

Chapter 5

Climate Change Impacts on Infrastructure

5.1 Introduction

South Asia, in general, and India, in particular, is considered vulnerable to climate change and its adverse socio-economic effects. A preliminary analysis of climate change impacts in India has been carried out by various agencies (SAARC, 1992; ADB, 1994). However, further studies are required to develop a better understanding of climate and human system interactions along with adaptation strategies for mitigating adverse impacts.

Most experts agree that, average global temperatures could rise by 1 to 3.5 degrees Celsius over the next century. Climate change is more than just a warming trend. It will lead to changes in many aspects of weather. Climate change primarily manifests itself in terms of temperature increase, sea level rise, variability of precipitation pattern, change in the frequency and intensity of extreme events like cyclones, etc. Effects of these primary changes are observed on humidity, water availability, flooding and water logging, vegetation growth, structural stability, land slides and land erosion. These secondary changes, along with the primary manifestations of climate change, act as main force causing impacts.

Infrastructure typically is designed to tolerate a reasonable level of variability within a climate regime that existed when it was designed and built. However, climate change can affect both average conditions and the probability of extreme events, which may influence the infrastructure in the long run.

Infrastructure is more vulnerable to flooding and landslides as compared to temperature changes. Detailed modelling of frequency and intensity of rainfall in the context of global warming has been linked with considerable damage to infrastructure. Landslides are a current threat in many hilly areas and can increase with more intense rainfall events. Sea level rise is likely affect infrastructure in coastal areas. Current estimate of average global sea level rise is 25-70 cm for the year 2100. Sea level rise at the regional level can be as much as twice or as little as half the global average. Tropical cyclones are expected become more destructive under climate change. Tropical cyclones combine the effects of heavy rainfall, high winds, storm surge, and sea level rise in the coastal areas. The effect of cyclones can be

experienced far inland, but the cyclones are not as universally distributed as floods and landslides.

Flooding and other extreme weather events may damage buildings. Potential changes in humidity and climate may cause a variety of problems. There can be adverse effects of storms, heat, and humidity on walls and insulation, which will affect infrastructure durability and energy usage. Thus, climate change will require a modification in the level and the type of climatic effects that need to be addressed by infrastructure design codes.

Climate change will have some direct effects on transportation infrastructure and the operation of transportation systems. These may be divided into three categories: the effects of climate on operations, the effects of sea level rise on coastal facilities, and the effects of climate on infrastructure.

A future climate with more rainy days, somewhat higher rain rates, and more rainstorms may also increase total vehicular accidents and total injuries in vehicular accidents, reduce travel on public transportation systems, and cause longer delays. Although, the effect of climate change on transport is not clear, transportation by air is known to be sensitive to adverse weather conditions; major system-wide effects sometimes follow from flight cancellations, rerouting, or rescheduling (IPCC, 2001). There is a high level of confidence that sea level rise will increase the cost of protecting infrastructure located in the coastal regions.

Transportation operations are sensitive to local weather conditions. Fog, rain and snow slow down transport movements and increase risks of accidents. In addition, maintenance costs and durability of infrastructure are also dependent on weather events. Changes in frequency and intensity of extreme events such as hurricanes, floods, high speed winds and cloudbursts may have significant impacts on the safety and reliability of transportation.

Any asset like infrastructure, having a long life, has tub shaped cost curve for repair and maintenance. In the initial stabilisation period it may require frequent maintenance. The maintenance requirement decreases once the system has stabilised. It increases again due to wear and tear as the asset reaches the end of its useful life. Attention to climate change impacts becomes important because as per the present predictions the climate change impacts

will occur only in the later half of the present century and by that time most of the present infrastructure assets would be nearing the end of their useful life.

In the following section, climate change impacts for the Konkan Railway have been assessed, through application of an impact matrix. An analysis of the current conditions, lessons from the past climate variability, potential climate change impacts, knowledge and information gaps, and the point of view of the stake holders has also been presented.

5.2 Case of Konkan Railway

Konkan is a coastal strip of land bounded by the Sahyadri hills on the east and Arabian Sea on the west on the western coast of India. It is a region with rich mineral resources, dense forest cover, and a landscape fringed with paddy, coconut and mango trees. This Railway project was conceived with the objective of bridging the 'Konkan gap' and reducing the distance and travel time between Mumbai, and coastal Karnataka and Kerala.

It is the first major infrastructural project in India to be taken on the Build, Operate, and Transfer (BOT) basis. Indian Railway set up Konkan Railway Corporation Limited (KRCL) as a BOT operator in July 1990 with active participation of the central government and 4 state governments of Maharashtra, Karnataka, Goa and Kerala (Shivdasani and Kane, 1998). The Railway line from Roha to Mangalore passes through Raigad, Ratnagiri and Sindhudurg districts of Maharashtra, North and South districts of Goa and Uttar Kannada and Dakshina Kannada districts of Karnataka state.

Konkan Railway is a broad gauge (1676 mm) single line, between Roha (about 150 km south of Mumbai) and Thokur (22 km north of Mangalore), a distance of 760 km, built at a cost of Rs. 33750 millions. There are 59 stations on the line, as many as 179 major bridges (total linear waterway 20.50 km) and 1819 minor bridges (total linear waterway 5.73 km). This is for the first time that Indian Railways have constructed tunnels longer than 2.2 km and there are 9 such tunnels in the project (KRCL, 1999). The Konkan Railway commenced commercial operations on January 26, 1998.

From the very beginning of the project, environmental concerns were raised by various interest groups and researchers. The alignment proposed by KRCL was accepted by the states of Maharashtra and Karnataka. The alignment in Goa developed into a contentious issue with a see-saw battle between various interest groups (Raghuram, 1999).

Geologically, the entire western coastal strip from Roha to Mangalore falls in two distinct zones. The first zone extends from Roha to Kankavali and the second from Kankavali right up to Mangalore. The Western Ghats, through which the Konkan Railway passes, experience moderate to heavy rainfall and the marine ecosystems are sensitive to climate changes. Many studies were carried out to analyse the impacts of Konkan Railway project on the surrounding ecosystems and environment. However, no study has analysed the environmental impacts on Konkan Railway. In the present study we have explored the potential impacts of climate change on Konkan Railway infrastructure.

5.3 Impact Matrix

Indices make it possible to compare two or more complex, multifaceted systems at one time by analysing the interactions among the systems and converting the information related to varied impacts in a single observable outcome. While this reductionism enhances understanding about the phenomenon, it works contrary to both the complex behaviour of the system and potentially disparate nature of impacts. Modelling requires simplification of complex realities and the matrix approach provides the required simplification mechanism.

In the present study, cause-effect analysis was carried through a causal matrix where various identified indices were assessed for their capacity to force changes in the other elements. This type of analysis is suitable for pre-modelling studies since it identifies the key relationships that need to be quantified. This causal analysis in the present study was carried out through a qualitative approach. Table 5.1 shows this analysis for Konkan Railway for 10 identified indices. The table shows a two-way matrix where 'L' denotes a weak link, 'M' a moderate link and 'H' a strong link. Rows show the forcing variables and the columns dependent variables. The strength of the causal link was determined in consultation with the officials of Konkan Railway. A total of eight senior officials were interviewed. A two-stage process of interviewing was adopted for this purpose. In the first stage, relevant causal variables were identified, and in the second, strength of the link was determined. Analysis matrix presented here shows the perceptive importance assigned by the persons working in the field and therefore no quantification of the relative strengths of the linkages has been attempted.

Table 5.1: Causal matrix for impact analysis for Konkan Railway

		Environmental Variables						Project Components			
Forcing Variables		Temperature	Rainfall	Sea level rise	Extreme events	Water logging	Vegetation growth	Land slide	Safety/Efficiency	Maintenance	Traffic volume
Environmental Variables	Temperature		L	M	L	--	L	--	--	--	L
	Rainfall	L		--	M	M	M	H	L	L	M
	Sea level rise	--	--		--	M	L	M	L	--	L
	Extreme events	--	L	--		M	--	M	L	--	M
	Water logging	--	--	--	--		--	L	L	--	M
	Vegetation growth	L	L	--	--	--		L	--	L	--
	Land slide	--	--	--	--	M	L		M	L	H
Project Components	Safety/Efficiency	--	--	--	--	L	--	L		M	M
	Maintenance	--	--	--	--	M	L	H	H		M
	Traffic volume	--	--	--	--	--	--	--	L	M	

The analysis carried out with the help of the causal matrix shows that low dependence and high-forcing factors such as rainfall is the major climatic driver having impacts on Konkan Railway. This factor is influenced by the elements external to the Konkan Railway and is beyond the control of the system. Some other factors such as temperature, sea level rise and extreme events have complex feedback loops and result in high forcing. Further research may be needed to improve the understanding of these linkages. On the contrary, factors such as landslides have a high forcing effect but are also highly influenced by other elements within and outside the system. There are some factors, such as traffic volume, which have a high dependence on all other factors and are very important for Konkan Railway. Low dependency/low forcing factors such as emission levels have a lesser effect on the system but may still exhibit important links with the global feedbacks loops.

From the matrix it is clear that, the most relevant factors for measurement of potential impacts are rainfall, having a strong negative influence; and preventive maintenance, being a strong positive influence. Rainfall being highly influenced by external factors cannot be

forced by the factors internal to the system, whereas preventive maintenance is internal to system and can help in minimising the extent of impacts.

5.4 Results and Analysis

5.4.1 Current stresses

In this section, we review the state of knowledge about current risks from climate hazards to Konkan Railway. In particular, we focus on the hazard of increased rainfall and coastal storm surge inundation and its effect on transportation systems.

Konkan Railway from its inception 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. The reports published from time to time in the newspapers (Indian Express, July 14, 1998 and July 19, 1999; The Hindu, July 10, 2001) and the records of Konkan Railway clearly indicate its sensitivity and vulnerability to the climatic impacts. From the very beginning, every year during the months of monsoon there have been disruptions in the operations due to water logging and landslides. There are numerous instances of trains running late during the rainy season every year. Analysis of the past data indicates that on an average the operations are suspended for about a week during the monsoons because of such problems along the track. Some of the major incidences recorded in the past are from year 2000 when it rained more than 300 mm in a day and the train operations were suspended for a duration of 14 days from 11 July to 25 July 2000 as a result of landslides at 36 locations along the track. The expected losses from the suspension of the operations were estimated to be Rs 10 crore. There were a total of 140 reported incidences of landslides during the entire monsoon season in year 2000.

Konkan Railway authorities have identified vulnerable points where preventive maintenance is carried out before the onset of monsoon, to deal with any such calamity. Measures like erecting nylon nets along danger-prone sections have also been adopted. Based on experiences over the years, the number of identified points has varied between 60 and 120 every year. In addition to the identification of these vulnerable points several capital projects have also been taken up to provide long-term solutions and preventive mechanisms to minimise the impacts.

5.4.2 Regional Climate Change

The most important feature of the climate of Indian subcontinent is the seasonal alternation of atmospheric flow patterns associated with the monsoons. Another important feature is regional variability. The annual rainfall increases by almost three orders of magnitude from west to east across India. Devastating floods in some areas and parching droughts in other areas occurring simultaneously is a common feature in the Indian subcontinent.

The summer monsoon contributes about 80% of total annual rainfall in a major part of India. Most of the studies during the last four decades have clearly pointed out that the monsoon rainfall is trendless. However, Kolli et al., (1992) have identified some broad contiguous areas showing statistically significant trend. A decreasing trend was noticed in the monsoon rainfall of northeast peninsula and northeast India (-6 to -8% of normal/100 years) while an increasing trend was noticed along the west coast and over central peninsula (+10 to +12% of normal/100 years).

Figure 5.1 shows that, the areas with increasing trend in the monsoon seasonal rainfall are situated along the west coast, north Andhra Pradesh and north-west India and the areas with decreasing trend, are situated over east Madhya Pradesh and adjoining areas, north-east India and parts of Gujarat and Kerala

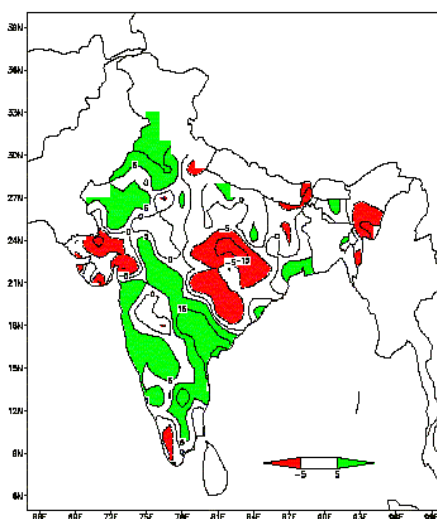


Figure 5.1 Spatial patterns of linear trend (% of mean/100 years) in summer monsoon rainfall during 1871-1990

Source: Kolli et al., (2002)

On an all-India scale, there is no correlation between the monthly rainfall within the season, mainly because the local variations dominate the rainfall variability. Thus, the seasonal total rainfall cannot indicate the monthly distribution of rainfall. Further, the daily variations in a particular season are also important. On the daily scale, heavy rainfall occurs independent of the annual average rainfall of the stations. There are many places in India, which record 40 to 100% or more of their mean annual rainfall in one day. Rakhecha et al. (1990), as quoted in Kolli et al. (2002), have published a chart showing the heaviest recorded 1 day rainfall over India based on data of over 300 stations for the period 1875-1982. About 50 stations out of these 300 stations have recorded more than 500 mm rainfall in a day. The heaviest rainfall was mostly recorded at coastal and hill stations. Extreme short-duration rainfall events show significant increasing trend over the northern parts of the west coast of India and decreasing trend over the southern parts of the west coast, while no spatially coherent trends could be noticed in other parts of India (Kolli et al., 2002).

5.4.3 Potential Impacts

After identifying the forcing variables, a major task for climate change impact studies is to explore critical thresholds to determine when the risk of an impact becomes 'dangerous'. The value of these elements can be assessed through case specific studies. The level of these factors interpreted as critical thresholds becomes important observation point where additional preventive measures are imperative. Further, the thresholds can be related to various climate change scenarios. In the present study, the main factor contributing to the potential impacts has been identified as increased rainfall. Based on the studies carried out in the past, rainfall threshold for landslides in the Konkan region has been identified as more than 200mm precipitation in 24 hours (Nagrajan, 1995). However, it should be noted that rainfall alone is not sufficient for causing landslides, which can be influenced by many other factors such as geology, soil structure, vegetation cover, slope, etc.

Future rainfall projections for India have indicated an increasing rainfall trend (Kolli et al., 2002). Given the increasing trend of rainfall and spatial variability, Konkan region is expected to receive more than 1000 mm rainfall in a month during monsoon season. With such a heavy concentration of rainfall, days with more than 200 mm precipitation, in a season, will definitely increase. If we set a threshold of 1000 mm rainfall in a month then the projected rainfall level crosses the threshold in 2080. Thus, a system having a rainfall threshold of 1000 mm would have a high vulnerability in the later half of the century. Further, the studies show that the statistical characteristics of the daily rainfall over India also have significant spatial variations. It has also been observed that, during the summer monsoon

season, heavy rainfall in just 10 to 20% of the total number of rain days accounts for 50% of the seasonal rainfall at most of the individual stations. A rainfall increase pattern in the Western Ghats adds to the problem. This further becomes important because in the later half of the century, when these impacts are likely to take place, the Railway infrastructure, having lived its normal life, would be more vulnerable to any such change.

The profit and loss account of the KRCL shows that 6% of the annual budget is spent on the repair and maintenance (Appendix 1). Out of the total repair and maintenance, close to 70% goes for repair and maintenance of permanent way, bridges and tunnels. As per the estimates of officials at KRCL, about 20% of this expenditure takes place for minimising climate related impacts. It is clear that any future climate change will definitely increase expenditure on repair and maintenance activities.

While studying the impacts, it is important to take into account the point of view of the officials at Konkan Railway. The officials said that the present design code takes into account the normal climate change variability. However, in case of extreme climatic events the threshold level may be crossed. Some of the officials were of the opinion that these impacts are more pronounced in the initial stabilisation years of any infrastructure project and will gradually reduce as the system stabilises. However, others opined that these are common impacts due to the climate and the geology of the region and problems like falling boulders and landslides plague other railway routes as well. Even 100-year-old Pune Ghats section of Central Railway is similarly affected once in a while.

As described above, a major task for climate change impact studies is to explore critical thresholds to determine when the risk of an impact becomes 'dangerous'. The next task will be to determine the value of these impacts. This can be assessed either economically; biologically, as levels of risk to population numbers or habitat area; or as financial losses. For carrying out detailed analysis of all the parameters, continued efforts will be required to develop and improve the databases. In addition, methods to better assess the damages under climate change scenarios are required which will include the maintenance regimes.

In this section, we have presented a simplified and somewhat idealised example of impact analysis for Konkan Railway. This example successfully brings out the complexity of impact analysis. It also shows the co-dependency of many factors, indicating that integrated analysis that includes external factors affecting both climate and the selected sector, and that

incorporates feedbacks affecting strong drivers within the system, will be the most useful for gauging the impacts of climate change. Such studies carried out for selected projects of different sectors will be able to provide richness to the available literature on impact analysis and enhance the understanding of climate change impacts.

5.5 Conclusions

KRCL analysis indicates that infrastructure having long life becomes more vulnerable to the climatic changes 50 years from now. Efforts will have to be made to minimise these impacts. Also there is a need to account for these impacts in the environmental impact analysis carried out for such projects.

Two important insights, which emerged in this study, are the need for awareness building about the potential impacts among the concerned people, and developing good quality databases. For instance, there is a 100-year long written record of climatic data for India. Historic data for storms and floods is also available. However, systematic efforts will have to be undertaken to compile this record in a form that is useful for impact assessment for coastal areas. There are presently no studies available on the impact assessments of different climatic parameters. Studies about future projections of changing regional climate are also underway.

For a detailed assessment of the impacts on infrastructure following tasks need to be completed:

- Preparation of a catalogue of historic extreme events, assessing the damages and providing the loss estimates in coastal and inland areas, showing the spatial distribution.
- Detailed GIS covers with topographic, vegetation and geological details showing the major infrastructure systems and components.
- Sensitivity assessment of the infrastructure components with respect to various climate parameters.

This will facilitate further model development and a GIS-based computer algorithm for computing the losses for individual scenario events. An integrated study covering all sectors for smaller geographical regions showing similar climatic characteristics can then be taken up.

Appendix 1: Profit and loss account of Konkan Railway

for the years 1997-2001 (Amount in Rs.)

	ITEM	2001	2000	1999	1998	1997
A	INCOME					
	a. Traffic Earnings	1,516,565,103	1,181,288,056	803,558,510	183,545,842	53,250,357
	b. Other income	158,971,362	120,893,360	181,272,648	5,497,890	
	(A)	1,675,536,465	1,302,181,416	984,831,158	189,043,732	53,250,357
B	EXPENDITURE					
1	Expenses on staff	402,946,772	356,529,825	321,779,421	131,611,574	36,030,877
2	Hire charges for Rolling Stock & Motive power	144,564,036	136,210,789	90,496,774	38,666,504	21,344,972
3	Fuel	262,305,042	203,918,225	134,369,372	38,985,935	8,698,569
5	Lease Rentals	201,740,177	199,650,000	199,650,000	202,609,444	157,787,834
6	Repairs and Maintenance					
	a) Permanent Way	193,022,868	154,448,563	71,846,589	53,751,451	16,464,760
	b) Station and Other buildings	26,945,011	12,845,718	8,465,268	1,759,736	3,235,914
	c) Equipment	54,437,834	54,133,583	31,115,348	18,110,044	1,450,971
	d) Bridges & Tunnels	17,001,515	15,186,779	31,732,149	4,253,052	2,685,235
	e) Rolling Stock	28,504,756	15,452,188	14,749,794	4,990,139	
	f) Others					781,719
	Total Repair & maintenance	319,911,984	252,066,831	157,909,148	82,864,422	24,618,599
7	Consumption on tools and other stores	0	0	0	0	40,590
8	Commission	0	0	91,834	48,794	52,563
9	Loss on sale of Assets	593,728	699,284	4,064,966	0	238,469
10	Depreciation	704,697,787	691,041,482	681,325,051	118,242,097	3,044,586
12	Depreciation for earlier years	6,551,561	1,615,202	0	0	0
13	Misc. & Other Operating Expenditure	179,197,762	147,637,384	168,205,286	94,704,376	12,023,890
15	Finance Charges	3,253,469,970	3,139,922,439	3,038,178	902,797,037	0
	(B)	5,475,978,819	5,129,291,461	4,795,929,598	1,610,530,183	263,880,949
	(A-B)	-3,800,412,354	-3,827,110,045	-3,811,098,440	-1,421,486,451	-210,630,592
16	Prior period Adjustments	-15,792,377	-19,848,386	408,040,615	-114,989,130	2,943,474
	Net Loss during the year	-3,816,234,731	-3,846,958,431	-3,403,057,825	-1,536,475,581	-207,687,118
	Add loss brought forward	-9,208,388,080	-5,361,429,649	-1,958,371,824	-421,896,243	-214,209,125
	Total loss transferred to Balance Sheet	-13,024,622,811	-9,208,388,080	-5,361,429,649	-1,958,371,824	-421,896,243

Source: Konkan Railway Annual Financial Statements 1997-2001