Planning for resilient transport infrastructure for disaster prone area – Case study of Munnar town

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Abstract. Critical infrastructure networks, including transport, are crucial to the social and economic function of urban areas and the state as a whole but are at increasing risk recently from natural hazards. Minimizing disruption to the transportation networks should form part of a strategy to increase resilience of infrastructure. The recent flood and landslide havocs in Kerala had a devastating effect in the state particularly in hilly regions like Munnar, wherein the landslides will aggravate the devastating effect of rain havoc. Absence of a resilient transportation network was well evident while the evacuation plans were sought for. This highlights the necessity of providing a befitting and robust transport means which would remain useful in all such tough times of emergency requirements for saving lives. This paper presents a GIS mapping of disaster affected locations in the roadway network of the study region. Alternate routes were identified which have the potential to be developed into all-weather bituminous surfaced roads for emergency use in times of disasters. Also, shelter locations are identified for emergency relief operations and were analyzed and mapped in GIS platform with attribute data regarding their accessibility. Hydrological studies were conducted in the study area in order to find the total discharge during the flood, the direction of flow, the flow accumulation, etc.

1. Introduction

The transportation system is a complex network of infrastructure, vehicles, power sources, communications, and human capital. The resilience in transportation sector refers to the ability of the transportation system to recover and regain functionality after a major disruption or disaster. The transportation fraternity worldwide is engaged in concerted efforts focused on characterizing a new challenge facing the transportation systems. Disaster resilience is everyone’s business and is a shared responsibility among citizens, the private sector and government. Increasing resilience to disasters will require decisions and actions that are informed and forward-looking. Although disasters will continue to occur, actions that move the nation from a reactive to a proactive approach will reduce many of the societal and economic burdens and impacts that disasters cause. Building the nation’s resilience is a long-term process, one that will be socially and politically challenging, but the reward for the efforts will be a safer, healthier, secure, and more prosperous nation.

The western flank of the Western Ghats covering the eastern part of Kerala is identified as one of the major land slide prone areas of the country. The landslides in the state include rock falls, rock slips, debris flow and in a few cases rotational types of slides. But the most prevalent recurring and
disastrous type of earth or tectonic movement noted in Kerala are the debris flow (Urul pottal) characterized by the swift and sudden down slope movement of highly water saturated overburden ranging in size from soil particles to boulders destroying and carrying with it everything that is lying in its path. About 1500 sq. km area in the Western Ghats is prone to landslides. Every year with the onset of monsoon, land slips and landslides are reported.

2. Literature Review

Kuriakose et al. (2009) identified that out of the 14 districts in Kerala, all the 13 districts except Alappuzha are prone to landslide during monsoon season. The landslide caused by mass movement of debris is locally known as Urul Pottal. The literature on history of landslides show that Wayanad and Kozhikode districts are more prone to deep-seated landslides due to high quantity of rainfall received, while Kottayam and Idukki districts are susceptible to landslides due to debris flow during monsoon (Kuriakose et al., 2009). The increase in pore pressure due to intense rainfall causes reduction in the effective stress and shear strength and hence causes failure in the slope. The debris flow occur in four phases wherein firstly there is movement of water in the form of surface runoff, interflow or by rainfall to the site of failure, secondly sliding of soil occur due to loss in cohesion, thirdly mobilization of materials as debris flow occur and finally the travel of debris (Kuriakose et al., 2009). Urul Pottal is the swift and sudden down slope movement of saturated rock or soil mass that destroys and carries everything in its path (Thampi et al., 1998). In recent years the landslides activities in Western Ghats of Kerala has been studied by Kuriakose et al. (2009), Sreekumar and Krishnanath (2000), Muthu and Muraleedharan (2005), Vijith and Madhu (2007), Abraham and Shaji (2013), Sreekumar and Aslam (2017), etc. Studies conducted by all these researchers indicate that the slope stability issues in Western Ghats of Kerala are generally confined to overburden and triggered by intense and prolonged rainfall. Also, the factors triggering the landslide can be the internal factor such as slope, geology and mineralogy, drainage characteristics; geotechnical properties of the rock and soil such as the shear parameters angle of internal friction and cohesion, bulk density, particle size and clay content, water table, vegetative cover and land use patterns which are inherent on the terrain or external factors such as high intensity rainfall, soil erosion, deforestation, construction of structures, traffic, seismic activity, etc., which trigger or initiate failure.

3. Scope and objectives

This study has the broad scope of identifying the elements of risk, vulnerability and resilience associated with the transport infrastructure and network of Munnar region.

- To identify the elements of risk, vulnerability and resilience associated with the existing transport plan of the study region
- To identify the basic parameters of resilience engineering and identify the key variables for a site specific resilience design
- To plan for a robust transport system for the region which can absorb the effects of unexpected events like natural calamities and comply with a desired performance level
- To evolve out a transport plan which can ensure operational continuity in times of natural disasters
- To frame recommendations on upgradation of existing transport system and introduction of apposite future transport systems which can remain resilient and serve the purpose in adverse climatic conditions

The study area of Munnar is vulnerable mostly to the risks of landslides than floods. Hence the resilience design needs to be focused in providing alternate routes and modes of transport which could be used in emergency. This paper focuses on a transport system design incorporating the different possibilities of transport which could be of use in case of emergency.
4. Study Area and Methodology

4.1 Study Area
Munnar town and its outskirts, which are most affected by the natural disasters like flooding and landslides are demarcated for this study. Munnar lies in the second largest district of Kerala, Idukki lying in the Western Ghats and having a vast forest reserve area. Munnar is a town and hill station located in Idukki district of the south-western Indian state of Kerala. Munnar is situated at around 1,600 metres (5,200 ft.) above mean sea level, in the Western Ghats mountain range. The study area is selected such that almost all roads in the region affected during the floods are included. The selected study extends up to 879.19 sq. km. The proposed alternative routes also lie in the study area. Munnar town being the centre of it, the area extends to Munnar top station on one side including Mattupetty dam, Eravikulam National Park, Devikulam, Lockhart museum, Pooppara, Bison Valley, Adimali, Kundala Dam, etc. The study area map is shown in Figure 1.

4.2 Methodology

- Inventory of the existing transport infrastructure and allied land use
- Identification and GIS mapping of disaster affected/prone areas and road routes with an attribute database on its inventory details
- Identification and GIS mapping of possible shelter locations which could be of use in emergencies with attribute database on its spatial and accessibility details
- Identification of alternate routes with potential for further upgradation
- Hydrology studies to investigate the cause and effect factors affecting the transport infrastructure
- Preparation of attribute database for each of the identified routes in the transport network
- Generation and Integration of various thematic layers, viz. landslide distribution, landslide hazard zonation, land use/land cover, etc
- Development of a resilient transport plan with proposals for upgradation of alternate routes and development of alternate modes of transport which could be of use in case of emergency situations
• Generation of a comprehensive database for purposes like development of flood warning and evacuation system using android app

5. Analysis and Results

5.1 Natural disasters in Munnar in the recent years

Catastrophic landslides occurred along the upslope Munnar town (10.087° N, 77.094° E) of Idukki district, Kerala in August 2018 and 2019 had claimed a number of human lives and affected the infrastructure heavily. Heavy rainfall over a week was identified as the triggering mechanism of slope failure. During the flood in Kerala in 2019, landslides occurred in many locations in Idukki district. But its severity was less compared to that which occurred during the flood of 2018. From August 8 to 16 2018, Munnar witnessed 12 major landslides and 18 deaths. Heavy rains have caused massive landslide at Rajamala in Munnar of Idukki district on Friday 6th Aug, 2020. Rajamala ward in Munnar gram panchayat lies 28 km north east from Munnar town. The incident happened at the Pettimudi Division of Kannan Devan’s tea estate at Neymakkadu in Idukki. The rain-triggered landslide occurred in the early hours of Friday when a hillock at a tea plantation at Rajamala near Munnar came down, burying a row of quarters of estate workers 83 people living in 30 rooms. About 63 dead bodies were recovered from the site after weeks of rescue operations and many are still missing.

The hill station Munnar was submerged during the floods in 2018 and 2019 and got isolated. Roads were blocked at various locations in the Kochi – Thondi point National Highway and on the National Highway 183 passing through Kuttikkanam- Peermade - Vandiperiyar route due to landslips. Heavy rains and landslides have destroyed most of the roads and some bridges in Idukki. Key roads and bridges connecting the hills were inaccessible or were swept away in the rains and landslides. Due to the landslides, the vehicular traffic at various points on the Kochi – Dhanushkodi National Highway on Devikulam - Munnar stretch got disrupted. Low lying areas near Munnar were flooded. The rain-triggered landslide occurred in August, 2020 at Rajamala near Munnar claiming the lives of more than 63 people who lived in a tea plantation. The impact of disaster occurred in Munnar region could be seen from pictures shown in Figure 2.

![Figure 2](image)

Figure 2. Pictures showing the disaster occurred on the road infrastructure.

5.1.1 Mapping of disaster affected areas

GIS Mapping of the disaster affected areas were undertaken using ArcGIS 10.7.1 software. Disasters have inherent features that can be modelled using the characteristics of the area (such as historic occurrences of slide, terrain conditions, depth or physical distribution) to support decision-making. GIS can incorporate geographical features into decision support systems to add to the advantages of mathematical models. GIS softwares with its inbuilt mathematical models come as a handy tool for efficient decision making. GIS-based models have been successfully integrated with logistic models.
before as well as with disaster management models. The GIS data base if created during preparedness phase for floods can be used in conjunction with the flooding data to adopt an evacuation strategy, rehabilitation planning and damage assessment in case of a critical flood situation. The disaster affected locations were mapped in GIS platform as shown in Figure 3.

![GIS Mapping of disaster affected locations](image1)

**Figure 3.** Major disaster affected locations in the study area and it’s GIS Mapping.

### 5.2 Hydrology and rainfall in the study area

The rainfall in the State is controlled by the South-west and North-east monsoons. About 90% of the rainfall occurs during six monsoon months. The high intensity storms prevailing during the monsoon months result in heavy discharges in all the rivers. The continuous and heavy precipitation that occurs in the steep and undulating terrain finds its way into the main rivers through innumerable streams and water courses. Hydrological studies are conducted in the study area, in order to find the total discharge during the flood, the direction of flow, the flow accumulation, etc. The data used for the study includes SRTM DEM (Shuttle Radar Topography Mission-Digital Elevation Model) of 30 m X 30 m resolution for the study area downloaded from USGS Earth Explorer. The stream network of the study area shows that the basin is a 5th order basin. Almost half of the study area is low lying. The stream network derived for the study area is shown in Figure 4.

![Stream network of the study area](image2)

**Figure 4.** Stream network of the study area.
It can be clearly seen that the entire study area has very low accumulated flow. The stream network of the study area is such that there are more 1st and 2nd order streams than the others. Periyavarai Bridge connecting Munnar with Marayoor and cities of Tamil Nadu like Udumalpet was built by the British almost 100 years ago. This bridge was damaged during the 2018 torrential rains. Hydrological studies are conducted to assess the depth of flow occurred during 2018 flood, causing the collapse of Periyavarai Bridge, using the available data. The peak flow was estimated using rational method. The coefficient of runoff was taken as 0.78 (CWC – Kerala Flood Report – 2018) and maximum rainfall intensity was 10.416 mm/hr. The catchment area draining up to Periyavarai Bridge is of area 2292.7 ha. The estimated peak flow is 51.741 m$^3$/sec. Considering the width of the river at the bridge as 16.5m, the depth of water raised to around 3.15 m during the flood and caused the collapse of the bridge. This value is obtained from the field surveys conducted just after the floods. Hydrological studies can reveal the effect of extreme floods on road infrastructure, which can be mitigated by proper planning.

5.3 Potential alternate routes proposed for upgradation
The investigation on possibility of alternate routes was conducted and four alternate routes are proposed for the purpose of evacuation in case of emergency. The alternate road routes are identified with the scope of potential upgradation that help in providing connectivity to highways when some of the stretches on highways are affected by landslides. The road network of the region including the alternate routes with potential for upgradation is mapped in GIS platform as given in Figure 5.

![Figure 5: Alternate routes proposed along with elevation profile.](image)

5.3.1 Evacuation Centres within and Outskirts of Munnar town
About 23 schools and colleges were identified within Munnar town and 7 outside the town but within the study area. Average elevation level of Munnar town was taken as 1450 m above mean sea level. Out of these 30 institutions, 9 were almost at the same elevation as Munnar town. Educational institutions having elevation above Munnar town are counting to around 13 numbers. Only one school is situated at an elevation below Munnar town area. 2 auditoriums were also identified at almost same elevation as that of Munnar town. Along with schools and auditoriums, churches also can be used as potential shelters for rescue operation during natural calamities. Munnar town and the study area have many churches and some of these churches also have adequate spaces available for the rescue operations when situation demands for. All the churches around Munnar town had elevation higher than that of town. Five churches were selected within Munnar town and nearby peripheries and
18outside the town. Geo-referenced maps showing the location of potential facilities available for relief camps in Munnar region are mapped along with the attribute database in GIS platform as shown in Figure 6.

![Figure 6](image)

**Figure 6.** Geo-referenced maps showing the location of potential facilities available for relief camps in Munnar region.

5.3.2 Prospects of Alternate Modes of Transport – Ropeways and Railways

Literatures confirm the historic co-existence of railways and ropeways in Munnar during the period from 1902-1924. Incidentally Munnar Top Station derived its name from its being the upper terminus of the Kottagudi Aerial Ropeway. It was also the location of the terminal railway station on the Kundala Valley Railway, built in 1902 between Munnar, Kundalai and this low point in the crest of the hills above steep cliffs. The historic coexistence of railways and ropeways are evident from its remnants existing in Munnar region and the related pictures are shown in Figure 7.

![Figure 7](image)

(a) The Kundaly Valley Light Railway – Old Train of Munnar in 1911

(b) Remains of Railway cum Ropeway Station at Top Station

**Figure 7.** Pictures showing the historic co-existence of ropeways and railways.

5.4 Flood Warning and Evacuation System Using Android App

It is proposed to develop a flood warning and evacuation system using Android App. As smart phones have become essential gadgets irrespective of rural / urban regions. Ubiquitous availability of smart phone will help in dissemination of information to the local mass through mobile App. In disaster situations, pinpointing locations of survivors is the key. Helpline numbers at times of disaster are not able to reach the people who required help due to the limited number of parallel calls that help lines could handle. This was negatively impacting rescue efforts and their timeliness. The Victims,
Volunteers and Officials would install the Android app and register using their Google account or mobile number. When the victim requests for rescue, the app will provide the locations of emergency shelters and disaster recovery centres in the area. Navigation through short cuts towards the emergency shelters will be provided if the victim is ready to navigate. If the victims are unable to navigate to the emergency shelters due to health issues or unavailability of transport modes, the app alerts the nearby Volunteers and Officials. Using this android and web solutions a sophisticated analysis tools can be built to help the concerned agencies to prepare better relief for future disasters.

6. Conclusion and Future Work
The transport infrastructure in Munnar is being affected by torrential rains and landslides for the past 3 consecutive years. This paper brings out GIS mapping of disaster affected/prone areas, road routes and shelter locations with an attribute database on spatial and accessibility details. Along with the upgradation of the existing road route networks, alternate routes identified and reported in this paper could be upgraded and developed which could be used in case of rescue and relief operations. Prospects of alternate transport modes are evident from the historic data and it was found that there existed a ropeway for the transport of goods from Tamil Nadu to Munnar in the early 1900’s. This could be re-created and developed for faster movement of goods and services in case of emergencies. The hydrological studies conducted in the study area reveals that the entire study area has very low accumulated flow. The stream network of the study area is such that there are more 1st and 2nd order streams than the others. The scope for future research includes conducting geotechnical investigations at disaster affected areas to recommend for suitable slope protection techniques and conduct of vulnerability analysis of the study area. There is a scope for development of advanced technologies for flood warning and evacuation system using tools like Android App as well.

References
[1] Kuriakose, L Sekhar, G Sankar and R Muraleedharan (2009), History of landslide susceptibility and a chorology of landslide-prone areas in the Western Ghats of Kerala, IndiaEnvironmental Geology, Volume 57, Issue 7, pp.1553-1568
[2] P K Thampi, J Mathai, G Sankar, S Sidharthan (1998) Evaluation study in terms of landslide mitigation in parts of Western Ghats, Kerala. Research report submitted to the Ministry of Agriculture, Government of India. Centre for Earth Science Studies, Government of Kerala, Thiruvananthapuram, India
[3] S Sreekumar, R Krishnanath (2000) Stability of Lateritic profiles in parts of Western Ghats, India, Proceedings of the 8th international symposium on landslides. Thomas Telford Ltd., London, pp 1395–1400
[4] R Pitchai Muthu, C Muraleedharan (2005), Causes and mechanism of Amboori landslide of 9th November, 2001, Thiruvananthapuram district, Kerala, Journal of the Geotechnical Society of India 66 (2):203-208
[5] G Madhu, H Vijith (2007) Estimating potential landslide sites of an upland sub-watershed in Western Ghat’s of Kerala (India) through frequency ratio and GISEnvironmental Geology 55(7):1397-1405
[6] P Biju Abraham, E Shaji (2013), Landslide hazard zonation in and around Thodupuzha-Idukki-Munnar road, Idukki district, Kerala: A geospatial approach, Journal of the Geological Society of India, 82 (6): 649-656
[7] S Sreekumar, Arish Aslam (2017), Geospatial approach for landslide disaster management: A case study from India, International Journal of Applied and Advanced Scientific Research, Vol 2, Issue 2, 2456 - 3080