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Geospatial Analysis of the Taliye Village Landslide : Pre- and Post-Event Insights Using Weighted Overlay Method

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Abstract: Landslides are one of the most prevalent catastrophes in the world, which can be caused by a variety of factors, human-related and natural. This study looks at the landslides that severely damaged Taliye village in the Raigad area of Maharashtra State, and it investigates the relationship between the causes of landslides and the primary contributory factor. Out of all the techniques for researching, detecting, and mitigating landslides, remote sensing and GIS have the best precision and dependability. Significant pre- and post-disaster changes in slope, land use, contour, hill shade, soil texture, NDVI, and rainfall were found through a comparative study of digitally processed thematic layers, highlighting the region's susceptibility to landslides. In this instance, we utilized the rainfall data and Weighted Overlay Method to analyze causative elements effectively. Efforts are made to identify the landslide key indicators in pre-landslide results and causative factors behind devastating landslides through post-landslide results. A major observation of the pre-and post-landslide susceptibility map classifies the area into six categories, with high-risk zones 5 and 6 showing 1.13 and 3.93%, respectively, reduced to 0 and 0.07%. It is obvious that the collapse of the zone vulnerable to landslides is what caused this alteration. Meteorological data, such as rainfall stats, serve as evidence to show that a significant amount of input led to triggering landslides. Therefore, it is crucial to apply these findings more broadly in order to formulate preventive strategies that are intended to mitigate potential repercussions and safeguard the welfare of every individual concerned.
Keywords: Landslides, Susceptibility, Weighted Overlay Method, Comparative investigation, Environmental factors.

I. INTRODUCTION

Landslides, characterized by the downslope movement of soil, rocks, debris, and mud, are natural phenomena that often lead to significant destruction of human life, infrastructure, and topography. These events are common worldwide, particularly in mountainous regions where steep and curved slopes act as catalysts, causing substantial injuries, fatalities, and property damage (Parise and Jibson 2000; Dai et al. 2002; Glade et al. 2005; Kanungo et al. 2006; Pan et al. 2008; Girma et al. 2015). Landslides can be triggered by various factors, including heavy and prolonged rainfall, earthquakes, rapid snowmelt, and human activities. Their movements can involve flowing, sliding, toppling, or falling, often displaying a combination of these types (Crozier 1986; Cruden and Varnes 1996; Dikau et al. 1996). Deccan Plateau's Western Ghats are already well-known for being a region of mountains and valleys. Mesas, buttes, and escarpments are among the geomorphological features that characterize the Western Ghats. This coastal section of Maharashtra state experiences the most rainfall during the monsoon season. Perhaps for the previously described reasons, the Western Ghats are prone to landslides.

Taliye, a village in Maharashtra's Raigad district, had a similar situation, with major landslide damage resulting in the loss of nearby communities near the slopes of mountains. On July 22, 2021, a major landslide occurred at midnight, devastating the village and resulting in multiple fatalities. Taliye village situated near is impacted by a sharp cliff, in the shadow of the Sahyadri Mountain. These days, the prediction, mitigation, and study of landslides largely depend on remote sensing and GIS. Because of inaccessible places, geospatial technology will precisely and promptly give us the most recent information. This case study highlights the need to identify and reduce high-risk regions by taking into account a variety of criteria. The notion of a landslide hazard was defined by Courture (2011) as the division of land into relatively homogeneous areas or domains and their ranking according to the degrees of risk or hazard associated with landslides, current or potential vulnerability to landslides, or the applicability of certain regulations on landslides. This research study aims to better investigate landslide analysis and identify suggestive qualities in pre-landslide circumstances by using the Weighted Overlay Method (WOM).

To identify the factors causing the landslide, post-landslide image processing is carried out using the same methodology. The weighted overlay approach assigns weights according on the correlation between the occurrence of landslides and the primary elements that contribute to them (Shit et al 2016). The graphical representation of yearly and monthly rainfall from the Indian Meteorological Department serves to determine the extent to which rainfall contributed to landslide event. To confirm the outcomes of the digital image processing, the boundary line of the affected area was established using a ground survey and the Global Positioning System (GPS). We will receive up-to-date information in these unreachable locations precisely and efficiently spatial technology. In order to map probable landslide susceptibility, ground-based observation and the weighted overlay method (WOM) are used in this study. The results demonstrate the value and efficacy of using the WOM technique to forecast landslide-prone areas before they have an adverse effect on the vicinity. Study stresses the urgent need for preventive measures such as preparation of early warning systems, forest conservation, construction regulations, and efficient evacuation protocols in vulnerable regions.

II. STUDY AREA

Indian subcontinent has a rich geological past marked by extensive tectonic, volcanic, and sedimentary activities. There are three main physiographic regions of the subcontinent: Vindhyan sedimentary basin in the centre, Deccan plateau in the south, Himalayan Mountain range, and Indo-Gangetic plain in the north. The Deccan plateau's Sahyadri Ghat region is dominated by high, steeply sloping hills with flat tops and surrounding plains that exhibit remarkable geographical diversity. The present investigation concentrates on Taliye village is nestled away among the Sahyadri mountain ranges. It is surrounded by the cities of Mahad to the east, Pasali to the north, Nigudaghar to the west, and Poladpur to the south. Geographically it is situated at an elevation of 408 meters above sea level and covering 990.21 hectares as of 2009. The landslide-affected zone is located at 18°06'35" N and 73°35'02" E and features an arcuate crown, spanning 40 meters wide at the main scarp and 230 meters wide at the toe. Study area is known for its highly variable climate, receiving abundant rainfall during the peak monsoon season. These unique geological and climatic conditions make Taliye particularly susceptible to landslides, highlighting the need for a comprehensive study of the dynamics behind landslide occurrences and their impact on human settlements. Taliye village and its surroundings are marked by the development of an extensive plateau due to a combination of factors: horizontal landslide debris near the source region, a gradual slope gradient in the deposition zone, and a small stream flowing through the landslide mass.

III. METHODOLOGY

This case study employed remote sensing and a GIS method to explore the clues of pre-landslide indicators and post-landslide repercussions in the examining area in order to show its adaptability and dependability. The QGIS and ArcGIS software's spatial analytic capabilities initially generated a geographic database for the causative components to conduct landslide susceptibility analysis in the research area. When choosing the causes of landslides, the literature review and the identical characteristics of the case study are taken into consideration. For WOM analysis, the following seven factors are taken into account: soil texture, distance to stream, land use and cover, rainfall, slope, aspect, hill shadow, and contour (Mersha and Meten 2020). To satisfy the need for research work, spatial data like DEM images and rainfall data were gathered from various websites. The Digital Elevation Model has already proven its vitalness in landslide-related research works we also preferred to use the same in this case study for pre-landslide. DEM data of study area is downloaded from Open Topography website. As DEM data was not available on any website for post-landslide changes identification the European Space Agencies (ESA) Copernicus website was used to collect spatial data like satellite imageries captured by Sentinel-I satellite thereafter it transformed into DEM format using the snap tool. The causal factor maps were converted to raster maps with a spatial resolution of 12.5 m and the same coordinate system (WGS 1984, UTM zone 43N).

About Weighted Overlay Method (WOM):

The Weighted Overlay Method is a widely used technique in spatial analysis for combining multiple raster layers to solve multi-criteria decision-making problems (Erener and Uzgun 2008; Bachri and Shresta 2010; Intarawichian and Dasananda 2010; Ahmed et al.2014). The first step is to identify and select the criteria (factors) that influence the analysis. Each criterion is represented as a raster layer, where each cell has a value that represents the condition of that criterion at that location. These layers need to be pre-processed to ensure they are in the same spatial resolution and coordinate system. Each raster layer is reclassified to a common scale, often from 1 to 9, where higher values indicate a higher contribution to the susceptibility. For example, steeper slopes might be given higher values because they are more prone to landslides.

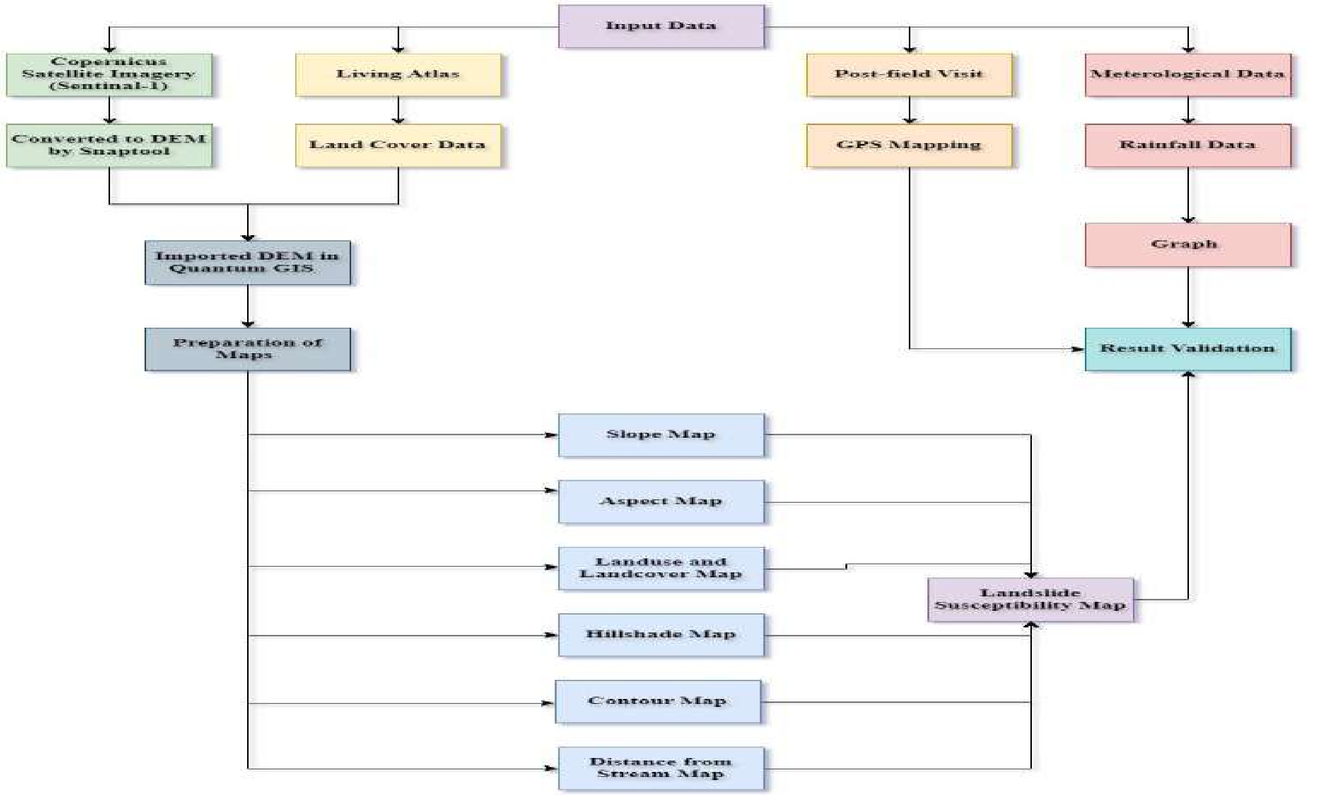


Fig 1. Flow Chart of Methodology

Assignment of Weights: Weights are assigned to each criterion based on their relative importance in influencing the outcome. These weights are usually determined through expert judgment, literature review, or statistical analysis. The sum of all weights should equal 100%.

Overlay Analysis: The reclassified raster layers are combined using a weighted sum approach. Each cell in the output raster is calculated using the formula:

$$\text{Susceptibility Index} = \sum(Ci \times Wi)$$

Where, Ci is the cell value of the reclassified criterion layer, and

Wi is the weight assigned to that criterion.

This method is particularly effective in environmental and geographical studies, such as landslide susceptibility mapping, where it integrates various factors contributing to the phenomenon.

1. Digital Elevation Model (DEM):

A Digital Elevation Model (DEM) is a 3D representation of a terrain's surface created from terrain elevation data. DEMs are essential in landslide research as they provide detailed information on topography, enabling the analysis of slope gradients, aspect, and elevation, which are critical factors in landslide susceptibility assessments. By utilizing DEMs, researchers can accurately model and predict landslide-prone areas, evaluate pre- and post-disaster changes, and develop effective mitigation and prevention strategies. The precision and resolution of DEM data significantly enhance the understanding of terrain dynamics and support comprehensive risk analysis in geologically vulnerable regions like Taliye village.

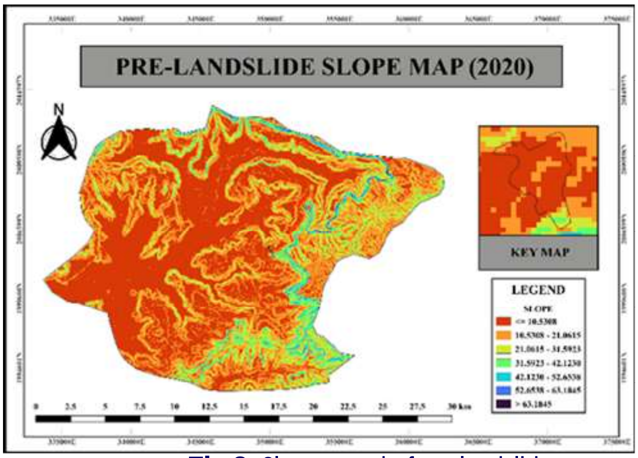


Fig 2. Slope map before landslide

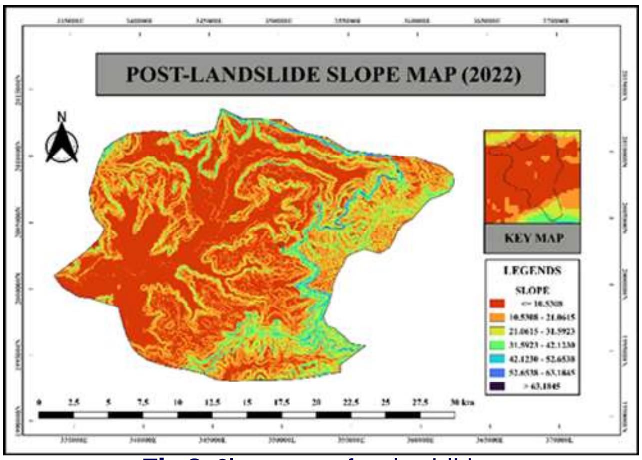


Fig 3. Slope map after landslide

a) Slope Map: Slope is a crucial characteristic for studying landslides since it directly correlates with their incidence. Slope maps are two-dimensional representations of a surface's gradient. It indicates how steep or gentle a slope is at any given location. Slope maps can help to detect possible problems. Landslides tend to occur more frequently on steeper slopes because of gravity pressure. The slope map was created utilising DEM data in QGIS Software 3.34.2, which was then classified into categories such as <=10°, 10°-21°, 21°-31°, 31°-42°, 42°-52°, 52°-63°, and >63°. The slope class >63° signifies a high possibility of landslides taking place in this class. Fig. 2 indicates the slope before the landslide had taken place where slope ranges in 31°-42° and Fig. 3 indicates the slope after the landslide had occurred. The slope changed from 21° to 31°.

b) Aspect Map: An aspect map depicts the aspect (direction) of a landscape (or another continuous surface). Aspect categories are represented using vibrant colours (e.g., red, orange, yellow, etc.). It also represents the slope direction represented as a degree range of 0° to 360°. This map was generated using DEM data from QGIS Software 3.34.2, classified into five categories: north, east, south, west, and north. As we can observe in figure 4 and figure 5 the face of slope hill is changed to north-west side after the landslide.

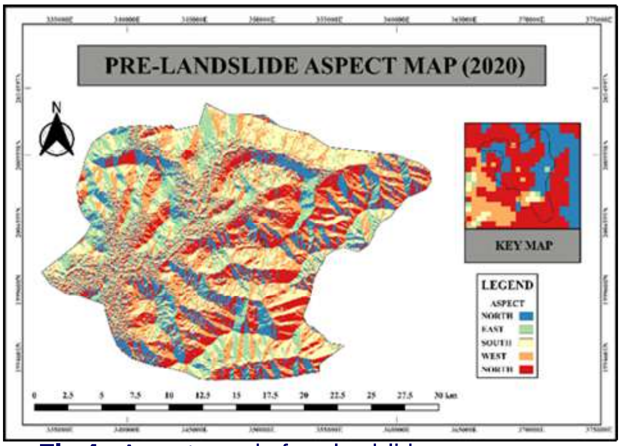


Fig 4. Aspect map before landslide

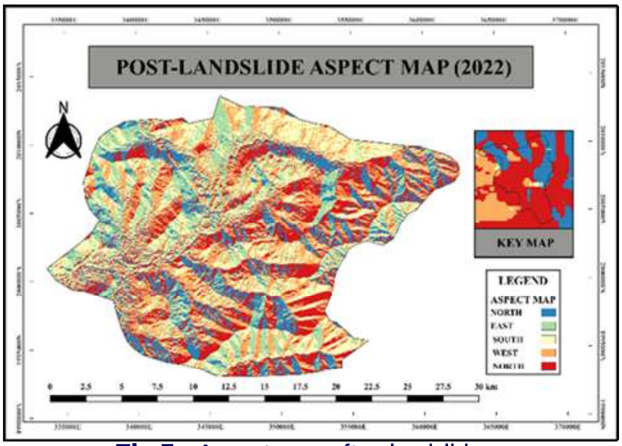


Fig 5. Aspect map after landslide

c) Hill Shade Map: The hill shade function creates a grayscale three-dimensional illustration of the topography surface, darkening the image based on the sun's relative position. Hill shading is a technique for viewing topography based on an illumination source and the slope and aspect of the elevation surface. The hill shade map of the study region was generated from the DEM data in the QGIS Software. The grayscale in the hill shade map runs from 1 to 255, representing white to black, as displayed in Fig. 6 and Fig. 7. There is a very s

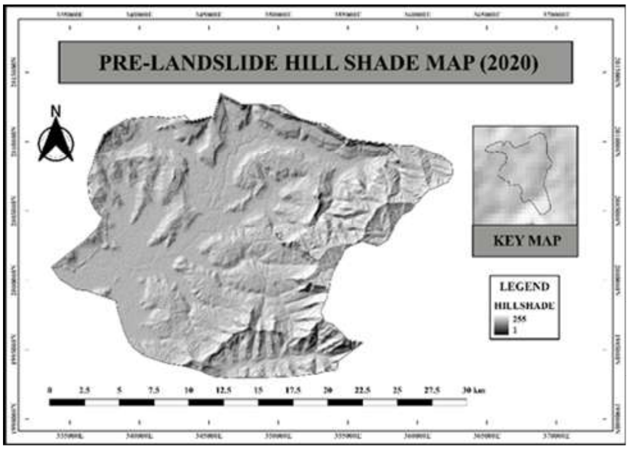


Fig6. Pre-landslide hill shade map

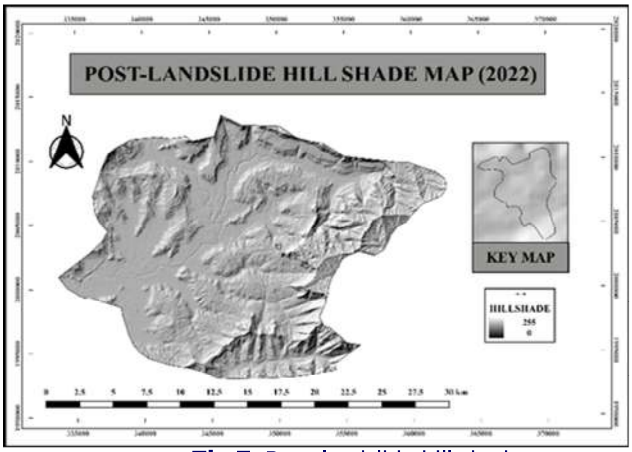


Fig 7. Post-landslide hill shade map

d) Distance from Stream Map: Areas closer to streams are supposed to be more susceptible to erosion and landslides especially in peak rainfall chances of triggering landslides increase. Landslides are more likely in rivers with multiple drainage networks due to erosion of the slope base and saturation of the submerged part (Akgun and Turk 2011). DEM data was used to create streams, which were then sorted according to their order. The spatial analyst tool in QGIS 3.34.2 was used to calculate the distance from a stream map using the SAGA Plugin's fixed distance buffering method. Proximity to streams is reclassified, with higher values closer to streams. Fixed distance buffer tool shows the distance from stream. Fig. 8 reveals that the edge of landslide area near the stream which causes the lead to a landslide. In Fig. 9 stream path has completely changed due to the landslide in the research area. The distance on the map is measured in metre.

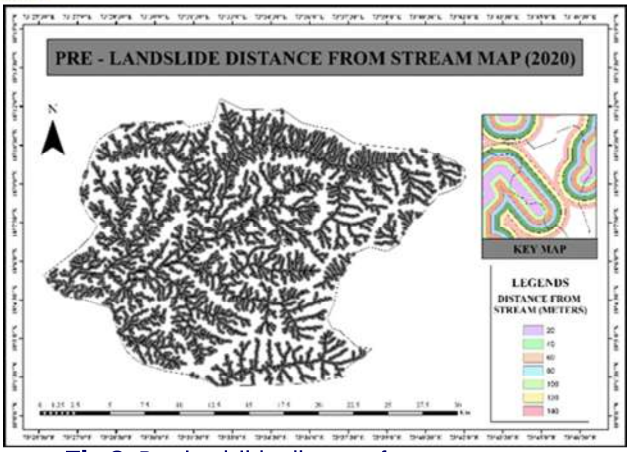


Fig 8. Pre-landslide distance from stream map

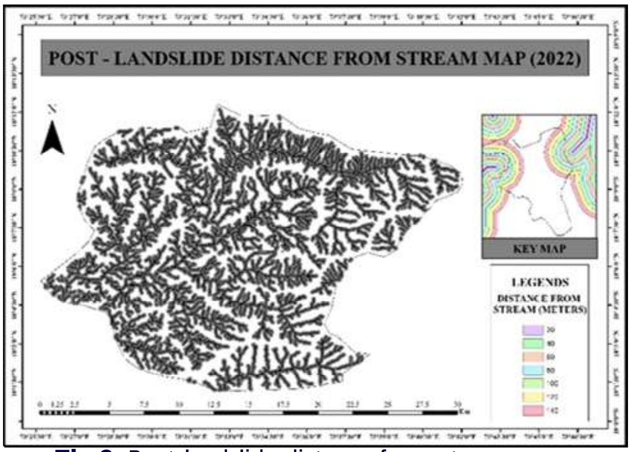


Fig 9. Post-landslide distance from stream map

e) Land Use and Land Cover: Land Use Land Cover (LULC) is the categorization or classification of human activities and biodiversity on the environment throughout a specified time period using established scientific and statistical methods of analysis of essential source data. Man-made activities including deforestation, overgrazing, intensive farming, and agriculture can cause instability on steep slopes. The land utilized by human occupations and dwellings destroyed during the landslide in the study geographical area. The LULC Map was generated with data obtained from the Living Atlas website, which was subsequently imported into QGIS software for map output. Figure 10 depicts the land cover data prior to the land slide, which showed the existence of trees at the top of the developed area and crops at the bottom of the terrain. Fig. 11 illustrates that the trees at the top, as well as the constructed area and crops, have vanished since the landslide took place.

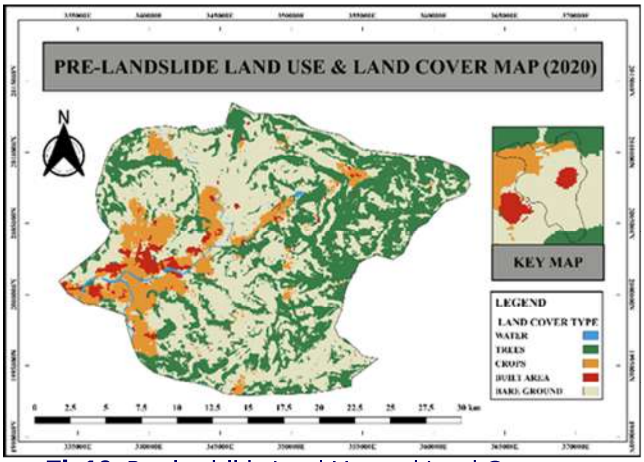


Fig10. Pre-landslide Land Use and Land Cover map

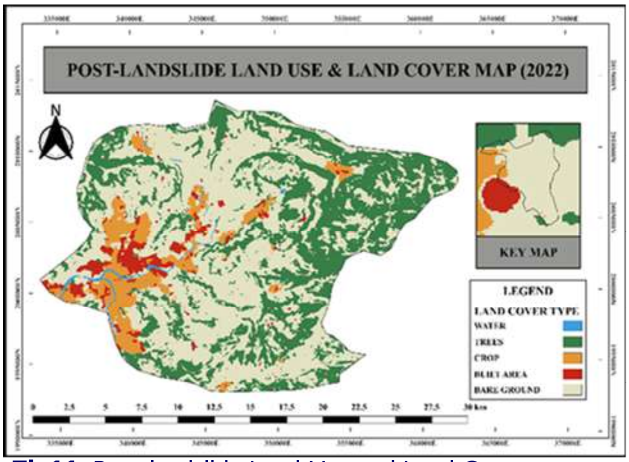


Fig11. Post-landslide Land Use and Land Cover map

f) **Contour Map:** A contour map is a form of map in which the contour lines depict the shape of the land surface, and the relative spacing between these lines reveals the slope of the particular region.

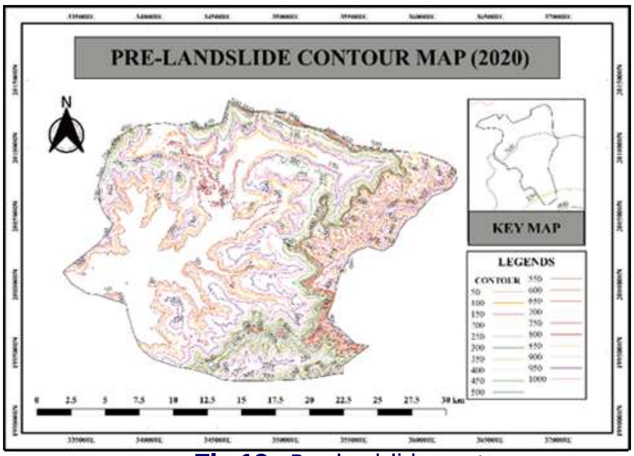


Fig 12. Pre-landslide contour map.

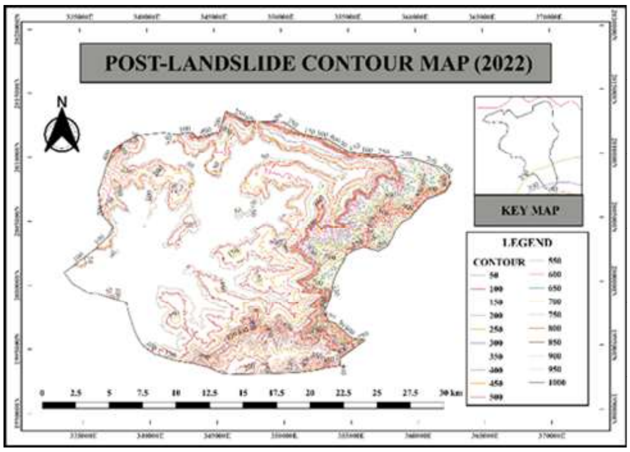


Fig 13. Post-landslide contour map

A topographic map accurately depicts the landscape and man-made features such as houses, roads, and bridges. While Contour maps use lines to indicate elevation changes. Contour lines on a map connect locations with equal heights. The contour map was generated using the QGIS software utilizing the DEM data of the study area.

Fig.12 shows that the elevation of the terrain ranged from 300m to 350m prior to the landslide; however Fig. 13 shows that the elevation has decreased to 250m to 300m post-landslide.

g) **Soil Texture Map:** Soil texture (such as loam, sandy loam or clay) describes the ratio of sand, silt, and clay-sized particles that comprise up the mineral component of the soil's structure. Soil texture may influence landslide susceptibility; sandy, loamy sand, and sandy loam soils particularly slippery and allow water to travel through quickly, resulting in fast landslides. The soil texture data were obtained from the Bhuvan website. This data was then imported into the QGIS software 3.34.2 for map advancement.

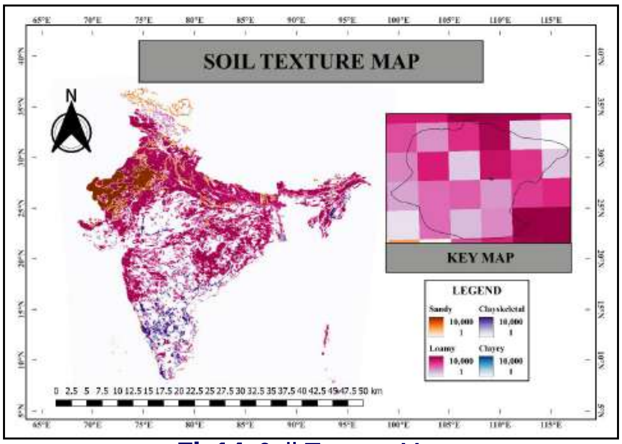
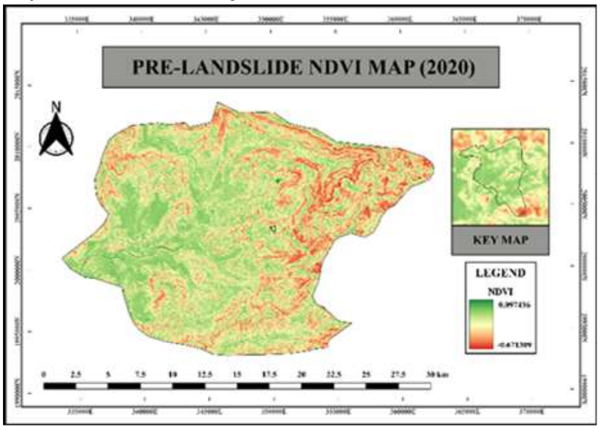


Fig14. Soil Texture Map

2. **Normalized Difference Vegetation Index (NDVI):** The Normalized Difference Vegetation Index (NDVI) assesses vegetation by comparing the difference between near-infrared (which vegetation strongly reflects) and red light (which vegetation absorbs).

NDVI = (NIR – RED) / (NIR + RED)

The NDVI map of the research area was created using QGIS's raster calculator tool. It can be seen in the created map of the research area before the landslide, there is relatively minimal vegetation on the topmost portion of the collapsed area, resulting in the landslide.



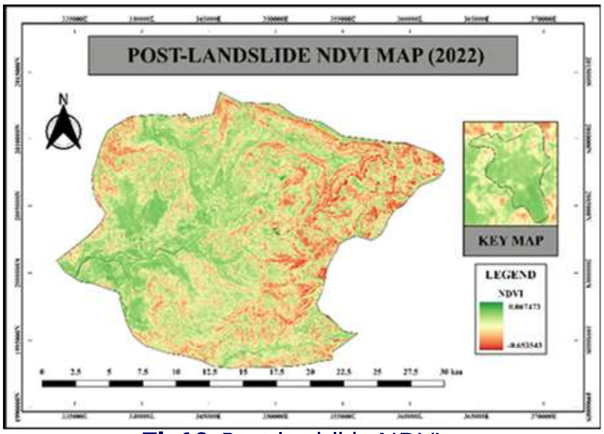


Fig 15. Pre-landslide NDVI map **Fig16**. Post-landslide NDVI map

3. **Rainfall Data:** The rainfall data for the research area is collected from the India Water Resources Information System (IWRIS) website for particular months' rainfall graph production. According to rainfall data, the actual rainfall on the 19th, to 23rd July, 2021 was 159.51mm, 122.99mm, 57.70mm, 200.05mm, and 137.92mm, respectively. The rainfall graph is generated for the month of July 2021. The highest level of rainfall was recorded on 19th, to 23rd July 2021.

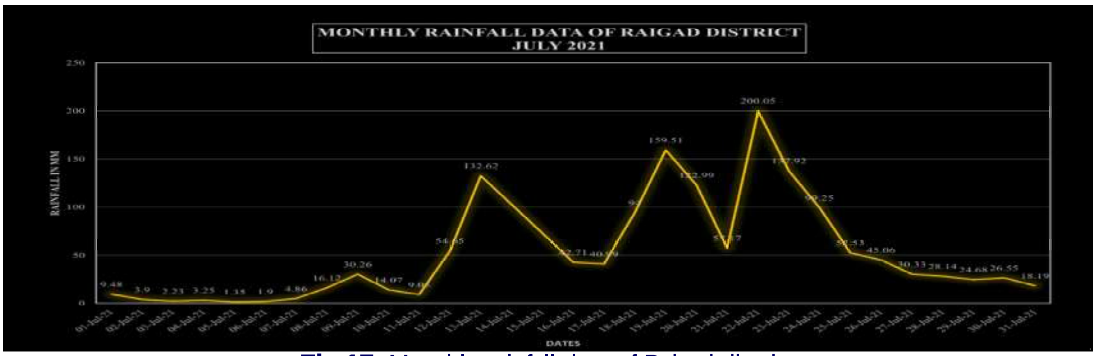


Fig 17. Monthly rainfall data of Raigad district

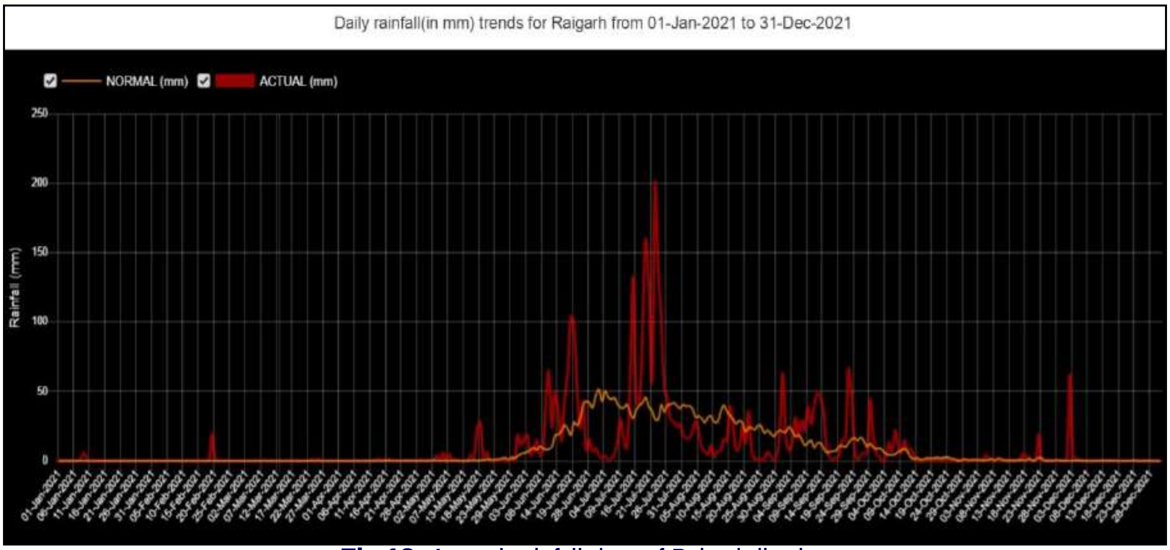


Fig 18. Annual rainfall data of Raigad district.

IV. GPS DATA FOR VALIDATION

Fig 19. GPS data of Taliye landslide

V. RESULTS

This study conducted a comparative investigation of the relationship between causal factors and landslide occurrence. Using the weighted overlaying method, we categorized the research region into six zones based on the potential severity of a landslide. Causative elements such as slope aspect, hill shade, distance to stream, land use and land cover, contour, soil texture, NDVI, and rainfall were identified. Landslides are more likely to occur on slopes that exceed 21°. Areas with slope class > 52° are the most prone to landslides, while those with slope class < 10° are the least. However, as the slope steepens, so does the likelihood of a landslide. In the instance of aspect classes, the slope classes that were facing north-east have now turned north-west. In the instance of the hill shade map, the minor undulations on the terrain were eradicated. The nature of land use influences the occurrence of landslides in the research area. Bare land has the highest weighted value because of its exposure to erosion and weathering. In terms of the relationship between landslide incidence and distance from stream, as the distance from the stream increases, so does the occurrence of landslides. The elevation of the ground on the contour map has been reduced to 250m to 300m, down from 350m to 300m before the landslide. Landslides are more likely to occur in areas with lower vegetation values on the NDVI map. It is evident from supporting annual rainfall statistics from the Indian Meteorological Department that July 2021 saw the most rainfall of the year. To be more precise, the study area saw previously unheard-of prolonged greatest rainfall in the week of devastating landslide in July (maximum 200 mm).

- **Landslide Susceptibility Map Using Weighted Overlay Method:**

Landslide susceptibility, also known as landslide hazard zonation, indicates the areas with the highest risk of landslides in a specific region. The landslide susceptibility map identifies where landslides are likely to occur and examines their causes. This map considers causative factors like slope, soil type, land use/land cover, proximity to water bodies, NDVI (Normalized Difference Vegetation Index), geological features, and proximity to streams within the designated area.

Using ArcGIS software, we generated the landslide susceptibility map through the spatial analysis tool "Weighted Overlay Method". The landslide susceptibility index, ranging from 1 to 7, was employed to pinpoint high-risk zones, with higher values indicating an increased likelihood of landslide occurrence. The pre-landslide key map highlighted the areas with higher landslide risk zones before actual event happened at the landslide's origin point, demonstrating that landslides can be predicted or at least forecasted using the Weighted Overlay Method well before. In contrast, the post-landslide susceptibility map shows that risk is reduced obviously due to landslide event due to changes in topography, geology, and other crucial factors. This further illustrates how a landslide's aftermath changes the terrain and influences future susceptibility, proving that the post-landslide susceptibility map also appropriately reflects the alteration in topography.

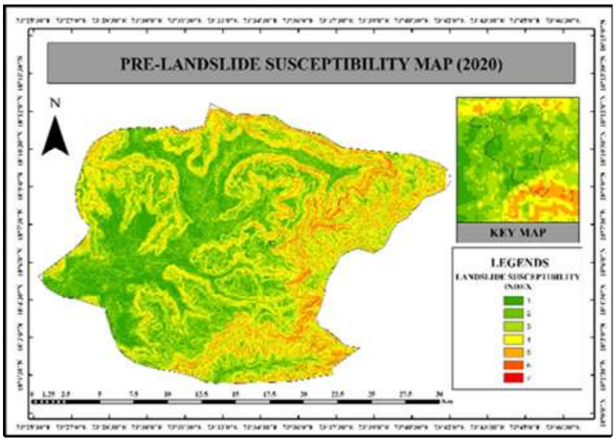


Fig20. Pre-landslide landslide susceptibility map.

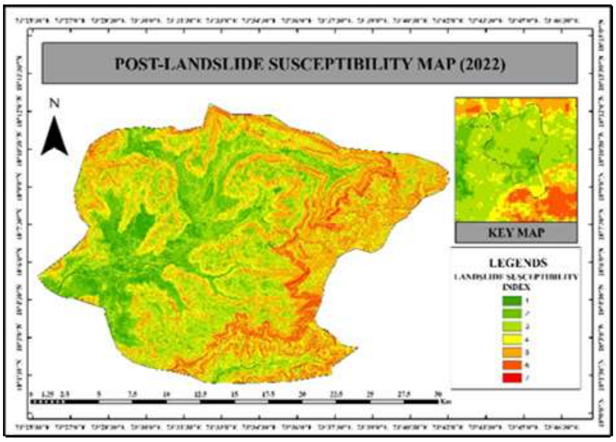


Fig 21. Post-landslide landslide susceptibility map.

VII. CONCLUSION

Landslides have intricate dynamics that result from internal as well as outside factors which initiate the process. In summary, this study examined the factors contributing to landslides, with a particular emphasis on Taliye village in the Raigad district of Maharashtra State, India. By employing a comprehensive methodology that incorporated various maps and data analysis, the research identified the correlations between causative elements and landslide occurrences. The comparative examination of the study's pre- and post-landslide data is noteworthy since it is essential for identifying landslide-prone zones in the future. This research exemplifies the effectiveness of remote sensing and GIS in predicting these zones. The study demonstrated the susceptibility of specific locations to landslide events by revealing notable post-landslide changes in slope, land use, vegetation index, and other parameters. Furthermore, the use of the Weighted Overlay Method to create a landslide susceptibility map highlighted the importance of taking into account many criteria when identifying and mitigating high-risk locations. Supporting annual rainfall data provided by the Indian Meteorological Department depicts a clear indication of the highest rainfall in year 2021. If being specific July month's rainfall in study area experienced unprecedented prolonged highest rainfall (max. 200 mm) for five days on and before a catastrophe. The findings highlight the urgent need for preventive measures such as forest conservation, early warning systems, regulations on construction as well as agricultural activities in vulnerable areas, and efficient evacuation protocols. This approach has demonstrated its value over time and may be more successful in mitigating the regular catastrophic landslides that occur in the Sahyadri mountain ranges. Thus, these findings should serve as the foundation for establishing preventative initiatives to reduce the impact of future landslides and safeguard the well-being of the affected population.

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