Adaptation policy framework for climate change impacts on transportation sector in developing countries

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Abstract

The global response to climate change threat has been through mitigation by reducing the GHG emissions, however, some of the climate change effects are inevitable and unavoidable. Adaptation is seen as a necessary means of addressing these inevitable climate change effects, some of which are projected to bring more frequent and severe precipitation resulting in floods. This threat of floods reinforced by rapid urbanization, resulting in urban flooding has become a looming threat to road transportation which disproportionally affects developing countries. There is an urgent need to adapt transport infrastructure to the anticipated climate change effects in order to minimize human as well as economic losses. In this paper, a consolidated review of literature on road transport-related climate change adaptation measures adopted across different countries around the world has been done, followed by the identification of barriers and adaptation challenges in developing countries such as India. Further, a novel methodological approach has been proposed for shaping adaptation policies in developing countries. It is aimed to enhance the resilience of transportation system specifically against urban flooding induced by climate change, reduce its impacts and strengthen the adaptive capacity of the system.

Keywords: Climate change; transportation; developing countries; adaptation; policy; urban flooding

1. Introduction

Global climate change has been unequivocally accepted in the scientific community as the greatest challenge facing humanity (Cook, John, et al., 2016**)**, although it is still a heavily debated issue politically. The average temperature of earth is increasing due to anthropogenic factors leading to deviant variations of weather events in terms of frequency and severity (Finn, 2013), making climate change one of the most important global issue, both at national & international level. It is expected that climate change disasters and extreme weather events will increase in future leading to significant escalation of risk and damage to infrastructure, resources, networks and human lives. (Finn, 2013) On these grounds, the global response to climate change threat has been through mitigation with an aim of reducing the GHG emissions as several studies (Hensher, 2008; D Satterthwaite, 2008; IPCC, 2014) indicate the pivotal role of industrial and transportation exhaust in changing the global climate scenario needs to be reduced. Many countries have formulated policies to counter the climate change by reducing greenhouse gas emissions. The Unites Nations Framework Convention on Climate Change (UNFCCC), Kyoto protocol and Paris agreement are the examples that climate change is considered as a serious threat globally (UNFCCC, 2016). In spite of global efforts to mitigate the associated anthropogenic factors, some of the climate change effects cannot be contained thereby making them inevitable. Consequently, there has been a shift towards evaluating the impacts of climate change on various vital sectors and focus more on adaptation.

1.1 Adaptation and Mitigation Measures

Adaptation measures in the present context refer to various measures and initiative taken, both at public and policy level vis-à-vis transportation sector, and put in place in advance to respond to impending climate change effects. As per IPCC (2014), the vulnerability to climate change are determined by three factors such as exposure to hazards, sensitivity to those hazards and capacity to adapt to those hazards. Adaptive measures are seen as a tool

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to reduce vulnerability of a system to the potential negative impacts of climate change. Adaptation measures are taken to reduce the vulnerabilities of transport sector from climate change impacts like urban floods in this paper. Adaptation measures are considered to be a local issue spatially and benefits are seen at local scale. These strengthen the inherent capacity of a system to undertake defensive as well as protective actions that help in avoiding loss and facilitate recovery from any impact, thereby, increasing the resilience of the entire system. In order to achieve effective adaptation measures in place, policy intervention is required at multiple levels across all vital sectors.

On the other hand, mitigation measures, in the present context, refer to the steps or initiatives taken to eliminate, reduce or control the adverse environmental impact of transportation sector. Mainly, with reference to transportation, mitigation measures are taken to reduce the greenhouse gas emissions which are main contributors for climate change. Transportation sector is one the major contributors of GHG's after electricity, agriculture and industry (IPCC, 2014). Various mitigation measures intended to reduce the impact of the transportation sector on climate change are restrictions on GHG emissions, promotion of electric vehicles, use of alternate fuels, etc. (Carolina, 2013) Spatially, mitigation measures are considered to be an international issue and provides global benefits. Mitigation and adaptation measures have notable differences but are interrelated to each other. Even with strong mitigation measures climate would still continue to change and adaptation to these changes are necessary. On, the other hand, adaptation measures will not eliminate all the negative impacts which is why strong mitigation measures are required to minimize the changes in climate system.

1.2 Transportation Sector: Relevance

Transportation is a critical sector that contributes to the smooth functioning of societies and fosters economic growth of a nation. It is under a constant threat of climate change and needs to cope up with climate change. Owing to the key role of transportation system in ensuring economic stability and growth of a nation, it is important to anticipate the impacts of climate change on the transportation system and prepare for it in time. Furthermore, the negative effects of climate change on transportation sector disproportionally affect the developing countries (Levy, 2015). Consequently, these need to adapt to unavoidable risks posed by climate change in a planned, structured and coherent methodological approach focusing on such arrays of measures and policies that can effectively and efficiently deal with climate change impacts. This requires the knowledge of challenges in assessing and implementing such policies as well as options or alternatives available to best suit the study area. According to IPCC (2007) report, climate change is projected to bring more frequent and severe precipitation resulting in floods and due to rapid urbanization, urban flooding is becoming a looming threat to road transportation. The occurrence of floods in India over past few years has made it more evident owing to colossal losses in terms of lives and property. Some sections of the huge cities like Mumbai, Chennai, and Bengaluru were flooded due to heavy rains paralyzing these cities transportation systems. With the growing number of vehicles and exponential increase in the urban areas concretizing the land creating more runoff, the cities become more vulnerable in the future years unless proper measures are taken.

This paper addresses the need to develop an adaptation strategy focusing on the urban transportation sector vulnerable to flooding as well as identifies the implementation barriers in developing countries such as India. Also, a review has been done on the adaptation strategies adopted across the globe to use them as a tool in formulating future strategies in the developing world. Further, a novel methodological framework has been developed to assess the vulnerability of the transportation system to urban flooding which involves modelling, identification of vulnerable road links and zones, and formulation of policies to reduce the impact of urban flooding by making the transportation system more resilient.

2. Climate Change Scenario in India

India is one of the world's most vulnerable countries to climate change (Eckstein et. al., 2017; IPCC, 2007; NAPCC, 2008). Consequently, India is faced with the challenge of maintaining its economic growth while combating the threat of climate change as the economy is closely tied to natural resources-based and climate-sensitive sectors such as agriculture, etc (INCCA, 2010). Further, India is vulnerable to extreme weather events, sea level rise, and potential climate change-induced shifts in precipitation patterns which may lead to increasing threats to human health, water availability and food security (Leiserowitz & Thaker, 2012). There have been significant increases in the frequency and intensity of extreme monsoon rain events over the past 50 years and the observed trend suggests an enhanced risk associated with extreme rainfall over India in the coming decades (Venugopal et al. 2006). The socio-economic impacts of extreme weather events have been increasing due to large growth of population and its migration to urban areas has led to greater vulnerability (De, U. S., Dube & Rao

2005). Some major weather events caused by extreme precipitation over the past two decades as tabulated in Table 01 have shown extreme vulnerability of India to the impacts of climate change. Every year, India faces extreme weather events, mostly in the form of floods, etc which take lives, destroys homes and agricultural yields, and result in huge revenue losses. In response to such an imminent catastrophes triggered by the climate change, the government of India established a Council for Climate Change in 2007 to coordinate the National Action Plan, in order to achieve a sustainable development path that simultaneously advances economic and environmental objective and reducing their vulnerability to the impacts of climate change.

Table 1: Major extreme weather events in India in last decade

Month, Year	**Event**	**Notable Incident**	**Deaths**	**Loss & Damage**	**Economic losses (in INR)**
Dec, 2015	South Indian Flood	246 mm rainfall between Nov 15-16; 490 mm 24 hrs rainfall on Dec. 01	500	1.8 million people displaced; Chennai severely hit with maximum damage	100,000 crores
September, 2014	Kashmir floods	Rainfall on Sept. 6 alone was 106mm	300	2000 homes devastated; Srinagar city submerged in water; 2600 villages affected; Huge loss to paddy & fruit crops	100,000 crores
June, 2013	Uttarakhand Flash Floods	Highest rainfall in last 80 years of about 385.1 mm	5700	1.6 million people affected; 4120 missing; 19590 business establishments devastated	998 crores
August, 2009	Ladakh Floods	250 mm of a single storm rain	249	71 towns and villages affected; 76 people dead	200 crores
July, 2005	Maharashtra floods	994 mm rainfall in 24 hours	5000	20 million affected; 437 primary health centers destroyed; 97 school buildings collapsed	4982crores

Source: (Khaladka et al. 2009; Gulzar S., 2014; South Indian Floods, 2015; India-Pakistan Floods, 2014; Downtoearth, 2014)

The National Action Plan for Climate Change (2008) outlines a mitigation plan which primarily focuses on protecting the poor and vulnerable sections of society through inclusive development strategies, enhanced ecological sustainability, improving energy efficiency and modification of industrial processes via research development, sharing and transfer of technology at an international level. To achieve this, eight National Missions have been launched which focus on promoting understanding of climate change, adaptation and mitigation, energy efficiency and natural resource conservation (PCGCC, 2008). However, GHG emissions continue to rise, hence focusing on mitigation is not sufficient and adaptation strategies must be worked out to address the critical issue of impact of climate change on transportation sector in an Indian context.

3. Review of adaptation strategies for transportation sector

Transportation is a complex system involving numerous actors and resources of different nature of varying uncertainties as such the approach to transport adaptation varies from country to country focusing on different key players and parameters found suitable based on implementation and future developments. The adaptation measures are aimed at reducing the vulnerabilities of road transportation system against the climate change impacts. Improvement of infrastructure, design of facilities, operations managements as well as building consistent interactions and knowledge dissemination systems with key stakeholders, researchers and users are few recommendations from the studies which are discussed later in this paper. Several policies have been suggested as undertaken in different countries to enable better resilience of transportation system to climate change impacts.

De Bruin et al. (2009) advocate for strong liaising with administrative authorities and strengthening consultations with key stakeholders to adjust and materialize adaptation strategies. German Agency for Technical Cooperation's (GTZ) Sustainable Transport Sourcebook (2009) puts forward the need to formulate urgency prioritization plans to ensure access to hospitals and other emergency services under adverse weather conditions. Other

recommendations include developing improved design methodologies of intersection design for acceptable drainage performance under adverse climatic conditions, creation of utility based networks of urban, regional and national stakeholders such as transport operators, authorities, civil administration and users to control traffic flow and coordinate directional distribution of vehicular congestion against minimal loss of travel time, innovative pavement materials resistant to water spikes as well as increase roadside vegetation and structural strength enhancement of road layers to prevent rutting and wash-off in adverse climatic conditions. McCarthy et al. (2001) highlights the need of enhancement of flood resilience of road infrastructure. They also emphasize on the need to design facilities with quick restoration capability as well as development of sustainable business models with the provision of emergency information systems to ensure swift action in terms of reducing pedestrian, passenger and freight loads on to the road network. Walker et al. (2010) chart out state of practices for ensuring alternate safe routes for emergency traffic operations. Parry et al. (2007) clearly emphasize on incorporation of climate change projections into the design of roads and drainage to cope with future flooding as well as calibration and implementation of international standards for climate change induced weather impacts. Stenek et al. (2011) and Kaufman et al. (2012) argue for the characterization of routes into primary, secondary, etc., to ensure road clearance in case of some catastrophic hazards based on importance, priority and precedence. It is also recommended to take measures towards strengthening the city water drainage system by effectively increasing the capacity of side drains and removing network bottlenecks to avoid any kind of blockages and subsequent inundation (Aparicio et al. 2013). National Transportation Policy Project (2009) highlights the process of development of emergency communication plans to regulate the traffic flow through unaffected road stretches in order to ensure minimum level of efficiency in the road transport network under adverse climatic conditions. TRB Special report (2008) and Schwartz (2010) explore alternatives for design of new heat-resistant as well as water-resistant bituminous mixes based on applicability. Kaufman et al. (2012), Parry et al. (2007) and McCarthy et al. (2001) recommended to develop plans to introduce flexible, staggered and adaptive time schedules and service intensities under adverse weather events triggered by climate change. Traffic assignment and distribution amongst transport modes and networks under emergency situation through adoption of integration of weather, traffic

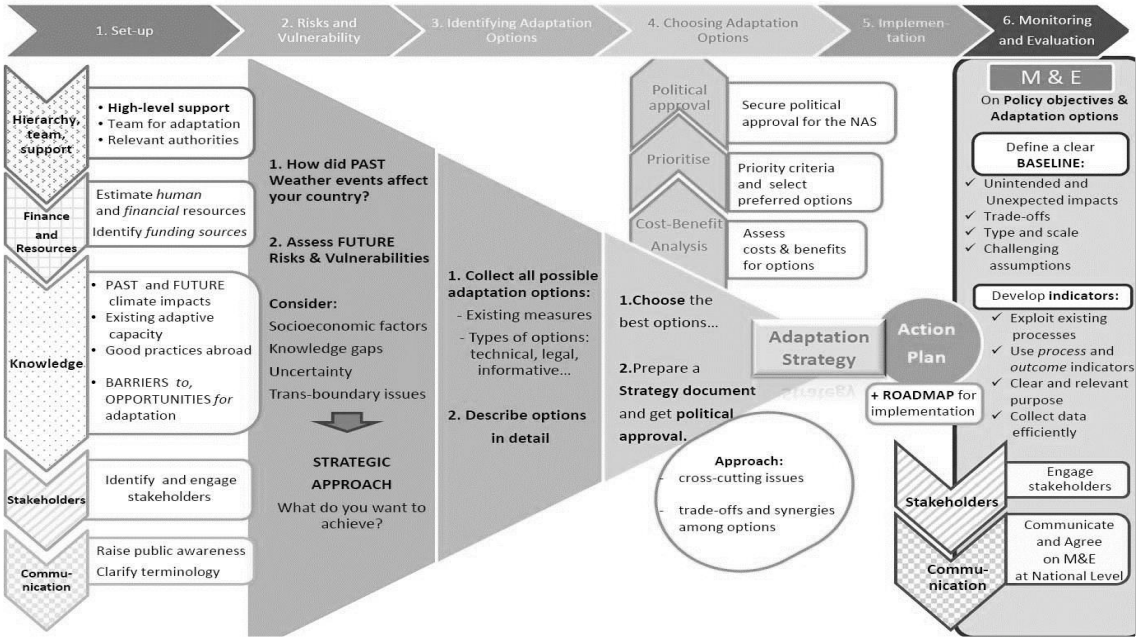

Figure 1: An EU strategy on adaptation to climate change (CSWD, 2013)

control devices as well as communication modes to disperse the alerts.

Adaptation strategies adopted across different countries are inherently diverse owing to the complexity involved in terms of varying multi-disciplinary attributes of a transportation system. In this work, attempts have been made to summarize the adaptation strategies undertaken in different parts of the world and discuss them region-wise based on the extent of work done in each region. This discussion is kept as precise as possible to ensure enlisting of maximum initiatives undertaken across the globe.

3.1. Europe

The European Commission Guidelines for Adaptation Strategies (2013) describe the process of development of Adaptation strategies starting initially by raising awareness among the stakeholders followed by exploration of sensitivities, risks and vulnerabilities leading to the identification and selection of adaptation alternatives which need to be monitored for effective implementation and analysis of results as shown in Figure 01. Although sufficient general information has been made available on the national information platform Climate-ADAPT[1], specific transport related measures are scarce indicating that the adaptation of transport sector to climate change is still in its early stage. Table 02 lists the various measures adopted across Europe to increase the resilience of transportation system to climate change.

Table 2: Initiative and projects undertaken by European countries for climate change adaptation of transportation sector

Initiation year	Country	Initiatives & Projects undertaken[2]	Progress/Outcome	Implementation barrier vis-à-vis developing countries
2000	Britain	Assessment of Climate change impacts on railways: TRaCCA Project Revision and application of drainage standards	British government directly manages the adaptation platform, however, Environmental Agency disseminates information. Continuous support for adaptation action across United Kingdom, including provision for guidance	Although there are autonomous environmental agencies in developing countries but there is lack of proper coordination with authorities to disseminate information and aid in adaptation policy-making
2005	Scotland	Study of sensitivities of road network to climate change (2005), follow-up reports (2008), continuous review of adaptation strategies (2011): Scottish road network climate change study	Carried out numerous studies to assess the impact of climate change Development of adaptation methodologies based on scientific research and data	Less agencies available to conduct filed assessments Lack of funding to support scientific research and collection of data
2006	France	Establishment of National Observatory on the effects of Climate Change (ONERC) Creation of national knowledge sharing platform: WIKLIMAT project Passenger and freight transport demand forecasting under climate change scenarios Development of methodologies for assessing the vulnerability of transport infrastructure	Revised in 2009 and 2013; Creation of knowledge database platform to enable effective decision making and selection of correct adaptation strategies. Connected various sections of society and streamlined all efforts towards a common goal. Category-wise sorting of data under 'Challenges', 'Environment', 'territories', 'knowledge/actors', etc sections to help in identifying main actors involved in adaptation.	Development of a common platform requires effective coordination between government, local authorities, scientific bodies and public. Setup of an independent body which maintains the platform and creates additional tools, indicators, reports and documents to aid policymakers to take on climate change challenges and build indigenous adaptation strategies.
2008	Denmark	Launch of online portal for Danish Adaptation planning Climate change adaptation plan as well as contingency plan for climate change impacts such a temperature increase, changes in precipitation, etc.	Main target groups are municipalities, however, businesses and citizens are also covered. Started work at grass root level and involved local bodies from the onset Attempt to integrate adaptation into decision-making at all levels	Local bodies are not empowered in developing countries. Further, there is lack of proper management and communication at different levels

[1] Climate-ADAPT web platform provides access to all reports, studies, etc, both ongoing and completed, available at : http://climate-adapt.eea.europa.eu

[2] These projects reflect the multi-disciplinary nature of adaptation for climate change impacts in transportation sector. Picketts et al. (2016) argue that climate change adaptation strategies include many socio-economic parameters as such diverse expertise is required to yield beneficial outcomes.

2008	Germany	Set-up an adaptation platform, hosted by the Federal Environment Agency of Germany (UBA) Scientific evidence on future climate impacts on inland waterways and coastal routes: KLIWAS project	Employed online survey tools to assess 172 stakeholders from various public institutions, business forums, etc Transformed complex technical information into layer-wise understandable knowledge dissemination tools Increase in subscription base	Continuous monitoring is required to ensure coordination and dissemination of information. Sustained efforts required to keep track of all activities are lacking in developing countries
2009	Austria	Launch of Austrian Adaptation Platform, revised and updated in 2013 Systematic data collection of disruption events for rail transport under extreme weather: KLIWA project Development of early warning system against climate change induced natural hazards: DESME & RISKCAST projects	Improved the communication and interactivity of users. Engagement of all stakeholders to create and effectively use the resources Several projects undertaken and creation of new methodologies, tools, handbooks, guidance, for developing adaptation strategies Improved performance of rail transport Extensive data collection and management to reduce the climate change impacts	Less uptake of online platforms across vital sectors of public institutions, businesses, transport players and public. E-governance if still in its infant stages. Lack of knowledge-base, infrastructure and tools for data collection, consultants to cater to local needs and development of indigenous methodologies to tackle climate change impacts.
2009	Norway	Set-up Norwegian Directorate for Civil Protection (DSB), followed by takeover by Norwegian Environment Agency in 2014 Development of an online tool for risk assessment, preparedness as well as monitoring and forecasting floods, landslides, etc: xGeo tool	Provided adaptation support for local-level action to facilitate interaction with an extended audience Considered the work areas of local planners, their challenges and vocabulary, and tagged it specific climate change impacts, made assessable via search criteria in a database	Easy uptake of information by key target groups involves creating tools and resources which are easily understandable and accessible. The heterogeneity, low literacy and lack of professional setup hinder the creation of such tools in developing countries.
2009	Sweden	Set-up Swedish Portal for Climate Change Adaptation (SPCCA) hosted by National Knowledge Centre for Climate Change Adaptation (NKCCCA) Creation of a homogeneous method for the inventory and analysis of climate change induced effects on road stretches. Identification of flood-sensitive sections in road network	Creation of national focal point for adaptation, both short-term and long-term Development of methods to assess roads against climate change Flood Modelling and development of flood maps, both based on land use and transport networks	Centralization of information and coordination amongst various actors is difficult Lack of assessment tools and techniques to study impacts
2010	Spain	Creation of national knowledge sharing platform: AdapteCCa Project Introduction of predictive weather tools adapted to transportation system enabling development of strategies for pre- and post-hazard situations.	Bidirectional flux of information amongst key administrations and stakeholders both private and public Strong links between national adaptation platform and regional level platforms at different scales More insights into transportation adaptation and incorporation of same in policy making	Limited resources and lack of strong network between national and regional bodies No standard protocols in practice Inactivity of local bodies to initiate or follow-up with adaptation initiatives

2013	Poland	Creation of national knowledge sharing platform: KLIMADA Project Development and implementation of a strategic adaptation plan for the sectors and areas vulnerable to climate change	Presentation of information in user-friendly mode by using infographics, tables and pictures Funding scientific projects to investigate the climate change impacts of various sectors including transportation	Lack of tools and proper methodologies to disseminate information to all stakeholders including public Insufficient funding and grants to foster scientific research in vulnerable areas of climate change

(Source: Atten et al. 2012; Barfod et al. 2013; BMVI, 2013; CEDEX, 2013; Devoli et al., 2013; Hansson et al. 2010; Jacobs Engineering U.K. Ltd, 2011; Klimatilpasning, 2014; Lindeberg et al. 2014; Lofling 2005; Moser et al. 2012; Network Rail, 2010; Capela Lourenco et al. 2014; Rachoy 2012; RENFE, 2012; RSSB, 2014; Scheikl et al. 2012; Scottish Executive, 2005; Trafikverket, 2014; Transport Scotland, 2008; xGeo, 2014)

3.2. United States of America

In United States of America, the Department of Transportation (DOT) has come up with Climate Change Adaptation Plans (2012, 2014) and several other studies such as (NYCPCC, 2010; Climate 101, Michael D. Meyer, 2010; Synthesis Report, 2015) which study the impact of climate change on US transportation and to confront climate change induced impacts, US DOT has committed itself for three priority actions described in Figure 02, against identified vulnerabilities as the risk of transport systems and infrastructure increases with the

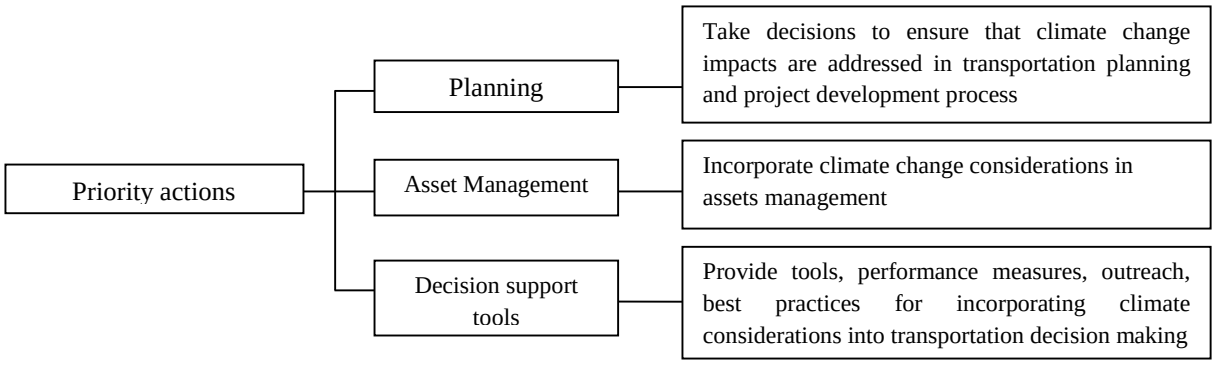

Figure 2: Priority actions for all US DOT modal administration (CCAP, 2014)

extent of vulnerability (CCAP, 2014). The capacity building measures are directed to ensure three primary objectives such as building existing and new infrastructure resilience as well as system resilience giving due importance to specific pivotal elements based on their critical roles.

Several adaptation strategies have also been proposed such as climate-conscious land-use planning, planning for new infrastructure, strengthening of existing infrastructure, relocation or abandonment of at-risk infrastructure, adding redundancy to reduce impacts to the system and provisions for rapid recovery. Further, state level adaptation planning and state climate action plans have been prepared and updated regularly to account for addressing the climate change impacts on various sectors. (BPC, 2012; CCSP, 2008; TRB Special Report 290, 2008; PEW, 2008; Guidebook, 2010).

3.3. Australia, New Zealand and Canada

Australian government has come up with National Climate Resilience and Adaptation Strategy (2015) which focuses on distribution of responsibility at all administrative levels, businesses and users to factor climate risks into decision and policy making to develop an evidence-based, risk management approach by reducing vulnerabilities and making collaborative adaptation choices to suit different circumstances distributed spatially and temporally[3] and ensuring that all policies are revisited and revised over time. Some of the adaptation actions include changing the use of land, upgrading the design of infrastructure, adjusting activities and lifestyle, emergency and business continuity planning and increasing community understanding of climate risks to enable

[3] Adaptation policies are region as well as time specific which vary from place to place for current and future circumstances.

collaborative and coordinated response in case of adverse weather events. (Michael A P Taylor, Michelle Philp, 2011; WAG, 2012; Maunsell, 2009)
New Zealand's National Infrastructure Plans (2010, 2011, 2015) acknowledge the need to consider climate change adaptation as part of planning and development projects following which it launched State Highway Resilience Programme (2014) focusing on better event preparedness., implementation of international standards, creation of alternatives to key routes., reduced risk, framework of assessing resilience risks and continuously updating the policy framework (BSR, 2012; Richard et al. 2010). In New Zealand's framework for adapting to climate change (2014), increasing the capacity of urban storm water drainage systems to cope up with extreme flooding events as well as distributing responsibilities between central government and local councils has been considered as a vital component of adaptation policy framework.
Transport Canada launched Northern Transportation Adaptation Initiative (2008) which is designed to understand climate impacts on transportation to facilitate integrated transportation planning and adaption strategies. It intends to design and develop tools, innovative technologies and best practices to make northern transportation infrastructure and operations adaptable to climate change by quantifying the impact of climate change. The Evaluation Report on NTAI (2015) recommends streamlining of adaptation measures through coordination and partnering with all the active organizations, development of knowledge transfer plan through a network of expertise and prioritize R&D initiatives for adaptation pilot-testing and implementation of adaptation techniques to validate the theoretical assertions of better performance of transportations systems under adaptive measures to climate change.

3.4. South Africa

The Department of Public Works' Strategic Plan 2012–2016 only mentions climate change once, in relation to its Green Buildings Framework. The Department of Transport also has a climate change mitigation strategy in place or in development. Policymakers' attention thus far has been devoted to reducing the transport sector's contribution to climate change, i.e. to mitigation, rather than adaptation, and discussions have not dealt with the impacts that the transport sector will face from climate change or how it can make itself more resilient and cope with such impacts (NAS, 2016).

Transnet is developing a climate change adaptation and response strategy, and is actively implementing it. This strategy is, in fact, considered a model by other publicly owned enterprises in South Africa (such as Eskom). It can be a useful reference for the Department of Transport as it develops a sector-wide strategy.

The key response options for the transport and public infrastructure sector are identified as follows (NAS, 2016):

1. Conduct a transport sector climate change risk and vulnerability assessment
2. Develop a transport sector climate change adaptation and resilience strategy, taking into account impacts on assets, systems, operations and resources.
3. Develop climate change risk and vulnerability assessments for priority public infrastructure assets (based on importance for national socio-economic development as well as asset value) – for (non-transport) state-owned infrastructure this should be done by the Department of Public Works.
4. Invest up front in high quality public infrastructure to ensure long term climate resilience.
5. Integrate climate change resilience into local government planning, given that transportation planning and development falls within the local government mandate, to ensure transport systems are climate-robust and help actively strengthen community climate change adaptation.
6. Partner with the insurance industry to identify priority needs and opportunities for climate resilience in the transport and critical infrastructure areas, linked with loss and damage debates.

3.5. Brazil

The new Master Plan (Plano Diretor Estratégico – PDE concluded in 2014), in particular, may be interpreted as a sign that São Paulo is trying to change its culture and urban sociability in the coming years. Sao Paulo's new master plan (Plano Diretor Estratégico – PDE concluded in 2014) is an indication that they are trying to change their culture and sociability in coming years (Di Giulio & Vasconcellos, 2014). An analysis of the PDE finds that the plan addresses many issues indirectly connected to climate change, without explicitly describing the synergies. Sau Paulo's master plan addresses many issues indirectly connected to climate change. There are two main reasons for not directly addressing the climate related impacts:

1. It creates an impression that there is less priority towards other societal and governmental agenda as suggested by the surveys which indicated that people in Sau Paulo understands the impact of climate change but they are not considering it as a high priority. Those issues compete with other stressors in the megacity, such as mobility, air pollution, water crises, and sanitation (Datafolha, 2014; Di Giulio & Vasconcellos, 2014; Di Giulio et al., 2015)
2. It gives the opportunity to address the climate change actions while tackling other urban and environmental issues, goals set by the government and development pressures. For example, the PDE pays substantial attention to future mobility and transportation alternatives, such as bicycle lanes and networks of bus lanes. Because transport and traffic are very high in the city's societal agenda (Fajersztajn, Veras, & Saldiva, 2016; Nossa São Paulo, 2015), tackling it may offer an opportunity to meet public demands and address the relationship between transit GHG emission and climate change.

As per Bonduki, 2014, PDE points out several other areas that overlap from climate change point of view as seen in Figure 3. After two years of PDE's implementation it is observed that only one issues is partly implemented: mobility and transportation. It is seen that 468 km of bike lanes and 30.3 km of paths where signals indicate the presence and preference of bicycles to other vehicles are added. More than 600 km of roads give some priority to public transport, and 484 km of exclusive bus lanes were implemented in 2013–2015 (PlanMob/SP, 2015). Although the above numbers suggest some improvement in the city's transportation system, use of non-fossil fuel for all municipal public bus is not achieved. Although, the Municipal Climate Law had established that all bus system should use non-fossil fuel up to 2018 it is observed that in 2016, less than 4% of the 14,800 municipal buses had operated with some clean fuel (Época, 2016). Enterprises and private companies have stepped back when it comes to implementation of climate law even if São Paulo awards multi-year concessions to private companies for the provision of public transportation (Setzer & Biderman, 2013). This may explain this delay in terms of green buses. Political disputes and successive leadership changes, private housing market and other sectors influence explains the delay in implementing the important points mentioned in the PDE. (G.M. Di Giulio et al., 2018, Isto é, 2017) The way planning is carried out in Brazil, characterized by technocratic and bureaucratic activity focused on prediction models, explains the difficulties and delays in planning and implementing public policies in cities (e.g. Municipal Climate Law, PDE) (Oliveira, 2006).

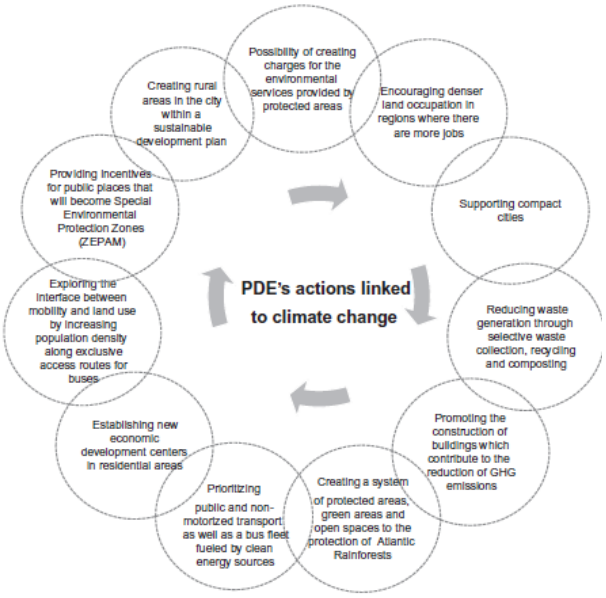

Figure 3: Brazil's Master Plan (PDE) issues linked to climate change (G.M. Di Giulio et al., 2018)

Figure 4: Singapore's Climate Change Resilience Framework *(NCCS, 2012)*

3.6. Singapore

Singapore's aim is to create a clean and green garden city by giving high priority to environmental issues. Singapore has been consistently pursuing its goals of growing economy and protecting the environment

simultaneously. Although Singapore generates relatively low amounts of CO_2 emissions per GDP dollar in the world, it is still committed to reduce the emissions growth further. (NCCS, 2012)

Recognizing that climate change affects the work and responsibilities of many Ministries and government agencies, the Government formed the National Climate Change Secretariat (NCCS). It is a dedicated unit started in July 2010 under the Prime Minister's Office to provide coordination at the highest level for Singapore's domestic and international policies, plans and actions on climate change. The NCCS also supports the work of the Inter-Ministerial Committee on Climate Change. Singapore's approach to addressing climate related Challenges is four-fold (NCCS, 2012): First, reduce carbon emissions in all sectors through fuel taxes, controlling vehicle ownership and usage, energy efficiency incentives and other policies. Although Singapore has proactively reduced the growth of carbon emissions but there is still that can be done. In particular, they must continue to improve energy efficiency and minimize wastage of energy (NCCS, 2012). The Government has collaborated with the academic and research community, as well as innovative companies, to assess and develop technologies addressing climate change that might be deployed in Singapore. Second approach is to be ready to adapt to climate change effects and improve Singapore's resilience to climate change (NCCS, 2012). A better understanding of the potential impacts of climate changes on Singapore is needed and appropriate measures to cope with climate related changes need to be formulated. Third is to harness green growth opportunities. Singapore is well positioned to support the development and export of climate-friendly technologies, services and solutions (NCCS, 2012). Singapore's economic agencies' efforts to grow the clean energy, water and carbon services sectors have started to yield results. A supportive business environment will help attract more investments in green industries and also create high value jobs for Singaporeans and propel their economy along a green growth trajectory. Fourth approach is to forge partnerships (NCCS, 2012). Singapore's domestic efforts are complemented by international collaboration. Besides the UNFCCC discussions, Singapore participates in related multilateral efforts, including discussions hosted by the World Trade Organisation (WTO), the World Intellectual Property Organisation (WIPO), the International Maritime Organisation (IMO) and the International Civil Aviation Organization (ICAO), in support of a holistic approach to deal with climate change. They are also actively engaged in environmental cooperation through regional and bilateral platforms such as the Asia-Pacific Economic Cooperation (APEC), the Association of Southeast Asian Nations (ASEAN), the C40 Cities Climate Leadership Group (C40) and the Sino- Singapore Tianjin Eco-city.

Singapore is constantly improving its strategies to understand the complexities of climate change. Adaptation measures which take time in implementing have to be taken early. A resilience framework is illustrated in figure 4 which is devised to guide the efforts in safeguarding the projected climate changes impacts for another 50 to 100 years. The adaptation plans are made to be flexible so that the future developments can be incorporated. Singapore's physical vulnerabilities to climate change are studied by a Resilience Working Group (RWG) which was setup under Inter-Ministerial Committee on climate change. RWG will review the existing strategies and infrastructure that contributes towards climate change and develop long term adaptation plans for Singapore.

From the Climate Action Plan of Singapore, it is observed that the country is doing very little when it comes to adaptation strategies of transportation sector. Singapore installed flood barriers at existing underground MRT stations in low-lying areas and also commenced upgrading of existing airport drainage system as a part of their adaptation strategies. Most of the strategies are formulated to mitigate climate change which in a way reduces its impact on transport sector eventually leading to less adaptation strategies. Singapore is investing heavily in Mass Rapid Transit (MRT), restricting car ownership, promoting NMT and investing in Bus transport to reduce the climate change impacts. (NCCS, 2012; Climate action plan, 2016)

3.7. Discussion

As evident from above discussion, several programs have been launched to cope up the transportation system to climate change in major developed countries focusing not only on improving the resilience of the transportation infrastructure but also strengthening the operations, network mobility and system redundancy by incorporating adaption strategies into the policy making, planning and development projects. It is argued that adaptation strategies offer viable and potential way to prepare transportation system for climate change impacts and help in making it more resilient, flexible and operational under adverse conditions if implemented properly. Countries like Brazil are hesitant to use the word Climate Change in their action plans but their strategies seem to address these issues indirectly. Most of their strategies are framed to develop the overall condition of the transportation infrastructure there by reducing emissions from transport sector. Usage of non-fossil fuel buses, investment in cycle lanes, encouraging private agencies to participate in running public transport system are some strategies

which address climate change issue. In South Africa the policymakers attention is leaned towards mitigation rather than adaptation in their climate change related strategies. Public transportation has been given the top priority in their adaptation strategies. Singapore's adaptation strategies in transport sector are weak and the strategies that are in place are mostly to reduce emissions from transport sector rather than impacts on transport sector due to climate change. Singapore also designed public transport and NMT related strategies to address the climate change issue.

4. Implementation barriers in developing countries for climate change adaptation

Susanne C. Mosera and Julia A. Ekstromc (2010) define *barriers*[4] as obstacles that can be overcome with concerted effort, creative management, change of thinking, prioritization, and related shifts in resources, land uses, institutions, etc. Among many other challenges in developing countries or even in developed countries, there exist numerous implementation barriers which influence the formation of policies as well as the transfer and transition of policies across various administrative units and key stakeholders. The various implementation barriers and their description is given in Table 03.

Table 03: Description of climate change adaptation implementation barriers

Barriers	Description
Coordination	Lack of coordination between various agencies leads to high transaction costs, repetition, inefficient use of resources besides incurring additional financial costs
Uncertainty	As adaptation involves multiple actors across different fields, future developments, climate change or technology, all of these pile us uncertainties which lead to deterred response from key stakeholders
Stakeholders	Convincing Stakeholders to incorporate adaptation strategies into the policy making is often termed as challenging, however, evidence based approach supported by research, has proved to be helpful in getting things across.
Policy making	Climate change adaptation is still not as a priority focus area in national policy making as a result of which there are only few takers, however
Funding	Allocating funds for projects, independent studies and research for drawing national action plans for climate adaptation is still not given the most priority
Lack of resources & information	In developing countries, there is a dearth of viable information on climate change impacts as very few or even no risk assessment studies have been done as such
Political barriers	Adaptation is often treated as a trivial dimension of climate policy against mitigation and not seen as politically feasible or even acceptable. As a result, adaptation till now has not been a focus area of policy making due to lack of political will
Behavioral obstructions	Social and cultural norms also influence adaptation-decision making, thus leading to irrational decisions based to less information without taking into account future developments
Assessment and Selection	Choice of assessment alternatives and agreement on assessment criteria and usability of data is often challenging. Further, selection of adaptation options within the ambit of authority is often limited

5. Effect of urban flooding on road transportation

Climate change has been predicted to bring more rains causing flooding which is amplified due to the rapid urbanization leading to urban flooding of unexpectedly high magnitudes. Weather condition affect road safety especially precipitation which is believed to increase traffic accidents by 75% in United States of America alone (Knapp et al., 2000). However, due to reduction in speeds due to adverse weather, there is reduction in severity of accidents. Extreme weather events lead to speed reduction, congestion, traffic jams and uncertainty in traffic safety. The changes in traffic volume and flow also occur, reflecting the variation in travel demand, route choices and even cancellation of trips due to bad weather. When certain segments of the road network are blocked due to flooding, riders need to take detours and on the roads which are partially flooded or congested, there could be stopped vehicles causing bottle necks, etc. These trips usually take much longer than regular trip time leading to increased travel time and this time cost even serves as an indicator of flood impact loss. The number of vehicles, both public and private, are also damaged due to partial or complete immersion in flooded sections as such vehicular damage also adds to overall loss (Suarez et al. 2005). There is also transportation infrastructure damage as most transportation roadways in developing countries are not constructed as per specifications or even maintained after construction. In the event of adverse weather events, many roads develop potholes, chipped off

[4] The authors argue that barriers are different from limits which are self-existent in the system and can't be removed while barriers are obstructions that can be eliminated by various means.

sections or some sections may even be washed-off which need complete replacement (Eisenack et al. 2012) which is a huge cost to the local government. Another cause of worry is the flooded parking areas which are a part of building basements with improper drainage or open parking areas with lower elevation. There is loss to parking infrastructure as well as immersed vehicles in the event of flooding. This could be a case with private vehicles as well as public vehicles. Suarez et al. (2005) use urban transportation modelling system to analyze the flows of traffic in Boston metro area simulating the effects of flooding and climate change using modified origin-destination matrix modelled to account for flooding impacts. The indicators of flooding impact on road transportation obtained from this comparative study are number of trips cancelled due to inability to travel from origin to destination, extra vehicle kilometers travelled and extra vehicle hours travelled. These account for transportation disruptions and alteration in network mobility while other indicators include infrastructural costs accounting for road infrastructure damage, vehicle damage, parking area damages, etc. Also, impact on road safety in terms of accident frequency and severity also serve as an important indicator of flooding impacts on road transportation. (Koetse, M. J., & Rietveld, P., 2009)

Based on the above discussion, a methodology has been developed which is described in the next section to assess the impact of climate change induced flooding on the road transportation under different flooding scenarios and identify specific vulnerabilities in the transportation system and based on review of adaptation policies, come up with various adaptation strategies and subsequently evaluate the proposed policies by some pilot-testing and implementation studies. In India, flooding remains a constant threat to its urban agglomerations and there is an urgent need to develop adaptation policy framework for addressing climate change impacts in transportation sector.

6. Framework for urban flooding adaptation methodology in developing countries

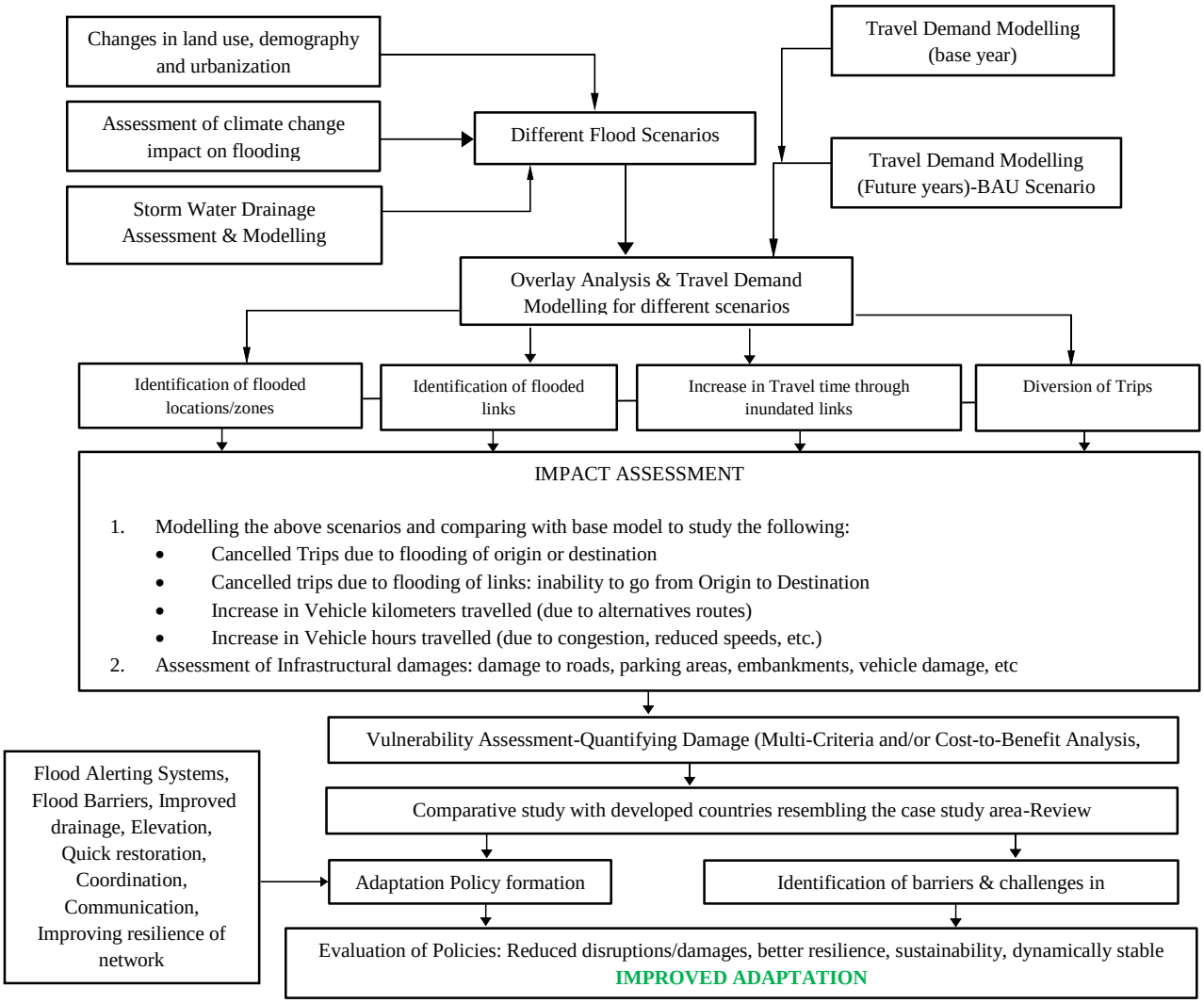

Figure 05: Framework flowchart for urban flooding adaptation methodology for transportation sector

The effects of urban flooding need to be integrated with transportation systems modelling to quantify its impacts as well as find the vulnerabilities in the road network to work out adaptation strategies that best suit the study area. The final step involves measuring the reduced impacts and methodology to validate the success of the adaptation policies. While developing different flood scenarios, change in land use, rate of urbanization and demographic variations along with storm water drainage system and expected climate change assessments need to be considered. Concurrently, four-step travel demand modelling is carried out for Business-As-Usual Scenarios for base year as well as future years. Once flood maps are prepared for different scenarios, overlay analysis is to be carried out for finding out vulnerable stretches, zones, etc in the transportation network, following which impact assessment is done to ascertain and quantify the impact of climate change induced adverse weather conditions which are analyzed using multi-criteria analysis and/or cost-to-benefit analysis leading to formulation of adaptation policies based on scientific assessment of vulnerabilities as shown in Figure 05. The framework addresses adaptation of transportation system to urban flooding and derives its input from travel demand and flood modelling which involve different sets of expertise which makes it inter-disciplinary in nature involving multiple actors at different stages of the framework.

7. Overcoming Implementation barriers of climate change adaptation policies

- Transparency and coordination between different agencies is necessary to make the adaptation policies work efficiently. A proper communication between these agencies regarding the sharing of works will help in reducing excessive costs.

- The stakeholders should come together and form a broader community to collaborate with educational, scientific research organizations for sharing science, technology and communications based knowledge. This will help the stakeholders in understanding the threat of climate change and the importance of adaptation strategies.

- Climate change adaptation should be given priority in the policy decision making. This can be done by selecting a pilot region and conduct a vulnerability assessment of climate change, estimating their impacts and to list out the losses and showing their significance. Along with this there should be other strategies like public awareness, applying for funds to gain political support.

- In order to overcome the data unavailability problem there should be separate organization that collects the information of climate change impacts on a regular basis. This organization should be collaborated with science and technological institutions for data sharing and assessing the impacts.

- It should be noted that simply mentioning social and cultural barriers in the adaptation policy framework will not pull them down. Instead **proper measures** should be taken to overcome these barriers. There have been studies done in India and Nepal on the aspects of social and cultural barriers.

    - The first and foremost thing that needs to be done is to make intense efforts educate and bring awareness about the climate change impacts and show them proper ways of adaptation.
    - Every climate change adaptation strategy that is thought to be implemented should be analyzed thoroughly to check how they deal with social barriers.
    - Climate change adaptation strategies should be designed in such a way that they are region specific and also at local level.

Although adaptation strategies can enhance the adaptive capacity of people who are vulnerable to climate change, attempts to enforce social and cultural change carry with them many complex and sensitive social concerns (Lindsey Jones, 2010). Many a times, the policy may need some changes at grass roots level such as change of alignment, forced shift in travel choices or limiting the movement of certain freight transport to fixed duration, which may face opposition from native population who entirely depend on freight such as agriculture and other professions in rural and faraway regions of a developing country. It may not seem important but at times, breaking the social barrier and convincing local people is not only challenging but can hamper the whole scheme. These interventions should be carried out in such a way that they complement and respect the social and cultural norms.

8. Conclusion

Adaptation is seen as a pivotal response to tackle climate change in all sectors including transportation sector. In this paper, it was observed that development of integrated adaptation methodologies for transport planning as well infrastructure development has been given due importance in developed countries and several pilot studies have been done to ascertain the applicability of such methodologies, however, more work needs to be carried out in developing countries to prepare well for the impending natural hazards. It is inferred that adaptation will be a key actor in policy making in near future across the globe but there is still a lot of scope for improvement. As discussed in section 2, India is highly vulnerable to climate change impacts as evident from Table 01 and the relevance of this study can be stated in equally important terms. It is reiterated that very high costs in terms of life and property and utilities will be incurred if transportation system is not adapted to climate change especially in developing economies such as India. A novel policy framework of adapting transportation system to urban flooding accounts for all the major agents has been proposed in this paper. It uses a systematic approach throughout, to reach to quantifiable outcomes and parameters which can be used as a benchmark in policy making. Further, the implementation barriers have been identified to help policymakers and stakeholders assess the applicability of any proposed scheme. It is to mention that these are tentative in nature and depend upon a host of other factors which should be duly addressed to enhance performance efficiency and yield better outcome.

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