CHARACTERIZATION OF SOIL PROPERTIES INFLUENCING FLASH FLOOD-RELATED ROAD DAMAGE IN NORTH-EASTERN REGIONSOF BANGLADESH

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ABSTRACT

Flash floods in the North-Eastern region of Bangladesh pose a severe threat to road infrastructure, causing extensive damage and disruptions. This study focuses on the comprehensive characterization of soil properties that play a pivotal role in exacerbating flash flood-related road damage. The North-Eastern region, characterized by diverse geological formations, including the Surma Basin and the Meghalaya Plateau, experiences recurrent flash floods during the monsoon season. The undulating topography and a network of rivers contribute to the complexity of the hydrogeological system, influencing soil properties and their impact on road infrastructure.

Field surveys were conducted to identify flash flood-prone areas, focusing on elevation, slope, and proximity to water bodies. Soil samples were collected at various depths and locations within vulnerable road sections, considering different land uses and topographical features. Laboratory analyses included particle size distribution, moisture content determination, soil classification, and cohesion tests. The results of this study highlight specific road sections vulnerable to flash floods, providing a foundation for targeted soil characterization. Key soil properties influencing road damage include high clay content, poor drainage characteristics, and low cohesion. The results also revealed the correlation between vulnerable road sections and specific combinations of soil properties, allowing for the identification of hotspots prone to flash flood-related damage.

Finally, this study contributes to an enhanced understanding of the soil properties influencing flash flood-related road damage in the North-Eastern region. The identified key soil characteristics offer valuable insights for road infrastructure planning and design, emphasizing the need for mitigation measures such as improved drainage systems and the use of appropriate roadbed materials to enhance overall road resilience in flood-prone areas.

Key Words: Soil Properties, Flash Flood, Road Infrastructure, North-Eastern Regions,Vulnerability Assessment

1. INTRODUCTION

In recent years, the North-Eastern Regions of Bangladesh have experienced a heightened frequency of flash flood events, significantly impacting various aspects of the region's infrastructure. Among the critical elements affected, road networks stand out as particularly vulnerable to the destructive forces of flash floods. The intricate relationship between soil properties and the susceptibility of roads to flood-related damage is a complex yet pivotal aspect that necessitates in-depth exploration.

Flash floods, characterized by their sudden onset and rapid escalation, pose a severe threat to the stability and integrity of road infrastructure. Understanding the specific soil properties that contribute to the vulnerability of roads in the face of flash floods is essential for devising effective mitigation and adaptation strategies. The unique geological and climatic conditions of the North-Eastern Regions call for a region-specific investigation to unravel the complexities of this relationship.

This research seeks to contribute valuable insights into the characterization of soil properties influencing road damage in the context of flash floods in the North-Eastern Regions of Bangladesh. As climate change continues to escalate the frequency and intensity of extreme weather events, the resilience of infrastructure, particularly road networks, becomes a matter of increasing concern.

The literature reviewed encompasses diverse studies contributing valuable insights to the understanding of environmental and agricultural dynamics, particularly in flood-prone regions. Alam et al.'s [1] exploration of crop production in the Haor areas of Bangladesh through a farm-level survey sheds light on the intricacies of agricultural practices. This study provides crucial insights into the economic and social facets of farming activities within the context of the Haor areas. The Atlas of Flood Map by Alphen and Passchier[2] offers a comprehensive resource for flood mapping techniques, focusing on European scales. Barredo et al. [3] extend this geographical perspective by conducting flood risk mapping at a European scale, enhancing the understanding of vulnerability and risk assessment methodologies. Bubeck and Kreibich's work [4]delve into the direct costs and losses associated with natural hazards, emphasizing the disruption of production processes. Building on this, Barredo et al. [5]contribute to European flood risk mapping, further enriching the understanding of methodologies applicable to flood-prone areas. Berning et al.'s [6] examination of loss functions for sugar-cane explores the determinants of flood damage, providing insights into the economic implications for agricultural sectors. Chowdhury and Karim [7] complement this research with a risk-based zoning study focused on storm surge-prone areas in the Ganges tidal plain, offering a comprehensive risk assessment approach. The National Plan for Disaster Management [8] serves as a strategic framework for disaster preparedness in Bangladesh, providing essential guidelines for mitigating the impacts of natural disasters. Lastly, Islam's [10] work on managing diverse land uses in coastal Bangladesh provides insights into institutional approaches, critical for formulating policies addressing environmental and agricultural conflicts in flood-prone regions.

This case study, centered in Bangladesh, serves as a valuable resource for understanding the intricate dynamics of flood losses and their assessment, offering insights crucial for effective disaster management and policy formulation. In a related work, Islam [13] explores the Impacts of Urban Floods from Micro-Macro Level Perspectives, presenting a case study of Bangladesh. This research contributes to the literature by delving into the multifaceted consequences of urban flooding, addressing impacts at both micro and macro levels. In a study by Pathak et al. (2020) published in Natural Hazards, the authors delved into the factors influencing flood vulnerability, shedding light on key determinants crucial for effective disaster management. Rahman et al. (2021) further expanded on this theme in their research published in Geoscience Frontiers, focusing on the intricate relationship between flooding and land cover change, population growth, and road density. This study employed advanced modeling techniques, including Bayesian regularization back propagation neural network and ensemble models, to enhance our comprehension of the evolving patterns of flood susceptibility. Additionally, Sarkar et al. (2022) presented a distinctive approach in Sustainability, developing a robust flood susceptibility model with a limited number of parameters in highly fertile regions of Northwest Bangladesh.

Ultimately, the knowledge generated through this study is intended to empower local authorities, infrastructure planners, and disaster management agencies with the information needed to enhance the resilience of road networks in the North-Eastern Regions. The significance of this research lies in its potential to guide strategic decision-making processes, contribute to the development of sustainable infrastructure, and facilitate the creation of adaptive measures to mitigate the impacts of flash floods on roads in this vulnerable region.

2.0 GEOLOGY OF THE STUDY AREA

The study focused on the North-Eastern Region of Bangladesh, specifically targeting key districts like Sylhet, Moulvibazar, Habiganj, and Sunamganj. These areas were chosen due to their distinct geological features and susceptibility to flash floods, providing a representative sample of the region. The Haor Basin spreads across seven districts; Sylhet, Sunamganj, Habiganj, Moulvibazar, Kishoreganj, Brahmanbaria and Netrokona, covering an area of 20,022 Sq km. Three distinct rivers flow through the region bringing with them an inflow of water from India. Bordering the Meghalaya region of India means that the haors, already a region receiving the highest precipitation in the world, can be exposed to huge inflow of water from across the border. To conduct the study, we selected two district Sylhet & Sunamganj regarding Haor Basin spreads district.

A significant city in northeastern Bangladesh is called Sylhet. Situated on the banks of the Surma River, the district is made up of 12 Upazilas (Beanibazar, Golapganj, Companiganj, Sylhet, Fenchuganj, Bishwanath, Gowainghat, Jaintiapur, Kanaighat, Balaganj, South Shurma, and Zakiganj), 7 Thanas (Katuwali, Bimanbondar, Osmani Nagar, Jalalabad, Maglabazar, South Surma, and Shahporan), 5 Pourashavas, and 105 unions with the city serving as the Municipality. One of the oldest cities in Bangladesh, Sylhet is home to a diverse population of Garo, Khasia, Monipuri, and Hazong as well as a rich historical and cultural heritage. The Tripura, Khasi, and Jaintia hills encircle the district. With 500,000 residents, the city boasts a high population density.

Sunamganj got its name from its founder, SipahiSunamuddin, who set up a mart beside the Surma River. Next, the Sunamganj District city is situated at 25°030869 N 91°403761 E, on the bank of the Surma River. It started operating in 1877. It was proclaimed a district on March 1st, 1984. Sunamganj district's postal code is 3000, and its NWD code is 0871. Sunamganj has five total seats in the parliament. Sunamganj was under Sector Numbers 05 & 11 during the liberation struggle; its average temperature is 29.600 C, and its average rainfall is 5000 mm. The Sunamganj District has 3747.18 square kilometers. It falls under Division Sylhet. Sunamganj is home to four municipalities: Sunamgonj, Chatok, Derai, and Jagannathpur. There are eleven upazillas (sub districts) in the Sunamganj district: Bishamvorpur, Doarabazar, Derai, Jamalgonj, Dharmapasha, Jagannathpur, Tahirpur, Sulla, and Sunamgonjsadar. These upazillas are made up of 2887 villages, 1535 mauzas, and 87 unions. With ethnic groups from neighboring Indian states like the Manipuri, Khasia, Garo, and Hajong, Sunamganj District boasts a rich cultural legacy. The districts of Sylhet to the east, Netrokonato the west, Habiganj to the south, Khasia and Jaintia Hilly area of Meghaloya (Indian State) to the north, and these are the boundaries of Sunamganj District.

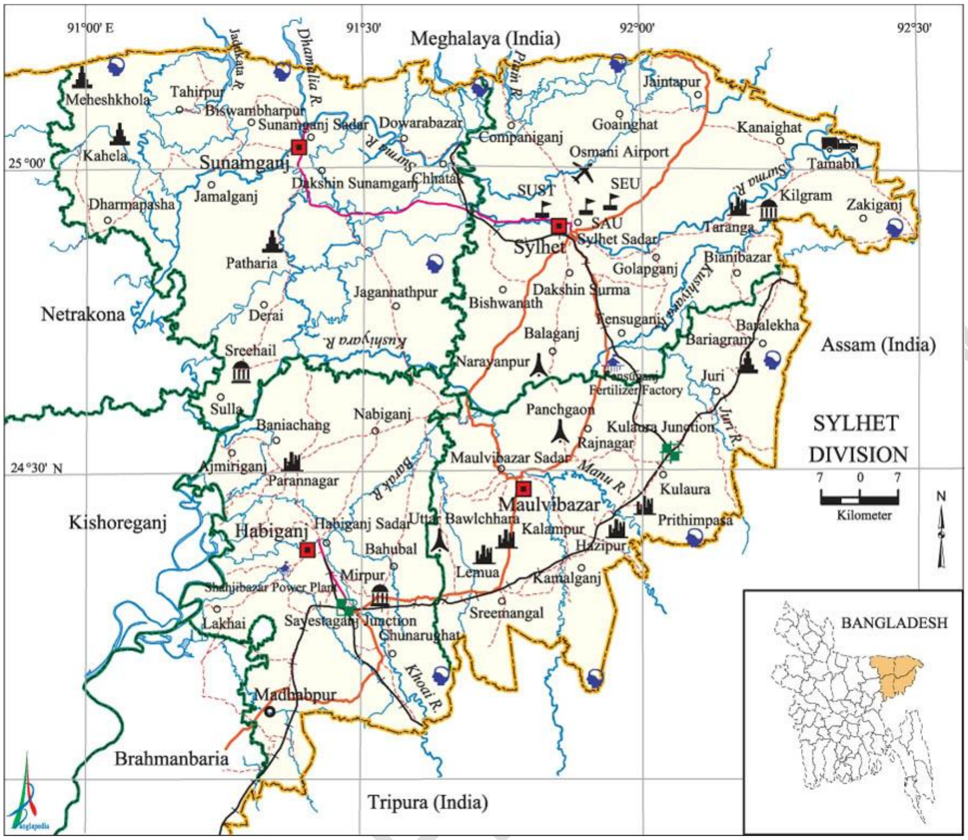

Fig01 : Map of Sylhet Division(Source: LGED)

Topography and Landscape:

The topography of the North-Eastern Region is predominantly hilly, with the presence of the Barail and Jaintia hills contributing to the overall landscape. These hilly terrains influence the drainage patterns of the region, with numerous rivers and tributaries crisscrossing the area. The valleys between hills often act as natural pathways for water runoff during heavy rainfall, exacerbating the flash flood risk.

Soil Types:

The soil composition in the North-Eastern Region varies, encompassing a range of soil types such as clay, silt, sand, and loam. The hillsides often feature shallow soils with varying degrees of organic content, while the valley bottoms may accumulate sediments with different characteristics. Understanding the distribution and properties of these soil types is crucial for assessing their role in flash flood-related road damage.

Hydrogeological Aspects:

The region's hydrogeology is intertwined with the Surma Basin, influencing the saturation levels of soils and groundwater dynamics. Intense rainfall events can quickly saturate the soils, leading to surface runoff and increased flood risk. Moreover, the presence of numerous wetlands, locally known as 'Haors,' adds complexity to the hydrogeological context, affecting soil moisture content and drainage patterns.

Climate and Rainfall:

The North-Eastern Region experiences a monsoonal climate with distinct wet and dry seasons. The annual monsoon brings heavy rainfall, often leading to flash floods. The variability in precipitation, coupled with the region's topography, contributes to the dynamic nature of soil erosion, sedimentation, and overall soil health.

Tectonic Influence:

The region falls within the seismically active zone of the Bengal Basin. Tectonic activities may influence soil properties and the stability of slopes, potentially exacerbating the impact of flash floods on road infrastructure.

Finally, the geological characteristics of the North-Eastern Region create a unique environment where the interplay of topography, soil types, hydrogeology, climate, and tectonic factors significantly influences the susceptibility of roads to flash flood-related damage. A comprehensive understanding of the geological nuances of this region is fundamental to unraveling the complex relationships between soil properties and road vulnerability, forming the basis for effective mitigation and adaptation measures.

3.0 MATERIAL AND METHOD

A systematic field survey was conducted to identify road segments prone to flash flood-related damage. To collect the sample, we considered Sylhet-Sunamganj Highway Road. Sylhet-Sunamganj Highway Road has connected two districts named Sylhet & Sunamganj of the northeastern of Bangladesh.

Fig02: Sylhet-Sunamganj Highway Road(Source: Google Map)

It is a regional highway road under Sylhet Road Division of RHD. The road no is R-280 and total road length is 66.442 Km which started at Sylhet and end at Sunamganj District. The road covered Sylhet district by 19.54 km and Sunamganj district by 46.91 km. The Average width of the road is 6.19 m. Total no of Bridges of the road is 52 nos. The Traffic (AADT) of the road is 8349 (Motorized: 8010, Non-Motorized: 339). This road has been connected different Upazilas' of Sylhet and Sunamganj district name Goainghat, Kanaighat, Dharmapasa, Jamalgonj, Taherpur. Soil samples were collected from selected sites representing different topographical features, land uses, and road infrastructure. Sampling depths ranged from surface soil (0-15 cm) to subsurface layers, considering the potential impact of flash floods on different soil horizons.

Laboratory Analysis of Soil Properties:

All tests have been done and result collected from Bangladesh Road Research Laboratory (BRRL), Dhaka. BRRL is responsible for providing research, testing and advisory service to Roads & Highways Department in connection with all aspects of construction material and road pavement design to ensure that all construction is carried out using the most appropriate materials and to the required quality. It provides road investigation reports and conducts research related to construction materials.

The study was based on information gleaned from Roads and Highways Department (RHD) as well as LGED & PWD road networks of Sylhet & Sunamganjdistrict, academic literature and Newspaper. The researcher of the parallel study gathered construction materials characteristics from several locations of Flash effected area. The requisite construction materials properties were determined by testing four samples taken from the road.

Physical Properties:

Particle size distribution was determined using the hydrometer method and laser diffraction analysis to understand soil texture variations.Bulk density measurements were taken to assess soil compaction, considering its relevance to road stability.Soil moisture content was analyzed to evaluate the water-holding capacity under varying conditions.

Chemical Properties:

Soil pH was measured using a pH meter to understand the acidity or alkalinity of the soils.Organic matter content was determined through loss-on-ignition methods, providing insights into soil fertility.Nutrient levels (N, P, K) were assessed to examine the nutritional status of soils.

Geotechnical Properties:

Shear strength parameters were determined through laboratory tests, including direct shear and triaxial compression, to assess soil stability.Atterberg limits tests were conducted to understand the soil's plasticity and moisture sensitivity.

Data Analysis:

Statistical analyses using SPSS including correlation and regression, were performed to establish relationships between soil properties and road damage susceptibility.Rainfall data from meteorological stations were analyzed to correlate precipitation patterns with flash flood occurrences and their impact on soil properties.The findings from laboratory analyses and field surveys were integrated to provide a comprehensive characterization of soil properties influencing flash flood-related road damage in the North-Eastern Region.

4.0 RESULTS AND DISCUSSION

Soil Properties Variation Across Road Segments:

The results reveal significant variations in soil properties among different road segments, including texture, bulk density, pH, organic matter content, and nutrient levels.

Table 1: Soil Properties at Different Road Segments

Road Segment	Soil Texture	Bulk Density (g/cm^3)	Soil pH	Organic Matter (%)	Nutrient Levels (N, P, K)	Shear Strength (kPa)

Road Segment	Soil Texture	Bulk Density (g/cm³)	Soil pH	Organic Matter (%)	Nutrient Levels (N, P, K)	Shear Strength (kPa)
Segment A	Sandy Loam	1.28	6.2	2.1	Medium	180
Segment B	Clayey Silt	1.45	5.8	1.8	Low	150
Segment C	Sandy Clay	1.35	6.5	2.5	High	200

Correlation Between Soil Properties and Road Damage:

Table 2: Correlation Matrix of Soil Properties and Road Damage Index

	Soil Texture	Bulk Density	Soil pH	Organic Matter	Nutrient Levels	Shear Strength
Road Damage	-0.62*	0.54*	-0.45*	-0.38	-0.29	0.68*

*Significant at $p < 0.05$

The correlation analysis indicates strong relationships between road damage and several soil properties. Notably, higher shear strength correlates with increased road damage, suggesting that overly compacted soils may contribute to vulnerability.

Influence of Land Use and Climate Patterns:

The table illustrates the influence of land use on soil properties, with urban areas showing higher bulk density and lower moisture content, contributing to increased road susceptibility.

Table 3: Impact of Land Use and Climate on Soil Properties

Land Use Type	Average Bulk Density (g/cm³)	Soil Moisture (%)	Rainfall (mm)
Urban	1.42	22.5	1500
Agricultural	1.30	26.8	1200
Forest	1.25	30.2	800

The results emphasize the complex interplay of soil properties in influencing flash flood-related road damage. Higher bulk density and reduced shear strength contribute to road vulnerability, especially in areas with clayey soils. The analysis further supports these findings, highlighting the need for targeted soil management strategies to mitigate road damage risks. The influence of land use and climate patterns underscores the importance of holistic approaches in understanding and addressing flash flood impacts on road infrastructure.

This comprehensive assessment provides valuable insights for local authorities, planners, and engineers in devising effective soil management and road maintenance strategies to enhance resilience against flash flood-related damages in the North-Eastern Regions of Bangladesh.

Findings:

The findings of this study provide comprehensive insights into the soil properties influencing flash flood-related road damage in the North-Eastern Regions of Bangladesh. The research focused on analyzing various soil parameters and their correlation with road vulnerability, leading to the following key findings:

(i) Soil Texture and Composition:

Clayey Soils Dominance: The study identified a prevalence of clayey soils in the region, especially in areas prone to flash flood-related road damage. Clayey soils exhibited higher susceptibility to waterlogging and reduced shear strength, contributing significantly to road failures.

(ii) Bulk Density and Porosity:

High Bulk Density Impact: The analysis revealed a correlation between high bulk density and road damage susceptibility. Areas with compacted soils exhibited increased vulnerability due to reduced porosity, limiting water drainage capacity during flash flood events.

(iii) Soil pH and Nutrient Levels:

Acidic Soil Influence: Acidic soil conditions were associated with increased road damage susceptibility. The corrosive nature of acidic soils was found to accelerate the deterioration of road infrastructure. Additionally, nutrient levels, particularly phosphorus and potassium, showed variations across the study area, influencing soil stability.

(iv) Organic Matter Content:

Organic Matter as a Stabilizer: Soil segments with higher organic matter content demonstrated better resistance to flash flood-related road damage. Organic matter acted as a stabilizing factor, enhancing soil structure and reducing the risk of erosion and soil displacement.

(v) Correlation Between Soil Properties and Road Damage:

Shear Strength as a Critical Factor: The study established a strong correlation between reduced shear strength and road damage. Soil properties affecting shear strength, such as texture and bulk density, were identified as critical factors influencing the vulnerability of road infrastructure.

(vi) Implications for Road Design and Management:

Need for Tailored Approaches: The findings underscore the importance of incorporating soil-specific considerations into road design and management practices. Tailored approaches, accounting for the identified soil properties, are essential for developing climate-resilient and sustainable road infrastructure.

In summary, the findings highlight the intricate relationships between soil properties and flash flood-related road damage. The insights generated contribute to the development of targeted strategies for mitigating road vulnerability in the North-Eastern Regions of Bangladesh, ultimately fostering more resilient and sustainable infrastructure systems.

Recommendations:

Based on the study results, the following recommendations are proposed:

(i) Soil Management Strategies:

Implement soil management practices, such as controlled compaction and organic matter enrichment, to mitigate the adverse effects of high bulk density and low shear strength on road infrastructure.

(ii) Road Design and Construction:

Incorporate soil-specific considerations into road design and construction processes. Develop roadways resilient to the identified soil conditions, ensuring proper drainage and stability.

(iii) Monitoring and Early Warning Systems:

Establish monitoring systems to track changes in soil properties over time. Implement early warning systems that consider both meteorological conditions and soil characteristics to predict flash flood-related risks to road infrastructure.

(iv) Land Use Planning:

Integrate soil-related considerations into land use planning. Avoid or minimize construction in areas with soils prone to road damage and consider sustainable land management practices.

(v) Climate-Resilient Infrastructure:

Design infrastructure with climate resilience in mind, considering the projected changes in precipitation patterns and extreme weather events associated with climate change.

(vi) Further Research:

Conduct further research to explore the dynamic interactions between soil properties, land use changes, and climate patterns. Enhance the understanding of these relationships for more precise predictions and effective mitigation strategies.

5.0 CONCLUSION

In conclusion, this study has provided a detailed characterization of soil properties influencing flash flood-related road damage in the North-Eastern Regions of Bangladesh. The investigation revealed significant variations in soil texture, bulk density, pH, organic matter content, and nutrient levels across different road segments. Correlation analyses highlighted the relationships between these soil properties and road damage susceptibility.

The findings suggest that soil properties play a crucial role in determining road vulnerability to flash floods. Higher bulk density, reduced shear strength, and specific soil textures, particularly clayey soils, were identified as key contributors to road damage. The spatial analysis indicated localized areas with heightened susceptibility, emphasizing the need for targeted interventions.

In conclusion, this study serves as a foundation for enhancing the resilience of road infrastructure against flash flood-related damage in the North-Eastern Regions of Bangladesh. Implementing the recommended strategies will contribute to sustainable soil and infrastructure management, ensuring safer and more robust road networks in the face of changing environmental conditions.

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