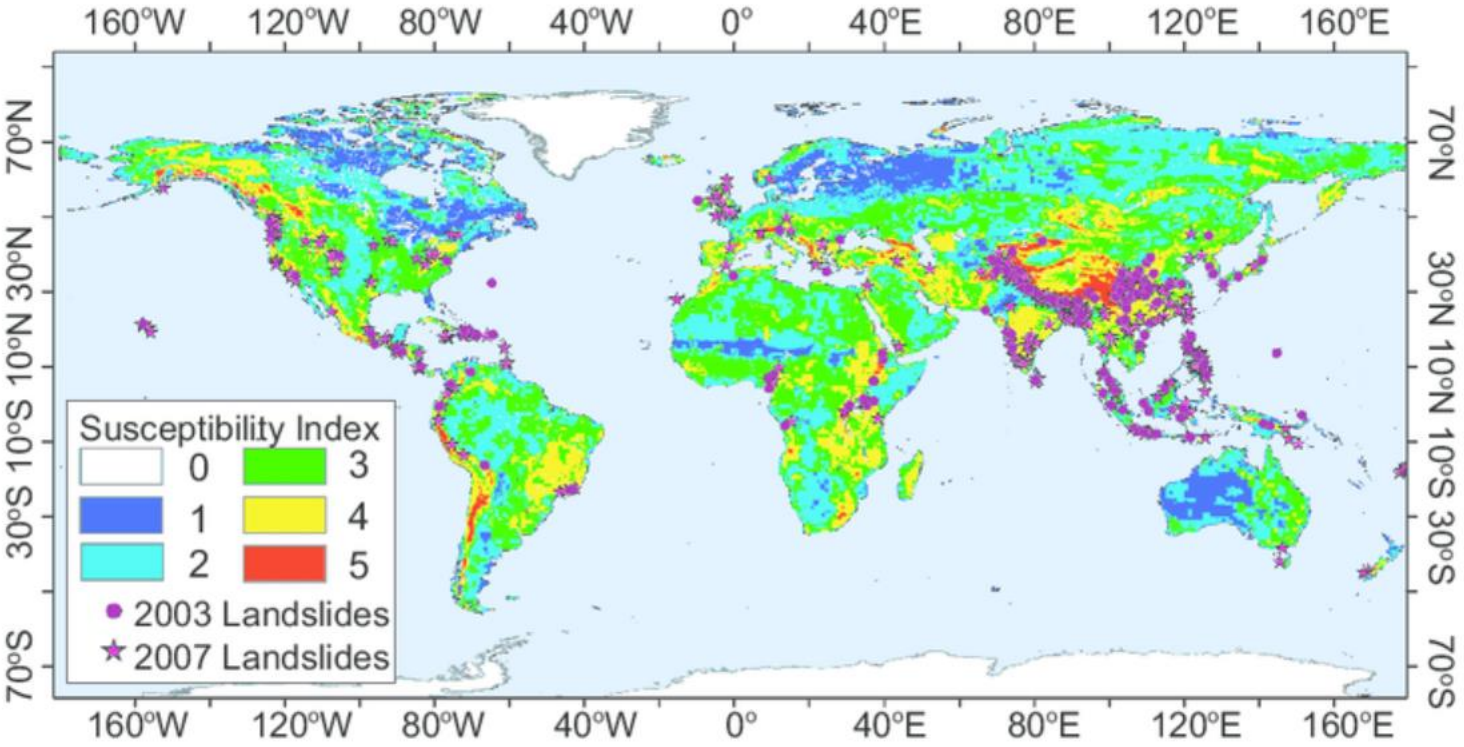
"Landslides during 2023 monsoon and Satark program"

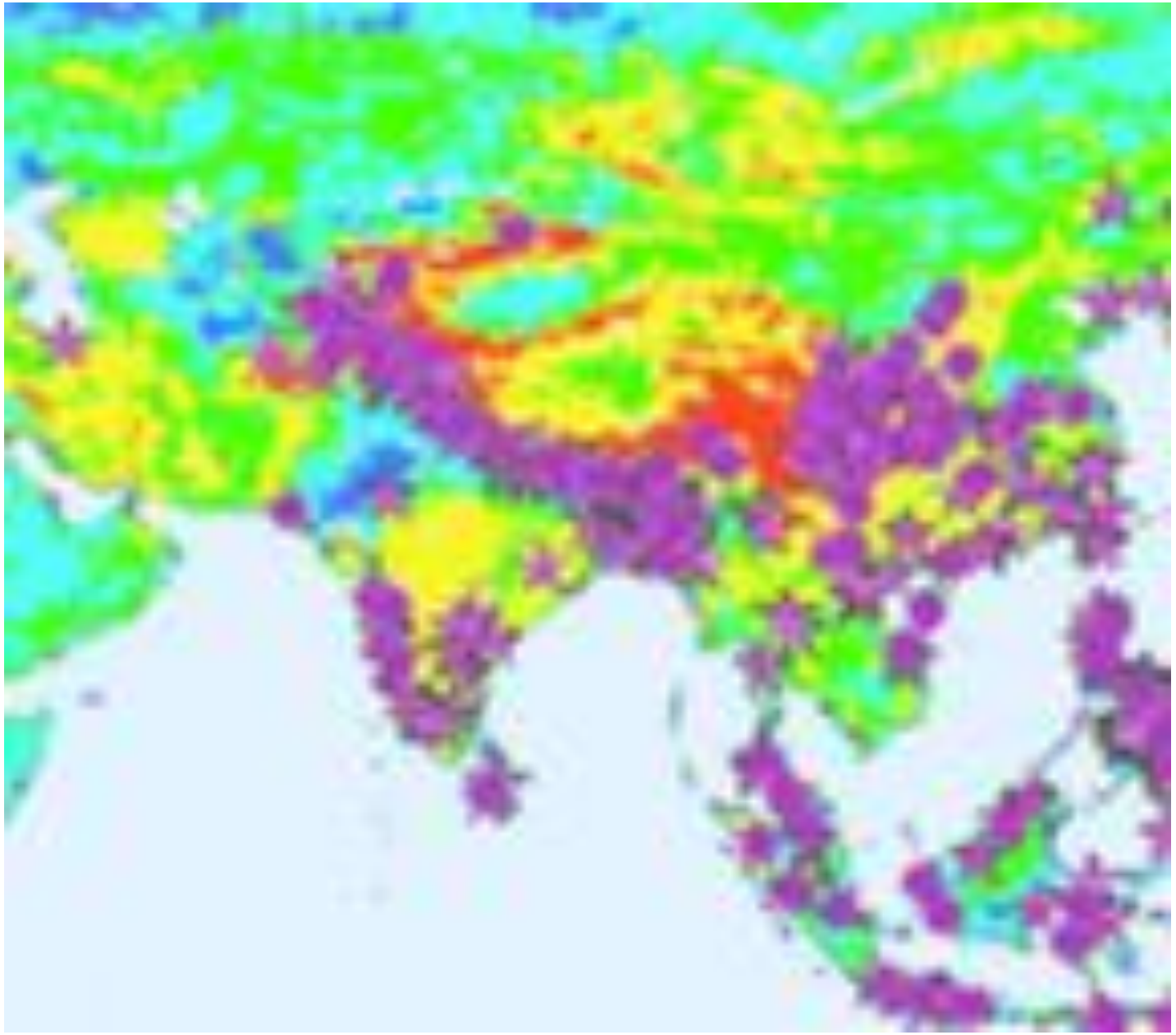
J. R. Kulkarni

weathermartsolutions.

IMSP conference, 18 March 2024



World Map of landslide susceptibility



Land slides prone areas over India. 1) western Ghats and Himalayan region

Aug 22, 2023

Falling in seismic zone IV and highly vulnerable to landslides, Shimla saw over 100 buildings suffering damage or collapsing during recent incessant rains, with experts attributing it to water saturation in soil, construction on drains, seepage and overburdening

c

Himachal Pradesh Rains Landslides ...

Himachal suffered loss of ₹10,000 cr; ...

Land slides in India in the year 2023

- August 12-13, 2023, Shimla, landslides, 57 people died.
- 24 August 2023, Anni land-slide in Himachal Pradesh, district Kulu.
- 14-15 August 2023 at Mandi and Simla.
- Biggest Land slide in India occurred on 18 August 1998 at Malpa in Pittorgarh district.
- Rudraprayag is having has 147 vulnerable sites. The highest LS density

The **Malpa landslide** was one of the worst landslides in India.
On 18 August 1998 at 3.00 a.m., massive landslide wiped away the entire village of Malpa in the Pithoragarh district of Uttarakhand, then in Uttar Pradesh in Kali Valley of Higher Kumaon division of the Himalayas.

The rockfall started on 16 August bringing down huge rocks which initially killed three mules.
A total of 221 people died, including 60 Hindu pilgrims travelling to Tibet as part of "Kailash Manas Sarovar Yatra". One noted death was that of the Indian dancer Protima Bedi.
The rockfall continued till 21 August.

Landslide-Hit Krishna Nagar In Shimla ...

Dozens dead as floods, landslides hi...

Landslide hits Shimla's Summer Hill, 20...

Himachal rains: Over 50 killed in landsli...

Shimla on shaky ground, caution stru...

Land slide prone areas in India

Landslide Prone Areas	States & Cities
Western Himalaya	Himachal Pradesh, Jammu & Kashmir, Uttar Pradesh, Uttaranchal
Eastern & North-Eastern Himalaya	West Bengal, Arunachal Pradesh, Sikkim
Naga-Arakan Mountain belts	Tripura, Nagaland, Mizoram, Manipur
Western Ghat region & Nilgiri	Kerala, Karnataka, Tamil Nadu, Maharashtra, Goa
Meghalaya Plateau comprising Peninsular India	The north-eastern part of India

On 30 July 2014, an LS occurred in the village of Malin (19.16° N, 73.68° E) in the Ambegaon Taluka of the Pune district in Maharashtra,

A total of 151 people died

Two representative examples of disastrous LS events which occurred due to high rainfalls

(1) Ghatkopar (19.08° N, 72.91° E) LS event on 12 July 2000. Ghatkopar is a suburb in the thickly populated city of Mumbai. Total of 78 people died. The 24-h rainfall was 350 mm.

(2) The Jui (18.0° N, 73.4° E) LS event on 25 June 2005. Jui is a village in Mahad district on the west coast of Maharashtra. Three villages in the surrounding area were completely buried. The number of reported human deaths was 48.

Lack of studies regarding LS

LS events were overlooked by the citizens, media, and government authorities and did not attract serious attention from the geological and meteorological community in India.

Therefore, studies regarding LS events over the WG region are almost non-existent before the Malin event.

Impact

- After the Malin LS incident, the Geological Survey of India (GSI) initiated an action to identify LS-prone sites in the WG.
- The Malin LS event was an eye-opener for taking a serious note about the impacts of LS events.
- It raised concerns about the safety of the people residing in such LS-prone areas.

In recent years frequency of extreme events has increased due to climate change impact

Vulnerable LS-prone areas have increased many times in the WG region due to increased anthropogenic activities, such as deforestation, improper land use planning, and road and building constructions on hillslopes.

These have exposed people residing in such vulnerable areas to more losses and deaths in recent times.

Demand increased in all the sections of society for identifying LS-prone areas

if possible, an early warning system of LS occurrences over the WG region.

The early warning system is considered to be a proactive measure in reducing the death toll by evacuating the people staying in vulnerable areas.

The factors which trigger LSs

1) preparatory variables and (2) dynamic triggering.

Preparatory variables include topography, tectonics, geological history of the region, land use, anthropogenic activities such as deforestation, terracing of the hills for agriculture, and construction activity.

Dynamic variables Heavy rainfall, earthquake, and coastal erosion

Earthquake phenomenon shows no regularity and is therefore impossible to predict well in advance. The LS events occur due to coastal erosion during the landfall of a cyclonic storm on the coast.

The cyclonic systems form over the Indian region in pre-monsoon (April–May), sometimes in the early part of June, and post-monsoon (October–November) seasons.

Therefore, in non-seismic and noncyclonic conditions, rainfall activity in the monsoon season is the most common trigger re-responsible for LS occurrences

Mechanisms

LS occur:

(a) In high rainfall cases, the rainwater percolates in the soil layer covering rock. After soil is saturated by rainwater, some rainwater drains out through the channels in the rocks and soil cover.

(b) In some cases, if the channels on surface are open, then rainwater drains out easily, forming waterfalls.

Percolated rainwater to the bottom of the soil layer forms a thin layer of mud between the rock's surface and soil resting on the rock. This decreases the frictional force between the two. The frictional force keeps the layer of deep soil in stable conditions on the surface of the rock.

The shear strength at a point on the slope depends upon (1) the cohesive force of the material and (2) the total stress on the hill-slope, which is proportional to the weight of pore-water.

When the total weight of a volume of saturated soil exceeds the shear strength of rock, a sliding force is generated, overcoming the geological resisting force to trigger Land Slide.

The thick vegetation and roots of big trees hold the soil together in stable conditions against the sliding force

At Malin, the soil thickness was 10 m.

An important factor that was responsible for the LS in the Malin case terracing of the hill-slope for agriculture activity.

The soil and rocky material after terracing were dumped on the slopes.

This choked the natural drainage channels and caused obstructions to the free flow of the rainwater.

All the rainwater percolated in the soil 10 m deep. This destabilized the slope, resulting in the LS.

“rainfall-intensity-duration (RID)” for triggering LS.

Santa Cruz Mountains, California.

San Francisco Bay

North Island of New Zealand

Central and Southern Europe.

Land slide susceptibility

- Parameters causing Land slide are
- (1) slope, (2) soil type, (3) soil texture, (4) elevation, (5) land cover, and (6) drainage density.

India lies in the top-ranked countries based on a number of LS-related fatalities

Global land slide atlas (GLC)

In India, studies related to LS events do not come under the roof of one department of government agencies as they occur due to combined meteorological and geological forcings.

Therefore, neither the IMD nor India's geological department has a dedicated group or unit to systematically gather and archive LS data and predict LS activity

Land slide prediction

TRMM Multi-satellite Precipitation Analysis (TMPA) rainfall data at 0.250 × 0.250 km 3-h intervals have shown promise in predicting LS events using satellite rainfall data.

In the world algorithms for LS predictions were developed using LS susceptibility and satellite-derived rainfalls.

Landslide Hazard Assessment for Situational Awareness

In India, a good number of LS studies are carried out in geography and geological departments of universities,
however, these are scattered.
The studies regarding predictions of Land Slide events are lacking in India.

Association of Engineering Geology (IAEG) Commission on
Land Slides to compile a list of worldwide LS events for UNESCO annual summary of information on natural disasters in 1971

Asia records the highest number of LSs, and a substantial number are in the Himalayan region

Land slide prediction system

Objectives:

(1) Prepare LS inventory over the WG region to find a place in Global Landslide Catalog (GLC).

(2) To develop the real-time LS forecasting system “Satark”.

Center for citizen Science, Pune (CCSP)

- CCS is an international movement
- CCSP chapter at Pune has been estabilshed

To Involve citizens in advancement of science.

Jeevan R. Kulkarni [1,*], Sneha S. Kulkarni [1], Mitali U. Inamdar [1], Nitin M. Tamhankar [1], Spandan B. Waghmare [1], Kiran R. Thombare [1], Paresh S. Mhetre [1], Tanuja Khatavkar [1], Yashodhan Panse [1], Amey Patwardhan [1], Yogini Soman [1], Prasad Bhagat [1], Sumit Bhale [1], Mayuresh G. Prabhune [1] and Vinay Kumar [2]

CCSP

- Completed nearly 50 projects and received many awards
- Some of the completed projects are:
- Study of Ganga water pollution
- Lonar lake preservation
- Biodiversity over Western Ghats
- Identification of new variety of mushroom in Western Ghat section
- Site seeing tours to scientific important places.
- Setting of AWS in different parts of Maharashtra as a part of weather awareness activity.

What is citizen science?

Citizen science is a broad term for scientific investigation activities which are undertaken with the general public. The public (i.e. the 'citizens') participate, with scientists, to collect, categorise, transcribe, analyse, and report data.

Citizen science may be known under different names, such as community science, participatory assessment, community-based monitoring, volunteer biological monitoring, etc.

Citizen science has its roots in the physical sciences. Today, citizen science projects engage in different fields including ecological restoration, water monitoring, conservation, meteorology, public health, telecommunications, disaster response and climate change.

CCSP activity

- Open to all irrespective of age, qualification, experience, education.
- Voluntary organization, no monetary assistance.
- Structure: Basic course to introduce societal issues which need studies. Photography, documentation, internet radio station, cloud computing etc.

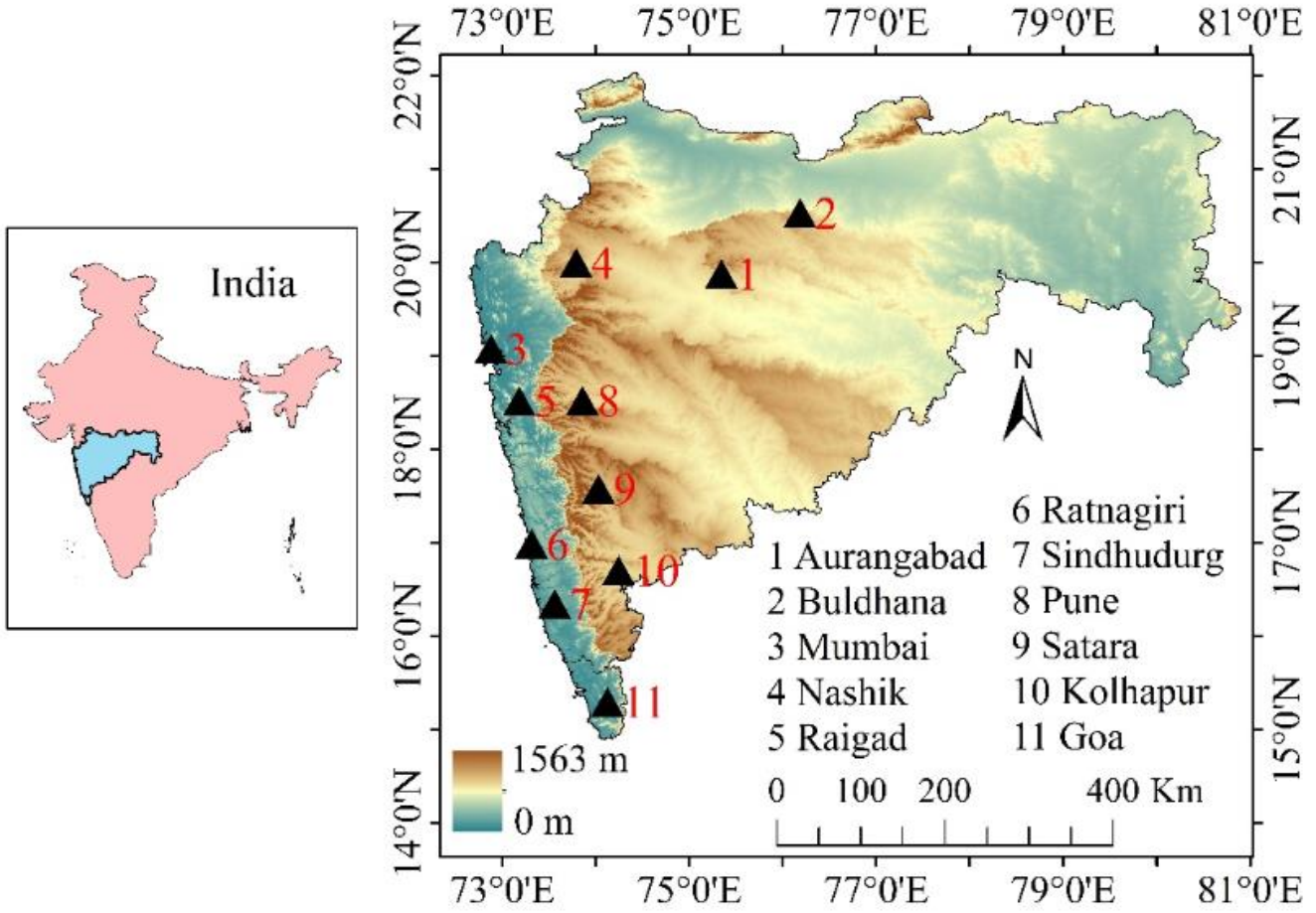


Figure 3. Topography of the WG mountains. Location of cities in six subareas of Maharashtra state was considered in the study.

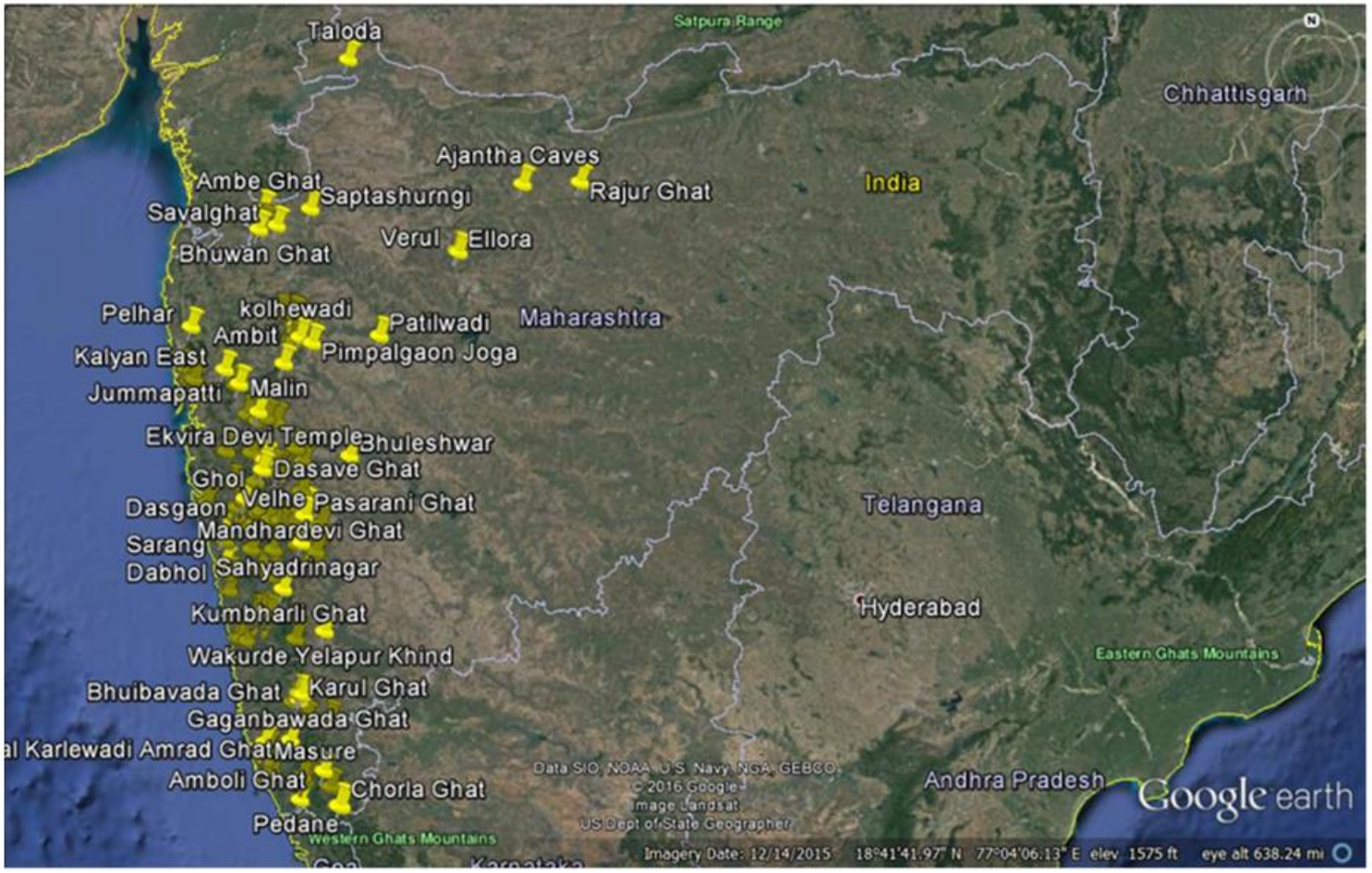

Taloda
Satpura Range
Chhattisgarh
Ajantha Caves
Ambe Ghat
Saptashurngi
Rajur Ghat
India
Savalghat
Verul
Ellora
Bhuwan Ghat
Pelhar
kolhewadi
Patilwadi
Maharashtra
Ambit
Kalyan East
Pimpalgaon Joga
Jummapatti
Malin
Ekvira Devi Temple
Bhuleshwar
Ghol
Dasave Ghat
Dasgaon
Velhe
Pasarani Ghat
Telangana
Mandhardevi Ghat
Sarang
Dabhol
Sahyadrinagar
Hyderabad
Kumbharli Ghat
Eastern Ghats Mountains
Wakurde Yelapur Khind
Bhuibavada Ghat
Karul Ghat
Gaganbawada Ghat
Karlewadi Amrad Ghat
Masure
Amboli Ghat
Chorla Ghat
Andhra Pradesh
Pedane
Western Ghats Mountains
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
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Image Landsat
US Dept of State Geographer
Google earth
Imagery Date: 12/14/2015 18°41'41.97" N 77°04'06.13" E elev 1575 ft eye alt 638.24 mi

No.	Site and location in Bracket	Latitude N	Longitude E
1	Ajanta caves (DLS)	20°33′6.84″	75°4′13.26″
2	Ellora caves (DLS)	20°1′32.88″	75°10′40.8″

No.	Site and Location in Bracket	Latitude N	Longitude E
1	Saptshrungi (ILS)	20°18′0″	73°54′0″
2	Ambe Ghat (DLS)	18°6′0″	75°18′0″
3	Savil Ghat (ILS)	17°54′0″	74°18′0″
4	Bhuwan Ghat (ILS)	17°48′0″	74°12′0″
5	Pimplegaon Joga (ILS)	19°18′0″	73°54′0″
6	Ambit Ghat (DLS)	18°6′0″	75°18′0″
7	Rajur Ghat (ILS)	19°12′0″	73°48′0″
8	Pelhar (ILS)	17°42′0″	74°6′0″
9	Taloda (ILS)	21°33′46.08′′	74°12′48.6′′

No.	Site and Location in Bracket	Latitude N	Longitude E
1	Kalyan (ILS)	19°12′0″	73°6′0″
2	Jummapatti (ILS)	19°1′22.8′	73°19′3″
3	Antop Hill (ILS)	19°0′0″	72°54′0″
4	Malin (ILS)	19°12′0″	73°42′0″
5	Karla (ILS)	18°48′0″	73°30′0″
6	Velhe (ILS)	18°12′0″	73°36′0″
7	Katraj Pune (ILS)	18°27′10.44″	73°51′54.72″
8	Sinhgad (ILS)	18°21′58.68″	73°45′21.24″
9	Malshej Ghat (ILS)	19°20′26.16″	73°46′28.56″
10	Matheran (windward)	18°59′19.32″	73°16′16.32″
11	Urse khind (ILS)	18°44′15.36″	73°40′28.92″
12	Adoshi Tunnel (ILS)	18°49′50.16′	73°17′4.56″
13	Lonawale (windward)	18°45′20.52″	73°24′32.76″
14	Khopoli (ILS)	18°47′38.04″	73°20′4.56″
15	Fosandi (ILS)	19°5′41.28″	74⁰.74′ 80.0″
16	Ghatkopar (windward)	19°4′44.4″	72°54′28.8″
17	Chembur (windward)	19°3′7.92″	72°54′1.8″
18	Gibert Hill (windward)	9°6′48.96″	72°52′10.92″
19	Panjarpol (windward)	19°2′33.72″	72°54′36.72″
20	Lavasa (windward)	18°24′34.92″	73°30′23.76″
21	Male (windward)	18°8′44.96″	73°50′34.73′
22	Ghatghar (windward)	19°17′41.28″	73°42′23.76″
23	Tikona (windward)	18°37′54.48″	73°30′46.08″
24	Varandha Ghat(ILS)	18°8′44.88″	73°50′34.8″

No.	Site and Location in Bracket	Latitude N	Longitude E
1	Sukeli Khind (windward)	18°28′11.72″	73°11′40.80″
2	Rohan (windward)	18°4′37.13″	73°20′50.03″
3	Jui (windward)	18°4′17.23″	73°20′57.26″
4	Dasgaon (windward)	18°6′0.64″	73°21′18.47″
5	Poladpur (ILS)	17°59′4.18″	73°27′48.27″
6	Cholai (ILS)	17°58′17.56″	73°27′46.75″
7	Wazarwadi (ILS)	17°59′51.91″	73°29′39.94″
8	Kashedi Ghat (ILS)	17°54′19.18″	73°26′4.83″
9	Morbe Ghat (windward)	18°12′53.24″	73°14′55.77″
10	Raigad Fort (ILS)	18°14′4.81″	73°26′45.23″
11	Chirekhind (ILS)	17°56′5.91″	73°33′52.98″
12	Ambenali Ghat (ILS)	17°55′57.63″	73°33′4.98″
13	Mahabaleshwar (ILS)	17°55′45.69″	73°39′1.31″
14	Ruighar Ghat (ILS)	17°55′24.48″	73°46′48.18″
15	Pratapgad (ILS)	17°56′8.50″	73°34′43.08″
16	Kudpan (ILS)	17°52′58.16″	73°32′23.39″
17	Chikhali (ILS)	17°52′4.47″	73°41′6.95″
18	Medha Ghat (ILS)	17°52′12.12″	73°45′2.10″
19	Sahyadrinagar (ILS)	17°45′25.36″	73°49′58.15″
20	Kosumbi (ILS)	17°45′34.03″	73°48′36.65″
21	Kolghar (ILS)	17°44′35.81″	73°47′15.57″
22	Andhari (ILS)	17°43′39.31″	73°47′24.60″
23	Pasarani Ghat (ILS)	17°58′6.38″	73°51′35.00″
24	Shirgaon Ghat (ILS)	17°54′2.52″	74° 0′1.77″
25	Mandhardevi Ghat (ILS)	18° 2′50.61″	73°51′35.12″
26	Tapola (ILS)	17°45′52.03″	73° 44′ 28.32″
27	Yavateshwar Ghat (ILS)	17°41′17.27″	73° 57′ 2.52″
28	Pogarwadi (ILS)	17°38′22.75″	73°56′38.93″
29	Revade Ghat (ILS)	17°35′42.78″	73° 10′ 55.92″
30	Lamaj and nearby villages (ILS)	17°45′35.64″	73°39′34.85″
31	Chirekhind (ILS)	16°10′53.8356″	73°44′52.0296″
32	Medha Ghat (ILS)	17°47′39.48″	73°49′59.16″
33	Chiplun (windward)	17°31′54.84″	73°24′54.36′

Sr. No.	Site and Location (in Bracket)	Latitude	Longitude
1	Madangad (ILS)	17°59′0.63″ N	73°14′59.86″ E
2	Kelwat Ghat (ILS)	17°57′36.54″ N	73°16′45.11″ E
3	Chinchali Ghat ILS	18° 1′52.37″ N	73°17′11.99″ E
4	Sarang (ILS)	17°48′33.12″ N	73°10′15.61″ E
5	Dapoli (winward)	17°45′31.99″ N	73°11′11.55″ E
6	Harnai Road (wind-ward)	17°48′23.57″ N	73° 6′26.88″ E
7	Dabhol (windward)	17°35′18.45″ N	73°10′32.20″ E
8	Khed (windward)	17°43′10.39″ N	73°23′48.53″ E
9	Bhoste Ghat (windward)	17°42′9.86″ N	73°24′25.92″ E
10	Raghuveer Ghat (ILS)	17°41′59.12″ N	73°35′43.88″ E
11	Tulashi Bk (windward)	17°52′10.33″ N	73°23′23.96″ E
12	Gowalkot (ILS)	17°32′44.65″ N	73°29′15.71″ E
13	Chinchghari (ILS)	17°29′38.11″ N	73°34′5.09″ E
14	Kumbharli Ghat (ILS)	17°23′29.98″ N	73°40′33.16″ E
15	Kumbharkhani (ILS)	17°13′9.43″ N	73°30′41.19″ E
16	Sangmeshwar (ILS)	73°27′33.68″ E	73°33′18.22″ E
17	Manjare (ILS)	17°11′27.57″ N	73°26′8.82″ E
18	Pangri Ghat (ILS)	17°3′28.71″ N	73°28′2.26″ E
19	Kurdhunda (ILS)	17°9′21.12″ N	73°29′51.21″ E
20	Kondye (ILS)	17°11′20.79″ N	73°27′33.68″ E
21	Kolambe (ILS)	17°7′29.00″ N	73°30′10.65″ E
22	Pethkilla (windward)	16°59′41.36″ N	73°16′43.49″ E
23	Pomendi Ghat (wind-ward)	16°58′42.03″ N	73°22′5.33″ E
24	Ratnagiri (windward)	16°59′28.47″ N	73°18′41.50″ E
25	Amba Ghat (ILS)	16°59′50.58″ N	73°46′28.47″ E
26	Wakurde Yelapur Khind (windword)	17°3′34.96″ N	74°1′16.91″ E
27	Aini (windward)	16°21′53.33″ N	74°2′52.40″ E
28	Karul Ghat (ILS)	16°30′42.02″ N	73°48′6.83″ E
29	Mahad (windward)	18°4′59.49″ N	73°25′20.40″ E
30	Varkude Yelapa (ILS)	16°51′8.64′′ N	74°34′53.4′′E

Sr. No.	Site and Location (in Bracket)	Latitude	Longitude
1	Gaganbawada Ghat (ILS)	16°33′27.61″ N	73°49′32.31″ E
2	Bhuibawada Ghat (ILS)	16°33′48.70″ N	73°47′55.66″ E
3	Karul Ghat (ILS)	16°30′42.02″ N	73°48′6.83″ E
4	Vaibhavwadi (ILS)	16°29′47.01″ N	73°44′45.39″ E
5	Phonda Ghat (ILS)	16°21′30.13″ N	73°50′49.36″ E
6	Malsure (ILS)	16°10′19.03″ N	73°30′6.37″ E
7	Bilwas (ILS)	16° 7′13.31″ N	73°31′15.42″ E
8	Devali (ILS)	16° 1′39.58″ N	73°30′0.63″ E
9	Kasal Karlewadi Amrad Ghat (ILS)	16°11′32.17″ N	73°43′15.68″ E
10	Sawantwadi (ILS)	15°54′12.18″ N	73°48′57.22″ E
11	Insuli Ghat (ILS)	15°52′21.26″ N	73°50′12.58″ E
12	Pedane (ILS)	15°42′57.65″ N	73°47′33.82″ E
13	Pargad Namkhol Road (DLS)	15°49′28.14″ N	74° 2′56.40″ E
14	Amboli Ghat (ILS)	15°57′1.13″ N	73°59′50.66″ E
15	Chorla Ghat (DLS)	15°38′59.31″ N	74° 7′6.69″ E
16	Chandgad (ILS)	15°56′44.14″ N	74°10′31.17″ E
17	Malwan (ILS)	16°3′47.16″ N	73°28′15.96″ E

Table 7. Rainfall-triggered landslides over the WG region from 2000 to 2016. Date (date/month/year), location, latitude/longitude of the LS location, rainfall, and major losses.

No.	Date	Location	Lat N, Long E	Rainfall	Major Losses
1	12/7/2000	Ghatkopar, Mumbai	19.08 N, 72.91 E	350 mm/24 hr	78 people died
2	23/6/2003	Vaibhavwadi, Sindhudurga District	16.50 N, 73.74 E	346.7 mm/7 days	23 People died
3	25/6/2005	Jui, Mahad	18.03 N, 73.36 E	476.0 mm/168 hrs	3 villages buried, 48 people died
4	31/5/2006	Ratnagiri	17.25 N, 73.37 E	210 mm/day	4 people died
5	3/09/2012	Taloda District, Nandurbar	21.56 N, 74.21 E	381 mm/7 days	8 people died
6	25/09/2012	Chembur, Mumbai	19.05 N, 72.9 E	Not available	Not available
7	17/06/2013	Ratnagiri	17.25 N, 73.37 E	256.2 mm/7 days	No injuries
8	10/07/2013	Antop Hill, Mumbai	19.03 N 72.87 E	Not available	5 people buried
9	22/08/2013	Panjrapol, Mumbai	19.04 N 72.91 E	Not available	Not available
10	30/07/2014	Malin, Pune district	19.00 N, 73.93 E	215 mm/7 days	160 people and 1 village buried
11	31/07/2014	Chembur, Mumbai	19.03 N 72.89 E	Not available	1 child died
12	12/06/2015	Gilbert Hill, Andheri West, Mumbai	19.12 N 72.84 E	Not available	Not available
13	2/06/2015	Kalyan-Nagar Road	19.09 N, 74.74 E	340 mm/7 days	Not available
14	23/06/2015	Ekvira Devi Temple, Karla	18.47 N 73.28 E	128 mm/7 days	5 deaths
15	23/06/2015	New Katraj Highway	18.45 N 73.87 E	39 mm/7 days	Highway block
16	23/06/2015	Malshej Ghat	19.34 N 73.77 E	287 mm/7 days	Highway block
17	19/07/2015	Adoshi Tunnel, Lonavla	18.44 N 72.28 E	462 mm/7 days	Highway block
18	18/09/2015	Saptashringi Gad, Nashik	20.39 N 73.90 E	136 mm/7 days	Road block
19	4/10/2015	Ellora Caves, Aurangabad	20.02 N, 75.17 E		No loss

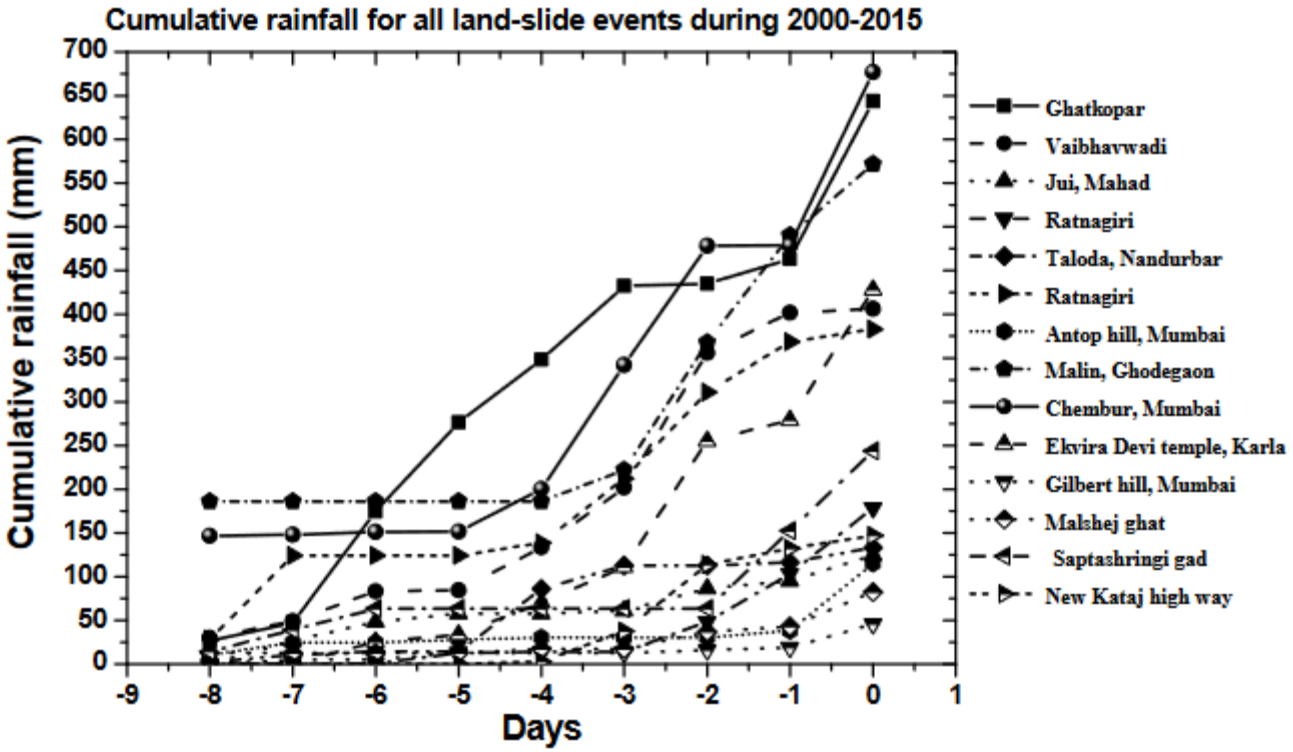
20	1/07/2016	Ambenali Ghat	17.97 N 73.03 E	343.2 mm/7 days	Road block
21	2/07/2016	Sukeli Khind	18.31 N 73.51 E	480 mm/7 days	Rockfall, traffic Jam
22	2/07/2016	Yawateshwar Ghat	17.68 N, 73.95 E	29.2 mm/7 days	No loss
23	3/07/ 2016	Malshej Ghat	19.34 N 73.77 E	70 mm/7 days	Road block
24	3/07/2016	Matheran	18.99 N 73.27 E	576 mm/7 days	Unknown
25	3/07/2016	Urse Khind	18.73 N, 73.67 E	184 mm/7 days	Intense rockfall
26	4/07/2016	Vakurde Yalapur	14.96 N, 74.71 E	618 mm/7 days	Mudflow
27	4/07/2016	Tapola- Mahable-shwar	17.92 N 73.66 E	736 mm/7 days	Unknown
28	7/07/2016	Medha- Marli Ghat	17.79 N, 73.83 E	300 mm/7 days	Unknown
29	9/07/2016	Malshej Ghat	19.34 N 73.77 E	352 mm/7 days	1 death
30	9/07/2016	Sawantwadi	15.90 N 73.82 E	454 mm/7 days	Unknown

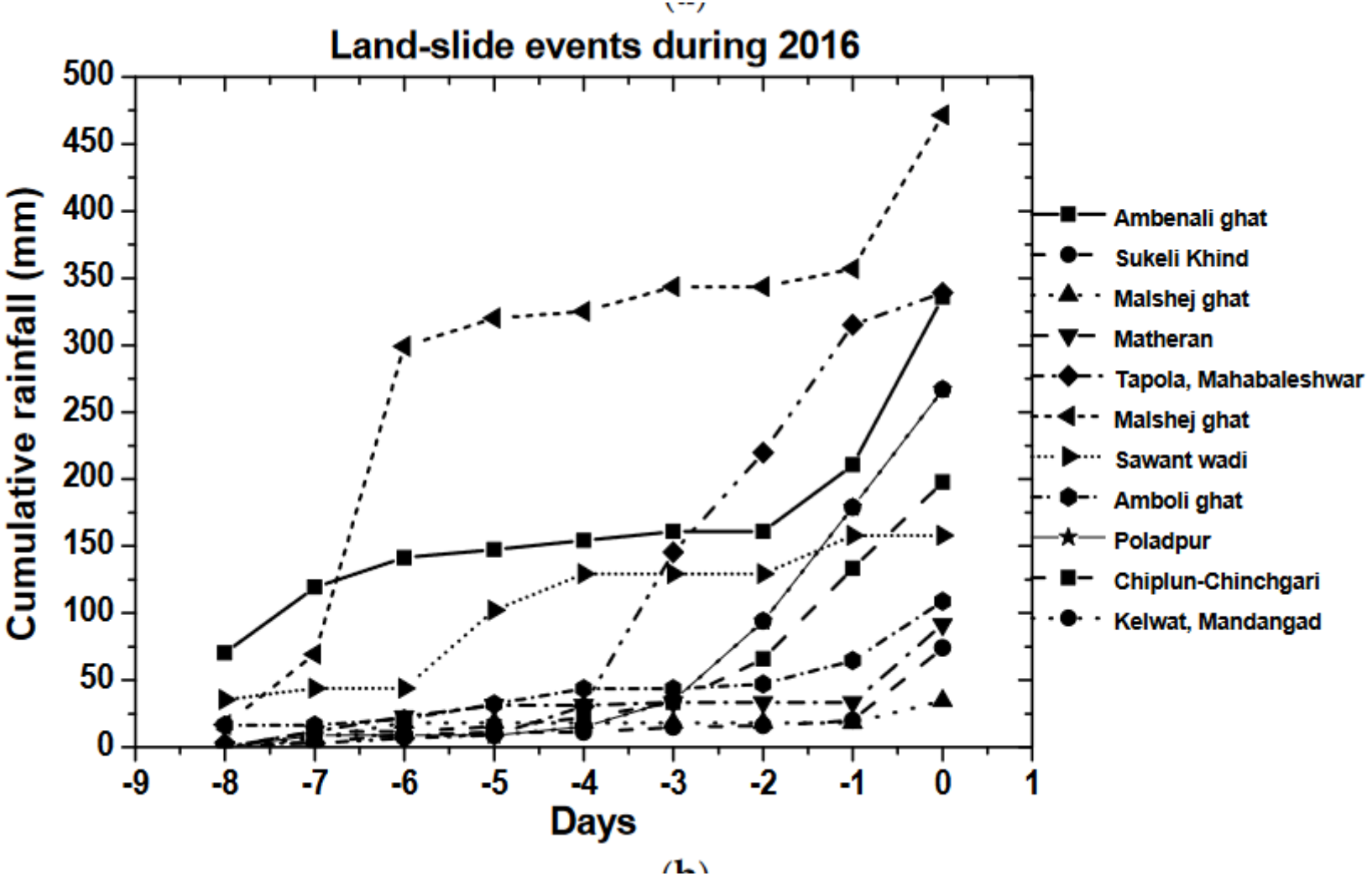
31	9/07/2016	Phosandi	16.99 N, 73.31 E	195 mm/7 days	Unknown
32	11/07/2016	Karul Ghat	16.373 N, 73.79 E	396 mm/7 days	Unknown
33	1/08/2016	Amboli Ghat	15.94 N 73.99 E	346 mm/7 days	Unknown
34	1/08/2016	Poladpur	17.98 N 73.47 E	283 mm/7 days	Debris on truck
35	1/08/2016	Chiplun- Chinchgari	17.53 N 73.52 E	324 mm/7 days	Unknow
36	1/08/2016	Swarde	16.81 N, 74.35 E	346 mm/7 days	Unknown
37	1/08/2016	Rajur Ghat	19.24 N, 73.80 E	50 mm/7 days	Trees on roads with mud
38	1/08/2016	Kelwat Mandangad	17.99 N 73.26 E	387 mm/7 days	Unknown
39	1/08/2016	Ambenali Ghat	17.97 N 73.03 E	285.4 mm/7 days	Road block
40	1/08/2016	Sukedi khind	16.88 N, 73.81 E	351.8 mm/7 days	Unknown
41	1/08/2016	Chir khind	18.87 N, 73.05 E	319 mm/7 days	Unknown
42	1/08//2016	Mandherdevi, Bhor	17.68 N 73.99 E	30.2 mm/7 days	No loss
43	2/08/2016	Saptashringi, Nashik	20.39 N 73.90 E	10 mm/7 days	Loose soil, rocks on road
44	2/08/2016	Chorla Ghat	15.64 N, 74.11 E	469 mm/7 days	Unknown
45	4/08/2016	Karlewadi	18.40 N, 74.68 E	248 mm/7 days	Rocks on houses
46	4/08/2016	Malshej Ghat	19.34 N 73.77 E	298.1 mm/7 days	Unknown
47	4/08/2016	Lavasa, Pune	18.40 N 73.51 E	542 mm/7 days	Unknown
48	4/08/2016	Varandha Ghat, Bhor	18.11 N 73.66 E	249 mm/7 days	Unknown
49	6/08/2016	Kelghar, Satara	17.69 N 74.06 E	713 mm/7 days	Unknown
50	6/08/2016	Ambenali Ghat	17.97 N 73.03 E	>500 mm/7 days	Road block
51	6/08/2016	Kashedi Ghat	17.90 N 73.43 E	600 mm/7 days	Unknown
52	7/08/2016	Gaganbawda Ghat	16.54 N 73.83 E	543 mm/7 days	Unknown
53	7/08/2016	Bhuiwada	19.00 N 72.85 E	358 mm/7 days	Unknown
54	7/08/2016	Karul Ghat	16.37 N, 73.79 E	419 mm/7 days	Unknown

Temporal Distribution of Land slide events

June	July	August	September
15%	74%		10%

second mechanism discussed above.




Land-slide events during 2016
Cumulative rainfall (mm)
500
450
400
350
300
250
200
150
100
50
0
-9
-8
-7
-6
-5
-4
-3
-2
-1
0
1
Days
Ambenali ghat
Sukeli Khind
Malshej ghat
Matheran
Tapola, Mahabaleshwar
Malshej ghat
Sawant wadi
Amboli ghat
Poladpur
Chiplun-Chinchgari
Kelwat, Mandangad

(b)

SATARK LS Prediction model

- Persistent high rainfalls on the ILS region are due to convection generated by the Hydraulic Jump (HJ) phenomenon. The HJ is estimated using the Froude (Fr) number.
- Fr = U/(NH).
- Fr is the ratio of zonal wind speed (U) to the product of Brunt Vaisala frequency (N) and the
- Height of the mountain (H). N is estimated using standard formula N.

$$N = \sqrt{\frac{g}{\theta}\frac{d\theta}{dz}}$$

If Fr ≥1, then wind flows over the mountain and experiences HJ.
If Fr < 1, the winds go around the mountain.

Daily Fr values were estimated using

daily radiosonde data for the period 2000–2016 of stations Mumbai and Goa from the Wy-

Land slide prediction Model

The cumulative rainfalls curves are taken as reference curves for initiating predictions of LSs for those locations. The forecast system operates in three stages.

Stage 1 Watch: If the IMD forecast charts show presence of transient systems, southerly position of MT, an increase in rainfall over the LS-prone areas for the ensuing 7 days,

Stage 2 Alert: If the IMD synoptic charts show presence and westward movements of transient systems and arrival of the systems near to the north of the Maharashtra state, southward displacement of MT, Fr > 1, and cumulative rainfalls for 3 days are higher than the reference cumulative rainfalls, then the "Alert" stage is invoked. The people in area are informed to be ready for moving out from their houses in LS areas.

Stage 3 Warning: If the high rainfalls persist for the next 3 days and cumulative rainfalls at LS locations are more than the reference values, then the prediction of LS is continued. Then, LS forecasts are given for the next day. The people in the areas are suggested to move to safe shelter locations with essential material to survive for a few days till the debris/stony materials fallen due to an LS are removed.

Model Prediction Skill

: Heidke skill score (

Chi square *test for testing interdependancy of two variables*

Chi square = summation (observed-expected)2/(expected)2

HSS = 0.4

Conclusions

- Inventory of LE events over WG region has been prepared with latitude, longitude locations using various sources, like Press, Media
- SATARK LS prediction model has been developed using LS events in years 2000-2015.
- Test period of independent predictions in 2016-2019.
- Real time LS predictions 2020 onwards.
- HSS = 0.45

Publication in journal

land

MDPI

Article

"Satark": Landslide Prediction System over Western Ghats of India

Jeevan R. Kulkarni [1,*], Sneha S. Kulkarni [1], Mitali U. Inamdar [1], Nitin M. Tamhankar [1], Spandan B. Waghmare [1], Kiran R. Thombare [1], Paresh S. Mhetre [1], Tanuja Khatavkar [1], Yashodhan Panse [1], Amey Patwardhan [1], Yogini Soman [1], Prasad Bhagat [1], Sumit Bhale [1], Mayuresh G. Prabhune [1] and Vinay Kumar [2]

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https://doi.org/10.3390/land11050689

Real time LS predictions

- Land Slide predictions in real time are made available since 2020 onwards on SATARK website for government agencies, media, common people in general and to disaster management authority.
- satark wordpress.com
- Demands and requests from Himalyan region to cary the study. It is in our future plan.

Thanks

Questions