# Impacts of Climate Change on Transport and Adaptation in Asia

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**Abstract:** This paper examines impacts of climate change on Transport in Asia. It identifies vulnerable components of transport infrastructure which are at high risk to climate change. It discusses adaptation options of transport infrastructure development during planning, design, construction, operation and maintenance phases. Findings of a survey of climate change impacts and adaptation in Asia with respect to awareness, existing polices and guidelines and institutional setup and coordination are presented. The research reveals that the design consideration is an important aspect for adaptation. The paper further stresses the need to strengthen institutional capacity to initiate policy guidelines and implementation of adaptation programmes. It proposes to extend the existing environmental impact assessment guidelines to include assessment of climate change impacts and adaptation. Availability of limited literature in Asian context indicates further research needs in the area of transport and climate change, costing adaptation measures and design review.

***Key Words:*** *Climate Change, Impacts, Adaptation, Design Guidelines*

## 1. INTRODUCTION

There have been extreme weather events in Asia recently signaling increase in intensity and frequency of such events. The Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report predicts that Asia will experience rise in temperature, longer summer heat spells, more intense and frequent precipitation, increase in extreme rainfall and tropical cyclones, rise in sea levels in coastal areas around the Indian Ocean and northern and southern Pacific Oceans (Christensen et al., 2007).

The climate change threatens basic elements of life for people around the world- access to water, food, health and use of land and environment (Stern, 2007). Transportation system will be affected by climate change. Increase in temperature, precipitation, sea level and storm surges will have significant impact on transportation infrastructure.

Some obvious impacts to the transportation systems are traffic disruption due flooding and heavy snow and rains, difficult driving conditions, increase in maintenance requirement to the pavement due to high temperature and more frequent icing-thawing phenomenon, overflow

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of side drains and cross drainage works, submerged bridges due to floods induced by intense precipitation, inundation of coastal roads due to sea level rise, and road blocks due to landslides.

Transport sector not only affected by climate change it also contributes to the climate change due to carbon emissions. Various studies have assessed the impacts of climate change on transport in developed countries (Wooller, 2003; Andrey et al., 2003; Harvey et al., 2004; Galbraith et al., 2005; Humphrey, 2008). These studies show that climate change will have substantial impacts on design, construction, operation and maintenance of the transport system.

These studies have identified research gaps in the area of impacts assessment and quantification, implications for design guidelines, appropriate adaptation strategies for transport sector (Lemmen et al., 2004). The IPCC Synthesis Report suggests the need to integrate climate change considerations into national transport policies and on research and development (IPCC, 2007). However, there are limited studies conducted in the area of climate change and adaptation in the transport sector in Asia.

The conceptual framework for the research builds on the ongoing research in the area of transport and climate change. The scale of impacts is related to the severity of extreme climate events triggered by the climate change. The climate prediction is not uniform for all parts of Asia therefore the scale and nature of impacts on transportation system will be different. South and South Asia transportation will be subject to impacts due to high intensity rain and hot weather. Northern Asia and Tibetan Plateau will be subjected to increase in winter precipitation. The islands and coastal areas in the Indian Ocean and Pacific Ocean will be affected by the rise in sea level. Similarly, different level of economy and national capacity also affect proper planning and implementation of climate change and adaptation policies.

The adaptation measures to be planned depend on the intensity and frequency of climate events, scale of impacts, location and topography. In this context, the research aims to answer the following research questions: What are the most vulnerable transport infrastructure components to the climate change and what are the impacts? How the climate change will affect current practice of design, construction and operation of transport infrastructure? How can we develop more resilient transport infrastructure through adaptation? What is the level of awareness, institutional capacity in Asian developing countries needed to plan and implement adaptation measures in the transport sector?

## 2. LITERATURE REVIEW

### 2.1 Key definitions

Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs (WCED, 1987). Climate is defined as the average weather. Climate change refers to change in the state of the climate that can be identified by changes in the mean and/or the variability of its properties, and that persist for an extended period, typically a decade or longer. Impacts refer to the effects of climate change on natural and human systems. Adaptation refers to initiatives and measures to reduce the vulnerability of natural and human systems against actual or expected climate change effects. While mitigation refers to implementing policies to reduce greenhouse gas emissions and enhance sinks (IPCC, 2007).

There is now little expectation that adaptation or mitigation alone can avoid all climate change impacts. However, they can complement each other and can significantly reduce the risks of climate change (Sperling et al., 2009). Pachauri (2008) says adaptation alone cannot cope with all the projected impacts of climate change, so greenhouse gas mitigation efforts are urgent. This study however focuses on adaptation only.

### 2.2 Recent Studies on Transport and Climate Change

Koetse et al. (2009) have extensively surveyed literature on the effects of climate change on transport and concluded most studies focus on short term impacts and the transport sector has received little attention. Some of observed impacts listed are effects on coastal transport infrastructure due to sea level rise, effect on traffic safety and congestion on roads by precipitation, delay in rail transport, high winds and visibility have effect on safety and delay for air transport, low and high water levels affect water transport.

Meyer (2008) has examined potential changes in design and engineering practices due to climate changes in the United States. He argues that the current design standards developed 50 years ago, may not be sufficient to accommodate the impacts of climate change. He suggests projects in highly vulnerable locations should be built with higher standards and stresses the need to review the US highway standards and develop new design standards to address future climate conditions.

Dasgupta et al. (2007) looked at impact of sea level rise in the coastal area globally. The study concentrates on population and infrastructure planning but not on transport, however it suggests that planning should consider all risks associated and recommend avoiding coastal and vulnerable areas while planning infrastructure. In terms the impacts they predict that Vietnam will be worst affected in Asia. There are 11 mega-deltas in Asia among them Dhaka, Kolkata and Shanghai are at high risks of being severely impacted by the rise in sea level (IPCC, 2007).

Klein et al. (1999) doubt the IPCC guidelines for assessing climate change impacts and adaptation which focuses more on implementation and suggest a four step approach collaboration, coordination, policy formulation and implementation.

### 2.3 Current State of Climate Change Adaptation

Asian Development Bank (ADB) has initiated incorporating adaptation measures in project design and implementation (ADB, 2008). Some example includes climate proofing of the design of the Avatiu Harbor in the Cook Island, water resource management infrastructure in Indonesia and coastal infrastructure project in Vietnam. ADB's adaptation programme for the Pacific has initiated "climate proofing" of some infrastructure projects. One of the projects in Micronesia was road construction (Hay, 2004).

There are many examples in countries considering the climate change while planning and designing transport infrastructure. Meyer (2008) mentions that the clearance of a bridges have been increased after the Hurricane Katrina and one meter sea level rise was incorporate into the design of Confederation Bridge in Canada (Andrey et al., 2003). Dasgupta et al. (2007) suggest integrating transport and land use planning to consider vulnerable area. Some local authorities in US are planning to outlaw transport and infrastructure development in

vulnerable coastal area.

Costing is a key factor in deciding the adaptation measures. How safe and strong should be the infrastructure and at what cost? There are limited research in costing and life cycle costing of adaptation measures in transport sector (Agrawala et al., 2008). Ozbay et al. (2004) have analyzed the application of life cycle cost analysis in highway agencies in US and found implementation gaps, mistrust between theory and knowledge and its implementation. It was mainly applied in road pavement but not extensively for other road structure.

## 3. CLIMATE IMPACTS STUDIES FROM OTHER REGIONS

The main focus of research on transport and climate change is concentrated on reducing $CO_2$ emissions from transport. In addition, there are ongoing efforts to study the impacts of climate change on transport infrastructure and operation. As no exclusive climate change studies on transport sector are available in Asian context. This chapter provides brief analysis of impacts studies conducted in roads in Australia and Scotland and transport transportation system in Canada, UK and USA. It then looks at similarity of impacts based on the predicted climate change for Asia.

### 3.2 Impact of Climate Change on Roads

#### 3.2.1 Australia

Harvey et al. (2004) assessed the likely impacts of climate change on road infrastructure for next 100 year in Australia. They predicted Australia to be generally hotter and drier, rise in temperature 1-6ºC by 2070, sea level rise 9-88 cm by 2100, and maximum wind surge may increase by 5-20%. Rain and rise in temperature will further triggers deterioration of pavement causing pot holes and loss of surface chips due to high temperature. Flood heights and frequency affect location and design of road and bridges. Sea level rise and storm surges will affect coastal roads. Freight traffic is expected to rise until 2060 and stabilize there after. Average freight payload expected to increase by 25% from 2000 to 2100. Using pavement life cycle costing they predicted road maintenance cost would substantially increase in Queensland and Northern Territory by 51% and 108% respectively.

The rate of pavement deterioration will be slow due to decrease in rainfall and correspondingly design thickness could be reduced. In northern parts of Australia due to wetter climate the cost of pavement maintenance may increase, capacity of existing culverts and waterway may be inadequate. Due to sea level rise the problems becomes bigger for low lying coastal road in northern Australia. The study suggests that the planners and designers need to take account of projected sea level rise in designing the clearance of bridge over tidal water. Higher water table can accelerate pavement deterioration and need to raise levels of existing embankments when rehabilitation is being planned at the end of their useful life. Flooding impacts are cited as worthwhile- bridges, causeways and alignments are the most long lived feature on road. The study suggests that adaptation need to be planned considering future trend of flood heights and frequencies.

#### 3.2.2 Scotland

Galbraith et al. (2005) examined potential trend of climate change and how these may affect Scottish road network. The study concluded that even small change in climate may warrant

changes in current practices in design and operation of transport system. Rise in temperature, rain, snow and icing phenomenon, high wind, storm surge, fog, coastal flooding, rise in sea level are some climate events that will affect roads in Scotland. The study suggests that predicted increase in rainfall and rise in sea level are of particular concern. The sea close to Edinburgh is rising at a rate of 0.05 m/year. There is a question of risk associated with the occurrence of events. The study recommends revising the storm design parameter used to design surface water drainage, bridges and culverts and to review design return period, even though flooding is not a cause of concern in Scotland. It further says that the reduction in freeze-thaw cycle due to warming will reduce damage to road infrastructure.

### 3.3 Impacts of Climate Change on Transportation System

#### 3.3.1 Canada

Canada has different types of impacts of climate change on the transportation system because of its existing weather condition. Many studies predict that Canada will have net positive impacts due to global warming. But increased summer and more frequent freeze-thaw cycle would increase pavement damage and increase maintenance costs too (Andrey et al., 2003). The operation of “ice road”, shoreline rails, and icy airports on northern part of Canada would be affected due to shorter winter period. Warmer temperature will improve operation of all modes transport. It is also expected that warmer temperature would translate to longer construction period and generating cost efficiency. However, rise in sea level will have affect causeways, bridges, coastal road and railways. Air transport will also be affected by sea level rise as 52 airports are situated just 5m above the sea level or less in Canada. Sea level rise will provide deep navigation channel for maritime transport while some ship building yards and dry docs would be affected. Warmer climate could reduce icebreaking service for marine transport. Canada may have positive impacts due to reduced snow and ice control measures. However, design and construction adaption measures may be costlier.

#### 3.3.2 United Kingdom

Wooller (2003) looked at three climate change scenarios at 2020, 2050 and 2080 using models developed by United Kingdom Climate Impact Project and the Hadley Centre. It says while scenarios of 2050 and 2080 will depend on future $CO_2$ emissions, the 2020 scenario is largely fixed. The study identified increased risks of flooding from river and sea and inadequate drainage, deterioration of highway infrastructure as key impacts. Increase in flooding during winter, seal level rise between 26-86 cm by 2080 and inundation of coastal stretches, and more extreme heat during summer, difficult driving conditions due to snow and icing are the some of critical impacts predicted. The study concludes considering climate change while planning maintenance and improvements of roads and rail and coordination are main areas for actions. It considers improving understanding and awareness about the likely impacts of climate change on transport is very important. It recommends the need to review technical standards in the light of climate change scenarios, design manual for roads and bridges, additional research to understand impact on railways. Contingency plans will also be required to cope with more extreme events and impacts.

United Kingdom has initiated to develop a transport strategy for climate change adaptation (Department for Transport, 2007). It stress that the infrastructure need to be resilient to the climate of at least 2050 and beyond and mention that adaptation need not require significantly extra resources. It was realized that the general level of awareness of the impacts of climate

change was not high. So the effectiveness of communication and awareness programme was recognized. They also suggested to improve risk management approach and to promote cross-modal knowledge-sharing networks.

### 3.3.3 United States

Humphrey (2008) has comprehensively studied the potential impact climate change on US transportation. The study finds that the impact will be vary by mode and will be widespread and costly in both human and economic terms and will require significant changes in planning, design, construction, operation and maintenance of the transportation system. The study makes details recommendations such as: incorporating climate change into investment decisions, integrate evacuation planning and emergency response into transport operations, reevaluate design standards, include climate change and transportation and land use planning and develop new organizational developments. The study makes the case that focusing on the problem now should help avoid costly future investments and disruptions to operations.

Another US study (ICF International, 2008) assesses the impact of global sea level rise on infrastructure. The projected global sea level rise under various scenarios range from 18-59 cm. They study concludes that rising sea levels, combined with hurricanes and other weather related incidents, could cause permanent inundation and more frequent temporary flooding of roads, railroads, and airports, and could have major consequences for port facilities and coastal shipping in US.

### 3.4 Discussion and Relevance to Asia

We see some similarity as well as difference on the type and scale of impacts in above listed five cases. The difference is the weather pattern in Australia and Canada and their impacts. While Canada will have positive impacts due to warming, further warming in Australia affecting maintenance needs and expenditure. The US and Canadian studies covers all modes of transport. Most of the above case studies suggest similar types of impacts due to the climate change. They advocate planning the transport infrastructure taking account of climate events. Others include review the design standards and infrastructure need to cope with the impact of climate change- incorporating more robust design. Based on the above cases and predicted climate patterns for Asia the identification of vulnerable transport infrastructure and key design parameters and impacts will be identified.

## 4. CLIMATE CHANGE IMPACTS AND ADAPTATION IN ASIA

### 4.1 Regional Climate Projections for Asia

The IPCC Fourth Assessment Report (Christensen et al., 2007) predicts warming is likely[1] to be well above the global mean in Central Asia (3.7ºC), the Tibetan Plateau (3.8ºC) and northern Asia (4.3ºC), above the global mean in eastern Asia (3.3ºC) and South Asia (3.3ºC), and similar to the global mean in Southeast Asia (2.5ºC). Precipitation in boreal winter is very

[1] The IPCC report uses standard terminology for the likelihood of occurrence: virtually certain >99% probability; very likely>90% probability; likely>66% probability; more likely than not>50% probability; about as likely as not 33 to 66% probability; unlikely <33% probability; very unlikely <10% probability; exceptionally unlikely<1% probability.

likely to increase in northern Asia and the Tibetan Plateau, and likely to increase in eastern Asia and the southern parts of Southeast Asia. Precipitation in summer is likely to increase in northern Asia, East Asia, South Asia and most of Southeast Asia, but is likely to decrease in central Asia. It is very likely that heat waves/hot spells in summer will be of longer duration, more intense and more frequent in East Asia. Fewer very cold days are very likely in East Asia and South Asia. There is very likely to be an increase in the frequency of intense precipitation events in parts of South Asia, and in East Asia. Extreme rainfall and winds associated with tropical cyclones are likely to increase in East Asia, Southeast Asia and South Asia.

Sea levels are likely to rise from 18 cm to 59 cm under various scenarios during the century. Around the Indian Ocean and northern and southern Pacific Ocean the sea level rise likely to be on average. Indian Ocean and North and South Pacific Islands are very likely to warm during the century. The warming is likely to be somewhat smaller than the global annual mean. Annual rainfall is likely to increase in the northern Indian Ocean. Annual rainfall is likely to increase in the equatorial Pacific.

The annual runoff of major Siberian Rivers would increase significantly, expansion of deserts and periodic sever water crisis, increased rainfall intensity during summer monsoon could increase flood prone areas in Asia.

Recent notable intense rains and floods are: sever flood in 1999 in China; serious flood in 2000 in Japan brought by 10 typhoons; serious and recurrent floods in Bangladesh, Nepal, northeast states of India during 2002, 2003, 2004; a record 944 mm rainfall in Mumbai in 2005; 2003 flood in Sri Lanka; Viet Nam 2008, Philippines 2004 and Cambodia 2000. Philippines, China, Japan and South Asia were frequently hit by cyclones and typhoons. These extreme events had severely damaged transportation infrastructure and operations.

The damage done to transport infrastructure by 2007 floods in Bangladesh was 34% (US $ 363 million)[2]. The Aceh Flood 2007 in Indonesia caused significant damage to the transportation sector amounting US $ 35 million that is 25% of infrastructure costs.[3]

### 4.2 Impacts of Climate Change in Asia

These predicted climate change will severely impact the transport infrastructure. The potential impacts on transport infrastructure and operation due to the climates are given below:

(i) Temperature: The extended warm weather would affect pavement deterioration due to melting of bitumen, heating and thermal expansion of bridges and rail tracks, buckling of joins. Decrease in temperature affects transport operation as well as snow and ice removal costs including salts used.

(ii) Rainfall: The increase in winter precipitation would affect drainage capacities, road pavement, driving condition and visibility. Increase in intensity of summer precipitation creates flooding, affect drainage, bridges affecting waterways and clearance, damage pavement and affect road, rail, airport, ports and harbours,

2 Consolidated Damage and Loss Assessment, Lessons Learnt from the Flood 2007 and Future Action Plan, Disaster Management Bureau, Ministry of Food and Disaster Management, Bangladesh.

3 Aceh Flood, Damage and Loss Assessment, Government of Indonesia, 2006

water transport channels, damage bridges foundation due to scoring. Road blocks due to landslides and mudslides.

(iii) Storms and Storm surges: Rainfall and winds associated with cyclone would create flooding and affect roads, rail and airports and water transport. Disrupt traffic and safety and emergency evacuation operations; affect traffic boards and information signs. May lead to inundation and create

(iv) Sea level rise: Rise in sea level can affect the coastal roads, railways, port and harbour, airport near to coastal area, marine transport in the affected areas. In many cases there may be need to realign or abandon the affected coastal infrastructure.

Table 1 shows the impact matrix between the vulnerable infrastructure components and the climate events.

**Table 1: Impact Matrix of Climate Events and Vulnerable Infrastructure in Asia**

| Vulnerable Infrastructure | Bridge | Drains | Rail tracks | Pavement | Culvert | Side slopes | Coastal Road and rails | Ports and Harbour | Airports | Water transport | Road signs |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Temperature** | X | | X | X | | | X | X | X | | |
| **Precipitation** | | | | | | | | | | | |
| **-Winter** | X | X | X | X | X | X | X | X | X | X | X |
| **-Summer** | X | X | X | X | X | X | X | X | X | X | X |
| **Wind** | X | | | | | | | | X | X | X |
| **Storm/Cyclone** | X | X | X | X | X | X | X | X | X | X | X |
| **Sea level rise** | X | | | | | | X | X | X | X | |

We see from the above the precipitation, storm and cyclone are most destructive climate events affecting all vulnerable components of transport system. All infrastructure components bridges, drains , culverts, rail track, pavement, side slopes, coastal roads and rails, ports and harbour, airports, water transport and road signs are impacted by precipitation, storm and cyclones. In many instances it may not be possible to quantify the impacts and qualitative data to express impacts could be used (ADB, 1996).

Therefore, appropriate consideration of potential weather evens in planning, designing and maintenance of the transportation system would increase their serviceability and life. Given the importance of the transport infrastructure both socially and economically, it is important that the transport system adapts to the projected changes in climate.

### 4.3 Design Parameters Related to Vulnerable Infrastructure Components

Key design parameters corresponding to vulnerable infrastructure identified based on the literature and studies related to the climate events in Asia are shown in table 2.

**Table 2: Design parameters of vulnerable infrastructure components in Asia**

| Infrastructure component | Design parameters needing consideration |
|---|---|
| Bridge | -Flood estimation, return period, design discharge |

| | |
|---|---|
| | -High flood level<br>-Free board (clearance above High Flood Level)<br>-Length of waterway<br>-Design load, wind load<br>-foundation, river and bank protection<br>-corrosion protection |
| Drains | -Discharge estimation (return period)<br>-size and shape of drain<br>-drain slope |
| Rail tracks | -heat resistance material<br>-rail line joints<br>-expansion joins |
| Road and Pavement | -camber to quickly remove surface water<br>-stiff bitumen to withstand heat or workable in winter<br>-soil moisture and maintenance planning |
| Culvert | -Discharge estimation (flood return period)<br>-size and discharge capacity<br>-cross slope<br>-Free board (clearance) |
| Side slope | -slope protection work<br>-subsurface drains<br>-catch drains |
| Coastal road and rails | -protection wall<br>-warning signs<br>-realignment<br>-edge strengthening |
| Ports and harbour | -height of platform<br>-protection work<br>-design for storm and surge actions |
| Airports | -wind direction<br>-runway alignment<br>-snow and ice removal plan<br>-pavement material<br>-drainage capacity |
| Water transport | -bridge clearance<br>-dredging<br>-flood protection at sea entrance |
| Road signs | -wind load<br>-structural design<br>-foundation<br>-corrosion protection |

To overcome the impacts of climate change on the vulnerable infrastructure components listed in the table 2 due considerations should be given to the corresponding design parameters. While designing bridges, culverts and drains consideration should be given to increasing design parameter such as the frequency and intensity of rains, introducing sufficient subsurface water drains, increasing design high flood level of bridges. While designing costal road consideration should be given to predicted rise in sea level and providing high and strengthened side barriers. Depending on the estimation of rise in water level it may be feasible to realign an existing coastal road to a higher location. Adequate slope stabilization measures, river bank protection works and raising embankment height in

flood plains would safeguard road closure and damage to road due to excessive rains and floods.

### 4.4 Survey of Impacts and Adaption in Asian Countries

A survey of climate change impacts on transport and adaptation in Asia was conducted to understand level of awareness, emergency preparedness, design standards and practices, institutional arrangements, and coordination, existence of policies, rules and design guidelines, and current practices of incorporating climate change impacts on transport projects. Total 24 responses from 21 counties (70% response rate) among 30 countries were received namely from: Azerbaijan; Bhutan; Cambodia; China; India; Indonesia; Iran; Japan; Kazakhstan; Kyrgyzstan; Malaysia; Mongolia; Myanmar; Nepal; Pakistan; Republic of Korea; Singapore; Thailand; Turkey; Uzbekistan; and Viet Nam. The following outlines the findings of the survey.

#### 4.4.1 Awareness of Climate Change and Adaptation

Most of the respondents (63%) indicated that the policy makers and transport officials are adequately or highly aware of environment, climate change and adaption. Eight respondents (27%) rated low or very low level of awareness. Majority of respondents (75%) rated the awareness of general public as low and very low. Only six respondents (25%) rated the awareness as adequate or very high. The survey indicates that there is a need to raise awareness of general public and as well as policy makers and transport officials.

The respondents were asked to rate 14 climate changes and transport related statements on a five point scale (1-strongly disagree, 2-disagree, 3-neutral, 4-agree, and 5-strongly agree). The outcome confirmed with broad beliefs on climate change and their potential impacts on various transport infrastructure. Some of the high ranking statements are: (i) climate change is a cause of concern (100); (ii) coastal infrastructure are vulnerable to climate change (100); (iii) climate events will affect transport and operation (99); (iv) poor driving condition due to fog, storm (98); and (iv) design standards and criteria may need to be revised (97). Most of the respondents (79%) strongly disagreed or disagreed with the statement “Our region will not be much affected by climate change.”

#### 4.4.2 Emergency Preparedness

As transport play vital role in mobilizing immediate help and relief to the area affected by the extreme climate events, a section related to emergency preparedness was included in the questionnaire. All respondents indicted that there had been occurrence of extreme climate events within last three years. Majority (67%) of respondents rated that the responses to the climate events by the relief and transport agencies have been normal, fast or very fast when asked to rate the response as very fast, fast, normal, slow and very slow.

#### 4.4.3 Design Standards and Practices

The respondents were asked to check appropriateness of sixteen design standards and practice related statements. The ranking of statements clearly demonstrate that rain, floods and related damages are major cause of concerns in Asia. Highly ranked statements are: (i) ensure effective drainage of surface water from pavement (camber, subsurface drains) (16); (ii) increase capacity of side drains (14); (iii) design flood estimation, storm water taking account

of predicted climate (14); (iv) Increase clearance above high flood level for bridges (13); and (v) raise height of embankment in flood plains (12).

Almost all respondents (92%) indicated the need to review design standards for critical structural components. While 83% of respondents expressed the need to revise design flood estimation methods and indicated lack of clear guidelines to consider impacts of climate change. All expect one (96%) voiced that potential impacts of climate change should be considered while planning and designing vulnerable transport infrastructure. Many respondents (79%) agreed that adopting higher standards will have higher initial cost but may be economical in long run. These finding clearly show that Asia lags in mainstreaming climate change consideration while planning and designing transport infrastructure.

### 4.4.4 Policy, Guidelines, Institutions and Coordination

Mixed response was received as majority respondents (50%) saying that there are no existing laws, rules and guidelines to assess environmental and climate change impacts. Respondents from Bhutan, India, Indonesia, Iran, Kyrgyzstan, Mongolia, Nepal, Pakistan, Republic of Korea, Thailand, and Turkey indicated that there are existing laws, rules and guidelines. But most of the laws, policy and guidelines listed are related to the environmental, global warming, air pollution and very few were related to climate change. There seems to be clear need for revision and extension of rules, polices and guidelines to include climate change and adaptation as 13 respondents indicated the need, while nine indicated the need for new policy and guidelines and two indicating no need to revise or introduce new policy or guidelines. Most of the respondents (88%) favoured extension of existing environmental guidelines to include the climate change and adaption issues. Eight respondents indicated having projects related to environment, climate change and adaptation in transport sector. Some of the listed projects are: road project in Nargis affected area in Myanmar; double tracking of railways in Indonesia; Qinghai-Tibet Railway line in China; eco-friendly logistics and green port master plan in the Republic of Korea; study on adaptation and application on clean development mechanism into transport sector projects in Thailand; and formation of climate change working group and national inventory report for transport sector in Turkey. Most of the respondents (79%) indicated the existence of central level coordination body responsible for environment and 63% indicated the existence of a coordinating unit/division in the line ministries and road/ highway department. While many respondents also indicated non existence of such units/divisions in railway organization, air transport and water transport thus demonstrating a need to establish such unit. While asked to rate the coordination majority of respondents (63%) rated as good or satisfactory level of coordination among various transport sector organizations, while nine respondents (27%) rated coordination as being poor or very poor. There is also a mixed response in terms of implementation of environmental polices, rules and guidelines, majority (54%) rating as satisfactory and good and eleven respondents (46) rating as poor or very poor. This clearly indicates the need for greater collaboration and effective implementation of policies.

All but one respondent (96%) indicated the need for an awareness programme on climate change. Eleven respondents indicated the need for awareness programme targeting high level policy makers, followed by programme targeting project officers and managers (6) and then high level government officials (5), and programme targeting general public (5). Therefore, the survey demonstrates the need of environmental and climate change awareness programme targeting all stakeholders in Asia.

### 4.4.5 Additional Feedback from the Survey

The survey also included questions seeking respondents suggestions for making transport infrastructure safe and what should be done to safeguard transport infrastructure from impacts of climate change. Some of the notable suggestions provided are: undertake detail study of impacts change on transport; integrate impacts of climate change in the present planning and design; need to change traditional way of dealing with climate events; update and revise construction and drainage, standards, guidelines and code of practices; strengthen EIA process to take account of climate change; plan awareness and education campaigns through trainings, workshops and seminar to increase understandings and awareness of politicians, policy makers and general public; utilize available technology to predict weather more accurately and provide timely information to the designer and planners; develop a network of meteorological centers; undertake a detailed survey of impacts of climate change; increase planning and design time horizon; ensure adequate periodic supervision of transport infrastructure; provide adequate maintenance funds; avoid cost cutting measures however evaluate technical and economic viability as well as life cycle costing of the proposed design; incorporate climate proofing while developing national plans; undertake reasonable risk assessment; increase investment in the road transport sector; plan adaptation measures on the capability and affordability of the country; and ensure good cooperation among all stakeholders and people in the society.

### 4.5 Adaptation Measures to Develop Resilient Transport

### 4.5.1 Adaptation Strategy

The survey disclosed that despite global efforts- Asia still lags in policy formulation and implementation of adaptation measures for climate change impacts. The scale of impacts will be different and are localized and much depends on the existing topography. Bangladesh, Vietnam, Pacific Island countries and flat plains would mostly be affected. Tibetan plateau and Central Asia would have different types of impact due to dry weather. All transport sector road, railways, airports, and marine and river transport will be affected in every aspect of development and operation from planning, design, constriction, operation and maintenance. Therefore, the adaptation strategy should cover all aspects of transport.

The following table 3 shows the adaptation options/strategy and policy measures in the transport sector.

**Table 3: Adaptation options and policy framework**

| Options/strategy | Policy frameworks | Constrains | Opportunities |
|---|---|---|---|
| Realignment/relocation; design standards and planning for roads, rail and other infrastructure to cope with warming and drainage | Integrating climate change consideration into national transport policy; investment in R&D for special situations, e.g. permafrost areas | Financial and technological barriers; availability of less vulnerable routes | Improved technologies and integration with key sectors 9e.g. energy) |

*Source: Adapted from Climate Change 2007: Synthesis Report*

One of the adaptation strategies is to make infrastructure more robust against economic cost of failure. A climate risk screening and management approach called ORCHID (Opportunities

and Risks of Climate Change and Disasters) methodology has been developed by the Institute of Development Studies (Tanner et al., 2007). The methodology helps development organizations and their partners to integrate risk reduction and adaptation processes into their programmes. They have implemented pilot projects in India and Bangladesh. In one transport project in Bangladesh the study have evaluated options of raising road embankment level to 0.5 to 1.0 m to protect from flood and found that it is economically viable option. This example clearly demonstrates the importance of design consideration while planning and benefit over life span while considering economic cost of failure.

Adaptation can add costs, but not adapting can be more costly. Agrawala et al. (2008) have studied costs of adaptation measures and mention that only limed cases are available in the transportation sector. They conclude that there is a need to conduct a careful cost-benefit analysis of adaptation measures. The design of adaptation progamme must be based on comparison of cost avoided with costs of adaptation. Therefore proper adaptation measure needs to be planned in well advances. Appropriate consideration of potential weather evens in planning, designing and maintenance of transportation system would increase their serviceability and life. The following section provides key adaptation measures during planning, design, construction and maintenance phases.

### 4.4.2 Coordinated Planning

As the impacts of climate change are widespread proper coordination and planning of adaptation measures are essential to ensure synergy. The survey showed that central level coordinating body dealing with climate change existed in many Asian countries. The adaption measures are site specific and localized collaboration is essential with central, regional and local agencies and to enhance sustainability of transportation system. Proper planning of adaptation measures depends on the accuracy of impact assessment. While planning new transport infrastructure it is therefore essential to consider the climate change. Studies have advocated integrated transport and land use planning avoiding coastal and areas for infrastructure development.

Further, as transportation system is vital for evacuation planning and emergency response, more frequent monitoring of infrastructure condition during these events would be required. The transport providers should also be integrated to the emergency response team and should receive advance weather warnings so as predict potential failure and plan appropriate response to safeguard the infrastructure, warn public to stay away from the road as well as to facilitate evacuation and emergency response.

### 4.4.3 Designing Adaptation Measures

Incorporating new standards is relatively easy while planning new infrastructure. The only issue would be to look at cost implication. The literatures also suggest that- if infrastructure is nearing rehabilitation they could be planned with higher standards. There would be very little additional investment to incorporate design to adapt to climate changes. In many cases it is economically feasible to design infrastructure components such as bridges, drainage, slope protection walls- considering impacts of climate change and related design parameters such as design high flood level, waterway, drainage area, subsurface drains, need due consideration. While designing costal road consideration should be given to predicted rise in sea level and providing high and strengthened side barriers. Depending on the estimation of rise in water level it may be feasible to realign an existing coastal road to a higher location.

The survey clearly indicated that the rain, floods and related damages are major cause of concerns in Asia. It also confirmed the importance of need to review design standards for critical components of transport infrastructure such as drainages, bridges, culverts, pavements, coastal roads and railways, slopes which were highly ranked. Many literatures have indicated that it may be beneficial to review the design life of various components of the transport infrastructure. Studies have suggested that as current design standards may not be sufficient to accommodate climate change and it stresses the need to develop new design standards to address future climate conditions and projects in highly vulnerable locations should be built with higher standards (Wooller, 2003; Humphrey, 2008). Short (2009) has outlined that there is evidence already that our infrastructure design standards need to be re-examined to better deal with the consequence of climate change.

Surprisingly, despite scientific evidence of benefits of 'superpave' binder it took 25 years to adopt and introduce the new standards in US (Meyer, 2008). In Asia the decision making process may not take that long – but all proposals must be backed by technical and economic feasibility with due consideration of climate impacts. It could be quite simple and easy to raise clearance of the bridge the above high flood level, to increase the size of a drain or capacity of culvert. Therefore, while planning and designing infrastructure which needs considerable investment- it would always pay to consider climate change in addition to fulfilling the requirement to follow existing standards and guidelines. It could be the proper time in Asia as well to review the estimation of floods, design storm parameters, discharge estimations, design life, clearance of bridges, and other key design parameters.

### 4.4.4 Construction, Maintenance and Operation

The construction materials also play important role in adaptation and mitigating likely impacts. Construction use of different grade of bitumen to suite the climate, comparison between rigid (cement concrete) and flexible pavements, use of stiffer bituminous binding material for road and airport runway pavement with low penetration value would overcome affect of rise in temperature. In road construction to facilitate drainage the porosity of aggregates and pavement materials are also very important.

Due to excessive heat, extreme rainfall and snow the frequency of maintenance activities have to be increased. Regularly clearing the drains, vegetation, more frequent inspection of steel bridges for corrosion, road signs will be required. Installment of additional warning information boards and signs, strengthening of coastal protection are needed.

## 4.5 Advocacy of Climate Change Impact and Adaptation

Despite numerous global research and efforts in tackling the issues of climate change, the level of understanding and coordination has yet to be matched with the requirement. It was pointed out that there is still scope of improving awareness and coordination even in United States and United Kingdom at least in the transportation sector (Wooller, 2003; Humphrey, 2008). The survey clearly demonstrated the need to raise awareness of policy makers, transport officials and general public. In majority of developing Asian countries greater awareness among all stakeholders is essential. The awareness initiative should target all professional, policy makers, technical and politicians and private sector consultants and contractors working in the transport sector. Asia needs to learn from experience of the other region- Europe and America as they are leading in terms of policy debate and analysis. Japan

and Europe has demonstrated successfully the carbon emission reduction. More studies should be commissioned and implemented in Asia.

Multilateral institutions have just started to begun to integrate adaptation concern in their programmes but it has not yet penetrated the policy makers. One of the important aspects of adaptation is to streamlining responses to climate change policy in development planning (Burton et al., 2004; The Multilateral Development Banks, 2007). Most of these approaches are general- not transport sector specific. Of the six case studies reviewed by the OECD not a single case was related to transport (Agrawala, 2005). Mills et al. (2002) also acknowledged the gap in understanding climate change impacts, adaptation and its costs. Bouwer et al. (2006) have looked at the financing options and suggest that climate adaption should be seen as general risk management issues and linking "climate proofing" of development projects to management practice in national sectors and multilateral donors as a viable option. Therefore, awareness programme targeting the policy makers in developing countries on impact of climate change and adaptation as well as targeting developed countries and multilateral institution on the needs of developing countries is essential.

### 4.6 Funding Adaptation Programme

Funding for climate change adaption programme is available. Developing countries can approach for funding support available from the Global Environmental Facility (GEF) programme. Two types of funds are available from GEF- least developed countries' fund and special climate change fund. Other funding opportunities are also available under the framework of UNFCC. But there are very few adaptation projects on transport within Clean Development Mechanism (CDM) under the mechanism of the Kyoto Protocol and under the Global Environment Facility is relatively small in comparison with other sector (Wright et al., 2005). The CDM may not be well suited to stimulate investment in transport sector in developing nations. Project proponents and countries may approach GEF, UNFCC, UNDP, ADB, World Bank or other donors to enquire about the technical and financial resources for planning and implementation of climate change adaptation projects and programmes. Asia needs support- technical to know how dissemination as well as financial.

### 4.7 Guidelines for Mainstreaming Adaptation in Transport Projects

The environmental impact assessment process is well recognized and followed in Asia while designing and implementing a project. The current practice is to assess the potential environmental impacts of projects and mitigate and monitor the identified impacts during construction and operation. Lemmen et al. (2004) felt the need of new standards, guidelines and policies to enhance understandings of climate change.

The survey revealed that many countries have environmental guidelines and indicated the need to revise and extend these standards to incorporate the issues of climate change and adaptation. This impact assessment and adaption process should also take into account the risks; uncertainty and vulnerability of climate change and incorporate the effect of predicted climate events into project design. Impacts quantification involves expressing the expected magnitude of each impact in terms of appropriate quantitative physical units. Although there are some initiatives by donors to introduce guidelines on climate change and adaptation- they are general and not sector specific. It is felt that there is a need to have comprehensive adaptation guidelines for the transport sector. As transport infrastructure needs very high investment – a thorough analysis following a prescribed/suggested process would ensure 'fit

for purpose' for intended life time. It may take some time to develop guidelines for the transport sector on Assessment of climate change and adaptation. Therefore, it may be feasible to extend existing IEE/EIA guidelines (United Nations, 2002; ADB, 2003) to include climate change considerations.

### 4.8 Institutional setup

The climate change will impact every sector. There should be coordination between various agencies from central to the local level. To advocate, initiate and implement climate change and adaption policy strong institution is essential. The institution need to properly plan, coordinate and implement adaptation programmes. Though there have been many campaigns in Asia on the issues of climate change and adaptation the region still lacks qualified professionals particularly in developing countries. UK's Office of Climate Change is a good example of climate change policy coordination. Srinivasan (2006) argues adaptation must be considered in an intergraded manner locally, nationally and internationally by mainstreaming adaptation concerns in development planning and policy. A regional forum to elaborate frameworks, capacity building and mechanism to transfer additional funding from developed to developing countries. Therefore, the transport sector needs to train professional in assessment of climate change impacts and implementation of adaptation measures. Many developing countries in Asia need technical and financial support to set up institution and for capacity building training to implement adaptation programmes.

## 5. CONCLUSIONS

The study looked at the impacts of climate change on transport, identified vulnerable infrastructure components and related design parameters. The study highlighted the importance of planning and designing transport infrastructure considering the likely impacts of climate change. There is still much to be done to initiate policy guidelines for adaptation and its implementation. The process of reviewing designing standards and practices could be relatively easier in Asia. Introduction of separate guidelines for designing infrastructures considering climate impacts may take some time. It may be advisable that the existing environmental impact assessment guidelines (UN, 2002; ADB, 2003) be extended to cover climate change issues. Policy advocacy, awareness and institution are other factors essential effective implementation of climate change adaptation programmes. Climate change being relatively new area and the impacts of climate change being widespread effective institutional arrangements is essential to ensure proper coordination among various stakeholders. Availability of limited literatures on transport and climate change in Asia indicate further research needs in area of country specific assessment of impacts and adaptation, costing adaptation measures and review of design and guidelines for developing resilient infrastructure.

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