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Landslide susceptibility zonation using analytical hierarchy process and GIS for the Nandakini River Valley, Central Himalaya

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Abstract: **Nandakini River is a tributary of Ganga located in the central Himalayas of the Indian state of Uttarakhand. The area lies in the upper Ganga basin of the Himalayan rugged train. Landslide susceptibility mapping is of the foremost importance in an area like this one. It is required to alert the people. For the present study, eleven responsible causatives were considered namely drainage density, drainage, elevation, geology, geomorphology, groundwater depth, LULC, NDVI, rainfall, slope, and temperature. Analytical Hierarchy Process has been used to prioritize the factors. The degree of slope varies from 0 to 84. 54 where the high slope is in the northeastern and the low is in the northwestern part. Elevation varies from 827 meters to 6586 meters. Drainage density (0 to 4.67/sq.km), Rainfall (1224 to 1230 mm), Groundwater depth (41.79 to 42.29) etc. All the hydrological factors also accelerate landslide susceptibility. Rugged geomorphology with vulnerable geology helps the region to be landslide prone. The final landslide susceptible map indicates the area is highly vulnerable to landslides.**

Index Terms: **Landslide, zonation, GIS, LULC, NDVI, Central Himalaya**

I. INTRODUCTION

Landslide is one of the recurrent natural problems that are widespread throughout the world, especially in mountainous areas which caused significant injury and loss of human life, and damage to properties and infrastructures (Parise and Jibson 2000). Landslides are caused by different triggering factors such as heavy or prolonged precipitation, earthquakes, rapid snow melting, and a variety of anthropogenic activities. Landslides can involve flowing, sliding, toppling, or falling movements and many landslides exhibit a combination of two or more types of movements (Crozier 1986). Nandakini River is one of six prime tributaries of the river Ganga. It originated from a glacier located below Nanda Ghunti near the Nanda Devi sanctuary. It further joined the river Alakananda. It is the area of Central Himalayas which is highly rugged in the Indian states of Uttarakhand.

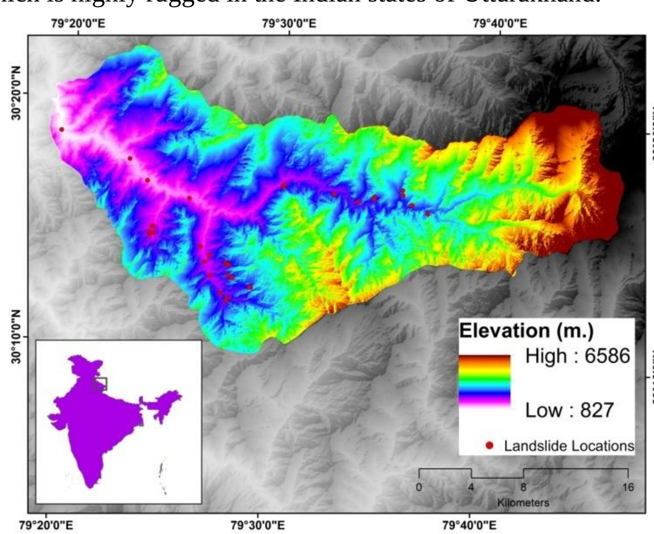

Fig. 1. Location map of Nandakini Basin

II. GEO-ENVIRONMENTAL CAUSATIVES TO LANDSLIDES

In modern times researchers are trying to prepare the landslide susceptibility mapping (LSM) for alarming the area in advance. For the preparation of Landside susceptibility mapping

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(LSM) various landslide-related parameters are required. The mathematical GIS-based data is used for processes that can affect the standard of methodology. In RS and GIS platforms all the landslide-related parameters will be conditioned for getting a clear and accurate output. Here eleven responsible causatives were considered namely drainage density, drainage, elevation, geology, geomorphology, groundwater depth, LULC, NDVI, rainfall, slope, and temperature. They are used as raw data to predict the landslide-prone area in the landslide susceptibility hazard zonation map. These all causal parameters may be classified as follows:

Table I. Database and sources

Sl No.	Parameters	Source	Details
1	Geomorphology	Geological Survey of India	1:63,300
2	Elevation	ALOS PALSAR DEM, (Japan Aerospace Exploration Agency)	12.5 m spatial resolution
3	Slope	ALOS PALSAR DEM, (Japan Aerospace Exploration Agency)	12.5 m spatial resolution
4	Geology	Geological Survey of India	1:63,300
5	Rainfall	India Meteorological Department (IMD)	Interpolation with same resolution with other parameters
6	Temperature	India Meteorological Department (IMD)	Interpolation with same resolution with other parameters
7	Groundwater	Central Ground Water Board (CGWB)	Interpolation with same resolution with other parameters
8	LULC	Sentinel 2A (European Space Agency)	10 m spatial resolution
9	NDVI	Sentinel 2A (European Space Agency)	10 m spatial resolution
10	Drainage	ALOS PALSAR DEM, (Japan Aerospace Exploration Agency)	12.5 m spatial resolution
11	Drainage Density	ALOS PALSAR DEM, (Japan Aerospace Exploration Agency)	12.5 m spatial resolution

III. METHODOLOGY AND DISCUSSION

A. Topographical

Here the slope and elevation are considered topographical factors. These control the geographical setup of a particular area. The higher elevation zone was found in the northeastern and eastern portion accordingly and the low portion was found in the northwestern portion. Here the degree of slope varies from 0 to 84. 54 where the high slope is in the northeastern and the low is in the north-western part. Related data are collected from the topographical sheet at 1:50,000 scale and ALOSPALSER DEM digitallywith 12.5 m resolution**.**

B. Hydrological

The hydrological parameters are geomorphic that lead to landslides through an unstable conditions (Guzzetti et al., 1999). Rainfall is one of the most important parameters which can trigger a landslide (Segoni et al., 2018). The sudden flood by rainfall may produce landslides (Keefer et al., 1987). Rapid infiltration due to heavy rainfall increases the degree of saturation. The temperature which is directly related to rainfall pattern and its distribution establishes the perfect environment for landslide and also responsible for weathering process (Napolitano et al., 2016). Here the rainfall, temperature, drainage density, drainage, ground water depth are considered as such types of data. Here drainage density and drainage are extracted from ALOSPALSER DEM. The drainage density is the length of streams per unit area (Horton, 1945; Melton, 1958; Strahler, 1952). This parameter can adversely affect slope stability by eroding the materials of the lower part. It also helps to determine the degree of streams that are affected by landslides.

$$DD = \frac{\sum_{i=1}^{n} S_i}{a} \quad (1)$$

Where, $\sum_{i=1}^{n} S_i$ indicates the total length of all drainages in km and 'a' is the total area of the drainage basin in km^2.

The annual rainfall and temperature data were collected from the Indian meteorological Department (IMD). The CGWB has provided groundwater-related information. Here the drainage density calculation is as follows:

Drainage density which varies from 0 to 4.67/sq.km of the area is indicative of accelerating landslide vulnerability. High Rainfall in the area (1224 to 1230 mm) also helps in a landslide. Groundwater depth varies from 41.79 meters to 42.29 meters in the area.

C. Environmental

Land use and land cover area, geomorphology of this area, and NDVI are considered as such kinds of parameters. DEM with 12.5 m spatial resolution and sentinel images have provided the information about them.

Here the land use land cover area (LULC) map was categorized into nine zones such as cropland, mixed forest, shrubland, barren land, fallow land, wasteland, water bodies, slow and ice, and the evergreen needle leaf forest.

NDVI (Normalized Difference Vegetation Index) was prepared from sentinel 2A images and is calculated using the formula as:

$$NDVI = \frac{NIR - RED}{NIR + RED} \qquad (2)$$

Where, the positive NDVI value shows healthy vegetation which covers the slope surface and reduces the soil erosion. The negative value shows low or no vegetation zone that portion is vulnerable to erosion and landslide**.** Low NDVI accelerates the landslide vulnerability.

D. Geology and geomorphology

The geomorphology of this region has been shown into 9 different parts such as a river, moderately dissected hills and valleys, highly dissected hills and valleys, snow cover, glacier terrain, younger alluvial plain, piedmont alluvial plain, piedmont slope, and mass wasting products. This data will be sourced from the Geological Survey of India at 1: 63,360 scale.The more important parameter is the geological setup of this research study area.The final zonation map indicates the basin is highly vulnerable to landslides. The areas of the high slope with rugged geomorphology, high drainage density, and low NDVI of the basin are mostly susceptible rather than the areas of low slope, plain geomorphology.

Conclusion

Landslide zonation mapping in hilly terrain areas is highly challenging. Visiting the sites and monitoring things is highly risky. The Nandakini river basin in the present study is one of them. The final landslide susceptible map has been derived after considering the eleven factors with their relative effects in a landslide after using the advanced AHP techniques. Overall the basin is highly susceptible not only because of its rugged train characteristics but also due to its location in the Himalayas like young fold mountain where mountain building processes are still going on.

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