https://doi.org/10.5194/egusphere-2026-96
Preprint. Discussion started: 19 January 2026

Global Fatal Coastal Landslides

Malia N. Reiss[1], Adam P. Young[1], and Jessica Carilli[1]

[1]Scripps Institution of Oceanography, University of California San Diego, 9500 Gilman Dr., La Jolla, CA 92093-0209, USA

Correspondence: Adam P. Young (adyoung@ucsd.edu)

Abstract. Coastal cliffs shape the world's coastlines, providing areas of beauty, habitat, scientific discovery, and recreation. However, as erosional features, coastal cliffs can also pose fatal hazards. This paper presents a database of global fatal coastal landslides from public databases and media articles. In total, the coastal landslide database includes 292 fatalities resulting from 114 landslide events from 1927 – 2024. Landslide events occurred in 32 countries, with the most events in Spain (20), the United States (19), France (14), and the United Kingdom (10), and include two 10-event hot spots on Reunion Island, France, and San Diego County, California, USA. Most fatalities occurred in temperate regions, with about half of events occurring during months with above average precipitation (and half below), differing from databases that include non coastal fatal landslide events driven largely by rainfall. The database is likely incomplete in part from reporting bias, and the analysis presented here should be interpreted with caution. However, the present results suggest that the timing of coastal fatal landslides may be influenced by (a) elevated rainfall causing reduced cliff stability, leading to more failures in wet seasons and (b) time periods of increased tourism and recreational beach activity, exposing more people to coastal cliff failure hazards in relatively dry seasons. The results can help inform beach hazard management.

Short summary: Globally, coastal cliffs can pose fatal hazards. We present a global fatal coastal landslide database, with 114 fatal events that killed 292 people from 1927-2024. Using this database, we found that deaths from coastal landslides are partly associated with elevated rainfall, and partly associated with dry periods with elevated human beach activity. These results can help inform beach hazard management.

1 Introduction

About half of the world's coastlines contain coastal cliffs (Young and Carilli, 2019). Coastal slopes and cliffs are erosional landforms and often naturally unstable from a variety of marine and subaerial erosional processes (Kline et al., 2014; Sunamura, 1982; Trenhaile, 1987; Trenhaile and Kanyaya, 2007; Young et al., 2009). Cliffs are valuable aesthetic, cultural, and scientific resources, often contributing to increased tourism and recreation on beaches that closely border these features (Bird, 1994). However, this increased use also elevates risk of potentially fatal hazards from coastal cliff failures. Slope failures are often difficult to predict and rapid (Petrucci, 2022).

Physical processes weaken rocks over time (Hampton et al., 2004), eventually leading to collapse. These processes include wet-dry cycles, water infiltration, daily or seasonal temperature changes, groundwater flow, and wave energy reaching the cliffs (Duperret et al., 2005; Hampton et al., 2004; Sunamura, 1992; Trenhaile and Kanyaya, 2007). Wave-driven erosion at the cliff

https://doi.org/10.5194/egusphere-2026-96
Preprint. Discussion started: 19 January 2026

base can cause a basal “notch” to form, increasing tensile and shear stress on cantilevered cliffs, and eventually leading to failure of the upper overhanging cliff (Kline et al., 2014; Moreiras, 2005; Young and Ashford, 2008). Breaking waves also compress air into crevices, generating cyclical stress that can lead to fracture (Sunamura, 1982). Cliff lithology and beach geometry also influence collapse susceptibility, as well as sea-level oscillations, climate, and tectonic activity (Emery and Kuhn, 1982; Kogure, 2022; Sunamura, 1992; Trenhaile, 2010; Trenhaile, 2004). For all (coastal and inland) landslides, more are recorded in wetter years driven by cycles such as the El Niño Southern Oscillation (ENSO) (Moreiras, 2005). Sea level rise is generally expected to increase cliff erosion in many areas (Gornitz, 1991), but local response could vary widely (Matsumoto et al., 2024).

Coastal rockfalls can be triggered by tectonic movements (Bird, 1994), severe storms (Bird, 1994), freeze-thaw cycles (Bird, 1994; Letavernier, 1984), stress relief and fatigue (Duperret et al., 2005), heavy rainfall (Bird, 1994; Duperret et al., 2004; Letortu et al., 2015), sudden rain during dry periods (Duperret et al., 2004), cold and dry weather (Letortu et al., 2015), high wind (Letortu et al., 2015), and recreation such as fossil or mineral hunting (Bird, 1994), or specific combinations of these factors (Letortu et al., 2015).

When unstable cliffs back popular beaches, landslides can have fatal consequences. For example, in August 2019, three women died on Grandview Beach, Encinitas, California, USA when a 30-by-25-foot rock mass collapsed (Riggins, 2019). On Christmas Eve of 2021, a 30 meter cliff collapsed on Australia’s Bells Beach killing one person and injuring 3 others (Blair, 2021). Other similar incidents have occurred globally. Coastal landslide fatalities often receive media coverage and public anger, leading to demands for increased beach safety (Bird, 1994). However, measures to increase beach safety, such as building seawalls, sometimes result in public protest over decreased scenic beauty, high construction costs, and other unintended negative erosional impacts (Bird, 1994; Clemente et al., 2023; Griggs, 2005).

Total (combined coastal and inland) landslide fatalities have been previously compiled. For example, The Global Fatal Landslide Database (Froude and Petley, 2018) recorded 4862 fatal landslides from 2004 to 2017 using extensive English language media searches and found that fatal landslides coincide with regional rainfall driven by climate anomalies, occur most frequently in countries with lower gross national income, and are impacted by human disturbance and land use change. However, a database of coastal landslide fatalities is lacking. This study compiled a database of fatalities related to coastal landslides, drawing from existing databases and media reports in multiple languages. Similar to Froude and Petley (2018), the dataset was used to evaluate potential causative factors with the goal to help inform coastal hazard management.

2 METHODS

2.1 Database Development

This study builds on previous research and compiles a global fatal coastal landslide database using 13 public databases (Table 1) and online media. The database includes the following information for each entry if available: date, location, location precision, number of fatalities, whether the victim was a local or tourist, listed landslide trigger, media source, web link, and a small summary of the event.

https://doi.org/10.5194/egusphere-2026-96
Preprint. Discussion started: 19 January 2026

Table 1. Regional and global databases used to compile the Fatal Coastal Landslide Database

Country	Database Name	Source
Global	Global Fatal Landslide Database	Froude and Petley, 2018
Global	The Global Landslide Catalog – NASA Cooperative Open Online Landslide Repository (COOLR) project	Kirschbaum et al., 2021; Kirschbaum et al., 2015; Kirschbaum et al., 2010
Global	EM-DAT DISASTER database (10+ fatalities)	Delforge et al., 2025
Brazil	Brazil Disaster Database	Brasil, 2021
Ireland	GSI Landslide Data Viewer Ireland ITM: Landslides	Geological Survey Ireland
Italy	Italian Landslide Inventory 2018–2024	ISPRA
Italy	Italian Landslides 2010+	Calvello and Peco raro, 2025
Norway	Avalanche Events	NVE kartkatalog
Portugal	Portugal DISASTER Database	Zêzere et al., 2014
Spain	Inventory of Rockfalls 1800–2021	Corominas Dulcet et al., 2023
Sweden	SGI Landslide Database	Swedish Geotechnical Institute
United Kingdom	BGS National Landslide Database	Foster et al., 2012
United States	U.S. Landslide Inventory and Susceptibility	Mirus et al., 2020

Froude and Petley (2018) define landslides as slope failures that occur in any terrestrial environment; for the coastline, these slopes include cliffs, bluffs, or steep coastal mountains or slopes. Fatalities occur when people are exposed to these landslides, killed by vital organ injuries or traumatic asphyxia from burial (Petrucci, 2022). This study defines a fatal coastal landslide as one of the following:

1. Death from falling rocks or rock burial from a cliff or bluff on a beach or along a coastal highway or other infrastructure built into or below a coastal cliff, including fjords but excluding rivers and lakes.
2. Death from a landslide that originates in an immediate coastal area where the base of the slope was in contact with the ocean. Landslides that occurred on mountainous terrain near a coastline, but that lacked recent wave-driven erosion, were not considered coastal.
3. Death from being carried downslope with a cliff collapse.
4. Death from coastal cliff failure triggered by an earthquake or tsunami (but not from other hazards such as drowning caused by those events).

https://doi.org/10.5194/egusphere-2026-96
Preprint. Discussion started: 19 January 2026

Bodies "found" at the base of a cliff, or those that died without evidence of underfoot breakage or rockfall were not included. Slips, trips, and falls, cliff jumping, and climbing accidents were also not included if there was no evidence of breakage of the cliff underfoot. Though a common beach hazard, burial by human-dug sand holes on beaches was not included, as these are not natural coastal slope hazards. Fatalities associated with playing in caves or digging for fossils in cliffs were included as the events were influenced by existing cliff-related hazards. We only include events resulting in fatalities; however, many more coastal rockfalls and landslides resulted in documented injuries.

All database entries were either visually inspected on a map interface or filtered by proximity to the coastline, and then manually reviewed to confirm the landslide was coastal as defined with our criteria. Some national landslide datasets, such as the Inventory of Rockfalls in Spain (Corominas Dulcet et al., 2023), lacked web links to original sources, but entries were included if they clearly mentioned a fatality via landslide at a beach or coastal cliff. Mouvements de terrain (BDMvt) [France] (Migron, 2002), British Geological Survey National Landslide Database (Foster et al., 2012), and the New Zealand National Landslide Database Webmap (Rosser et al., 2017) were accessible but did not include fatality information, and we did not find a fatal coastal event using database-provided supplemental links, so data from those sources were not included. Many other national and regional datasets were identified but are not publicly accessible, and therefore were not included.

Fatal landslide events that could not be confirmed as coastal were compiled in a supplemental spreadsheet. This included entries from some databases (EM-DAT DISASTER database [Delforge et al., 2025] and the SGI Landslide database [Swedish Geotechnical Institute] that show fatal landslides mapped at the coast, but could not be verified as 'coastal' due to missing media links or lack of further information. The supplemental spreadsheet also includes some entries from the Global Fatal Landslide Database and the Global Landslide Catalog with missing or now-unavailable media links. The supplemental sheet also contains events that marginally met the defining criteria, such as sand dune burial, and events from the Portugal DISASTER Database (Zêzere et al., 2014) where the number of fatalities and injuries are not separated. Events that occurred in 2025 are also included in the supplemental database because we stopped our media searches before the end of 2025.

Other events had confirmed fatalities, but did not include information on the number of fatalities that we could attribute to a coastal-specific landslide; for example, a 2022 South Africa multi-landslide flood event included 443 fatalities and 40,000 missing people (Petley, 2022a). While some of these fatal landslides occurred at the coast, it is unknown how many of these fatalities were from coastal versus inland landslides. For fatal coastal landslide events with confirmed fatalities, but an unknown number of victims, the event was included in the main database, and the "event" analysis, but not the "number of fatalities" analysis.

Our other data sources include web based searches on media sites and the Google News Archive using a mix of search words such as "beach," "coastal," "landslide," "rockfall," "cliff," "death," "fatality," "kill," etc. Media searches were conducted using translations of the search word combinations in Spanish, French, Italian, Hindi, Chinese, Portuguese, Japanese, Arabic, Swahili, Ukrainian, Russian, Indonesian, Hebrew, Finnish, Albanian, Greek, Vietnamese, Thai, Turkish, Persian, Bosnian, Serbian, Norwegian, Danish, Swedish, Croatian, Bangla, German, and Polish. Several native speakers of non-English languages (Japanese, French, Hindi, Chinese, Polish) also aided our search by using appropriate search phrases that were not direct

https://doi.org/10.5194/egusphere-2026-96
Preprint. Discussion started: 19 January 2026

translations from English. This method follows Froude and Petley (2018), with the addition of using non-English languages in searches.

Our fatal coastal landslide database includes the estimated spatial precision of the location in kilometers if available. Often, the original source location and/or spatial precision estimates were updated using additional information obtained in the media searches. An example “1 km” precision indicates the landslide likely occurred within a 1 km radius of the point location. The database includes the event date obtained from publication dates of media reports and key phrases such as, “Last Friday,” “This weekend,” etc.

2.2 Coastal Setting Analysis

To evaluate possible drivers of either the number of fatal coastal landslide events or the number of fatalities, we used linear regression analysis (MATLAB r2024b) to compare these metrics, aggregated by country, against the following coastal setting variables: total length of cliffs (km), total length of coastline (km), percentage of coastline backed by cliffs, population, annual international tourism visits, and gross domestic product (GDP). Countries without a recorded fatal coastal landslide event were excluded. Per-country lengths of cliffs and coastlines were sourced from Young and Carilli (2019). The population of each country in 2024 was sourced from the US Census International Database (IDB). Annual international tourism visits were sourced from the United Nations Tourism Organization, using values from 2018, to avoid bias from low tourism numbers during the COVID pandemic and data gaps in recent years (Herre and Samborska, 2023; United Nations, 2024). Few countries provided data for the percentage of tourism that is coastal (European Commission, 2023), and was therefore not included in the analysis. We defined fatal coastal landslide “hot spots” as locations with 3 or more events in clusters within a 25 km radius. We defined fatality outliers as those exceeding 3 standard deviations above the database mean; for this analysis, outliers include a Philippines 2022 event (53 fatalities) and a 2010 Brazil event (22 fatalities).

2.3 Rainfall Analysis

To evaluate relationships between rainfall and fatal coastal landslides, we used gridded 1.0° mean monthly precipitation from the NOAA Global Precipitation Climatology Center (Schneider et al., 2022) following Froude and Petley (2018). Using MATLAB, the nearest grid point within the global precipitation grid was identified for each fatal coastal landslide and the precipitation value for the month, prior month, and year of the landslide event was extracted. 32% (36 events out of 114) landslides lacked precipitation matches if they occurred outside the time frame of the precipitation data (1989-2025) or occasionally from gaps in the precipitation data.

Relative precipitation was evaluated by plotting monthly mean rainfall for the month of a fatal landslide event compared to the long term monthly mean rainfall for that site. To determine whether the event fell in the given location’s wet, dry, or transitional season, months were ranked according to average precipitation over the entire time series; the 4 months with highest precipitation were identified as “wet,” the 4 with lowest were “dry,” and all others were transitional.

Additional analysis was conducted on a fatality hot spot in San Diego County, California. To evaluate local relationships between rainfall and tourism for San Diego County rainfall data was obtained from the National Oceanic and Atmospheric

https://doi.org/10.5194/egusphere-2026-96
Preprint. Discussion started: 19 January 2026

Administration's NOW Online Weather Data. Tourism data was sourced from San Diego International Airport's (SAN) records of total passengers by month for June 2024 to May 2025, and were used to estimate the seasonality of visits.

3 RESULTS

3.1 Spatial Distribution

We recorded 114 individual fatal coastal landslide events (Fig. 1) from 1927 to 2024, and 292 fatalities. 25 of these events were sourced from the Global Fatal Landslide Database, 25 from English media, 38 from non-English Media, 4 from the Global Landslide Catalog, 1 from the Italian Landslide Inventory 2018-2024 (IFFI), 13 from the Inventory of Rockfalls in Spain 1800-2021 (Corominas Dulcet et al., 2023), 6 from newspaper archives, and 2 from scientific papers. The preceding list provides the chronological order of sources reviewed, and some sources included duplicate information. The Spain and Italy databases were the only national databases that contained events not also found in media searches.

Fatal coastal landslide events occurred in 32 countries (Fig. 1), with the most events in Spain (20), the United States (19), France (14), and the United Kingdom (10). On average, there were 2.6 fatalities per event; however, 64% of fatal coastal landslide events resulted in single fatalities. 70% of coastal landslide fatalities were from direct rock falls, with many fatalities from individuals recreating on beaches, for example sunbathing, strolling with a pet, kayaking, or camping. Landslide events binned by 5 degrees of latitude peak at 20-30 degrees S in the southern hemisphere, and at 30-40 degrees N in the northern hemisphere (Fig. 1).

https://doi.org/10.5194/egusphere-2026-96
Preprint. Discussion started: 19 January 2026

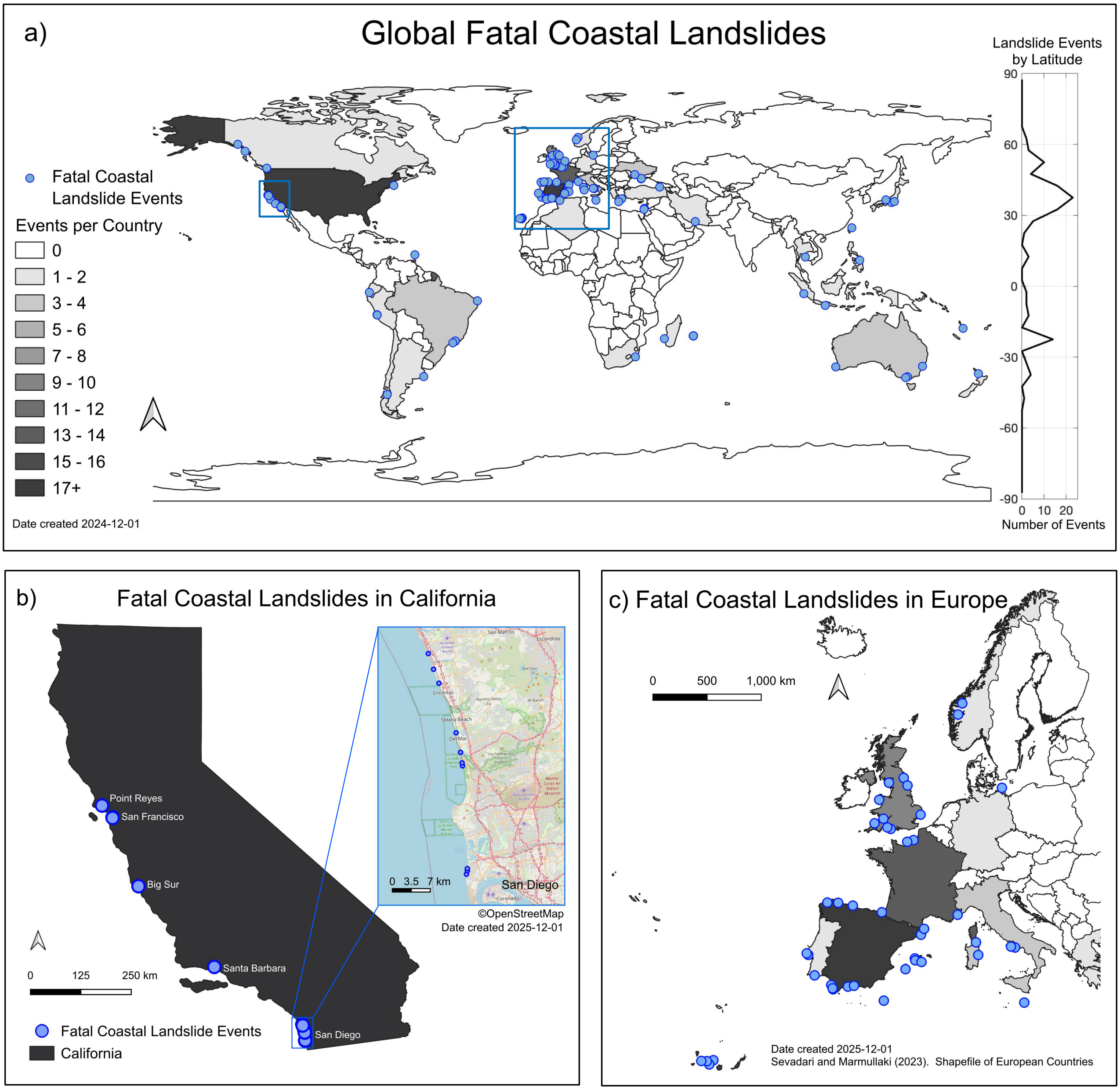

Figure 1. The location of (a) global fatal coastal landslide events (blue dots) between 1927-2024, with insets showing (b) California (further inset to San Diego), and (c) Europe. Countries are color coded by the number of events within each country. Global political boundaries are from *Natural Earth*, Accessed 7/8/2025. Europe political boundaries are from Sevdari and Marmullaku (2023). California boundaries are from *California Open Data Portal*, Accessed 12/1/2025.

https://doi.org/10.5194/egusphere-2026-96
Preprint. Discussion started: 19 January 2026

The Philippines, Brazil, and the United States had the highest number of coastal landslide fatalities (Fig. 2). The Philippines high fatality count resulted from a 2022 event with 53 fatalities that occurred at a seaside resort (Petley, 2022b). Brazil's high fatality count is primarily related to a 2010 event where 22 vacationers and staff were buried in a coastal landslide at Sankay Inn Resort, two hours west of Rio (Carvalho, 2010), and a 2009 event where 17 people were killed at Pousada Sankay Island resort in Ilha Grande (Azzoni and Dana, 2010). The Philippines 2022 event (53 fatalities) and the 2010 Brazil event (22 fatalities) are statistical outliers.

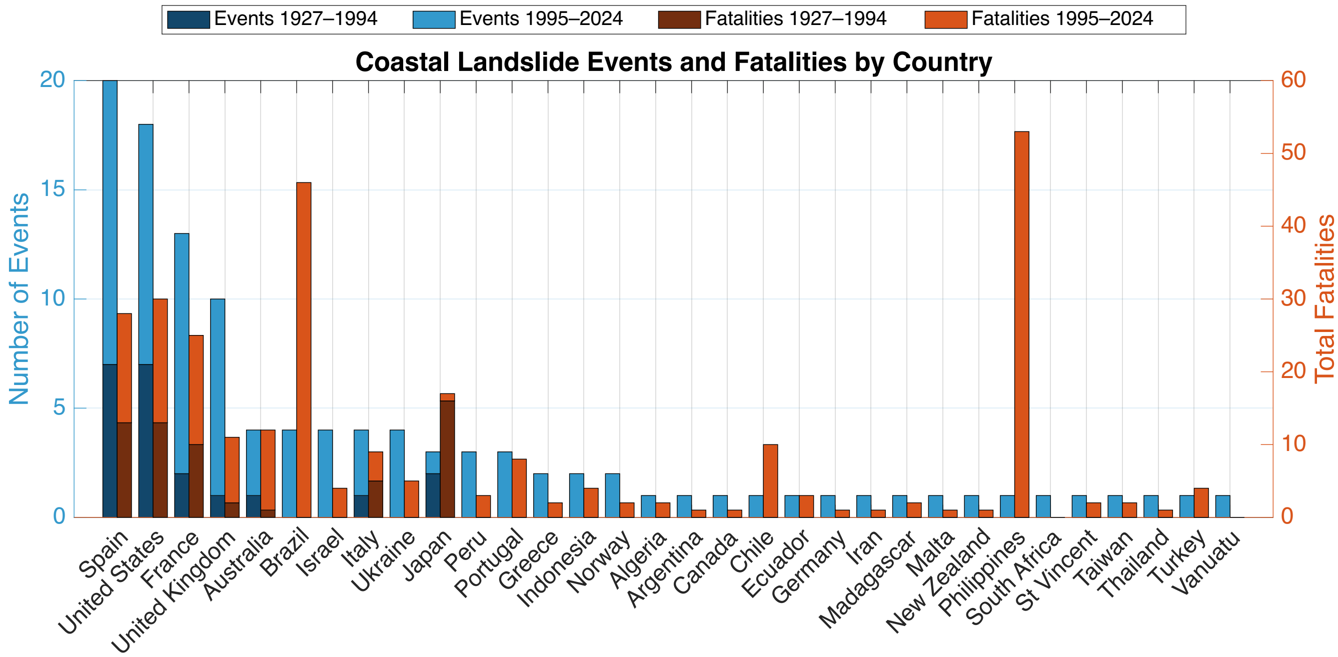

Figure 2. Coastal landslide fatalities (red) and events (blue) binned by country, and stacked by time periods 1927 to 1994 (darker, pre-Internet access), and 1995-2024 (lighter, post-Internet).

Spain had the highest number of fatal coastal landslide events (20, Fig. 2) and these were generally spread spatially, with only 1 hot spot (4 events) concentrated on the SW coast. The United States had both a high number of fatal coastal landslide events (18) and fatalities (25), mostly concentrated in a hot spot in San Diego County, California, which represented 63% of the fatalities and 56% of the events in the US. France events (14) were also geographically concentrated in a hot spot on Reunion Island, representing 79% of the France events. The United Kingdom fatal events (10) were not geographically concentrated. Other fatal coastal landslide hot spots include: Netanya, Israel; San Francisco/Point Reyes, California, United States; Crimea, Ukraine; and Costa Verde, Peru.

https://doi.org/10.5194/egusphere-2026-96
Preprint. Discussion started: 19 January 2026

3.2 Coastal Setting

Annual international tourism arrivals were positively correlated (r^2 = 0.62, $p = 3.58e-07$) with the number of fatal coastal landslide events (Fig. 3d). Per-country population was weakly, but not significantly, correlated with the number of fatal coastal landslide events (Fig. 3e; r^2 = 0.13 , $p = 0.051$), and there was no significant correlation between tourism and country population (r^2 =0.11, $p = 0.078$). The length of coastal cliffs, percentage of coastline comprised of cliffs, and total length of coastline also did not significantly explain the number of fatal coastal failures on a per-country basis. GDP was significantly correlated to per-country fatal coastal landslide events (Fig. 3f; r^2= 0.33, $p = 0.001$), but was strongly influenced by fatal coastal landslides in the United States; the correlation was insignificant without inclusion of the United States (r^2 = 0.06, $p = 0.199$).

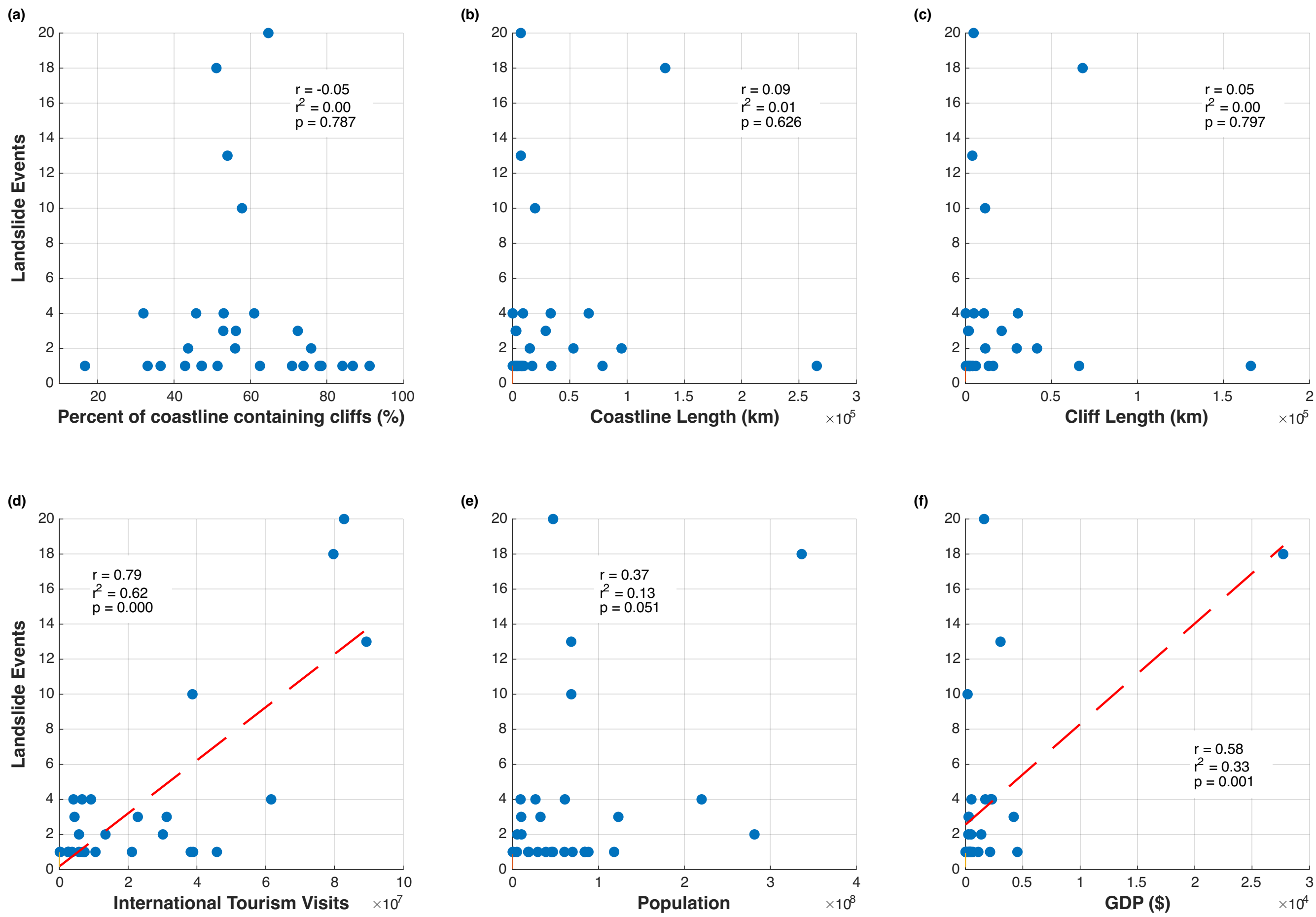

Figure 3. Comparison of fatal coastal events vs. (a) percent coastline as cliffs, (b) coastline length, (c) kilometers of cliffs, (d) international tourist arrivals, (e) population, (f) Gross Domestic Product (GDP).

Per-country population was correlated with the total number of coastal cliff landslide fatalities (Fig. 4e; $r^2 = 0.25$, $p = 0.008$). Tourism was not significantly correlated when all data points were used (Fig. 4d; r^2 = 0.10, $p = 0.117$), but correlated if two

https://doi.org/10.5194/egusphere-2026-96
Preprint. Discussion started: 19 January 2026

outliers (Philippines 2022 and Brazil 2010) were removed ($r^2 = 0.45$, $p = 0.0002$). GDP, length of coastal cliffs per country, percentage of coastline composed of cliffs, and total length of coastline were not significantly correlated with per-country coastal landslide fatalities (Fig. 4). Locals and tourists were impacted almost equally, with 66 locals and 69 tourists killed (and unknown affiliations of other victims).

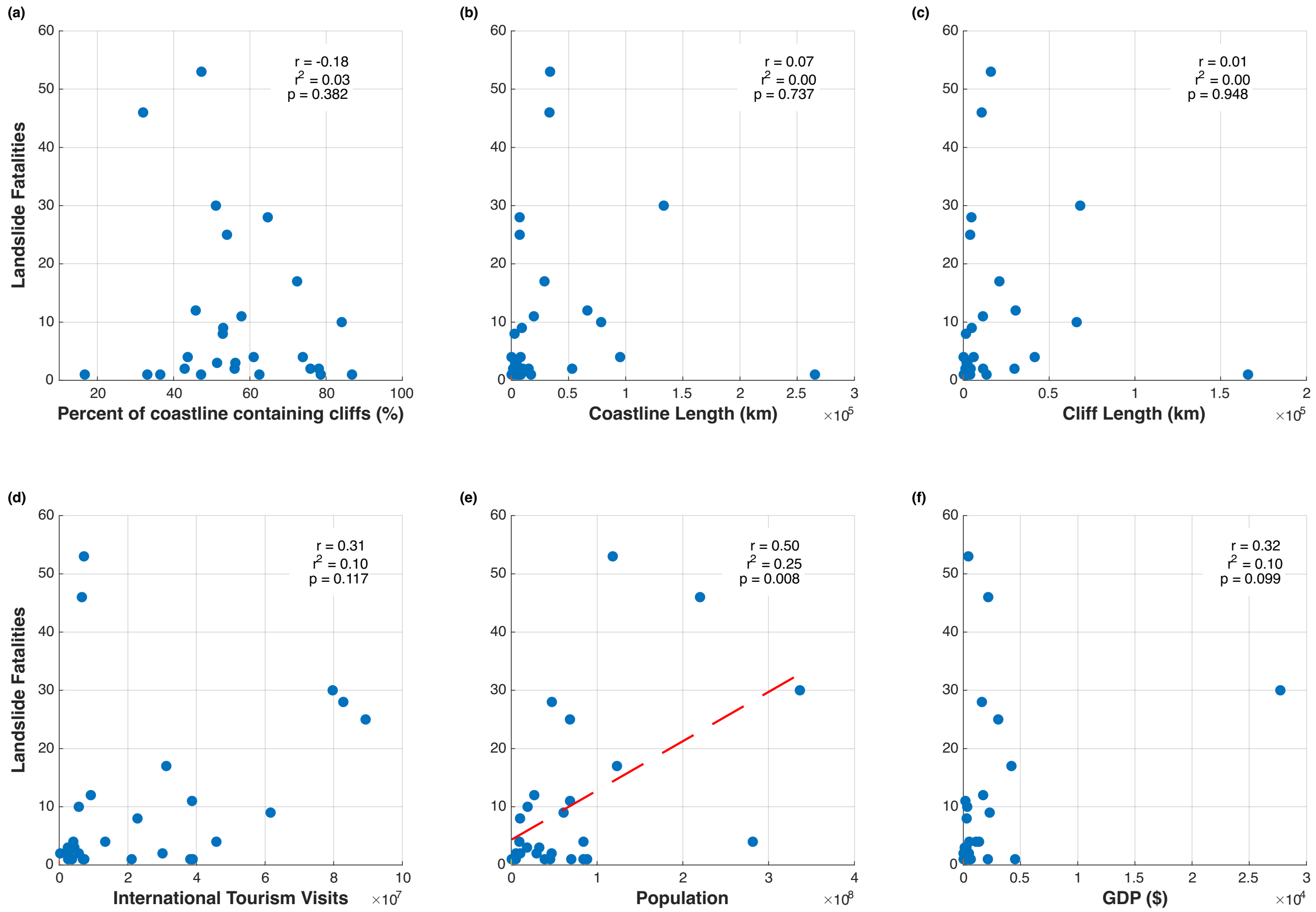

Figure 4. Comparison of coastal fatalities vs. (a) percent coastline as cliffs, (b) coastline length, (c) kilometers of cliffs, (d) international tourist arrivals, (e) population, (f) Gross Domestic Product (GDP).

3.3 Time History and Seasonality

The number of fatal coastal landslide events and fatalities in our database generally increased with time (Fig. 5a). By month, the number of fatal coastal landslide events and fatalities exhibit a bimodal distribution, with more events in July-August (31 events) and January-February (22 events), and more fatalities in July-August (61 fatalities) and December-January (39 fatalities; Fig. 5b). The April fatality peak resulted from the 2022 Philippines outlier. When separated by hemisphere (Fig. 6), most fatal coastal landslide events and fatalities (excluding outliers) occurred in the summer months in each hemisphere: July-

https://doi.org/10.5194/egusphere-2026-96
Preprint. Discussion started: 19 January 2026

August in the Northern Hemisphere (30 events, 60 fatalities) and January-February in the Southern Hemisphere (10 events, 10 fatalities).

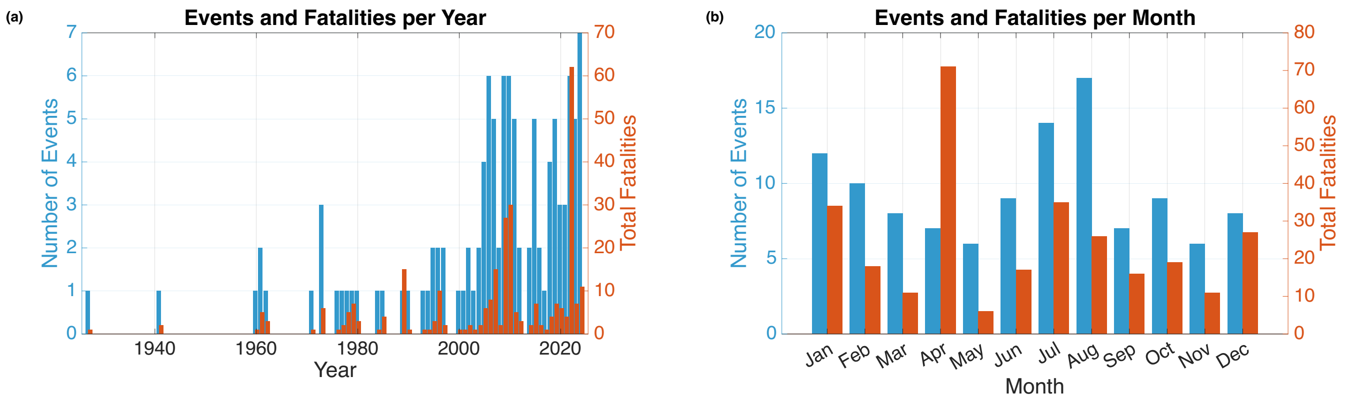

Figure 5. Number of fatal coastal landslide events and fatalities globally binned per (a) year, and (b) month.

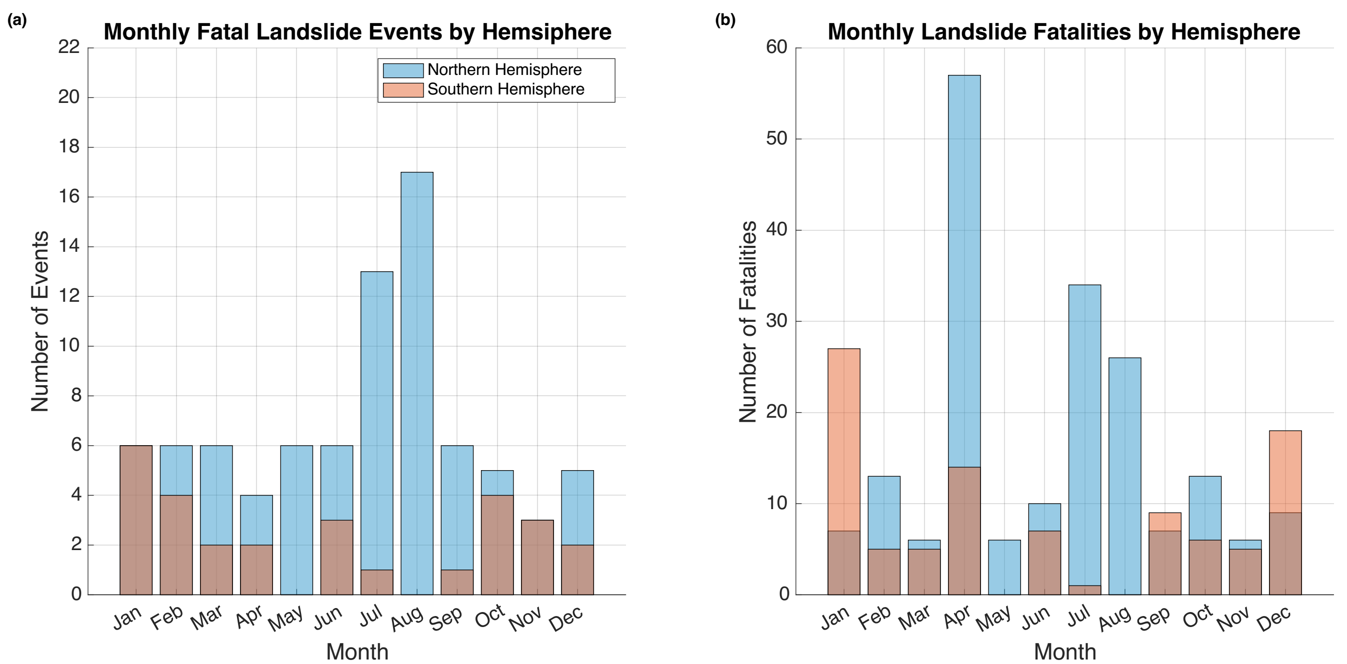

Figure 6. Monthly number of fatal coastal landslide (a) events (b) and fatalities in the Northern and Southern Hemispheres.

https://doi.org/10.5194/egusphere-2026-96
Preprint. Discussion started: 19 January 2026

190 ### 3.4 Rainfall

While most media reports did not cite a particular landslide trigger (72.7%), rainfall or rainfall combined with other triggers such as wind was attributed to 21.3% of events (Fig. 7). Other triggers included earthquake (2.7%), recreation (1.8%), ice (0.9%), and wave erosion (0.9%).

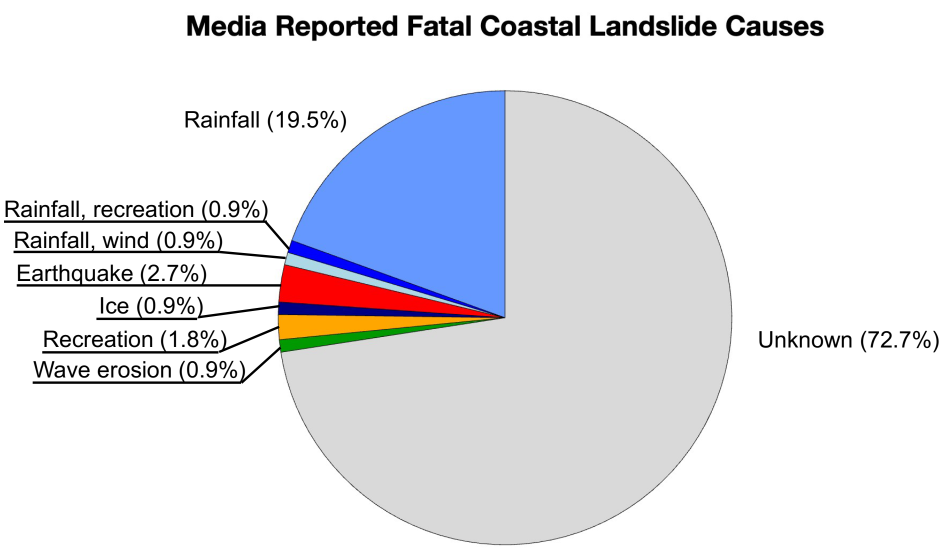

Figure 7. Media reported fatal coastal landslide causes.

41% of events occurred during average rainfall conditions (25-75 percentile). 40% of events occurred during months that
195 were much wetter than normal (above 75 percentile), and 19% events occurred during months that were much drier than usual (below 25 percentile). 33% of events occurred during a monthly rainfall less than 25mm. About an equal number of fatal coastal landslide events occurred during months with rainfall above or below the long term monthly mean rainfall (1:1 line, Fig. 8). 32% of fatal coastal landslide events occurred in the dry season, 35% in the wet season, and 33% in transitional seasons.

https://doi.org/10.5194/egusphere-2026-96
Preprint. Discussion started: 19 January 2026

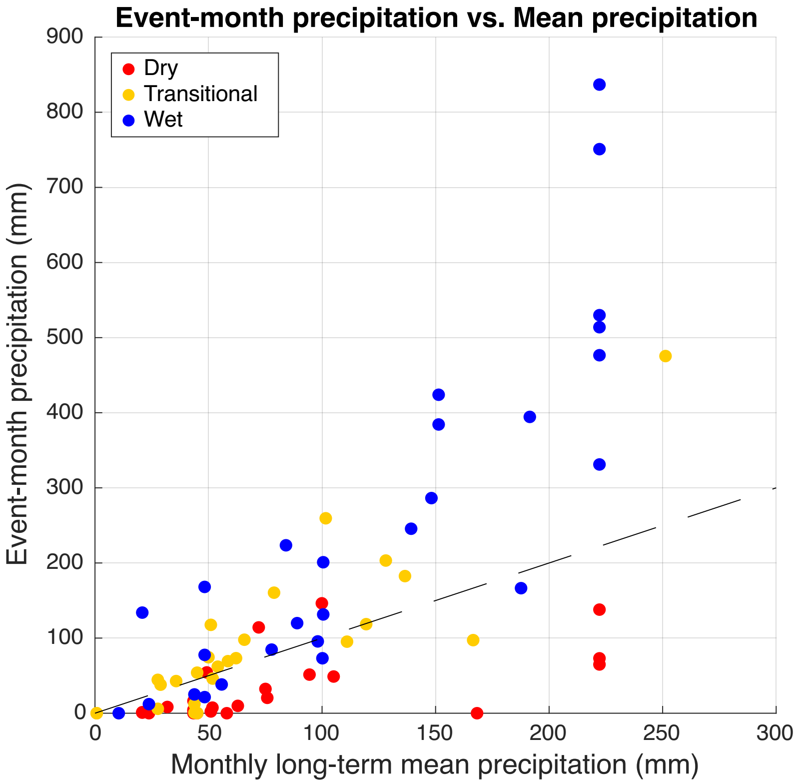

Figure 8. Monthly precipitation at the location of each landslide event compared to the mean monthly precipitation of that location over the entire time series (1989-2025). Points are color-coded corresponding to the location-based season, based on long-term rainfall data.

In San Diego County, 10 events (19 fatalities) primarily occurred in two time periods: January-Feb and August. The number of passengers arriving at San Diego International Airport peaks in the summer (June-August), while rainfall in San Diego County peaks in the winter (December-March). The tourism and rainfall peaks align with the two peaks in San Diego fatal landslide events (Fig. 9). However, the overall low number of events precludes further robust statistical analysis.

https://doi.org/10.5194/egusphere-2026-96
Preprint. Discussion started: 19 January 2026

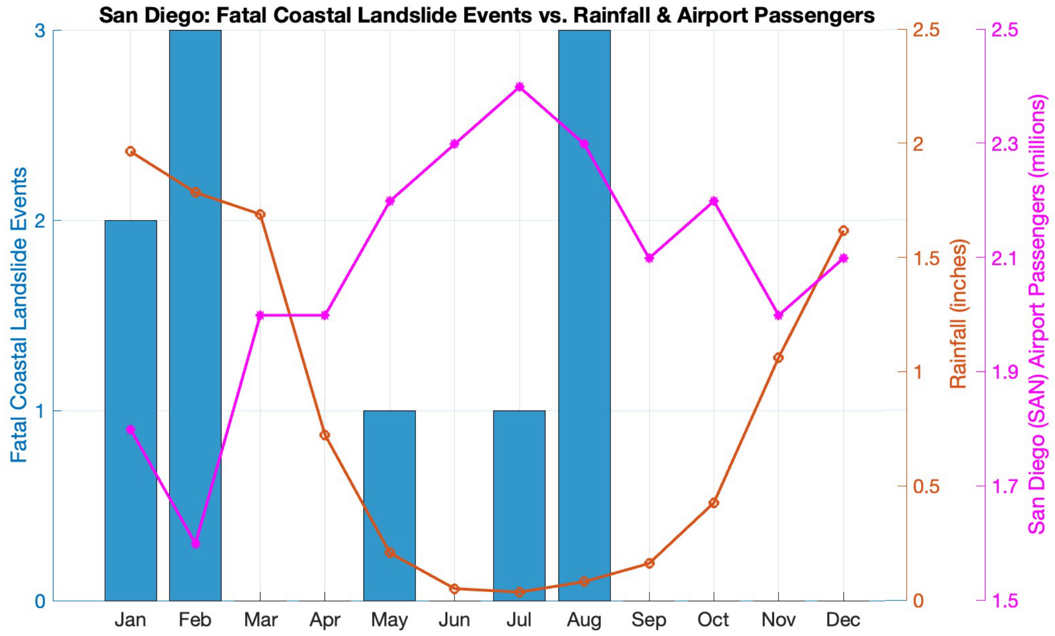

Figure 9. San Diego County fatal coastal landslide events in relation to average monthly rainfall (1927-2024) and airport passenger traffic (2024-2025). Each fatal coastal landslide event in San Diego County resulted in 1-3 fatalities.

4 DISCUSSION

4.1 Database completeness

The database presented here underestimates the actual number of fatal coastal landslides worldwide. Landslides in remote areas and those that result in a small number of fatalities are less likely to be reported (Petley, 2009). Regional communication systems are also inconsistent in less developed or politically isolated nations (i.e. North Korea; Kirschbaum et al., 2010; Petley, 2010). For example, African countries, despite having many coastal cliffs (Young and Carilli, 2019), lack online national databases or online media records of coastal landslide fatalities. This database also only used records still available in 2025, while other databases like Froude and Petley (2018) used some data sources that are no longer accessible online (and thus could not always be verified for this database). Underestimations could also result if victims died weeks or months after the event (Petley, 2012) and from difficulties searching non-English media (Froude and Petley, 2018). Our use of translators and searches in alternative languages aimed to reduce this bias. The majority of entries in this database were sourced from online media searches using both English and non-English keywords. A comparison study (Sepúlveda and Petley, 2015) of the English-based Global Fatal Landslide Database with an independently compiled database of Spanish and Portuguese language reports found a reporting difference of only 5% of records. However, the inclusion here of non-English media search keywords between 2004-2017 identified 25 of the fatal coastal landslide events included in the Global Fatal Landslide Database and an additional 23 events not included, highlighting the importance of non-English data searches for global database compilations. Some non-English languages used for media searches yielded zero results, such as Bosnian, Serbian, Norwegian, Danish, Swedish, Croatian, Bangla, and German. While it is possible that no fatal coastal landslides occurred in countries that speak those languages, this may also suggest a potential translation error.

The regional and national databases used here often contained information already identified in the media searches, and were thus most important to provide entries for time periods before online reporting. However, databases that included pre-internet entries were limited and often inaccessible. This reporting bias results in an apparent increase in the number of fatal landslide events and fatalities towards the present (Fig. 5). Internet accessibility (and online searchable media records) only attained global coverage after 1995, suggesting that landslides occurring before 1995 will be underrepresented (Haque et al., 2016). Although our dataset contains events back to 1927, early records are limited and only included for countries with publicly accessible records that extend that far back (ref. Fig. 2), such as Spain's Inventory of Rockfalls (Corominas Dulcet et al., 2023), and the Google News Archive for United States newspapers. The number of reported events per year becomes more consistent after 2004, which aligns with the release of the Global Fatal Landslide Database (2004 to 2017) which contains some records from media no longer available online.

Currently, a comprehensive global landslide database utilizing regional and national databases does not exist. Successful combination of these databases would provide a useful tool toward future analysis. Wood et al. (2020) found that current global catalogs lack consistency because of the "wealth and variety of data" in individual, smaller-scale databases. Van Den Eekhaut et al. (2012) analyzed national landslide databases in Europe and found that 68% of the databases contained less than 50% of all landslides in each country, and that different language and classification systems result in poor integration of multiple databases. They also found that public access to these databases is normally limited, which was also encountered for this study. Gómez et al. (2023) compiled four global databases (EM-DAT, the Global Landslide Catalog, the Global Fatal Landslide Database, DesInventar) to form the Unified Global Landslide Database (UGLD), which is not yet publicly available; however, we used the first three databases in our analysis.

4.2 Drivers of fatal coastal landslides

Fatal coastal landslide events and fatalities were not related to the proportion of coastlines backed by cliffs, total length of cliffed coastline, or coastline lengths by country, despite these factors providing more opportunities for fatalities associated with cliff failures. Instead, tourism ($r^2 = 0.62$; $p = 3.58e-07$ [events]) and the population of each country ($r^2 = 0.25$, $p = 0.008$ [fatalities]) had the highest correlations with fatal coastal landslide events and fatalities, respectively.

The results show 51% of fatalities associated with coastal landslides were tourists. Pereira et al. (2017) found that cliff-related landslide fatalities in southern Portugal increased recently because of increased exposure from "careless intensive use of coastal areas for tourism and leisure." This suggests hazards may increase with expanding coastal tourism and rapidly growing settlement in coastal areas (McGranahan et al., 2007). 60% of the world's population lives within 60 km of the coast, and this is expected to increase with the increasing world population (Castedo et al., 2017).

https://doi.org/10.5194/egusphere-2026-96
Preprint. Discussion started: 19 January 2026

Globally, rainfall is the dominant factor driving landslide risk (Kirschbaum et al., 2012). Froude and Petley (2018) found that rainfall explained 93% of variance in the Global Fatal Landslide Database, and Haque et al. (2019) found that more than half of fatal landslides analyzed occurred in areas exposed to extreme rainfall. However, fatal coastal landslides have a more complicated relationship, with only 35% of events occurring during location-based wet seasons, and only half of events occurred with above average monthly rainfall conditions, and half below. 41% of fatal coastal landslide events occurred during months with about average rainfall conditions (25-75 percentile). 10 events (13%) occurred during months with twice the average monthly rainfall, but 26 (33%) events occurred during low rain conditions (monthly rainfall <25mm). This pattern differs from the full dataset of fatal landslides which includes more events during wet periods (Froude and Petley, 2018). The pattern difference is potentially from the increased hazard during dry periods as more people recreate on beaches.

The latitudinal peak in fatal coastal landslide fatalities and events between 30-40 degrees shows that most coastal landslide fatalities occur in temperate, dry-summer climates, coinciding with some of the wealthiest nations and locations of high tourism with more beach use (Stringham, 2015). Thus, the distribution is potentially related to elevated landslide activity in wet seasons and elevated coastal recreation in the summers (Georgopoulou et al., 2018). These findings are consistent with a bimodal pattern observed at the San Diego County hot spot, where fatal coastal landslide events peaked in both dry and wet seasons. Fatality risks related to coastal landslides are therefore potentially related to a combination of environmental triggers (i.e. elevated rainfall), and human activity on the coast (i.e. intensive beach use during dry weather; Georgopoulou et al., 2018). The complicated relationship between rainfall and fatal coastal landslides could also be related to the coarse nature of the rainfall analysis. For example, Biasutti et al. (2016) found that even over shorter (daily or less) timescales, the relationship between landslide occurrence and rainfall varies.

The Global Fatal Landslide Database found that most fatalities occurred in developing, low GDP countries and areas characterized by significant poverty (Froude and Petley, 2018). Other datasets also include more landslide fatalities in developing countries with high poverty, more corrupt governments, and weaker healthcare systems (Dowling and Santi, 2014), leading to descriptions of landslides as “disasters of social vulnerability” (Petrucci, 2022; Santi et al., 2011). Developed countries tend to have a higher level of disaster preparedness and larger use of warning systems leading to a lower number of fatalities per landslide event (Petrucci, 2022). This negative relationship contrasts with the fatal coastal landslide events, which show a positive relationship with GDP, and no relationship when the United States data point was excluded. These differences may be related to media reporting bias (Haque et at, 2016), or reflect higher beach use in higher GDP locations (Risso, 2018), counteracting the tendency towards more overall landslide fatalities in low GDP countries.

4.3 Hazard Perception

Differences between the number of fatalities and the number of fatal coastal landslide events can influence hazard perception. Spain, The United States, France, and the United Kingdom had the highest number of fatal coastal landslide events in the database (Fig. 2), while the Philippines and Brazil had the most fatalities, but lower numbers of fatal coastal landslide events (Fig. 2). High-fatality events may impact analyses, leading to results biased toward singular events. However, 64% of coastal landslides in our database were single fatality events, compared to only 29% of events in the Global Fatal Landslide Database

https://doi.org/10.5194/egusphere-2026-96
Preprint. Discussion started: 19 January 2026

(Froude and Petley, 2018). Many of the landslides in the Global Fatal Landslide Database with high fatalities were large-scale events often impacting entire towns, while fatal coastal landslides in this dataset were more likely to represent smaller rockfalls that affected one or a small number of people.

4.4 Hazard reduction

Various methods to reduce coastal landslide hazards include eliminating rockfall, mitigating erosional processes, predicting landslides, and prioritizing human education. Methods to prevent rockfalls include cliff reshaping and terracing (Pradeepkumar et al., 2014), rock bolting (McInnes et al., 2007), seawalls and riprap (Griggs and Fulton-Bennett, 1988), and stabilizing via mesh or netting (Harp and Youd, 1995). Direct manual or mechanical removal of hazardous loose rocks, overhangs or protrusions is also used on inland slopes and cliffs (Maerz et al., 2016).

Some hazard reduction methods attempt to eliminate or reduce erosional processes. Beach nourishments are widely used in the U.S. and Europe to provide a buffer to wave-cliff erosion (de Schipper et al., 2021; Griggs and Kinsman, 2016; Marinho et al., 2019). Controlling groundwater seepage into cliffs by improving drains and sewers has also been proposed (Brampton, 1998). Nature-based solutions for coastal protection, such as bio-fencing, are also increasingly popular (Clemente et al., 2023; Pradeepkumar et al., 2014). Artificial reefs and cobble berms are used to reduce wave energy and erosion and to help retain sand on beaches (Foss et al., 2023; Silva et al., 2016). These methods can also directly reduce interaction between coastal users and potential cliff failures; for example, on the Basque Coast of northern Spain, dunes placed at the cliff base provide a barrier between cliffs and people (Clemente et al., 2023).

Current research in hazard forecasting and monitoring is also increasing. Thermal remote sensing (Melis et al., 2020) and microseismic monitoring (Arosio et al., 2009) help identify growing fractures, water intrusion, and weathered areas. Lidar monitoring can determine specific failure mechanisms and sequences of erosional events (Olsen et al., 2008; Swirad and Young, 2025). 3D rockfall modeling (Morales et al., 2021) and topographic monitoring can also help establish maximum runout reach and can inform management and protection measures.

Other methods prioritize the human aspect of hazard mitigation, such as public and lifeguard education, regional weather warnings, warning signs, and restricting unstable areas. The BGS National Landslide Database highlighted many non-fatal landslides that triggered warnings, barriers, and closures of beaches, trails, and cliff sections in recently impacted areas or predicted hazardous areas. In 2024, Australia implemented a Cliff Safety Month to occur every February, prioritizing public education on the issue (Coast & Parks Authority, 2025; Rivalland, 2025). In 2024, Albufeira, Portugal implemented an awareness campaign to raise awareness for sun exposure and cliff danger by distributing leaflets in Portuguese and English (The Portugal News, 2024). However, there is large variation in public perception of coastal cliff hazards and responses to educational or warning signs (Bird 1994; Williams and Williams, 1991). Even after an obvious recent landslide, people continue to visit coastal areas and even walk on recent rock falls (Fox, 2023; Williams and Williams, 1991).

https://doi.org/10.5194/egusphere-2026-96
Preprint. Discussion started: 19 January 2026

5 Conclusions

This study builds upon previous landslide research to develop a database of coastal fatal landslides. In total, the database includes 114 events and 292 fatalities with event hot spots in San Diego County, California, and Reunion Island, France. Aggregated by country, tourism and population were correlated to the number of coastal landslide fatalities, suggesting the likelihood of fatal coastal landslides increases with beach use. Unlike general (including coastal and inland) fatal landslide databases, the number of coastal fatal landslide events and fatalities were not well correlated with rainfall, suggesting dry seasons should also be considered in hazard mitigation planning for coastal landslides. Overall, the results suggest event timing is driven by a combination of rainfall triggered events and elevated recreation on beaches during dry periods. The database is likely incomplete as evidenced by no entries from some large geographic areas such as Africa, and the analysis presented here should be interpreted with caution. In the future, better records and systematic reporting of coastal failures can help create a more comprehensive coastal fatal landslide database and identify potential drivers of coastal cliff failures and fatalities to improve risk management.

Data availability. The coastal fatal landslide database and supplementary sheet are available at GFCL_Database.xlsx for download

Author contributions. **Malia N. Reiss:** Writing - Original Draft, Methodology, Investigation, Visualization, Formal analysis, Data Curation
Adam P. Young: Conceptualization, Methodology, Writing - Review & Editing, Supervision, Project administration, Funding acquisition
Jessica Carilli: Methodology, Writing - Review & Editing, Investigation

Competing interests. The authors declare that they have no conflict of interest.

Acknowledgements. The project was supported by the State of California.

References

Arosio, D., Longoni, L., Papini, M., Scaioni, M., Zanzi, L., and Alba, M.: Towards rockfall forecasting through observing deformations and listening to microseismic emissions, Natural Hazards and Earth System Sciences, 9, 1119–1131, https://doi.org/10.5194/nhess-9-1119-2009, publisher: Copernicus GmbH, 2009.

Azzoni, T. and Dana, F.: Brazilian mudslides kill at least 17, CantonRep, https://www.cantonrep.com/story/news/2010/01/02/brazilian-mudslides-kill-at-least/42579463007/ (last access: 3 September 2025), 1 January 2010.

https://doi.org/10.5194/egusphere-2026-96
Preprint. Discussion started: 19 January 2026

Biasutti, M., Seager, R., and Kirschbaum, D. B.: Landslides in West Coast metropolitan areas: The role of extreme weather events, Weather and Climate Extremes, 14, 67–79, https://doi.org/10.1016/j.wace.2016.11.004, 2016.

Bird, E. C.: Cliff Hazards and Coastal Management, Journal of Coastal Research, pp. 299–309, https://www.jstor.org/stable/25735606, publisher: Coastal Education & Research Foundation, Inc., 1994.

Blair, A.: 28-year-old man dies after cliff collapses at Bells Beach, news.com.au, https://www.news.com.au/national/victoria/news/three-injured-as-cliff-collapses-at-bells-beach/news-story/c65cd2d62546460ff1967e5236ffcaaf (last access: 5 December 2025), 31 December 2021.

Brampton, A. H.: Cliff conservation and protection: methods and practices to resolve conflicts., in: Coastal Defence and Earth Science Conservation, pp. 21–31, Geological Society of London, ISBN 978-1-897799-96-3, google-Books-ID: 4g2hynOBd4MC, 1998.

Brasil: Disaster database and records: integrated disaster information system, Ministry of National Integration National Secretary of Civil Defense [data set], http://s2id.integracao.gov.br/ (last access: 10 October 2025), 2021.

California Open Data Portal: CA Geographic Boundaries - California Open Data [dataset], https://data.ca.gov/dataset/ca-geographic-boundaries (last access: 1 December 2025), 2023.

Calvello, M. and Pecoraro, G.: FraneItalia: a catalog of recent Italian landslides, https://zenodo.org/records/15144334, 2025.

Castedo, R., Paredes, C., Santos, R. d. l. V.-P. a. A. P., Castedo, R., Paredes, C., and Santos, R. d. l. V.-P. a. A. P.: The Modelling of Coastal Cliffs and Future Trends, in: Hydro-Geomorphology - Models and Trends, IntechOpen, ISBN 978-953-51-3574-6, https://doi.org/10.5772/intechopen.68445, 2017.

Clemente, J. A., Uriarte, J. A., Spizzichino, D., Faccini, F., and Morales, T.: Rockfall hazard mitigation in coastal environments using dune protection: A nature-based solution case on Barinatxe beach (Basque Coast, northern Spain), Engineering Geology, 314, 107 014, https://doi.org/10.1016/j.enggeo.2023.107014, 2023.

Coast & Parks Authority: Stay Safe on the Coast: Annual Cliff Safety Campaign Kicks Off, Great Ocean Road Coast & Parks Authority, https://www.greatoceanroadauthority.vic.gov.au/ Latest-News/Stay-Safe-on-the-Coast-Annual-Cliff-Safety-Campaign-Kicks-Off (last access: 8 December 2025), 1 February 2025.

Corominas Dulcet, J., Lantada, N., and Núñez Andrés, M. A.: Inventario de desprendimientos de rocas en España desde 1800 a 2021, https://doi.org/10.34810/data238, 2023.

de Carvalho, U. W.: Textos Mastigados: Mountain falls onto Brazil resort; 22 killed, Tesclasap, https://www.teclasap.com.br/textos-mastigados-mountain-falls-onto-brazil-resort-22-killed/ (last access: 5 December 2025), 2 January 2010.

de Schipper, M. A., Ludka, B. C., Raubenheimer, B., Luijendijk, A. P., and Schlacher, T. A.: Beach nourishment has complex implications for the future of sandy shores, Nature Reviews Earth & Environment, 2, 70–84, https://doi.org/10.1038/s43017-020-00109-9, publisher: Nature Publishing Group, 2021.

Delforge, D., Wathelet, V., Below, R., Sofia, C. L., Tonnelier, M., van Loenhout, J. A. F., and Speybroeck, N.: EM-DAT: the Emergency Events Database, International Journal of Disaster Risk Reduction, 124, 105 509, https://doi.org/10.1016/j.ijdrr.2025.105509, 2025.

https://doi.org/10.5194/egusphere-2026-96
Preprint. Discussion started: 19 January 2026

Dowling, C. A. and Santi, P. M.: Debris flows and their toll on human life: a global analysis of debris-flow fatalities from 1950 to 2011, Natural Hazards, 71, 203–227, https://doi.org/10.1007/s11069-013-0907-4, 2014.

Duperret, A., Genter, A., Martinez, A., and Mortimore, R. N.: Coastal chalk cliff instability in NW France: Role of lithology, fracture pattern and rainfall, in: Coastal Chalk Cliff Instability, edited by Mortimore, R. N. and Duperret, A., vol. 20, p. 0, The Geological Society of London, ISBN 978-1-86239-150-5, https://doi.org/10.1144/GSL.ENG.2004.020.01.03, 2004.

Duperret, A., Taibi, S., Mortimore, R. N., and Daigneault, M.: Effect of groundwater and sea weathering cycles on the strength of chalk rock from unstable coastal cliffs of NW France, Engineering Geology, 78, 321–343, https://doi.org/10.1016/j.enggeo.2005.01.004, 2005.

Emery, K. O. and Kuhn, G. G.: Sea cliffs: Their processes, profiles, and classification, GSA Bulletin, 93, 644–654, https://doi.org/10.1130/0016-7606(1982)93<644:SCTPPA>2.0.CO;2, 1982.

European Commission: Coastal tourism - EU Blue Economy Observatory, https://blue-economy-observatory.ec.europa.eu/eu-blue-economy-sectors/coastal-tourism_en (last access: 12 November 2025), 2023.

Foss, O., Blenkinsopp, C. E., Bayle, P. M., Martins, K., Schimmels, S., and Almeida, L. P.: Comparison of dynamic cobble berm revetments with differing gravel characteristics, Coastal Engineering, 183, 104 312, https://doi.org/10.1016/j.coastaleng.2023.104312, 2023.

Foster, C., Pennington, C. V. L., Culshaw, M. G., and Lawrie, K.: The national landslide database of Great Britain: development, evolution and applications, Environmental Earth Sciences, 66, 941–953, https://doi.org/10.1007/s12665-011-1304-5, https://www.bgs.ac.uk/datasets/national-landslide-database/, 2012.

Fox, T.: Huge section of cliff collapses in East Sussex next to footpath, Sussex News, https://www.sussexlive.co.uk/news/sussex-news/huge-section-cliff-collapses-peacehaven-7988514 (last access: 1 August 2025), 3 January 2023.

Froude, M. J. and Petley, D. N.: Global fatal landslide occurrence from 2004 to 2016, Natural Hazards and Earth System Sciences, 18, 2161–2181, https://doi.org/10.5194/nhess-18-2161-2018, publisher: Copernicus GmbH, 2018.

Geological Survey Ireland: GSI Landslide Data Viewer Ireland ITM: Landslides. Contains Irish Public Sector Data (Geological Survey Ireland) licensed under a Creative Commons Attribution 4.0 International (CC BY 4.0) licence, https://www.gsi.ie/en-ie/data-and-maps/Pages/default.aspx (last access: 1 October 2025), 2025.

Georgopoulou, E., Mirasgedis, S., Sarafidis, Y., Hontou, V., Gakis, N., and Lalas, D. P.: Climatic preferences for beach tourism: an empirical study on Greek islands, Theoretical and Applied Climatology, 137, 667–691, https://doi.org/10.1007/s00704-018-2612-4, 2019.

Gornitz, V.: Global coastal hazards from future sea level rise, Palaeogeography, Palaeoclimatology, Palaeoecology, 89, 379–398, https://doi.org/10.1016/0031-0182(91)90173-O, 1991.

Griggs, G. and Kinsman, N.: Beach widths, cliff slopes, and artificial nourishment along the California Coast, Shore & Beach, 84, 1–12, 2016.

Griggs, G. B.: The Impacts of Coastal Armoring, Shore & Beach, 73, 13–22, 2005.

Griggs, G. B. and Fulton-Bennett, K.: Rip rap revetments and seawalls and their effectiveness along the central California coast, Shore & Beach, 56, 3–11, 1988.

Gómez, D., García, E. F., and Aristizábal, E.: Spatial and temporal landslide distributions using global and open landslide databases, Natural Hazards, 117, 25–55, https://doi.org/10.1007/s11069-023-05848-8, 2023.

Hampton, M. A., Griggs, G. B., Shipman, H. M., Edil, T. B., Guy, D. E., Kelley, J. T., Komar, P. D., and Mickelson, D. M.: Processes that govern the formation and evolution of coastal cliffs, US Geological Survey professional paper, pp. 7–38, 2004.

Haque, U., Blum, P., da Silva, P. F., Andersen, P., Pilz, J., Chalov, S. R., Malet, J.-P., Aufli˘ c, M. J., Andres, N., Poyiadji, E., Lamas, P. C., Zhang, W., Peshevski, I., Pétursson, H. G., Kurt, T., Dobrev, N., García-Davalillo, J. C., Halkia, M., Ferri, S., Gaprindashvili, G., Engström, J., and Keellings, D.: Fatal landslides in Europe, Landslides, 13, 1545–1554, https://doi.org/10.1007/s10346-016-0689-3, 2016.

Haque, U., da Silva, P. F., Devoli, G., Pilz, J., Zhao, B., Khaloua, A., Wilopo, W., Andersen, P., Lu, P., Lee, J., Yamamoto, T., Keellings, D., Wu, J.-H., and Glass, G. E.: The human cost of global warming: Deadly landslides and their triggers (1995–2014), Science of The Total Environment, 682, 673–684, https://doi.org/10.1016/j.scitotenv.2019.03.415, 2019.

Harp, E. L. and Youd, T. L.: Landslides, Earthquake Spectra, 11, 41–48, https://doi.org/10.1193/1.1585838, publisher: SAGE Publications Ltd STM, 1995.

Herre, B. and Samborska, V.: Tourism, Our World in Data, https://ourworldindata.org/tourism (last access: 26 August 2025, 26 July 2023.

ISPRA: Inventory of Landslide Phenomena in Italy – IFFI, ISPRA – Regione/Provincia Autonoma [dataset], https://www.progettoiffi.isprambiente.it/, last access: 10 September 2025.

Kirschbaum, D., Adler, R., Adler, D., Peters-Lidard, C., and Huffman, G.: Global Distribution of Extreme Precipitation and High-Impact Landslides in 2010 Relative to Previous Years, https://doi.org/10.1175/JHM-D-12-02.1, section: Journal of Hydrometeorology, 2012.

Kirschbaum, D., Stanley, T., and Zhou, Y.: Spatial and temporal analysis of a global landslide catalog, Geomorphology, 249, 4–15, https://doi.org/10.1016/j.geomorph.2015.03.016, 2015.

Kirschbaum, D. B., Adler, R., Hong, Y., Hill, S., and Lerner-Lam, A.: A global landslide catalog for hazard applications: method, results, and limitations, Natural Hazards, 52, 561–575, https://doi.org/10.1007/s11069-009-9401-4, 2010.

Kirschbaum, D. B., Stanley, T. A., Kostis, H.-N., and Fitzgibbons, R.: Global Landslide Catalog, NASA's Scientific Visualization Studio [dataset], https://svs.gsfc.nasa.gov/4632#section_credits (last access: 9 October 2025), 2021.

Kline, S. W., Adams, P. N., and Limber, P. W.: The unsteady nature of sea cliff retreat due to mechanical abrasion, failure and comminution feedbacks, Geomorphology, 219, 53–67, https://doi.org/10.1016/j.geomorph.2014.03.037, 2014.

Kogure, T.: Rocky coastal cliffs reinforced by vegetation roots and potential collapse risk caused by sea-level rise, CATENA, 217, 106 457, https://doi.org/10.1016/j.catena.2022.106457, 2022.

https://doi.org/10.5194/egusphere-2026-96
Preprint. Discussion started: 19 January 2026

Letavernier, G.: La gélivité des roches calcaires. Relations avec la morphologie du milieu poreux. Par G. Letavernier. Thèse Doctorat 3e cycle Géographie, Univ. de Caen, 1984, https://www.persee.fr/doc/karst_0751-7688_1986_num_8_1_2144_t1_0058_0000_5, publisher: Persée - Portail des revues scientifiques en SHS, 1984.

Letortu, P., Costa, S., Cador, J.-M., Coinaud, C., and Cantat, O.: Statistical and empirical analyses of the triggers of coastal chalk cliff failure, Earth Surface Processes and Landforms, 40, 1371–1386, https://doi.org/10.1002/esp.3741, _eprint: https://onlinelibrary.wiley.com/doi/pdf/10.1002/esp.3741, 2015.

Maerz, N. H., Youssef, A. M., Pradhan, B., and Bulkhi, A.: Remediation and mitigation strategies for rock fall hazards along the highways of Fayfa Mountain, Jazan Region, Kingdom of Saudi Arabia, Arabian Journal of Geosciences, 8, 2633–2651, https://doi.org/10.1007/s12517-014-1423-x, 2015.

Marinho, B., Coelho, C., Hanson, H., and Tussupova, K.: Coastal management in Portugal: Practices for reflection and learning, Ocean & Coastal Management, 181, 104 874, https://doi.org/10.1016/j.ocecoaman.2019.104874, 2019.

MATLAB version: 24.2.0.2863752 (R2024b): https://www.mathworks.com.

Matsumoto, H., Dickson, M. E., Stephenson, W. J., Thompson, C. F., and Young, A. P.: Modeling future cliff-front waves during sea level rise and implications for coastal cliff retreat rates, Scientific Reports, 14, 7810, https://doi.org/10.1038/s41598-024-57923-0, publisher: Nature Publishing Group, 2024.

McGranahan, G., Balk, D., and Anderson, B.: The rising tide: assessing the risks of climate change and human settlements in low elevation coastal zones, Environment & Urbanization, 19, 17–37, https://doi.org/10.1177/0956247807076960, publisher: SAGE Publications Ltd, 2007.

McInnes, R., Jakeways, J., Fairbank, H., and Mathie, E.: Landslides and Climate Change: Challenges and Solutions: Proceedings of the International Conference on Landslides and Climate Change, Ventnor, Isle of Wight, UK, 21-24 May 2007, CRC Press, ISBN 978-1-000-00670-4, google-Books-ID: _smnDwAAQBAJ, 2007.

Melis, M. T., Da Pelo, S., Erbì, I., Loche, M., Deiana, G., Demurtas, V., Meloni, M. A., Dessì, F., Funedda, A., Scaioni, M., and Scaringi, G.: Thermal Remote Sensing from UAVs: A Review on Methods in Coastal Cliffs Prone to Landslides, Remote Sensing, 12, 1971, https://doi.org/10.3390/rs12121971, number: 12 Publisher: Multidisciplinary Digital Publishing Institute, 2020.

Migron, C.: Base de données mouvements de terrain (BDMVT), Geologists (Paris), 132, 85–87, https://www.georisques.gouv.fr/donnees/bases-de-donnees/base-de-donnees-mouvements-de-terrain, 2002.

Mirus, B. B., Jones, E. S., Baum, R. L., Godt, J. W., Slaughter, S., Crawford, M. M., Lancaster, J., Stanley, T., Kirschbaum, D. B., Burns, W. J., Schmitt, R. G., Lindsey, K. O., and McCoy, K. M.: Landslides across the USA: occurrence, susceptibility, and data limitations, Landslides, 17, 2271–2285, https://doi.org/10.1007/s10346-020-01424-4, 2020.

Morales, T., Clemente, J. A., Damas Mollá, L., Izagirre, E., and Uriarte, J. A.: Analysis of instabilities in the Basque Coast Geopark coastal cliffs for its environmentally friendly management (Basque-Cantabrian basin, northern Spain), Engineering Geology, 283, 106 023, https://doi.org/10.1016/j.enggeo.2021.106023, 2021.

Moreiras, S. M.: Climatic effect of ENSO associated with landslide occurrence in the Central Andes, Mendoza Province, Argentina, Landslides, 2, 53–59, https://doi.org/10.1007/s10346-005-0046-4, 2005.

Natural Earth: Natural Earth » Blog Archive » Admin 0 – Countries - Free vector and raster map data at 1:10m, 1:50m, and 1:110m scales, https://www.naturalearthdata.com/downloads/110m-cultural-vectors/110m-admin-0-countries/, last access: 8 July 2025.

NVE kartkatalog: Avalanche events, https://kartkatalog.nve.no/, last access: 10 July 2025.

Olsen, M. J., Johnstone, E., Ashford, S. A., Driscoll, N., Young, A. P., Hsieh, T. J., and Kuester, F.: Rapid Response to Seacliff Erosion in San Diego County, California Using Terrestrial LIDAR, pp. 573–583, https://doi.org/10.1061/40968(312)52, publisher: American Society of Civil Engineers, 2012.

Pereira, S., Zêzere, J. L., and Quaresma, I.: Landslide Societal Risk in Portugal in the Period 1865–2015, in: Advancing Culture of Living with Landslides, edited by Sassa, K., Mikoš, M., and Yin, Y., pp. 491–499, Springer International Publishing, Cham, ISBN 978-3-319-59469-9, https://doi.org/10.1007/978-3-319-59469-9_43, 2017.

Petley, D.: On the impact of climate change and population growth on the occurrence of fatal landslides in South, East and SE Asia, Quarterly Journal of Engineering Geology and Hydrogeology, 43, 487–496, https://doi.org/10.1144/1470-9236/09-001, 2010.

Petley, D.: Global patterns of loss of life from landslides, Geology, 40, 927–930, https://doi.org/10.1130/G33217.1, 2012.

Petley, D.: The Pilar landslide in the Philippines, The Landslide Blog, https://blogs.agu.org/landslideblog/2022/05/03/pilar-landslide-1/ (last access: 5 August 2025), 3 May 2022a.

Petley, D.: Understanding the deadly landslides in the Durban area of South Africa, The Landslide Blog, https://blogs.agu.org/landslideblog/2022/04/22/durban-1/ (last access: 5 August 2025), 22 April 2022b.

Petley, D. N.: On the impact of urban landslides, in: Engineering Geology for Tomorrow's Cities, edited by Culshaw, M. G., Reeves, H. J., Jefferson, I., and Spink, T. W., vol. 22, pp. 83–89, Geological Society of London, ISBN 978-1-86239-290-8, https://doi.org/10.1144/EGSP22.6, 2009.

Petrucci, O.: Landslide Fatality Occurrence: A Systematic Review of Research Published between January 2010 and March 2022, Sustainability, 14, 9346, https://doi.org/10.3390/su14159346, number: 15 Publisher: Multidisciplinary Digital Publishing Institute, 2022.

Pradeepkumar, A. P., Behr, F. J., and Shaji, E. Proceedings of the 2nd Disaster, Risk, and Vulnerability Conference: 24-26 April, 2014. Dept. of Geology, University of Kerala, Thiruvanan, 2014.

Riggins, A.: 'Normal beach day gone awry': 3 killed in Encinitas bluff collapse, San Diego Union-Tribune, https://www.sandiegouniontribune.com/2019/08/02/normal-beach-day-gone-awry-3-killed-in-encinitas-bluff-collapse/ (last access: 6 August 2025), 2 August 2019.

Risso, W. A.: Tourism and Economic Growth: A Worldwide Study, Tourism Analysis, 23, 123–135, https://doi.org/10.3727/108354218X15143857349828, 2018.

Rivalland, N.: Authority urges safety near cliffs, Surf Coast Times, https://timesnewsgroup.com.au/surfcoasttimes/news/authority-urges-safety-near-cliffs/ (last access: 1 August 2025), 5 February 2025.

Rosser, B., Dellow, S., Haubrock, S., and Glassey, P.: New Zealand's National Landslide Database, Landslides, 14, 1949–1959, https://doi.org/10.1007/s10346-017-0843-6, 2017.

San Diego International Airport (SAN): Passenger Traffic Data, https://www.san.org/passenger-traffic-data/, last access: 26 August 2025.

Santi, P. M., Hewitt, K., VanDine, D. F., and Barillas Cruz, E.: Debris-flow impact, vulnerability, and response, Natural Hazards, 56, 371–402, https://doi.org/10.1007/s11069-010-9576-8, 2011.

Schneider, U., Finger, P., Rustemeier, E., Ziese, M., and Hansel, S.: Global Precipitation Analysis Products of the GPCC, https://opendata.dwd.de/climate_environment/GPCC/PDF/GPCC_intro_products_v2022.pdf, 2022.

Sepúlveda, S. A. and Petley, D. N.: Regional trends and controlling factors of fatal landslides in Latin America and the Caribbean, Natural Hazards and Earth System Sciences, 15, 1821–1833, https://doi.org/10.5194/nhess-15-1821-2015, publisher: Copernicus GmbH, 2015.

Sevdari, K. and Marmullaku, D.: Shapefile of European countries, Technical University of Denmark [dataset], https://doi.org/10.11583/DTU.23686383.v1 (last access: 1 December 2025), 2023.

Silva, R., Mendoza, E., Mariño-Tapia, I., Martínez, M. L., and Escalante, E.: An artificial reef improves coastal protection and provides a base for coral recovery, Journal of Coastal Research, 75, 467–471, https://doi.org/https://doi.org/10.2112/SI75-094.1, 2016.

Stringham, T.: Climate, Latitude and Wealth, All Graduate Plan B and other Reports, Spring 1920 to Spring 2023, https://doi.org/https://doi.org/10.26076/a211-21b7, 2015.

Sunamura, T.: A wave tank experiment on the erosional mechanism at a cliff base, Earth Surface Processes and Landforms, 7, 333–343, https://doi.org/10.1002/esp.3290070405, _eprint: https://onlinelibrary.wiley.com/doi/pdf/10.1002/esp.3290070405, 1982.

Sunamura, T.: Geomorphology of rocky coasts. Chichester: Wiley. x + 302 pp. £55.00 cloth. ISBN: 0 471 91775 3, Progress in Physical Geography: Earth and Environment, 18, 616–617, https://doi.org/https://doi.org/10.1177/030913339401800416, publisher: SAGE Publications Ltd, 1992.

Swedish Geotechnical Institute (SGI): SGI Landslide Database, https://gis.sgi.se/hajk/?m=skred, last access: 10 August 2025.

Swirad, Z. M. and Young, A. P.: Hazard of coastal cliff top failure through time, Geomorphology, 481, 109 791, https://doi.org/10.1016/j.geomorph.2025.109791, 2025.

The Portugal News: Algarve cliff danger awareness, The Portugal News, http://www.theportugalnews.com/news/2024-07-20/algarve-cliff-danger-awareness/90748 (last access: 8 December 2025), 20 July 2024.

Trenhaile, A. S.: The geomorphology of rock coasts, Oxford Oxfordshire : Clarendon Press ; New York : Oxford University Press, 1987.

Trenhaile, A. S.: Modeling the accumulation and dynamics of beaches on shore platforms, Marine Geology, 206, 55–72, https://doi.org/10.1016/j.margeo.2004.03.013, 2004.

Trenhaile, A. S.: The effect of Holocene changes in relative sea level on the morphology of rocky coasts, Geomorphology, 114, 30–41, https://doi.org/10.1016/j.geomorph.2009.02.003, 2010.

Trenhaile, A. S. and Kanyaya, J. I.: The Role of Wave Erosion on Sloping and Horizontal Shore Platforms in Macro- and Mesotidal Environments, Journal of Coastal Research, 23, 298–309, https://doi.org/10.2112/04-0282.1, 2007.

https://doi.org/10.5194/egusphere-2026-96
Preprint. Discussion started: 19 January 2026

United Nations: UN Tourism Data Dashboard | International Tourist Arrivals, http://www.unwto.org/tourism-data/un-tourism-tourism-dashboard, last access: 8 July 2024.

US Census Bureau: International Database (IDB), https://www.census.gov/data-tools/demo/idb/#/dashboard?dashboard_page=country&COUNTRY_YR_ANIM=2018&COUNTRY_YEAR=2018, last access: 28 August 2025.

US Department of Commerce.: NOWData - NOAA Online Weather Data, https://www.weather.gov/wrh/climate?wfo=sgx, publisher: NOAA's National Weather Service, last access: 8 July 2025.

Van Den Eeckhaut, M. and Hervás, J.: State of the art of national landslide databases in Europe and their potential for assessing landslide susceptibility, hazard and risk, Geomorphology, 139-140, 545–558, https://doi.org/10.1016/j.geomorph.2011.12.006, 2012.

Williams, A. T. and Williams, M. J.: The perceived effectiveness of coastal warning signs, in: Coastlines of the Caribbean, pp. 70–84, Amer. Soc. Civil Eng., New York, g. cambers edn., 1991.

Wood, J. L., Harrison, S., Reinhardt, L., and Taylor, F. E.: Landslide databases for climate change detection and attribution, Geomorphology, 355, 107 061, https://doi.org/10.1016/j.geomorph.2020.107061, 2020.

Young, A. P. and Ashford, S. A.: Instability investigation of cantilevered seacliffs, Earth Surface Processes and Landforms, 33, 1661–1677, https://doi.org/10.1002/esp.1636, _eprint: https://onlinelibrary.wiley.com/doi/pdf/10.1002/esp.1636, 2008.

Young, A. P. and Carilli, J. E.: Global distribution of coastal cliffs, Earth Surface Processes and Landforms, 44, 1309–1316, https://doi.org/10.1002/esp.4574, _eprint: https://onlinelibrary.wiley.com/doi/pdf/10.1002/esp.4574, 2019.

Young, A. P., Guza, R. T., Flick, R. E., O'Reilly, W. C., and Gutierrez, R.: Rain, waves, and short-term evolution of composite seacliffs in southern California, Marine Geology, 267, 1–7, https://doi.org/https://doi.org/10.1016/j.margeo.2009.08.008, publisher: Elsevier, 2009.

Zêzere, J. L., Pereira, S., Tavares, A. O., Bateira, C., Trigo, R. M., Quaresma, I., Santos, P. P., Santos, M., and Verde, J.: DISASTER: a GIS database on hydro-geomorphologic disasters in Portugal, Natural Hazards, 72, 503–532, https://doi.org/10.1007/s11069-013-1018-y, 2014.