission, 2008). A majority of this has gone to infrastructure creation in the power and transport sectors, implying that less than one-sixth of the outlays were planned for social infrastructures such as education and health facilities. Traditionally, the public sector has invested three to four times as much as the private sector in creating these infrastructures. However, private investments are now increasing considerably since India has liberalised its investment rules (Table 1).

Table 1: Investment in infrastructure as a percentage of GDP in billion USD at 2004–05 prices

	2006–07		2011–12	
	Investment	% of GDP	Investment	% of GDP
Public Sector (Centre + State)	36.2	4.23	80.6	6.45
Private Sector	10.3	1.20	36.1	2.89
Total	46.5	5.43	116.7	9.34

Source: Naswa and Garg (2011)

The 12th Five-Year Plan (2012–2017) has projected 200 billion USD investments each year in various infrastructure projects (Planning Commission, 2011). The plan also envisions climate change as a threat to these investments. These huge investments in infrastructures are planned based on the past and present climatic conditions, without any consideration for climate change related impacts that these infrastructures might face in the future. In developing countries, governments have to bear the losses arising from any weather related damage to public infrastructure. Since currently 95% of infrastructure is government-owned, they bear the responsibility for its repair, maintenance and associated losses (Kapshe, *et al.*, 2003). Even for privatised infrastructure, the force majeure provisions largely allocate financial responsibility for catastrophe risk, directly or indirectly, to governments (Gibbon, 1996).

As the developmental needs are substantial, climate related concerns for infrastructure are becoming increasingly significant for the planning process. Most infrastructure projects, large or small, traditionally assess the infrastructure's adverse impact on the environment. Environmental Impact Assessment is a mandatory exercise in India for large infrastructure projects. However, the environmental risks to infrastructure are rarely assessed, although the phenomenon can have far-reaching consequences on economic development. During the 12th Five-Year Plan, the Government of India planned detailed sectoral, regional and integrated studies for risk assessments of Indian infrastructure due to climate change, especially to establish the damage functions and costs, including impacts of climate change on new infrastructure projects in the short, medium and long-term. This case study aims to cover these particular aspects using the Reverse Impact Matrix methodology, a term coined by Kapshe *et al.* (2003), which entails the study of environmental impact on infrastructure assets.

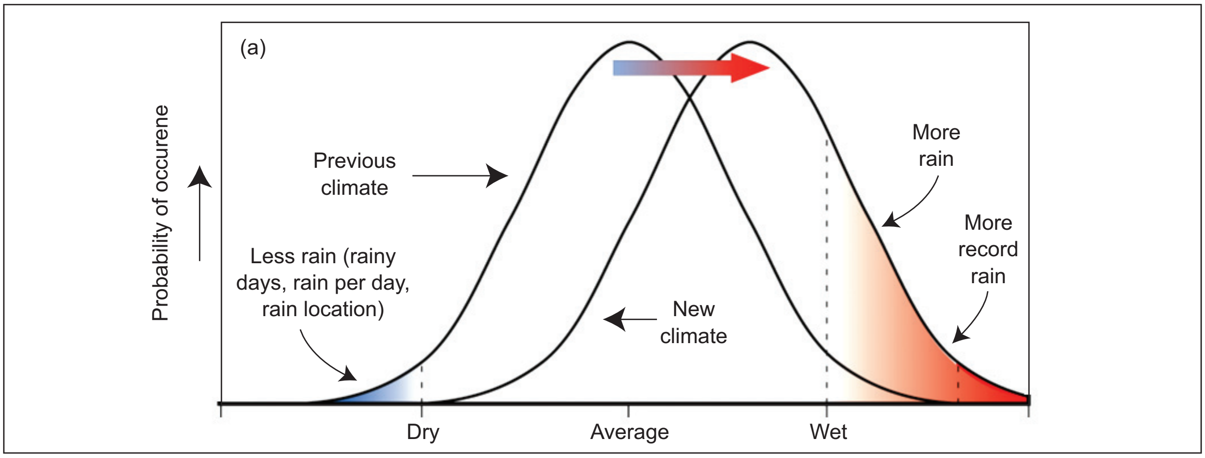
Photo credit: Noblevmy, 2011

2. Climate Change Impacts and Adaptation for Infrastructure Assets

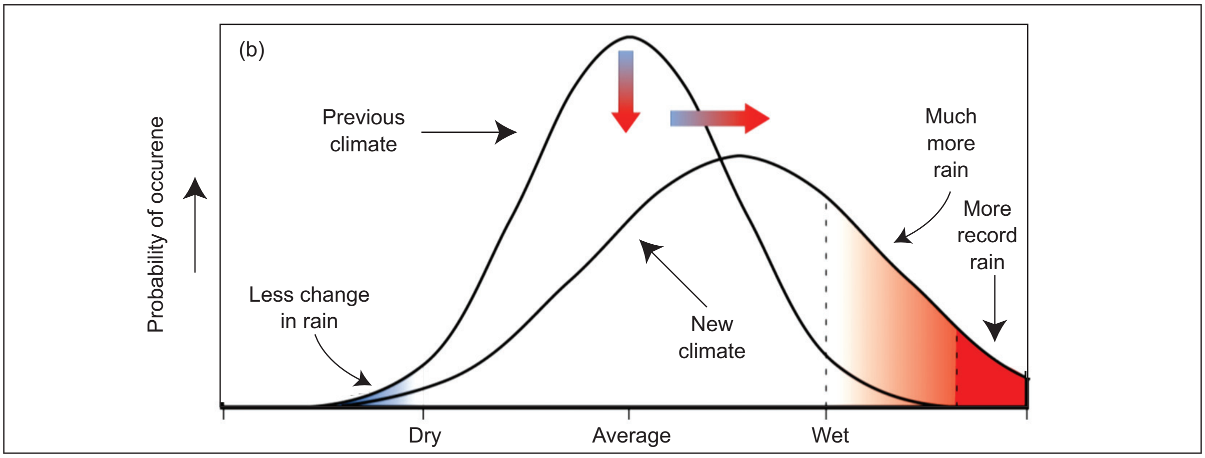
2.1 Why is adaptation to extreme climatic events a challenge for infrastructure assets?

'Climate' and 'weather' are related terms. While climate is what one expects as '30-year average weather', weather is what one gets (Allen, 2003; WMO, n.d.). Climate change, therefore, manifests as weather of the day. Generally, infrastructure planning and design is based on historical weather data, and not on future projections of climatic parameters. Climate systems can change abruptly with understated signals (or often times without any signals), indicating that planned system thresholds are likely to be crossed (Stocker, 1999). The impacts of climate change on infrastructure can be due to both change in average weather conditions and extreme weather events (Figure 1).

Figure 1: Climate change manifests as changes in weather parameters



Large percentage change in extremes



Larger percentage change in extremes

Weather averages and extremes may vary under climate change, as shown in Figure 1, exposing the assets to altered risks – such as greater number of rainy days, higher rainfall per day, and altered locations for rainfall. While averages are generally increasing, they are accompanied by extreme weather conditions which contribute to accelerate their increase. It is easier to prepare a system for an increased average than for an extreme event. Extreme weather tests the planned thresholds of a system's resilience, while an increase in the average weather maybe mostly within the system threshold but will reduce the life span of the asset. The IPCC (2007a) defines an 'Extreme Weather Event' as "an event that is rare at a particular place and time of year". Definitions of "rare" vary, but an extreme weather event would normally be as rare as or rarer than the 10^{th} or 90^{th} percentile of the observed probability density function (IPCC, 2007a). Assuming that adverse weather events follow a normal curve, the extreme weather event would fall in the tails. Managing weather extremes is, therefore, more critical for safe and economic operation of infrastructure assets, particularly when dealing with fat tails (Figure 1).

2.2 What are climate-induced risks for infrastructures?

Preparing the systems for extremes requires studying the reverse impact, i.e., the impact of environmental variables on infrastructure assets. The following 'Reverse Impact Matrix', proposed by Kapshe *et al.* (2003), outlines the project-environment inter-linkages (Table 2). Quadrant 1 represents the conventional form of impact of infrastructure on the environment. Quadrant 2 represents the environmental impact inter-linkages, and quadrant 4 represents the impact of infrastructure on other such infrastructure projects. Quadrant 3 is the focus of this section, which looks at the potential impact of the environment on infrastructure projects.

Table 2: Reverse impact matrix

Forcing Variables/Dependent Variables	Environmental Variables	Project Components
Environmental Variables	2	3
Project Components	1	4

Source: Kapshe et al. (2003)

Since infrastructure is a limited resource in developing countries, reducing vulnerability and consequent economic exposure due to extreme weather conditions is becoming extremely important (Botzen, *et al.*, 2009). Managing extreme weather conditions can be done at cause and impact level. At the impact level, thresholds of system resilience need to be managed in order to make them less prone to damages. This is also the underlying principle of adaptation. Managing at the level of cause is somewhat difficult and complex. The root cause of the incremental increase in extreme weather conditions (i.e., without climate variability) is anthropogenic activities that lead to GHG emissions, and it is virtually impossible to establish a one to one relationship between a particular anthropogenic activity and a specific adverse event. Linnerooth-Bayer *et al.* (2008) use a loaded die analogy to explain this. When throwing a loaded die, if a 'six' appears, one cannot attribute this outcome to loading but can certainly say that loading has increased the probability of throwing a 'six' (Linnerooth-Bayer, *et al.*, 2008). One still has to control the factors leading to extreme weather conditions caused by climate change, which has many limitations. First, there are no one-to-one effects on vulnerability reduction of a specific infrastructure asset, because while emissions are a global phenomenon the impacts are experienced locally. Second, any collective vulnerability reduction that happens due to a reduction in GHG emissions is too small to be apportioned to a specific infrastructure project. The exercise of apportioning is also an infeasible task. Finally, the average temperature will continue to rise for some time even if all GHG emissions stop immediately, as carbon dioxide has a life of more than 100 years in the atmosphere (Katoch, 2007). Therefore, the vulnerability reduction process will not happen with an immediate effect by controlling emissions.

What concerns the developing world today is that the adverse impacts of climate change will be uneven and disproportionate to the contribution in GHG emissions (Muller, 2007). When scaled down to cities, many vulnerable small and medium-sized cities in developing countries are not big emitters of greenhouse gases (Huq, *et al.*, 2007). This also raises concerns of justice and equality (Paavola and Adger, 2006). In the Indian context, the country's contribution to historical GHG stock is very low and, in per capita terms, the emissions are not likely to meet those of developed countries in the near future. However, low resilience will ensure that the adverse impacts of climate will be experienced more in terms of burden of damage.

The continuous and accelerated pace of climate change demands immediate action. In India, the mean minimum and maximum temperatures may increase by 2–4°C as a result of climate change (Kumar, *et al.*, 2006), which could significantly affect existing and upcoming infrastructures. Chaturvedi *et al.* (2012) project a decrease in the number of rainy days expected throughout much of India, but an increased frequency of heavy rainfall during the monsoon season (Chaturvedi, *et al.*, 2012). In the coastal regions, sea level rise combined with an increased frequency and intensity of tropical cyclones will lead to an increase in extreme sea levels, due to storm surge (Unnikrishnan, *et al.*, 2006). The Arabian Sea is also witnessing an increase in cyclonic activity (Evan and Camargo, 2011). A vulnerability study of a coastal district in India (Patnaik and Narayanan, 2010), pointed out that the growth of infrastructure index is very low with respect to the population growth rate. As a result, the impact of any extreme event is experienced more due to the pressure on limited assets. The impact of any adverse event is dependent on the resilience. The less the resilience, the more adversely an extreme event impacts. Weak infrastructure vis-à-vis the population's requirements adds to poor resilience.

The effect of climate change will be seen distinctly in the form of four critical climate parameters, i.e., temperature rise, precipitation variability, sea level rise and other extreme events. Climate change is creating new risks, altering the existing risks, and more importantly, affecting the interdependencies between these risks (Kousky and Cooke, 2009). A targeted approach towards risk reduction and management necessitates concrete adaptation efforts. Adapting to newer risks posed by climate change will not only require responding to the physical effects of the changing climate, but will also involve reviewing our understanding of these, and our measures of risk management. The critical climate parameters of temperature, precipitation, sea level rise and other extreme events pose physical, supply chain, regulatory, and product and technology risks for infrastructure assets. Lash and Wellington (2007) have cited some of these climate risks in the business context. While physical and supply chain risks are more commonly seen, regulatory and product and technology risks are futuristic and have long-term effects.

Physical risks – Physical risks refer to exposure. Increased frequency and variability of disasters can damage the tolerance of infrastructure and have the potential to disrupt the entire socio-economic system associated with it.

Supply chain risks – Supply chain risks are generally the allied risks that physical and regulatory risks pose. A cyclone at a major port, such as Kandla (Gujarat, India), can not only bring about damage to the port infrastructure but also allied risks such as shortage of essentials, fuel supply for refineries, coal supply for power, etc.

Regulatory risks – International agreements and domestic regulations will pose risks on financial stability and functioning of infrastructure assets. While the environmental impact assessment is a mandatory exercise in India, regulations for reverse impact assessment may also come into existence. These could make certain investments mandatory. For example, for certain coastal zone infrastructures, it could become mandatory to invest in dykes.

Product and technology risks – New regulations and uncertainties in climate variables necessitate improvements in products and technologies. Physical challenges such as land slides, as in the case of Konkan Railways, can be managed with safety nets, and better communication. Adaptive technology choices made today may be inadequate to meet future uncertainties. In the long run, if these measures are inappropriate or inadequate, they can render the infrastructure asset financially redundant. For example, it could be a case where the water levels in an inland waterway are receding, and dredging activities have not accounted for climate change. If the drop in water level is too high, maintenance dredging may be inappropriate and inadequate to manage the situation. Perhaps reducing the width of the river would be a far more appropriate choice. In such a case, if other technological interventions are not taken, it may be more financially viable to discard the waterway as a transport route.

Table 3: Critical climate parameters for transport infrastructure, and their impacts

Sector	Associated CCC Parameters	Physical (Primary Impact)	Supply Chain (Secondary Impact)
Railways	Precipitation Extreme Events	Konkan Railways met with a massive accident due to landslides caused by heavy rainfall in June 2003 (Hindustan Times, 2003). The two-day cumulative rainfall before the incident was 283 mm. The rainfall statistics from the Indian Meteorological department for Ratnagiri show that from 1991–2010, on an average, daily rainfall crossed the 140mm mark two to three times a year. In this incident, 141 and 142 mm rains happened in two consecutive days before the accident.	Affects passenger and freight travel. The popular Roll On- Roll Off service initiated to meet industrial demands affected.
Roads	Precipitation Extreme Events Sea Level Rise	Torrential rains washed away roads in Garhwal and Kumaon regions of Uttarakhand (India) in June 2013. During the period of 15–18 June 2013, Uttarakhand received 261 cm of rain, while the average rainfall for June is about 16 cm, and for the monsoon period about 123 cm (Financial Express, 2013; Live Mint, 2013).	Roads are an important means of transport in this region, which has limited rail connectivity. Connectivity to small and large towns, essential supplies, and food was hit.

Sector	Associated CCC Parameters	Physical (Primary Impact)	Supply Chain (Secondary Impact)
Aviation	Extreme Events Precipitation	Heavy fog in the northern region of India is increasingly affecting the aviation sector during winter months. The timing and severity remain uncertain. It poses a great safety threat for operations. Such events, under extreme cases, can render the infrastructure redundant for specific periods every year (The Hindu, 2013).	Aviation sector operations directly affect the service sector and financial hub around the National Capital Region of India.
Ports	Sea Level Rise Extreme Events	Kandla Port in Gujarat was hit by a super cyclone in June 1998, causing massive damage to port infrastructure (WMO-ESCAP, 2010).	Important port in the western region, where significant transshipment of coal and petroleum happens. Industrial supplies and electricity sector were hit.
Inland Waterways	Precipitation Extreme Events	In general, a decrease in surface runoff due to climate change has been projected (Shukla, *et al.*, 2003). This is likely to affect the six national inland waterways that are attempting to play significant roles in the transport sector.	The IWT in India connect ports and industries to hinterlands. Likely commodities to be effected include coal, fertilizer, cement, iron ore, and agricultural and industrial products.

Source: Critical Climate Parameters identified from IPCC (2007b)

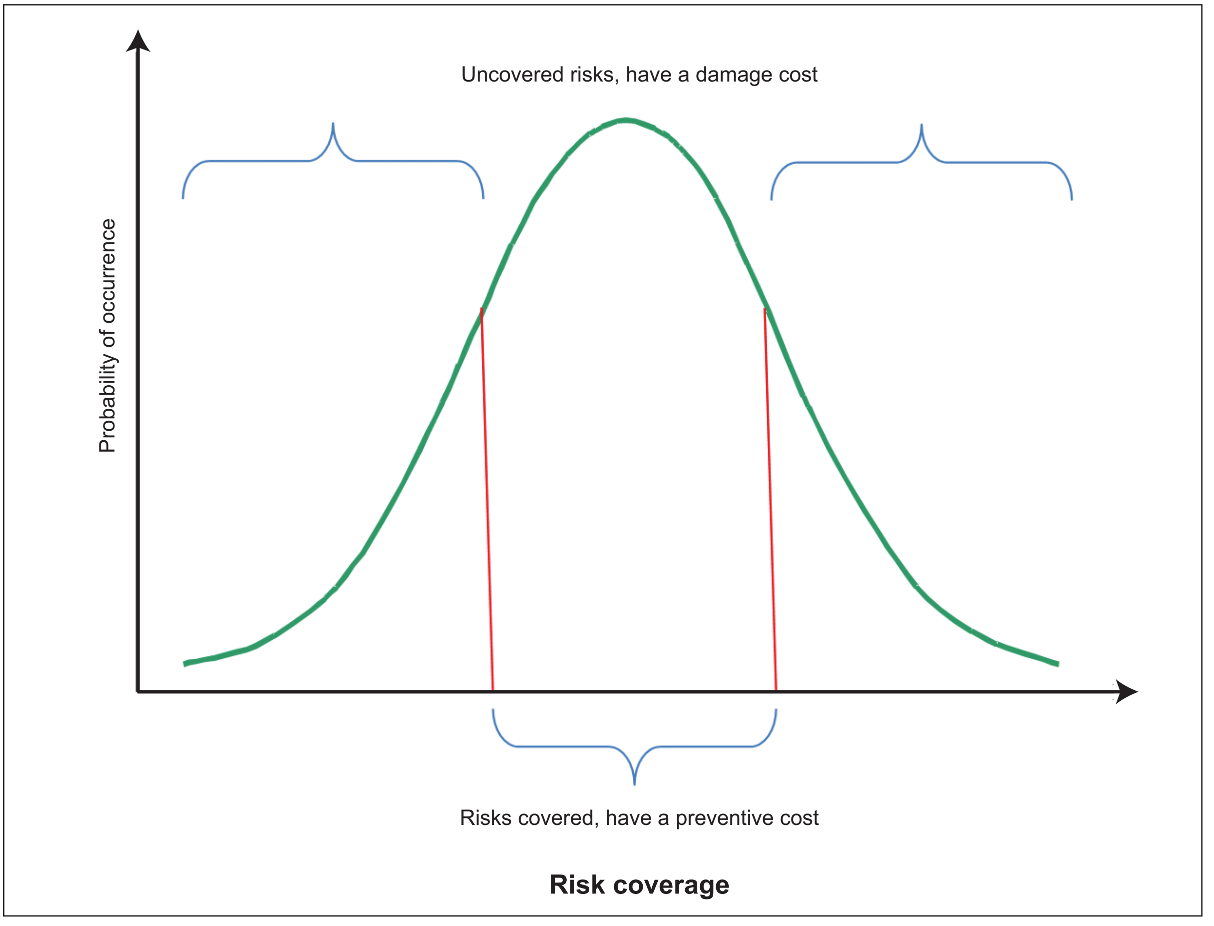
Table 3 shows some infrastructure assets and their associated critical climate parameters. These parameters are project-specific, and in many cases multiple variables may be critical at different times in the year. The primary impact that any climate change variable has on infrastructure is physical damage. For transport infrastructure, these physical risks directly translate into secondary risks, in the form of supply chain risks. Some impacts are likely to be seasonal in nature, while others could be permanent. The key to managing these risks lies in more sustainable transport, which allows for better inter-modal connectivity using clean fuels, with appropriate adaptive investment that meets the demands of the population during its life span.

2.3 The adaptation dilemma

Preventive adaptation measures could help reduce the damages due to extreme climatic events. However, covering all climatic risks could require very large resources. The policy decision on how much risk to cover and how much to leave uncovered sums up the adaptation dilemma. Climate change adaptation measures depend heavily on the risk perception, and the carrying capacity of the infrastructure.

There are two possible types of errors in judgment while resolving the adaptation dilemma: excessive adaptation and under adaptation. Excessive adaptation is also sometimes referred to as Type-I error (alpha error). It involves taking preventive measures for an extreme climatic event, which eventually does not occur. Excessive adaptation results in sunk cost of insurance and surplus spending on preventive measures. Under adaptation is termed as Type-II error (beta error). It is the opposite of Type-I error. In this error, some risks are left uncovered; preventive measures are not taken to cover the risks of extreme climatic events – thinking it would not happen, but the event does happen. The consequences of a Type-II error could be massive destruction and excessive palliative costs. While a Type-I error may lead to adaptation expenditures when the risk is hedged, and the system becomes more resilient to withstand adverse impacts of climate change, a Type-II error may lead to under-adaptation, leaving certain risks to chance. Figure 2 depicts this adaptation dilemma. The probability of Type-I and Type-II errors occurring could be plotted, mainly based on past occurrences, and then linked to critical climatic parameters. Locating the red lines is the adaptation dilemma, and represents the distribution of preventive and palliative costs (damage and restoration costs after the event has occurred).

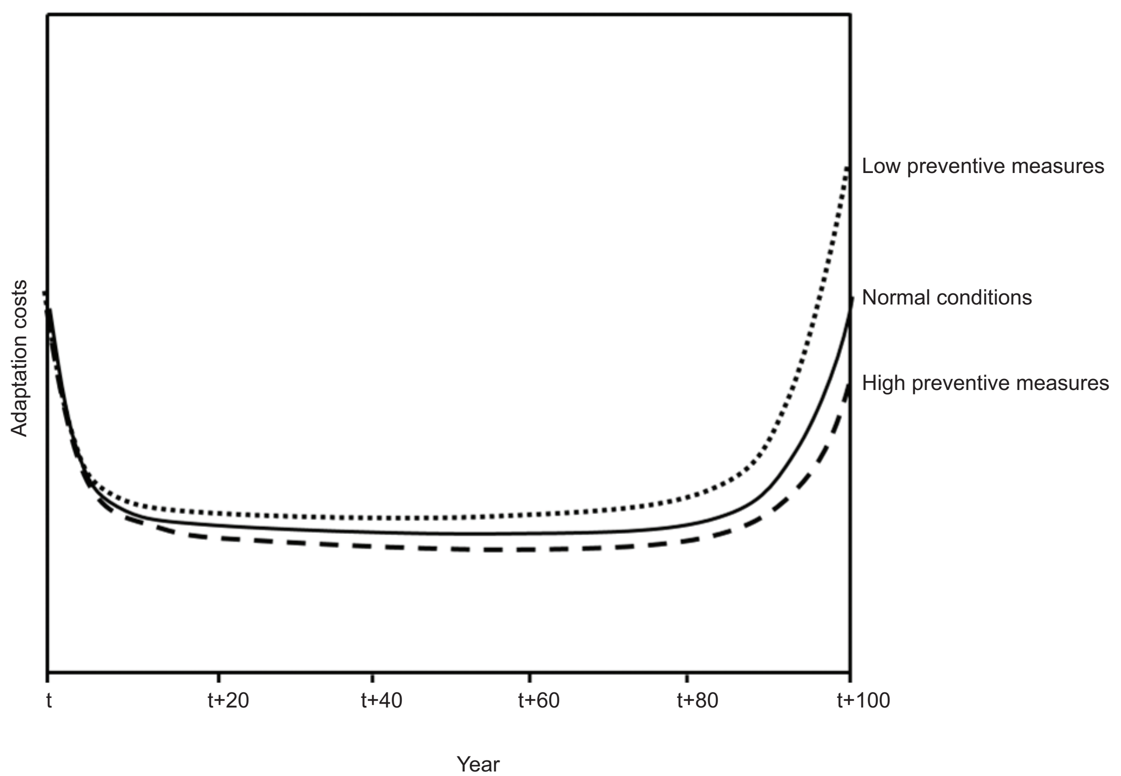
Figure 2: The adaptation dilemma – How much to adapt?



Adapting infrastructures to climate change risks does not come cheap; therefore, it is important to be careful about these errors. The adaptation dilemma could be constraining for developing countries and emerging economies that must still build considerable infrastructures in various domains, and decide the extent to cover climate change risks for each of these assets. The World Bank has estimated that the incremental costs of adapting towards climate change impacts in developing countries could be upwards of 9–41 billion USD per year (World Bank, 2010). A study on New York State estimates that adaptation costs to cover damages to all modes of transportation in low lying areas (including increased transportation outages) due to permanent and temporary coastal flooding from SLR and storm surges will be approximately 290 million USD (2010 costs) by 2050 (Leichenko, *et al.*, 2011). This study uses sea level rise projections from the New York City Panel on Climate Change (NPCC).

Studies on future adaptation costs specific to the transport sector in India are limited. According to the Draft 12th Five-Year Plan of the Government of India (2013), some early assessments for specific sectors and locations suggest that adaptation costs for new infrastructure could be in the range of 3–10% of the total investment, although for certain sectors and locations this may be higher (Planning Commission, 2013). This indicates likely adaptation costs of 6–20 billion USD per year for new infrastructures, alone, in India over the next five years. This range of costs is pathway dependent i.e., costs would be closer to 6 billion USD in the case of low concentration pathway (RCP 2.6) and closer to 20 billion USD in the case of high concentration pathway (RCP 8.5). These figures, however, do not include cost of likely future damages due to climate change. According to the Planning Commission (2013), the adaptation costs for existing assets could be as much as 25% of present costs of creating similar assets.

Figure 3: System adaptation cost curve

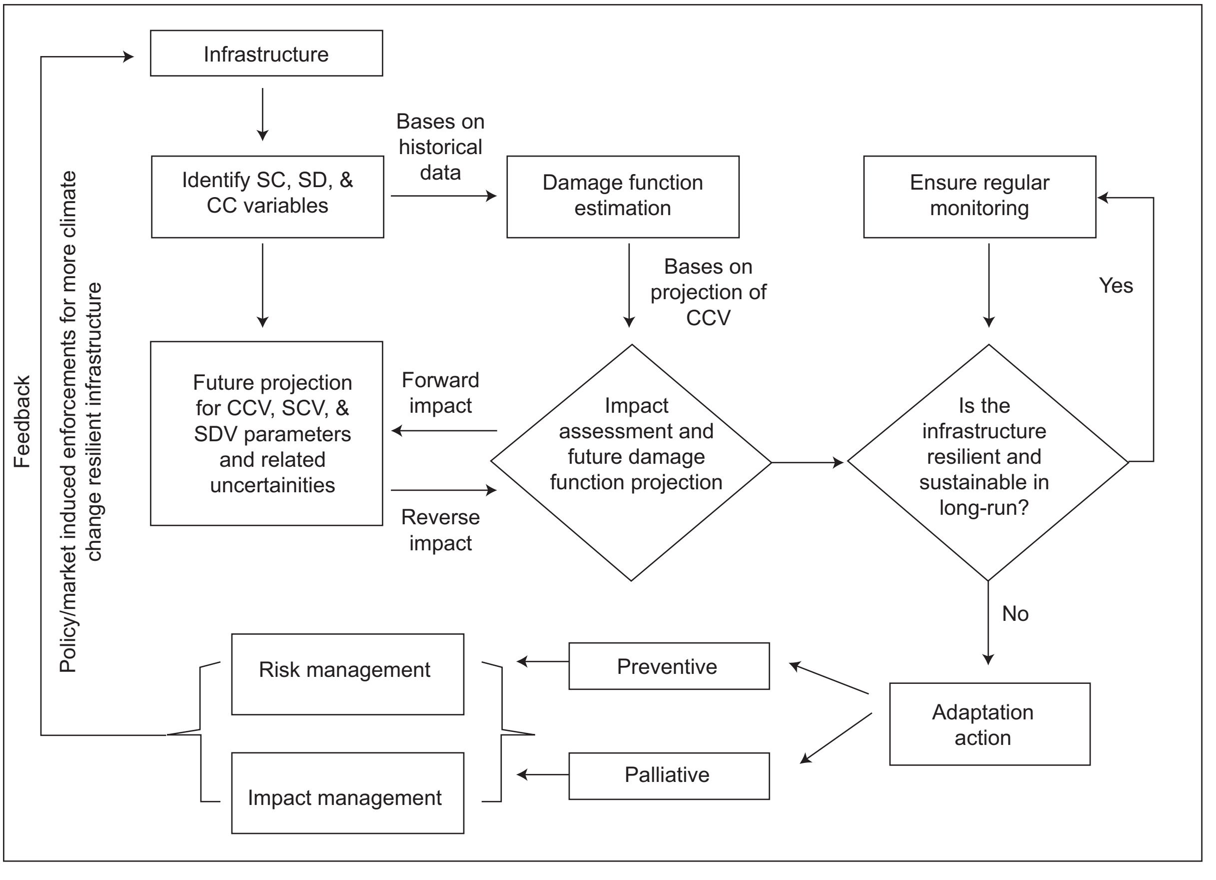


Preventive adaptation repairs and maintenance costs form a 'Classical Bathtub Curve'. Typically, these have been studied for failure rates in the manufacturing domain, where equipment failure rate follows a bathtub curve (Glaser, 1980; Hjorth, 1980). Rajarshi and Rajarshi (1988) have presented several methods to construct bathtub curve failure rates, while Bebbington (2007) has studied bathtub curves in the context of aging and human mortality. In the context of Konkan Railways, the system failure rate follows a bathtub curve and, likewise, the subsequent preventive adaptation and maintenance costs must complement the failures. Therefore, preventive adaptation and maintenance costs should follow a bathtub curve. The costs are usually higher during the initial period after inception, during which time the system is 'running-in'. These go down with time as the system stabilises, giving a period during which there is a constant, stable, and low failure rate. As the asset ages, the maintenance and repair costs will increase since it reaches the wear-out period during which the failure rates increase dramatically (Figure 3). This increase in maintenance and repair costs will also depend on the initial preventive adaptation taken. Higher initial preventive measures would mean subsequent lower maintenance and repair expenditures.

2.4 Integrated climate change impact and adaptation framework

Figure 4 presents a framework for impact and adaptation to climate change. The climate change induced vulnerability of any infrastructure is a function of three sets of variables, namely, the climate change variables (CCV), system condition variables (SCV), and sustainable development variables (SCV) (Garg, *et al.*, 2007). Climate change variables are the forcing variables that are critical for a specific infrastructure project. In the case of the road network of Uttarakhand, for example, it is precipitation that makes the roads vulnerable (Financial Express, 2013). Heavy rainfall during the monsoon period causes loose soil and boulders to fall from mountain slopes, or patches of the road to sink. In extreme cases of flash floods, entire roads can be washed away.

Figure 4: Integrated climate change assessment framework for infrastructure



Source: Adapted from Naswa and Garg (2011)

The system condition variables are those that define the conditions in which the system operates. Some of these are fixed, while others can be varied to achieve a desired level of resilience. For Kandla Port, the fixed system conditions would be the location of the port, the draft levels, and the soil type for roads connecting the port. The flexible variables include insurance, investment in geo-safety, etc. The sustainable development variables include forests, plantations, etc., that help in making the entire system durable. The essential part of the framework is the policy and market-oriented cues these risk management practices can provide.

As will be demonstrated for the Konkan Railway Corporation Limited (KRCL) case, if insurance is taken for potential future losses, a feedback loop in the form of market demand for risk pooling emerges. An insurance company would want KRCL to take certain precautions or exercise discretion in adopting risk management practices. The premium determination between KRCL and the insurer would be another optimisation case where both are weighing costs and benefits with their own position on probability distribution of damage function. KRCL's choice would understandably be one where the benefits are high, i.e., assured monetary compensation in case of damage, by paying annual premium or marginal costs involved in improving the system resilience. The losses of KRCL will be a function of CCV, SCV and SDV.

$$\text{Economic Loss} = \text{fn}\,(SDV_i, CCV_j, SCV_k)$$

Here, 'i' could be technology, policies (e.g., forestation, community participation, etc.); CCV projections for relevant climate change variables with j= temperature, rainfall, sea level rise, extreme events, etc.; SCV= projections for relevant system condition variables where k= physical life of the asset, maintenance levels, usage patterns, soil type, etc.; i, j, k would depend on the system under study (Garg, *et al.*, 2007).On the insurer's end, the market will also have to decide what level of risk is acceptable. At the policy level, the government may decide some mandatory levels of risk pooling for public infrastructure. Some extreme events may also lead to a regulatory base for comprehensive risk management strategies without compromising on pooling effect and proactive risk reduction strategies.

In practice, studying this phenomenon at the national level is far more complicated. As a nation, many infrastructure assets that are crucial for the country's development are under threat from climate change. Each category of asset will have specific characteristics that make it vulnerable to climate change shocks. The relationship of that asset with peer assets, non-peer assets, and other components of the system constitute the system-generated stresses. Even the degree to which the damage should be assessed is debatable. Infrastructure does not directly contribute to production, and associated economic benefits attributable to an asset become difficult to calculate. Economic loss functions, therefore, can only be suggestive and exhaustive.

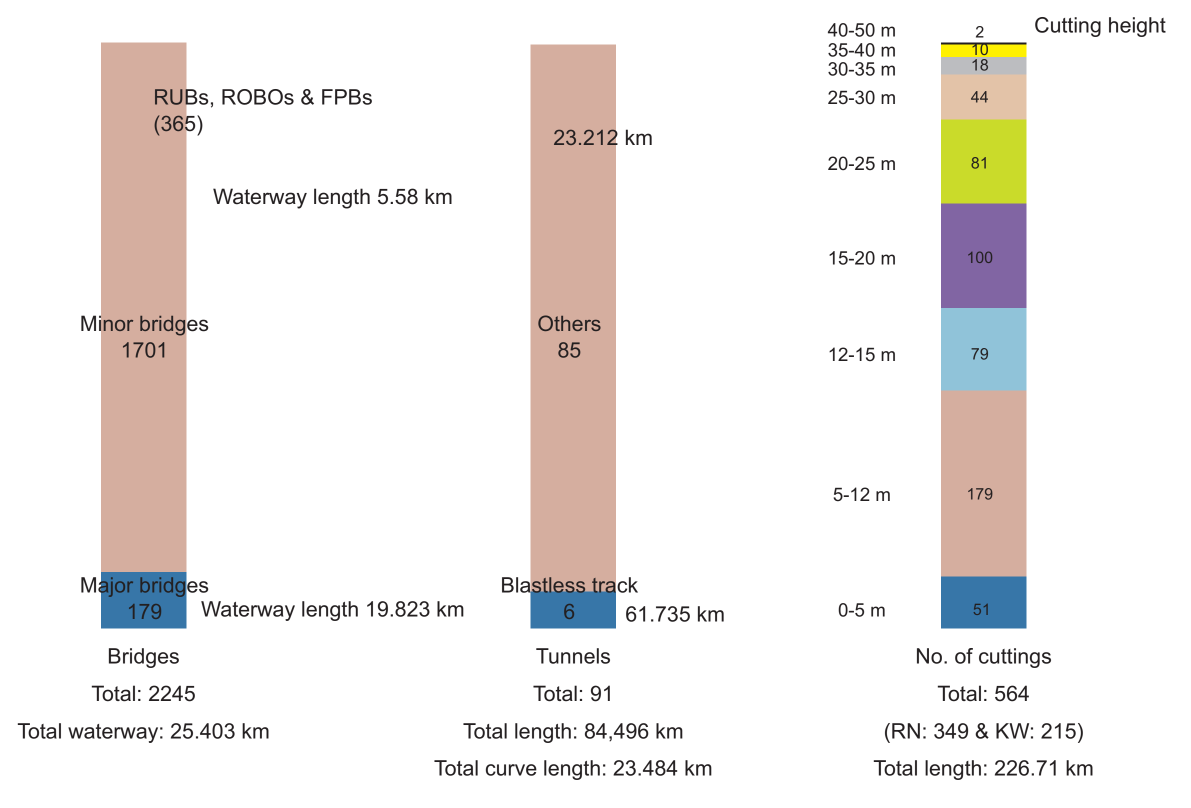
Photo credit: Vinayraj, 2007

3. Konkan Railway Corporation Limited (KRCL) Case Study

3.1 Background

The Konkan region is located on the western coast of India. It is the part of land bounded by the Sahyadri hills on the east and Arabian Sea on the west, on the western coastal ghats (hills) of India. The basic aim behind developing this project was to bridge the connectivity gap between Mumbai, and coastal Karnataka and Kerala, in order to reduce the distance and travel time. This project was one of the most challenging engineering projects due to the rough terrain in the Konkan region. The region is marked by innumerable creeks and rivers, and hill ranges that reach out to the sea from the Western Ghats.

Figure 5: Profile of Konkan Railway: Bridges, Tunnels and Cuttings



Source: Right to Information Application (KR/CO/PR/IA/12/17/00/000) & Engineering Digest (KRCL) available at http://www.konkanrailway.com/

The Konkan Railway is a broad-gauge (1,676 mm) single line, from Roha to Mangalore (760 km). It was built at a cost of about 755 million USD. There are 59 stations on the line, as many as 179 major bridges (total linear waterway 20.50 km) and 1,819 minor bridges (total linear waterway 5.73 km), as can be seen in Figure 5. It is the first time that Indian Railways constructed a tunnel more than 2.2 km. The Karbude tunnel (between Ukshi and Bhoke) has a length of 6.45 km, which until 2013, i.e., before the construction of the Pir

Panjal tunnel in Jammu and Kashmir, was the longest railway tunnel in India (India Today, 2012). As per the information provided by KRCL, there are nine tunnels in the project longer than 2 km on the railway track. The track passes through more than 1,000 cuttings, with 224 being deeper than 12 m. Further information on the project can be found on the corporate website of KRCL (http://www.konkanrailway.com/).

Since its inception, the Konkan Railway has been a discussion point for the environmental impacts that it might have on the surrounding region. However, no studies have discussed the environmental impacts on Konkan Railway (Garg, *et al.*, 2007). The occasional reports published in the newspapers, and the records of Konkan Railway clearly indicate its sensitivity and vulnerability to the climatic impacts. Since the operationalisation of Konkan Railway, there have been two major accidents. On 22 June 2003, a passenger train derailed after hitting a boulder on the track near a tunnel, during heavy rains, killing 51 passengers and injuring nearly 60 (Hindustan Times, 2003). Again, on 16 June 2004, boulders on the hillside adjacent to the track were dislodged by soil loosened due to incessant rain, and rolled onto the track near a bridge (Frontline, 2004; The Hindu, 2004). A train collided with these boulders such that the engine and four coaches fell almost 20 meters into the ravine, killing 16 passengers and injuring almost 100. Data provided by KRCL shows 22 reported incidents of train cancellations since its inception in 1998, all due to natural and rainfall related causes (Right to Information Application: KR/CO/PR/IA/11/16/57/403). Figure 6 shows some accidents on the Konkan Railway.

There have been many reported cases of boulder falling and landslides during the monsoon along the Konkan Railway track. About 72% of these have happened in the monsoon period of June–July–August–September. In the year 2000, alone, there were a total of 163 such incidences. On one day in 2000, 36 landslide instances were recorded after more than 300 mm of rain fell in a day. At that time, the train operations were suspended for duration of 14 days from 11–25 July 2000; consequently, an estimated 2.25 million USD were the expected losses. Past records indicate that such operational suspensions occur for almost a week every year, leading to huge economic losses. Data provided by KRCL (Right to Information Application: KR/CO/PR/IA/11/16/57/403) shows that, on average, each accident could bring about a damage cost of 150,000 USD. The damage costs of the 2004 accident were as high as 2.3 million USD.

Figure 6: Some accidents on Konkan Railway

Rescue operations in progress at Vaibhavwadi, the site of the Konkan Railway accident of June 22, 2003, in which more than 50 persons were killed.

http://www.frontlineonnet.com/fl2015/stories/20030801006911900.htm

The smashed coaches of the Matsyagandha Express after it hit a boulder and derailed at Amboli village on the Konkan Railway in Maharashtra's Raigad district on June 16. 2004.

http://www.hindu.com/fline/fl2114/stories/20040716001904200.htm

One of the boulders that derailed the Matsyagandha Express near Mahad in Maharashtra on June 16, 2004.

http://www.hindu.com/2004/06/17/2004061706301100.htm

The collapse of retaining wall between Nivasar and Ratnagiri stations in Konkan Railway

http://manipalworldnews.com/news_local.asp?id=3499

3.2 Analysing boulder falling and soil slippage cases

The Konkan belt falls on the windward side of the southwest monsoon and,thus, witnesses heavy rainfall, which often leads to boulder falls and soil slips in the region. The soil type in the region comprises lateritic soil, boulder mixed with soil and jointed basalt rock. These rocks are porous in nature, and in rainfall periods lead to water seepage into the underlying clay soil. This increases the density of the rocks and decreases their hold in the soil base, which becomes soft due to water absorption, resulting in boulder falling and soil slippage from slopes, cuttings, and tunnels. Each case of boulder falling is a potential accident, traffic disruption, loss of property and life. From 1998 to 2011, the railway track witnessed 949 cases of boulder falling and soil slippage. Of these 949 cases, 15.6% (148 cases) resulted in traffic disruptions. These events are mostly confined to the districts of Ratnagiri and Sindhudurg, which have witnessed approximately 71% of the total cases of boulder falling and soil slippage (Table 4).

Table 4[1]: District-wise distribution of boulder falling and soil slippage incidents from 1998–2011

District	Grid	BFSS	% of BFSS
Raigad	6	24	2.5
Ratnagiri	11, 12, 16, 20	597	62.9
Sindhudurg	20, 24, 28	88	9.3
North Goa	28	45	4.7
South Goa	32	74	7.8
Uttar Kannada	32, 35, 37	81	8.5
Udupi	39, 41	30	3.2
Dakshin Kannada	41	10	1.1

Source: Data provided by KRCL (Right to Information Application: KR/CO/PR/IA/11/16/52/398)

[1] Figure 7 shows the 8 districts spanning Konkan Railways, and the respective grids that correspond with the districts.

The Konkan Railway system has many variables under play, which determine the occurrence of a boulder fall or soil slippage incident. The primary trigger is heavy rainfall. To understand the relationship of boulder falling and soil slippage with rainfall, it is necessary to study their trends. The Konkan belt has been divided into grids of 0.5°latitude x 0.5°longitude (i.e., approximately 50k m x 50 km). There are 12 grids that span the entire stretch of the railway track. These grids are aligned with international climate change models so that climatic projections could be utilised for such analysis.

The grid map of Konkan Railways matched with global climate models is given in Figure 7. The grids have been labelled as 6, 11, 12, 16, 20, 24, 28, 32, 35, 37, 39, 41. RCP 4.5 rainfall data provided by IIT-Gandhinagar was used for this. Boulder falling and soil slippage are very specific to location and day. Since there are 12 grids, on a particular date, for example 1 January 2004, there are 12 different observations of rainfall and 12 observations of boulder falling across the track. For a 14-year period, from 1998 to 2011, there are a total of 61,356 observations for each variable across the 12 grids (12 grids x 11 years x 365 days + 12 grids x 3 years x 366 days). The 949 incidents of boulder falling and soil slippage have occurred in 761 days, between 1998–2011. Grids 16 and 20 span the districts of Ratnagiri and Sindhudurg and, thus, witness more than 50% of the incidents of boulder falling and soil slippage.

Figure 7: Grid map of Konkan Railways (0.5° latitude x 0.5° longitude)

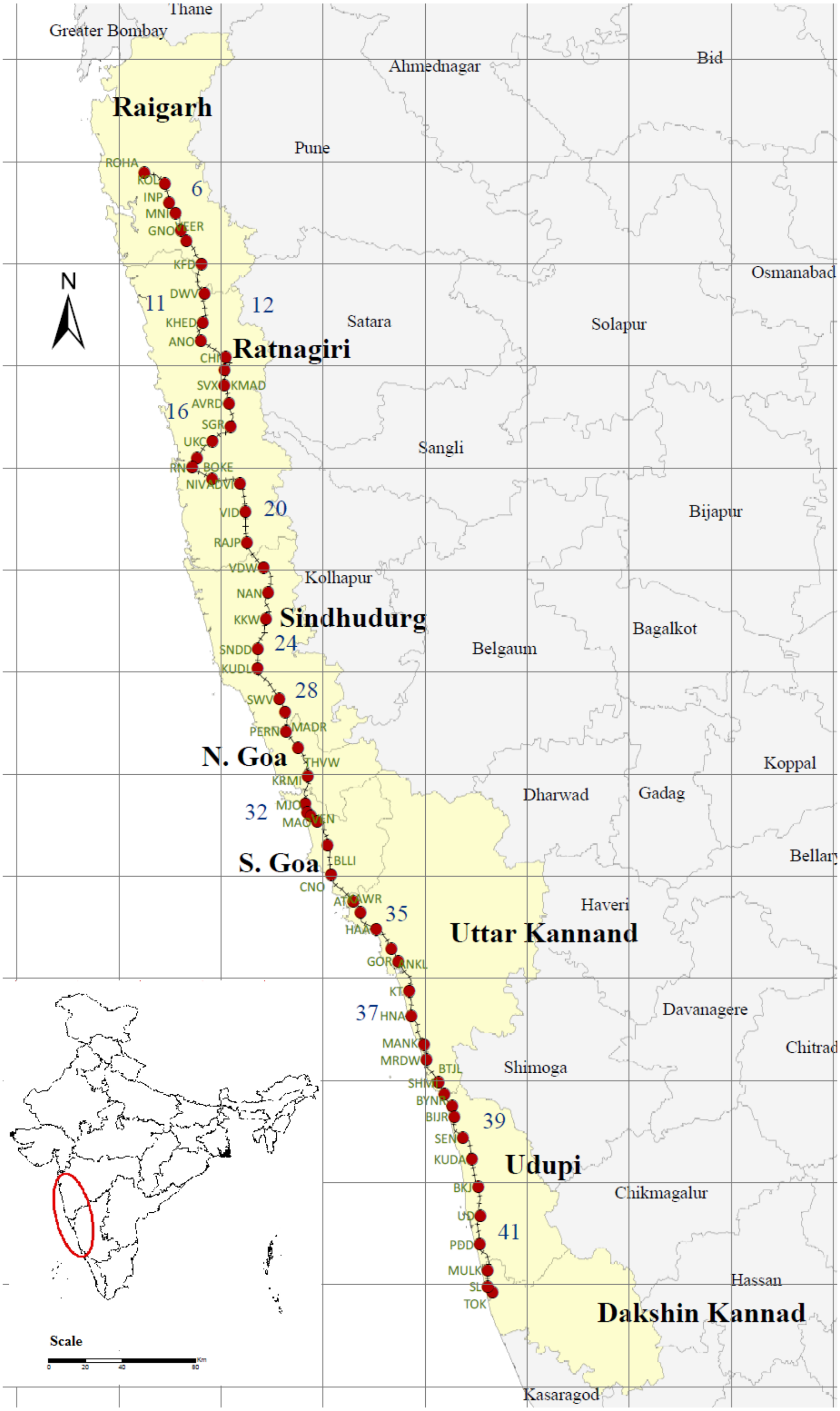
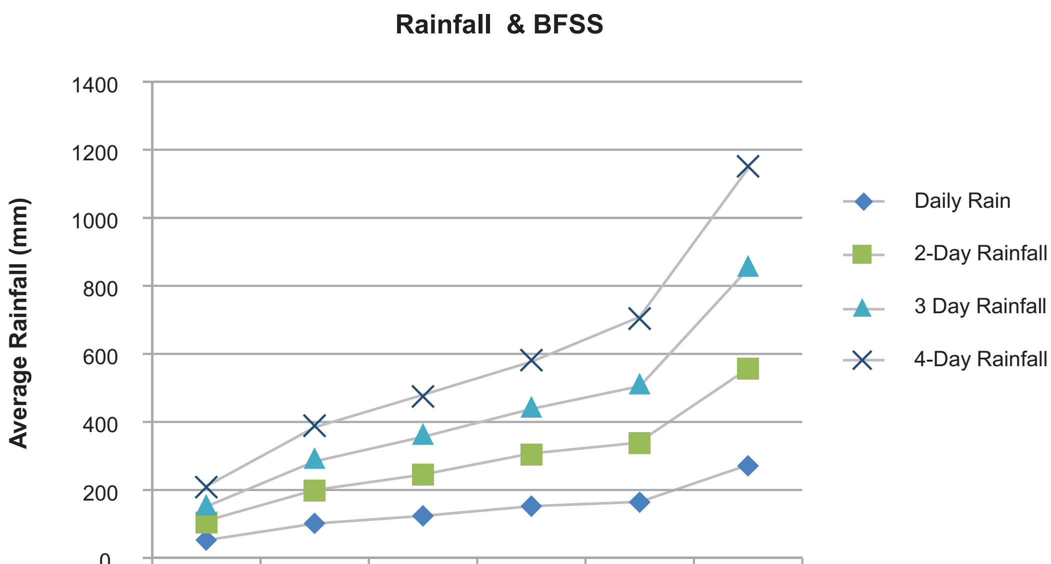


Figure 8, below, plots these 61,356 observations, demonstrating the relationship between rainfall, and boulder falling and soil slippage incidents. On the horizontal axis is the incidents of boulder falling and soil slippage. On the vertical axis is the average rainfall, in mm, for all the days where a particular number of boulder falling and soil slippage incidents occurred. The number of days with 0 boulder falling and soil slippage incidents across the 12 grids is 60,595, and the average rainfall for these days is 52 mm. Similarly, two-day, three-day and four-day cumulative rainfall have been plotted. The two-day cumulative average of rainfall on these 60,595 days is 104 mm.

The reason for including cumulative rainfall is to demonstrate that while rainfall on a particular day may not necessarily trigger boulder falling or soil slippage, a continuous rainfall across two, three or four days could make the boulders or soil loose.

Figure 8: Rainfall pattern on boulder falling and soil slippage



	0	1	2	3	4	5
Daily Rain	52	102	123	152	164	271
2-Day Rainfall	104	198	245	303	337	557
3 Day Rainfall	156	293	364	444	512	858
4-Day Rainfall	208	389	475	582	704	1152

BFSS

BFSS	0	1	2	3	4	5
BFSS	60595	643	85	18	6	5

The increasing trend shows that the days with incidents of boulder falling or soil slippage also have a higher average rainfall, as compared to those days without any incidents of BFSS. The more incidents of boulder falling or soil slippage, the higher the average rainfall. This increasing trend is also witnessed in the averages of the two-day, three-day and four-day cumulative rainfall. This reinforces that boulder falling is not only affected by the rainfall that happens on that particular day, but also by the rainfall events of the previous day or the cumulative rainfall in the previous three or four days.

These rainfall averages are also indicative of system thresholds beyond which there is a possibility of a boulder falling or soil slippage incident. The data table shows that 102 mm of rainfall in 24 hours can lead to an incident of boulder falling or soil slippage, while cumulative rainfalls of about 198 mm in a span of 48 hours, 293 mm in 72 hours, and 389 mm in 96 hours can trigger incidents.

The slope of the graph shows the amount of incremental rainfall needed to induce an additional incident of boulder falling or soil slippage. The slope is sharp for 0–1 region in the graph. This means that a significant rainfall is needed to induce boulder falling or soil slippage. After 0–1, the slope becomes moderate for 1–2, 2–3 and 3–4 regions in the graph. This implies that once an incident has occurred, less rainfall can induce an additional incident of boulder falling or soil slippage. An incremental rainfall of 21mm is enough to increase the number of incidents from 1 to 2.

An important conclusion from this figure is that every time rainfall thresholds are crossed, it may not necessarily lead to boulder falling and soil slippage, but it does make the region vulnerable. When the raw data of daily rainfall is observed, it is clear that these average thresholds are being crossed many times without corresponding to any incidents of boulder falling and soil slippage. While heavy rainfall can be traced as the trigger in boulder falling and soil slippage incidents, it does not always result in such incidents. There is, therefore, a one-way causality in the rainfall, and boulder falling and soil slippage incidents.

Photo credit: Amey Hegde, 2005

4. Future Climate Projections

In the Indian context, annual mean surface air temperature might rise within the range of 1.7°C to 2°C by the 2030s (INCCA, 2010). It has been projected that the number of rainy days over most of India will decrease. In addition, a 3–7% increase in summer monsoon rainfall in the 2030s (w.r.t. 1970) has been observed in the simulation results (INCCA, 2010). The frequency of heavy rainfall during the monsoons has also been projected to increase. Sea level rise, combined with an increased frequency and intensity of tropical cyclones will lead to an increase in extreme sea levels due to storm surges (INCCA, 2010). Mean sea level rise along the Indian coasts are estimated to be about 1.3 mm/year. As far as the cyclonic disturbances are concerned, the frequency is seen to be decreasing marginally, while the intensity is observed to be increasing (Evan and Camargo, 2011).

The future climate change projection models also have some uncertainties and data range. The data for the years 1961 to 1990 are modelled as baseline information in the climate change projection models. These models consider the time line from 2021 to 2050 as the medium-term, and 2071 to 2098 as long-term climate projections. The simulation models run by the scientists at the Indian Institute of Tropical Meteorology (IITM, Pune) indicate a considerable increase in the mean annual surface air temperature in the country of almost 4°C by the end of the 21st century (2071–2098). The summer monsoon precipitation in India may increase by 15% towards the 2080s, relative to the baseline period corresponding to the 1970s. However, on a smaller regional scale, some regions may experience slightly lower rainfall compared to the baseline period, in the future (Krishna Kumar, *et al.*, 2011).

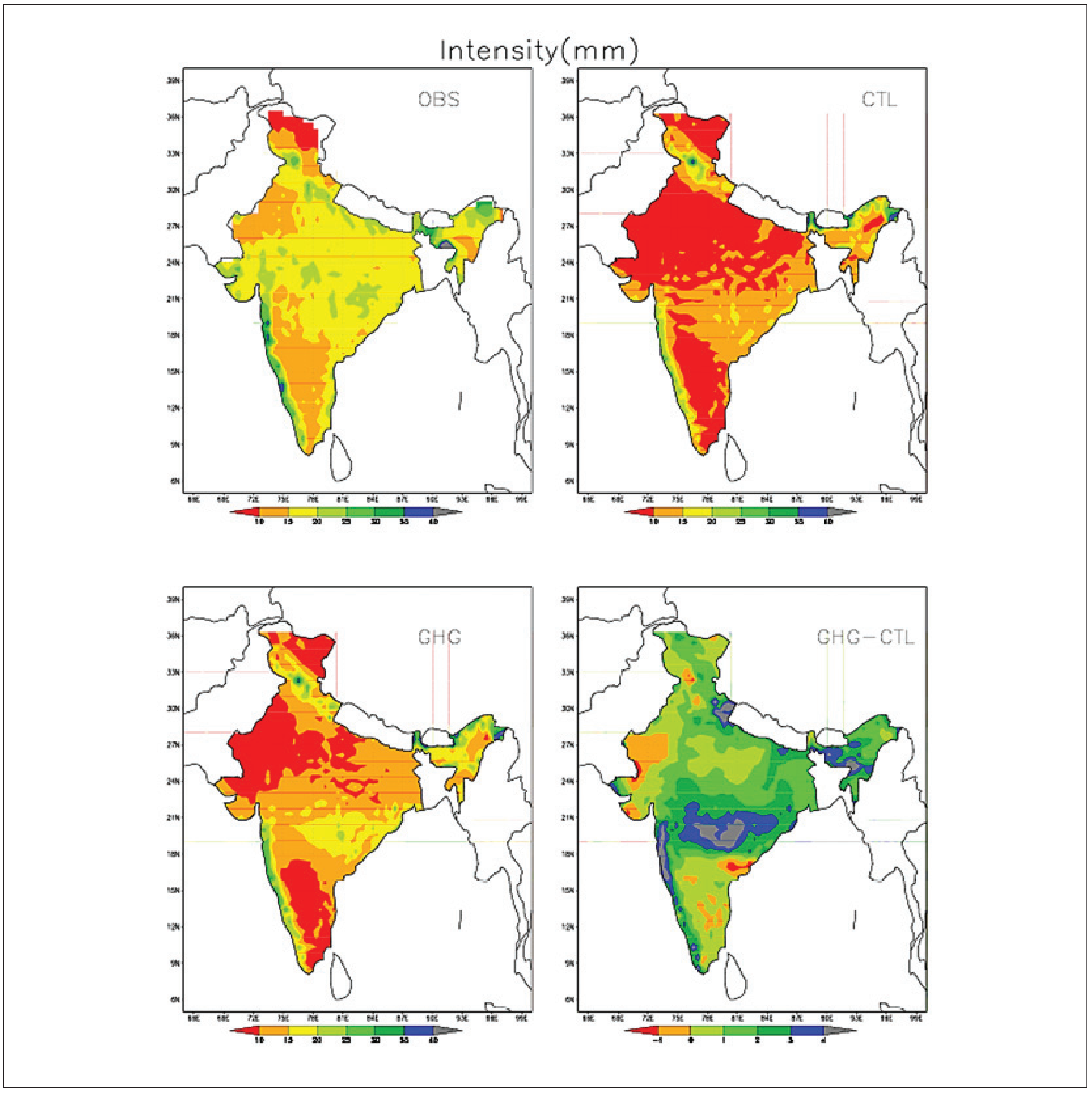
Regional annual summer rainfall projections from INCCA (2010) forecast a 5–13% increase for the Himalayan region, 6–8% increase for the west coast, 0.2–4.4% for the east coast, and 0.3–3% increase for the north-east region. A significant decrease in winter rainfall has also been projected. The rainfall intensity is projected to increase, while the number of rainy days is expected to decrease. The change in the number of rainy days per year projected for the country may be non-uniform in the physical sense, indicating uncertainty in the spatial pattern of the climate projections. Table 5 gives a summary of trend projections for mean annual rainfall and temperature for three models.

Table 5: Regional projections for annual rainfall and temperature for the 2030s w.r.t. 1970

	Mean Annual Rainfall	SD	Mean Annual Temperature	SD
Himalayan	↑↑↑	↑↓↔	↑↑↑	↑↑↑
West Coast	↑↑↑	↑↓↑	↑↑↑	↑↔↔
East Coast	↑↓↑	↓↓↓	↑↑↑	↑↑↑
North East	↑↑↑	↑↑↑	↑↑↑	↑↑↑

Source: INCCA (2010)

Figure 9: Observed and simulated mean intensity of rainfall (mm/day)



Source: Rupa Kumar et al. (2003)
© Shukla et al. (2003)

5. Adaptation Planning under Uncertainty at KRCL

KRCL has mainly adopted technological interventions to mitigate risks. These are termed as geo-safety works that KRCL has undertaken to reduce vulnerability, and are done based on existing system conditions and weather variability (Figures 10 and 11). These include measures such as flattening of slopes and cuttings, refixing of boulder nets, boulder netting, micropiling, soil nailing, wire mesh, etc. It has yet to be seen whether these need to be repeatedly done over a period of time to keep high alertness level. This is because heavy rainfall is an annual occurrence, and geo-safety works are not permanent. Of the various measures for geo-safety that Konkan Railways has adopted, 79.11% of the total expenditure, since its inception, has been on cuttings and tunnels. Earthwork for flattening of slopes, creation of berms, refixing of high strength boulder netting, and boulder netting are done for slopes and cuttings. Micropiling and grouting are done for soil foundation stability, and shotcreting and rock bolting are done in both tunnels and cuttings. Tables 6 and 7 show the investments in various categories of geo-safety work, and the annual expenditure incurred by KRCL.

Figure 10: Adaptation work example – Flattening of slope is visible on right side of track

Source: Google Earth (2010)

Figure 11: Adaptation work example – Flattening of approach slopes and retention at tunnel entrance are visible on right side of track

Source: Google Earth (2004)

Table 6: Geo-safety work done on Konkan Railway (1999–2012)

	Type of Work	Quantity	Cost'000 USD
1	Earthwork for flattening of slopes and creation of berms and refixing of HSBN	8,115,504 cubic meter	22,727
2	RCC Retaining Wall	19,756.70 cubic meter	7,162
3	Gabion Wall	38,234 cubic meter	620
4	Micropiling	56,944 running meter	2,711
5	Grouting	80,096 bags	
6	Catch water drain lining	30,618 cubic meter	2,487
7	Pitching	25,975.21 square meter	69
8	Shotcreting	633,843 square meter	15,522
9	Rock Bolting	1,927.39 metric tonne	
10	Soil Nailing	37,119 square meter	898
11	Geomatting	148,000 square meter	171
12	Loose scaling	23,701 cubic meter	276
13	Boulder netting	1,216,000 square meter	8,258
14	Sand Dampers and Laterite Stone Masonry	883,763 bags / 950 cubic meter	444
15	ACDs	807 unit	107
16	Catch fencing	5,659 running meter	429
17	Vetiver Grass Plantation	7.9 million saplings	333
		TOTAL	62,213

Source: Engineering Digest (KRCL) available at http://www.konkanrailway.com/

Table 7: Annual expenditure on geo-safety work

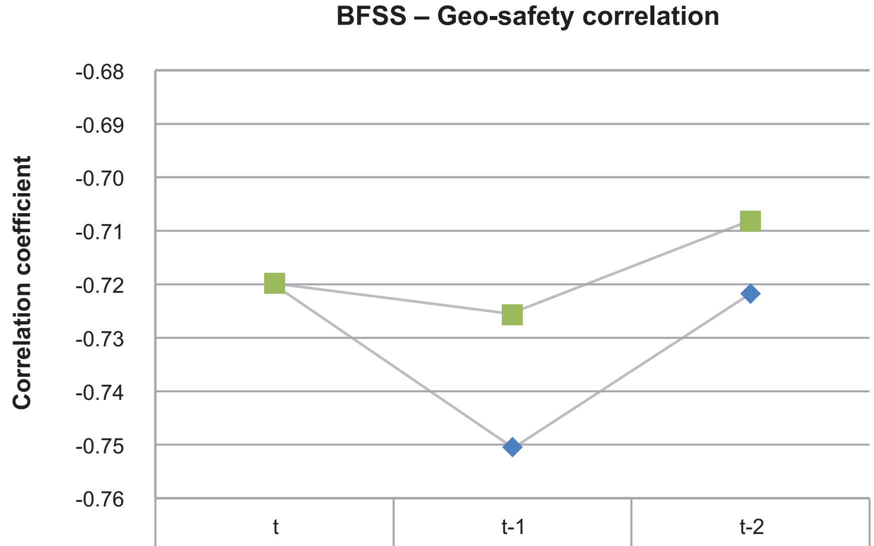
Year	Geo-Safety & Maintenance Expenditure (million USD)[2]	Boulder Falling Incidents
1999–2000	4.54	194
2000–01	6.14	153
2001–02	7.49	69
2002–03	5.78	47
2003–04	15.84	85
2004–05	18.70	42
2005–06	10.97	76
2006–07	14.54	24
2007–08	15.06	31
2008–09	14.17	15
2009–10	12.83	12
2010–11	10.94	19
TOTAL	137	767

Source: Data provided by KRCL (Right to Information Applications: KR/CO/PR/IA/11/16/47/393 & KR/CO/PR/IA/11/16/52/398) & Engineering Digest (KRCL) available at http://www.konkanrailway.com/

Investments in geo-safety measures show a high negative correlation with the incidents of boulder falling and soil slippage. This implies that investment in geo-safety curbs these incidents. Geo-safety works have a lagged effect on incidents of boulder falling and soil slippage, implying that investments made this year may prevent boulder falling and soil slippage next year. The correlation coefficient of boulder falling and soil slippage incidents increases in absolute terms with geo-safety investment of the previous year. This is also true for cumulative expenditure on geo-safety for two years. The absolute value of the correlation coefficient declines for investments made two years ago, i.e., t-2 year as compared to year t-1. Hence, geo-safety works done more than one year ago may not have incremental effects in inhibiting boulder falling and soil slippage. This is also evident from the following graph, which shows the point of inflexion as t-1 (Figure 12). Absolute correlation coefficients in the following years continue declining. In terms of policy relevance, it could mean that adaptation investments must regularly continue for Konkan Railway, and possibly even increase steeply in the future when the infrastructure assets become old and climate change variables become more severe.

[2] Includes annual geo-safety expenditure, maintenance expenditure on bridges and tunnels, and permanent way

Figure 12: Effect of investment in geo-safety work diminishes



	t	t-1	t-2
GeoSafety	-0.719769	-0.750447	-0.721749
GeoSafety Cumulative	-0.719769	-0.725639	-0.708214

The relation of boulder falling and soil slippage with rainfall (CCV) and investment in geo-safety work (SCV) have been discussed. Other than system condition variables, sustainable development variables also help in preventing adverse effects of climate change, at a slower yet sustained pace. In the case of Konkan Railways, the soil tends to become loose during monsoons, leading to boulder falling and soil slippage incidents. Konkan Railways has adopted the latest, and highly mechanised ways of holding soil. Measures such as boulder netting, rock bolting, micropiling, etc., are absolutely essential to maintaining safety under such irregular terrain and high rainfall conditions. However, these measures are inadequate if they are not complemented with enough sustainable development measures. In this case, specifically, it is the forests that hold the soil and prevent boulder falling and soil slippage. Total forest cover, as a percentage of land area, holds a moderately strong and inverse relationship with boulder falling and soil slippage incidents, with a correlation of -0.315.

Forest cover statistics in the eight districts of Raigad, Ratnagiri, Sindhudurg, North Goa, South Goa, Uttar Kannada, Udupi and Dakshin Kannada show an increase in the total forest cover. With regard to types of forest, the districts of Maharashtra and Karnataka have improved their moderately dense forests, while their very dense forest area remains approximately the same (Forest Survey of India, 1997–2011). Only in districts of Goa, a significant area under moderately dense forests has been stepped up to very dense forests, as reported by India State of Forest Reports published by MoEF. Konkan Railways, on its end, has spent about 333,000 USD on the planting of 7.9 million saplings of Vetiver grass over a 12-year period, from 1999 to 2010.

Photo credit: Donar Reiskoffer, 2006

6. Conclusions

In this case study of the Konkan Railways, the risks and uncertainties have been identified, as well as the consequent impacts that the railway system faces. Furthermore, the important SCV, CCV, and SDV that have a significant role in the boulder falling and soil slippage incidents have been identified. The association with preventive adaptation investment, in the form of geo-safety works and maintenance expenditure, shows that they contribute to making the system stable and resilient to adverse climate change impacts. For the adaptation benefits to be significant, pervasive, and long lasting, the right adaptation choices have to be made, keeping in mind the future climate uncertainty. This makes it important to extend the analysis to the next level.

It is important to identify the system dynamics, and create an impact matrix. In the case of Konkan Railways, there is an indirect impact of climate variables, i.e., rainfall in and of itself is not dangerous. In fact, Konkan Railways has invested enough in technology, communication, anti-collision devices, etc., that heavy rainfall (except in cases of flooding) does not affect safety or train operations. It is the indirect impact of rainfall that makes the soil loose and results in boulder falling and soil slippage incidents, which creates problems. After identifying the SCV, CCV, and SDV, and how they affect an infrastructure system, system thresholds should be identified based on past data. Whenever these thresholds are crossed, the system becomes vulnerable. In the case of Konkan Railways, a threshold of 198 mm of two-day cumulative rainfall has been identified as making the system vulnerable (Figure 8). These variables should then be used to quantify the long-term loss in the form of a damage function. While creating this damage function, future climatological projections must be incorporated to adjust for increased frequency and variability of relevant critical climate parameters.

The idea of damage functions is not to delve into accuracy of equations, but to have an estimate of the impact that significant variables have on the system. Each CCV will have uncertainty associated with its projections, and, therefore, a range of possible losses must be identified. Adjustments have to be done in the controllable variables in order to keep future uncertainty at an acceptable level. What constitutes the acceptable risk is the adaptation dilemma (Figure 2), i.e., how much to adapt. Of the three categories of variables, an infrastructure project, as a unit, can exercise maximum control over the system variables, i.e., SCV. The SCV can be easily managed and planned at a unit level. In Konkan Railways, investment in geo-safety works is one important SCV that strongly affects boulder falling and soil slippage incidents. A strong negative correlation (Figure 12) shows the same. The SDV need comprehensive integration with other entities, and only a small part of it will be under the control of the unit. Konkan Railways can influence vegetation along the track, but it cannot affect the overall forest cover of the region, which is equally important for the sustainability of the project. While SDV are far more reliable in the long-term, SCV give immediate results. For emerging infrastructure, the SDV can be managed far more efficiently, compared to existing infrastructure. Therefore, it makes sense to allocate resources appropriately between these two categories of variables in order to reap maximum benefits. Managing the SCV and SDV would also entail identifying the best instruments, be it insurance or any specific geo-safety work. To sum up, adaptation planning is an extensive exercise with a long-term focus. It is gaining importance, particularly for infrastructure assets, but now needs to be adopted universally.

Infrastructure is a constrained resource in developing countries that face challenges from climate change. As such, long-life assets that are currently being built have to be prepared for climate extremes. This requires active involvement in reverse impact study. The best way to manage investment lock-ins in infrastructure is to plan for them, incorporating relevant projections of climate variables. This entails identifying the risk factors, quantifying and then managing them. Complete climate proofing is not possible; hence, the adaptation dilemma exists. Adaptation is expensive, and the right amount of investment would ideally mean optimisation between alpha and beta errors. In situations where risk cannot be managed, alternate mechanisms to ensure that the shock period is minimal should be adopted. These include insurance, risk pooling, etc. While developed countries have already reached a stage where market-based risk management instruments are actively used, developing countries like India will now have to bring about policy and market-induced enforcements for resilient infrastructures.

Studying climate change, system condition, and sustainable development variables is extremely important for resilient infrastructures. As demonstrated by the case of Konkan Railways, one can determine the climate thresholds and identify, to some extent, which system condition variables have significant impact on influencing resilience. The analysis presented above shows that preventive geo-safety works must be done regularly, as their effects wear off in about two years. These costs will be higher during the initial period, and will stabilise in the subsequent years only to increase again. While sustainable development variables may require policy intervention to be pursued actively, system condition variables are usually project controlled and, therefore, can be pursued aggressively.

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