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Climate and Disaster Resilient Transport System and Infrastructure Development for Nepal

(Background Paper for Plenary Session 2 of the Programme)

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Climate and Disaster Resilient Transport System and Infrastructure Development for Nepal

<u>**Prepared and Submitted by**</u>

Kamal Pande,

Transport Infrastructure Specialist

Government of Nepal

Ministry of Physical Infrastructure and Transport (MoPIT)

with technical support from

United Nations Center for Regional Development (UNCRD)
Nagoya, Japan

Executive summary

Nepal's topography runs from flat terrain in south to rugged terrain of High Himalayas in north within a span of 200km distance. Typical to the terrain condition, the type, magnitude and the nature of disaster is also changing. Nepal has seen a tremendous growth of road expansion over the last six decades, maintaining its serviceability against natural disasters and climate change remains a challenge.

Transport sector development in Nepal is guided by National Transport Policy, 2001. Roads are broadly classified into a) Strategic Road Network (SRN) comprising National Highways and Feeder Roads; and, b) Local Road Network (LRN). The current road length in the country is around 65,000 km of which 83% is local roads. The road classification is based on political and the road hierarchy is not tied to any particular traffic level. Larger part of SRN and LRN (36% of SRN and 68% of LRN) are unpaved and are not passable during monsoon period (June to August) when the country receives more than 80% of annual rains.

Nepal experienced a steady growth of vehicle population over the last five decade. Recently the growth has picked up significantly (vehicle population of 90 thousand in FY 1991/1992 to 1.6 million in FY 2013/2014) with higher growth registered for the motorcycle category.

In order to meet the increasing demands of transportation, the government has taken several initiatives to increase the level of investment in the transport sector.

Impact of climate change and natural disasters on transport infrastructure

The transport sector is the major contributor of Carbon Dioxide (CO_2) emissions in Nepal, which accounts to 45% of the per capita emission produced in the country. Although, the per capita emission of CO_2 Nepal is lowest but the growth is considerably higher than that of south Asia and World average.

Over the decade, Nepal has been experiencing early impacts of climate change that has caused unprecedented heavy rain and massive floods followed by long spells of drought. A rise in the maximum temperature by 1.8^0C between 1975 and 2006 has caused rapid depletion of glaciers in many regions such as Dudh Koshi basin, Imja Glacier, etc. The heavy rains followed by flood in 1974, 1981, 1993, and 2004 have caused a substantial damage to the road assets including bridges in various parts of the country.

Over the period of 1971 – 2011, the disaster[1] (earthquake, flood and landslide) has caused 160 deaths and 235 injuries. This has further caused the loss of 1,213 houses and damaged 2,261 houses in Kathmandu Valley. In addition, drought is an emerging weather condition due to climate change in Nepal. Seven districts have already been listed as districts with high vulnerability to drought. As more and more areas are vulnerable to extreme weather conditions, it could pose a bigger challenge in planning investment for infrastructures in the future.

Since Nepal is a country with varying topography, different parts of the country is subjected to differing climatic conditions. The mountainous region of Nepal is more prone to landslides, mud flow, debris flow and rock-falls, due to heavy rainfalls, that blocks the flow of traffic and can also cause damage to the road infrastructure. In the Terai region, the increase in the temperature escalates the instances of cracks on the roads and heavy precipitation leads to potholes. The poor

[1] http://www.desinventar.net/DesInventar/main.jsp

road conditions resulting from such natural calamities increase the chances of accidents and delay the transportation of basic necessities and increase the consumption of fuels.

Nepal is significantly affected by temperature increase as it causes the melting of the glaciers and as a result, washout of the roads. High temperature also causes increased fatigue to the bituminous pavement, deterioration of gravel surface, thermal expansion of bridges, buckling of joints of steel structures, etc. When there's a temperature drop, the infrastructure becomes vulnerable to snow conditions. High rainfall and flooding cause significant damage to the road drainage structures, breaching of road embankments, scouring of bridge foundation, washouts, etc. Apart from climate change impacts, there are natural disasters (such as earthquakes and landslides) impacts that have been significantly felt in Nepal. These also cause major road blockages and failures.

Adaptation measures

The cost of building and maintaining road infrastructure in Nepal is high compared to other countries in this region. Road building in extreme terrain condition, maintaining it and facing frequent disaster leading to premature failures of the road structures are common issue of road system in Nepal. To be able to adapt to such adverse conditions and disasters, special consideration is needed while designing transport infrastructures. These infrastructures needs to be emphasized to be able to adapt in such a way that the operation and maintenance costs are kept to a minimum. A long-term life cycle cost (LCC) principle needs to be adopted while making investment decision. In order to make proper assessment on infrastructure planning, Nepal took several initiatives to prepare the "Climate Resilient Planning – A Tool for Long-term Climate Adaptation" along with the National Adaptation Programme of Action (NAPA) and Local Adaptation Plans for Action (LAPA) in 2011. These documents were prepared to facilitate the preparation of resilient periodic development plans and to aid in making the environment and the people adapt to the adverse impacts of climate change. The Climate Change Vulnerability Mapping of Nepal under NAPA has been established as a tool to help identify the areas that are the most vulnerable to different kinds of disasters in Nepal

In Nepal, bioengineering has been successfully adopted in an effort to decrease the occurrence of landslides and its negative impact on roads. However, no design specifications have been formulated to climate proofing roads. To address these, it is extremely necessary that the country develop a framework to i) identify locations for extreme climate conditions, ii) carry out risk analysis and impact assessment in that location, iii) plan an appropriate response to the risks, iv) calculate the life-cycle costs of building roads, v) design the infrastructure accordingly, vi) implement the plan and vii) carry out continuous monitoring and evaluation. Although this does not prevent extreme climate conditions, it will help in reducing the life cycle costs of the road.

Since the rate of vehicle ownership has been increasing on an average by 13% every year, the need to switch to cleaner fuels in order to decrease the GHG emissions in the country is inherent. In addition, promoting clean energy-based alternate transport, converting public utility vehicles to LPG and RE, promoting non-motorized transport especially the dedicated bicycle lanes and walk way facilities and conducting public awareness activities are some measures that can be taken to reduce the increasing stress (GHG emissions and air pollution) to the environment.

Eight strategies have been identified to reduce the impacts of climate change and disasters on road infrastructure. The consideration of these strategies will be useful while revisiting the much waited revision on "National Transport Policy". The strategies focuses on a) building awareness; b) developing project screening guidelines; c) integrating "Avoid – Shift – Improve" strategy in formulating, designing transport mode; d) classifying road system based on vulnerability to climate change impacts and disasters; e) developing design standards; f) operationalization of maintenance practices to minimize secondary impact; g) strengthening environmental and social safeguards; and, h) enhancing institutional capacity.

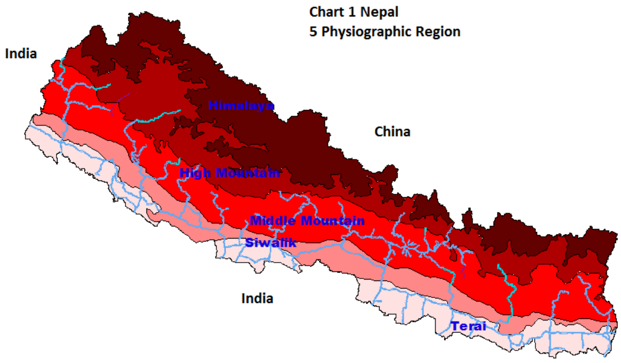
Abbreviation

ADB	Asian Development Bank
CO_2	Carbon dioxide
DDC	District Development Committee
DCRN	District Core Rad Network
DoR	Department of Roads
DRSP	District Road Support Programme
DoTM	Department of Transport Management
EST	Environmentally Sustainable Transport
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GON	Government of Nepal
IPCC	International Panel on Climate Change
JICA	Japan International Cooperation Agency
LRN	Local Road Network
LAPA	Local Adaptation Plan for Action
LCC	Life Cycle Cost
MoUD	Ministry of Urban Development
MoPIT	Ministry of Physical Infrastructure and Transport
NPC	National Planning Commission
NAPA	National Adaptation Programme of Action
SRN	Strategic Road Network
VDC	Village Development Committee
VDC	Village Development Committee
WB	World Bank

Table of Contents

1. Background

Nepal is a landlocked country with an area of 147,181 sq km and a population of approximately 27 million. The northern part of the country, bordering with the People's Republic of China, is a rugged terrain with Himalayas and the southern part is a plain land bordering with India. Nepal's topographical location is unique in the sense that within a 200 km distance, the ground altitude changes from 50m of msl to 8488m. Due to this drastic change in elevation within a short distance, Nepal offers a distinctive profile of five physiographic regions: Terai, Siwaliks, Middle Mountains, High Mountains and High Himalaya extended from the south to the north, respectively (Chart 1). Terai is mostly flat lands, which consists of extensive road networks. Geologically, Siwaliks are most unstable and unpredictable slopes that are very fragile in nature. The Middle Mountains and High Mountains are relatively stable. High-speed water currents that cause river cutting of the road toe is the only risk to roads in in the middle and high mountainous regions.



Despite several constraints and challenges, physical infrastructure has always remained at the center stage of the planned development. Over the last three decades, the Per Capita GDP has increased from USD 180 in 1980 to USD 706 in 2012 and the population below the poverty line has dropped to 25.16% (refer to Table 1). Road network which was virtually nonexistent in 1950 has now increased to around 65,000 km (refer to Table 2). Only two district headquarters (Humla and Dolpa) are yet to be connected to the road network. Although domestic airlines operate more than 30,000 flights a year connecting remote areas of the hills and mountains, the service is limited to those who can afford the services. In 2012[3], there were 70,877 aircraft movement by 17 domestic operators serving only 1.57 million passengers including tourists.

Table 1 Nepal Economic Indicator

Poverty and Social[2]	2011
Population (million)	26.5
Population growth (annual % change)	1.4
Maternal mortality ratio (per 100,000 live births)	170.0(2012)
Infant mortality rate (below 1 year/per 1,000 live births)	46.0
Life expectancy at birth (years)	68.8
Adult literacy (%)	56.5
Primary school gross enrollment (%)	122.0
Child malnutrition (% below 5 years old)	36.4(2010)
Population below poverty line (%)	25.16
Population with access to safe water (%)	84.0
Population with access to sanitation (%)	56.0

Road remains the predominant form of transport infrastructure in Nepal as 90% of the passengers and goods are transported through roads since air transport services is limited and expensive to the common people. Although accessibility has increased, lack of effective connectivity has hindered balanced economic growth and hence increased transport costs.

[2] Central Bureau of Statistics
[3] Civil Aviation Annual Report, 2013

The transport sector consumes a considerable part of the overall infrastructure investment in Nepal. A major proportion of the transport sector budget is expended in improvement and maintenance of roads. Transport sector expenditures[4] increased fourfold from 2006 to 2010. In 2005/06, it was 4.17 million US$ and reached 27.34 million US$ in 20011/12. Between 2006 and 2010, resources allocation to Roads Board for road maintenance[5] increased from NRs. 3.30 million US$ (2005/06) to NRs. 40.18 million US$ (2012/2013).

Roads Board is responsible for funding the road maintenance. Currently, it is funding the routine/recurrent maintenance of around 5,900 km of SRN, 500 km of urban roads and around 1300 km of district roads. In addition to the routine/recurrent it is also funding 700 km of periodic maintenance of SRN for the last two years.

Nepal is one of the few countries in the world with significant proportion of its total population living in areas not served by an all-weather motorable road. In 2006, 58% of population in hills has motorable access within a reach of 4 hours whereas, 94% of population has a motorable access within a reach of 2 hours in Terai. An overall accessibility was 78%. A recent study[6] carried out by DoR has estimated that there has been an improvement in accessibility in hills from 58 % in 2006 to 77.5% in 2011 and in Terai from 94% in 2006 to 98% in 2011 with an overall accessibility of 88 % of the population reaching motorable road head within 4 hours in hills and 2 hours in Terai. In 2012, the road density[7] for Terai and Hills/Mountains are 11.63 and 6.78 km/100 sq. km respectively. This road density does not take into account of the seasonal road that is passable only during winter time.

The transport sector is the major contributor of Carbon Dioxide (CO2) emissions in Nepal, which accounts to 45% of the per capita emission[8] produced in the country. Although per capita emission of CO_2 (133 kg in 2011) in Nepal is lowest in terms of the World average of 4,504 kg/capita[9], the current trend suggests that the fossil fuel emission growth[10] of 395% over the last decade has been considerably higher than the world average of 49.3%.

The high topography, stiff cliffs, active tectonics and the fragile geology of Nepal, which is still young, remains vulnerable to various types of disasters including floods, landslides, debris flows, glacial lake outburst, earthquake etc. Numerous such disasters have caused substantial loss of human life and properties in the previous century. The growing threats of climate change have prompted actions to prepare the country for adaptation. ADB[11] specifies that there are basically three types of adaptation strategies that can be implemented to climate proof the roads: i) Anticipatory adaptation – implementation of adaptation measures in anticipation of specific impacts of climate change, ii) Autonomous adaptation – adaptation measures taken due to the changes in the natural and human systems and iii) Planned adaptation – adaptation measures that are the result of policy decisions geared towards adjusting to the changing environment.

Transport infrastructure is directly affected by extreme climate events such as storm surges, floods, droughts and temperature changes due to which recognizing a need for implementing adaptation measures is important. Insufficient attention to these infrastructures can incur high long-term costs.

4 Economic Survey, Ministry of Finance, GoN
5 Roads Board Nepal
6 DoR Study on accessibility, April 2012
7 Nepal Road Statistics for Strategic Road Network, 2012
8 Nepal Environmentally Sustainable Transport Strategy for Nepal, Draft Report, 2014
9 Nepal Environmentally Sustainable Transport Strategy for Nepal, Draft Report, MoPIT, GoN
10 Nepal Environmentally Sustainable Transport Strategy for Nepal, Draft Report, MoPIT, GoN
11 Asian Development Bank (ADB). (2011). Guidelines for Climate Proofing Investment in the Transport Sector: Road Infrastructure Projects.

In order to address the immediate need of the infrastructure planning, Nepal took several initiatives to prepare the "Climate Resilient Planning – A Tool for Long-term Climate Adaptation" along with the National Adaptation Programme of Action (NAPA) and Local Adaptation Plans for Action (LAPA) in 2011. These documents were prepared to facilitate the preparation of resilient periodic development plans and to aid in making the environment and the people adapt to the adverse impacts of climate change. It envisaged the vision of "Achieving a society and economy that is resilient to climate change". They also provide frameworks for broadly recognizing various issues of climate change, including its drivers and impact vulnerability, and outlines mitigation and adaptation measures to achieve its fundamental goal of sustainable development under the felt and anticipated climate scenarios. The framework also identifies cross-cutting issues that are crucial for the effective implementation of climate-resilient development interventions in order to realize the nation's development vision.

The Climate Change Vulnerability Mapping of Nepal under NAPA has been established as a tool to help identify the areas that are the most vulnerable to different kinds of disasters in Nepal[12]. This resource can be used for swift planning and decision on the type of adaptation measures needed for transportation infrastructure around Nepal.

In addition, the LAPA initiative works to identify climate vulnerable communities and their accessibility to systems. Under LAPA, transport and infrastructure have been identified to be secondary systems, which are accessed based on their "existence", "quality" and "accessibility". LAPA focuses on using the Gateway System Analysis (GWS) as a tool for vulnerability and adaptation assessment. GWS allows policy makers and development projects to determine the extent to which the quality and accessibility of these systems can cause households in that area to adapt to climate change impacts[13].

2. Nepal Road Network and Management

2.1. Current Status

Road network development in Nepal is based on political classification rather than functional classification. Because of political classification, roads built with significant investment are found to be under-utilized. Substantial road length within Strategic Road Network is all-weather, but the roads under Local Road Network is largely fair-weather and unpaved. Without proper motorable bridges, these fair-weather local roads become impassable during rainy season (road closed for a duration extended to months). The

Table 2 Nepal Road System

Road Class	Length Km (2012)	Description	Respective Network
National Highways	11633[14]	The Main Arterial Route	DOR
Feeder Roads		Important Roads with a more Localized Nature	
District Core Roads Network	23,136[15]	Roads Connecting Group of Village HQ	DDC
Urban Roads	3,000[16]	Roads Within a Municipal Boundary	Municipality
Villages Roads	>27,000[17]	Non-through roads linking single villages to roads of a higher class.	VDC

[12] Climate Change Vulnerability Mapping for Nepal. National Adaptation Programme of Action (NAPA) for Nepal. Ministry of Environment. Government of Nepal. September 2010.
[13] LAPA Manual: Local Adaptation Plans for Action (LAPA). Climate Change Management Division. Ministry of Science, Technology and Environment. Government of Nepal. 2011.
[14] Statistics of Strategic Road Network, SSRN 2011/2012
[15] Based on District Transport Master Plan (actual and projected)
[16] Estimated by the author
[17] Estimated based on rural road statistics.

restriction of movement during the rainy season promotes deficiency of road system, which in turn seriously threatens the return on investment made on rural roads

National Transport Policy, 2001 provides a classification of roads in Nepal: Strategic Road Network (SRN) and Local Road Network (LRN). SRN comprising of National Highways and Feeder Roads is under the jurisdiction of the Department of Roads. The LRN which comprises of district, village and urban roads is under the jurisdiction of the respective local institutions namely District Development Committees (DDC), Village Development Committees (VDC) and Municipalities. The Interim District Transport Master Plan (DTMP) Guideline (2010) define the rural roads as all roads that are not urban roads and do not form part of the SRN. In a hierarchical order, district roads are the link between village roads and the SRN.

Substantial part of SRN and LRN (36% of SRN and 68% of LRN) are unpaved and are not passable during monsoon period when country receives more than 80% of annual rains during these periods (June – August)[18]. The gravel loss (estimated to 22 – 25 mm/year)[19] of the graveled paved road is also substantially high due to 9 months complete dryness of the surface, which causes a loss in the gravel moisture, and 3 months excessive rains during monsoon.

Nepal experienced a steady growth in vehicle population till the nineties. From FY 1991/1992 to FY 2013/2014, the growth picked up significantly (vehicle population from 1.0 million in FY 1991/1992 to 1.6 million in FY 2013/2014) with higher growth registered for the motorcycle category[20]. With easy access to the credit facilities, vehicle ownership in general and motorcycle in particular is increasing[21]. Out of 1.6 million[22] vehicles registered in Nepal, around 44% are concentrated in and around Kathmandu Valley. Car ownership is expected to increase as residents become more affluent and young families riding motorcycles switch to cheap cars manufactured precisely for their needs[23].

In FY 2013/14, the country consumed approximately 721,203 kilo-liter of diesel, 223,087 kilo-liter of petrol and 115,896 kilo-liter of aviation fuel[24]. This constitutes a growth of 40%[25] over 1991 consumption patterns. The per capita diesel fuel consumption for transport sector has been estimated as 14.22 kg for 2010 and it has doubled since 2006[26].

The transport sector of Nepal continues to be guided by the National Transport Policy 2001, 20-year SRN Master Plan and Priority Investment Plan (2007-2016). The Government recognizes the need to connect all the districts of the country as well as develop and extend a Strategic Road Network for an effective inter and intra mobility. This aims to bring people closer to the all seasonal road within four hours and two hours walking distance in Hills/Mountains and Terai respectively.

2.2. Development Scenario

As part of the long-term strategy the government has taken several initiatives in the extension of road network to support and facilitate the social and economic development of the country. These initiatives are targeted to support to the fulfillment of the objectives of other economic sectors in conformity in achieving the national goals. The major initiatives are:

[18] Nepal Disaster Report. 2013. Ministry of Home Affairs. Government of Nepal.
[19] Estimated by author using HDM III
[20] Department of Transport Management.
[21] Vehicle registration record, DoTM
[22] As of FY 2013/2014, DoTM
[23] General trend observed in developing countries.
[24] Nepal Oil Corporation
[25] Nepal Oil Corporation
[26] http://www.indexmundi.com/facts/nepal/road-sector-diesel-fuel-consumption-per-capita

- Construction and operationalization of Mid Hill Highway (approx. 1776 km) to support the development of 10 major cities identified along the road corridor. This highway runs from the eastern border to the western border of the country, parallel to the existing East-West Highway. The alignment lies mostly in Middle Mountainous and High Mountains and substantial part of the alignment runs along the river banks.
- Construction and operationalization of Kathmandu – Terai Fast Track (76 km). Four-lane highway to link Kathmandu Valley with the Terai in plain. It is a north-south link crossing over most fragile Siwalik Hills. The project is expected to be implemented under Public Private Partnership and with an investment of 900 million US$.
- Upgrading and operationalization of Postal Highway running east to west along the side of Indian border in south plain. The design and construction of postal highway is very challenging in terms of a) providing adequate drainage structure as the embankment could pose serious threat to the inundation of larger area of Terai; and, b) building stable embankment to allow overtopping of flood during high flood and keeping the maintenance cost to a minimum. The estimated length of highway is 1141 km of which 592 km is in serviceable condition, 76 km under construction and 77 km is planned for track opening.
- Developing roads along major river corridors: Koshi, Gandaki and Karnali. The track opening of river corridor in progress. The track opening is in progress.
- Construction of roads leading to development of hydropower, tourism and trade.
- Bridge Construction on Strategic Road Network: In addition to the current bridge stock of 80 km on SRN, Department of Roads is currently engaged in the construction of 121 bridges (6000 m) and is due for completion within the next two years. DoR has also identified[27] additional 751 bridges on SRN to be built within next five years.
- Construction and upgrading of District Core Road Network. District Transport Master Plan has identified the need of connecting all Village Development Center with the road network. Out of 3,634 VDCs, 815 remains to be connected with Local Road Network. The estimated District Core Road Network (DCRN) stands around 29,967[28] km road. Around 8,000 km of road is yet to be opened while remaining 22,000 km needs urgent upgrading/rehabilitation or reconstruction depending upon their condition. 844 river crossing[29] on DCRN has been identified for the provision of bridges.
- Construction of tunnel linking Thankot to Japlekhola on Thankot - Naubise Section of Tribhuvan Highway. The feasibility study for 2.40 km tunnel is complete and design is in progress under JICA funding.
- Widening and strengthening of Pritvi Highway (Naubise – Mugling Section). Design work in progress to upgrade the highway to cope the current level of traffic with the provision of additional climbing lane.
- Widening and strengthening of Mugling – Narayanghat Highway. Existing highway is planned to upgrade to four-lane highway under WB assistance. Construction is going to commence soon.

[27] Source: Bridge Improvement and Maintenance Program Support, WB supported, Department of Roads

[28] Estimated and projected by the author on the basis of 44 DTMPs available from DoLIDAR

[29] Estimated and projected by the author on the basis of 44 DTMPs available from DoLIDAR as part of Study Report submitted to DoLIDAR under Local Road Bridge Program.

- Widening of existing East-West Highway from two-lane to four-lane. Preliminary study is planned to commence soon.
- Development of Railways. Five border town (Biratnagar, Janakpur-Bardibas, Bharahawa, Nepalgunj, Kakadvitta) are being planned to get connected with the Indian Railway Network. Construction work for linking Biratnagar and Janakpur is in progress. Feasibility study for East West Railway has also been completed. Government is soliciting funding support for the East West Railway,

3. Transport Sector Vulnerability to Climate Threats/Challenges

Transportation is directly affected by climate change. The transport infrastructure, an asset created over the last six decades is susceptible to the impacts of rapid climate change. The traditional way of designing and implementing transport infrastructure is not adequate if long-term sustainability of the road network is to be considered. There is a need to respond to the impacts of climate change, which are often limited to designing measures to address the felt impacts in transport infrastructure development. Enhancing the resilience of development plans to climate risk in its entirety is a strategic and proactive move requiring that anticipated climate threats be assessed before implementing plans so that measures to reduce those threats can be built into the plan itself.

A proactive move helps to assess how climate change might impact the sustainability of a proposed development work and the possibility that the proposed development work might impact natural systems, inadvertently amplifying the climate threats. A proactive effort to enhance the resilience of development plans and programs can be concurrent or anticipatory. For adaptation to impacts of climate change, what needs to be looked at is the means of disaster reduction strategy and management. The following table explores various stages of transport infrastructure development and its linkages to the possible disaster resulting from climate change and other natural calamities.

Table 3. Stages of transport infrastructure development and linkage to disaster threats

Stages	Elements to be considered	Disaster threats to investment
Feasibility	• Alignment selection • Design life • Annual maintenance cost	• Premature failures (frequent) due to excessive rain, toe cutting of road slopes by high flowing rivers. • Continuous drought situation and massive migration • Shifting agriculture activities in hills and road slope vulnerability due to change in drainage pattern
Detail design/construction	• Design standards for road works • Standards for drainage structures • Bridge standards • Pavement including the use of bitumen • Assessment of aggregates availability and haulage distance • Use of other construction materials • Slope protection	• Availability of natural construction materials • Exhaustion of river source • Increased haulage of natural materials • Pavement behavior and life • Adequate capacity of existing drainage structure • Resilience of bituminous pavement (additional fatigue due to temperature rise) • Limitation on thermal expansion of bridges • Limitation on free board provision on bridges • Limitation on overtopping of bridges by flood • In urban area, maintaining and aligning utilities along with the standards of road infrastructure
Maintenance	• Maintenance standards • Asset preservation	• Emergency maintenance and readiness plan • Frequency of maintenance cycle • Rehabilitation/reconstruction cost • Social cost

Since, significant percentage of rural roads are not built with adequate engineering input, they are found most vulnerable to damages if disaster of any kind strikes. These roads have high gradient sections with seriously tight horizontal curves and the structures that are not properly secured. These road not only contribute to the higher cost of transportation but also demand for higher share of maintenance allocation.

3.1. Assessment of Disaster Impact on Road Infrastructure

Over the decade, Nepal has been experiencing early impacts of climate change that has caused unprecedented heavy rain and massive floods followed by long spells of drought. Different research has reported that there has been a rise in maximum temperature[30] in Nepal by 1.8^0C between 1975 and 2006. This has caused rapid depletion of glaciers in many regions such as Dudh Koshi basin, Imja Glacier, etc. The heavy rains followed by flood in 1974, 1981, 1993, and 2004 have caused a substantial damage to the road assets including bridges in various parts of the country. During the monsoon time the vulnerability of the road increases due to landslide triggered by rains and constant toe cutting by the flooding river. The economic and social implications during road closures caused by these natural disasters are huge.

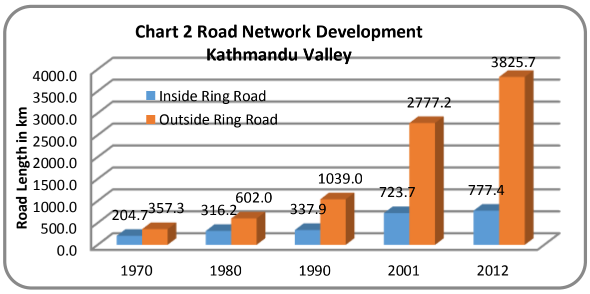
In between 1970 and 2010, there were 35 flooding instances[31] recorded at various parts of the country damaging around 3.1 km of highways and feeder roads with economic loss in terms of road closures lasting up to 3 days. The damage to the rural road has not been properly accounted for so far. The road closure during monsoon is very common in Nepal. There is a disruption on the movement of traffic, but resulting economic loss is yet to be assessed.

3.2. Impact to Road Infrastructure in Terai, Middle Hills and Mountains

The Terai region is prone to disasters such as floods and landslides causing premature failures of roads. Flood poses high risks of bank cutting and sediment deposition on roads that are lower in altitude. As the topography changes from flat lands to hills, the roads are more vulnerable to landslides induced mostly by earthquakes and humans. As the terrain becomes steeper, the chances of glacial lake outbursts and landslides increase[32]. These disasters are severe threats to the existing road networks in Terai, Hilly and Mountainous region. A complete account of disasters that have negatively impacted road transportation in Nepal from 1979 to 1993 is outlined in Annex 2.

3.3. Impact to Road Transportation in Kathmandu Valley

Chart 1 shows road network expansion in Kathmandu valley over the last 40 years period. After nineties, the road expansion outside ring road is significant. The expansion that took place in rural sector is mainly contributed due to increase flow of fund to the local institutions (Village Development Committees) under the program of building their own infrastructures. Substantial amount of resources were spent on building rural road but without proper engineering input. These non-engineered roads are not only disastrous to the environment but also contributing to higher production of CO_2 due to higher



[30] Climate Resilient Planning – A Tool for Long-term Climate Adaptation, 2011
[31] http://www.desinventar.net/DesInventar/main.jsp
[32] Nepal Disaster Report. (2011). Ministry of Home Affairs, Government of Nepal.

consumption of fuels. The total road length in the valley stands at 4,603 km in 2012 (shown in Chart 2). Out of total valley roads, only one third is paved and rest are either in gravel or earthen condition.

There are approximately 750,000 vehicles registered in the Bagmati Zone[33] which is almost half of the total vehicles registered in Nepal and significant proportion of these fleet are concentrated in Kathmandu Valley. The number of registered vehicles is rapidly increasing in Kathmandu, particularly, in the recent five years accompanied with the rapid increase of urban population and economic development. The share of motorcycle has increased at an alarming rate of more than 20% in the past five years. The motorcycle now constitutes around 74% of the total vehicle fleet in Nepal and in absence of effective public transport system, it is bound to grow more in future.

In Kathmandu Valley, public transport system is running under the private investment. The quality of the services is considered below the satisfactory level. Vehicles used for public transport are usually old and the total number is not sufficient to cater with the demands of the riding public. Since there is no railway system in the valley at all, public transportation in Kathmandu Valley has been provided by bus and minibuses on major roads, micro buses, and tempo network on secondary roads. In absence of effective road hierarchy, the services are very complicated and most of these routes end in the central area of the city contributing to the chaotic traffic jam of the city road. Organizing and operating effective public transport system in Kathmandu valley remains a challenge. Government is currently pursuing the agenda to promote public transport in the valley as part of the sustainable transport initiatives.

Kathmandu Valley occupying 5% of the land but represents around 9.5% of the country's population according to population census of 2011. Over the period of 1971 – 2011, the disaster[34] (earthquake, flood and landslide) has caused 160 deaths and 235 injured. This has further caused the loss of 1213 houses and damaged 2261 houses in the Valley.

Climate change adaptation measures have not been used in the construction and maintenance of these roads in Kathmandu. With careful consideration of the life cycle costs, adaptation practices should be integrated into these processes to lessen the impact of climate change on the population living in the surrounding areas.

3.4. Impact of Climate Change on Road Transport

In Nepalese condition, defining the climate impact linkage for infrastructure, the Climate Resilient Planning document[35] has stated that "infrastructure sector is influenced by floods, mass wasting and debris flow, sedimentation, rise in ground water levels, and rain and windstorms. The anticipated problems include damage to infrastructures, increased fatigue of infrastructures, silting of drains, increased instability of land through the weakening of river banks or hill toes or land subsidence, and inundation and submergence of infrastructures." Drought[36] is now emerging as one of the possible result of the climate change in Nepal. Despite increased forest cover, water sources is drying up and forcing the villagers to opt for permanent migration. Seven districts (Jajarkot, Mugu, Kalikot, Dailekh, Saptari, Achham and Siraha) have already been listed as districts with high vulnerability index[37]. Fifteen districts have been classified with high vulnerability index. This could turn out to be a bigger challenge in future in planning investment

[33] Transport Management Department, 2014
[34] http://www.desinventar.net/DesInventar/main.jsp
[35] Climate Resilient Planning – A Tool for Long-term Climate Adaptation, National Planning Commission, 2011
[36] Environmental Causes of Displacement, National Planning Commission, 2013
[37] Source: National Adaptation Program of Actions, 2010

for infrastructures including transport. The criticality of the road infrastructure, compared to other physical infrastructure, lies in maintaining the serviceability at the time of disaster and during post recovery period. This checks on reducing further damage, which may be caused by secondary impacts.

IPCC's Fourth Assessment Report predicts the weather pattern in South and Southeast Asia to be dominated by rainfall and increased temperatures and Northern Asia to be affected by heavy winter rain. As Nepal is a landlocked country, the rise in sea level does not have as much an impact as the melting of glaciers in the Himalayan region.

Climate change poses a major challenge to the policy makers in developing the most appropriate guidelines for construction and maintenance of road infrastructure. Since Nepal is a country with varying topography, different parts of the country will be subjected to differing climatic conditions. In addition to this, the increase in the temperature and rainfall will have substantial impact from the planning stage through the operation stage of the roads. The mountainous region of Nepal is more prone to landslides, mud flow, debris flow and rock-falls, due to heavy rainfalls, that will block the flow of traffic and can also cause damage to the road infrastructure. In the Terai regions, the increase in the temperature escalates the instances of cracks on the roads and heavy precipitation leads to potholes[38]. The poor road conditions resulting from such natural calamities increase the chances of accidents and delay the transportation of basic necessities to the rural communities. Increase in the consumption of fuel, which is mostly associated with high costs, is another consequence of the traffic jams caused due to the damaged roads.

The central region of Nepal faced a major climate change impact in 1993 when heavy rainfall and flood washed away bridges and numerous road sections. In July 1993, heavy rainfall with a maximum daily rainfall of 540 mm with hourly rainfall of 70 mm on 19th July, created havoc in central Nepal with serious damages[39] to the transport infrastructure. Kathmandu Valley remained isolated (no land transport connection) for 21 days from the rest of the country. In Both highways (Tribhuvan and Prithvi) linking Kathmandu valley with the rest of country, three bridges (washed out), 23 culverts and 534 meters of road section at 19 places suffered major damage.

Regmi and Hanaoka (2011) outline the potential impacts of climate change on road infrastructure and the design parameters that should be adopted in order to avoid damage caused by the different climatic conditions. The table below has been adapted to include dimensions of climate change impacts on roads in Nepal. The specific changes to design of the infrastructure, in order to adapt to the climate as well as to improve the existing roads in the country, is also mentioned for a future development outlook.

[38] Regmi, M. B. Hanaoka, S (2011). A survey on impacts of climate change on road transport infrastructure and adaptation strategies in Asia. Environ Econ Policy Stud; 13:21–41.

[39] Flood Damage Report, Maintenance and Rehabilitation Coordination Unit (MRCU), Department of Roads, August 1993,

Table 4: Impact of Climate Change and Disaster on Road Transportation and Potential Design Considerations for the Future

		Primary Impacts	Secondary Impacts	Design Considerations
Climatic Condition	Temperature increase	<u>Road Investment</u> • Road investment marginalized by excessive migration due to water scarcity (local roads)		• Consideration of appropriate design life • Stage construction • Design based on existing traffic (Low Volume Road)
		<u>Pavement</u> • Increased fatigue bituminous pavement needing additional maintenance cost • Deterioration of gravel surface due to excessive moisture loss leading to additional cycle of resurfacing.	• Increased VOC with additional consumption of fuel. • Possibility of increase in road accidents.	• Use of stiff bitumen • Soft bitumen with solvent in water (emulsion) • Control soil moisture • Adapt gravel sealing (Otta seal/grav-seal) • Additional road safety provision
		<u>Bridges</u> • Thermal expansion of bridges • Buckling of joints of steel structure • Higher corrosion activity at locations with high humidity.		• Careful attention to material used for joints • Extensive use corrosion protection material
	Temperature decrease	<u>Pavement</u> • Exposure to snow condition • Affect road transport operations • Increased OM costs	• Increase in road accidents	• Adapting micro-texture pavement standards for urban and high volume roads.
	High rainfall/flooding	<u>Pavement</u> • Deterioration of gravel surface due to excessive moisture. • Deterioration of bituminous pavement with faster deterioration trend calling for early intervention for periodic maintenance or overlay.	• Increased VOC with additional consumption of fuel. • Possibility of increase in road accidents. • Increased maintenance cost	• Adopt resilience drainage system • Improve soil strengthening and rock stabilization technique • Resilience asphalt and concrete pavement • Regular survey and maintenance measures
		<u>Road Embankment & Drainage Structures</u> • Damage to road drainage structures including foundation resulted due to high runoff. • Breaching of road embankments resulting loss of road section. • Submersion of road • Landslides and road blocks • Erosion	• Traffic disruption • Road closure for indefinite period • Weakening of pavement structures due to submersion of road embankment for longer period of time.	• Proper discharge estimation to design the size and shape of drains and drain slope • Slope protection in Mountainous roads • Proper subsurface drains and catch drains • Increase road surface camber for quick removal of surface water for pavement • Building line defense for embankment to prevent complete failure (reinforced earth)
		<u>Bridges</u> • Scouring of bridge foundation • Submersion of bridge • Bridge washout	• Disruption of traffic	• Creating additional free-board (flood return period estimation) • Protection of river and banks • Revising bridge selection criteria specific to location with possible climate change impact.
Earthquake		<u>Road Embankment & Drainage Structures</u> • Failure of embankment and drainage structures. • Bridges • Damage to bridge bearing & column	• Traffic disruption • Damage to utilities (urban roads) • Traffic disruption	• Building second line defense for embankment to prevent complete failure (reinforced earth) • Classifying roads and developing and implementing special code/norms for roads and associated utilities (urban roads). • Quality control regime developed and implemented in bridge building in remote area (local road)
Landslides		<u>Road Embankment & Drainage Structures</u> • Failure of embankment and drainage structures.	• Traffic disruption • Damage to utilities (urban roads)	• Vulnerability of the road slopes regularly checked and monitored (Highways and Feeder Roads).

4. Adaptation of road infrastructure to climate change and disaster impacts

Since the majority of the local population as well as tourists in Nepal predominantly use road transportation, a need to plan and construct roads that can withstand extreme weather conditions is increasingly necessary.

Adaptation, in general, is either adaptation through making changes in the structural design (engineering) such as specifying materials, having standard dimensions, constructing proper drainage systems, etc or through non-engineering methods such as planning for maintenance, alignment, land use and environmental management. In addition to this, ADB's report on the "Guidelines for Climate Proofing Investment in the Transport Sector" (2011)[40] emphasizes that a "do nothing" approach could also be one of the actions to take in order to minimize costs on roads that have low economic feasibility.

In addition, there are two types of responses that can be planned by the government: i) Pre-disaster response and ii) Post-disaster response. In the pre-disaster section it is important to discuss about policy, resilience design, quality of material use, regular basis inspection and maintenance (I/M), research and institutional development, etc to resist with the climate induced disasters and climate impacts. Post-disaster includes how to make the people and infrastructure adapt during and after the disasters. This part mainly covers management, maintenance, medical facilities, and public awareness, etc. for the resilience society.

Box 1: Example of Bioengineering to reduce impact of landslides on roads.

"Bio-engineering is the use of living plants for engineering purposes in conjunction with civil engineering structures to reduce shallow- seated instability and erosion on slopes." - Balephi-Jalbire Road in Sindhuplachowk during the 2002 monsoon was blocked due to a landslide which is now known as Balephi landslide. This road is important in providing access to Kathmandu, Kavre and Dhulikhel. The landslide completely washed away 120m of the road section. In addition to designing the structural support, DRSP employed bioengineering method to hold the loose soil in the future.

At the moment in Nepal, most of the adaptation measures being taken are geared at mitigating the effects of natural disasters such as landslides, which frequently occur in different parts of Nepal. Bioengineering has played a major role in stabilizing the slopes of hills in different parts of Nepal. It is a cost effective, environmentally friendly and sustainable method that has proven to be successful in solving road weathering and blockage caused by landslides[41]. However, bioengineering is only one way of disaster proofing roads. Other adaptation measures need to be included in the plan in order to make the road infrastructure of Nepal disaster as well as climate resilient.

Currently, road construction and rehabilitation projects in Nepal don't consider the impacts climate change can have on road infrastructures. The only consideration that is made is on flood proofing road sections with priority, keeping in mind the 50 years and 100 years flood cycles. Significant consideration should be given to flood proofing roads that are lower in the hierarchy in order to avoid flooding and damage to the roads. These roads, although low in priority for employing flood proofing method, could be the only access point for the population living in the vicinity.

[40] Asian Development Bank (ADB). (2011). Guidelines for Climate Proofing Investment in the Transport Sector: Road Infrastructure Projects.
[41] District Road Support Programme (DRSP). (2011). Bioengineering for Slope Stabilization in Rural Road Construction in Nepal. Swiss Agency for Development and Cooperation (SDC). Ministry of Local Development, Government of Nepal.

ADB outlines the steps to screening and scoping projects in order to determine the risks associated with the infrastructure development projects due to climate change[42]. The existing framework of the Local Adaptation Plan for Action (LAPA) has similar steps but is more focused on the local level rather than the national context[43]. Key steps to plan for roads that are durable during changing climate, in developing countries like Nepal, have been adapted from ADB (2011) and Regmi and Hanaoka (2011)[44] :

I. Identification of roads that are most prone to extreme climate conditions and disasters
   a. Project screening and scoping – To screen the project's exposure to climate change and establish the objective of adaptation. In this step, identification of the key stakeholders is very important.

II. Prediction of climate events in the future in the identified areas

III. Risk analysis and impact assessment
   a. Vulnerability assessment – It is important to continuously carry out the vulnerability assessment even after the program has been implemented.
   b. Adaptation assessment – Similar to the vulnerability assessment, the adaptation assessment should also be continuous so that future adaptation practices are incorporated into the roads and the population accessing it.

IV. Planning the response to the risks present.
   a. In the context of LAPA, in this stage, the local adaptation plans are developed.

V. Life cycle costing – This will provide the decision makers with criteria in assessing the feasibility in including adaptation measures into the road structures. Priority should be given to roads that have high and medium traffic density.

VI. Design the infrastructure

VII. Implementation and construction

VIII. Monitoring and Evaluation

Identification of roads that are most vulnerable to varying climate conditions, however, is very challenging due to the uncertainty in the weather patterns as well as the differing topography of the country. In addition, majority of the roads in Nepal are earthen roads, which may require higher costs to implement the adaptation policy. As per the study carried out in Ghana to assess the cost of climate change in road infrastructure, the cost of implementation of adaptation policy is higher than the "no adapt" policy[45]. Chart 3 shows the cost difference and the study makes the inference that since majority of the roads in Ghana are unpaved, it will initially require higher cost for its government to construct roads that withstand the changes in the weather conditions. However this cost of adaptation decreases as construction and maintenance practices are much

[42] Asian Development Bank (ADB). (2011). Guidelines for Climate Proofing Investment in the Transport Sector: Road Infrastructure Projects.
[43] Local Adaptation Plans for Action (LAPA): LAPA Manual. (2011). Climate Change Management Division. Ministry of Science Technology and Environment. Government of Nepal.
[44] Regmi, M. B. Hanaoka, S (2011). A survey on impacts of climate change on road transport infrastructure and adaptation strategies in Asia. Environ Econ Policy Stud; 13:21–41.
45 Twerefou, D. K. Adjei-Mantey, K and Niko Lazar Strzepek. (2014). the economic impact of climate change on road infrastructure in sub-Saharan Africa countries: Evidence from Ghana. World Institute for Development Economic Research.

more efficient and refined.

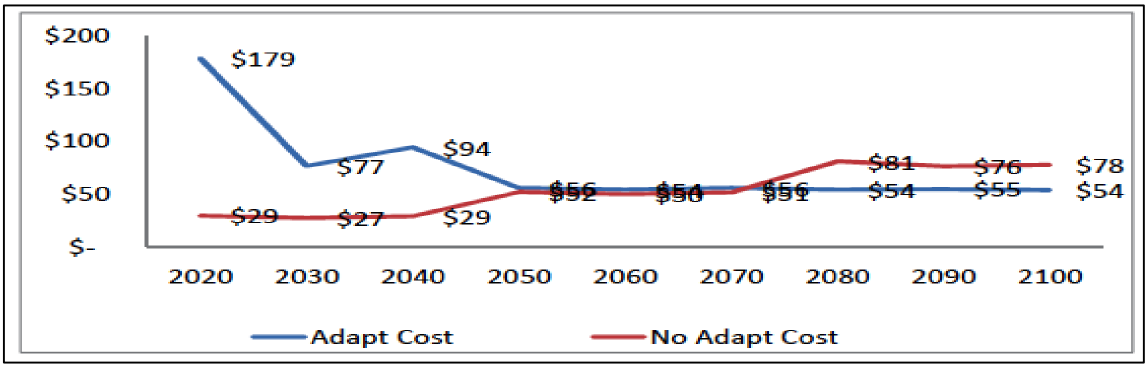


Chart 3 Investment requirement for roads in Ghana with the "adapt" and "no adapt" policy.[46]

Although the Nepali government as a policy of allocating NPR 3 million to each VDC for development including road construction and maintenance, the VDCs utilize this resource without proper design addressing the climate change issues.

5. Opportunities to make transport infrastructure climate and disaster resilient

There are many opportunities inherent in Nepal's energy generation as well as transport system that can be tapped to adopt clean transport and have a well-managed road network. From 2008 to 2013, the consumption of fossil fuels for transportation in urban areas increased by 2.2 times[47] which clearly prompts the need for shifting to cleaner energy for transportation. Since Nepal has tremendous potential of hydropower energy (43,000 MW technical feasibility), the increase in the use of electric vehicles and decrease in the use of fossil fuels, such as petrol, can minimize CO_2 emissions and pollution[48] as well as decrease Nepal's dependency on fossil fuels. In this case, proper planning is also extremely necessary to shift majority of the population's mode of transportation from private transport to public transport decreasing the stress on roads and the environment due to increasing vehicle ownership.

According to Climate Framework adapted in Nepal[49], improving the road networks and shifting to cleaner fuels through proper planning and implementation in the transport sector, is important in the effort to mitigate climate change impacts. The GHG emissions, mainly from petrol and diesel consumption in the transport sector in Nepal increased from 643.7 Gg in 1994/95 to 2442.1 Gg in 2010 and is expected to reach 3768.6 Gg by 2020. With the rate at which vehicle ownership has been increasing (13% per annum), the GHG emissions could be more than what has been estimated in the business as usual scenario. This not only will cause a steep growth in the country's carbon footprint but will also increase pollution in the urban areas. Thus, a low-carbon path in the transport sector is essential. The climate framework envisages improving the transport sector's efficiency through the following activities:

- Promoting clean energy-based alternate transport system such as railways and ropeways;
- Promoting models that improve the transport sector's efficiency and to demonstrate modal shifts;

[46] Twerefou, D. K. Adjei-Mantey, K and Niko Lazar Strzepek. (2014). The economic impact of climate change on road infrastructure in sub-Saharan Africa countries: Evidence from Ghana. World Institute for Development Economic Research.
[47] National Environmentally Sustainable Transport Strategy for Nepal, Ministry of Physical Infrastructure and Transport, United Nations Centre for Regional Development, 2014.
[48] Average PM10 concentration is higher than national standards.
[49] Climate Resilient Planning – A tool for long-term climate adaptation, National Planning Commission, Nepal, 2011

- Converting public utility vehicles to liquid petroleum gas and renewable energy sources and establishing and expanding an efficient mass transport system;
- Ensuring the movement of vehicles at optimum speed of fuel consumption by reducing congestion and maintaining road sand vehicles;
- Promotion of non-motorized transport especially dedicated bicycle lane and walk way facilities;
- Educating the public on the need for and advantages of clean energy transport; and,
- Creating awareness among the local and national stakeholders in addressing the issues of climate change and its impacts on the transport infrastructure.

With a clear vision of incorporating adaptation planning and activities at the local level, the LAPA aims at strengthening the local communities' understanding of the uncertainty in the changing climate so that they can effectively develop adaptation priorities. At the moment, 70 LAPAs in 14 districts are at the stage of implementation with emphasis on localizing climate resilient plans, flexible enough to respond to changing climate and vulnerability conditions. The adaptation options for these 14 districts have been identified with priority given to agriculture, food security, livelihood, forest, and biodiversity as well as capacity development. Adaptation measures for infrastructure development has also been identified in which approximately 50,000 climate vulnerable people receive adaptation services[50].

6. Strategic Component

In order to make Nepal's road infrastructure sustainable and resilient to climate change and disaster, the Government of Nepal needs to integrate economic, social and environmental aspects during policy formulation, project planning and implementation. In this light, the concept of Environmentally Sustainable Transport (EST), and its integration into the national policy, has been in principle, agreed by the Government of Nepal with the aim of building a sustainable transport system in the country. National strategies aiding the establishment of an EST with climate change adaptation.

I. Awareness-raising among key stakeholders at local and central level

Awareness about the vulnerability to climate change as well as the country's need to build its infrastructure to adapt to such changes, among stakeholders, is key in developing sustainable policy and practices. The stakeholders' knowledge about the challenges to the transport infrastructure and determination of specific solutions to those challenges is the most important aspect in establishing the right pathways to achieve EST. Experience in professional fields such as engineering, for technical aspects, as well as non-engineering, for economic and climate adaptation aspects, is vital in making appropriate decisions regarding policy, planning, design, construction and maintenance of disaster and climate resilience infrastructure.

In addition, the private and the public sector need to increase their level of awareness about the inter-linkages of climate variability with climate change impacts and vulnerability to infrastructure. The development of climate resilient infrastructure is a prerequisite to recognizing climate risks, which, in turn, is required to make a plan for climate resiliency.

[50] Building Climate Resilience in Nepal: Integrating Climate Change into Poverty Reduction. (2013). Second Meeting: Durban Forum on Capacity-building.

II. Developing and mainstreaming project screening guidelines for selecting and assessing climate and disaster resilient transport infrastructures. – for local and strategic roads

As transport infrastructure requires substantial amount of investment for both construction and maintenance, as well as to cope with the changing climatic conditions, increasing initial investment should be given priority. Since a majority of the roads in Nepal are earthen, immediate investment should be channeled to upgrade these roads. In addition to this, life cycle cost of the roads should be fully assessed in order to gain better insight on the initial investments required and the operations and maintenance costs required at later stages. A similar kind of study carried out in Ghana (see Figure -2) projects that the life cycle cost of building a road with climate change adaptation requirements needs higher initial investment than roads with the “no adapt” policy.

Investment costs need to be estimated by keeping in mind the costs for the risks associated with projected traffic on the road as well as climate change. The NAPA vulnerability index outlines districts that are prone to floods, landslides, and flood from glacial lake outbursts and droughts[51]. Before construction of roads in these districts, the Government of Nepal should determine the feasibility of investing in such natural disaster prone districts because migration from these districts will be high which might lead to abandonment of the roads. Thus, instead of investing on roads that might not be used in the future, the government should focus on identifying those infrastructures where investment will make a key difference in passenger mobility as well as thru traffic.

III. Integrating the strategy of “Avoid – Shift – Improve” in formulating and designing transport mode in Nepal into National Transport Policy.

The National Environmentally Sustainable Transport Strategy for Nepal stresses on integration of the “Avoid”, “Shift” and “Improve” in the policy and implementation. Since roads in Nepal are fairly new, compared to the roads in the developed countries, this strategy can be developed effectively for the optimum utilization of the existing transport infrastructure limiting the need of further road expansion. The word “Avoid” here means to prevent those travel that need not take place through extensive use of on-line market facilities; “Shift” is to move from one mode of transport to public transport or mass transit which occupy lesser road space; and “Improve” means to upgrade the existing fleet to climate change and environmentally friendly modes. With integration of this strategy into the National Policy, Nepal can decrease its CO_2 emissions as well as build transportation systems that can moderately sustain the direct and indirect impacts of climate change.

IV. Classification of road system based on location and the degree of vulnerability to the disaster and climate change impact.

In order to develop and maintain road structures that withstand to climate change and disaster impact, there is need to review and revise the existing road classification system. This will facilitate the need by identifying and monitoring road infrastructures that are susceptible to disasters. This classification will lead to developing the design standards of that particular category of road system to meet the challenges of potential disaster.

V. Developing design standards to incorporate, adapt and accommodate to the climate change impact

The design of Highways and Feeder Roads are carried out according to the Nepal Road Standards 2027 and 2045, Feeder Roads Standards (Third Revision) 1997 and Nepal Design Standards 2070.

[51] Environmental causes of Displacement, National Planning Commission, Kathmandu, 2013.

The local roads are designed as per Local Road Design Standards. These road standards needs to be reviewed in the light of climate change adaptation and disaster resilient. The general design elements that needs to be deliberated are: a) limiting the road gradients to minimize fuel consumption; b) strategy for maintaining the functionality of the road pavement; c) type and use of bitumen in road pavements; promotional use of emulsion for road pavement (low volume roads); d) extensive use of gravel with appropriate seal to extend its life (Otta-seal/grav seal); e) revising hydrological design parameters for designing drainage structures including bridges and f) extensive study of the geological, tectonic and rock quality in the area of road construction.

VI. Operationalization of road maintenance practices to minimize secondary impact caused by disaster or climate change.

Road maintenance is the priority activity of road management system. Effective maintenance system needs a) timely warning system; b) immediate response mechanism; c) regular asset condition survey; d) practice of engaging long-term maintenance contract; e) maintenance standards appropriate to the location and criticality to the vulnerability of disaster and climate change.

VII. Environmental and social safeguards

As mentioned earlier, Nepal has varied topography due to which construction of road infrastructure not easy. When planning for and constructing these kinds of roads, the policy makers and other down the chain should give careful consideration to the geography as well as Nepal's high vulnerability to earthquakes, landslides and flooding. To avoid pollution, aging vehicles should be banned and promotion of clean, newer and more efficient vehicles should be encouraged as well as vehicles should be monitored for compliance of the emission standards.

In order to enhance the mobility, integrated modal approach need to be further explored. This include short stretch river transport complemented to the road head will not only curtail the road construction in difficult terrain but also helps to safeguard the environment by minimizing the slope cutting in hills.

VIII. Enhance institutional capacity and undertake reform

The strength of the institutional capacity of the transport sector determines the potential of the sustainability aspects mentioned above. The policies for the transport sector should address all the challenges. In order to have a strong institutional capacity, the technical capacity of the private sector firms should be built, alternative transport modes should be emphasized and researched on and maintain basic database of the data on transport infrastructure as well as the different areas associated with. The establishment of linkages with the concerned agencies and stakeholders is also necessary to be able to have clear policies and guidelines.

It is also necessary to set up a database of climate change vulnerable areas in Nepal for reference in building climate resilient roads. These resources can be used to take appropriate measures for design of the roads as well as building capacity of the locals to adapt to the changes in the surrounding. Thus, the government institutions should focus on building the capacity of the local population in construction and maintenance of roads. The main aim of projects such as District Road Support Programme (DRSP), which began in 1999, was to build, rehabilitate and maintain rural roads using labor based, environmentally friendly and participatory methods[52]. In this way, the local community should be trained to understand and employ adaptation methods to minimize the effects of climate change.

[52] Building Roads and Improving Livelihoods in Nepal. (2013). External Review of the District Roads Support Programme.

7. Conclusion

Nepal has varying topography, geological, and climatic conditions that have posed challenges in building transport infrastructure that is resilient to landslides and flood. The country is also highly vulnerable to seismic waves, which is yet another fact that needs to be taken into account during construction of the road infrastructure. In addition, in the recent years, the rate of emission of CO_2 has been increasing at an alarming rate in the country causing massive pollution as well as contributing towards climate change.

With the use of the NAPA and LAPA directives, the Nepali government can employ bottom up capacity building and adaptation measures to minimize the impact of climate change on transportation infrastructure as well as the humans.

Direct and indirect impacts of climate change on transport infrastructure prompts the need for careful consideration on planning and designing infrastructure that is climate change and disaster resilient. In addition, vigorous consultation with the climate vulnerability mapping will aid the government and development stakeholders in selecting priority areas that require adaptation. Currently, numerous road projects are in the pipeline as well as in the implementation phase. In addition to road projects, the government has also taken steps to build railway system that connect to the Indian railway network. The government needs to give special consideration to the investment needs of these projects keeping in mind its economic opportunities and positive impacts. Review of these projects to integrate adaptation measures into the design and implementation phase is also extremely necessary.

Adaptation of these infrastructures to climate change impacts will have positive effects on the social, environmental as well as economic aspects of the country. The development of Environmentally Sustainable Transport (EST) primarily requires awareness among the key stakeholders in understanding climate change as well as its consequences on the livelihood of the people.

Investment needs, in the initial years, is yet another key area that the stakeholders and policy makers need to plan and discuss about. Life cycle costs should be considered in order to assess the difference in building roads with and without the adaptation measures. In the long run, not just the road costs but social and environmental costs will be higher if adaptation measures are not incorporated during planning, designing and constructing infrastructures.

Annex 1

A complete account of disasters that have negatively impacted road transportation in Nepal from 1979 to 1993

Year	Region	Type of Disaster	Description of Damage	Economic Loss
1979	• 80 m bride across Bijayapur Khola on Prithivi Highway • 60 m bridge across Karra Khola on the Hetauda – Birgunj road	Monsoon rains	Washout of road sections and minor bridges and culverts	Rehabilitation cost = Rs. 8 million
1981	• 27 km of the 114 km Arniko Highway	Floods along the Bhote Koshi caused by glacial lake outbursts from Tibet	Severely damaged	Rs. 62 M
1983/84	500 m length at various sections of the Dharan-Dhankuta Highway	Monsoon Rains	Washout	Rs. 23 M/km
1987	380 km road of all roads 50 km of 114 km of Arniko Highway	Monsoon Rains	Road failures at 37 locations with damage to 41 bridges. Total of 15 km of road and 3 bridges were completely washed out 21% of entire road was under the risk of major failure	Rehabilitation cost= Rs. 520 M to Rs. 730 M. Additional maintenance cost – Rs. 6 – Rs. 7 M/year (1990 prices)
	Several sections of the Dharan-Dhankuta Highway	Monsoon Rains Earthquake	Washout of 0.5 km of road	Rs. 10 M (1987 prices)
	3 km section near Charnawati area of the Lamosangu-Jiri road	Monsoon Rains	Washout of the Charnawati Bridge and major gullying and landslides	Rehabilitation cost – Rs. 190 M (between 1987 and 1991)
	Thankot- Naubise	Monsoon	Washout	Rehabilitation cost = Rs. 91 M (1991

	Road	Rains		prices)
	East West Highway	Monsoon Rains	Damage to bridges, river protection and several road sections	Rehabilitation costs = Rs. 168 M (1991 prices)
1991	33 m span bridge over the Seti Gorge on the Prithvi Highway	Heavy Rainfall	Severe undercutting of banks of Seti River caused the collapse of the bridge	
1993	• Prithvi Highway	Heavy Rainfall Flood	Massive damage	Rehabilitation cost = Rs. 1290 M (1993 prices)
			22 m out of 44m of Malekhu Bridge, 66m of Balkhu Bridge and 66 m of 88 m Mahadevbesi bridge washed out Failures of retaining structures in 60 places	Rs. 572 M
	• Tribhuvan Rajpath, Naubise – Hetauda Section	Flood	3 bridges (10m, 6m and 7m), 23 culverts and 534m of road completely washed out Retaining structures failure along more than 103 m of road	
		Landslides	Road failures in a total of 1019 m road 2 bridges damaged 15 km of roads in six sections were the most affected	
	• East-West Highway	Flood	10 bridges were damaged including minor damage to the embankment	Rs. 48 M
	• Phidim-Taplejung Highway	Landslides	16 km damaged	Rs. 23 M
	• Bardibas – Sindhuli Road • Dhalkebar – Birtamod road			