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Frequency Ratio-Based Landslide Susceptibility Zonation of the Upper Koyna River Basin in the Western Ghats, India

Dr.Gaikwad M. R.

Abstract

Monsoon slope failures regularly hit roads, settlements and water-related structures in the Western Ghats of Maharashtra. This paper applies the Frequency Ratio (FR) model to identify the most failure-prone ground in the Upper Koyna River Basin (474.24 km^2) of Satara district. A landslide inventory of 771 points was prepared from high-resolution satellite imagery. The inputs were slope, elevation, surface relief index (SRI), topographic wetness index (TWI), geomorphic units, land use/land cover (LULC) and rainfall. Each class of each layer received an FR value, and the layers were summed into a landslide susceptibility index, which was split into five classes. From very low to very high, the classes take up 20.1%, 20.4%, 19.5%, 20.7% and 19.3% of the basin respectively. About 40% of the basin lies in the two upper classes, yet these hold 91.1% of the mapped landslides, whereas the two lower classes hold just 1.3%. Landslide density increases from 0.02 per km^2 (very low) to 4.94 per km^2 (very high). Based on the five classes, the success rate curve yields an area under the curve (AUC) of 0.80. The highest FR values were found in highly dissected plateau, the 650–800 m elevation class, 30–40° slopes, evergreen and semi-evergreen forest and areas with more than 3700 mm of rainfall. High susceptibility is concentrated on the steep, deeply dissected western and north-western slopes, where rainfall is also highest. The map can help planners decide where to locate roads and settlements and where slope protection and field checks are most needed in the Koyna catchment.

Keywords: *Landslide susceptibility; Frequency ratio; Koyna River Basin; Western Ghats; GIS; Remote sensing*

Introduction

Hilly terrain is exposed to frequent slope failure. Bhagya et al. (2023) name the Himalaya, the Western Ghats and the Eastern Ghats as the most affected parts of India. Along the Western Ghats, failures cluster in the monsoon, when steep slopes, weathered rock and intense rain act together (Avinash et al., 2008; Patil and Panhalkar, 2019).

Every year western Maharashtra is hit by such failures. In July 2021, intense rainfall set off landslides in several districts, among them Raigad, Ratnagiri, Satara and Kolhapur. Nitnaware (2022) reports an estimate by the Advanced Centre for Water Resources Development and Management (ACWADAM) of up to 10,000 landslides across Maharashtra in that month.

The Koyna River Basin deserves attention for several reasons. The river rises close to Mahabaleshwar and descends the Western Ghats, and the basin contains the Koyna reservoir, which supplies hydropower and water to Maharashtra. Deccan basalt underlies most of the region (Gupta et al., 2014). Reservoir-linked earthquakes have also occurred here since the dam was impounded in the early 1960s (Gupta et al., 2014). Tourist places such as Mahabaleshwar and Tapola also attract many visitors. Slope failures can harm roads, villages and the reservoir catchment, so knowing which areas face the highest risk is important.

A susceptibility map identifies the places where slope failure is most probable. The FR model is a straightforward statistical way to produce one: for every class of a factor (a slope range, for example), the share of landslides is set against the share of area. Values above 1 point to a higher chance of landslides in that class. It has been tried in many regions (Lee and Pradhan, 2007; Pradhan et al., 2010). In the Western Ghats, applications include the Sharavathi basin in Karnataka (Avinash et al., 2008) and Phonda Ghat in Maharashtra (Patil et al., 2022). In the Chenab Valley of the Himalaya, the Landslide Numerical Risk Factor (LNRF) model and the Information Value model have been applied (Patil et al., 2020; Patil et al., 2021).Several studies cover this or nearby areas. Patil and Panhalkar (2019) applied the Analytical Hierarchy Process (AHP) to hazard zonation in the south-western Ghats of Maharashtra. The same authors applied the LNRF model to part of the Western Ghats (Patil and Panhalkar, 2023),

Examined how soil erosion relates to landslide incidents (Patil and Panhalkar, 2024a) and mapped shallow landslides in the Gaganbawada region with a support vector machine (Patil and Panhalkar, 2024b). Susceptibility maps also exist for Ratnagiri district (Potekar et al., 2023) and, through weighted overlay, for Mahabaleshwar tehsil (Karande, 2021). For the Koyna River Basin as a whole, Patil et al. (2024) compared SVM, FR and AHP using 1,823 landslide events. As far as we know, no earlier work has examined the upper Koyna basin on its own or described in detail how individual factor classes control landslide occurrence there. The present work therefore applies the FR model, with seven conditioning factors, to the Upper Koyna River Basin and explains how each factor affects landslide occurrence.

The aim is to build a landslide inventory for the Upper Koyna River Basin from Google Earth imagery, to derive seven conditioning layers, and to see with the FR model how each one is related to landslide occurrence. A five-class susceptibility map is then produced and tested with landslide density and the success rate curve.

Study Area

1 Location

The Upper Koyna River Basin lies in Satara district, Maharashtra (Fig. 1). It spans 474.24 km² between roughly 17°41′N and 17°58′N and between 73°33′E and 73°48′E. Parts of Jawali and Mahabaleshwar talukas fall within it. From its source near Mahabaleshwar the Koyna flows south and meets the Krishna River at Karad. In the south, the basin is cut off across the Koyna reservoir (Shivsagar Lake), which means that a long arm of the lake falls within it. The area is also a popular tourist region. Visitors are drawn to the hill station of Mahabaleshwar and to Tapola, a spot on the shore of Shivsagar Lake that is popular for boating.

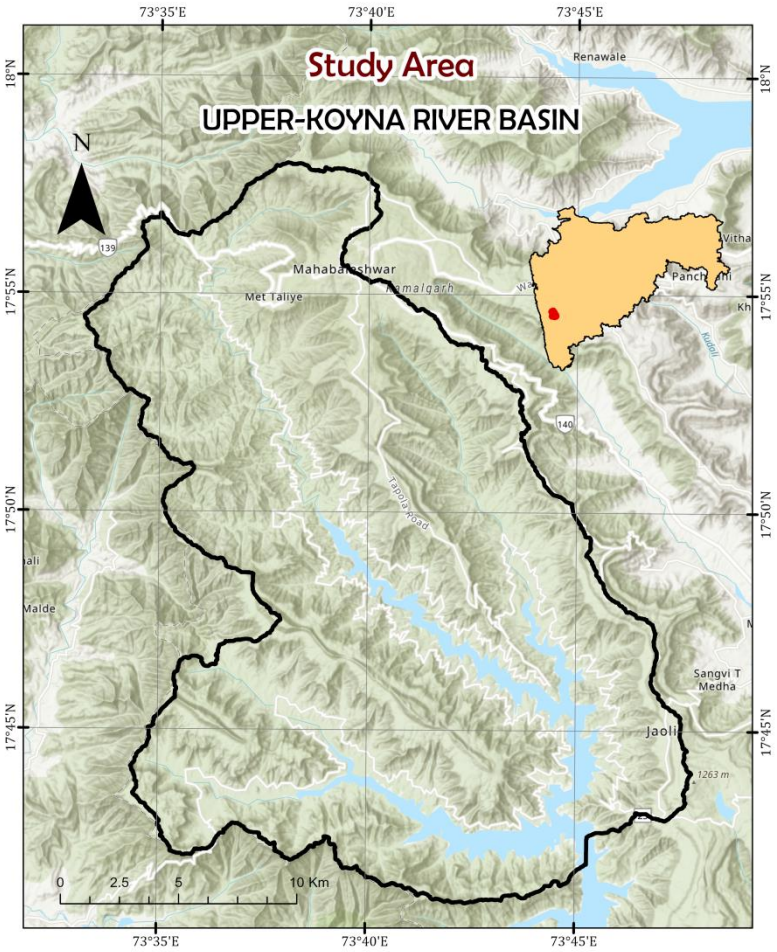

Fig. 1. Location of the Upper Koyna River Basin in Satara district, Maharashtra.

2 Physiography

The basin sits on the Western Ghats (Sahyadri) escarpment, a steep mountain front looking towards the Arabian Sea. Ground height drops from over 1,100 m on the northern and north-eastern ridges to under 650 m beside the reservoir and on the valley floors. Plateau tops and valley floors are gently sloping, while incised valleys and scarp edges exceed 40° (Figs. 5 and 6). The Koyna and its tributaries have carved deep valleys into the plateau and flow into Shivsagar Lake, a long and narrow reservoir.

The bedrock is Deccan basalt, a stack of lava flows roughly 65 million years old (Gupta et al., 2014). Near Mahabaleshwar, horizontal flows are exposed along the escarpment, with laterite caps on the plateau tops and deep gorges (UNESCO World Heritage Centre, n.d.). Most of the basin is highly dissected plateau; moderately dissected plateau lies mainly on the eastern

side, and pediment–pediplain complexes follow the valleys (Fig. 4). Evergreen/semi-evergreen and deciduous forest is dense in the north and north-west, while crop land and scrub land lie mostly in the south and along the main valley (Fig. 9). The Sahyadri Tiger Reserve, which combines Koyna Wildlife Sanctuary and Chandoli National Park, forms part of the Western Ghats World Heritage Site (Sahyadri Tiger Reserve, n.d.).

3 Climate

The basin has a monsoon climate: rain comes mainly between June and September, and the remaining months are largely dry. Mahabaleshwar, close to the basin, receives very heavy rain, and in July 2021 it received more than 1,500 mm in three days (Deccan Herald, 2021). Rainfall drops quickly towards the east. In the NASA POWER layer used here, it falls from above 3,700 mm in the west of the basin to below 3,000 mm in the east (Fig. 10), although this coarse layer smooths out local peaks (see Section 5.4).

Data and Methodology

1 Overview

The work had four steps (Fig. 2). First, a landslide inventory was prepared. Second, seven factor layers were made from the data sources in Table 1 and divided into classes. Third, the landslide points were used to compute an FR value for every class. Fourth, the FR layers were added to give a susceptibility index, which was divided into five classes and checked against the landslide inventory.

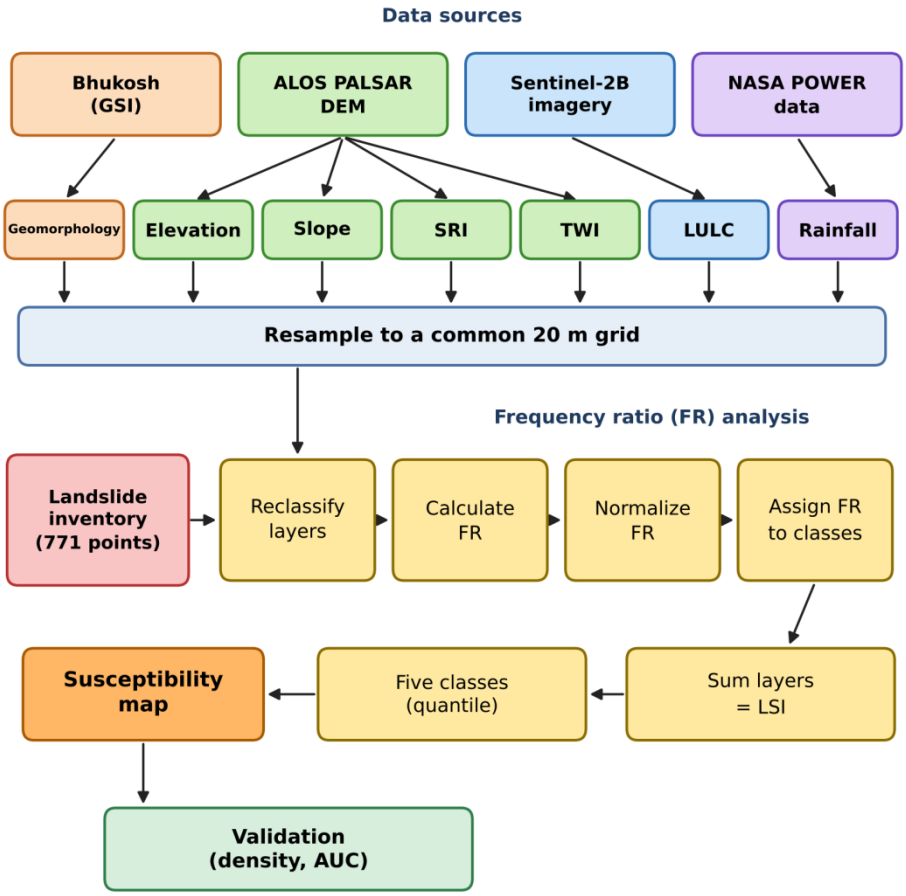

Fig. 2. Flowchart of the methodology.

Table 1. Data used in the study.

Data	Source	Resolution / date	Used for
Geomorphology	Bhukosh, Geological Survey of India	Thematic map	Geomorphology layer
Digital elevation model	ALOS PALSAR	12.5 m	Elevation, slope, SRI, TWI
Land use / land cover	Sentinel-2B	10 m	LULC layer

Data	Source	Resolution / date	Used for
Rainfall	NASA POWER	0.1°	Rainfall layer
Landslide locations	Google Earth imagery	2020–2025	Landslide inventory

2 Landslide inventory

Landslides were marked as points through visual interpretation of high-resolution Google Earth images from 2020 to 2025, using visible signs such as bare scars, scarps and debris at the foot of slopes. The inventory holds 771 landslide points (Fig. 3). All 771 points went into the FR calculation; none was held back for testing. Some of the landslides were found close to the reservoir.

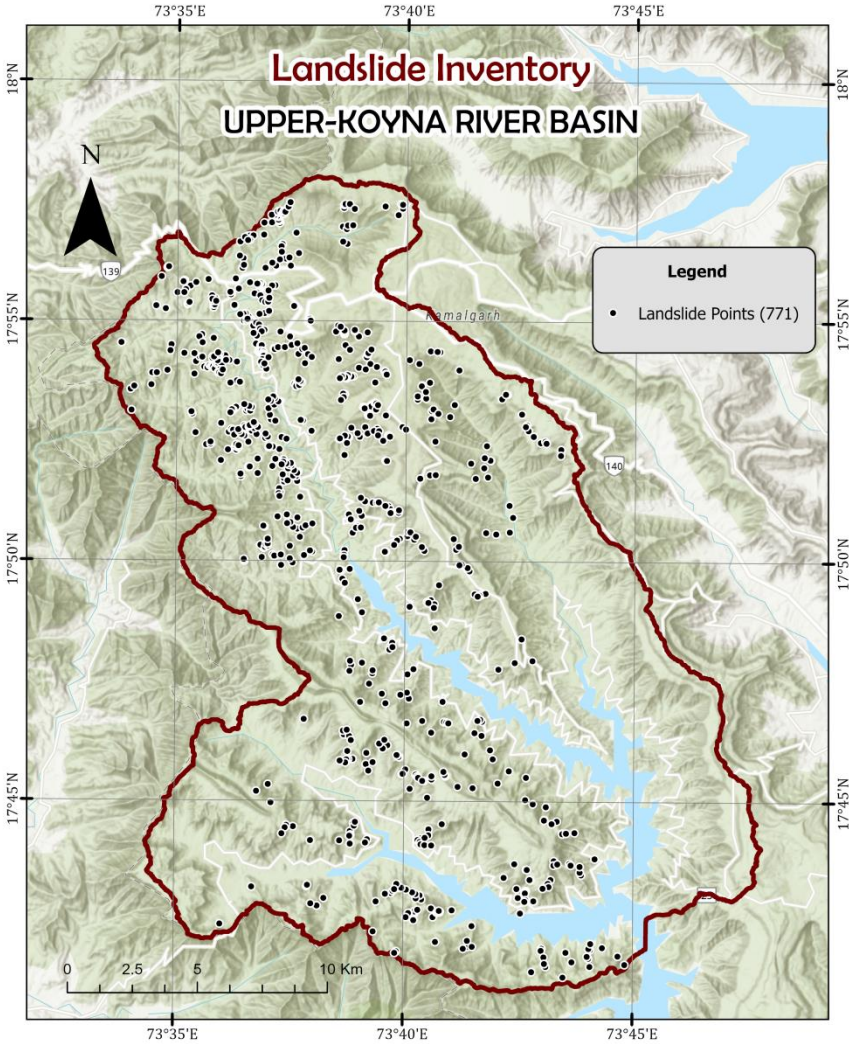

Fig. 3. Landslide inventory of the Upper Koyna River Basin (771 points).

3 Landslide conditioning factors

Seven factors were used, all brought to one 20 m grid (1,185,328 cells for the 474.24 km² basin) in the UTM zone 43N projection. Each factor was divided into classes: five for elevation, slope, SRI, TWI and rainfall, six for geomorphology and ten for LULC (Tables 2–8).

Geomorphology. Landform units were taken from Bhukosh. They describe the shape of the land and how much it has been cut by streams (Fig. 4). *Elevation.* Elevation was taken from the DEM (Fig. 5). It affects rainfall, vegetation and the depth of weathering. *Slope*. Slope in degrees was calculated from the DEM (Fig. 6). Steeper slopes put more stress on soil and rock. *Surface relief index (SRI).* SRI describes how rough or dissected the ground surface is; higher values mean more uneven terrain. It was calculated from the DEM and ranges from 1.001 to 3.2 (Fig. 7). *Topographic wetness index (TWI).* TWI indicates where water tends to accumulate. The index is ln(α / tan β), where α stands for the upslope area draining through a

unit length of contour and β for the local slope angle (Beven and Kirkby, 1979) (Fig. 8). *Land use/land cover (LULC).* LULC was prepared from Sentinel-2B imagery (10 m) and has ten classes (Fig. 9). *Rainfall.* Rainfall was taken from NASA POWER at 0.1° for 2015–2025 and resampled to the common grid (Fig. 10).

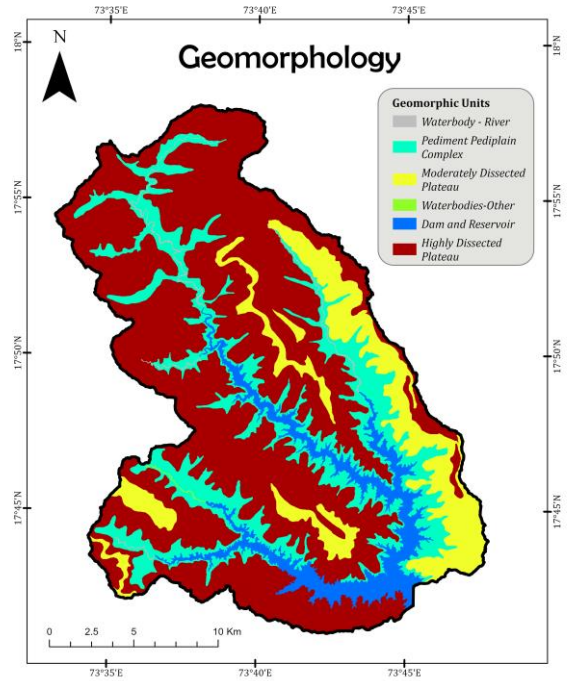

Fig. 4. Geomorphology.

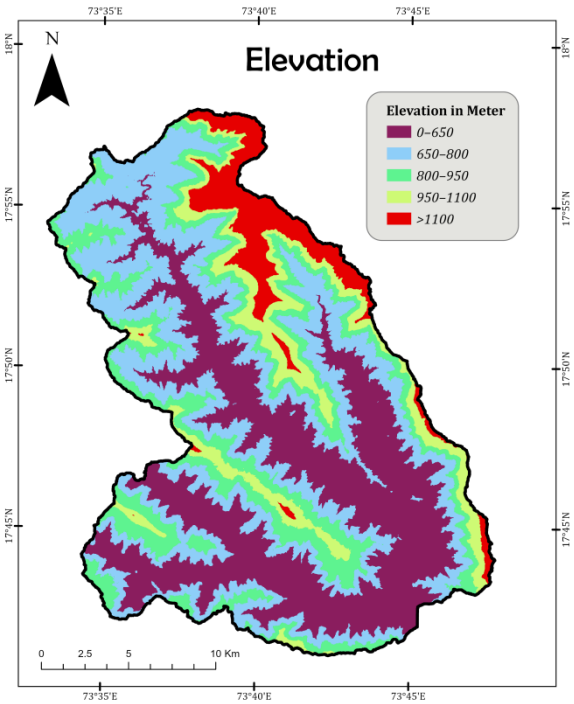

Fig. 5. Elevation.

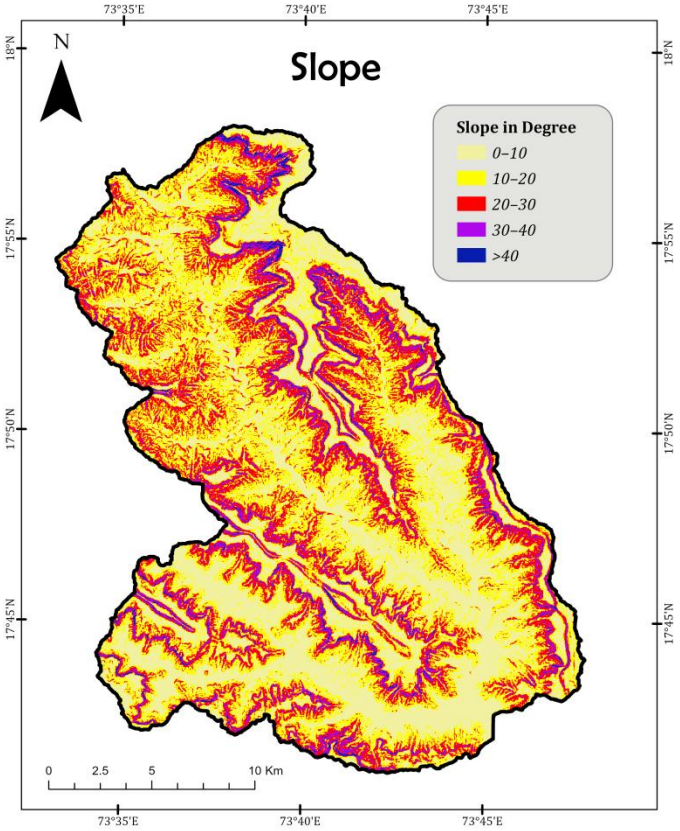

Fig. 6. Slope.

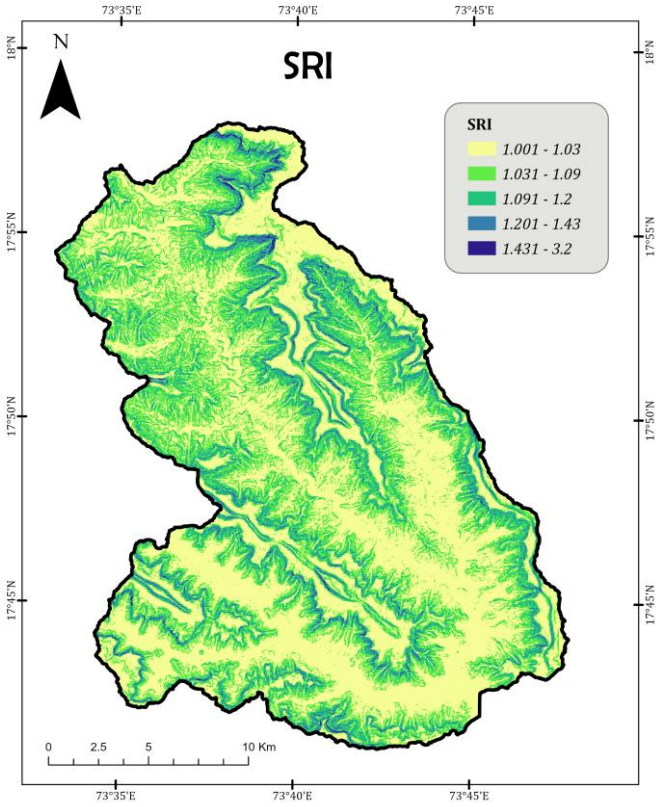

Fig. 7. Surface relief index (SRI).

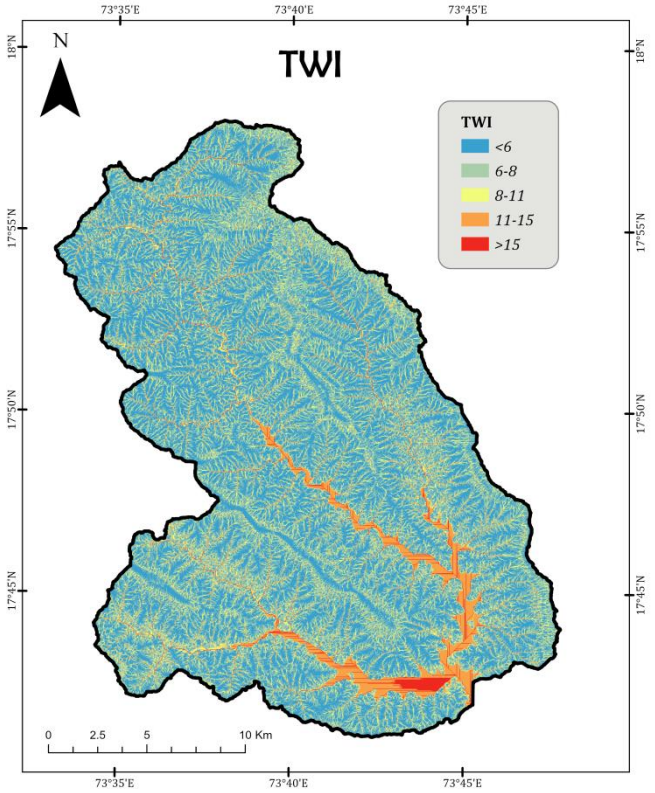

Fig. 8. Topographic wetness index (TWI).

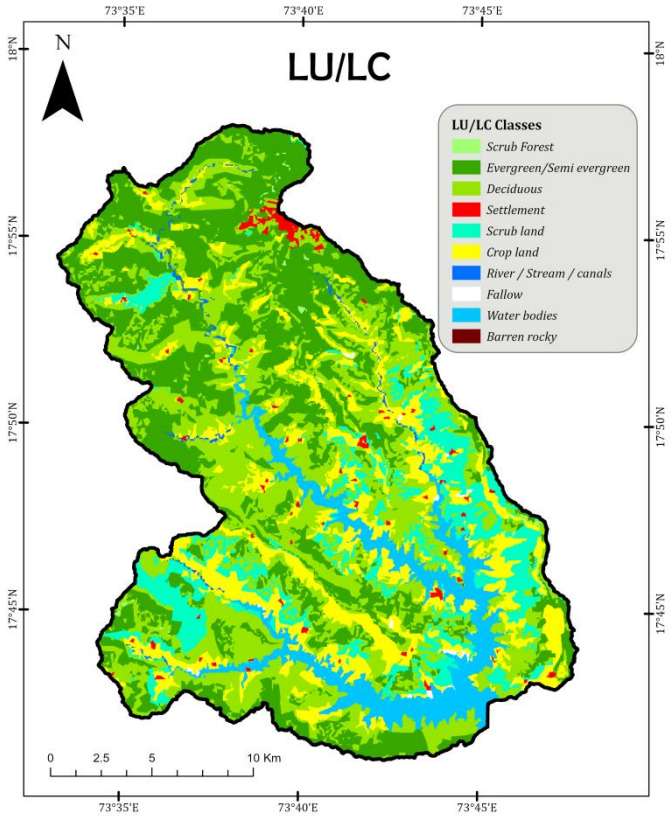

Fig. 9. Land use/land cover (LULC).

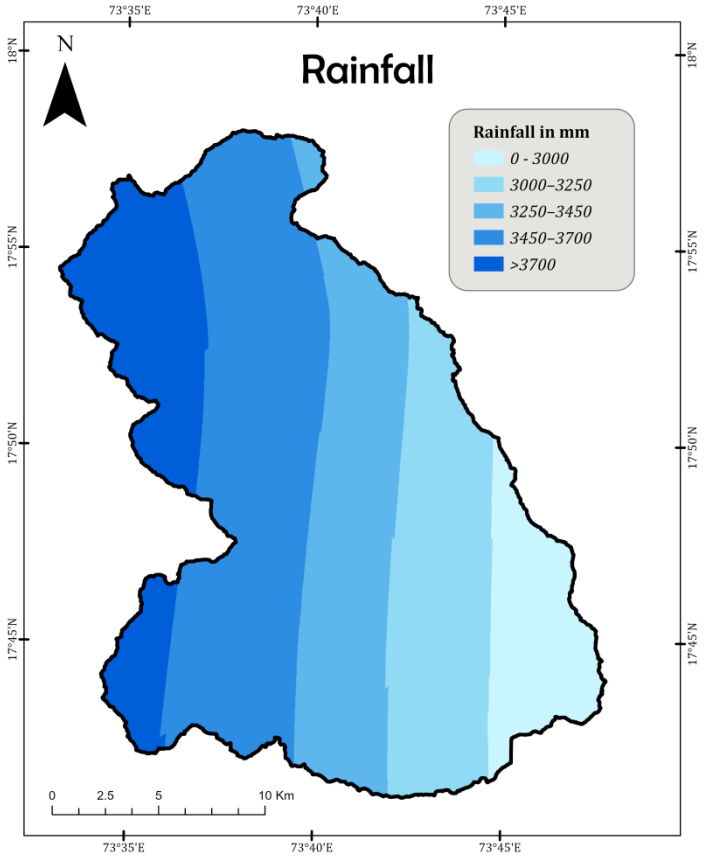

Fig. 10. Rainfall.

4 Frequency ratio model and susceptibility index

The FR of a class compares the share of landslides in that class with the share of the basin area it covers (Lee and Pradhan, 2007):

$FR_i = (NL_i / NL_t) / (NC_i / NC_t)$ (1)

where NL_i is the number of landslide points in class i, NL_t is the total number of landslide points, NC_i is the number of pixels in class i and NC_t is the total number of pixels. An FR above 1 means landslides are more common in that class than its area alone would suggest, and an FR below 1 means they are less common. The FR of each class was then normalized within its factor:

$FR_n = FR_i / FR_{max}$ (2)

where the denominator (FRmax) is the highest FR value among the classes of that factor, so the best class of every factor has a normalized value of 1. Each class was given its normalized FR value to make seven layers (Tables 2–8). These layers were added to give the landslide susceptibility index (LSI):

$LSI = \Sigma FR_n$ (3)

The LSI values were then sorted into five quantile classes, ranging from very low to very high. This gives classes of nearly equal area, as the 19.3–20.7% shares in Table 9 show.

5 Checking the map

The map was checked in two ways. First, each susceptibility class was described by its number and share of landslide points and by landslide density (points per km²). Second, a success rate curve was drawn, plotting cumulative landslide share against cumulative area share from the very high class downwards. The AUC condenses the curve into a single score; the nearer it is to 1, the better the map agrees with the landslides. As the same points both built and tested the model, the result is a success rate, not a prediction rate: it shows how well the map fits known landslides, not how well it would forecast new ones.

Results

1 Relationship between factor classes and landslides

Tables 2 to 8 give the area, the number of landslide points and the FR value of each class of the seven factors. Across the seven factors, the classes with the highest FR values were highly dissected plateau (1.55), 650–800 m elevation (1.86), 30–40° slope (2.08), SRI of 1.091–1.2 (1.99), TWI below 6 (1.36), evergreen/semi-evergreen forest (1.96) and rainfall above 3700 mm (1.61). Normalized FR (FR divided by the highest FR of that factor) is also shown.

2 Geomorphology

The highly dissected plateau is the only geomorphic unit with an FR above 1 (1.55). It covers 59.91% of the basin but holds 715 of the 771 landslide points (92.74%) (Table 2). The pediment–pediplain complex (FR 0.20) and the moderately dissected plateau (FR 0.24) have far fewer landslides than their area would suggest. The dam and reservoir unit and the other water bodies have no landslide points (FR 0). This is expected because the deeply cut plateau carries the steepest slopes and most exposed scarps, whereas the other units are gentler or covered by water.

Table 2. Frequency ratio of Geomorphology classes.

Class	Area (%)	Landslide points	Landslide points (%)	FR	Normalized FR
Waterbody - River	0.49	2	0.26	0.53	0.34
Pediment Pediplain Complex	18.89	29	3.76	0.20	0.13
Moderately Dissected Plateau	13.36	25	3.24	0.24	0.16
Waterbodies-Other	0.06	0	0.00	0.00	0.00
Dam and Reservoir	7.29	0	0.00	0.00	0.00
Highly Dissected Plateau	59.91	715	92.74	1.55	1.00

2 Elevation

The FR is highest (1.86) in the 650–800 m class, which holds 59.53% of the landslide points on 32.00% of the area (Table 3). The 800–950 m class is close to 1 (FR 1.06), and the 1100+ m class is just below it (0.94). The 950–1100 m class has an FR of 0.67 and the lowest elevations (0–650 m) have 0.24. Landslides thus gather at mid elevations, where the main valley sides are steep, and not on the high plateau tops or the low flat ground. Some of the landslides in this range lie close to the reservoir.

Table 3. Frequency ratio of Elevation (m) classes.

Class	Area (%)	Landslide points	Landslide points (%)	FR	Normalized FR
0–650	33.12	61	7.91	0.24	0.13
650–800	32.00	459	59.53	1.86	1.00
800–950	18.30	150	19.46	1.06	0.57
950–1100	9.23	48	6.23	0.67	0.36
1100+	7.35	53	6.87	0.94	0.50

3 Slope

FR is very low (0.09) on gentle slopes of 0–10°, which cover 32.82% of the basin but hold only 22 points (Table 4). It rises to 0.97 in the 10–20° class, to 1.99 in the 20–30° class and reaches its highest value (2.08) at 30–40°. In the steepest class (above 40°) the FR falls to 1.55. This fall may be because the steepest slopes cover only 1.50% of the basin and hold just 18 points. In general, slopes steeper than 20° are much more likely to fail in this basin.

Table 4. Frequency ratio of Slope (degrees) classes.

Class	Area (%)	Landslide points	Landslide points (%)	FR	Normalized FR
0–10	32.82	22	2.85	0.09	0.04
10–20	35.96	270	35.02	0.97	0.47
20–30	21.87	335	43.45	1.99	0.95

Class	Area (%)	Landslide points	Landslide points (%)	FR	Normalized FR
30–40	7.84	126	16.34	2.08	1.00
40+	1.50	18	2.33	1.55	0.74

4 SRI

Landslides are rare in the lowest SRI class (1.001–1.03; FR 0.21), which covers 47.79% of the basin (Table 5). The FR is above 1 in the next three classes: 1.55 for 1.031–1.09, 1.99 for 1.091–1.2 and 1.95 for 1.201–1.43. The highest class (1.431–3.2) has an FR of 0.62, but it covers only 0.42% of the basin and holds just two points, so this value is uncertain. In short, landslides are more common on moderately to strongly dissected ground.

Table 5. Frequency ratio of SRI classes.

Class	Area (%)	Landslide points	Landslide points (%)	FR	Normalized FR
1.001 - 1.03	47.79	79	10.25	0.21	0.11
1.031 - 1.09	30.33	362	46.95	1.55	0.78
1.091 - 1.2	16.60	255	33.07	1.99	1.00
1.201 - 1.43	4.86	73	9.47	1.95	0.98
1.431 - 3.2	0.42	2	0.26	0.62	0.31

5 TWI

The FR falls steadily as TWI increases. It is highest (1.36) in the driest class (Table 6), which holds 66.02% of the landslide points on 48.52% of the area. It is 0.80 in the 6–8 class, 0.55 in the 8–11 class and 0.12 in the 11–15 class, and there are no landslides where TWI is above 15. Low TWI occurs on steep, convex slopes that shed water quickly, and high TWI on flat valley floors and beside the reservoir. The pattern therefore reflects slope rather than any tendency of dry soil to fail.

Table 6. Frequency ratio of TWI classes.

Class	Area (%)	Landslide points	Landslide points (%)	FR	Normalized FR
<6	48.52	509	66.02	1.36	1.00
6-8	34.41	213	27.63	0.80	0.59
8-11	10.29	44	5.71	0.55	0.41
11-15	5.48	5	0.65	0.12	0.09
>15	1.29	0	0.00	0.00	0.00

6 LULC

Evergreen and semi-evergreen forest has the highest FR (1.96); it covers 29.86% of the basin but holds 451 landslide points (58.50%) (Table 7). Deciduous forest has an FR of 1.05, and scrub forest has 0.54. Scrub land (0.35), crop land (0.15) and river or stream channels (0.23) all have low values. Settlement, fallow land and barren rock have no landslide points, but each covers about 1% of the basin or less. Water bodies (8.19% of the basin) also have none, as expected. The high value for evergreen forest probably reflects where the forest grows (steep, wet western slopes) more than any effect of the trees, and it may also be shaped by how landslides were identified from imagery.

Table 7. Frequency ratio of LULC classes.

Class	Area (%)	Landslide points	Landslide points (%)	FR	Normalized FR
Scrub Forest	0.24	1	0.13	0.54	0.28

Class	Area (%)	Landslide points	Landslide points (%)	FR	Normalized FR
Evergreen / Semi evergreen	29.86	451	58.50	1.96	1.00
Deciduous	33.47	271	35.15	1.05	0.54
Settlement	1.03	0	0.00	0.00	0.00
Scrub land	10.77	29	3.76	0.35	0.18
Crop land	15.63	18	2.33	0.15	0.08
River / Stream / canals	0.56	1	0.13	0.23	0.12
Fallow	0.24	0	0.00	0.00	0.00
Water bodies	8.19	0	0.00	0.00	0.00
Barren rocky	0.01	0	0.00	0.00	0.00

7 Rainfall

The FR increases steadily with rainfall. It is only 0.01 in the driest class (below 3000 mm), 0.49 at 3000–3250 mm and 0.93 at 3250–3450 mm (Table 8). It rises above 1 at 3450–3700 mm (1.35) and is highest (1.61) in the wettest class (above 3700 mm). About 70.6% of all landslide points lie in the two wettest classes, which cover 49.2% of the basin. Rainfall is the only factor in which the FR rises in every step from the lowest class to the highest.

Table 8. Frequency ratio of Rainfall (mm) classes.

Class	Area (%)	Landslide points	Landslide points (%)	FR	Normalized FR
0–3000	10.15	1	0.13	0.01	0.01
3000–3250	19.41	74	9.60	0.49	0.31
3250–3450	21.21	152	19.71	0.93	0.58
3450–3700	33.02	343	44.49	1.35	0.84
3700+	16.20	201	26.07	1.61	1.00

Landslide susceptibility map

Fig. 11 presents the susceptibility map of the Upper Koyna River Basin. Very low ground occupies 20.1% (95.3 km²), low ground 20.4% (96.8 km²) and moderate ground 19.5% (92.5 km²). The high class occupies 20.7% (98.2 km²) and the very high class 19.3% (91.5 km²), so roughly 40% of the basin lies in the two top classes.

These upper classes sit mostly in the west and north-west and along the steep sides of the main valley. The gentler central valley, the reservoir and the eastern part belong largely to the two lowest classes. Moderate susceptibility forms narrow belts between the two (Fig. 11).

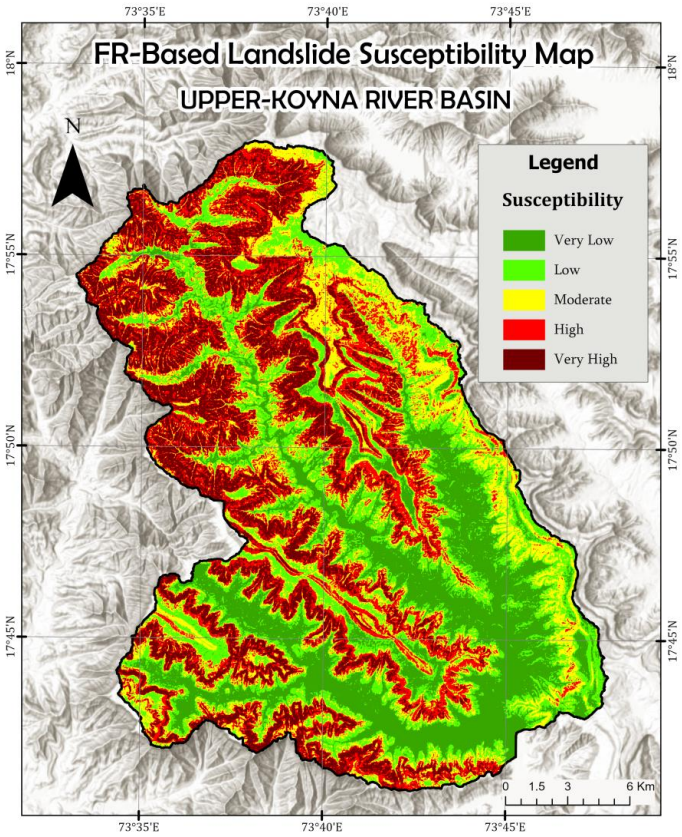

Fig. 11. Frequency ratio based landslide susceptibility map of the Upper Koyna River Basin.

Distribution of landslides and accuracy

Table 9 shows that most mapped landslides lie in the two top classes: 702 of the 771 points (91.1%) on 40.0% of the area. At the other end, the two lowest classes take up 40.5% of the basin yet hold only 10 points (1.3%). The FR value rises steadily from 0.01 in the very low class to 3.04 in the very high class, and landslide density rises from 0.02 to 4.94 points per km², against a basin average of 1.63. Density in the very high class is thus over 200 times that of the very low class.

Table 9. Area and landslide points in each susceptibility class.

Class	Area (%)	Area (km²)	Landslide points	Landslide points (%)	FR	Density (per km²)
Very low	20.1	95.3	2	0.26	0.01	0.02
Low	20.4	96.8	8	1.04	0.05	0.08
Moderate	19.5	92.5	59	7.65	0.39	0.64
High	20.7	98.2	250	32.43	1.57	2.55
Very high	19.3	91.5	452	58.63	3.04	4.94
Total	**100**	**474.3**	**771**	**100.0**	-	**1.63**

In the success rate curve (Fig. 12), the first 19.3% of the area, the very high class, already captures 58.6% of the landslides, so the curve climbs sharply. The AUC was 0.80 when calculated from the five susceptibility classes, which shows an acceptable fit between the map and the mapped landslides.

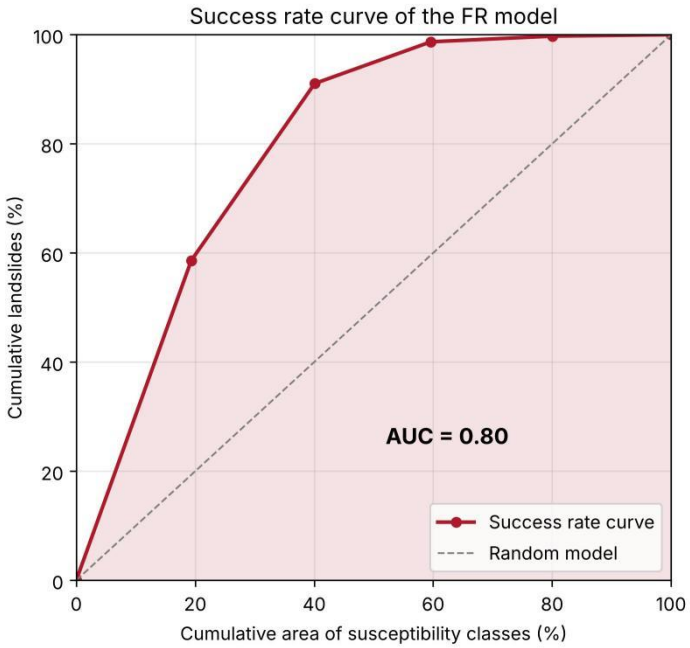

Fig. 12. Success rate curve of the FR model.

Discussion

1 Spatial pattern of susceptibility

The susceptibility pattern follows the terrain. Highly susceptible ground lies mainly in the west, the north-west and along steep valley sides, where the factor maps display highly dissected plateau, steep slopes and high SRI values (Figs. 4, 6 and 7). The western part also receives the most rainfall in the NASA POWER layer (Fig. 10), and many landslide points are clustered there (Fig. 3). In contrast, the central valley and the east have gentler slopes, lower SRI and less rainfall, and mostly belong to the very low and low classes. The TWI map shows high values only along the reservoir and the valley floors (Fig. 8). The FR tables support this pattern: 92.74% of the landslide points fall in the highly dissected plateau, 62.1% fall on slopes steeper than 20°, and 70.6% fall where rainfall is above 3450 mm. Landslide occurrence is therefore controlled mainly by terrain steepness and dissection, with rainfall adding to the risk in the wettest western part.

2 Comparison with earlier work

Earlier FR studies in the Western Ghats (Avinash et al., 2008; Patil et al., 2022) also link landslides to terrain and rainfall conditions. For the whole Koyna River Basin, Patil et al. (2024) compared SVM, FR and AHP models using 1,823 landslide events. They found that SVM performed best (AUC 0.87) and that high susceptibility occurred mainly in forested areas around the Koyna Wildlife Sanctuary, which agrees with the high FR of forest classes in this study. Because the study areas, inventories and factor classes differ, the class values cannot be compared directly. This study instead concentrates on the upper basin and examines each factor class in turn (Tables 2–8).

3 Use of the map

Local planners can use the map in three ways: to decide where new roads, buildings and farm terraces should be avoided or built with extra care; to select sites for slope protection, drainage works and pre-monsoon field checks; and to spot parts of the reservoir catchment where slope failures could add sediment to the lake. It shows relative susceptibility only and says nothing about the timing or size of future landslides, so it should be read together with rainfall warnings and local field knowledge.

4 Limitations

Several limits should be kept in mind. First, the same 771 points were used to build and to check the model, so the AUC is a success rate and may be higher than the true predictive skill. A future study should keep part of the points for testing. Second, the landslide points came from Google Earth imagery, so small landslides, and those hidden under dense forest, may be missing. Third, the NASA POWER rainfall layer is coarse (0.1°) and gives much lower values than those reported for Mahabaleshwar, so it cannot show local rainfall peaks on the windward slopes. Fourth, several factors (elevation, slope, SRI and TWI) come from the same DEM and may be related to each other, and no collinearity test was done. Fifth, the five classes were made with the quantile method, which gives classes of equal area whatever the true hazard is. Sixth, the reservoir and other water areas were kept in the analysis; they have no landslides and so lower the FR of the water classes and raise the share of area in the lower susceptibility classes. Finally, the FR model treats each factor on its own and adds the results, so it does not capture how factors act together.

Conclusion

This study mapped landslide susceptibility in the 474.24 km² Upper Koyna River Basin using the Frequency Ratio model, 771 landslide points and seven conditioning factors. The map has five classes of nearly equal area. Roughly 40% of the basin is classed as high or very high, and these zones hold 91.1% of the mapped landslides. Landslide density increases from 0.02 per km² in the very low class to 4.94 per km² in the very high class, and the success rate AUC was 0.80. High susceptibility is found mainly on the steep, deeply dissected western and north-western slopes and valley sides, where rainfall is highest. The classes with the highest FR values were highly dissected plateau, slopes of 30–40°, SRI of 1.091–1.2, 650–800 m elevation, evergreen and semi-evergreen forest and rainfall above 3700 mm.

The results are useful for planning and for choosing where to inspect slopes before the monsoon. They should be treated as relative susceptibility and not as a prediction of when or how large a landslide will be. Further work could validate the model with an independent landslide set, bring in rain-gauge or finer rainfall data, add factors such as soil, lineaments and distance to roads and streams, and test other methods against FR.

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Conflicts of interest

The authors declare that there are no conflicts of interest regarding the publication of thesis paper**.**

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