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A Study on Landslide Vulnerability of Guwahati City using Remote Sensing and GIS Approach

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ABSTRACT

In hilly areas, landslides can result in significant loss of life and damage to property. To improve the effectiveness of managing landslide risks, new approaches are necessary to gain a deeper understanding of the threat and to make informed decisions about allocating financial resources. Recent advancements in risk evaluation and assessment have led to systematic and rigorous procedures for better slope management. Given the uncertainty surrounding landslide hazards, the importance of risk assessment and analysis has increased in recent years. The land use and land cover of Guwahati City have been transformed drastically from 2000 to 2022. 157% of the change in built-up areas has been recorded as causing severe damage to natural resources, including vegetation cover and waterbodies. Due to the lack of proper settlement planning, most of the parts of the Guwahati city area face hazards like landslides and urban flooding in the monsoon seasons, as the Guwahati city area receives more than 2500 cm of rainfall annually and creates 8.83% and 10.92% of the total area at very high and moderate risk for landslide events, respectively. There is a need for strict guidelines from the government to restrict the construction of settlements in hillside areas or in hilly areas. This study shows there is a need for proper urban planning strategies to mitigate landslide hazard issues.

Key words: *Landslide, Disaster Management, Land-use, Urban planning.*

Introduction

Landslide is a major natural disaster, cause a great deal of property damage every year, including both immediate and long-term costs. They are defined as a sizable mass of earth, rock, or debris sliding down a hill (Dai *et al*., 2002). A landslide in simplest definition means the movement of a mass of rock, debris or earth down a slope. It generally refers to the mass wasting along a slope. Landslide events constitute 5% of natural disasters, globally. The stress that occurs along the slope may result in such wasting. There are various factors associated with the landslide. Mountainous areas are more vulnerable to such mass movements due to triggering causal factors. Triggering causal factors mainly includes rainfall, anthropogenic pressure and land use are responsible or the initiation of mass movements. There are many conditional factors which includes weathering, soils, topography (Gao *et al*., 2020) which triggers slope instability (Nakileza and Nedala, 2020). The concept of vulnerability is defined in natural hazards terminology as: "The characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard" In landslide spatial studies, often, vulnerability is related to the physical predisposition (Nseka *et al.*, 2019). Topographic variables

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play one of the most important roles (Arrogante-Funes *et al*., 2021). The other most important factor that is taken into account while studying the vulnerability is the soil type and the bed material that the surface is made up of. Soil mainly forms the top layer of the earth's crust and it is expected that various soil characteristics like depth, surface texture, depth texture, soil erosion, hydraulic conductivity, stoniness, etc., play significant roles in the occurrence of the landslide (Sharma *et al*., 2012). The texture of the soil that occurs in the mountainous areas are more susceptible to the landslides than the plain areas. Slopes with different soil compositions respond differently to rainfall. The proportion of gravel in soils has a great influence on the density and void ratio, which determines the timing and type of landslides (Liu *et al*., 2021). Another important factor that triggers the landslide is the precipitation which forms a part of the local climatic condition. Climate change is impacting precipitation patterns worldwide by impacting the frequency of the rainfall which will likely have a profound influence onlandslide activity in the coming days (Handwerger *et al*., 2022). The duration and the intensity of the rainfall induce change in the texture of the soil by loosening the materials triggering a mass movement. Furthermore, the landslide may be instigated by the vegetation cover (Chen *et al*., 2019). A bare surface is more susceptible to the landslides rather than a area which has much of its area under vegetation. The main reason being the water holding capacity of the roots. This provides a protective cover to the surface which reduces the risk to the landslide evulnerability. Vegetation, as an integral component of bio geotechnics, plays a indispensable role in modifying soil properties and influencing the stability of slopes (Li and Duan, 2024). Hence it can be concluded that all the factors are interlinked. A change in one factor may give rise to a series of changes.

Methodology and Data Collection

The purpose of this study is to identify the areas inside the city limits of Guwahati, Assam, that are most vulnerable to landslides and to explore the elements that contribute to the development of landslide hazards there. As is evident from Table 1, data were gathered from a variety of sources, primarily

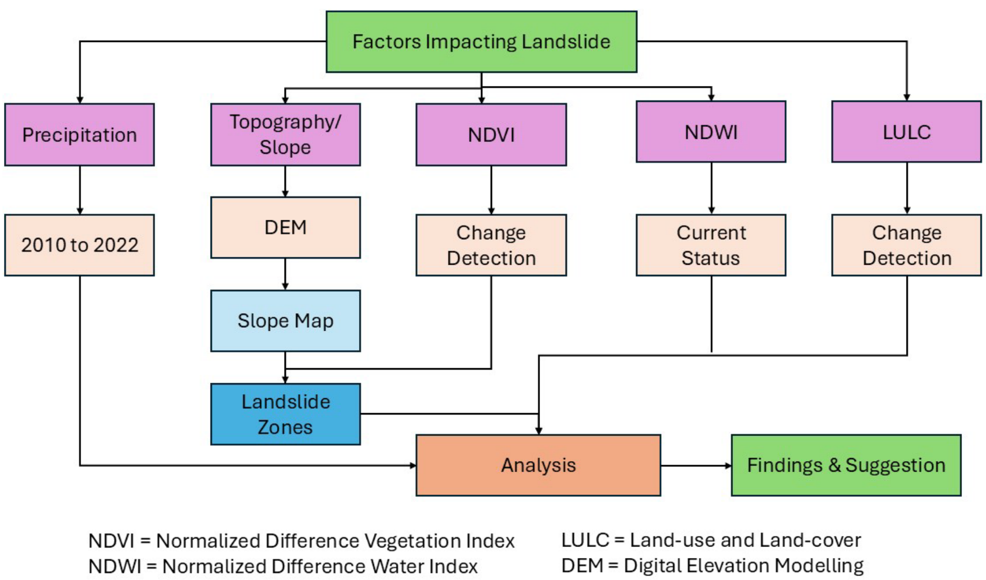

Fig. 1. Methodology Flowchart

Table 1. Data Collection Sources

Data	Data Sources	Resolution	Date
Landsat 4-5 TM	USGS earthexplorer	30 m	14/12/2000
Sentinel 2B	Copernicus web	10 m	12/11/2022
Precipitation	NASA Power	10 m	2010 to 2022
SRTM	USGS earthexplorer	30 m	——-

secondary data sources. The records of field trips and remote sensing instruments are what define the locations of danger zones.

Study Area

Located in Assam's Kamrup Metro district, Guwahati is a major urban center serving the rest of North-East India. Guwahati town's geographical range is 26°05′03.78"N to 26°13′12.05"N on the latitude, and 91°36′07.69"E to 91°53′35.30"E on the longitude. Nearly 9.6 lakh people live in the Guwahati Municipal area. The city experiences significant rainfall during rainy seasons due to the influence of the monsoonal environment.

Change of Land-use and Land-cover

Every place on Earth's surface has different land feature characteristics. However, with the population growing so quickly, the characteristics have been adjusted to better suit the demands of the population (Chen *et al.,* 2019). LULC plays a major part in the occurrence of landslides (Glad, 2003). Due to human activities like mining, building towns and highways, and other projects, the topography of the land has changed, creating slopes that are very vulnerable to landslide dangers. Therefore, land-use planning is crucial at every area to reduce the danger of hazards (Meneses *et al.,* 2019).

Table 2 highlights the fact that the built-up area has been continuously increasing in the last two decades. This clearly throws light on the fact that the population has been increasing at a faster rate. The percentage of change is 157.03%. The light vegetation cover has been decreasing at a tremendous rate, indicating the phenomenon of deforestation and the conversion of the land area to the built-up area in order to hold the increasing population. Both the light vegetation is decreasing at 77.9% and the dense vegetation has been decreasing at a rate of 17.29%. The other most important factor that has been going through drastic change is the change in the open, which has been showing an increase of about 70.76%. The other most important change is the reduction in the area of water bodies, with a decrease of about 34.21% in the last decades. Therefore, it can

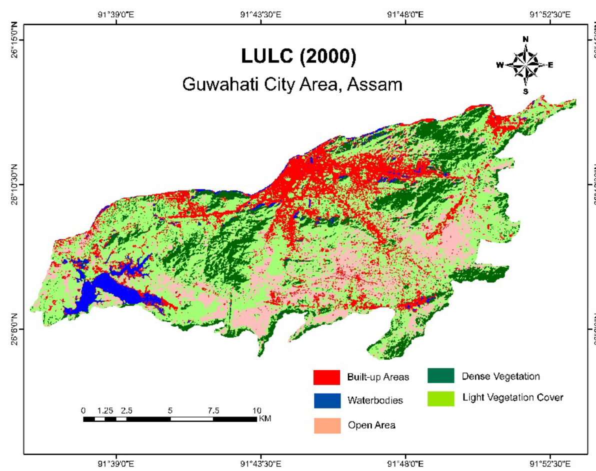

Fig. 3. LULC map of Guwahati city area 2000.

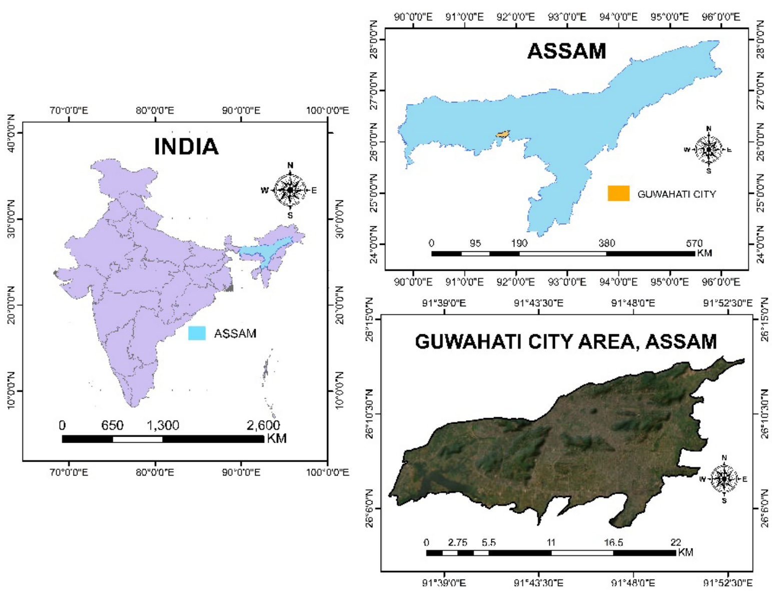

Fig. 2. Study area

Table 2. LULC classes with area covered for the year 2000 and 2022

Legends	Total Area in 2000 (Km^2)	Total Area in 2022 (Km^2)	Percentage of Change
Built-up areas	36.4	93.56	(+)157.03%
Waterbodies	7.57	4.98	(-)34.21%
Open area	36.63	62.55	(+)70.76%
Dense vegetation cover	34.64	28.65	(-)17.29%
Light vegetation cover	95.48	21.1	(-)77.9%
Total area	210.72	210.84	

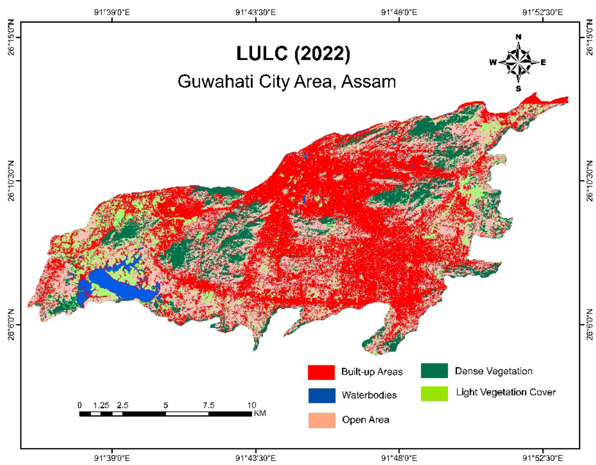

Fig. 4. LULC map of Guwahati city area 2022.

be concluded that there is a continuous increase in population pressure, which is positively giving rise to the problem of deforestation.

Digital Elevation Model (DEM)

The most important model for examining topographical features on the surface of the globe is Dem. This can be a very helpful tool for researching a landform feature's elevation, slope, and other characteristics. This tool appears to be the most crucial when discussing landslide research (Saleem *et al.*, 2019) since it allows us to distinguish between variously elevated places. Through the undermining of other features, such as settlements and other manmade concrete places, this model depicts the true ground information (Qiu *et al.,* 2022). In topographically uneven terrain, this model can aid in the planning and urban development process of urban centers.

Above figure shows the different classes of elevations which ranges from 40 m to 290 m above mean sea level and higher elevated areas showing more risk of landslide to the nearby residents.

Pattern of Precipitation

One of the most important factors in maintaining the human life cycle is rainfall (Zhao et *al.,* 2022). Humans can only be content when there is moderate

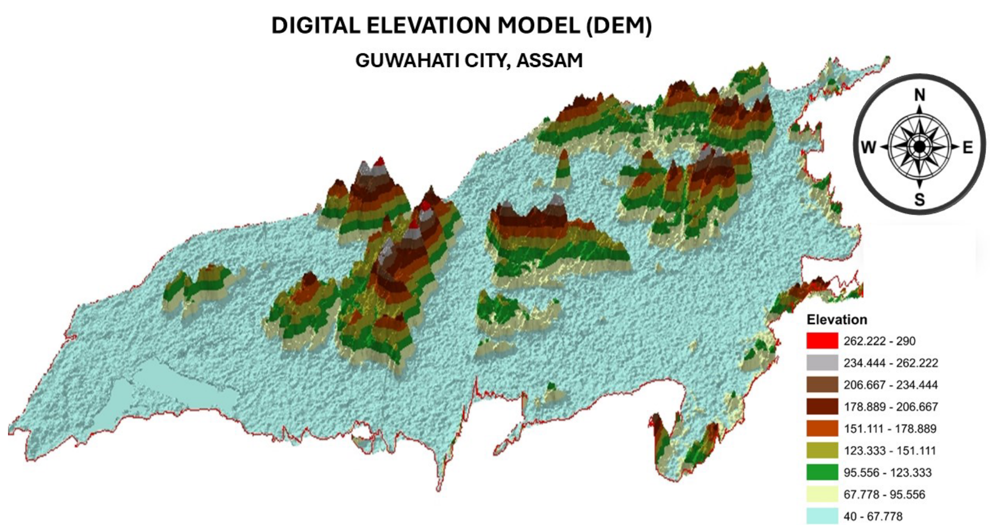

Fig. 5. DEM of Guwahati city.

rainfall; excessive or low rainfall might result in floods or drought. Rainfall intensity is the primary cause of landslides; landslides occur when parent bed soil can no longer hold the same amount of water above a certain threshold.

Monsoon rainfall, which occurs from June to September, has a direct impact on the climate of Assam and Guwahati city. The total amount of rainfall that Guwahati City got annually from 2010 to 2022 is displayed in the above table. In comparison to the years 2010 to 2016, it demonstrates that the trends of rainfall intensity have grown by 150 to 400 cm, with May through August being the highest months in Guwahati city. This shows the months with the highest likelihood and possibility for urban problems, such as urban flooding, and the most catastrophic landslide occurrences in areas with significant variations in slope and elevation.

Normalized Difference Vegetation Index (NDVI)

The NDVI and NDWI are complimentary indices that display the health of the vegetation and the condition of open waterbodies in relation to the available soil and vegetation quality, respectively. These indexes are essential for planning and managing the environment (Fiorucci *et al.*, 2019). In order to maintain ecological balance and the ability to withstand natural disasters and some catastrophic catastrophes like landslides, green, healthy vegetation is absolutely important (Yang *et al.*, 2012). The presence of naturally occurring dense vegetation can change the likelihood and consequences of landslides by stabilizing the ground with their root systems.

NDVI can be calculate for Sentinel 2 satellite using the following method,

$$\text{NDVI} = \frac{Band\ 8 - Band\ 4}{Band\ 8 + Band\ 4}$$

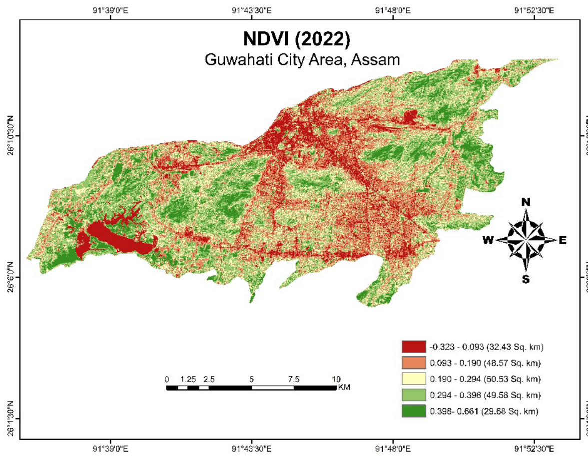

Fig. 6. NDVI of Guwahati city area for the year 2022

NDWI also can be calculated for Sentinel 2 satellite images by using the following method,

$$\text{NDWI} = \frac{Band\ 8 - Band\ 12}{Band\ 8 + Band\ 12}$$

The NDVI and NDWI statistics above demonstrate that the studied area lacks healthy vegetation. There is only 67 km^2 of vegetated area; the rest areas have either very little or no vegetation. Nearly 70% of all places have a shortage of water resources throughout the winter, according to the NDWI. However, during the wet seasons, they are more likely to experience flash floods or urban flooding.

Table 3. Precipitation in the Guwahati City area from 2010 to 2022.

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
2010	0	0	63.28	358.59	321.68	500.98	311.13	253.12	284.77	116.02	0	5.27	2214.84
2011	0	10.55	42.19	36.91	174.02	442.97	237.3	448.24	247.85	5.27	10.55	0	1655.86
2012	10.55	5.27	10.55	258.4	184.57	627.54	442.97	242.58	163.48	110.74	10.55	15.82	2083.01
2013	0	10.55	15.82	121.29	485.16	290.04	311.13	210.94	131.84	205.66	0	0	1782.42
2014	0	31.64	10.55	36.91	242.58	395.51	179.3	268.95	395.51	52.73	0	0	1613.67
2015	5.27	21.09	31.64	237.3	326.95	348.05	284.77	400.78	295.31	63.28	10.55	21.09	2046.09
2016	21.09	0	68.55	432.42	363.87	342.77	580.08	105.47	168.75	100.2	10.55	0	2193.75
2017	0	58.01	147.66	348.05	210.94	479.88	421.88	453.52	263.67	174.02	10.55	5.27	2573.44
2018	0	15.82	58.01	179.3	274.22	384.96	295.31	279.49	253.12	36.91	10.55	21.09	1808.79
2019	0	21.09	47.46	216.21	400.78	332.23	569.53	158.2	353.32	195.12	10.55	0	2304.49
2020	21.09	10.55	15.82	242.58	553.71	580.08	495.7	247.85	421.88	152.93	0	0	2742.19
2021	0	5.27	52.73	115.42	259.29	354.49	302.58	338.62	147.65	97.74	0.04	6.26	1680.09
2022	21.89	56.79	56.43	278.28	456.87	725.76	211.19	177.57	151.96	210.24	0.31	2.48	2349.75

Source: NASA Power.

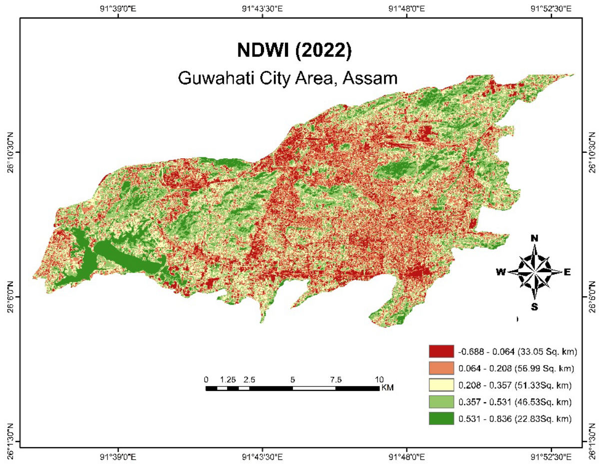

Fig. 7. NDWI of Guwahati city area for the year 2022

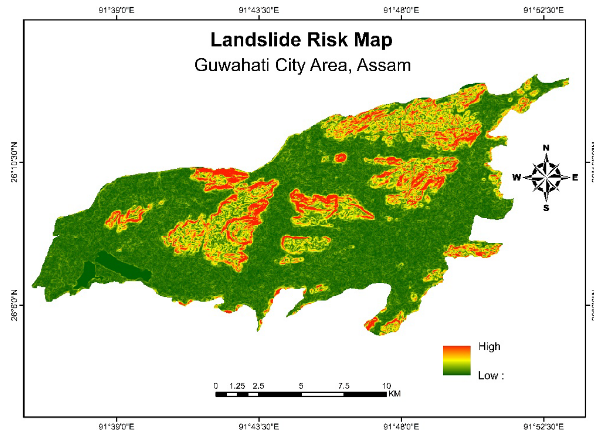

Fig. 8. Landslide risk map of Guwahati city area

Findings and Suggestions

This study mentioned above has produced the following key findings;

1. There has been a noticeable shift in the land's use and cover between 2000 and 2022. As the amount of vegetation and waterbodies decreases, the built-up areas rise to 157%. In addition to the mountainous locations where landslides are most likely, people have erected their settlements in an uncontrollably increasing number of built-up areas.
2. The absence of vegetation cover and the cities' susceptibility to water problems, such as flooding or landslides during the rainy season, are shown by the NDVI and NDWI indices.
3. During the course of just 12 years, there has been a noticeable variation in the monsoonal rainfall, which has increased sharply to 150-400 cm.
4. The landslide risk map indicates that there is a moderate danger of landslides at 23.03 km^2 and a very greater risk of landslides at 18.61 km^2.

After gone through this study following suggestions can be made;

1. The use of urban planning and city planning to regulate unauthorized settlements in steep and elevated terrain. Strict laws need to be in place to limit urban growth.
2. Since there has been an alarming decline in vegetation, it is imperative that healthy green vegetation be conserved.
3. To protect people from future landslide incidents, the construction of hillside regions must be permanently prohibited, and permission must be granted by proper studying the topographical suitability for house construction.
4. There should be well-managed drainage system that will drain the waters that are comes downward due to excess precipitation.
5. A rapid reaction team for managing hazards within a one-kilometer radius is required, as is soil quality testing to alert people to the possibility of landslides when precipitation levels are predicted to be exceeded.

Table 4. Classes of landslide risk map

Classes	Area (km^2)	Percentage of total area
Very high risk	18.61	8.83%
Moderate risk	23.03	10.92%
Low risk	31.39	14.89%
No risk	131.71	62.49%

Conclusion

The years 2000 to 2022 have seen a significant change in Guwahati City's land usage and land cover. Natural resources, such as waterbodies and vegetation cover, have been shown to be severely damaged by 157% of the change in built-up areas. The Guwahati city area receives more than 2500 cm of rainfall annually, which puts 8.83% and 10.92% of the total area at very high and moderate risk for landslide events, respectively. Without proper settlement planning, most of the area is vulnerable to hazards like landslides and urban flooding during the monsoon seasons. To limit the development of communities in hilly or sloping terrain, the government must establish stringent regulations. This investigation demonstrates need of proper urban planning in the Guwahati city area.

Conflict of Interest

Authors declare there is no conflict of interest.

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