Template/Pro forma for Submission

NMHS-Himalayan Institutional Project Grant

NMHS-FINAL TECHNICAL REPORT (FTR)

Demand-Driven Action Research and Demonstrations

NMHS Grant Ref. No.:	**NMHS/201920/SG64/64**

Date of Submission:	1	5	1	2	2	0	2	2
	d	**d**	**m**	**m**	**y**	**y**	**y**	**y**

PROJECT TITLE (IN CAPITAL)

ANALYSIS OF EVACUATION OPTIONS CONSIDERING CITIZEN MOBILITY PATTERNS AND DISASTER VULNERABILITY IN A HIMALAYAN REGION TRANSPORTATION NETWORKS

Project Duration: *from* (**10.10.2019**) *to* (**10.10.2022**).

***Submitted to*:**
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GENERAL INSTRUCTIONS:

1. The Final Technical Report (FTR) has to commence from the start date of the Project (as mentioned in the Sanction Order issued by NMHS-PMU) till completion of the project duration. Each detail has to comply with the NMHS Sanction Order.
2. The FTR should be neatly typed (in Arial with font size 11 with 1.5 spacing between the lines) with all details as per the enclosed format for direct reproduction by photo-offset printing. Colored Photographs (high resolution photographs), tables and graphs should be accommodated within the report or annexed with captions. Sketches and diagrammatic illustrations may also be given detailing about the step-by-step methodology adopted for technology development/ transfer and/ or dissemination. Any correction or rewriting should be avoided. Please provide all information under each head in serial order.
3. Any supporting materials like Training/ Capacity Building Manuals (with detailed contents about training programme, technical details and techniques involved) or any such display material related to project activities along with slides, charts, photographs should be brought at the venue of the Annual Monitoring & Evaluation (M&E) Workshop and submitted to the NMHS-PMU, GBP NIHE HQs, Kosi-Katarmal, Almora 263643, Uttarakhand. In all Knowledge Products, the Grant/ Fund support of the NMHS should be duly acknowledged.
4. The FTR Format is in sync with many other essential requirements and norms desired by the Govt. of India time-to-time, so each section of the NMHS-FTR needs to be duly filled by the proponent and verified by the Head of the Lead Implementing Organization/ Institution/ University.
5. Five (5) hard-bound copies of the Project Final Technical Report (FTR) and a soft copy of the same should be submitted to the **Nodal Officer, NMHS-PMU, GBP NIHE HQs, Kosi-Katarmal, Almora, Uttarakhand**.

The FTR is to be submitted into following two (02) parts:

Part A – Project Summary Report

Part B –Detailed Project Report

In addition, the Financial and other necessary documents/certificates need to be submitted along with the Final Technical Report (FTR) as follows:

Annexure I	**Consolidated and Audited Utilization Certificate (UC) & Statement of Expenditure (SE)**, including the interest earned for the last Fiscal year and the duly filled GFR-19A (with year-wise break-up).
Annexure II	**Consolidated Interest Earned Certificate**
Annexure III	**Consolidated Assets Certificate** showing the cost of the equipment in Foreign/ Indian currency, Date of Purchase, etc. (with break-up as per the NMHS Sanction Order and year wise).
Annexure IV	**List of all the equipment, assets and peripherals** purchased through the NMHS grant with current status of use, including location of deployment.
Annexure V	**Transfer of Equipment** through Letter of Head of Institution/Department confirming the final status of equipment purchased under the Project.
Annexure VI	**Details, Declaration and Refund of any Unspent Balance transferred through Real-Time Gross System (RTGS)/ PFMS in favor of NMHS GIA General**

NMHS-Final Technical Report (FTR) *template*

Demand-Driven Action Research Project

DSL: Date of Sanction Letter

3	0	0	9	**2**	**0**	**1**	**9**
d	d	m	m	y	y	y	y

DPC: Date of Project Completion

1	0	1	0	**2**	**0**	**2**	**2**
d	d	m	m	y	y	y	y

Part A: Project Summary Report

1. Project Description

i.	Project Grant Ref. No.:	NMHS/2019-20/SG64/64					
ii.	Project Category:	Small Grant	✓	Medium Grant		Large Grant	
iii.	Project Title:	Analysis of Evacuation Options Considering Citizen Mobility Patterns and Disaster Vulnerability in a Himalayan Region Transportation Network					
iv.	Project Sites (IHR States/ UTs covered) (*Location Maps attached*):	Sikkim					
v.	Scale of Project Operation:	Local	✓	Regional		Pan-Himalayan	
vi.	Total Budget:	0.45 (in Cr)					
vii.	Lead Agency:	Indian Institute of Technology (IIT) Delhi					
	Lead PI/ Proponent:	Dr. Manoj M., Asst. Professor, Départment of Civil Engineering, IIT Delhi					
	Co-PI/ Proponent:	Dr. Dhanya C.T. and Prof. Geetam Tiwari, Indian Institute of Technology (IIT) Delhi Dr. Bhavathrathan, Indian Institute of Technology (IIT) Palakkad Dr. Rahul T.M., Indian Institute of Technology (IIT) Ropar					
viii.	Implementing Partners:	Addl. Chief Town Planner, Urban Housing Department, Govt. of Sikkim (***Full project support and sharing data; Support letter enclosed; Appendix-7***)					
	Key Persons (Contact Details, Ph. No., E-mail):	Dr. Manoj M., Asst. Professor, Départment of Civil Engineering, IIT Delhi. Email : manojm@civil.iitd.ac.in; Ph : 011 2659 1219					

2. Project Outcomes

2.1. Abstract/ Summary (not more than 250-300 words)

Background: The Indo-Himalayan region is vulnerable to many natural extremities such as landslides, earthquakes, flashfloods, among others. Post-disaster, the main issue is the evacuation of the population that has been affected by the event and ensuring mobility.

Objectives/Aim: The project aims to develop a computer-based scenario analysis set-up to investigate the performance of transport network and population allocation under business-as-usual transport demand scenarios and disaster (e.g., flashfloods, rainfall induced landslides) situations. The scenario analysis would also inform the potential population allocation/evacuation strategies to be considered during adversity.

Methodology: The study involves data collection from several secondary and primary sources and transport modelling and optimization analysis to discuss infrastructure availability and possible transport network-based evacuation. Details of study methodology is presented in **Appendix-1**.

Approach: The project involves the following stages: (a) Description of travel demand, transport supply, rainfall patterns, and disaster vulnerability (b) Transport network and zonal vulnerability analysis due to disasters (c) Transport network-based evacuation analysis

Results: Based on the input data, the project proposed a method to select shelter point locations that maximizes the post-disaster connectivity reliability and developed a computer program that utilizes optimization algorithm for solving the problem of locating the most nearby shelter point locations. A web-interface for the program has been developed that can be used by the disaster management operators to monitor the path reliability between demand-supply nodes and relief points and designate a suitable number of people from the desired demand nodes to relief points.

Conclusion: In business-as-usual traffic conditions, the allocation of entire population could be challenging because of the heavy traffic congestion involved. Only a fraction of the overall population could be considered for allocation in such situations. However, the potential for analyzing the complete-population allocation framework could be developed with the help of the methodology explained here.

Recommendations: The project recommends a comprehensive audit of the transportation network in Gangtok, and planning shelter locations considering the spatial trends in natural disasters and network accessibility. The general transportation plans can consider the zonal and network vulnerability under different disasters while deciding upon land use and transport policies.

Exit Strategy: The project outcomes will be handed over to the funding agency and the details will also be shared with interested parties upon genuine request and after the publication of manuscript. The project proponents would also seek funding from different agencies to continue their research on the subject.

2.2. Objective-wise Major Achievements

S. No.	Objectives	Major achievements (in bullets points)
1	*To understand present and future citizen mobility needs, rainfall patterns, and transport network structure in Gangtok city of Sikkim*	• Development of transportation demand model and application • Digital maps/data of the road network (88 Km) with attributes on road geometry and estimated capacity • Established travel desire line diagrams showing the O-D travel demand in the city • An exploratory study on rainfall trends in the study region
2.	*To rank travel zones based on vulnerability induced by rainfall, mobility patterns and transport network structure*	• Conducted zonal and network-level vulnerability analysis • Developed risk matrices for links by hazard category and link volume • Performed zonal-level vulnerability analysis and ranked zones based on vulnerability by different disaster types on road links
3	*To suggest possible transport-related evacuation strategies based on scenario analysis*	• Outcomes of scenario analysis based on mathematical programs have been discussed
4	*To develop a computer program to (a) assess present and future transport demand and supply for business-as-usual scenario (b) aid evacuation strategies during transport network disruption due to extreme rainfall events*	• A GIS-based travel demand model developed for assessing travel demand • A computer program based on mathematical optimization tool to assess evacuation strategies considering the vulnerability of zones and transportation network • A web-based portal – integrating outcomes of travel demand model, link vulnerability analysis and scenario analysis tool – to understand the availability of shelter locations and reliability of network

Note: Further details may be summarized in DPR Part-B, Section-5. Supporting materials may be enclosed as annexure/ appendix separately to the FTR.

2.3. Outputs in terms of Quantifiable Deliverables*

S. No.	Quantifiable Deliverables*	Monitoring Indicators*	Quantified Output/ Outcome achieved	Deviations made, if any, & Reason thereof:
1	Digital maps/data of the road network (88 Km) with attributes on geometry and estimated capacity.	Digitized the road connectivity (Km)	Shape files of road links and transportation network	No deviation

2	Assessment report of the business-as-usual traffic flow for 2021 and 2031 (at around 40 location; 18-20 NH and 20-22 SH Location)	Established travel desire line (Nos of Wards)	O-D matrix/travel desire line diagrams using travel demand model	No deviation
3	Evacuation strategies/plans under different disaster scenarios (5-8 disasters)	Report / Chapter discussing scenario analysis	1 chapter summarizing study findings	Deviation – 3 scenarios and combinations scenarios considered
4	Reports on Transport network component ranking based on criticality index	Database generated (Nos.) + Reports/Chapter	Database on zone and link vulnerability indices + 1 chapter discussing the development of indices	No deviation
5	Computer based program to assess transport demand and evacuation strategies	Computer Programme developed (Nos.)	1 GIS-based travel demand modelling program + 1 optimization algorithm to plan evacuation strategy and its web interface implementation	No deviation
6	At least 03 Knowledge products: 01 Research publications including journal articles, 01 book chapters, and 01 policy briefs.	No. of Reports/Research articles/Policy documents prepared and published (Nos.)	1 International conference paper + 1 National conference paper+ 1 Journal paper to be submitted + 1 book chapter to be submitted	Deviation – the journal article is planned to be submitted to a special issue, whose advertisement came recently [**Journal '*Sustainability'***] +Waiting for a suitable call for book chapters

*As stated in the Sanction Letter issued by the NMHS-PMU.

2.4. Strategic Steps with respect to Outcomes (in bullets)

S#	Particulars	Number/ Brief Details	Remarks/ Attachment
1.	New Methodology/ Technology developed, *if any*:	Mathematical model for identifying shelter locations have been formulated	Section-7, Appendix-1
2.	New Ground Models/ Process/ Strategy developed, *if any*:	A web-based interface set up has been proposed	Section-8, Appendix-1
3.	New Species identified, *if any*:	*Not applicable*	

S#	Particulars	Number/ Brief Details	Remarks/ Attachment
4.	New Database established, *if any:*	A database on O-D patterns, traffic capacity and volume, and accessibility of shelter points	Data have been submitted
5.	New Patent, *if any*:	*Not applicable*	
	I. Filed (Indian/ International)		
	II. Technology Transfer, *if any*:		
6.	Others, *if any*	*Not applicable*	

Note: Further details may be summarized in DPR Part-B, Section-5. Supporting materials may be enclosed as annexure/ appendix separately to the FTR.

3. New Data Generated over the Baseline Data

S. No.	New Data Details	Status of Existing Baseline	Additionality and Utilisation New data
1	Audit of shelter points	Data do not exist	In identifying possible shelter points for evacuation
2	Traffic volume data and O-D survey data	2010 data available and outdated	In transport modelling and network vulnerability assessment
3	Road inventory data	2010 data available and outdated	In transport modelling and network vulnerability assessment

Note: Further details may be summarized in DPR Part-B. Database files in the requisite formats (Excel) may be enclosed as annexure/ appendix separately to the soft copy of FTR.

4. Demonstrative Skill Development and Capacity Building/ Manpower Trained

S#	Type of Activities	Details with number	Activity Intended for	Participants/Trained			
				SC	**ST**	**Women**	**Total**
1.	Workshops	1 virtual workshop held on 01-10-2022	Training and knowledge dissemination				**56**
2.	On-Field Trainings	*Not applicable*					
3.	Skill Development	*Not applicable*					
4.	Academic Supports	Used project findings to teach/train post-graduate and undergraduate students	To train students about the methods required for planning post-disaster evacuation (Course ID: CVL741 at IIT Delhi)				**33**
	Others (if any)	*Not applicable*					

Note: Further details may be summarized in DPR Part-B. Supporting materials may be enclosed as annexure/ appendix separately to the FTR.

5. Linkages with Regional & National Priorities (SDGs, INDC, etc.)/ Collaborations

S#	Linkages /collaborations	Detail of activities (No. of Events Held)*	No. of Beneficiaries
1.	Sustainable Development Goals (SDGs)/ Climate Change/INDC targets addressed	*Not applicable*	
2.	Any other:	*Not applicable*	

Note: Further details may be summarized in DPR Part-B, Section-6. Supporting materials may be enclosed as annexure/ appendix separately to the FTR.

6. Project Stakeholders/ Beneficiaries and Impacts

S#	Stakeholders	Support Activities	Impacts in terms of income generated/green skills built
1.	Line Agencies/ Gram Panchayats:	*Not applicable*	
2.	Govt Departments (Agriculture/ Forest/ Water):	Urban housing and development department, Govt. of Sikkim	Full research support, data sharing and insights into model development
3.	Villagers/ Farmers:	*Not applicable*	
4.	SC Community:	*Not applicable*	
5.	ST Community:	*Not applicable*	
6.	Women Group:	*Not applicable*	
	Others, *if any*:		

Note: Further details may be summarized in DPR Part-B, Section-6. Supporting materials may be enclosed as annexure/ appendix separately to the FTR.

7. Financial Summary (Cumulative)

Please attach the consolidated and audited Utilization Certificate (UC) and Year-wise Statement of Expenditure (SE) separately, *ref*. **Annexure I.**

Enclosed

8. Major Equipment/ Peripherals Procured under the Project** (*if any*)

S#	Name of Equipment	Quantity	Cost (INR)	Utilisation of the Equipment after project
1.	Arc GIS Software License	3 (1 license for each partner institute)	450000.00	For geospatial database development and modelling; for teaching PG and UG students
2.				

Details should be provided in details **(*ref.* Annexure III &IV).

9. Quantification of Overall Project Progress

S. No.	Parameters	Total (Numeric)	Remarks/ Attachments/ Soft copies of documents
1.	IHR States/ UTs covered:	1	
2.	Project Sites/ Field Stations Developed:	1	
3.	Scientific Manpower Developed (PhD/M.Sc./JRF/SRF/ RA):	1	
4.	Livelihood Options promoted	*Not applicable*	
5.	Technical/ Training Manuals prepared	*Not applicable*	
6.	Processing Units established, if any	.... (attach photos)	
7.	No. of Species Collected, if any	*Not applicable*	
8.	No. of New Species identified, if any	*Not applicable*	
9.	New Database generated (Types):	3	*Data has been shared*
	Others (if any)	*Not applicable*	

Note: Further details may be summarized in DPR Part-B. Supporting materials may be enclosed as annexure/ appendix separately to the FTR.

11. Knowledge Products and Publications:

S#	Publication/ Knowledge Products	*Number*		*Total Impact Factor*	*Remarks/* Enclosures
		National	International		
1.	Journal – Research Articles/ Special Issue:		1		To be submitted
2.	Book – Chapter(s)/ Monograph/ Contributed:		1		To be submitted
3.	Technical Reports:				
4.	Training Manual (Skill Development/ Capacity Building):				
5.	Papers presented in Conferences/Seminars:	1	1		Attached in Appendix-2
6.	Policy Drafts/Papers:				
7.	Others, if any:				

Note: Please append the list of KPs/ publications (with impact factor, DOI, and further details) with due Acknowledgement to NMHS. Supporting materials may be enclosed as annexure/ appendix separately to the FTR.

12. Recommendation on Utility of Project Findings, Replicability and Exit Strategy

Particulars	Recommendations
Utility of the Project Findings:	The project findings help assess the criticality of traffic analysis zones and transportation network links in terms of traffic demand and disaster susceptibility, and also help assess and plan population evacuation by considering the transportation network and zonal conditions.

Replicability of Project/ Way Forward:	It is possible to replicate the project findings with data collected from different time points in Gangtok or any other hilly region in the country.
Exit Strategy:	The project outcomes will be handed over to the funding agency and the details will also be shared with interested parties upon genuine request and after the publication of manuscript. The project proponents would also seek funding from different agencies to continue their research on the subject.

Dr. MANOJ M.
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(PROJECT PROPONENT/ COORDINATOR)

(Signed and Stamped)

निदेशक भा. प्रौ. सं.दि. की ओर से
For & on behalf of the Director, IIT Delhi

प्रो. सुकुमार मिश्र
Prof. Sukumar Mishra
सह-अधिष्ठाता (अनुसंधान एवं विकास)
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हौज़ खास, नई दिल्ली-110016
Hauz Khas, New Delhi-110016

(HEAD OF THE INSTITUTION)

(Signed and Stamped)

Place: IIT Delhi
Date: 08/12/2022

PART B: DETAILED PROJECT REPORT

The Detailed report should include an Executive Summary and it should have separate chapters on (i) **Introduction**, (ii) **Methodologies/Strategy/Approach**, (iii) **Key Findings and Results**, (iv) **Overall Achievements**, (v) **Project's Impacts in IHR** (vi) **Exit Strategy** and Sustainability, (vii) **References**, and (viii) **Acknowledgements** (acknowledging the financial grant from the NMHS, MoEF&CC, GoI).

Other necessary details/ Supporting Documents/ Dissemination Materials (*New Products/ Manuals/ Standard Operating Procedures (SOPs)/ Technology developed/Transferred, etc, if any*) may be attached as Appendix(ces).

1 **EXECUTIVE SUMMARY** (not more than 2–3 pages)

Extreme weather events and natural and manmade hazards are on the rise in different parts of the world. Globally, several thousands of people are affected due to the impacts of such incidents. One of the important issues, which have implications for the life and well-being of populace, is planning of evacuation of the population affected by a disaster event. Although, there have been studies focusing on allocating population to different relief/shelter points and monitoring system performance and evacuation strategies, very limited information exists about cities in developing economies and particularly in cities of hilly regions. Besides, the models/computer programs considering population allocation, in general, exclude the disaster vulnerability and condition of transportation networks.

Indian cities and towns have been witnessing frequent incidences of different disaster situations. The availability of transport infrastructure and effective transport plans are essential to the safe evacuation and overall economic well- being of citizens during extreme events. The contexts of cities and their geography decide the transport-based evacuation plans. While there are studies emphasizing on transport-based evacuation plans for urban areas during extreme events such as sea level rise, urban flooding, and earthquakes, very few have emphasized on towns and cities in hilly regions. The present project aims to contribute to the knowledge of transport network-based evacuation for a city in a hilly region in India. The project focuses on the mobility patterns, disaster vulnerability and transport network-based evacuation plans in the context of Gangtok city, Sikkim. Although the focus of the project is to contribute to the broad theme of population allocation to shelter locations (evacuation analysis), the scope of the project is limited to the following. The project discusses potential evacuation strategies as aggregate population allocation problem. This is achieved by using an aggregate travel demand model and transport network and zonal disaster vulnerabilities identified using disaster susceptibility maps and link-level volumes. The disaster vulnerability due to rainfall is captured using susceptibility maps related to flash floods and landslides. The potential suggestions are based on the statistical analysis and optimization model findings and are related to the data and model assumptions made in the project.

The project employed a sequential approach to accomplish the project objectives. Using baseline transportation planning and transportation network data, the project calibrated a four-stage model understand the transport network loading under different transport demand scenarios. The model predicts travel demand for 2021 and 2031 based on the population and employment projections and assuming business-as-usual transportation network scenario. The model provided link-level loadings based on traffic volume and helped understand the critical road links in the city for the future transportation demand scenarios. After the transport model building exercise, the project explored the rainfall trends in the study area utilizing both secondary sources and an extreme rainfall analysis. To better understand the rainfall effects, the project also explores how the amount of rainfall precipitation is related to runoffs and soil moisture conditions. The study used the early warning system [http://inrm.co.in/Applications/IMD_FF/leaflet_map_Index.html] available in IIT Delhi to understand the river flows and soil moisture conditions. It is found that the amount of rainfall is highly correlated with the discharge and soil moisture conditions under Brahmaputra basin. Taking a cue from this finding, the project considered landslide and flash flood as the disasters, indicative of extreme rainfall 'disaster', to understand the network vulnerability under different individual disasters and their combinations. Subsequently, the project identified and estimated the criticality of transportation links in the city, and link vulnerability matrices were estimated for individual and combinations of disaster scenarios, and travel demand. The vulnerable links are identified based on susceptibility maps and PCU values obtained from the travel demand model. A risk matrix has been formulated by ranking the PCU value of a link and vulnerability level obtained from hazard susceptibility map. The length of vulnerable links is calculated for every zone for various vulnerability levels. Then finally, the weighted length is calculated for every zone for ranking the zones based on the link vulnerability. The risk matrices have been developed for flash floods, landslides, and earthquake hazards. Utilizing the primary data on spatial audit of shelter locations, and the details of disaster vulnerability of zones and network links, the project developed a computer program following optimization formulation based on Reliable Facility Location Problems (RFLPs). It used a combination of two components: the degradation state and the traffic state of the road network to define the post-disaster network state and employ it in shelter location selection.

The project reveals that the overall travel demand in the city is growing, and the impacts of traffic demand is visible on its road infrastructure. The major roads of the city, such as NH-10, have v/c ratios reaching >2 in future demand scenarios. In addition, most of the critical infrastructure is located in highly disaster-susceptible locations. This shows that the criticality of transportation network and zones have to be considered in the transportation planning for the region. In addition, the situation also calls for considering the disaster vulnerability of transportation links while proposing evacuation options. The mathematical program for scenario analysis incorporated this information. The scenario analysis shows that the allocation pattern considering susceptibility of the hazard and connectivity reliability of the network could be significantly different from a straight-forward relief-point allocation where that relief point which is at the shortest distance is usually allocated to a population centroid. It can also be seen that the capacity of relief points plays a primary role in allocating the population centroids to their respective relief points. From the allocation pattern, it is also evident that when multiple relief points are to be allocated to a population centroid, its nearest relief point need not always have to be allocated with the higher proportion of demand. The project finally embedded the outputs of the travel demand model, link vulnerability analysis and the computer program onto a Python-html programming-based web interface. The test bed of the interface is available at [https://fast-woodland-42116.herokuapp.com/init/].

2 INTRODUCTION

2.1 Background (max. 500 words)

Extreme weather events and associated challenges have been on the rise in many parts of the world. Indian cities and towns have been witnessing frequent incidences of such weather situations. The availability of transport infrastructure and effective transport plans are essential to the safe evacuation and overall economic well- being of citizens during extreme events. The contexts of cities and their geography decide the transport-based evacuation plans. While there are studies emphasizing on transport-based evacuation plans for urban areas during extreme events such as sea level rise, urban flooding, and earthquakes, very few have emphasized on towns and cities in hilly regions. The present project aims to contribute to the knowledge of transport network-based evacuation for a city in a hilly region in India. The project focuses on the mobility patterns, disaster vulnerability and transport network-based evacuation plans in the context of Gangtok city, Sikkim.

Gangtok is the capital city of smallest state, Sikkim, in the North-eastern Himalayan region of India. It is also the administrational and divisional headquarters of the East district of Sikkim. Sikkim is located in the Himalayan region and is characterized by high altitudes and mountain peak regions. The mountain peaks like Kanchenjunga, world's third largest mountain and Nathula pass are in Sikkim. The place Gangtok came into existence and considered it as the pilgrimage center from 1840. Until then, the city was remained as small hamlet of hermitic Gangtok monastery until the construction of Enchey Monastery. The city turned into the capital city of Sikkim after the invasion of the British. Due its geographical location, the state boosts with biological wealth and cultural diversity. The state stands top in terms of human resources index, blessed with the Himalayan scenic beauties and high ranges of Himalayan Mountains with rich biodiversity, culture, peace and tranquillity (DDF Consultants Pvt. Ltd., 2010). As Gangtok is the only major urbanized centre in the state, the population and population growth of this city is noteworthy when compared with the other hilly regions of the state. The national highway, NH-10, passes through the major parts of Gangtok city and reaches up to Siliguri, a major town in the state of West Bengal. The nearest airport is at Bagdogra, which is about 124 km away from the city (DDF Consultants Pvt. Ltd., 2010).

2.2 Overview of the major issues addressed (max. 500 words)

Sikkim is considered as a disaster-prone area, especially landslide hazards of varying magnitudes. Being in the seismic zone IV, the state is also considered as an earthquake prone region as well. Characterized by heavy rainfall and other anthropogenic factors, the Sikkim region has witnessed major landslides. Road network is the major transport infrastructure, which has been affected due to landslides. This type of situations occurs mainly during the time of monsoons, affecting daily human life, and disruptions to communication, and commercial and tourism activities. The movements of tectonic plates in the hilly terrain region trigger landslides. Besides, human activities such as deforestation, mining and other heavy infrastructure construction also disturb the geographical and geotechnical stability of the region. Also, rainfall is one of the contributors of extreme geographical events in Gangtok. The city receives precipitation for 150-180 days in a year and the average annual rainfall notches approximately to 3000mm. There have been several instances of rainfall-induced landslides in the city. The lifeline of the city, NH-10, has experienced blockages due to landslides induced by rainfalls, making the city remain separated from the rest of the country. Therefore, assessing the disaster vulnerability of transportation networks and how that affects population evacuation during an extreme event is relevant for the city.

2.3 Baseline Data and Project Scope (max. 500 words)

The proponents have procured secondary mobility data from the Urban Housing Department related to the comprehensive mobility plan for Gangtok city in 2010 and the cable car project 2019. This secondary data is then updated using primary travel demand, traffic volume, road network inventory and shelter point audit surveys collected through the project. Information on rainfall trends, and disaster susceptibility details of the region were also procured from secondary sources.

The scope of the project is limited to the following:

- The project discusses potential evacuation strategies as aggregate population allocation problem. This is achieved by using an aggregate travel demand model and transport network and zonal disaster vulnerabilities identified using disaster susceptibility maps and link-level volumes.
- The disaster vulnerability due to rainfall is captured using susceptibility maps related to flash floods and landslides. The rainfall analysis is primarily based on secondary data analysis and a primary analysis on extreme rainfall.
- The potential suggestions are based on the statistical analysis and optimization model findings and are related to the data and model assumptions made in the project.

2.4 Project Objectives and Target Deliverables (as per the NMHS-Sanction Order)

The following are the objectives of the project, as per the NMHS Sanction order:

1. To understand present and future citizen mobility needs, rainfall patterns, and transport network structure in Gangtok city of Sikkim.

2. To rank travel zones based on vulnerability induced by rainfall, mobility patterns and transport network structure.

3. To suggest possible transport-related evacuation strategies based on scenario analysis.

4. To develop a computer program to (a) assess present and future transport demand and supply for business-as-usual scenario (b) aid evacuation strategies during transport network disruption due to extreme rainfall events.

The following are the project deliverables, as per the project sanction order:

1. Digital maps/data of the road network (88 Km) with attributes on geometry and estimated capacity.
2. Assessment report of the business-as-usual traffic flow for 2019 (at around 40 location; 18-20 NH and 20-22 SH Location).
3. Evacuation strategies/plans under different disaster scenarios (5-8 disasters).
4. Reports on transport network component ranking based on criticality index.
5. Computer based program to assess transport demand and evacuation strategies.
6. At least 03 Knowledge products: 01 Research publications including journal articles, 01 book chapters, and 01 policy briefs.

3 METHODOLOGIES/STARTEGY/ APPROACH – *supporting documents to be attached.*

3.1 Methodologies used (max. 500 words)

The project employed a sequential approach to accomplish the project objectives. Using both primary and secondary data, the project first established the travel demand in terms of production and attraction and the pattern of movements in terms of origins and destinations. Based on the calibrated models for trip production and attraction, the control total for the TAZs of the city are established and a synthetic gravity model was applied to identify the trip patterns in the city. Subsequently, a modal split model was applied on the trip matrix to get the travel demand by different modes, and finally a traffic assignment algorithm was applied to identify the link-level volumes on the network. Both the demand model and the transportation network was calibrated with close association of the Urban Housing Department office, in Gangtok, Sikkim. The calibrated four-stage model was then utilized to understand the transport network loading under different transport demand scenarios. The model predicts travel demand for 2021 and 2031 based on the population and employment projections and assuming business-as-usual transportation network scenario.

After the transport model building exercise, the project explored the rainfall trends in the study area utilizing both secondary sources and an extreme rainfall analysis. From the analysis of the past 12-year rainfall data, we observed that the Gangtok district receives an average of 2500 mm of annual rainfall. Approximately 70% of the rainfall is observed during the southwest monsoon season (June-September).

Further, the project conducted extreme event analysis for Gangtok city (27°33' × 88°61'), using daily gridded (0.25° × 0.25°) (Pai et al., 2014) precipitation data from January 1951 to December 2019, provided by India Meteorological Department (IMD). Extreme rainfall intensity events were extracted using an annual maxima approach, where the maximum intensity event (events falling above 90th percentile of long-term precipitation series is selected) for a given duration (1, 2, 3, 4, 5, and 6 days) was extracted for each year. Since, the time series was long-term and enough data was available, the alternative Peaks Over Threshold (POT) analysis was not adopted. Also, it was felt that POT method may not ensure independent selection of events and may also lead to inconsistency in the frequency of extremes considered. The annual maximum intensity time series for each duration was fitted to the Generalized Extreme Value (GEV) distribution, owing to the distribution's accurate performance and popular usage pertaining to extreme event analysis. To better understand the rainfall effects, the project also explores how the amount of rainfall precipitation is related to runoffs and soil moisture conditions. The study used the early warning system [http://inrm.co.in/Applications/IMD_FF/leaflet_map_Index.html] available in IIT Delhi to understand the river flows and soil moisture conditions. It is found that the amount of rainfall is highly correlated with the discharge and soil moisture conditions under Brahmaputra basin. Taking a cue from this finding, the project considered landslide and flash flood as the disaster, indicative of extreme rainfall 'disasters', to understand the network vulnerability under different individual disasters and their combinations. Based on this, the project identified and estimated the criticality of transportation links in the city, and link vulnerability matrices were estimated for individual and combinations of disaster scenarios, and travel demand. The vulnerable links are identified based on susceptibility maps and PCU values obtained from the travel demand model. A risk matrix has been formulated by ranking the PCU value of a link and vulnerability level obtained from hazard susceptibility map. The length of vulnerable links is calculated for every zone for various vulnerability levels. Then finally, the weighted length is calculated for every zone for ranking the zones based on link vulnerability. The risk matrices have been developed for flash floods, landslides, and earthquake hazards.

Using the information from the above steps, and the primary data on spatial audit of shelter locations, the project developed a computer program following optimization formulation based on Reliable Facility Location Problems (RFLPs). It used a combination of two components: the degradation state and the traffic state of the road network to define the post-disaster network state and employ it in shelter location selection. The former component is inferred from susceptibility maps generated using historic disaster data and existing models and represented as link-vulnerability on each link of the road network. The latter component, i.e., the post-disaster traffic state, is in fact a function of the former, and of the pre-disaster traffic and the predictability of the disaster in question. Capacity (supply) is assumed to be available at all the relief points to meet the demand from the demand nodes (expressed in terms of a fraction of population of each zone). The reserve capacity values are estimated for each link by deducting the assigned traffic from its assumed capacity. Their average values are then found out, for obtaining the reserve capacities of all the paths. Connectivity reliability values are also estimated for all node-node combinations. The optimization program was then used to perform scenario analysis. The project finally embedded the outputs of the travel demand model, link vulnerability analysis and the computer program onto a Python-html programming-based web interface. The test bed of the interface is available at [https://fast-woodland-42116.herokuapp.com/init/].

3.2 Data collected and Equipments utilized (max. 500 words)

Scientific data:

- TAZ-level population and employment for four-stage model development
- Spatial data on sub-arterial, arterial, national, and state highways for transportation network development
- Road inventory data for transportation network development
- Traffic volume data for transportation network link capacity estimation
- Spatial audit of shelter points
- Disaster susceptibility maps for various disasters
- Secondary data on rainfall

Software/Equipment:

- ArcGIS Package – For storing, sorting and visualizing spatial data
- PTV VISUM – For travel demand modelling and traffic assignment
- Python-HTML Interface – For web-based interface development
- Python – For solving facility location choice optimization problems

3.3 Details of Field Survey conducted, if any (max 500 words)

Survey	Outputs	Method	Remarks
Land use data	• Population and employment data by TAZs	Secondary data	Use in travel demand modeling
O-D survey	• External to internal trips • Internal to external trips	Questionnaire based	OD data at cordon points
Road Inventory Survey	• Road Geometry • Capacity Restriction Points	Manual survey	Use in improving the road network
Traffic Volume Survey	• Mid-block volume count at NH • Intersection volume count within zone on major road	Video recording	Use in validation and correction of OD matrix
Relief/Shelter point inventory survey	• Existing conditions • Accessibility	Manual survey	For use in scenario analysis

3.4 Strategic Planning for each activity with time frame (max. 200 words)

The project is divided into main activities such as data collection, transport network digitization, travel demand modelling and demand prediction, and development of a computer program to conduct scenario analysis. In the first stage of the project, data were collected from government offices, previous studies, and primary surveys. The data regarding the origin-destination of travel, rainfall trends, and network inventory were also collected. Detailed on-field surveys were conducted to collect the details like traffic volume count, shelter point inventory, spot speed, road inventory details, and OD movements in Gangtok. The data were assembled on GIS platforms for further analysis and visualization.

In the second stage of the project, transport network and traffic analysis zones were digitized. The mobility patterns of citizens were represented as origin-destination flows – generated through the travel demand model – which were observed for 2021 and 2031 using business-as-usual transportation network scenarios. Using the link-level loadings and inputs from an exploratory rainfall analysis, and using the susceptibility maps for disasters such as land slide, flash flood, and earthquake, the project developed link criticality matrices to assess vulnerability of transportation networks and traffic analysis zones.

In the final stage of the project, a computer program is developed to allocate population to different shelter points considering shelter point capacity and vulnerability of transportation links. The program performs scenario analysis under different disasters and with different levels of population demand and outputs the population demand to be allocated to shelter points and the criticality of transportation links.

The outcomes of the travel demand analysis, link vulnerability analysis and the scenario analysis are also embedded in a web-based interface. The timeline adopted in the project is shown in the following figure.

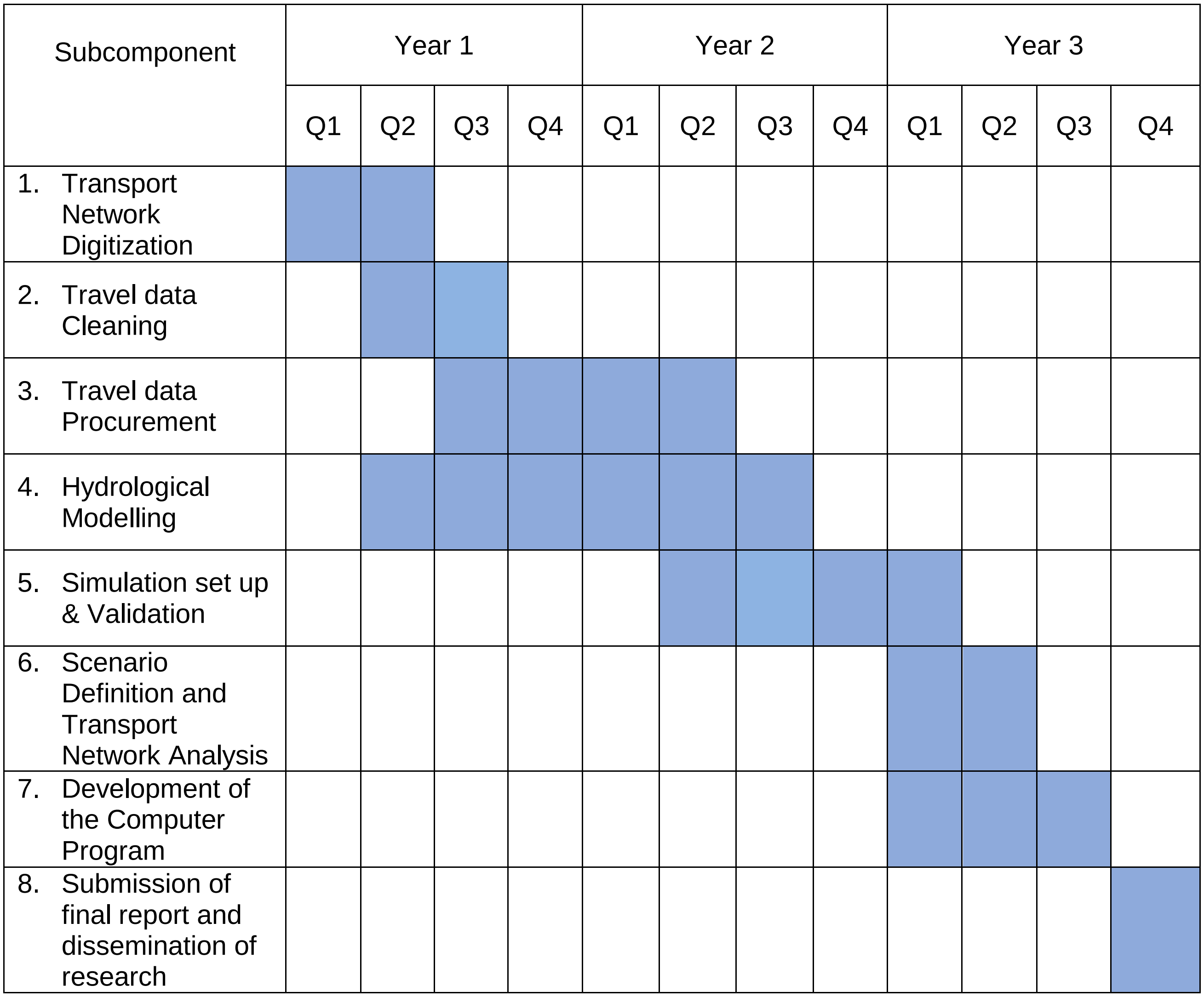

Figure 1: Activity-wide time chart

4 KEY FINDINGS AND RESULTS – <u>*supporting documents to be attached.*</u>

4.1 Major Activities/ Findings (max. 500 words)

The major findings from the project are briefly discussed here. A preliminary analysis of travel patterns suggests that the main mode of transportation in Gangtok is Car/Jeep/Van with a 79% share followed by motorised two-wheelers that holds 18% share. Besides, in general, traffic movement happens between 8:00 AM to 5:00 PM, and after 5:00 PM the traffic gradually decreases. Overall, the primary data analysis showed that the traffic movements is happening on NH-10 which is a major road connecting most of the tourist places in Gangtok. In addition to this, the forecasting of mobility patterns shows that the highest V/C ratios were observed on the NH-10 links between Ranipool to Tibet Road. This road is highly vulnerable as most of the stretches on this network have a V/C ratio greater than 1, with the highest V/C ratio is 1.876997 for the year 2021 and 2.258355 for the year 2031. The highest PCU for the year 2021 is

2769.993172, and for 2031, it is 3460.3616 PCU. Both values are observed on NH-10 at the Ranipool location which is the major entry point for all the vehicles which are entering Gangtok city. Our network vulnerability analysis also show that the road network from Ranipool to Tibet Road is highly vulnerable to earthquakes, landslides, and flash flood. The rainfall trends in the city show that there is a reduction in the overall intensity of precipitation. For instance, a reduction in return period from 100 year to 1 year, substantially reduces the rainfall intensity from 200 mm/day to 60 mm/day for 1 day duration. Additionally, in general, intensities reduce with durations for all return periods. However, for 5-day duration a minor peak is observed for all return periods, owing to the occurrence of higher annual maxima rainfall intensity. Our scenario analysis reveals that the allocation pattern considering susceptibility of a hazard and connectivity reliability of the network could be significantly different from a straight-forward relief-point allocation where that relief point which is at the shortest distance is usually allocated to a population centroid. The total distance to be travelled to the relief point to be allocated (aggregated over the network) was found to be, on average, $1/3^{rd}$ times in excess to the scenario when nearest relief point would have been allocated to every population centroid in the network.

4.2 Key Results (max. 500 words in bullets covering all activities)

The major achievements/results of the project are summarized as follows.

- The project developed an aggregate travel demand model and applied to investigating the travel demand in the study area. It is seen that the highest V/C ratios were observed on the NH10 network between Ranipool to Tibet Road. This road is highly vulnerable as most of the stretches on this network have a V/C ratio greater than 1, with the highest V/C ratio is 1.876997 for the year 2021 and 2.258355 for the year 2031. The highest PCU for the year 2021 is 2769.993172, and for 2031, it is 3460.3616 PCU.

- The project ranked traffic analysis zones and transportation network using travel demand and disaster susceptibility. The vulnerable links are identified based on susceptibility to hazard maps and PCU values obtained from the travel demand model. A risk matrix has been formulated by ranking the PCU value of a link and vulnerability levels read from hazard susceptibility maps. According to five levels defined in the risk matrix, the network links are categorized separately for all of the three-hazard conditions.

- The project developed a methodology to allocate population to shelter points during a disaster event. The methodology considers the susceptibility of the network and zones to disasters. The mathematical program performs the selection of shelter locations considering the post-disaster state of the network with the objective of uncovering the most reliable paths so as to improve the overall connectivity of the road network. The mathematical program has been utilized to perform scenario analysis to understand the population allocation to different shelter points.

- The project also proposed a web-interface by integrating the findings of the travel demand model, scenario analysis program and link vulnerability analysis.
- Both the transport demand model and the optimization program are embedded in a web-based interface to visualize and understand the population demand to be served. The web-interface application is based on Python programming background. This stage essentially develops a web application that utilizes the algorithm of solving the problem of locating the most nearby shelter place but keeping consideration of the state of the local road connectivity and network.

4.3 Conclusion of the study (max. 500 words in bullets)

Based on the analysis performed in the project, the study concludes that the critical infrastructure element in the city is NH-10, since it caries higher traffic loads in the current and future population scenarios and being located in disaster prone locations. The scenario analysis shows that the allocation pattern considering susceptibility of the hazard and connectivity reliability of the network could be significantly different from a straight-forward relief-point allocation where that relief point which is at the shortest distance is usually allocated to a population centroid. It can also be seen that the capacity of relief points play a primary role in allocating the population centroids to their respective relief points. From the allocation pattern, it is also evident that when multiple relief points are to be allocated to a population centroid, its nearest relief point need not always have to be allocated with the higher proportion of demand.

5 OVERALL ACHIEVEMENTS – *supporting documents to be attached.*

5.1 Achievement on Project Objectives/ Target Deliverables (max. 500 words)]

The objective-wise achievements are summarised below.

Objective-1*: To understand present and future citizen mobility needs, rainfall patterns, and transport network structure in Gangtok city of Sikkim.*

Gangtok is a hilly region, and the major contributor to the city's economy is tourism. From the traffic volume count analysis, it is observed that the main mode of transportation in Gangtok is Car/Jeep/Van with 79% share followed by two-wheelers with 18% share. The peak period of traffic is observed from 8:00 AM to 5:00 PM and after 5:00 PM the traffic gradually decreases, perhaps due to the tourist vehicles mostly operating in the daytime. Our primary survey reveals that Holy Cross School/St.Paul church location has highest traffic volume count with 24,759 vehicles from 8:00 AM to 12:00 AM this is due to this Holy Cross School/St.Paul church situated on NH10 between the Ranipool and Gangtok city which is the only major passage for all the vehicles which are going to Gangtok. 'Sikkim continental' has the second highest traffic volume count with 19,244 vehicles. This place is also situated on NH10 road near the MG Marg. SNT bus stand and North Taxi stand are also situated on NH10 road. From this, we can observe that most of the traffic is operated on NH10, which is the only major road network connecting most of the tourist places in Gangtok. Chandmari shiv temple and Burtuk helipad are the upper outer cordon points in our analysis, which has less traffic volume compared to the other places. Ranipool taxi stand is the outer cordon point in the Southern part of Sikkim, which also experience higher traffic volume because all the vehicles which are coming from Siliguri are entering through this location.

To further aid in the travel pattern/demand analysis, the project also developed a four-stage aggregate travel demand forecasting model. The base-year for the model was 2019 (project start state), and projections were made for 2021 and 2031. Figure 2 shows the projected travel demand for 2021 and 2031, in terms of travel desire line diagram, for the city. It can be concluded that, for both projections, the demand patterns remains nearly the same. As intuition suggestion, the traffic on the NH-10 segments gets worsened in the future demand scenarios.

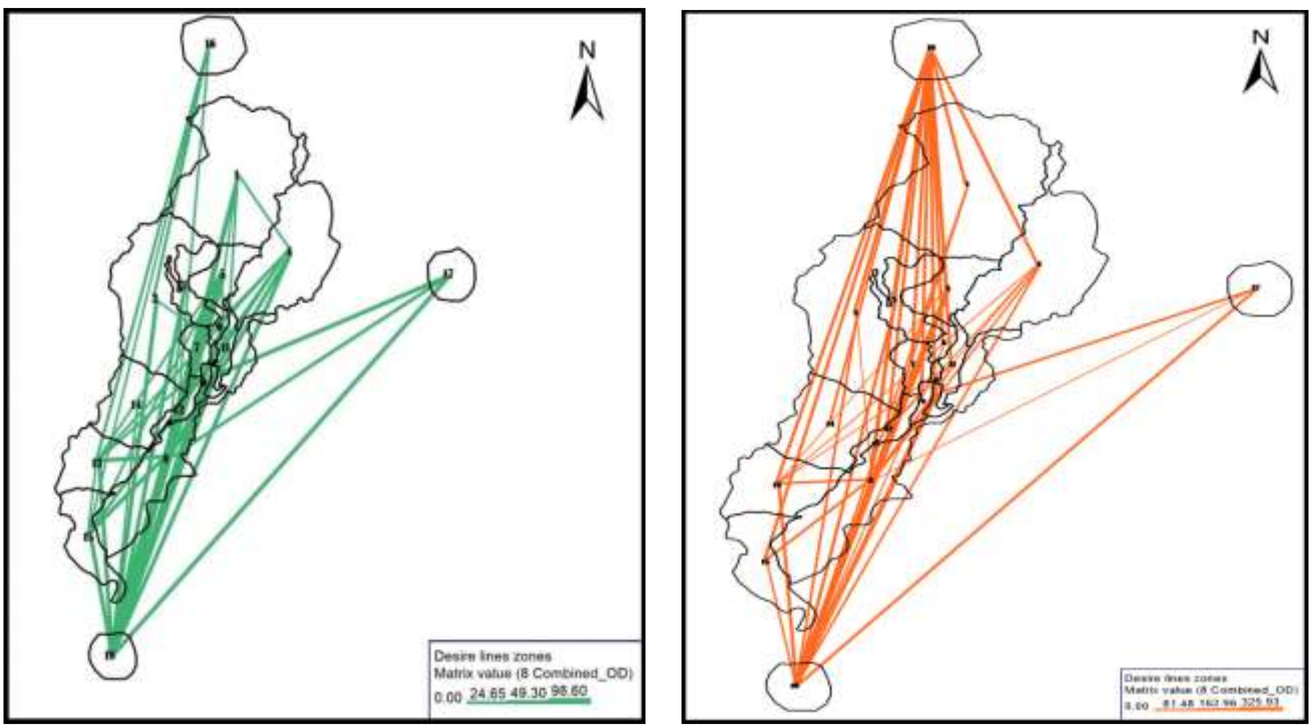

Figure 2: Travel desire line diagram for 2021 and 2031

Gangtok city is surrounded by the left bank tributaries of river Teesta: Ranikhola river in the west, the Rorochu river in the east, and the Rate chhu river in the Northern end. Ranikhola and Rorochu rivers meet at the southern boundary of Gangtok city and merge into the river Teesta at Singtam. Rainfall is one of the contributors to extreme geographical events in Gangtok. Figure 3 Shows the annual rainfall trend in the Gangtok district from 2009 to 2020. From the analysis of the past 12-year rainfall data, we observed that the Gangtok district receives an average of 2500 mm of annual rainfall. Approximately 70% of the rainfall is observed during the southwest monsoon season (June-September) (Figure 4). Burtuk and Chadmari zones receive more rainfall compared to the other zones. 93.32% of the Gangtok municipality area falls under the low-risk zone.

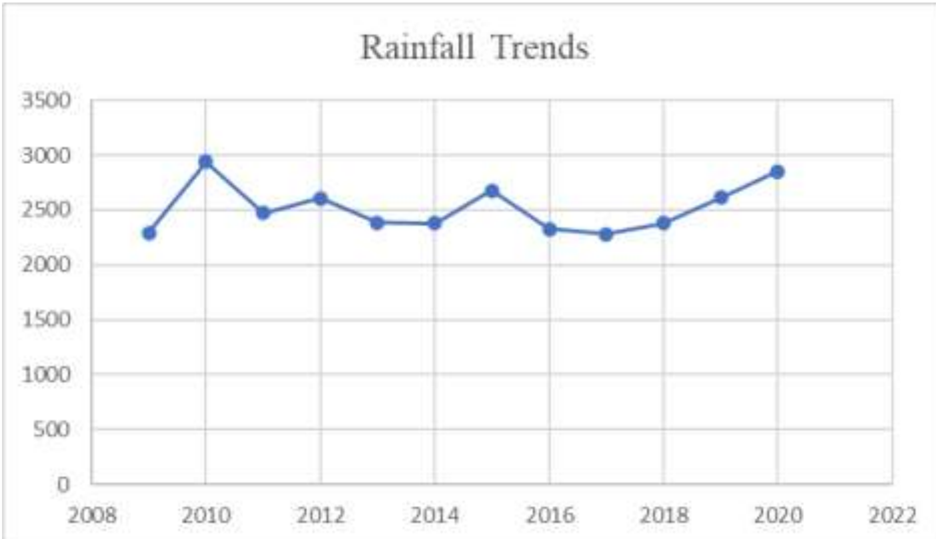

Figure 3: Annual Rainfall of Gangtok district from the years 2009 to 2020

Further analysis on rainfall has been conducted to understand the flood vulnerability in the region. Using a hydrological model implemented at IIT Delhi, the rainfall has been translated into runoffs at different locations of the river basins and predicted the occurrence of floods. Gangtok city falls under the Teesta River basin. Since river Teesta River Teesta is the tributary of Brahmaputra and in this analysis, we have selected the Brahmaputra River basin to understand the rainfall. The following figure (Figure 4) shows the rainfall prediction for the city.

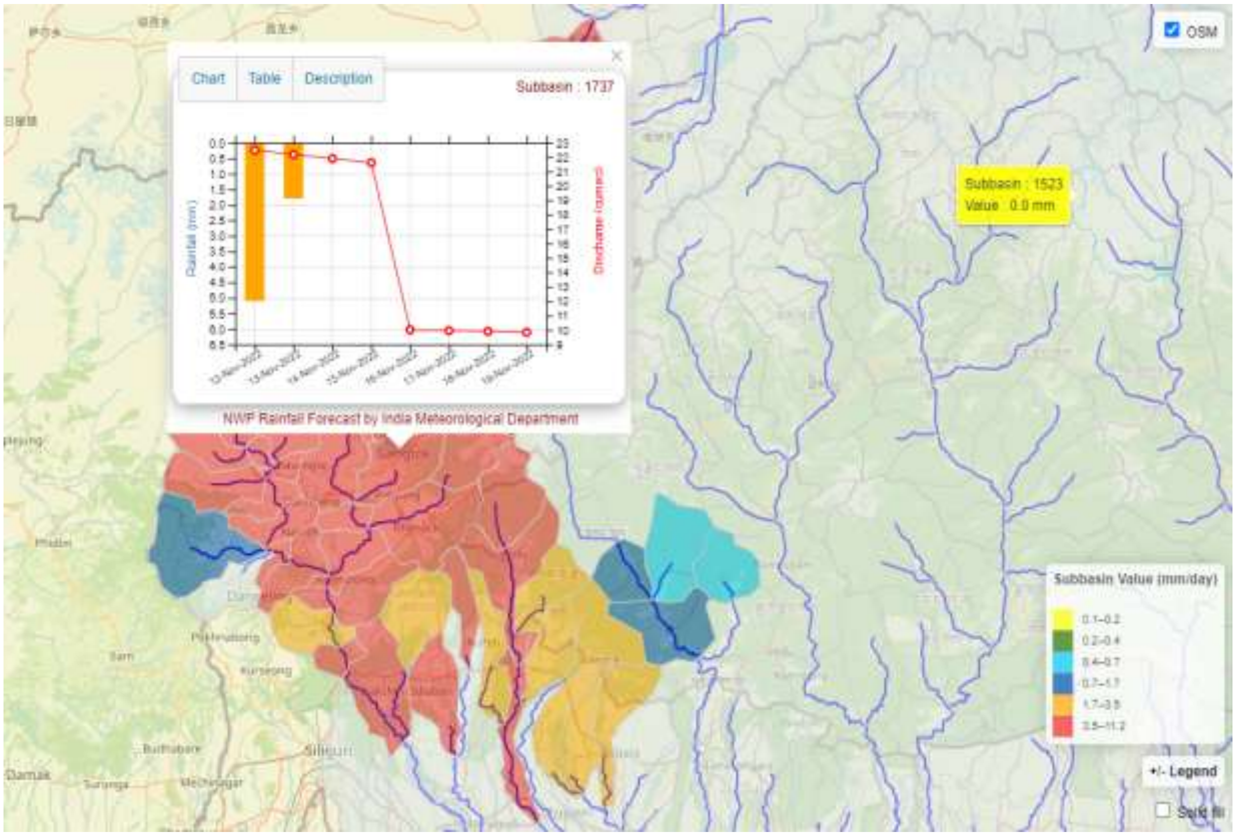

Figure 4: Rainfall forecast for the Gangtok city

The discharge predicted from the model is shown in Figure 5.

Chart | Table | Description

Subbasin : 1737

Date	Discharge	Rainfall
12-Nov-2022	22.48	5.1
13-Nov-2022	22.19	1.8
14-Nov-2022	21.9	0
15-Nov-2022	21.61	0
16-Nov-2022	10.01	0
17-Nov-2022	9.957	0
18-Nov-2022	9.899	0
19-Nov-2022	9.839	0

NWP Rainfall Forecast by India Meteorological Department

Figure 5: Forecasted Discharge

Objective-2*: To rank travel zones based on vulnerability induced by rainfall, mobility patterns and transport network structure.*

The vulnerable links are identified based on susceptibility to hazard maps and PCU values obtained from the travel demand model. A risk matrix has been formulated by ranking the PCU value of a link and vulnerability levels read from hazard susceptibility maps. The risk matrix (dimension 5*5) has been obtained from five levels of link PCU and five levels of hazard vulnerability. A particular cell in the risk matrix is presenting the link PCU rank and the hazard vulnerability rank. The risk matrix obtained afterward has been divided into five levels of link vulnerability. Based on the levels defined for a risk, the vulnerability of the links are categorized separately for all three-hazard conditions. Thus, a link with high PCU value and situated at a vulnerable location is considered as a highly vulnerable link and vice-versa. The following figure shows the vulnerability levels of the transportation network in Gangtok for flashflood hazard.

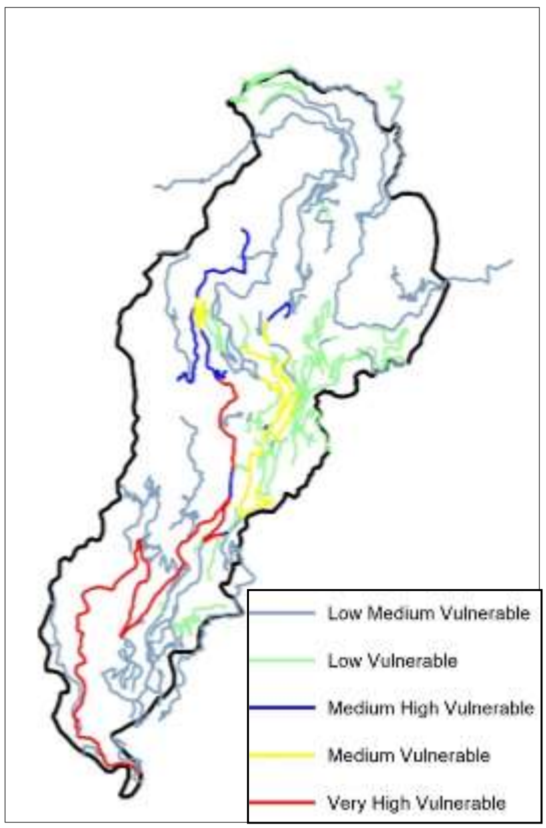

Figure 5: Link Vulnerability map for Flash flood hazard

To rank the TAZs, the length of vulnerable links is calculated in every zone for every disaster vulnerability level. The ranking of TAZs based on link vulnerability is shown in the following table.

Table 1: TAZ Ranking based on Link Vulnerability length

S.No.	Zones	Rank		
		Earthquake	Flash Flood	Landslide
1	Chandmari	1	3	1
2	Burtuk	2	2	3
3	Syari-Tathangchen	3	1	2
4	Lower Sichey	4	4	4
5	Tadong	5	7	5
6	Ranipool	6	6	6
7	Dara Gaon	7	5	7
8	Deorali	8	9	8
9	Upper Sichey	9	8	9
10	Tibet Road	10	11	11
11	Development Area	11	10	10
12	Arithang	12	12	12
13	Upper M.G. Marg	13	13	13
14	Lower M.G. Marg	14	15	14
15	Diesel Power House	15	14	15

Objective-3*: To suggest possible transport-related evacuation strategies based on scenario analysis*

Here, a methodology has been formulated to allocate population to shelter points during a disaster event. The methodology considers the susceptibility of the network and zones to disasters. The project employed a combination of two components: the degradation state and the traffic state of the road network to define the post-disaster network state, and employ it in shelter location selection. The former component is inferred from susceptibility maps generated using historic disaster data and existing models, and represented as link-vulnerability on each link of the road network. The latter component, i.e., the post-disaster traffic state, is in fact a function of the former, and also of the pre-disaster traffic and the predictability of the disaster in question. The pre-disaster traffic is estimated by employing conventional transport planning tools that determines business-as-usual link-flows, and adjusted based on the disaster predictability levels. The predictability will be different for different disaster types, and therefore is treated as exogenous to our analysis. The network's expected post- disaster state will therefore be defined in terms of the above said link-flows and link- vulnerabilities. Based on the network's expected post-disaster state, shelter locations are chosen such that they provide maximum possible connectivity reliability.

Table 2 shows the outcome of a scenario analysis considering evacuation to ten relief points under landslide

Table 2: Relief point allocation for expected landslide

Population centroid	Relief point to be allocated	Distance to be travelled to the relief point to be allocated (km)	Is the relief point to be allocated, the nearest one to the population centroid	Additional distance to be travelled from the nearest relief point (km)
n_0	s_8	0.936	Yes	0.000
n_1	s_2	4.764	Yes	0.000
n_2	s_5	0.873	Yes	0.000
n_3	s_7	2.854	Yes	0.000
n_4	s_6	2.672	No	0.798
n_5	s_1	0.137	Yes	0.000
n_6	s_6	1.047	Yes	0.000
n_7	s_6	1.488	No	0.232
n_8	s_6	2.116	No	0.633
n_9	s_4	1.337	Yes	0.000
n_{10}	s_4	1.258	Yes	0.000
n_{11}	s_4	0.330	Yes	0.000
n_{12}	s_4	7.181	No	6.850
n_{13}	s_7	0.262	Yes	0.000
n_{14}	s_7	2.301	Yes	0.000
n_{15}	s_3	1.193	Yes	0.000
n_{16}	s_0	2.522	No	0.183

It could be observed from the allocation results in Table 2 that, population centroids n4, n7 and n8 would have to be allocated to relief point s6, whereas n12 and n16 would have to be allocated to relief points s4 and s0 respectively. Thus, the allocation pattern considering susceptibility of the hazard and connectivity reliability of the network could be significantly different from a straight-forward relief-point allocation where that relief point which is at the shortest distance is usually allocated to a population centroid. The total distance to be travelled to the relief point to be allocated (aggregated over the network) was estimated to be 33.271 km. This was found to be 8.696 km in excess to the scenario when nearest relief point would have been allocated to every population centroid in the network. The details of scenario analysis are provided in Appendix-1.

Objective-4*: To develop a computer program to (a) assess present and future transport demand and supply for business-as-usual scenario (b) aid evacuation strategies during transport network disruption due to extreme rainfall events.*

The project developed computer programs for – (i) a four-stage aggregate forecasting model to understand the network-level travel demand, and (ii) a numerical optimization program/scenario analysis tool to allocate population to different shelter points considering network vulnerability as a function of transportation demand, network capacity and disaster susceptibility. Both the transport demand model and the optimization program are embedded in a web-based interface to visualize and understand the population demand to be served. The web-interface application is based on Python programming background. This stage essentially develops a web application that utilizes the algorithm of solving the problem of locating the most nearby shelter place but keeping consideration of the state of the local road connectivity and network, as described in the documentation related to Objective-3. The main objective of this web application is to be used by a disaster management operator to monitor the path reliability of demand nodes and relief points and designate a suitable number of people from said demand nodes to relief points, determined by the previously stated algorithm.

Figure 6 shows the workflow diagram associated with the web-interface. To load initial data to web application the user is required to visit the “URL/init/” page. This loads the CSV data to the table and renders the relief and demand nodes on the map.

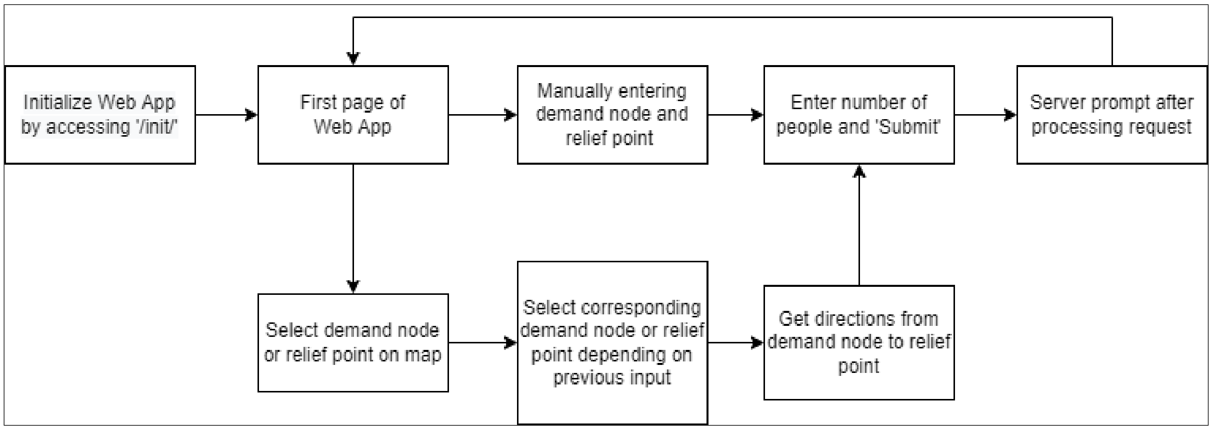

Figure 6: User interface workflow

The screenshot of the scenario analysis tool developed is shown in Figure 7.

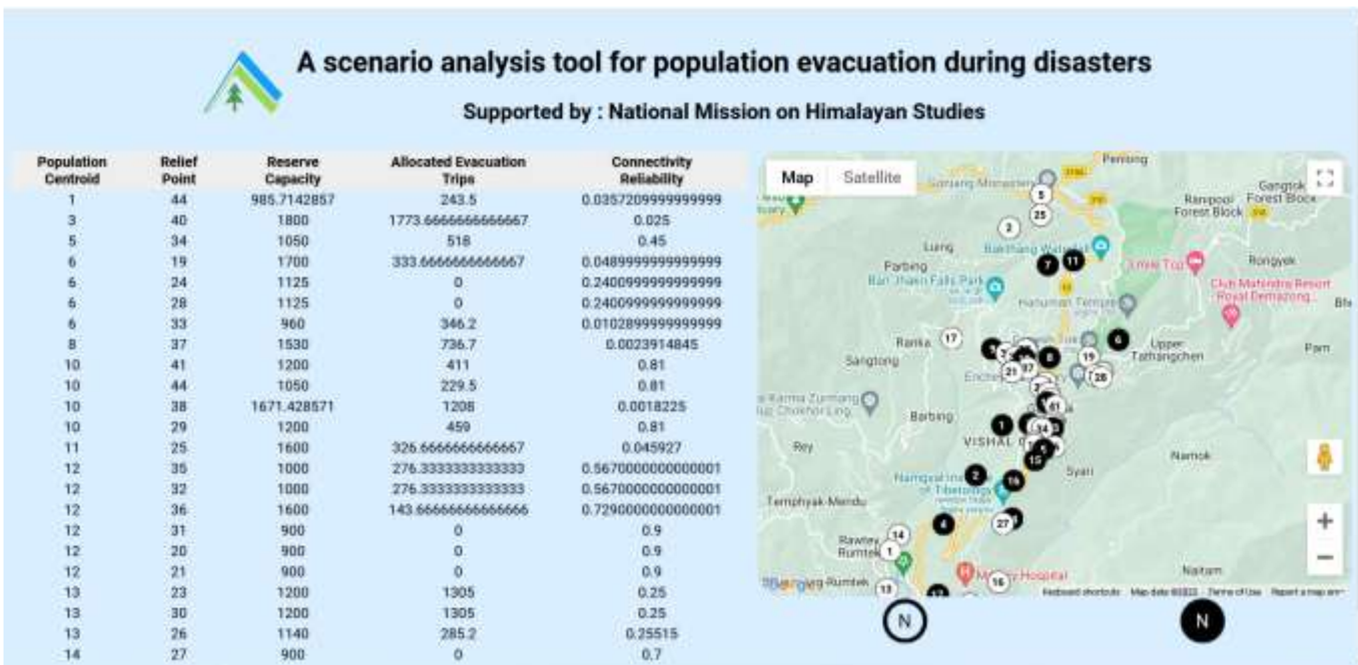

Figure 7: A screenshot of web-based inerface for the scenario analysis tool

5.2 Interventions (max. 500 words)

The project develops an optimization-based analytical framework to explore the potential evacuation strategies considering the population demand and transportation network characteristics. The framework can be considered as a scenario analysis tool to understand and plan population evacuation under disaster scenarios. The project does not directly contribute to the technological interventions in the IHR.

5.3 On-field Demonstration and Value-addition of Products, if any (max. 500 words)

The project does not contribute to on-field demonstration and value-addition of products.

5.4 Green Skills developed in in State/ UT (max. 500 words)

The project does not contribute to developing green skills in IHR.

5.5 Addressing Cross-cutting Issues (max. 200 words)

- The project was started in October 2019 and most of its phases was affected by the COVID-19 and associated disruptions.
- The data collection which was planned in 2020 was disturbed due to the lockdown. The project activities were initiated with the transport data available with the urban local bodies and the adherence to the timelines were ensured.
- The models and methods were revised and updated on primary data collected after the lockdown restrictions were eased.
- Most of the in-person visits planned during the initial phases of the project were converted to online meetings and the unspent amount related to the travel has been returned to the funding agency.

6 PROJECT'S IMPACTS IN IHR – *supporting documents to be attached.*

6.1 Socio-Economic impact (max. 500 words)

The project does not contribute to socio-economic development in IHR directly. However, the models and scenario analysis tool developed through the project can help understand the population demand to be evacuated, the availability of reliable paths to the shelter points, and the potential allocation population allocation mechanism based on the capacities of shelter points. Timely response to evacuate people during a disaster can save life and improve the economic conditions of a society. Besides, a-priori understanding of the road vulnerability and capacity and the shelter point conditions can help the decision-makers allocate resources efficiently and plan during a disaster scenario.

6.2 Impact on of Natural Resources/ Environment (max. 500 words)

The project does not contribute to the scientific management of natural resources in IHR.

6.3 Conservation of Biodiversity/ Land Rehabilitation in IHR (max. 500 words)

The project is not contributing towards biodiversity protection.

6.4 Developing Mountain Infrastructures (max. 200 words)

The project does not contribute to the development of mountain infrastructure. However, it considers the transport infrastructure and potential shelter points in scenario building and analysis.

6.5 Strengthening Networking in State/ UT (max. 200 words)

The projects calls for networking among urban planners, traffic police, disaster management authorities, and transport operators for efficient planning of evacuation operations during a disaster.

7 EXIT STRATEGY AND SUSTAINABILITY – *<u>supporting documents to be attached.</u>*

7.1 Utility of project findings (max. 500 words)

The project can contribute to the social and economic sustainability of IHR. The models and scenario analysis tool developed through the project can help understand the population demand to be evacuated, the availability of reliable paths to the shelter points, and the potential allocation population allocation mechanism based on the capacities of shelter points. Timely response to evacuate people during a disaster can save life and improve the economic conditions of a society. Besides, a-priori understanding of the road vulnerability and capacity and the shelter point conditions can help the decision-makers allocate resources efficiently and plan during a disaster scenario. Thus, the project does not contribute to the sustainable development directly, but have many indirect impacts on the broad goals of sustainable development.

7.2 Other Gap Areas (max. 200 words)

i. The project preforms a macro-level analysis of travel demand assessment and evacuation scenario analysis. A micro-level assessment of both attributes can provide greater resolution for transportation planning considering disaster vulnerability.

ii. The project uses susceptibility maps to include disaster vulnerability into the analysis. Inclusion of hazard assessment models can provide more realistic details of disaster vulnerability into the analysis.

7.3 Major Recommendations/ Way Forward (max. 200 words)

i. Update the land use trends and transportation network regularly

ii. A complete inventory of shelter points to be considered during evacuation and their accessibility and disaster vulnerability

iii. Inventory of susceptibility maps related to different types of disasters

7.4 Replication/ Upscaling/ Post-Project Sustainability of Interventions (max. 500 words)

It is possible to replicate the project findings with data collected from different time points in Gangtok or any other hilly region in the country. The project findings can be replicated using data available from other parts of IHR as well. It is expected that the findings would be unique to the region of interest. The input data required for the model replication includes traffic analysis zone (TAZ) details, transportation network details, zonal level population and employment, susceptibility maps for different disasters, and accessibility and disaster vulnerability of different shelter points. The travel demand models calibrated in the project can help assess the network loading and develop zonal and link-level vulnerability conditions for different disaster. Using this network details and the details of population to be evacuated and attributes of shelter points, the optimization algorithm can indicate the potential evacuation possibilities. From an exit strategy standpoint, the project outcomes will be handed over to the funding agency and the details will also be shared with interested parties upon genuine request and after the publication of manuscript. The project proponents would also seek funding from different agencies to continue their research on the subject.

8 REFERENCES/BIBLIOGRAPHY

References are included in Appendix-1

9 ACKNOWLEDGEMENTS

The project proponents are grateful to **the National Mission on Himalayan Studies (NMHS), Ministry of Environment, Forest, and Climate Change, for awarding the project, NMHS/2019-20/SG64/64**. The research could not have completed without the financial support of the NMHS. The proponents are also grateful to **Mr. Dinker Gurung, Addl. Chief Town Planner**, **Gangtok City** for providing full support to the project, granting access to base line data used in the project, and being available there for clarifying our queries. We are also grateful to him for sharing us with the updated network data of Gangtok city for use in the project. The proponents also thank their parent institutions for extending all necessary infrastructure and administrative support for the successful completion of the project.

APPENDICES

Appendix 1 – Details of Technical Activities [**Enclosed**]
Appendix 2 – Copies of Publications duly Acknowledging the Grant/ Fund Support of NMHS [**Enclosed**]
Appendix 3 – List of Trainings/ Workshops/ Seminars with details of trained resources and dissemination material and Proceedings [**Workshop details Enclosed**]
Appendix 4 – List of New Products (utilizing the local resources like NTFPs, wild edibles, bamboo, etc.)
Appendix 5 – Copies of the Supporting Materials like Manual of Standard Operating Procedures (SOPs) developed under the project
Appendix 6 – Details of Technology Developed/ Patents filled, if any
Appendix 7 – Any other [**Support/permission letters Enclosed**]

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