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Understanding Disaster Risks through Vulnerability Analysis in Indo-Nepal Terai Region

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Abstract
Vulnerability is a multi-dimensional and multi-layered concept that encompasses a range of factors affecting individuals, communities, and systems. It is a crucial lens through which to understand the susceptibility of various entities to harm and their inability to cope with adverse impacts. Vulnerability is particularly relevant in the context of disasters and climate change. A comprehensive vulnerability analysis can help in understanding and assessing potential disaster risks for better planning. This study provides a comprehensive vulnerability analysis of the Indo-Nepal Terai region, which is highly prone to natural disasters. Being geologically young and tectonically active, the region exhibits a dynamic and unstable terrain, a condition further exacerbated by the high-intensity monsoonal rainfall. The presence of several Himalayan rivers, combined with heavy precipitation, often triggers a range of mass-wasting processes, including landslides, debris flows, and recurrent flooding. This study seeks to identify the physical and socio-economic vulnerabilities within the Indo-Nepal Terai region. Relying on secondary data sources, Principal Component Analysis (PCA) was employed for vulnerability mapping. The findings reveal that several districts in the Terai region fall within high and moderate vulnerability zones, indicating higher risks. The study emphasizes the urgent need for a robust internal as well as cross-border disaster management mechanism between Nepal and India for effective preparation to mitigate the risks.
Keywords: *Natural Disasters, India and Nepal, Principal Component Analysis, Trans-Boundary cooperation, Vulnerability*

INTRODUCTION

The concept of vulnerability became a central focus in disaster studies during the late 1980s and 1990s (Watts & Bohle, 1993; Wisner, 1993; Blaikie et al., 1994). Vulnerability exists along a spectrum, meaning that some individuals and groups face greater risks than others depending on a variety of factors (Wisner et al., 2004). Although the concept carries multiple interpretations depending on context, a more analytical understanding emerges when vulnerability is studied in relation to the impacts of natural hazards as well as broader socio-economic and political conditions. In essence, vulnerability is shaped by an interplay of physical, social, and economic dimensions. Physical vulnerability stems from exposure to extreme natural events within fragile environmental settings. Social vulnerability arises from factors such as social exclusion, gender discrimination, poverty, marginalization of specific communities, age, and psychological stress. Economic vulnerability is associated with high dependency ratios, fragile rural livelihoods, and the pressures of globalization. Collectively, these dimensions determine the degree to which communities are susceptible to disasters and influence their capacity to cope with and recover from them.

Given the frequent disasters experienced in the Terai, the impacts extend far beyond immediate losses, affecting communities, infrastructure, public health, and sanitation systems. As Rakhal et al. (2021) emphasize, comprehensive multi-hazard risk assessments are crucial for the region. Such assessments enable local communities to better understand their risks, prepare accordingly, and develop resilience strategies tailored to the multi-dimensional nature of vulnerability in the Indo-Nepal Terai region.

This study holds particular significance as it integrates both physical and social dimensions of vulnerability, thereby addressing a notable gap in the literature. While most existing research tends to examine these aspects in isolation, relatively few studies have attempted to analyse them in combination. By adopting this holistic approach, the present work advances a more comprehensive understanding of vulnerability in the Indo-Nepal Terai region. Furthermore, this study is pioneering in its scope, as it encompasses the cross-border context of Nepal and India. As Dutta (2021) aptly notes, disasters transcend political boundaries, underscoring the importance of transnational perspectives in disaster research. In this regard, the Indo-Nepal Terai presents a compelling case for developing collaborative disaster management mechanisms that are sensitive to the region's unique physiography. Recognizing that nature itself provides critical insights for resilience building, such an approach not only strengthens disaster preparedness and response but also carries broader implications for fostering cooperation and stability within the geopolitical landscape of South Asia.

RESEARCH METHODOLOGY

This study employs a comprehensive methodological framework grounded in an extensive review of literature. A holistic understanding of vulnerability requires examining the interaction between physical and social factors, as vulnerability analysis yields the most robust results when both dimensions are integrated. To achieve this, the research incorporates dual approaches, combining physical and socio-economic perspectives.

First of all, the study analyses the physical vulnerability based on three recurring disasters in the study region. For Physical Vulnerability Mapping, landslides, earthquakes, and floods ArcGIS 10.5 entails a comprehensive process integrating various spatial data and analytical techniques. All three natural disaster-related datasets have been taken from different geospatial data sources, such as the National Information Centre on Earthquake Engineering by IIT Kanpur, the European Commission's Directorate-General for European Civil Protection and Humanitarian Aid Operations, and the SRTM (30m) satellite imagery portal. These datasets undergo the processing of data under Spatial Analyst, Masking, Reclassification, and Conversion tools to ensure accuracy and compatibility, and also involve steps like georeferencing, data cleaning, and normalization. In ArcGIS 10.5, separate spatial data layers for each hazard are created. For landslides, factors such as slope gradient and vegetation cover stability are analysed; for earthquakes, seismic zones and fault lines are mapped; and for floods, hydrological models incorporating rainfall data and river discharge rates are developed. Using spatial analysis tools, hazard-specific vulnerability maps are generated through techniques such as weighted overlay and hazard zonation. Each hazard map is then integrated into a composite physical vulnerability map, highlighting areas susceptible to multiple hazards. This composite map is validated by cross-referencing with historical disaster events and field surveys. The final vulnerability map is visualized using ArcGIS's advanced cartographic capabilities, providing a crucial tool for disaster risk management, urban planning, and emergency response strategies.

To prepare a Landslide Map, Earthquake Map, Flood Map, and Natural Hazard (Landslide, Earthquake, and Flood) map, the working space in the ArcGIS has been adjusted into 2 different data frames (one small data frame (inset) and one data frame in a bigger size for the Location map. The other 4 maps are prepared in a single data frame.

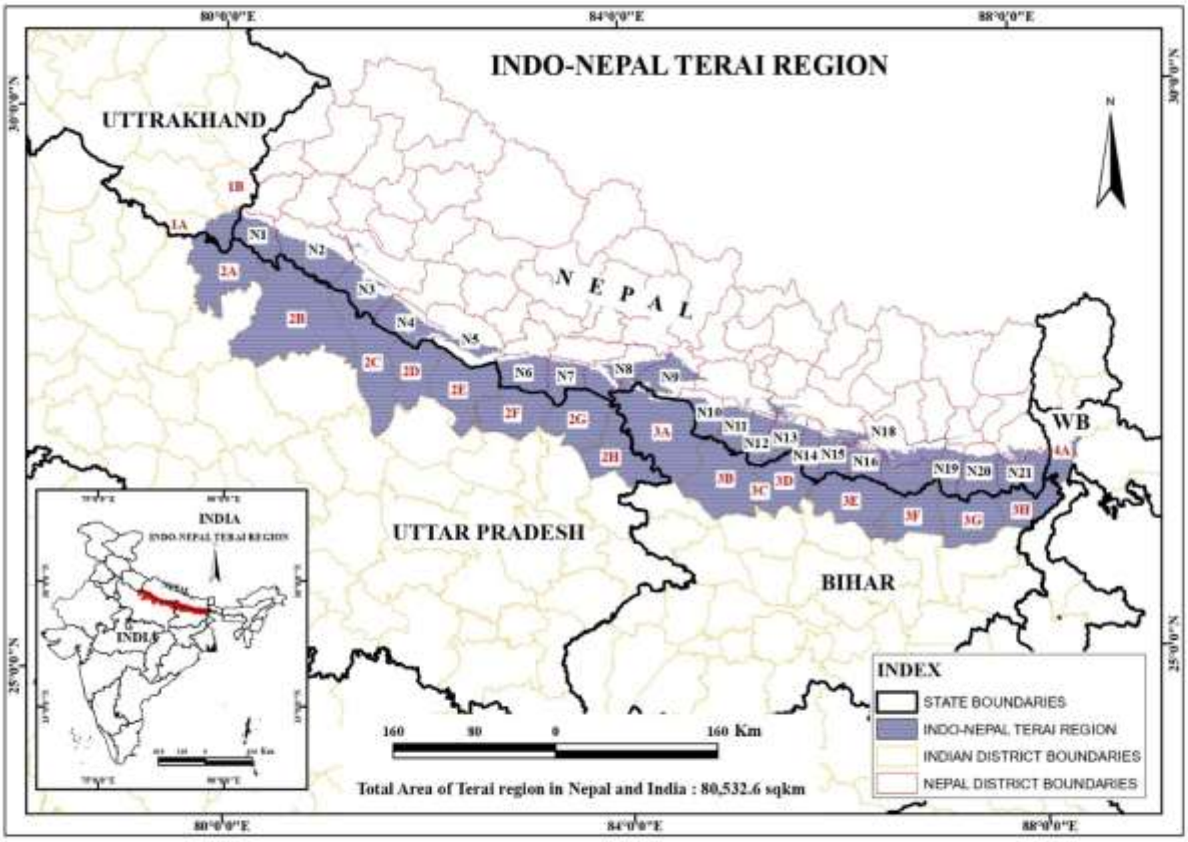
While for the socio-economic vulnerability mapping, the methodology followed the popularized Social Vulnerability Index (SoVI) developed by Cutter et al. (2003), a method that quantifies and identifies social vulnerability indicators, offering deeper insights into the underlying nature and drivers of vulnerability (Cutter & Morath, 2014).

Building on this, Aksha et al. (2019) adapted the SoVI methodology, which was originally developed in the United States using over 200 variables, and they modified it to the Nepalese context. Their version incorporated 15 major categories and 39 subcategories, thereby tailoring the model to local socio-physical realities. Drawing inspiration from these modifications, the present study similarly applies the SoVI framework to assess socio-economic vulnerability in the Indo-Nepal Terai. For greater contextual accuracy, 14 major categories were selected for analysis based on the regional analysis. Data were sourced from the Central Bureau of Statistics, Government of Nepal (CBS, 2011), and the Census of India (2011), ensuring comprehensive representation of both national contexts. These adjustments strengthen the applicability of the SoVI methodology to the distinct socio-economic landscapes of the Terai region.

Taken together, these dual assessments provide a holistic understanding of vulnerability dynamics across the Indo-Nepal Terai, a region characterized by multi-hazard risks as well as ongoing socio-economic and political challenges.

Study Area

The Terai region spans the southern plains of Nepal and the northern part of Uttar Pradesh in India, extending further into Uttarakhand, Bihar, and West Bengal. Administratively, it covers 21 districts in Nepal (Central Bureau of Statistics, Government of Nepal, 2011) and 19 districts in India (Census of India, 2011). Physio graphically, the Indo-Nepal Terai is marked by diverse landscape features, including fertile plains, rolling hills, and interconnected river systems that sustain agricultural livelihoods (Talchabhadel et al., 2018). The region lies along the northern edge of the Indo-Gangetic plain (Upreti, 2001 and Kshetri, 2023), and while it is highly fertile and densely populated, it is also one of the most disaster-prone zones. Floods, cyclones, earthquakes, droughts, and landslides recur almost every year, significantly affecting the lives and livelihoods of local populations (Upadhyay & Arora, 2023).



Source: Prepared by Researcher

Map 1: Location map of the Study Area

The environmental setting of the Indo-Nepal Terai reflects a dual character. On one hand, it offers abundant opportunities for production, supporting agriculture, pastures, and energy resources; on the other, it is highly vulnerable to recurrent extreme natural events such as floods, earthquakes, and landslides. These hazards significantly disrupt the lives and livelihoods of millions of people, while also damaging infrastructure and creating widespread socio-economic challenges. As established in disaster studies, hazards only evolve into disasters when they intersect with human populations and adversely affect their livelihood systems; otherwise, they remain natural phenomena. Therefore, disasters should not be understood merely as physical or environmental events but as socially constructed outcomes, shaped and intensified by human systems, socio-economic conditions, and patterns of vulnerability. A comprehensive understanding of disasters in the Indo-Nepal Terai thus requires an appreciation of both hazard dynamics and the underlying vulnerabilities of the communities at risk.

Objectives

To identify the physical vulnerabilities of the study area by examining the three recurrent disasters: flood, earthquake, and landslide.

To identify the socio-economic vulnerability of the study area.

RESULT AND DISCUSSION

In this study, the processing and analysis of data were conducted utilizing a diverse set of tools. To map the physical disaster vulnerability, ArcGIS is used. Similarly, for the socio-economic vulnerability principal component analysis (PCA), an important statistical tool has been used with the help of STATA software.

1. Physical Vulnerability

To analyse the physical vulnerability, a Physical Vulnerability Map for the Indo-Nepal Terai region is prepared. The map is meticulously prepared by overlaying Landslide, Earthquake, and Flood maps, utilizing multiple layers to determine the physical vulnerability.

1.1 Landslide

Landslides are a pervasive natural hazard that poses significant challenges across various countries, leading to the loss of lives and substantial property damage (Khodadad and Jang, 2015). Particularly prevalent in mountainous

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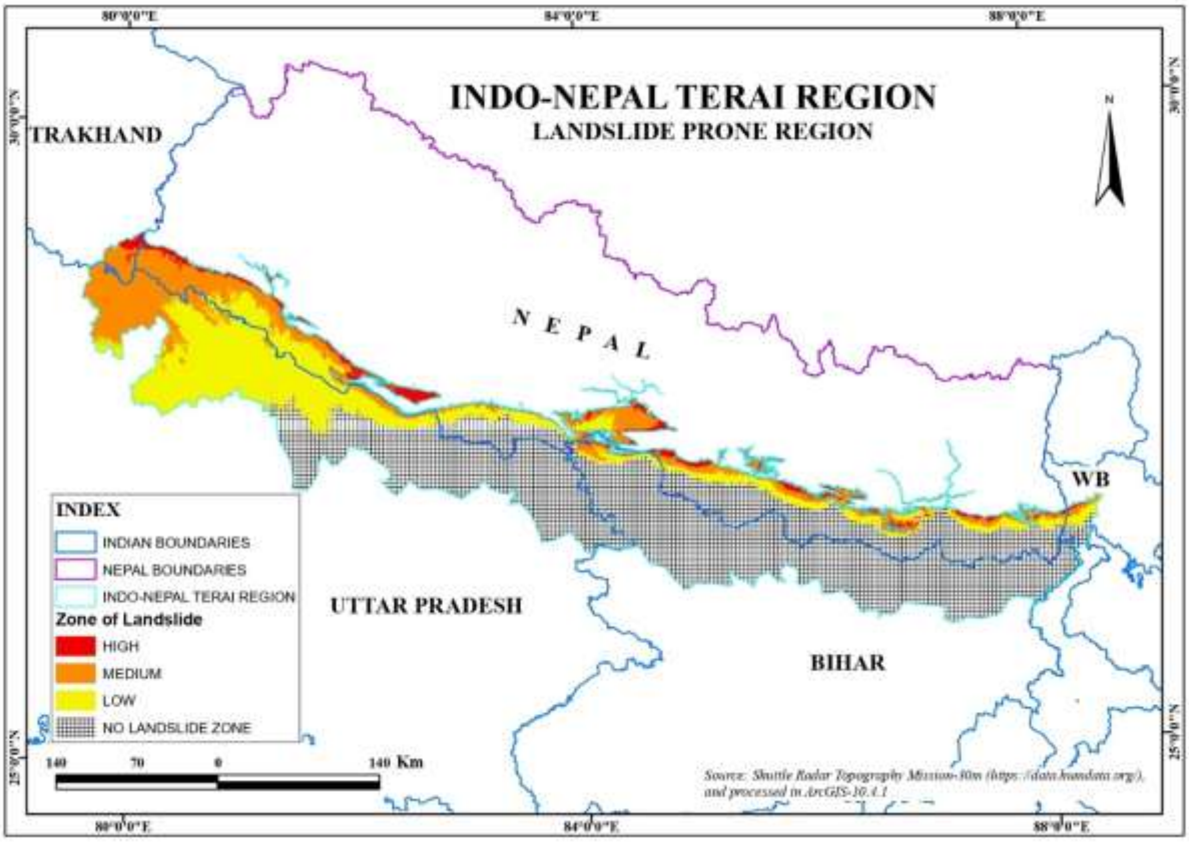
and unstable terrains, landslides are often triggered by heavy rainfall and saturation, underscoring the need for identifying vulnerable areas to mitigate casualties (Dai & Lee, 2002).

The unpredictable and uncertain predisposing factors associated with landslides contribute to an increased potential threat (Wang et al., 2015). Encompassing various mass movements such as rock falls, topples, and debris flow, landslides manifest in diverse forms with little to no sliding involved. Recognizing and identifying areas prone to landslides is of paramount importance for local populations and is particularly crucial for comprehensive studies in this domain.

Bhandari and Dhakal (2018) emphasizes that a thorough understanding of landslides requires elucidation of landslide boundary shears, concurrent monitoring of time-dependent piezometric pressures, surface and sub-slope displacements, and mapping of ground deformations and shear zones. Behavioural studies of human settlements associated with landslides also form an integral part of landslide investigations. In contemporary research, the integration of remote sensing and Geographic Information Systems (GIS) has emerged as a powerful tool for mapping landslide-prone regions.

To get the landslide map for the Indo-Nepal Terai region, first, all delamination of the Terai Region has been done through the elevation classification process, in which an elevation of 0-300 m has been chosen. For the classification, Digital Elevation Model (DEM) Data has been used. SRTM 30 of India and Nepal have been downloaded from the USGS Portal by logging in through a valid account ID and Password. Classification of the DEM is done with the help of layer properties in ArcGIS and classified into several classes. 0-300 m has been chosen for the Terai Region.

After the delimitation of the Terai region, the SRTM 30 data have been added to the data frame, and a mosaic to a new raster has been performed to carve out a DEM for the Terai region. Through the Toolbar section, with the help of the Spatial Analyst tool Slope, Aspect Slope, and curvature have been extracted. The Contour has been drowned by using the Spatial Analyst tool. The Union of Contours and elevation (Curvature) has been calculated. The output raster data is further classified into 4 different classes i.e., Low, Medium, High, and No landslide Zone.



Source: Prepared by Researcher

Map 2: Landslide Map of Indo-Nepal Terai Region

Examining the map reveals that the region highlighted in red, designating a high-vulnerability zone, is predominantly situated within Nepal, spanning all districts from the eastern to the western regions. Notably, the high landslide-prone zone is primarily concentrated in the western part of the Indian Terai region, specifically in

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Uttarakhand. In contrast, the impact of landslides is relatively minimal in the Indian Terai, particularly in the eastern Indian Terai region, which remains largely unaffected. However, the entirety of Nepal exhibits a varied landscape of landslide-prone areas, showcasing distinct zones characterized by varying levels of susceptibility to landslides.

1.2 Earthquake

Earthquakes are among the most devastating natural disasters, and the entire Indo-Nepal Terai region lies within a high-seismic activity zone. This vulnerability stems primarily from the geological movement of the Indian plate pushing northward into the more stable Tibetan plate (Kshetri, 2023). An earthquake, often referred to as a quake, tremor, or temblor, is caused by the sudden release of energy in the Earth's crust, generating seismic waves. These events manifest at the Earth's surface as ground shaking and, in some cases, ground displacement.

Large earthquakes, particularly those with offshore epicentres, can displace the seabed, triggering tsunamis. Additionally, earthquakes can lead to secondary hazards such as landslides and, rarely, volcanic eruptions. In a broader context, the term "earthquake" encompasses any seismic activity, whether naturally occurring or human-induced, that generates seismic waves. While geological faults are the primary cause, other triggers include volcanic eruptions, landslides, mining blasts, and nuclear tests. The point of initial rupture during an earthquake is referred to as the focus or hypocentre, with the epicentre being the point directly above it on the Earth's surface.

For earthquake risk assessment, a base map sourced from the National Information Centre on Earthquake Engineering at the Indian Institute of Technology, Kanpur, was georeferenced and digitized to cover the regions of India and Nepal. Historical earthquake data, including coordinates of past seismic events, were analysed to project earthquake-prone areas. Using the Kriging process under the Spatial Analyst tool, a raster density map was generated, which was then converted into a vector map and categorized into three risk zones:

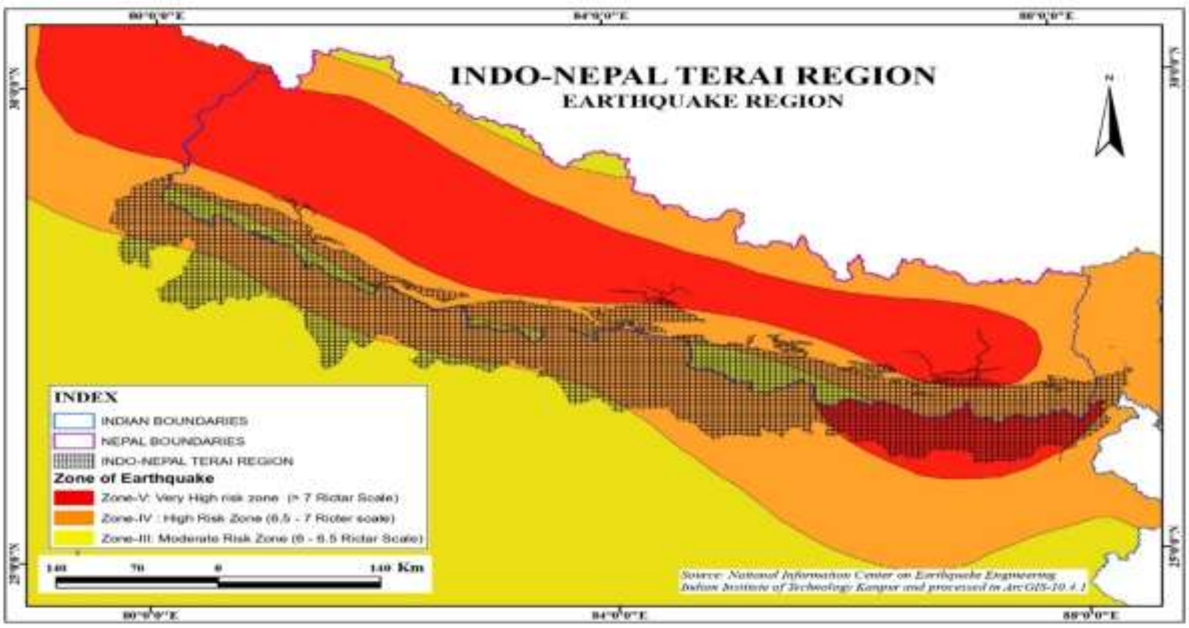
Zone V: Very High-Risk Zone – Representing areas where earthquake magnitudes on the Richter scale are equal to or greater than 7.0.

Zone IV: High-Risk Zone – Covering regions with magnitudes ranging from 6.5 to 7.0.

Zone III: Moderate Risk Zone – Encompassing areas where magnitudes range from 6.0 to 6.5.

The delineated Terai region was overlaid on these zones to create a comprehensive earthquake risk map. Upon analysing the prepared map, the regions shaded in red (Zone V) emerge as the most vulnerable, highlighting the very high-risk areas for seismic activity. The eastern Terai region falls predominantly within this zone, surrounded by Zone IV (high-risk areas). The central region of Nepal also stands out as particularly susceptible to seismic events, emphasizing the urgent need for enhanced preparedness and mitigation strategies in these areas.

This zonation map is an essential tool for understanding regional seismic risks, guiding disaster preparedness measures, and prioritizing resource allocation to minimize the impacts of future earthquakes. The visualization underscores the critical need for awareness and proactive planning in high-risk zones, particularly in the Indo-Nepal Terai region.



Source: Prepared by Researcher

Map 3: Earthquake Map of Indo-Nepal Terai Region

1.3 Flood

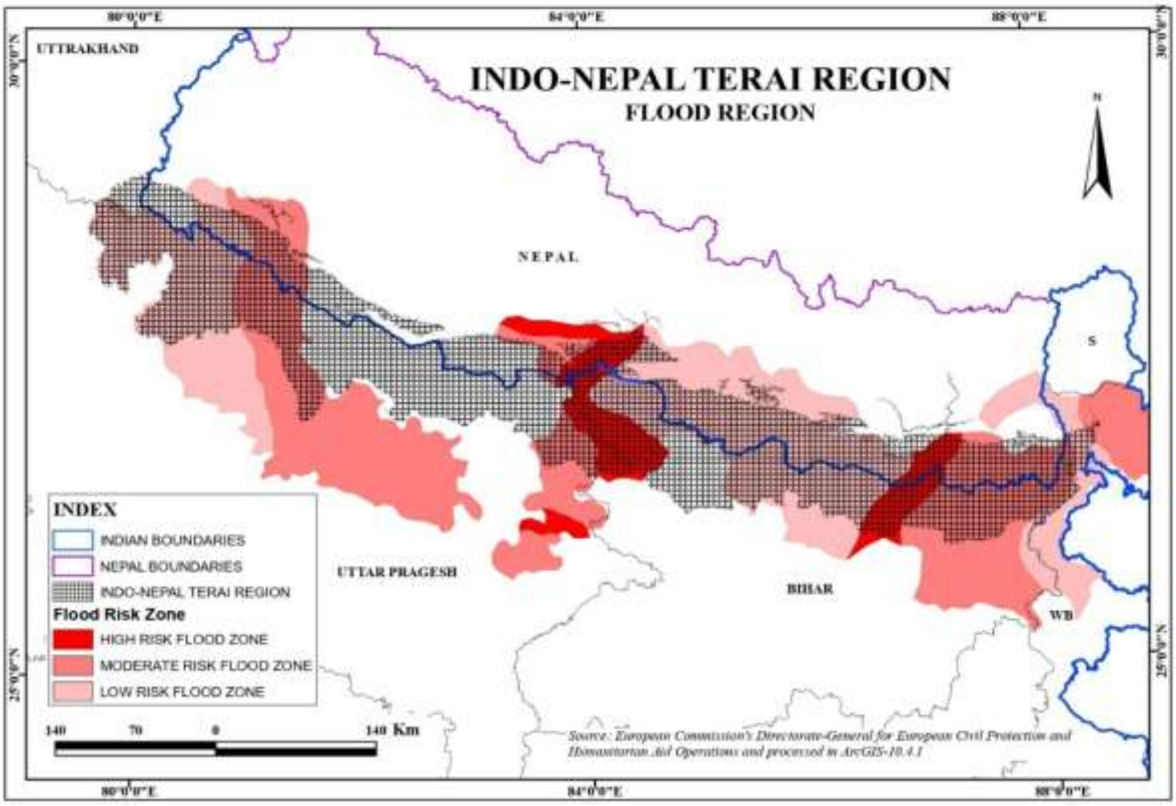
Flooding emerges as a formidable hazard in Nepal's Terai region, inflicting extensive damage on both built and natural environments and wreaking havoc on human settlements (Gurung,2024). The impact of floods in the Terai is particularly severe, surpassing the repercussions of other natural events, as it annually exacts a heavy toll on both people and their wealth.

The Terai experiences substantial rainfall, occasionally triggering landslides, compounding the flood-related challenges. Despite Nepal being an upper riparian country, the southern Terai region is most profoundly affected, with the Indian Terai region bearing the brunt of the flood's onslaught. This has contributed to the region witnessing some of Asia's most devastating floods (Sharma et al., 2013). The inundation of expansive urban areas serves as a forewarning, suggesting that human lives are increasingly vulnerable to future flood disasters (Manandhar et al., 2023) and Geoinformatics, Survey Department, Nepal). In the Indo-Nepal Terai region, it has been observed that the annual flood cycle typically begins in mid-June and continues until mid-September, especially during every monsoon season.

The flood mapping procedure is also based on the Basemap. The Basemap for the flood zones is taken from the European Commission's Directorate General for European Civil Protection and Humanitarian Aid Operations. The process involves rectification and Georeferencing of the map.

The Georeferenced Basemap is digitized and processed into the classification of flood zones into 3 major categories: i.e., High, Moderate, and Low Risk Zones. The Zoning was also assessed on the past flood situation based on satellite images, through which flood zones are further classified. The Landsat 5, 7, and 8 images from 2000, 2010, and 2020 have been processed through supervised classification. The processed Landsat 05, 07, and 08 Images were superimposed on each other and classified into three categories regarding the digitized Basemap (Map 4).

As indicated by the map, districts shaded in red denote regions falling under the high flood risk zone. Notably, Nawalparasi, Chitwan, and Sunsari in Nepal, along with West Champaran and Supaul in India, emerge as areas susceptible to elevated flood risks.



Source: Prepared by Researcher

Map 4: Flood Map of Indo-Nepal Terai Region

In the process of creating the Physical Vulnerability Map for the Indo-Nepal Terai region, a comprehensive approach was adopted. The map was meticulously prepared by overlaying Landslide, Earthquake, and Flood maps, utilizing multiple layers to discern the cumulative vulnerability. The base layer employed was the earthquake classification layer, utilizing a choropleth pattern for effective classification. Subsequently, the Flood

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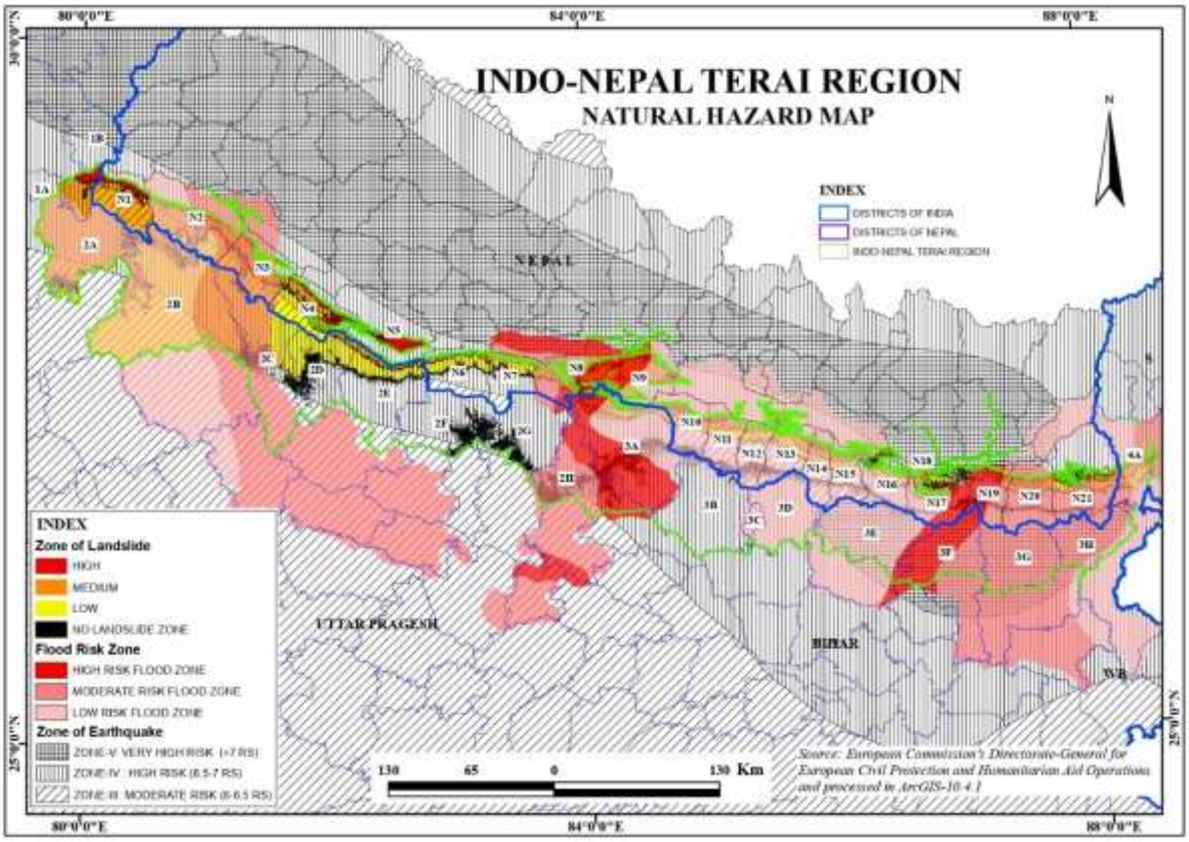
classification layer was superimposed, followed by the addition of the Landslide classification layer on both the earthquake and flood layers. To provide context, the Terai region layer was then placed atop all the hazard maps. Finally, the political divisions of Nepal and India, represented by districts, were integrated, resulting in the generation of an index (Map 5) and the ultimate production of the Natural Hazard Map for the Indo-Nepal Terai region.

Upon scrutinizing this map, it becomes evident that specific regions fall under the influence of two or more high-risk zones. Notably, Supaul and Sunsari are identified as districts at the intersection of the flood and earthquake zones. Additionally, other regions such as Nawalparasi, Chitwan, and certain parts of Kushinagar and West Champaran are categorized under the high flood risk zone based on the comprehensive assessment derived from the amalgamated hazard maps.



Source: Prepared by Researcher

Map 5: Natural Hazard Map of Indo-Nepal Terai Region

2. Socio-Economic Vulnerability Analysis of Indo-Nepal Terai Region

Socioeconomic vulnerability refers to the relative socioeconomic attributes of communities, including factors such as poverty levels, unemployment rates, literacy rates, the proportion of dependent populations, per capita income, and the nature of housing, whether kaccha or pucca. Living in areas prone to natural hazards, such as mountains susceptible to landslides or arid regions vulnerable to droughts, inherently exposes communities to risks. A comprehensive study conducted by Cutter et al. (2003) challenged the conventional belief that places with a higher susceptibility to hazards are also socially vulnerable. Contrary to this assumption, the research highlighted that social vulnerability is not solely determined by geographical location but is intricately linked to the socioeconomic structure of a community. In essence, vulnerability is defined by the interplay between the hazards inherent to a particular place, encompassing both the risks and mitigation measures and the social characteristics of the communities residing there (Cutter, 1996). Cutter proposed that vulnerability should be perceived as a dynamic interaction between the environmental hazards and the social profile of a community. This perspective on vulnerability has its roots in sociology and critical geography, emphasizing the pivotal role played by the inherent socio-economic structure as the fundamental driver of vulnerability. Therefore, a nuanced understanding of vulnerability necessitates an exploration beyond geographical factors, delving deeper into the socio-economic fabric that underpins a community's resilience to natural hazards.

At the micro level, numerous studies have employed regression analysis to discern income as a predictor of vulnerability to natural disasters, as demonstrated by research conducted by Phifer et al. (1988) and Pradhan et al. (2007). For instance, Pradhan et al. (2007) revealed a notably high flood-related fatality rate for children within families characterized by low socioeconomic status, gauged through indicators such as income-generating land ownership and the type of roof. Many of these investigations incorporated community characteristics, aligning with the categorization of community vulnerability outlined by King (2000). These characteristics encompassed demographic indicators such as population size, age distribution, living arrangements, and more, alongside household types and structures, and economic indicators including unemployment and income levels.

While a majority of studies considered factors listed by King (2000), education was a relatively underexplored predictor of vulnerability, with only a few studies, such as those by Phifer et al. (1988) and Shewmake (2008), delving into this aspect. The correlation between education and income, however, posed a challenge in interpretation when only one of the two factors was included in the analysis. Despite this, the studies acknowledged the established relationship between higher education and increased income, as documented by Lutz et al. (2008).

METHODOLOGY OF SOCIO-ECONOMIC VULNERABILITY MAPPING IN ARCGIS 10.5

The methodology for socio-economic vulnerability mapping of the Indo-Nepal border districts using ArcGIS 10.5 involves a multi-step, integrative approach leveraging diverse datasets and advanced spatial analysis techniques. Initially, comprehensive socioeconomic data is collected from various reliable sources such as national censuses, household surveys, governmental reports, and international databases. Socio-economic indicators are selected to provide a comprehensive understanding of the population's socio-economic conditions in this area. The mapping of this region relies on meticulously calculated data sourced from the national authorities (from the Central Bureau of Statistics (CBS), the Government of Nepal (CBS, 2011), and the Census of India, 2011) of both nations. Key indicators include gender distribution, migration patterns, per capita income, engagement in economic activities, occupational diversity, dependent population dynamics, health status, age distribution (life expectancy), housing types, religious composition, literacy rates, and caste demographics.

This data is then meticulously pre-processed to ensure consistency, accuracy, and compatibility within the GIS software. Processing steps include data cleaning to remove anomalies, normalization to standardize different data scales, and transformation to convert data into spatially referenced formats suitable for ArcGIS 10.5.

Following data preparation, spatial data layers for each socio-economic indicator are created. For the Indo-Nepal border districts, these layers include detailed demographic distributions, economic activity zones, educational attainment maps, and healthcare accessibility grids. In ArcGIS 10.5, these layers are overlaid onto the geographical base map of the border districts, allowing for spatial visualization and analysis. The analytical process employs techniques such as Tercile Density estimation (Cowie et al., 2016) to identify areas with high population concentrations and hot spot analysis to pinpoint regions with extreme poverty or low literacy rates. Weighted overlay analysis is a critical step in this methodology. Each socio-economic indicator is assigned a weight based on its relative importance and contribution to overall vulnerability, determined through principal component analysis (statistical methods). The weighted overlay method integrates these multiple layers into a composite index, highlighting areas of highest socio-economic risk. This composite index is then mapped to produce a comprehensive socio-economic vulnerability map of the Indo-Nepal border districts. These analyses help in understanding the spatial dependency and heterogeneity of socio-economic vulnerabilities across the border districts. The final socio-economic vulnerability map is visualized using ArcGIS's robust cartographic tools, ensuring that it is both informative and user-friendly. This visualization aids policymakers, development agencies, and local authorities in identifying priority areas for intervention, resource allocation, and policy formulation aimed at mitigating socio-economic vulnerabilities and enhancing resilience in the Indo-Nepal border districts. The indicators used in this analysis are as follows:

Table 1: Social Indicators

S.No.	Social Indicators	
1.	Population	
	Male Population	Female Population
2.	Sex Ratio	
3.	Life Expectancy	
4.	Rate of Migration	
5.	Literacy Rate	
6.	House type	

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	Kuccha house		Pucca house
7.	Religion		
8.	Hindu	Muslim	Other

Source: Prepared by Researcher

Table 2: Economic Indicators

S.No.	Economic Indicators
1.	Per Capita Income
2.	Engagement in Economic Activities
3.	Agricultural Labors
4.	Dependent Population

Source: Prepared by Researcher

Table 3: Socio-Economic Indicators of Indian Terai Districts

States	Codes	Total Population	Male	Female	Sex Ratio	Migration Rate	Per Capita Income
Bihar	3G	2811569	1463333	1348236	921	3.4	21123
Uttar Pradesh	2C	186223	1843884	1643847	892	9.8	29038
Uttar Pradesh	2E	2145665	1114721	1033944	928	15.8	32305
Uttarakhand	1B	259648	131125	128523	980	2.3	90596
West Bengal	4A	1846823	937259	909564	970	4.6	87695
Uttar Pradesh	2B	4021243	2123187	1898056	894	8.8	48188
Bihar	3H	1690400	283000	823430	950	4	20346
Uttar Pradesh	2H	3564544	1818055	561062	961	5.9	40309
Bihar	3E	4487379	283000	2158066	926	1.2	23908
Uttar Pradesh	2G	438527	182856	1302949	943	4.8	38141
Bihar	3A	3935042	2061110	1873932	940	2.5	38971
Uttar Pradesh	2A	2031007	1072002	959005	895	10.1	44210
Bihar	3B	5099371	38775	1873932	901	3.6	36847
Bihar	3C	656246	346673	309573	893	7.6	34734
Uttar Pradesh	2D	1117361	769811	188289	881	12.4	37252
Uttar Pradesh	2F	25422	1295095	1264202	970	2.5	29943
Bihar	3D	3423574	1803252	1620322	899	27.62	28778
Bihar	3F	2229076	1155283	1073793	929	2.8	22170
Uttarakhand	1A	1648902	858783	790119	1022	17	85541

Source: Prepared by Researcher

Table 4: Socio-Economic Indicators of Indian Terai Districts

States	Codes	Population Engaged in Economic Activities	Agricultural Labor	Dependent Population	Literacy	Kuccha House	Pucca House
Bihar	3G	1313003	644684	1068396	53.53	484625	83517
Uttar Pradesh	2C	136501	59787	407068	49.32	128884	14799
Uttar Pradesh	2E	1547024	632733	49350	49.51	80533	24465
Uttarakhand	1B	99566	51410	62316	79.83	51417	2536
West Bengal	4A	119175	54344	317654	79.56	62206	329028
Uttar Pradesh	2B	3048102	1981266	1178224	60.56	655668	89409
Bihar	3H	681231	332441	418036	55.46	54828	283617
Uttar Pradesh	2H	1653948	1045295	646608	65.25	460632	100430
Bihar	3E	2266126	1237305	650670	58.62	232294	76608
Uttar Pradesh	2G	193829	128702	75777	62.76	146651	36205
Bihar	3A	1530731	953645	777564	55.7	286316	424145
Uttar Pradesh	2A	1582154	131180	536186	72.7	82711	279862
Bihar	3B	1805177	1110184	115232	55.79	485850	495666

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Bihar	3C	276279	162176	131249	53.78	89486	60658
Uttar Pradesh	2D	903000	384678	80450	46.74	136321	51968
Uttar Pradesh	2F	1156802	821329	380312	59.2	298170	81181
Bihar	3D	1663857	930096	517644	52.05	480082	256240
Bihar	3F	1012001	540408	332355	57.67	380888	97014
Uttarakhand	1A	1246570	122686	245686	62.94	74194	234387

Source: Prepared by Researcher

Table 5: Socio-Economic Indicators of Indian Terai Districts

States	Codes	Hindu Population	Muslim Population	Other Religion
Bihar	3G	1593597	1207569	10402
Uttar Pradesh	2C	122367	62440	1415
Uttar Pradesh	2E	1331385	804839	9440
Uttarakhand	1B	246977	8698	3973
West Bengal	4A	1366649	105084	375089
Uttar Pradesh	2B	3078262	807466	135515
Bihar	3H	531293	1149134	9973
Uttar Pradesh	2H	2928629	620231	15684
Bihar	3E	3652278	818947	16155
Uttar Pradesh	2G	358847	74900	4779
Bihar	3A	3047296	864922	22823
Uttar Pradesh	2A	1448920	408842	173245
Bihar	3B	4086635	990298	22437
Bihar	3C	552493	99356	4397
Uttar Pradesh	2D	768633	344035	4692
Uttar Pradesh	2F	17778	7431	213
Bihar	3D	2672442	740177	10955
Bihar	3F	1810009	409258	9807
Uttarakhand	1A	1104452	372267	172183

Source: Prepared by Researcher

Table 6: Socio-Economic Indicators of Nepal Terai Districts

States	Codes	Total Population	Male	Female	Sex Ratio	Migration Rate	Per Capita Income
Central	N15	754777	378538	376239	993.9266	5.3	922.72
Central	N14	627580	311016	316564	1017.838	0	672.81
Central	N13	769729	3,89,756	379973	974.8997	2.3	188.07
Central	N11	687708	351244	336464	957.921	0.8	362.54
Central	N9	579984	279087	300597	1077.073	9	299.54
Central	N10	601017	312358	288659	924.1287	1.5	281.02
Central	N12	686722	351079	335643	956.0327	2.2	105.4
East	N20	965370	466712	498658	1068.449	4.21	187.45
East	N19	763487	371229	392258	1056.647	4.8	125.88
East	N21	812650	385096	427554	1110.253	10.8	192.99
East	N17	639284	313846	325438	1036.935	1.1	358.55
East	N16	637328	310101	327227	1055.227	0.2	454.3
East	N18	317532	149712	167820	1120.952	2400	683.88
Far-Western	N1	451248	216599	234649	1083.334	0	0
Far-Western	N2	775709	378417	397292	1049.879	9	97.36
Mid-Western	N4	491313	244255	247058	1011.476	0	180.56
Mid-Western	N3	426576	205080	221496	1080.047	0.53	367.65
Mid-Western	N5	552583	261059	291524	1116.698	6	107.03
West	N6	571936	285599	286337	1002.584	3.77	253.12
West	N8	643508	303675	339833	1119.068	2.5	262.46
West	N7	880196	432193	448003	1036.581	16.6	150.76

Source: Prepared by Researcher

Table 2.7: Socio-Economic Indicators of Nepal Terai Districts

States	Codes	Population Engaged in Economic Activities	Agriculture Labor	Dependent Population	Literacy	Kuccha House	Pucca House
Central	N15	286815	441922	50	1780	133054	671752
Central	N14	166309	315045	46	1020	109043	527167
Central	N13	191663	40352	46	1567	129237	658580
Central	N11	74272	300941	56	1207	105746	563921
Central	N9	417588	163671	77	895	130198	469787
Central	N10	9935	16278	84.8	1238	92577	498844
Central	N12	133636	302913	42	1709	102303	535643
East	N20	205624	283143	70	933	211046	775192
East	N19	292416	245385	68	1054	159589	559636
East	N21	117834	288572	75.2	1525	181458	649307
East	N17	351606	393288	54	850	117950	549784
East	N16	178452	89226	96.3	1379	115094	542047
East	N18	187344	143683	69	633	65513	231005
Far-Western	N1	24692	83975	70	2464	79670	205769
Far-Western	N2	62057	503047	45.18	2196	139057	736924
Mid-Western	N4	393050	192988	76.1	837	92826	383224
Mid-Western	N3	273009	261918	84.7	1148	81646	400981
Mid-Western	N5	55258	325858	45.18	499	114874	530480
West	N6	27453	80071	72.8	1251	88531	463268
West	N8	115831	205343	75	1164	126393	523429
West	N7	40489	290113	72	1065	160270	756969

Source: Prepared by Researcher

Table 8: Socio-Economic Indicators of Nepal Terai Districts

States	Codes	Hindu Population	Muslim Population	Other Religion
Central	N15	671752	60382	15096
Central	N14	527167	81585	6276
Central	N13	658580	60655	6543
Central	N11	563921	89402	6877
Central	N9	469787	5800	46400
Central	N10	498844	84142	6010
Central	N12	535643	137344	0
East	N20	775192	39580	105225
East	N19	559636	87801	93909
East	N21	649307	26005	113770
East	N17	549784	51143	6393
East	N16	542047	17845	20522
East	N18	231005	2159	53472
Far-Western	N1	205769	0	10830
Far-Western	N2	736924	7757	31028
Mid-Western	N4	383224	93349	14739
Mid-Western	N3	400981	12797	17064
Mid-Western	N5	530480	5526	16578
West	N6	463268	102948	0
West	N8	523429	28186	39319
West	N7	756969	70416	17604

Source: Prepared by Researcher

3. Principal Component Analysis (Statistical Method)

PCA is a potent statistical technique used to measure socio-economic vulnerability, offering a robust framework for understanding complex socio-economic dynamics. This method is particularly valuable because it highlights the significance of the initial factor by assigning it the highest weight post-calculation, thus closely reflecting the real-world scenario. In this study, Principal Component Analysis (PCA) has been employed to develop a composite index for the socio-economic vulnerability of the region.

The dataset utilized for this analysis consists of 40 observations, which include 19 districts from the Terai region of India and 21 districts from the Terai region of Nepal. These observations are based on a variety of socio-economic indicators, primarily focusing on 14 key factors. These factors encompass total population (male and female), sex ratio, migration rate, per capita income, population engaged in economic activities, agricultural labour, dependent population, literacy rate, types of housing (kaccha and pucca), and religion (Hindu, Muslim, and others). These indicators are widely recognized and utilized by scientists and researchers to evaluate socioeconomic vulnerability in disaster-prone regions (Aksha et al., 2018).

To create a comprehensive map of the socio-economic vulnerability across the entire Indo-Nepal Terai region, PCA has been meticulously chosen for this study. By integrating these diverse indicators, PCA facilitates the reduction of dimensionality, allowing for the synthesis of complex data into a single composite index that effectively captures the socio-economic vulnerability of the region. This index is instrumental in identifying areas of high, medium, and low vulnerability, thus providing critical insights for policy-making and targeted interventions aimed at enhancing socio-economic resilience in the Terai region.

The application of PCA in this context highlights its utility in dealing with large datasets and multifaceted socio-economic variables. It ensures that the resultant composite index is not only statistically sound but also practically relevant, providing a nuanced understanding of the socio-economic landscape of the Indo-Nepal Terai region. This approach not only aids in better visualization and interpretation of vulnerability patterns but also supports the formulation of data-driven strategies to address socio-economic challenges in the region.

The PCA, executed using STATA software, condenses these multifaceted factors into a standardized composite index, facilitating the seamless presentation of voluminous data. This index serves as a pivotal benchmark for understanding socio-economic vulnerability comprehensively.

Table 9: Representation of Eigenvalue through PCA

Factor	Eigenvalue	Difference	Proportion	Cumulative
Factor1	9.07306	6.65523	0.5041	0.5041
Factor2	2.41783	1.06617	0.1343	0.6384
Factor3	1.35166	0.15023	0.0751	0.7135
Factor4	1.20142	0.32710	0.0667	0.7802
Factor5	0.87432	0.01347	0.0486	0.8288
Factor6	0.86085	0.31696	0.0478	0.8766
Factor7	0.54389	0.21977	0.0302	0.9068
Factor8	0.32413	0.03171	0.0180	0.9248
Factor9	0.29241	0.02008	0.0162	0.9411
Factor10	0.27233	0.01631	0.0151	0.9562
Factor11	0.25602	0.06857	0.0142	0.9704
Factor12	0.18746	0.02505	0.0104	0.9809
Factor13	0.16240	0.07057	0.0090	0.9899
Factor14	0.09184	0.03859	0.0051	0.9950

Source: Prepared by Researcher

The table above presents the principal components or factors derived from Principal Component Analysis (PCA). PCA restructures the original variables into a new set of uncorrelated variables, known as principal components or factors, arranged according to the proportion of variance they account for. Each eigenvalue reflects the extent of variance explained by a corresponding principal component, with higher eigenvalues indicating that the component accounts for a greater share of the total variance.

The difference column shows the difference between the eigenvalue of the current factor and the eigenvalue of the subsequent factor, helping to see how much more variance each successive factor explains compared to the next one. The proportion is calculated as the eigenvalue divided by the total number of factors, representing the proportion of the total variance explained by each factor. The cumulative proportion indicates the cumulative variance explained up to and including the current factor, providing insight into how many factors are needed to explain a certain amount of the total variance.

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3.1 Interpretation of the Result

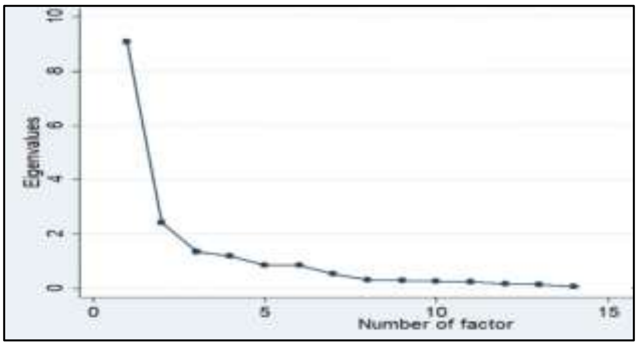
Factor 1 has an eigenvalue of 9.07306, which means it explains approximately 50.41% of the total variance in the data. This is a significant proportion, indicating that the first principal component captures a substantial amount of the information in the dataset.
Factor 2 has an eigenvalue of 2.41783 and explains an additional 13.43% of the variance. Combined with Factor 1, the first two factors explain 63.84% of the total variance.
Factors 3 to Factor 4 continue to add to the explained variance, but with decreasing contribution. By the time we include Factor 4, approximately 78.02% of the total variance is explained.
Factors Factor 5 through Factor 18 contribute increasingly smaller amounts of explained variance, with Factor 18 contributing virtually none (0.00006 eigenvalues).

3.2 Deciding the Number of Factors to Retain

A common approach in PCA is to retain factors that have an eigenvalue greater than 1. Based on this criterion: The first four factors (Factor1 to Factor4) have eigenvalues greater than 1 and together explain 78.02% of the total variance. This suggests that these four factors capture most of the important information in the dataset.

LR Test

LR Test: independent vs. saturated: chi2(153) = 1061.30 Prob>chi2 = 0.0000: This Likelihood Ratio test compares the independence model (where variables are assumed to be uncorrelated) against the saturated model (where all parameters are estimated). The chi-square value of 1061.30 with a p-value of 0.0000 indicates that the saturated model fits the data significantly better than the independence model. This further justifies the use of PCA as a suitable method for analysing the dataset.
The PCA results indicate that the first few principal components capture a significant portion of the variance in the socio-economic vulnerability data for the Indo-Nepal Terai region. Specifically, the first four factors explain around 78% of the variance, making them the most informative dimensions for summarizing the dataset. This analysis provides a powerful tool for understanding and visualizing the complex socio-economic dynamics in the study region.
A scree plot (Figure 2.1), based on eigenvalues, was constructed to discern the optimal number of components. This visual tool helps in identifying the “elbow point” where the explained variance by additional factors starts to level off, indicating the most meaningful components to retain.



Source: Prepared by Researcher

Figure 1: Scree Plot of Eigenvalues after Factor

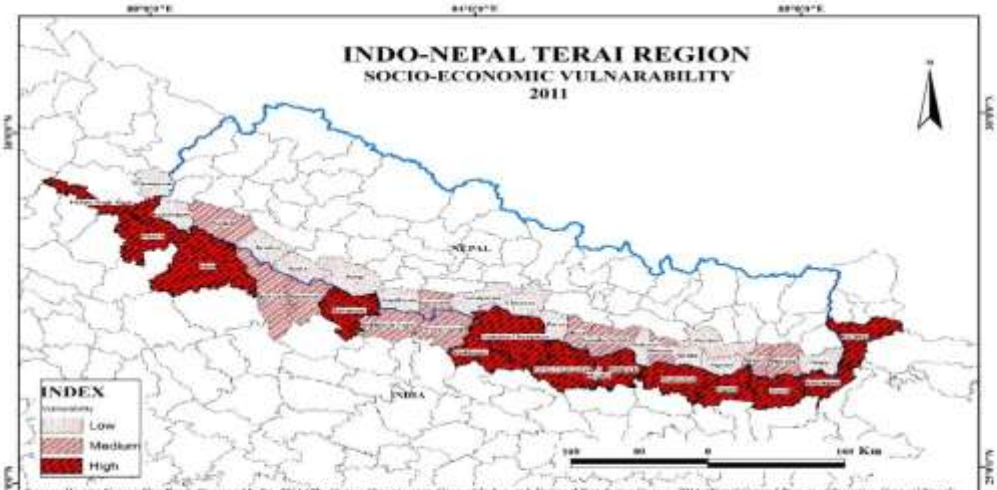
Additionally, the Cronbach’s alpha index for this PCA stands impressively at 0.8959, indicating robust internal consistency among the variables. This high reliability score suggests that the selected socioeconomic indicators effectively measure the underlying construct of vulnerability.
Based on this analysis, the data were stratified into tercile indices, paving the way for a nuanced socio-economic vulnerability mapping of the Indo-Nepal Terai region. The socio-economic vulnerability map was subsequently classified into high, medium, and low vulnerability zones for the entire Indo-Nepal Terai region, providing a clear visualization of areas that may require targeted interventions and policy attention. This classification aids in identifying regions most at risk, thereby facilitating more effective resource allocation and mitigation strategies.

Table 10: Tercile Index

District	Socio-Economic Vulnerability Index	Tercile
Udayapur	-1.11	1
Kanchanpur	-1.00	1
Bardiya	-0.89	1

Champawat	-0.79	1
Nawalparasi	-0.79	1
Kapilbastu	-0.78	1
Siraha	-0.77	1
Dang	-0.77	1
Banke	-0.74	1
Parsa	-0.72	1
Chitawan	-0.67	1
Jhapa	-0.63	1
Saptari	-0.60	1
Mahottari	-0.58	1
Sunsari	-0.56	2
Bara	-0.55	2
Rupandehi	-0.55	2
Kailali	-0.51	2
Rautahat	-0.50	2
Morang	-0.46	2
Sarlahi	-0.46	2
Maharajganj	-0.45	2
Sheohar	-0.45	2
Dhanusa	-0.43	2
Bahraich	-0.15	2
Shrawasti	-0.03	2
Siddharth Nagar	-0.01	2
Kishanganj	0.26	3
Udham Singh Nagar	0.28	3
Darjiling	0.29	3
Balrampur	0.57	3
Pilibhit	0.65	3
Supaul	0.66	3
Araria	1.44	3
Kushinagar	1.51	3
Sitamarhi	1.68	3
Pashchim Champaran	1.86	3
Madhubani	1.87	3
Purba Champaran	1.97	3
Kheri	2.90	3

Source: Prepared by Researcher



Source: Prepared by Researcher

Map 6: Socio-Economic Vulnerability in Indo-Nepal Terai Region, 2011

Upon scrutinizing the socio-economic vulnerability map, it is evident that most of the Terai districts fall under the high and medium vulnerability zones. In Map 6, the region shown in maroon colour indicates the highly socio-economically vulnerable zone. This study ensures a comparative analysis that enhances our understanding of the broader socio-economic dynamics in the Indo-Nepal Terai region.

Constraints of the Present Study

The socio-economic vulnerability mapping was done in 2024. The mapping relies on data from the Census of India 2011 and the Central Bureau of Statistics, Government of Nepal, in 2011. These sources provide comprehensive information regarding population distribution, socio-economic indicators, and other relevant data points. Considering the fact that the Indian government has not published census data beyond 2011, the 2011 dataset serves as the most recent and relevant source for the study's purposes.

However, the Central Bureau of Statistics, Government of Nepal, did release its 2021 data in July 2023. Despite the availability of more recent data about Nepal, the decision was made to utilize the 2011 data in the study to ensure coherence and reliability in the analysis.

CONCLUSION

In conclusion, the Indo-Nepal Terai region is marked by significant physical and socio-economic vulnerabilities exacerbated by natural disasters. The correlation between physical and socio-economic vulnerabilities in these districts offers a comprehensive understanding of the broader regional dynamics. This cross-national comparison enriches the understanding of regional phenomena and the existing diversification in these districts. By examining the socio-economic conditions and the impact of natural disasters on these conditions, the study aims to contribute to a more informed policy framework for effective disaster management and planning for vulnerable populations in the Indo-Nepal Terai region.

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