Unclassified **ENV/EPOC/GF/SD/RD(2004)5/FINAL**

Organisation de Coopération et de Développement Economiques
Organisation for Economic Co-operation and Development **07-Feb-2005**

English - Or. English

ENVIRONMENT DIRECTORATE
Environment Policy Committee

ENV/EPOC/GF/SD/RD(2004)5/FINAL
Unclassified

English - Or. English

Global Forum on Sustainable Development

DEVELOPMENT AND CLIMATE: IMPACTS AND ADAPTATION FOR INFRASTRUCTURE ASSETS IN INDIA

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Paris, 11-12 November 2004

JT00178103

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DEVELOPMENT AND CLIMATE: IMPACTS AND ADAPTATION FOR INFRASTRUCTURE ASSETS IN INDIA[1]

P.R. Shukla[2], Manmohan Kapshe[3], Amit Garg[4]

Abstract

Huge investments are being committed in new infrastructure projects in developing countries. Development of infrastructure enhances the scope of utilizing underemployed resources, besides creating new investment opportunities. Infrastructures are long-life assets and are designed to withstand normal variability in climate regime. The recent incidents of cyclones on east and west coast of India and landslides caused by heavy rainfall in Konkan region indicate that the infrastructures are vulnerable to extreme climatic changes. This paper presents a framework and case studies for assessing the likely climate change impacts on long-life assets using a methodology of reverse matrix for climate change impact analysis. The recently constructed Konkan Railway, a major project laid through the high rainfall western ghat (mountain) region, is a typical example of high value long-life asset exposed to climate extremes. The analysis of the project shows that the assessment of including adverse climate impacts would have altered the project design and configuration. A bi-directional impact matrix that includes the impact of project on the environment as well as impact of environmental changes on the project is proposed. Another case study examines the impact of temperature and rainfall changes on the future energy demand due to increased demand for space cooling and irrigation. A brief mention has also been made about the recent developments in large scale infrastructure projects of 'Linking the Rivers' and development of 'National Highways Network'. The paper suggests that the likely damages to long-life assets and dependent economic activities from climate change could be enormous. The need for developing the insurance market for spreading the risks of extreme climate impacts is discussed. The analysis indicates that the adaptation strategy should integrate the climate change impacts with the overall assessment of investment decisions and design of infrastructure projects.

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[1] *Suggested citation:* Shukla, P.R., Manmohan Kapshe and Amit Garg (2004), *Development and Climate: Impacts and Adaptation for Infrastructure Assets in India,* paper presented at the OECD Global Forum on Sustainable Development: Development and Climate Change, ENV/EPOC/GF/SD/RD(2004)5/FINAL, OECD, Paris.

The opinions expressed in this paper are those of the individual authors and do not necessarily reflect the views of their organisations or of the OECD.

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1. Introduction

Infrastructure is an engine for economic development. It may be broadly defined as a system of linkages that facilitate and enable the flow of goods and services. These linkages include road, rail and airways; river systems, electric power systems, and all the different types of communication and service lines. It also includes the built and engineered entities, the factories, buildings, dams, and all that comprise the cities and towns. Infrastructures are man made long-life assets. Infrastructure is most often forgotten as an explicit factor of the economy. It is so pervasive, affects so many of our activities, and shows up in so many different and seemingly unrelated guises that it is difficult to capture, cost or discuss as a single unit. Infrastructure is the backbone of economic activity. It incurs costs to maintain; it can be damaged, removed, or harmed, and must be taken care of for the economy to function properly.

With enhanced requirements of the economic development, investment in infrastructure is crucial to support a higher level of industrial growth. In various World Bank studies it has been estimated that a 1 per cent growth in infrastructure development translates into a 1 per cent growth in the economy. On the path of development, India's immediate goal is to achieve industrial growth of at least 10 per cent per annum and sustainable GDP growth of at least 7 per cent per annum. Enhancing infrastructure investment with giving diligent economic consideration of impact of climate change on infrastructure is crucial to attaining these objectives (PMC, 2003).

Infrastructure is designed to tolerate a reasonable level of variability within a climate regime that existed when infrastructure was designed and built. However, climate change can affect both average conditions and the probability of extreme events, temperatures, precipitation patterns, water availability, flooding and water logging, vegetation growth, land slides and land erosion in the medium and long-run (IPCC, 2001c; Rupa Kumar et al., 2003). These would impact long-life assets. Different sectors and assets display different level of sensitivity to climate change because of their different vulnerability and adaptive capabilities (Shukla et al., 2003). The damages to capital assets and dependent economic activities may be enormous. Damages to infrastructure occur primarily because of high vulnerability and low adaptive capacity of the built environment to natural disasters, and also because of its exposure to the event itself. An example is the tropical cyclone that struck Gujarat state on the western coast of India on 9th June 1998. It left thousands dead and resulted in damages worth more than Rs. 26 billion (US$ 570 million) (Raju and Sinha, 1998). The thriving industrial complexes of Kandla, Porbandar and Jamnagar were devastated by its destructive prowess.

Another recent incident is the Konkan Railway accident on the western Indian coastal ghats on 21st June 2003 night that left more than 50 dead (Deccan Herald, 2003). The accident was caused by landslide due to incessant heavy rains, presumably higher than the system’s adaptive capacity. Climate change might have taken its first toll on the Indian railway system since the accident site was not an identified vulnerable spot by the railway administration based on past rainfall history, because the slope and the cutting was geologically stable.

It is often assumed that the main impacts of climate change will be related to mean temperature change. There are different aspects of temperature that go beyond changes in mean temperature. These include spatial and seasonal distribution, inter-annual variability, and extremes. Furthermore, there are many other elements of climate, which can be as important as temperature, for environment and economic activity. These include changes in precipitation, length of seasons, sea level rise and the frequency, severity and duration of extreme events. The task of assessing these various impacts and the feedbacks between them is enormously complex and requires a number of simplifying assumptions. Although, there are complex macro-economic models to assess the costs and macroeconomic consequences of various mitigation policies, the state of the art in impacts work at present does not permit this kind of ‘top-down’ modelling. Instead, the dominant approach has been ‘bottom-up,’ aggregating the first, second, and third order impacts into a single overall estimate without much attention to the feedbacks between various sectors.

In India, a number of studies have been carried out to understand impact of climate change on all the sectors of the economy. However, impact on infrastructure has not received due attention, therefore, not many good studies are available nationally and internationally. This paper presents a framework for analyzing the likely climate change impacts on long-life assets, two case studies and an adaptation framework. The paper suggests enhancing the present scope of unidirectional mandatory impact assessment of infrastructure projects on surrounding environment, to a bi-directional impact assessment including adverse impacts of climate change on the project. The paper demonstrates a methodology of using a reverse matrix for this purpose through a case study of Konkan Railways in the western Indian coastal ghats. Another case study on climate change impacts on energy sector indicates that a rise in average temperature increases cooling space requirements for residential, services and transport sectors, requiring higher power capacity build-up. An exploratory study has been presented to assess the extent of likely impacts on infrastructure investments keeping in view the large scale infrastructure projects such as the Linking of rivers project and development of national highway development plan (NHDP) for Golden Quadrilateral connecting Delhi-Kolkata-Chennai-Mumbai, North-South-East-West Corridor, and Pradhan Mantri Gram Sadak Yojna – PMGSY (Prime Minister’s Rural Road Programme). The paper also briefly discusses an insurance framework as an adaptation strategy.

2. Infrastructure development in India

Economic growth in India demands development of its infrastructure. In the light of the continued need for development of infrastructure in India, successive five-year plans have devoted a large and increasing volume of outlays for the development of economic, social and institutional infrastructure (GOI, 1981 and 2001). Following broad generalization can be made about the trend of investment in infrastructure items over the planning period.

Firstly, the major share of plan outlay has gone for the development of a few infrastructure items, which reflects the high priority given to some sectors. In the first two five-year plans, nearly two-thirds of the total plan outlays were devoted to social and economic infrastructure. In the later Plans, this declined to about three-fifth. Secondly, economic infrastructure (transport, power, irrigation and communication) has claimed a lion's share - Around 45% of the plan outlays. Within the economic infrastructure, power and transport have received the largest share. Thirdly, social infrastructure has received a relatively less attention claiming about less than one-sixths of the plan outlays. Fourthly, the pattern of plan outlays on infrastructure in the 1950s is distinctly different from that of the later plans. After that, however, there is stability in the pattern of plan outlays, though certain marginal shifts have occurred from one plan to the other (Joshi, 1990). Table 1 presents the plan outlays for different plan periods for infrastructure related sectors.

The Ninth Plan Working Group on Housing had estimated the investment requirement for housing in urban areas at Rs. 526 billion (US$ 11.5 billion). The India Infrastructure Report (GOI, 1996) estimates the annual investment need for urban water supply, sanitation and roads at about Rs. 280 billion (US$ 6.15 billion) for the next ten years. The Central Public Health Engineering (CPHEEO) has estimated the requirement of funds for 100 percent coverage of the urban population under safe water supply and sanitation services by the year 2021 at Rs. 1,729 billion (US$ 37.9 billion). Estimates by Rail India Technical and Economic Services (RITES) indicate that the amount required for urban transport infrastructure investment in cities with population 100,000 or more during the next 20 years would be of the order of Rs. 2,070 billion (US$ 45.4 billion) (Indiacore, 2003). Table 2 shows the projected the investments needed in various sectors.

Obviously, these massive investments cannot be located from within the budgetary resources of Central, State and Local Governments. Private sector participation and accessing international finances are, therefore, required for infrastructure development projects. As a result investment opportunities are arising in the infrastructure sector especially in roads, ports, energy, telecommunications and urban services. India may require Rs. US$ 215 billion during 2001-2006 to meet the projected growth in demand for infrastructure (GOI, 1996).

Table 1. **Actual plan outlays for infrastructure sector investment for development in various plans in India (Rs. in Crores)**

	Energy (Power)	Transport	Irrigation& Flood
First Plan 1951-56	385.4	517.8	197.5
Second Plan 1956-61	452.0	1261.0	430.0
Third Plan 1966-69	1252.3	2111.0	664.7
Annual Plan 1966-69	*1212.5*	*1222.4*	*471.0*
Fourth Plan 1969-74	2931.7	3080.4	1354.1
Fifth Plan 1974-79	7399.0	6870.3	3876.5
Annual Plan 1979-80	*2240.5*	*2044.9*	*1287.9*
Sixth Plan 1980-85	18298.0	14208.0	10929.9
Seventh Plan 1985-90	37895.3	29548.1	16889.9
Annual Plan 1990-91	*11387.8*	*8074.3*	*3974.1*
Annual Plan 1991-92	*14517.9*	*9314.0*	*4231.9*
Eighth Plan 1992-97	76725.8	65173.0	32525.0
Ninth Plan 1997-2002	71997.3	39461.0	NA
Tenth Plan 2002-07			

Table 2. **Infrastructure sector investment requirement projection**

(All figures in Rs.'000 crore) Estimates at 1995-96 prices

	Projected Requirements			Cumulative for	
Sectors	1996-97	2000-01	2005-06	1996-97 to 2000-01	2000-01 to 2000-06
Power	36.0	50.0	69.0	200-210	300-310
Telecom	7.6	11.5	21.5	55	84
Roads	3.0	7.5	10.0	24	44
Railways	7.4	10.4	14.6	43	64
Ports	1.4	2.1	3.2	9	41
Urban Infrastructure	7.0	16.0	42.0	55	150
Total (incl. others)	67.5	107.6	182.6	432	755

Some recent initiatives of large-scale infrastructure development in India include the development of national highways network and linking of rivers for development of national water network. Both these infrastructure projects require huge investments. The national highways development project for four/ six-laning of around 13,146 km of road network, with another one thousand km of port and other connectivity, is expected to cost Rs. 540 billion (US$ 11.8 billion). More than 2,100 km has already been completed over the last three years and another 5,000 km are under various stages of completion. More than US$ 3.5 billion have been spent and/or committed (http://www.nhai.org/, dated 25th August, 2003). The river linking project is estimated to require Rs. 5,560 billion (US$ 122 billion) investment over next ten years. This project has been envisaged in the current climatic regime and assumes availability of water in the perennial Himalayan Rivers. If the climatic changes predicted by international scientific assessment (IPCC, 2001b) were to realize over the present century, the monsoon and rainfall patterns would alter (Rupa

Kumar et al., 2003) and the glaciers would recede (Hasnain et al., 2003; Tangri, 2003); thus changing the annual water flow patterns in the sub-continental rivers. This would alter the project's assumptions and the costs and benefits assessment.

It becomes necessary to point out here that such huge investments in infrastructure, having long life span, are presently being planned without any conscious analysis of climate change related impacts on them. It is indisputable that long-term climate changes are likely to have impacts on infrastructure. All over the world, extreme weather events are a major cause of damage to infrastructure. In developing countries, governments have to bear the losses arising from for this damage to infrastructure since currently 95% of infrastructure is government-owned and they bear the responsibility for its repair and maintenance. Even for privatized infrastructure, the force majeure provisions largely allocate financial responsibility for catastrophe risk to governments (Gibbon, 1996). An inevitable result of the increased damages to infrastructure from climate change will be a dramatic increase in resources needed to restore infrastructure. A developing economy like India has to take these issues into consideration while formulating appropriate policies.

3. Need for integrated analysis

The potential impacts of climate change have significant considerations for national planning. With an indication of likely climate related trends, the decision makers should be better equipped to manage the climate change impacts more effectively. Moreover, environmental management considerations are wide and varying: From the prevention of coastal flooding and erosion to the conservation of water resources, the control of forest and bush fires, and the conservation of vulnerable flora and fauna. Energy, environment and global climate change issues thus have significant overlaps and implications for national economy. However, their importance is secondary in the national policy agenda for developing nations, like India, whose policies are necessarily focused on more fundamental issues such as alleviation of poverty and creating basic conditions for human development. Thus, the decisions about emission mitigation and adaptation to climate change impacts have to be integrated with the decisions in other sectors such as energy and infrastructure plans, urban development and industrial location policies.

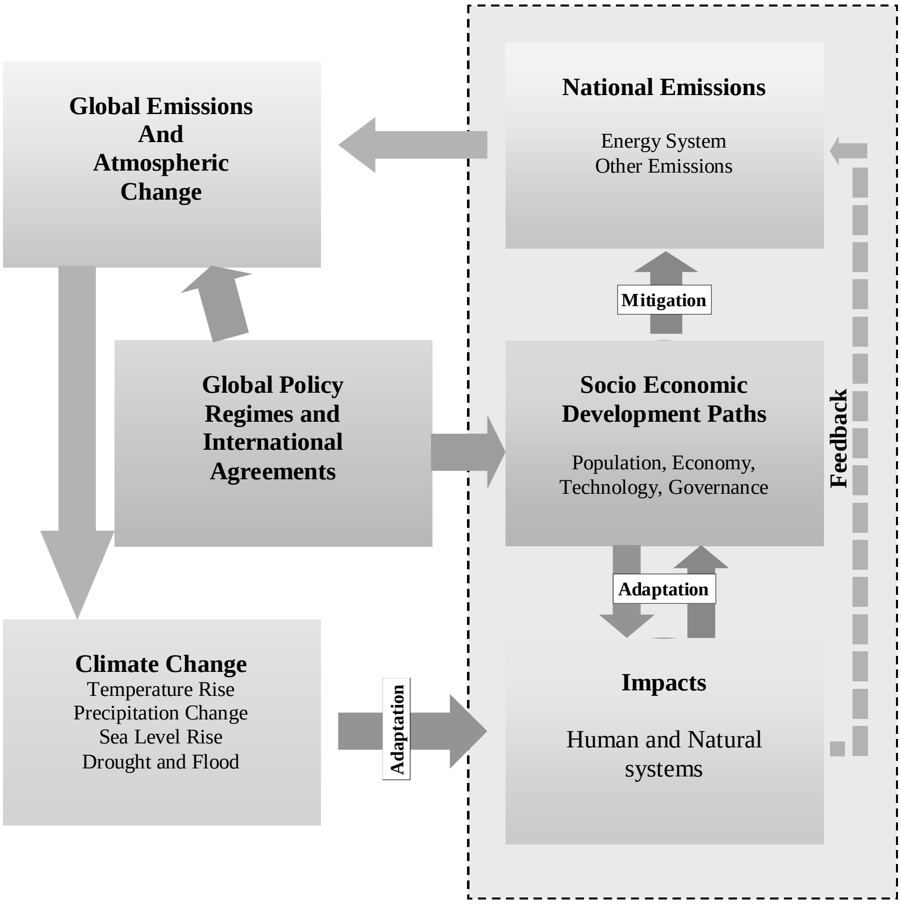
IPCC (2001a) outlines an end-to-end characterization of Integrated Assessment (IA) models. This structure has four categories: Emissions, Atmospheric Composition Climate and Sea level, and Impacts, which is intuitively appealing as it illustrates the process sequentially. However, it de-emphasizes the interactive character of IA Models. For our purpose while considering IA for policymaking and implementation at national level it becomes necessary to identify the categories, which differ at country level. Category 1 and category 4 of this structure, which deal with Emissions and Impacts respectively, can have a substantial difference at country level. We can exclude the category 2 (Atmospheric Composition) and category 3 (Climate & Sea level) from the national level assessment framework because these are representing global parameters and do not differ much on a country level.

A modified framework for IA of energy and environment analysis at a country level is given in Figure 1, which has been developed for the present study. The figure shows the interactions of the country level dynamics with the global emissions and atmospheric change, global policy regimes and international agreements, and climate change. These interactions have been taken as external to the present analysis. The country level IA of energy and environment deals with the national level emissions, the impacts of climate change and socio-economic developmental paths and decisions related to mitigation and adaptation to address these changes and impacts.

The proposed integrated framework deals with the interaction of energy and environment, with the issues of concern. The prime issues identified are national emission assessment of local and global pollutants, and assessment of impacts on natural and human systems. These interactions and their results are modified and managed by the socio-economic development paths selected by the country.

Independent analysis of each of the components provides input to the framework. National level emission analysis is carried out to understand the emission contribution from a country. Emission stabilization scenarios can be developed by application of various energy system optimization models for assessing the technology selection and energy choices. Energy technology optimization models are also used for future projections and scenario generation. These analytical models can be linked with GIS applications for spatial analysis. Alternate socio-economic development paths can be developed for various scenarios. For the impact analysis a case study approach needs to be adopted for studying the emerging issues in detail. A reversed impact matrix has been developed to study the climate change impacts on infrastructure matrix. As discussed above, different analysis tools are used for each of the above tasks. However, in the present work we have focused only on the component related to impacts. In this paper, we have presented the Konkan Railway case for the application of the reverse impact matrix.

Figure 1. **Framework for integrated assessment on national level**



4. Sensitivity, vulnerability and adaptability of infrastructure and energy

The following tables (Table 3 and 4) present a qualitative comparison of our assessment of the extent of magnitude and possibility of occurrence of the climate change impacts on the infrastructure and energy sectors in relation to the various climate change criteria. The tables also present the comparative assessment of the sensitivity, vulnerability and adaptability for various climate change criteria. The words high, medium and low have been used where appropriate to indicate judgemental estimates of confidence (based on the collective judgement of the authors using the observational evidence, established but incomplete modelling results, speculative qualitative assessment, and theory that they have examined). These efforts for characterizing and communicating uncertainties draw from similar treatment in IPCC reports (IPCC, 2001b).

Table 3. **Sensitivity, vulnerability and adaptability of infrastructure sector**

Climate Change Criteria	Magnitude	Occurrence	Sensitivity	Vulnerability	Adaptability
Temperature increase	Medium	High	Medium	Low	High
Increased precipitation	Medium	Medium	Medium	Medium	Medium
Sea level rise	Medium	Medium	Medium	Medium	Low
Extreme events	High	Low	Medium	High	Low

Table 4. **Sensitivity, vulnerability and adaptability of energy sector**

Climate Change Criteria	Magnitude	Occurrence	Sensitivity	Vulnerability	Adaptability
Temperature increase	High	High	High	Medium	High
Increased precipitation	Medium	Medium	Medium	Low	Medium
Sea level rise	Medium	Medium	Medium	Medium	Low
Extreme events	High	Low	Medium	High	Medium

Energy sector is highly dependent on temperature conditions and this is where, probably, climate change could have very strong direct impacts. The regional temperature would change significantly, thus affecting the future energy consumption behaviour. In residential and building sector, major change is expected to be in energy demand for space cooling and heating. Air-conditioning and refrigeration load is closely related to ambient air temperature and thus will have a direct relation to temperature increase. Temperature increase in the northern mountainous region, where space heating in winter is required, might result in some saving in heating energy. This will be more than compensated by increased energy requirement for space cooling in the plains, thus resulting in a net increase. Higher income levels will further increase demand for air-conditioning. There are many energy sources for space heating including coal, biomass and electricity. However, the main source of energy for cooling is electricity. A higher demand for air-conditioning will thus result in increased electricity demand. Similar to residential sector, commercial and industrial sector will also experience increased load for air-conditioning and refrigeration due to temperature rise.

During summers, in India, we experience power shortage on a regular basis. Most often it happens due to the increase in demand of electricity for cooling because of the intense heat during the summers. Some times this demand even goes beyond the maximum capacity of the transmission system. This was precisely the case during the blackout of July 30, 2002, which spread over five states of Western India. A heat surge that followed several months of intense drought had affected many regions of the country. The system could not cope with the load increase and resulted in tripping of the western grid, which took long hours to restore. One of its victims was the Indian railway system where service was interrupted for several hours. This shows that the different sectors have a high level of interdependency and are affected by changes in each other.

Similarly, many sectors affected by the climate change, will have indirect impacts on the energy sector. One major sector causing indirect impact on energy is agriculture. Agriculture is very sensitive to any type of climate changes. Climate change in India will result in temperature rise and changing precipitation pattern. Evaporation rate is also expected to rise because of temperature increase. This may be countered by increase in rainfall and humidity in some regions. All these put together will affect the water requirement for agriculture. More requirement of water for agriculture will result in higher demand of energy for irrigation. Residential water demand is also expected to increase which would also affect the energy required for the water supply system.

Climate change impacts on the transport sector will also affect the energy sector indirectly. Changes in the Energy demand from transport sector will also change primarily due to temperature increase. With higher temperature and better affording capacities more and more people will opt for air-conditioned vehicles. Warmer temperature in future will lead to increased use of air conditioning in passenger transport and higher requirement of refrigeration for freight transport, thereby adversely affecting fuel efficiency.

In addition to the direct and indirect demand side impacts discussed above, supply side of energy sector will also be adversely affected by climate change. Although the impacts will not be uniform but there is a general agreement that hydroelectricity production would be particularly affected. The perennial rivers of north India may experience excess supply of water due to melting of snow in glaciers but this will eventually reduce and then water availability in the perennial rivers will be adversely affected. Sea level rise could influence offshore activities of petroleum companies. Both, offshore and energy distribution sectors might be negatively impacted if extreme weather events were to become more intense and frequent.

Energy sector shows a high sensitivity to the changes in the temperature. However, infrastructure is more sensitive to changes in the rainfall pattern in comparison to other climatic parameters. 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 and may have a devastating effect on the infrastructure. Cyclones in Gujarat and Orissa in recent years are an example. A detailed discussion about the tropical cyclones and their impacts please refer Rupa Kumar et al., (2003).

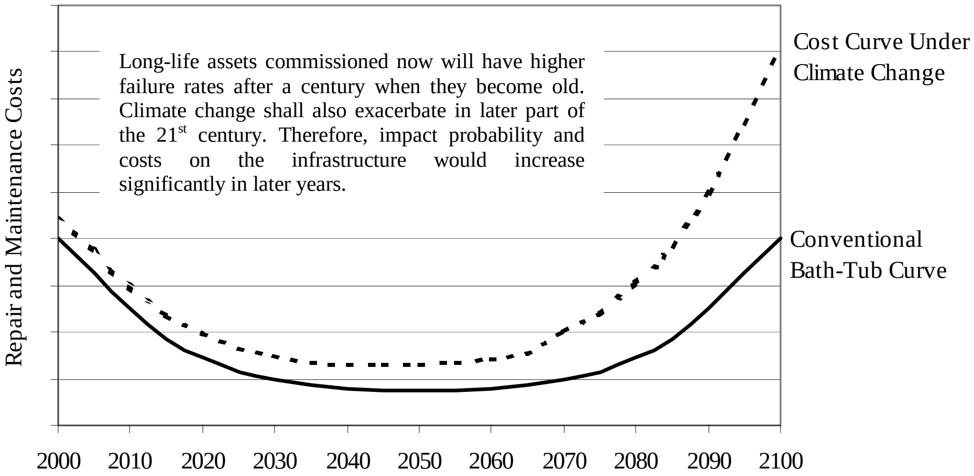
Flooding and other extreme weather events may damage buildings. Potential changes in humidity and climate may cause a variety of problems. There can be adverse effects of storms, heat, and humidity on walls and insulation, which will affect infrastructure durability and energy usage. Thus, climate change will require a modification in the safety limits and permissible design levels for type of climatic effects in the 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.

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 stabilization period it may require frequent maintenance. The maintenance requirement decreases once the system has stabilized (Figure 2). 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 since these may be more pronounced in the later part of the 21st century (IPCC, 2001b). These two effects coupled together, would increase the economic impact on infrastructures.

Figure 2. Infrastructure maintenance and impact costs



Long-life assets commissioned now will have higher failure rates after a century when they become old. Climate change shall also exacerbate in later part of the 21st century. Therefore, impact probability and costs on the infrastructure would increase significantly in later years.

In this section we discussed various climate change impacts on infrastructure and energy sectors. Sensitivity, vulnerability and adaptive capacity of these sectors with respect to various climatic parameters were also discussed. The above discussion has been summarized in Table 5.

Table 5. **Likely sensitivity of infrastructure and energy to climate change**

Sector	Impacts of climate change	Sensitivity, vulnerability and adaptive capacity
Infrastructure	Building material availability from forests Transport demand change due to migration Direct damages to infrastructure in the hilly and coastal areas Road may experience more bulking due to the temperature increase. In the hilly areas landslides will affect roads and railway. In the coastal areas main problem will be flooding due to the sea level rise. Frequent repair and maintenance requirements	Infrastructure is generally less vulnerable to small changes in the climate. It is more sensitive to the flooding and landslides as compared to temperature changes. Landslides are a current threat in many hilly areas and can increase with more intense rainfall events. Sea level rise is likely to affect infrastructure in coastal areas.
Energy	Major change is expected to be in energy demand for space cooling and heating in residential and building sector. Irrigation water for agriculture and residential water demand may change affecting the energy demand for these sectors. Energy demand from transport may change due to higher demand for air-conditioned vehicles and efficiency of the vehicles may also get affected	Energy sector is more sensitive to the changes in the temperature. The climate pattern in India shows a high variability in the temperature across various regions. Western India has a very high daily average summer temperature and had a high cooling energy demand where as the high altitude mountainous region in the northern India has a cool weather with heating demand. India also has high disparity in the regional energy consumption, which is because of the unequal regional development and urbanization patterns. The high consumption areas are primarily the metropolitan regions and industrialized areas.

5. Methodology and framework for impact analysis

For the present study, climate change impacts have been analyzed by developing an impact matrix. Matrix approach facilitates the identification of indicators, which may have impacts for a particular case study. Matrix approach with indicator analysis is also preferable because, indices make it possible to compare two or more complex, multifaceted systems at one time by analyzing the interactions among the systems and converting the information related to varied impacts in a single observable outcome. While this process of reductionism enhances understanding about the phenomenon, it works contrary to both the complex behaviour of the system and potentially disparate nature of impacts. However, modelling requires this simplification of complex realities and the matrix approach provides the required simplification mechanism.

For the present study the process of designing the matrix included the following stages:

- Defining existing conditions/components;
- projecting and estimating likely future changes;
- taking each component one by one and applying change (as 'thought experiment');
- recording extent of interactions;
- identifying major problem areas.

Traditionally the impact matrix approach used for environmental assessment carries out analysis of the impacts of economic activities on environment. Conventional impact matrix explores one-way relationship of the effect of the human activities on the environment. The reverse link is most often ignored. For the present study we have developed a reversed matrix, which links the impacts of change in environmental variables to the project activities. A schematic diagram of the matrix is given in Figure 3.

Figure 3. **Reverse impact matrix**

Dependent Variables Forcing Variables	Environmental Variables	Project Components
Environmental Variables	**2**	**4**
Projects Components	**1**	**3**

The first quadrant indicates the conventional impact matrix where impact of project components on the environment is analyzed. Quadrant 2 and 3 show the interrelationships of the environmental variables and project components. The 4th quadrant shows the impacts of changes in the environmental variables on the project components.

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

6. 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 infrastructure 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 Maharastra, 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 about Rs. 34 billion (US$ 745 million). 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). KRCL track passes through more than one thousand cuttings[5], with 224 being deeper than 12 meters. All these deep cuttings have been declared as vulnerable spots by KRCL after the June 2003 accident. Figure 4 presents the Konkan Railway layout.

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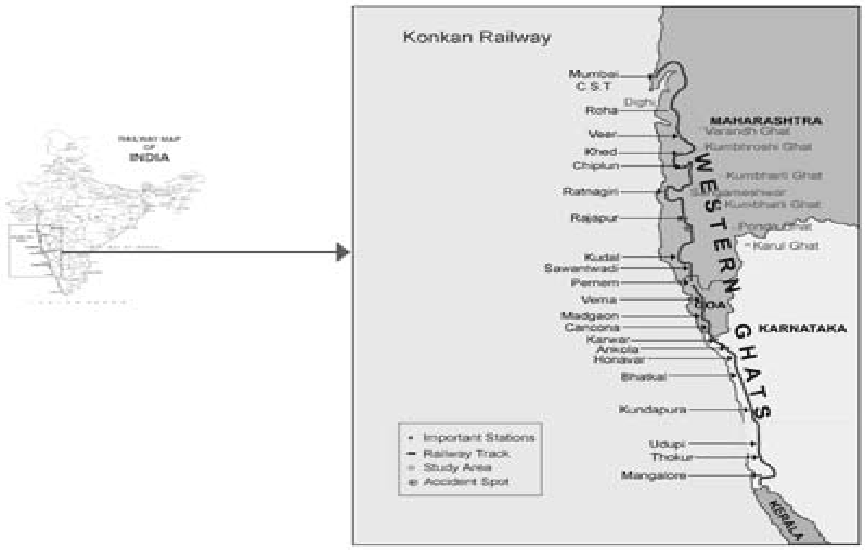
[5] Small hillocks are cut through to construct passage for the railway track duly maintaining reasonable slope for the track. These passages are called cuttings. Cuttings are like top open tunnels, with spread out slopes on either side. Some cuttings are deeper than 12 to 15 meters. Such deep cuttings pose higher safety hazards due to higher possibilities of water logging and landslides. Cuttings cave in mostly due to excessive rains. Unstable cutting-slope and geological characteristics of the soil determine its sensitivity to rains. Adaptation measures include regular monitoring during rainy season, temporary speed restrictions on the trains passing through these cuttings, nylon-net erection and retaining wall construction to trap sliding boulders, removing precariously placed boulders in anticipation, appropriate drainage construction and maintenance, further easing out and consolidation of the cutting-slopes, paving and sowing of grass on the cutting-slopes.

Figure 4. **Konkan Railway: Layout and vulnerable spots**



The 760 Km long Konkan Railway on the Western coastal ghats of India is an engineering marvel with 179 main and 1819 minor bridges, 92 tunnels (covering 12% of the total route) and over 1,000 cuttings (224 deeper than 12 meters). The longest tunnel is 6.5 Km long and the longest bridge is over 2 Km. The pillars of the tallest viaduct bridge are more than 64 meters high, taller than Qutab Minar.

- Presently 20% of repair and maintenance expenses on tracks, tunnels and bridges are due to climatic reasons.
- A recent accident on 21st June 2003 night (see ⊕ on the map), resulting in over 50 deaths, was caused by landslide at a deep cutting due to incessant heavy rains, presumably higher than the system's adaptive capacity. Consequent to the accident, maximum permissible speed of trains has been reduced from 120 Km/h to 75 Km/h.
- 200 mm rainfall within 24 hours increases system vulnerability (Nagrajan et al., 2000) (see present vulnerable regions as ▨ on the map). Future rainfall pattern shows that such events are likely to occur more frequently and with higher intensity (chapter 3 of this book).
- Adaptation measures should also consider vulnerable spot identification based on future climate change projections.

The Konkan Railway commenced commercial operations on January 26, 1998, Impact of KRCL on surrounding environment, including the route alignment through Goa, were major concerns raised by various interest groups and researchers from the project inception itself (Raghuram, 1999). 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 analyze the impacts of Konkan Railway project on the surrounding ecosystems and environment (Rajaram et al., 2001). However, no study has analyzed the environmental impacts on Konkan Railway. In the present study we have explored the potential impacts of climate change on Konkan Railway infrastructure. We have identified the relationship of the various climate change parameters with the likely impacts on the Konkan Railway through a series of impact and intervening parameters (Table 6).

After analyzing the likely impacts, the cause-effect analysis was carried out through a reverse causal matrix (discussed in the earlier section) where various identified indices were assessed for their capacity to force changes in the other elements. This type of analysis is suitable for pre-modeling 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 7 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 6. **Climate Change Impacts on Konkan Railway**

Climatic Parameter	Impact Parameter	Intervening Parameter	Impact on KRC
Temperature Increase	High evaporation rate	Stability and Strength of the building materials	Buildings gets weakened More and frequent repair and maintenance
	Surface and ground water loss	Crop productivity in the region may be affected	Agricultural fright traffic
	Need for Air-conditioning	Passenger traffic may shift to Air conditioned class	Affects efficiency, carrying capacity and composition.
Rainfall Increase	Ground and surface water level change	Flooding and water logging, Erosion reduces quality of land cover	Buildings affected, structural damages may take place. Increased maintenance and other related costs
	Improved water availability in the region	Agricultural production	Changes in agricultural freight traffic
	Humidity increase	Uncomfortable climatic conditions, Vegetation growth along the track	Passenger traffic, affected, increased maintenance cost
Sea Level Change	Land erosion	Tracks tunnels and bridges may be affected	Increased maintenance,
	Flooding	Land stability, and land slides	Damage to infrastructure, Reconstruction and relocation
	Water logging		Delays, risk increase
Extreme Events	Cyclone and high velocity winds and storms	Damage to buildings, communication lines etc	Disruption of services, repair and reconstruction costs
	Cloud bursts	Land erosion, floods, and land slides	Extensive damage to infrastructure, High cost of repair and reconstruction

The analysis carried out with the help of the impact 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 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 such as precipitation patterns, geological characteristics of the soil, stabilization and prevention mechanisms in place. There are some factors, such as traffic volume, which have a high dependence on all other factors and are very important for Konkan Railway.

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stabilization and prevention mechanisms in place. There are some factors, such as traffic volume, which have a high dependence on all other factors and are very important for Konkan Railway.

Table 7. **Causal matrix for impact analysis for Konkan Railway**

		Environmental Variables							Project Components		
	Dependent variables **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	

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 minimizing the extent of impacts.

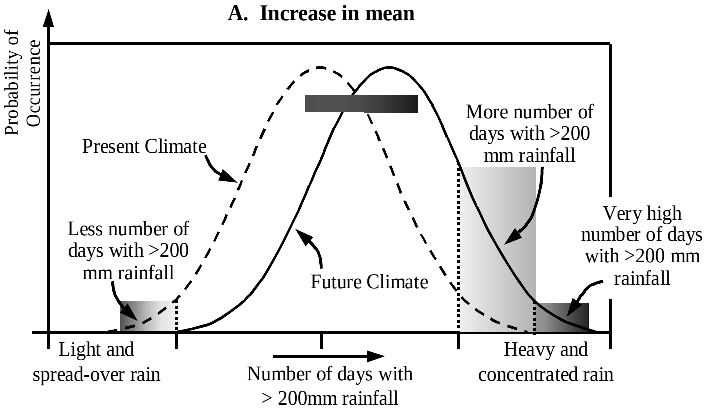
6.1 Current and future climate stresses

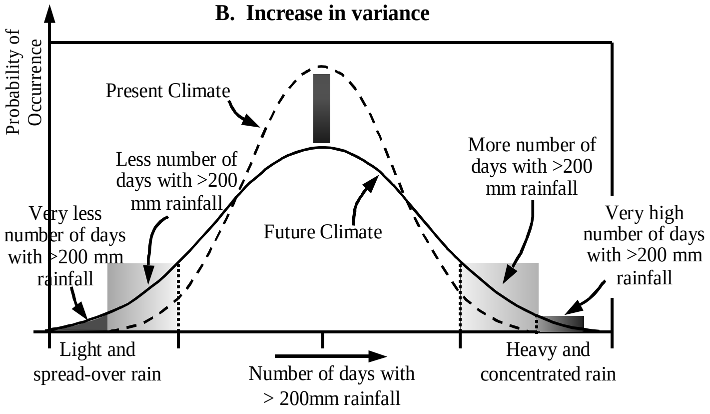
After identifying the forcing variables, the next step is to explore critical thresholds to determine when the risk of a climate change impact becomes 'dangerous'. These thresholds are case and climate change scenario specific. These indicate decision points where additional preventive measures become imperative. For the Konkan Railway case, rainfall has been identified as the main forcing variable. 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 et al., 2000). 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.

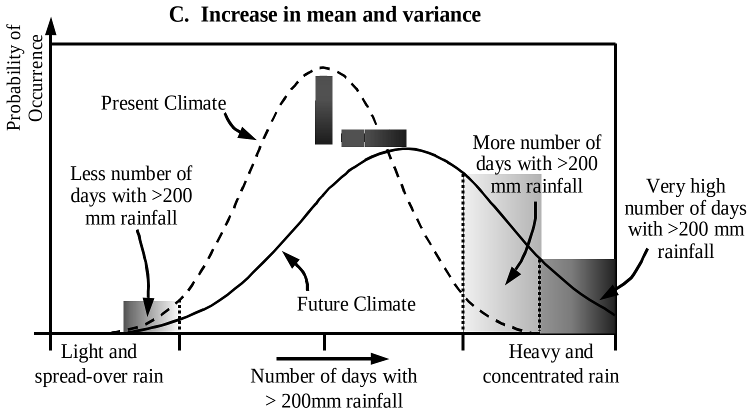
The number of days with more than 200 mm precipitation within 24 hours in a season is expected to increase as a result of climate change (Rupa Kumar et al., 2003). For instance, if these increase from 8 to 13 days per year, then the likelihood of landslides will also increase (Figure 5). Increasing mean and variability of the number of days with heavy rainfall will adversely affect the infrastructure. Figure 6 provides a stylized representation to explain this concept. The x-axis shows number of days in a year with more than 200 mm precipitation in 24 hours. The y-axis indicates probability of occurrence of this event.

In future, if the average number of days receiving more than 200mm rainfall in a year increase then the number of years reporting at least one day with more than 200 mm rainfall are also likely to increase. Thus, with increase in the mean, the probability of receiving heavy and concentrated rainfall increases resulting in increased threat to infrastructure Figure 5 (A). Increase in variability may cause extremely high concentration of rainfall. It may also result in many new locations getting high rainfall, and many existing locations with heavy rainfall getting more frequent and severe rainfall. Both these would increase system’s vulnerability to landslide occurrence Figure 5 (B). Simultaneous increase in mean number of days with increased variability will make the system highly vulnerable as this will result in very high number of days with heavy rainfall Figure 5(C).

Figure 5. **Probability distribution for the number of days with more than 200mm precipitation**


A. Increase in mean


B. Increase in variance


C. Increase in mean and variance

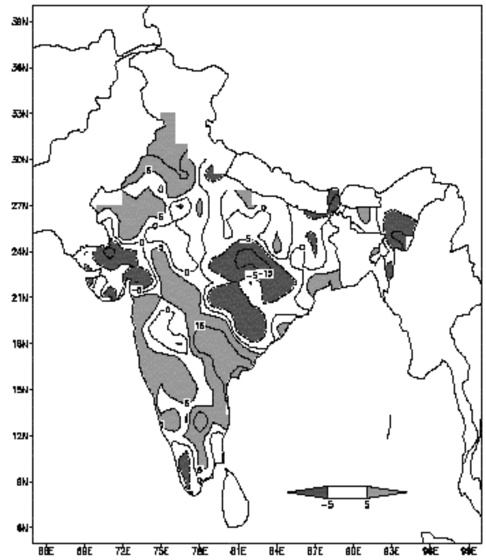
The probability distribution may also become skewed on either side and the variability may decrease (not shown in the figure). Any such likely changes will need to be further analyzed for their effect on the probability of extreme rainfall. The right hand side area of the curve represents heavy and concentrated rainfall; therefore, this portion is of more interest for adverse impact assessment. If the future distribution becomes more pronounced towards the right hand side, it indicates that more number of years will report higher number of days (per year) with more than 200 mm precipitation. These years may occur one after the other, or with discontinuous gaps, or with a trend. This will also increase the system’s vulnerability to landslides and may result in more disruptions and accidents, if adequate adaptation measures are not taken.

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 trend less. However, Rupa Kumar et al. (2003) 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 6 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 6. **Spatial patterns of linear trend (% of mean/100 years) in summer monsoon rainfall during 1871-1990**



Source: Rupa Kumar 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 Rupa Kumar 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 (Rupa Kumar et al., 2002).

Future rainfall projections for India have indicated an increasing rainfall trend (Rupa Kumar 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. Thus, a system having a rainfall threshold of 200 mm per day 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. Rupa Kumar et al., (2003) have run a Regional Circulation Model which can provide precipitation levels and frequency of intense rainfall events at about 50 km distance along the Konkan route for the years 2040 and 2080 under three alternate future scenarios. Further detailed analysis may be desirable to ascertain the probability distribution function of intense rainfall events for Konkan railway that may help in designing a suitable adaptation strategy.

6.2 Potential impacts and adaptation mechanisms

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.

Past weather records and traffic disruptions (Indian Express, 1998 and 1999; The Hindu, 2001) indicate KRCL’s sensitivity and vulnerability to climate impacts. From the very beginning, every year during the monsoon period, train operations have been disrupted due to water logging and landslides. There are numerous instances of trains running late due to preventive speed restrictions and disruptions 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. One of the major traffic suspensions was for fourteen continuous days during 11th to 25th July 2000 due to landslides at 36 locations caused by more than 300 mm rainfall on a single day. The expected losses were estimated to be about Rs 100 million (US$ 2.2 million). There were a total of 140 reported incidences of landslides during the entire monsoon season in 2000.

As a process of adapting to these likely impacts, Konkan Railway authorities annually identify vulnerable locations where preventive maintenance is carried out before the onset of monsoon, to deal with any such calamity. Based on experiences over the years, the number of identified vulnerable locations has varied between 60 and 120 every year. In the year 2002-03 more than 200 vulnerable spots have been identified. Several preventive adaptation activities[6] are taken up at these vulnerable locations to minimize adverse impacts. The purpose is to reduce the number of such locations gradually and stabilize the track over the years for trouble-free train operations. Konkan Railway spends over Rs 50 million (US$ 1.1 million) annually on such measures. However after the 21st June 2003 accident, all the cuttings deeper than 12 meters have been declared vulnerable locations apart from the other existing vulnerable locations. KRCL has taken immediate preventive measures at multiple levels to improve safety at these vulnerable locations. These include easing out and paving slopes at deep cuttings, increased patrolling, installing electronic systems for early landslide warning, and anti-collision devices. Seismographs are also planned at some sensitive locations in collaboration with Bhabha Atomic and Research Centre, Mumbai. These measures will considerably increase Konkan Railways' cost to adapt to climate change and may be KRCL could therefore access international funds available for adaptation to climate change.

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 stabilization years of any infrastructure project and will gradually reduce as the system stabilizes. 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 is similarly affected once in a while.

The profit and loss account of the KRCL shows that 6% of the annual budget is spent on the repair and maintenance. 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 minimizing climate related impacts. It is clear that any future climate change will definitely increase expenditure on repair and maintenance activities. This type of analysis becomes important because in the later half of the century, when these impacts are likely to take place, the currently commissioned Railway infrastructure, having lived its normal life, would be more vulnerable to any such change. Of course the existing older infrastructure would require much more retrofitting and up gradation to sustain the increased onslaughts of climate change.

In this section, we have presented a simplified and somewhat idealized example of impact analysis for Konkan Railway. This example successfully brings out the complexity of impact analysis. It shows the co-dependency of many factors and also indicates 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 enrich the available literature on impact analysis and enhance the understanding of climate change impacts.

7. Climate change impacts on energy infrastructure

Globally averaged temperatures, which would influence energy demand, are projected to rise by 0.15-0.25°C per decade. Many impact studies, however, typically assume a 4.5°C increase by the middle of next century. For the present study, we have assumed an average increase of 3.5°C over the Indian subcontinent in the next 100 years. The impacts on energy infrastructure have been modelled using ANSWER-MARKAL for India for a period of 100 years.

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[6] These include regular monitoring during rainy season, temporary speed restrictions on the trains, nylon-net erection and retaining wall construction to trap sliding boulders, removing precariously placed boulders on cutting-tops in anticipation, appropriate drainage construction and maintenance, further easing out and consolidation of the cutting-slopes, paving and sowing of grass on the cutting-slopes.

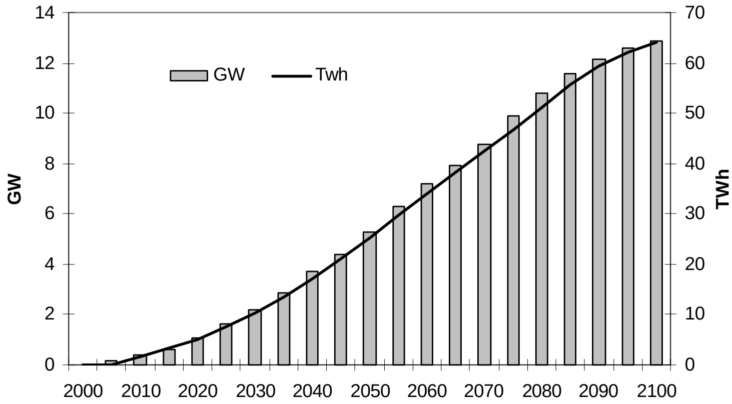
Climate change impacts will take place over a long period of time. The extent of impacts will depend on the nature of the system that is exposed to the climate change. Therefore, it is necessary to understand the socio-economic dynamics of the future society in which the impacts will take place. In the present analysis the socio-economic scenario is assumed to follow the trend of the reference scenario of previous analysis carried out for 100 years by Shukla et al., 2002. The reference scenario construction incorporates changes in the economic growth rates and structural changes in the economy. The key driving forces for these changes are economic growth, population, domestic energy resource supply, energy prices, and local environmental concerns and global climate change regimes. These would drive the future technology-fuel mix for the Indian energy and environment systems. In 100 years from now, India's population is projected to grow to almost 1.65 billion in 2100. The reference case GDP projection is assumed to increase by 5.5% per annum on an average during 2000-2025, by about 5% during 2025-2050, by 4.5% during 2050-2075, 3.5% during 2075-2085 and stabilizing at 2 % by year 2100. The future technological progress is assumed to consist of three factors: autonomous energy efficiency improvement, improvements in present technologies and investments in new technologies. All of the above assumptions for the reference case have been discussed in detail in chapters two, three, and four of Shukla et al. (2002). The important exogenous model specifications include the electricity demand trajectory, investment constraints, energy supply limitations, energy prices, technology costs and technology performance parameters. The reference scenario presumes continuation of the current energy and economic dynamics and provides a base for comparing the impacts of policies for alternate futures. We have identified various energy related impacts on different sectors and how they affect the energy demand to analyze climate change impacts on energy demand and the resultant emissions. The, model parameters were then modified to reflect these changes.

The paper presents a scenario of climate change impact on energy use. Important exogenous model specifications for this scenario include the electricity demand trajectory, energy supply limitations, energy prices, technology costs, and technology performance parameters. For all other parameters, the reference scenario assumptions of continuation of current energy and economic dynamics have been taken, which provide a baseline for comparing the impacts. The scenario of climate change impacts on energy takes in to account the sensitivity of various sectors, change in demand, and direct and indirect linkages as discussed above. The model parameters such as demand and technology efficiencies are modified to reflect the effects of the key drivers. There are no independent studies carried out to study the impact of climate change on energy demands for various activities, therefore, the change in demand trajectory and change in technology efficiency was estimated in consultation with the experts in industry, and the policymakers.

7.1 Results and analysis

In the reference scenario, Indian power generation capacity increases about nine times from 96 GW to 912 GW between 1995-2100. As a result of the impact of climate change, there will be an additional power generation capacity requirement of about 1.5% (Figure 7). Coal is expected to remain the main source of primary energy supply in Indian energy system. The fuel mix for power sector remains more or less the same with maximum burden of additional supply being carried by coal. The share of natural gas and oil continues to grow at a steady rate and reaches around 25%. The large hydro capacities have been utilized in the reference scenario and there is no additional capacity of the large hydro getting added in climate change scenario. Slow growth and declining share of large hydro capacities can be attributed to long gestation period of projects, high investment costs and total system capacity limitation due to natural resource constraints. Renewable technologies including small hydro, wind, cogeneration from biomass technologies, solar and geothermal, already seem to have reached the maximum supply level and since there is no increase in capacities, the share declines marginally. A number of barriers are, however, associated with the penetration of renewable technologies, including constraints on investment availability.

Figure 7. **Additional power capacity and power generation requirement due to climate change**



Additional electricity generation due to climate change, over and above the electricity generation in 2100, is 64 TWh, which is 1.5% of the reference scenario generation for the same year (Fig. 7). Domination of coal-based generation continues due to reliance on domestic resources for energy supply and a major share of this added generation requirement is taken up by the coal-based generation. The economic linkages with coal are also very strong due to large infrastructure associated to mining industry, coal transportation network, generation equipment manufacturers, etc., and coal remains competitive in the long run.

8. River linking project and climate change

India receives an annual precipitation of 4000 BCM, out of which 1869 BCM runs off in various rives basins. The utilizable water resource has been assessed as 1132 BCM. Therefore, it is necessary to find out ways for augmentation of utilizable water. Interlinking of rivers proposal is one option to increase the availability of utilizable water which is one of the great advantages of this infrastructure project.

Secondly, the availability of water resources in various river basins of the country is highly uneven. While the availability of water resources in Brahmaputra basin is of the order of 32 percent and in Ganga 28% of the total water resources, it is merely 0.2 percent in the Sabarmati basin. Any situation of water availability less than 1,000 cu.m per capita in a river basin is considered by International Standards as water scarcity condition. The water scarcity in river basins is growing with increase in population. Based on this criteria and availability of water in different river basins, some basins have already become scarce and many more basins are likely to become scarce with the growing population by year 2025.

Thirdly, even though lot of development of water resources especially in irrigation and hydropower sectors has taken place in the country during the last 55 years after independence, the situation still permeates the drought – flood – drought syndrome. This is due to the fact that the distribution of India’s water resources is highly uneven. Some parts of the country receive much more than the normal rainfall leading to floods especially in the Ganga and Brahmaputra rivers. At the same time, some other parts receive less than the normal rainfall leading to droughts. Every year, a number of districts in the various states are hit by drought and flood, thus compelling us to seriously deliberate on the possible options for lessening the severity of such occurrences. The implementation of interlinking of major river systems will provide some respite from this distressful and iniquitous situation and remove to a great extent the regional imbalance in the availability of water in different river basins of the country.

Mooted originally by the visionary engineer Visveswaraya in the first half of 20th century, the river linking schemes have been envisioned in India since long. The present project has origin in the proposals of the National Water Development Agency set-up in 1982. The proposals acquired urgency and legitimacy from an order by the Supreme Court of India that directed the government to consider linking of rivers by the year 2012. In December 2002, a "Task Force on Interlinking of Rivers" was appointed to prepare the schedule of feasibility studies, estimate the cost of the project and suggest options for funding. The mega scheme proposes to link major Himalayan and peninsular rivers through 30 inter-linking canal systems to transfer surplus waters from high rainfall areas to draught prone areas. The schemes objectives include mitigation of draughts and floods, additional irrigation to 34 million hectares of land, drinking water to 101 districts and five metropolises, supply 34,000 MW of hydropower and inland water transport. The project is estimated to cost Rs. 5560 billion (or $122 billion), nearly a quarter of country's current GDP.

India has been divided into twenty river basins which are classified as

- Twelve major basins with area exceeding 20 000 sq km each
- Eight composite river basins combining suitably the remaining medium and small river systems for the purpose of planning and development.

The details of these river basins are given in Table 8 and 9.

Table 8. **River basins in India**

SN	River Basin	Important rivers of the Basin	Catchment Area M Ha	Average annual water availability (BCM)	Per Capita Water Availability (CM)
1	Indus	Sutlej, Beas, Rabi, Chenab, Jhelum	32.13	73.31	1749
2a	Ganga	Yamuna, Chambal, Betwa, Ken, Son, Ramganga, Ghagra, Gandak, Kosi	86.15	525.02	1471
2b	Brahmap utra & Barak	Subansiri, Bhorelli, Manas, Buri, Dehang, Dhansiri, Kopili, Tista, Jaldhaka, Torsa, Gumti, Muhari, Fenny, Karna-Phulli, Kaladan, Imphal, Tuxu, Nantaleik	23.61	585.6	16589
3	Brahmani	Karo, Sankh, Tikra, Baitarni, Salandi, Matai	5.18	28.48	2915
4	Mahanadi	Seonath, Jonk, Hasdeo, Mand, Ib, Tel	14.16	66.88	2513
5	Godavari	Parvara, Purna, Manjra, Pranhita, Indravati, Sabri	31.28	110.54	2048
6	Krishna	Ghatprabha, Malprabha, Bhima, Tungbhadra, Musi	25.89	78.12	1285
7	Pennar	Jayamangli, Kunderu, Shgileru, Chitravati, Papagni, Cheyyeru	5.52	6.32	651
8	Cauvery	Harangi, Hemavathi, Arkavathi, Simsha, Lakshmnathirtha, Kabbani, Suvarnavati, Bhavani, Noyil, Amravathi	8.12	21.36	728
9	Tapi	Bhokar, Suki, Mor, Harki, Manki, Guli, Aneri, Arunavati, Gomai, Gomati, Valer, Purna, Bhogvati, Vaghur, Girna, Bori, Panjhra, Buray, Amravati, Shiva, Ranagavati, Nesu	6.51	14.88	1007
10	Narmada	Burhner, Banjar, Sher, Shakkar, Sudhi, Tawa, Ganjal, Chotta, Kundi, Goi, Karjan, Hiran, Tendoni, Kolar, Man, Uri, Hatni, Orsang	9.88	45.64	3109
11	Mahi	Som, Anas, Panam	3.48	11.02	1052
12	Sabarmati	Sei, Wakal, Harnav, Hathmati, Watrak	2.17	1.35	360

Source: RS Questions (2003)

National Water Development Authority has already identified the links which could be implemented based on the numerous water balance studies for different river basins, topographic studies of reservoir sites and link alignments etc. carried out systematically. Field surveys & investigations for preparation of feasibility reports for such identified links are currently under progress and planned to be completed by 2005.

Table 9. **Composite river basins in India**

SN	River Basin	Important rivers of the Basin	Catchment Area M Ha	Average annual water Availability (BCM)	Per Capita Water Availability (CM)
1	Subarnrekha	Kanchi, Karkari, Kharkai	2.92	12.37	1307
2	W Flowing rivers of Kutch-Saurashtra including Luni	Shetrunji, Bhadar, Machhu, Rupen, Saraswati, Banas	32.19	15.1	683
3	W flowing rivers from Tadri to Kanyakumari	Kodiyar, Pamba, Periyar, Chaliyar	5.62	113.51	3480
4	West flowing river from Tapi to Tadri	Netravati, Sahrawati, Kalindi, Mandori, Savitri, Ulhas, Vaitarna, Ambika, Purna	5.29	87.41	3383
5	East flowing rivers: Mahanadi to Pannar	Rushikulya, Bahuda, Vamsadhara, Nagawali, Sarda, Tandara, Eluru	8.66	22.52	953
6	East Flowing Pennar-Kanyakumari	Kunteru, Swarnmukhi, Araniar, Kortalaiyar, Kanyakumari Cooum, Adyar, Palar, Gingi, Ponnaiyar, Vellar, Varshalei, Vaigai, Gundar, Vaippar, Tambarparni	10.01	16.46	366
7	Area of inland drain in Rajasthan		6		
8	Minor river Basins draining into Bangladesh & Mayanmar		3.63	31	14629

Source: RS Questions (2003)

8.1 Impact of climate change on project assessment

Water management is central to the river-linking scheme. Thus, future climate change that could alter the monsoon or the rainfall patterns over the sub-continent would also affect the project's performance. While the experts and environmental groups have articulated the threat the river-linking project would pose to sustainable development (Bandyopadhyay and Sharma, 2002; Rath, 2003), the threat of climate change on the project performance is overlooked. The monsoon, rainfall pattern and the melt from the Himalayan glaciers are the determinants of water flows in the rivers flowing through the sub-continent. If the climatic changes predicted by international scientific assessment (IPCC, 2001a) were to realize over the present century, the monsoon and rainfall patterns would alter (Rupa Kumar et al., 2003) and the glaciers would recede (Hasnain et al., 2003; Tangri, 2003); thus changing the annual water flow patterns in the sub-continental rivers. This would alter the project's assumptions and the costs and benefits assessment.

8.2 Vulnerability and adaptation to climate change

The vulnerability of the project to climate change would depend on the nature and extent of climatic changes over the subcontinent. The increased variability of climate may mar the project's performance; at the same time the project can help adaptation to changing climate by improved water management to counter the impacts of excess rain and draught. The melting of Himalayan glaciers needs specific attention, as it would increase vulnerability of the project in the long run. The explicit consideration of climate change in project design is therefore vital to counter the vulnerability and to simultaneously make the project an instrument for adaptation to future climatic changes. The climate change assessment of the project is essential for correct and candid scientific, social and economic assessment of the River Linking Project. Such an assessment would not only enhance the project's benefits, but would also help to access international funds available for adaptation to climate change.

The project though itself vulnerable to the climate change may help in reducing the vulnerabilities of other sectors.It is because this project is estimated to produce substantial amount (up to 34 gigawatts) of non-polluting hydroelectric power and allow the substitution of a great number of fossil fuel-based transportation systems that currently cause considerable air pollution. The reduced particulate pollution might improve the regional air quality while saved greenhouse gas (GHG) emissions could impart benefits from the global climate change perspective. Thus, the interlinking of rivers is likely to play a significant and at least partially environment- friendly role in meeting the increasing energy demand of an expanding population and economy of India. That would otherwise be met in the long run by the consumption of additional fossil fuels as well as bio-fuels, which emit substantial amount of air pollutants and trace gases responsible for deteriorating ambient air quality, by reducing oxidizing power of the atmosphere. In turn this will influence the solar radiative balance and alter local and regional climate systems (Gurjar, 2003)

9. National highways network

India has one of the largest highway and road networks on the planet, second only to the road network of the United States. The total length of roads in the country exceeds 3.00 million kilometers (Table 10). This labyrinthine network consists of 52,516 km of national highways, 128,622 km of state highways, and an informal network running to an astounding2, 737,080 km. For the purpose of management and administration, roads in India are divided into the following five categories:

- National Highways (NH);
- State Highways (SH);
- Major District Roads (MDR);
- Other District Roads (ODR);
- Village Roads (VR).

Table 10. **Road transport network in India**

Category of Roads	Length (in kms)	Percentage of the Total Length
National Highways (NHs)	52000	1.58
State Highways (SHs)	128000	3.88
Major District Roads	470000	14.24
Village and Other Roads	2650000	80.30
Total Length	3300000	100.00

Freight transport by road has risen from 6 billion tonne km (BTK) in 1951 to 400 BTK till 1995 and passenger traffic has risen from 23 billion-passenger km (BPK) to 1,500 BPK during the same period. The annual growth of road traffic is expected to be 9 to 10%. Current boom in the automobile sector may even increase the future growth rate of road traffic. While the traffic has been growing at a fast pace, matching investment has not been made in the road sector, due to the competing demands from other sectors, especially the social sectors, and this has led to a large number of deficiencies in the network. Many sections of the highways are in need of capacity augmentation, pavement strengthening, rehabilitation of bridges, improvement of riding quality, provision of traffic safety measures, etc. There are congested road sections passing through towns where bypasses are required. Many old bridges are in need of rehabilitation/replacement along with capacity augmentation. NHs are the main arterial roads which run through the length and breadth of the country connecting ports, state capitals, industrial and tourist centers and neighbouring countries. NHs constitutes less than 2% of the total road network (Table 11), but carries nearly 40% of the total road traffic. There has been no matching growth of the main road network comprising of National and State Highways.:

Table 11. **Growth of roads transport network in India**

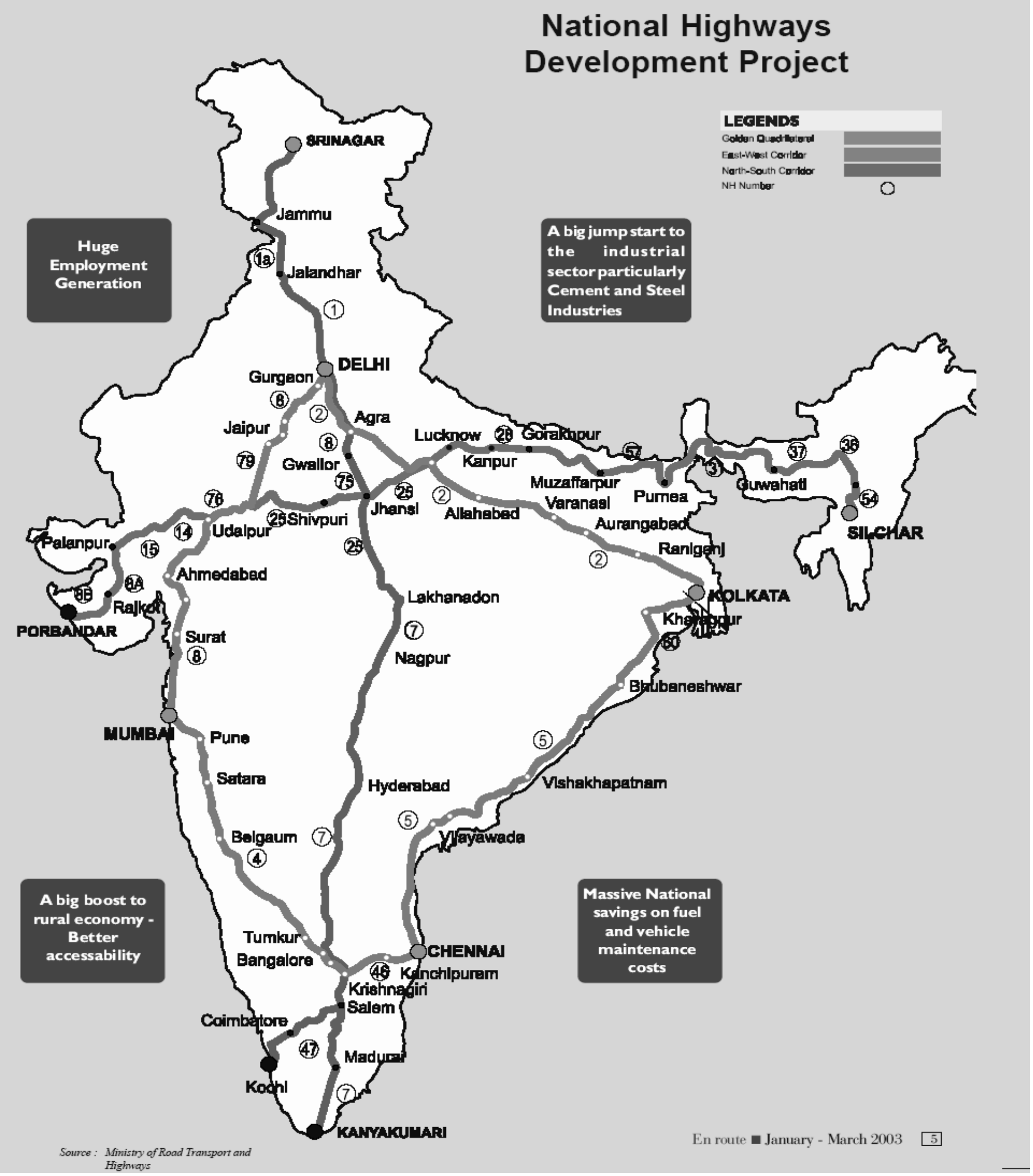
CATEGORY	1951	1998	% change over time	% of total in 1951	% of total in 1998
Expressways	0	0	-	0	0
National Highways	22255	38445	73	5.56	1.27
State Highways	60000	133000	122	14.99	4.41
Other Roads	318000	2846400	795	79.44	94.38
Total	400255	3015845	653	100.00	100.00

The main roads have not kept pace with traffic in terms of quality also. Out of the total 171,445 Km. Length of National and State Highways only 2 percent of their length is four-lane, 34% two-lane, and 64% single lane. As far as NHs are concerned, only 5% of their length is four-lane, 80% two-lane and the balance 15% continues to be single lane. Thus the road sector, in spite of its high priority is adversely affected by the poor quality and service levels. The poor quality of Indian roads is highlighted by congestion, old fatigued bridges and culverts, railway crossings, low safety, no by-passes, slow traffic movement and above all the impacts of vagaries of nature. The deficiencies in the road network are causing huge economic and environmental losses.

In order to improve the road network on a country wide level, the National Highway Development Project (Figure 8) was setup. The project aims to develop the Golden Quadrilateral and the North South as well as the East West corridor as these are the high volume sectors carrying the substantial portion of the road traffic in India. In the context of the NHDP, the framework for commercialization of highways, a comprehensive policy for improving the private sector participation in the Road sector has been initiated. The Model Agreement, as proposed takes into account the deficiencies in the present framework of private participation in infrastructure development projects. The model attempts to address the concerns of all the stakeholders like the investor, lenders, the government and NHAI, with an emphatic orientation in favour of the user and proposes a phased development of the Project Highway to avoid huge capital commitment and thus encourage private participation. In the agreement strict definition of technical parameters were formulated from the users' point of view. Issues such as risk allocation, concession period and concession fee are clearly dealt with special focus on encouraging private participation. It also provides for substantial flexibility to the concessionaire in terms of operation, construction and monitoring and supervision. The obligations of the concessionaire and the NHAI are clearly spelt out.

For rural roads, the a national programme called Pradhan Mantri Gram Sadak Yojna – PMGSY (Prime Minister's Rural Road Programme) has been instrumented aiming at all-weather road access to all villages with a population of over 1,000 people by 2003 and above 500 by 2007. For financing the infrastructure development project, an important development has been the implementation of a Central Road Fund (CRF) with an annual income of about Rs 5660 billion through a one-rupee tax on both petrol and diesel. At present, the fuel tax allocation is along the following lines: NHDP – Rs 20 billion, rural roads – Rs 25 billion, state roads – Rs 10 billion and rail over bridges and safety – Rs 3 billion. Though CRF generates funds from extra road user payments through an explicit tariff, there are some problem areas – (i) it is not separated from the general tax revenues; (ii) it is presently purely an accounting mechanism, thereby not imposing financial discipline.

Figure 8. **National highway development project road map**



Source: Ministry of Road Transport and Highways

Further, both central and state governments are making significant efforts to mobilize funds through multilateral agencies like WB, ADB, etc, the issue of government backed bonds and increasing allocation as the road infrastructure is now treated as priority sector. The government has also initiated several measures and introduced innovative models to increase private sector finance through BOOT, BOT and O&M concessions.

9.1 Impact of climate change on road transport

The road transport network has also not been spared by the vagaries of climate change. Major floods and landslides grossly affect the road networks with damaged roads, bridges, public and private properties. Weather vagaries in terms of heavy snowfall in the Himalayan region and unprecedented rains and flash floods in Eastern regions have caused heavy damage to the public and private property, including roads. Several road networks get blocked due to landslips in hilly regions. During recent droughts in the central region, soils on roads became friable as a result of high temperatures and dry weather. Such roads were easily washed away when the rains finally came, resulting in serious soil erosion and high repair costs.

Climate change may lead to industrial relocation, resulting either from sea-level rise in coastal-zone areas or from transitions in agro-ecological zones. This relocation would necessitate additional infrastructural investments. It also may render waterways in some areas dysfunctional, thereby necessitating additional road and rail investments to replace them. If sea-level rise occurs, the effect on the many harbors and ports around the continent will be quite devastating economically for many coastal-zones. Excessive precipitation, which may occur in some parts of the country, is likely to have serious negative effects on road networks. On the other hand, if climate change leads to drier conditions, maintenance costs may be reduced.

9.2 Vulnerability and adaptation to climate change in road transport

The potential impacts of climate change on Indian roads involve construction of consistent climate and socio-economic scenario and assessment of extreme events. At present many systems and policies are not well adjusted even to today’s climate and climate variability. Increasing costs, in terms of human life and capital, from floods, storms and droughts demonstrate current vulnerability of infrastructure sector specifically road networks. This situation suggests that there are adaptation options that would make this sector more resilient to present conditions and thus would help in adapting to future changes in climate. These options, so called 'win-win' or 'no-regrets' options, could have multiple benefits and most likely would prove to be beneficial even in the absence of climate change impacts. The economic policies and conditions (e.g., taxes, subsidies and regulations) that shape private decision making, development strategies and resource use patterns (and hence environmental conditions) hinder implementation of adaptation measures.

In India, for example, inappropriate land-use zoning and/or subsidized disaster insurance encourage infrastructure development in areas prone to flooding or other natural disasters, which could become even more vulnerable as a result of climate change. Adaptation and better incorporation of the long-term environmental consequences of resource use can be brought about through a range of approaches, including strengthening legal and institutional frameworks, removing pre-existing market distortions (e.g., subsidies) and rectifying market failures (e.g., failure to reflect environmental damage in prices or inadequate economic valuation of bio-diversity).

To identify opportunities that facilitate sustainable development by making use of existing technologies and developing policies that make climate sensitive sectors resilient to present climate variability is a big challenge. In this strategy, many regions of the country necessitate to have more access to appropriate technologies, information, and adequate financing. Based on the regional assessments, adaptation will also require anticipation and planning; failure to prepare systems for projected changes in climate means, variability and extremes could lead to capital intensive development of infrastructure or technologies that are ill-suited to future conditions, in addition, end up having missed opportunities to lower the costs of adaptation. Additional studies and analysis of current vulnerability to today’s climate fluctuations and existing coping mechanisms is required which will offer lessons for the design of effective options for adapting to potential future changes in climate.

10. Impacts and the role of adaptation

Adaptation here refers to all actions that can be taken to offset or reduce the impacts of climate change. Adaptation measures, strategies and policies help in reducing many of the impacts of climate change, which cannot be stopped otherwise. It can take place through the actions of individuals or enterprises, or it may be a government policy designed and implemented through those concerned with planning and infrastructure development. It is well accepted that as the adaptive capacity of a country or region decreases, the vulnerability to climate change increases, leading to greater costs associated with impacts. Successful adaptation will reduce the impacts associated with climate change, and will depend upon, among other factors, a country's or region's technological capability, institutional arrangements, availability of financing, and information exchange.

Actions, which can be taken for adaptation, have been classified in various ways in different studies. Burton (1997) provides a particularly useful typology of responses to natural hazards, which can be applied to climate change. Based on inputs from other researchers and previous studies, Canada country study (Mayer and Avis, 1998) categorizes the adaptive measures, ranging from organizing them according to different social, economic, temporal, and spatial scales, or differentiating them according to their 'software', i.e. programs, behavioural modification and 'hardware', i.e. machines, structures, status. They identify six categories of adaptation: bearing capacity, modifying capacity, preventative capacity, research capacity, education capacity, and avoidance capacity.

In case of India, the present day organization of society, in all its socio-economic activities and techno structures, includes many examples of adaptation to changes in climate. In fact, the difficulty is that the choices and decisions, both public and private, will have to be extensively reviewed. For a developing economy, adaptation is important not only to reduce the negative impacts of a changing climate but also to take advantage of opportunities that may present themselves. In some places, the growing season will be longer, more water may be available from the Himalayan Rivers and some desirable new species of plants and animals, not found now, may appear. None of these will actually produce economic benefits unless we set out to make use of them. Therefore, adaptive strategies will have to be made an integral part of the response options available to face the challenge of climate change.

An inevitable result of the increased damages to infrastructure from climate change will be a dramatic increase in resources needed to restore the infrastructure. The only immediate source to meet this need is international donor community, which plays a unique role by providing post disaster infrastructure lending. As the damages are expected to increase in the future the demand for such funding is bound to increase. Affected countries will mostly rely on the international donor community to provide leadership and funding for post disaster reconstruction. Toady, the private sector is also coming forward in the developing countries to invest in the infrastructure projects. Investments are also coming form the international agencies. In view of this, it becomes imperative for the lending agencies to promote the use of market mechanisms to assist those countries most prone to weather-related extremes to arrange ex ante reconstruction funding through insurance and other financial mechanisms**.**

10.1 Risk and insurance

The insurance sector has been participating in covering the risks of the large-scale infrastructure projects against future uncertainties. Climate change increases risks for the insurance sector, but the effect on profitability is not likely to be severe because insurance companies are capable of shifting changed risks to the insured, provided that they are "properly and timely informed" on the consequences of climate change (Tol, 1998). For example, in the event of a catastrophic event, the insurance sector reacts to increased risk and large losses by restricting coverage and raising premiums. It has been shown by various authors that the increased climatic variability necessitates higher insurance premiums to account for the higher probability of damages. Conventionally, there are various ways of risk management for the organizations faced with uncertain future. All these can be classified under four possible response options that the organization may adopt to deal with the risks; it may avoid, mitigate, retain or transfer the risk. The first two responses (avoidance and mitigation) may be categorized as risk control and the latter two (retention and transfer) as risk financing. The normal approach to risk management is to control all those risks that management feels it can control within the physical resources of the firm and finance the remainder. Effectively, risk financing funds those losses that remain after the application of risk control techniques, including both those risks accepted as not being able to be controlled and those where controls proved inadequate to contain the risk (AACI, 2003).

10.2 Risks and insurance for weather extremes in developing countries

The IPCC Third Assessment Report (IPCC, 2001a; IPCC, 2001b) has concluded that, during the 20th century, the frequency of extreme precipitation events has increased mid- and high northern latitudes (with 66-90% confidence), and that the occurrence of extreme weather events has increased in temperate and tropical Asia, including floods, droughts, forest fires and tropical cyclones (with 67-95% confidence). The IPCC has noted some indication of increases in extra-tropical cyclone activity during the latter half of the 20th century in the northern hemisphere. At the same time, more pronounced severe dry events have occurred in the past decades over Sahel, eastern Asia and southern Africa (IPCC, 2001a). For the 21st century, and based on emission scenarios estimating the human component of climate change, the IPCC has also projected the likely hood of the following climate change events (Table 12)

Table 12. **Estimates of confidence in observed and projected changes in extreme weather and climate events**

Confidence in observed changes (latter half of 20th century)	Changes in Phenomenon	Confidence in projected change (during 21st century)
Likely	**Higher maximum temperatures and more hot days over nearly all land areas**	**Very likely**
Very likely	**Higher minimum temperatures, fewer cold days and frost days over nearly all land areas**	**Very likely**
Very likely	**Reduced diurnal temperature range over most land areas**	**Very likely**
Likely, over many areas	**Increase of heat index over land areas**	**Very likely over most areas**
Likely, over many Northern Hemisphere mid- to high latitude land areas	**More intense precipitation events (for other areas, insufficient data or conflicting analyses)**	**Very likely, over most areas**
Likely in a few areas	**Increased summer continental drying and associated risk of drought**	**Likely, over most mid-latitude continental interiors**
Not observed in the few analyses available	**Increase in tropical cyclone peak wind intensities**	**Likely, over some areas**
Insufficient data for assessment	**Increase in tropical cyclone mean and peak precipitation intensities**	**Likely, over some areas**

Source: IPCC, 2001a

All over the world, over the past decade the premium for catastrophe insurance has been high and cyclical, ranging from double to 18-times the actuarial fair premium, although there have been periods where the price actually fell below pure premium. Thus the insurance instruments appear to be costly, however, this may change as investors gain more experience (Andersen, 2001). Auffret (2003) has pointed out that, surprisingly, in some cases catastrophe insurance premiums have exceeded the average estimated GDP losses. Terrorist attacks of September 11th has been a case where increasing concern was shown by the investment community in providing coverage for catastrophic events, and the price for this protection has risen (Kunreuther, 2002). Based on recent market data, the average XL (excess of loss) rates for different levels of catastrophe coverage based on probability of occurrence are shown in Table 13. The Index shows the "risk load" added to the pure probability premium (Pollner, 2000).

Table 13. **XL rates by event probability**

Probability	XL Rate	Index Rate/Prob.
15.0%	17.0%	1.1
5.3%	8.3%	1.6
3.5%	6.6%	1.9
2.5%	5.8%	2.3
1.5%	4.9%	3.3
1.2%	4.2%	3.5
0.8%	3.9%	5.2
0.7%	3.8%	5.4
0.4%	3.5%	10.0
0.2%	3.4%	18.9

Source: Bayer and Verheyen, 2003.

10.3 Risk transfer for public infrastructure

Despite the costs, there has been a great deal of excitement about the potential of insurance and other forms of risk transfer for hedging the risks of extreme weather-related and other disasters facing developing countries. Governments carry a large and highly dependent portfolio of infrastructure assets, some of which are critical for restoring economic growth, and for the same reason as firms they may wish to reduce the variance of their disaster losses by diversifying with insurance and other risk-transfer instruments.

A government of a country is, however, different from a firm since most governments can pass their infrastructure losses on to taxpayers. Thus it appears that the governments are less risk averse than firms, and risk aversion is the main justification for paying the additional costs for insurance (Arrow and Lind, 1970). A developing country may not be able to pass its losses fully on to taxpayers, and risk transfer may be the only available option for covering extreme-event losses. Many governments of developing countries do carry some limited insurance, some limited insurance on its quasi-private capital stock like airports, telecom energy facilities and state-owned enterprises, whereas roads, bridges, hospitals, government buildings remain without protection (Pollner, 2000).

Lacking more attractive financing alternatives, the government benefits from risk transfer since it reduces the variability of its disaster losses, but risk transfer requires resources that could otherwise be invested in the economy. In terms of economic growth there is thus an inherent trade-off: a reduction in funds spent on current growth permits a government to protect itself against extreme future losses.

11. Conclusion

The analysis of Konkan Railway project illustrates that infrastructure having long life becomes more vulnerable to the climatic changes 50 years from now. Efforts will have to be made to minimize 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 that 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. The studies shall also provide insights for methodological developments including models for integrated assessment and GIS-based computer algorithms for supporting policy assessments at regional levels.

Climate change impact analysis on energy infrastructure indicates that a rise in average temperature increases need for space cooling for buildings and transport sectors. The variability in precipitation can also impact the irrigation needs and consequent demand for energy. These would increase electricity demand, and consequently result in the need for higher power capacity. The demand for air-conditioned transport (cars, buses and train coaches) and their increased use may result in lower fuel efficiency, increasing petroleum product consumption. The increased energy demand shall result in higher emissions. The assessment for India suggests an increase of around 1%, which though not substantial, is still significant for examining the reverse links and feedback with climate change.

A long-term database involving glaciologists from within the country and abroad to conduct a detailed study to check climate signals and monitor temporal and spatial variations is needed. In-depth studies are necessary on glacier hydrology as the three main rivers--Ganges, Brahmaputra and Indus rely on glacier resources like snow and ice from the Himalayas. The existing database has to be first studied by an expert team of scientists before creating a new database on the discharge and climate patterns of the glaciers that fed about 80 per cent of the discharge to the rivers.

South Asia, in general, and India, in particular, is vulnerable to climate change and shall be adversely impacted. Assessment of climate change impacts in India has been reported (SAARC, 1992; ADB, 1994) though further studies are required to develop better understanding of climate and human system interactions and the adaptation strategies for mitigating adverse impacts. The detailed assessment of the impacts on infrastructure would require:

1. 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.

2. Detailed GIS covers with topographic, vegetation and geological details showing the major infrastructure systems and components.

3. Sensitivity assessment of the infrastructure components with respect to various forcing climate parameters.

The infrastructure sector is a vital sector where huge investments are being committed in developing countries. The sector creates long-life and open-to-weather assets that shall face increasing impacts from the changing climate. It would be prudent for developing country policymakers to pay attention to protect these assets, which may otherwise cause significant welfare losses to future generations. Myriad adaptation strategies are needed. These would include the incorporation of future climate extremes in the project design parameters in the immediate-term; improved operational and maintenance practices in the near-term; and improved climate predictions and creation of insurance markets in the long-term.

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