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Impact of Climate Disasters on Railway Infrastructure: Case Study of Northeast India

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Abstract: Climate disasters have become increasingly frequent in India, severely affecting the railway infrastructure every year. Physical damages to railway tracks, bridges, and signaling systems, caused by floods, cyclones, and landslides, are well documented. However, the impact of these disasters on the railway infrastructure was beyond direct physical damages. This paper aimed to explore the impact of climate disasters on railway infrastructure in Northeast India using case study approach. Three cases were studied to analyse the impact of climate disasters on railway infrastructure, including geological disasters and extreme weather. Infrastructure development and operation of railway transport system in Assam, Mizoram, and Manipur proved to be challenging, especially when coping with natural disasters, such as floods, landslides, and earthquakes. This paper found that disruption of railway services was associated with geo-physical structure of the region, which triggered the disaster vulnerability. The results showed that climate disasters had a significant impact on railway infrastructure in Northeast India in many aspects. Formulation and implementation of strategic policies might reduce the disaster risks. Therefore, policymakers and Ministry of Railways, Government of India should consider this possible probability approach over environmental determinism.

Keywords: Railway geography; Railway infrastructure; Northeast India; Environmental determinism; Possible probability

1. Introduction

Climate change has become a significant stimulating factor in many environmental disasters. Climate disasters refer to events that are either caused or worsened by climate change effects, including rising temperatures, changing rainfall patterns, sea level increments, and frequent violent weather [1], which harm human societies and ecosystems in countless ways [2], leading to loss of life, displacement, economic harm, and food scarcity [3]. Railway transport has been making significant contributions to the Indian economy, with the Indian Railways being one of the largest employers in the country [4]. Railway infrastructure plays a critical role in goods transport across India [5]. As an essential component of the transportation system, railways may be faced with immense challenges when dealing with the effects of climate change [6]. Climate disasters cause considerable harm to the railway infrastructure of India, because India has vast railway network in a wide range of regions [7, 8]. Landslides, floods, and cyclones are the major climate disasters affecting Indian railway infrastructure [9, 10], which only account for a small proportion of disasters due to the diverse geography of India [11]. Those climate events damage railway tracks, bridges, and railway stations [12, 13]. Apart from direct physical damages, those climate disasters significantly affect railway infrastructure [14], by disrupting railway services, which affects supply chains, resulting in delayed delivery of goods and increased transportation costs [15], as well as economic losses for the railways and the wider economy [16]. In Northeast India, there is a high risk of various climate disasters, including floods, landslides, and cyclones, which have a substantial impact on the railway infrastructure in the region [17]. Due to relatively young terrain, weak geologic foundation, and active tectonics, this region is susceptible to landslide events, which contains nearly one fifth of India's landslide-prone zones and has further exacerbated because of numerous development activities [18-20]. Indian Railways has adopted various measures to alleviate the impact of climate disasters on railway infrastructure [21], including construction of retaining walls, erection of bridges with increased spans, and utilization of geo-synthetic materials for slope stabilization purposes [22-24]. Moreover, Indian Railways has been investing in cutting-edge technologies, such as remote sensing and geographic information systems, to monitor and predict natural disasters, thus taking proactive steps to prevent or mitigate any harm to railway infrastructure.

This paper aimed to find the impact of climate disasters on railway infrastructure in Northeast India.

2. Methodology

Case study approach was used to study the impact of climate disasters on the railway infrastructure in Northeast India in the following steps:

Step 1: The research question was defined, "What is the negative impact of climate disasters on the railway infrastructure in Northeast India?"

Step 2: A suitable case study was selected after assessing several factors, including the severity of climate disasters and the availability of relevant data. Three events were considered for this purpose, namely, the Assam floods in 2022, the Mizoram landslides in 2020, and the Manipur earthquake in 2016, which caused extensive damages to the railway infrastructure in the region.

Step 3: Relevant data on the impact was collected from diverse sources, such as scholarly publications, media coverage, official government documents, and railway regulatory bodies.

Step 4: The collated data was thoroughly examined to determine the impact. Various methodologies were used to analyse the data, such as content and thematic analysis, statistical scrutiny, and logistic regression.

Step 5: The outcomes of scrutinized data were effectively used to identify the impact.

Step 6: Communicate the results to all relevant parties, such as the public, policy makers, and railway officials. The results may be presented by various means.

The case study methodology was used to examine the impact of climate disasters on Indian railway infrastructure, by describing the research question, identifying the specific case study, gathering empirical evidences, scrutinizing the data, interpreting the resultant discoveries, and effectively conveying the outcomes [16].

3. Study Area

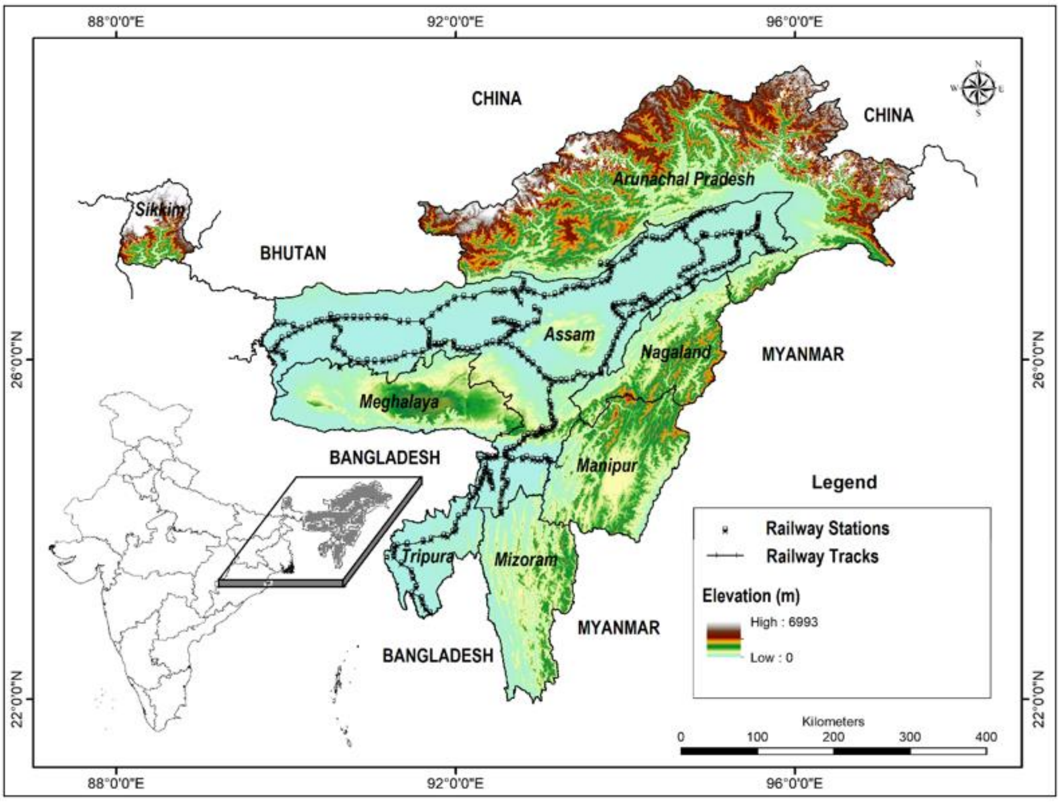

Figure 1. Location map of the study area
Source: Prepared by the authors, 2023

Northeast India is situated in easternmost India and comprises eight states, namely, Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim, and Tripura [25, 26]. This region shares its borders with neighbouring countries, such as Bhutan, China, Bangladesh, Myanmar, and Nepal (Figure 1), with the majestic Himalayan Mountain range in the north, the Patkai Hills and the alluvial plains of the Brahmaputra Valley in the south, and the verdant Barak Valley in the west [27]. Northeast India has several significant rivers, such as Brahmaputra, Barak, and Meghna [28]. This region is known for its rugged and mountainous landscape, dotted with countless hills, valleys, and plateaus [29]. Its geological formations are heterogeneous, encompassing rock formations from the ancient Precambrian era to the younger Tertiary period [30]. Furthermore, the region is prone to seismic activities and regularly experiences earthquakes due to its location in active seismic zones [31]. The climate of Northeast India is varied, with lower sub-tropical temperatures and higher alpine temperatures. The monsoon brings heavy downpour that often causes floods and landslides [32]. Climate change has significantly made extreme events more frequent and intense almost every year. Northeast India is renowned for its abundant cultural diversity because it has more than 200 ethnic groups and languages [33].

4. Results

4.1 Case Study 1: Assam Floods (2022)

Assam boasts a vast river system comprising the Brahmaputra, Barak and their tributaries. Although these rivers provide fertile land for agriculture and efficient transport system, they make the state vulnerable to frequent floods. Heavy rainfall upstream causes the rivers and their tributaries to overflow and submerges the surrounding areas, leading to recurring floods in Assam (Figure 2). Assam experiences devastating floods almost every year, and some regions are more susceptible to flooding, including Dhemaji, Lakhimpur, Biswanath, Sonitpur, Darrang, Nalbari, Barpeta, Bongaigaon, Kokrajhar, Dhubri, Goalpara, Morigaon, Nagaon, Hojai, and Karbi Anglong in the northern and central parts of the state, which are located along the banks of the Brahmaputra and its tributaries. Floods are not strange to Assam because about 77.97 percent of this state is flood-prone (Table 1). However, the floods in 2022 were particularly devastating, affecting millions of people and causing significant damages to the infrastructure in Assam, including railway transportation system [34].

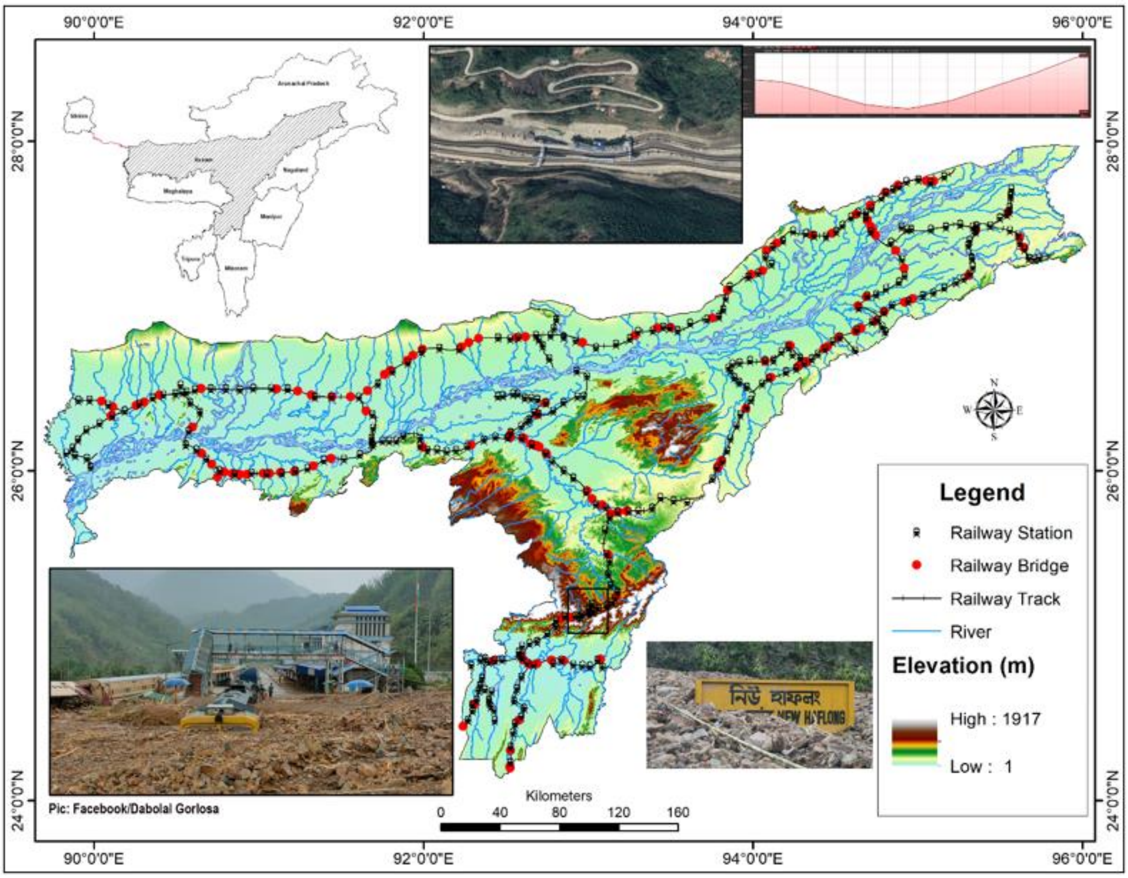

Figure 2. Railway infrastructure in Assam with drainage and relief
Source: Prepared by the authors, 2023

The floods in 2022 were caused by various factors, particularly heavy monsoon rains and water drainage from upstream dams in the neighbouring Arunachal Pradesh [35]. Heavy monsoon rains inundated low-lying areas from June to September in 2022 [36] and the resulting torrential rains triggered flooding across Assam [37]. The Brahmaputra River and its tributaries burst their banks, submerging huge expanses of land. The downpour also resulted in landslides and soil erosion, contributing further to the flooding [38]. In addition, the water drainage from upstream dams in Arunachal Pradesh worsened the flooding in Assam. The dams were part of a hydroelectric project on the Brahmaputra River, and water drainage was crucial to sustaining the water levels for power generation. However, the sudden gush of water swelled the river, flooding Assam downstream. The districts of Dibrugarh, Tinsukia, and Jorhat with several tea gardens were severely affected [39].

This output represented a linear regression model without specifying the dependent variable. However, it included coefficients, standard error coefficients, Z-values, p-values, and Variance Inflation Factors (VIF) for the predictor variable "number of railway stations" as well as the intercept term "constant".

Table 1. Railway infrastructure and flood prone districts in Assam state

No.	Name of the district	Number of railway stations	Flood prone district	Disaster category
1	Baksa	4	0	Non-flood prone
2	Barpeta	11	1	Flood prone
3	Biswanath	4	1	Flood prone
4	Bongaigaon	10	1	Flood prone
5	Cachar	15	0	Non-flood prone
6	Charaideo	1	1	Flood prone
7	Chirang	4	1	Flood prone
8	Darrang	7	1	Flood prone
9	Dhemaji	5	1	Flood prone
10	Dhubri	9	1	Flood prone
11	Dibrugarh	7	1	Flood prone
12	Dima Hasao	3	0	Non-flood prone
13	Goalpara	6	1	Flood prone
14	Golaghat	10	1	Flood prone
15	Hailakandi	5	0	Non-flood prone
16	Hojai	1	1	Flood prone
17	Jorhat	9	1	Flood prone
18	Kamrup	3	0	Non-flood prone
19	Kamrup Metropolitan	12	0	Non-flood prone
20	Karbi Anglong	7	1	Flood prone
21	Karimganj	7	0	Non-flood prone
22	Kokrajhar	6	1	Flood prone
23	Lakhimpur	10	1	Flood prone
24	Majuli	2	1	Flood prone
25	Morigaon	6	1	Flood prone
26	Nagaon	12	0	Non-flood prone
27	Nalbari	7	1	Flood prone
28	Sivasagar	6	1	Flood prone
29	Sonitpur	12	1	Flood prone
30	Mankachar	3	0	Non-flood prone
31	Tinsukia	12	1	Flood prone

Source: Prepared by the authors, 2023

The coefficient for "number of railway stations" was -0.016. This meant that for a one-unit increase in the number of railway stations, the predicted value of the dependent variable decreased by a factor of 0.016 when all other predictor variables were held constant. The standard error of the coefficient was 0.110, which indicated the amount of variability in the estimates of the regression coefficient. The Z-value (-0.14) was obtained by dividing the coefficient by the standard error. The p-value (0.887) of the coefficient was not significant (greater than 0.05), indicating that the variable (number of railway stations) did not significantly affect the dependent variable.

VIF indicated the amount of multi-collinearity between predictor variables. In this case, the VIF for the predictor variable was 1, which was relatively low and indicated no significant correlation between the predictor variable "number of railway stations" and any other predictors in the model.

On the whole, this model suggested that the variable (number of railway stations) was not a significant predictor variable of the dependent variable.

Table 2 shows information on the goodness of fit in statistical model. The deviance measured how well the model fit the data, with lower values indicating better fit. In this case, the deviance was relatively high, suggesting that the model was not a good fit.

Regression equation was as follows:

$$P(1) = \exp(Y')/(1 + \exp(Y')) \quad (1)$$

$$Y' = 1.004 - 0.016 \text{ Number of Railway Stations} \quad (2)$$

The R-squared value indicated the proportion of variability in the response variable that the model explained. In this case, the R-squared value was extremely low, indicating that the model explained only a tiny fraction of the variation in the data. The adjusted R-squared value considered the number of predictor variables in the model and was, therefore, a more accurate measure of goodness of fit when multiple predictor variables existed. AIC, AICc, and BIC were measures of model complexity and provided a method of comparing different models. Lower values of these measures indicated better models. In this case, all three values were relatively high.

Table 2. Summary of logistic regression model

Deviance R-Sq	Deviance R-Sq (adj)	AIC	AICc	BIC	Area under ROC curve
0.05%	0.00%	41.33	41.76	44.20	0.4773

Source: Computed by the authors, 2023

Finally, the area under the ROC curve measured the model's ability to classify cases into categories correctly. The value was 0.4773 in this case, indicating that the classification ability was not much better than chance.

The flooding in Assam in 2022 inflicted extensive harm on the infrastructure, particularly the railway transport system [40]. The Northeast Frontier Railway (NFR), operating in Northeast India, suffered serious damages to its tracks and bridges. The entire railway service network was severely affected. In conclusion, heavy monsoon rains and subsequent water drainage from upstream dams in Arunachal Pradesh caused the 2022 flooding in Assam. Geographic location, low-lying areas and proximity to the Brahmaputra River aggravated the vulnerability of Assam to flooding.

Figure 3. Major hydro-meteorological hazards and their impact on railway infrastructure in Assam, 2022
Source: different newspapers. A. Down To Earth, B. Deccan Herald, C. Scroll. in and D. Mint

According to a report from Northeast Now, the Haflong railway station in the Dima Hasao district was completely submerged by torrential rains in 2022. Pictures revealed that devastating floods and landslides inundated and destoryed train tracks (Figure 3). Train services between Haflong and Silchar were completely affected by flooding at Kapurcherra. Heavy landslides in different areas also affected Haflong-Lanka rail transportation. During extreme floods, railway services were affected in certain parts of Tripura, Mizoram and Manipur, threatening human safety and causing significant disruption and associated economic crisis. Assam State Disaster Management Authority reported about 200,000 people in different districts of Assam were affected by the recent flood. The Dima Hasao railway line, which dated back to 1899, underwent a conversion from metre-gauge to broad-gauge that was approved between 1996-1997. The railway became a national project in 2004 and began to transport passengers in November 2015. However, the principal director of audit issued a theme-based audit report during the conversion process, which warned the railway authorities of potential issues caused by inadequate geotechnical investigation, flawed planning, and failure to anticipate soil strata behaviour. Subsequently, the Commissioner of Railway Safety issued a report, which highlighted significant deficiencies to be addressed before operating passenger trains safely. The disruption of train services was significant, because many passengers relied on the railway transport system for daily commuting and goods transportation. The floods suspended several passenger trains, causing inconvenience and hardship to passengers.

Impact on the railway transport system in Assam showed that infrastructure planning and investment needed to be improved urgently to enhance its resilience against natural disasters [41]. Many tracks and bridges of the NFR were either washed away or severely damaged, disrupting train services throughout the region. NFR officials estimated that around 200 km railway tracks were damaged in Assam alone, with the worst-hit areas in the districts of Dibrugarh, Tinsukia, and Jorhat. Landslides, erosion, and embankment breaches caused the damages, making it challenging to repair the tracks quickly [42].

Moreover, floods significantly affected the economy of Assam, particularly tea transport from gardens to markets, resulting in decreased production and revenue [43]. The floods also damaged many roads and highways, making it difficult to transport goods by road. The NFR worked tirelessly to repair the damaged tracks and bridges in order to restore train services promptly. However, due to continuing rains and difficult terrain, it took several weeks to fully restore train services. Therefore, the floods in 2022 were a stark reminder that the infrastructure in Assam was vulnerable to natural disasters. The impact on the railway transport system highlighted the need for better planning and investment in infrastructure, thus making it more resilient to such events.

There are several strategic solutions to mitigate the effects of floods on railway infrastructure in Assam. The first step is to map the flood-prone areas using satellite imagery, topographic maps, and other remote sensing techniques. Once the flood-prone areas are identified, it becomes easier to plan and design the railway infrastructure accordingly. The railway infrastructure can be elevated or designed to resist flood events. Other steps can be taken, such as flood-resistant infrastructure, proper drainage systems, monitoring systems, and emergency response plans. These solutions require collaborative efforts between government agencies, railway authorities, and local communities, thus ensuring that the transportation system maintain normal operation during floods.

4.2 Case Study 2: Mizoram landslides (2020)

Situated in a region with high seismic activities, Mizoram has complex geological structure, including sedimentary, igneous and metamorphic rocks. The area is prone to tectonic movements and earthquakes, which trigger landslides by destabilizing slopes. Geologically, Mizoram was formed in the tertiary era, and the dominant rock types are shale and unconsolidated sandstone. It is hilly with rugged terrain and steep slopes and the topography is characterized by deep valleys, narrow ridges, and sharp crests. The soil in Mizoram is predominantly clayey and highly weathered, with poor permeability and low shear strength, which makes the slopes prone to erosion and landslides, especially in case of heavy rainfall. Situated in Northeast India, Mizoram has abundant rainfall, which often make it susceptible to landslides and other natural calamities [44]. Mizoram experiences heavy landslides every year during the monsoon season, mainly caused by heavy rainfall and soil erosion. In July 2020, several parts of Mizoram, including the districts of Sairang and Lunglawn, were devastated by landslides triggered by heavy rainfall. Four children, with two of them under the age of five, died on the spot, in accordance with local police report. The landslides caused significant damages to roads, bridges and other infrastructure, including railway tracks [45]. The NFR identified many of its railway tracks and bridges were severely damaged or washed away, disrupting train services in the region. According to NFR officials, around 15 km railway tracks were destroyed in Mizoram alone, with Sairang and Lunglawn districts damaged the most (Figure 4).

Damages to railway infrastructure significantly affected the people of Mizoram, many of whom depended on the railway transport system for daily commuting and goods transportation. Disruption of train services caused inconvenience and hardship to passengers and also affected the economy in the state. The Ministry of Railways data showed that the NFR operated around 3,000 km railway tracks in Northeast India, including Mizoram. The NFR has been developing a new broad-gauge railway line project, which is 51.38 km long and connects Bhairabi with Sairang at an estimated cost of 65.27 billion rupees. Once completed, this project will link the state capital of Mizoram, Aizawl, with the rest of the region, making it a "project of national importance". As a part of this project, four new stations, 55 crucial bridges, 87 smaller bridges, 11 Road Over Bridges/Road Under Bridges, and 12.6 km tunnel will be constructed. This initiative is a crucial step in enhancing socio-economic growth and connectivity in the region [46]. The railway network is vital in connecting the remote areas of the region with the rest of the country and serving as a lifeline for goods transportation [47].

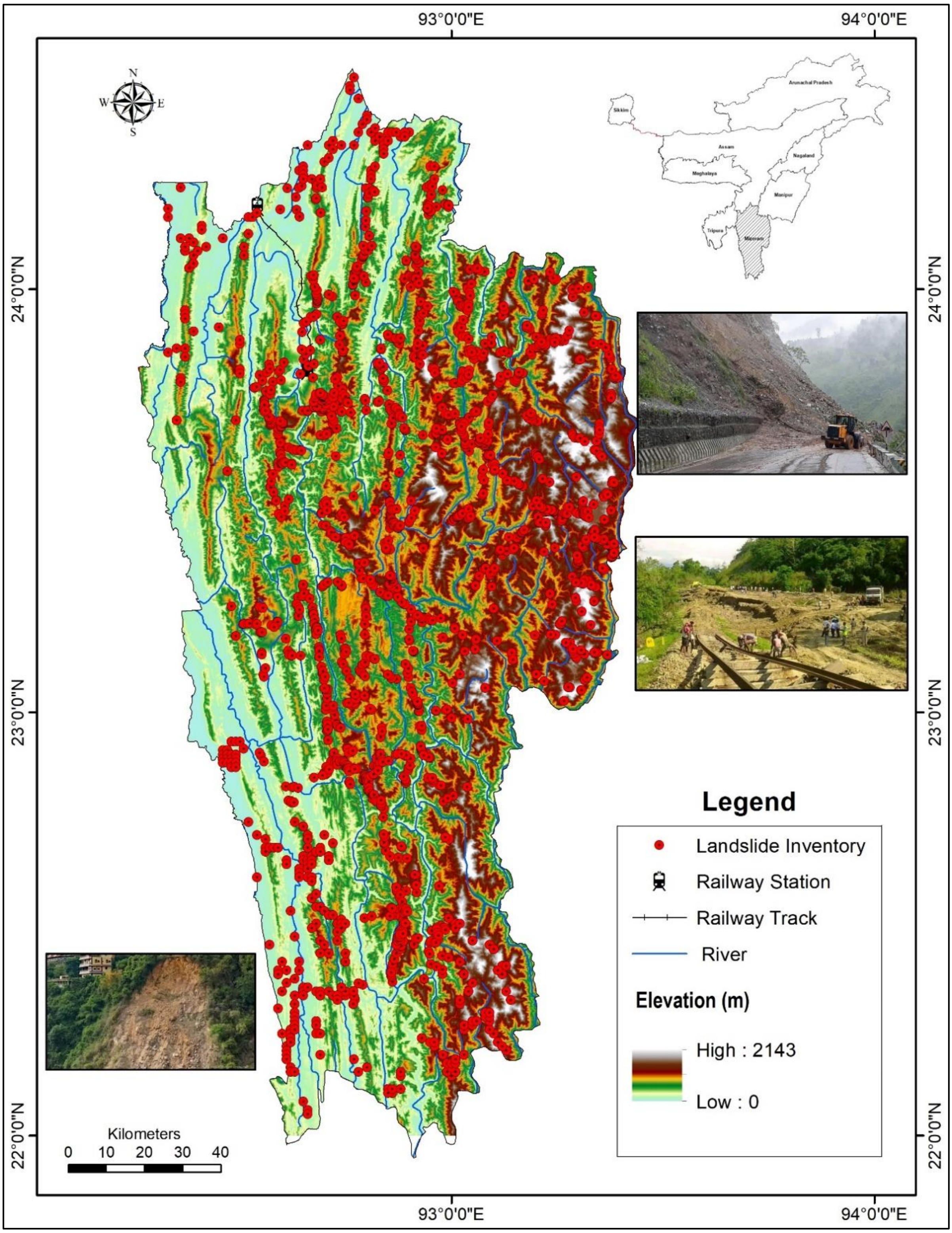

Figure 4. Railway infrastructure of Mizoram with landslide data
Source: prepared by the authors, 2023

The 2020 Mizoram landslides have highlighted the pressing need to improve infrastructure planning and investment in order to enhance its resilience to natural disasters. The state government and NFR have taken actions to repair the damaged tracks and bridges and improve the safety of railway infrastructure. With adequate measures in place, the railway transport system can continue to play a critical role in connecting remote areas in Northeast India with the rest of the country.

Geotechnical investigation and monitoring along the railway not only help identify areas prone to landslides, but also provides information on the stability of slopes and the nature of soil and rock formations, thus helping design effective slope stabilization measures. Proper drainage management is critical in preventing landslides. Drainage system design should prevent water from accumulating on the slopes, which increases the weight and pressure on the soil and rock formations, leading to landslides. Drainage system should also be regularly inspected and maintained to ensure effective functioning. The combination of various measures helps mitigate the impact of landslides on railway infrastructure in Mizoram, such as geotechnical investigation and monitoring, slope stabilization measures, drainage management, vegetation management, and early warning systems. These strategic solutions help ensure the safety and stability of railway infrastructure, while reducing economic losses caused by transportation disruptions.

4.3 Case Study 3: Manipur Earthquake (2016)

Located in Northeast India, Manipur has been grappling with issues of underdevelopment and poor connectivity for a long time [48]. However, the state has been making strides in infrastructure development in recent years, including railway transport system. The railway transport system in Manipur has several challenges [14], because the hilly terrain is prone to landslides, which makes the construction process difficult. Figure 5 shows the challenges confronting the railway construction from Jiribam to Imphal.

In addition, Manipur has insurgency issue, which has delayed the construction process. Another challenge of the railway transport system in Manipur is lack of proper maintenance, because heavy rainfall and landslides often damage tracks and disrupt train services.

In early January 2016, Manipur experienced a strong earthquake measuring 6.7 on the Richter scale, caused by the collision of the Indian and Eurasian tectonic plates. The earthquake, with its epicentre in the Tamenglong district and approximately 17 km deep, caused widespread damages to infrastructure and buildings across the state. The region where the earthquake occurred is characterized by several active faults, including the Imphal fault, which is known to be a highly active fault. Due to the movement along the Imphal fault, energy was suddenly released in the form of seismic waves and caused earthquake. The Imphal fault is a part of the larger Indo-Burmese arc, which is the boundary between the Indian plate and the Burmese microplate. The movement along this boundary formed the Himalayas, and the region is characterized by high-level seismic activities. The impact of earthquake on the railway infrastructure in Manipur was significant, with several railway bridges and tracks damaged.

The NFR said that many tracks and bridges were severely damaged or washed away by the earthquake. According to NFR officials, around 30 railway bridges were damaged in Manipur alone, with the worst-hit areas in the districts of Tamenglong and Noney (Figure 6). Damages to the railway infrastructure had a significant impact on the people of Manipur, many of whom depended on the railway transport system for daily commuting and goods transportation. Disruption of train services caused inconvenience and hardship to passengers and also affected the economy in the state. According to data from the Ministry of Railways, the NFR operated around 3,000 km railway tracks in Northeast India, including Manipur. The railway network plays a crucial role in connecting the remote areas of the region with the rest of the country and also serves as a life-line for goods transportation.

The earthquake in Manipur in 2016 has highlighted the need for better planning and investment in infrastructure, thus making it more resilient to natural disasters [49]. The state government and the NFR have taken steps to repair the damaged tracks and bridges and improve the safety of railway infrastructure. With proper measures in place, the railway transport system can continue to play a crucial role in connecting the remote areas in Northeast India with the rest of the country.

The railway transport system in Manipur has the potential to transform the state's connectivity and improve its overall development. However, the state government needs to address the challenges faced by the system. With proper planning and implementation, the railway transport system in Manipur can become a vital component of infrastructure in the state and contribute to its growth [50].

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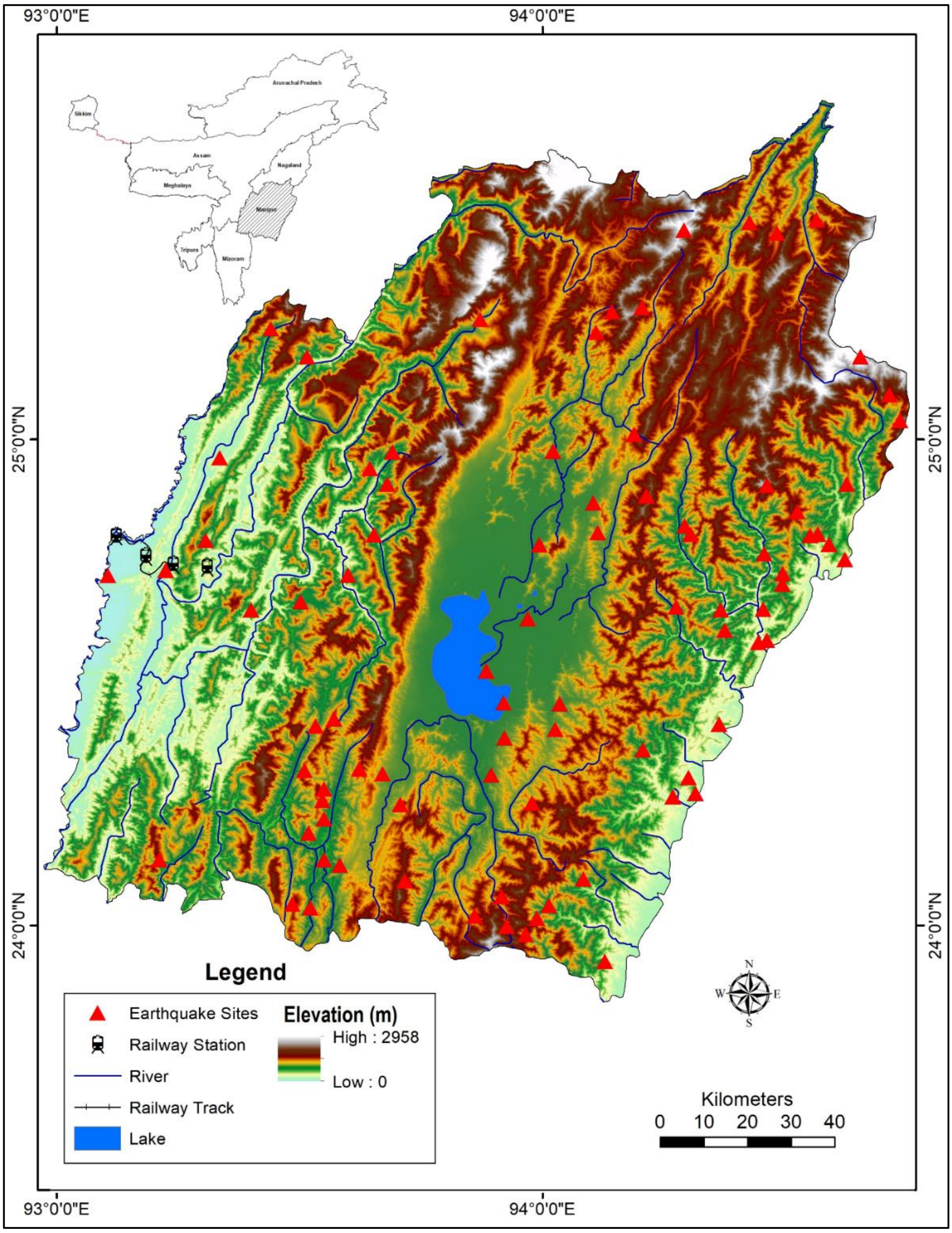

Figure 5. Railway infrastructure of Manipur with earthquake sites
Source: Prepared by the authors, 2023

This paper suggested some strategic solutions to mitigate the impact of earthquakes on railway infrastructure in Manipur. The first step is to make comprehensive seismic hazard analysis, which helps identify the areas most susceptible to earthquake events and provide information on the expected intensity and frequency, thus helping engineers design earthquake-resistant railway infrastructure. Then the next step is to transform the existing railway infrastructure to resist earthquakes, including reinforcing railway structures, tracks, bridges, tunnels, and viaducts, as well as stabilizing slopes and embankments. Advanced technologies, such as sensors and real-time monitoring systems, can be used to help detect seismic activities early and provide alerts to railway operators, thus allowing them to take precautionary measures, including slowing down or stopping trains in high-risk areas. It is crucial to have a well-defined earthquake emergency response plan in place, including procedures for evacuating passengers and personnel from trains, as well as repairing any damages to railway infrastructure. Finally, it is essential to increase public awareness of earthquake safety and preparedness, including providing information on what to do in earthquake, as well as conducting drills and exercises to help people prepare for such events.

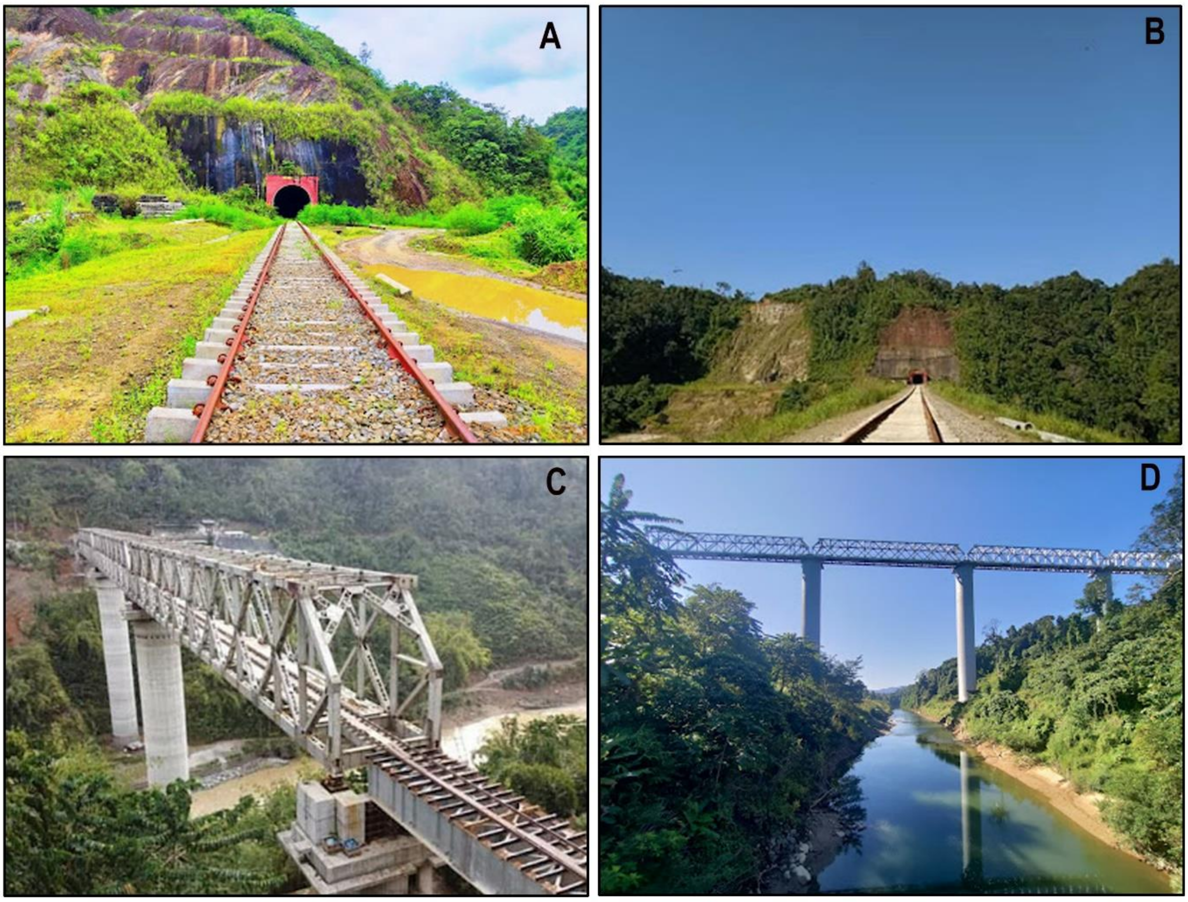

Figure 6. Different railway tunnels (A-B) and bridges (C-D) in Manipur railway

5. Findings

Climate change poses significant challenges for railways in India. Extreme weather events, such as landslides, floods, and earthquakes, cause severe damages to railway infrastructure. Disruption of railway services caused by climate disasters leads to economic losses for the railways and the wider economy. Indian Railways has adopted various measures to alleviate the impact of climatic disasters on railway infrastructure, including use of advanced technologies for monitoring and predicting natural disasters. The railway transport system plays a significant role in Indian economy and daily life of many citizens. The states of Assam, Mizoram and Manipur have faced challenges in railway infrastructure development and maintenance, particularly in dealing with natural disasters, such as floods, landslides, and earthquakes.

To mitigate the effects of climate change, Indian Railways has adopted various measures, particularly use of advanced technologies for monitoring and predicting natural disasters, including satellite imaging, remote sensing, geographic information systems (GIS), and other advanced data analysis tools. By using these tools, the railways can identify areas with higher-risk natural disasters and take preventative measures to mitigate the risks. Another important measure taken by Indian Railways is the development and maintenance of railway infrastructure, including construction of new railways and maintenance of existing railways to ensure their durability and resilience to climate disasters. In addition, Indian Railways has been investing significantly in infrastructure development and maintenance, thus ensuring that rail passengers and cargo can be transported safely and efficiently, even in climate disasters. However, more efforts always can be made to reduce the impact of climate change on railway infrastructure.

6. Policy Recommendation

Climate disasters have a significant impact on railway infrastructure and operation, which in turn affects the safety and well-being of passengers and staff. It is critical for Indian Railways to make clear disaster response plans to deal with floods, earthquakes, landslides, and other related events. One critical aspect is emergency rescue planning, which involves contingency plans in place for evacuating passengers and staff in disasters, as well as ensures emergency response teams are well equipped and trained to respond effectively. Another critical aspect is investment in funding, manpower, and material resources. Indian Railways should allocate resources to ensure that adequate infrastructure and safety measures are in place to prevent and mitigate the impact of disasters, including technology investment to monitor and detect impending disasters, such as weather forecasting equipment, and investment in strong and durable infrastructure and safety equipment.

Furthermore, Indian Railways should clearly know the potential risks and challenges associated with different types of disasters, and tailor their response plans accordingly. For example, Assam is prone to flooding, and the Indian Railways should take steps to strengthen the infrastructure in that region to resist the potential impact of flooding. To sum up, climate disaster response plans for railway infrastructure should be comprehensive, flexible, well funded, and tailored to the specific risks and challenges of different types of disasters. By prioritizing emergency rescue planning and investing in infrastructure and safety measures, Indian Railways can help protect their passengers and staff from the potentially devastating impact of climate disasters.

7. Conclusions

Climate events, such as floods, landslides, earthquakes with specific set of geo-physical structure, create disasters in unique form, which have a negative impact on railway infrastructure. Due to its unique topography and location, Northeast India is particularly vulnerable to climate disasters. A wide range of disasters, including floods, landslides, and earthquakes, significantly affect the railway transport system in the region. Three case studies of different climate disasters showed that geo-physical structure of the region mainly caused the disaster vulnerability. Risks of disaster vulnerability vary in different regions. However, in order to prevent disasters and reduce their effects, Indian Railways should invest resources to ensure that necessary infrastructure and safety procedures are in place, including investment in both technology for tracking and predicting disasters, such as weather forecasting tools, and sturdy and long-lasting infrastructure and safety gear. In addition, Indian Railways should understand the potential dangers and difficulties of various disasters to adjust their reaction strategies.

It is feasible to assume philosophically that environmental determinism is a significant factor to railway development in Northeast India. However, policy interventions at different levels have created possible probability, which might reduce the disaster risks on railway system in the region.

Author Contributions

The contributions of each author in the following statement: "Conceptualisation, S.R. and S.M.; methodology, S.R. and P.D.; software, S.R.; validation, S.R., S.M. and P.D.; formal analysis, S.R.; investigation, P.D.; data curation, S.R.; writing—original draft preparation, S.R.; writing—review and editing, S.R., S.M and P.D.; visualisation, S.R.; supervision, S.M. All authors have read and agreed to the publication of the manuscript.".

Data Availability

The data [Geo-spatial Data] supporting our research results are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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