Natural Hazards and Risk Analysis

Long report

Franz-Joseph-Strasse 10, 80801 München

Latitude, Longitude 48.1577, 11.5825

Asset type Multi-story apartment building / office building - 3-7 floors

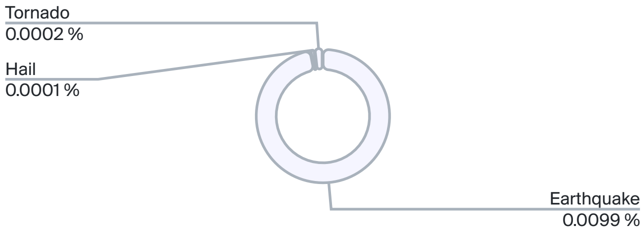
Terrain elevation 519.89 m above sea level

Flood defense target (return period) 100-year

Total value (EUR) 1,000,000

Total expected annual loss

0.0102% Very low



No risk
Coastal flood
Riverine flood
Storm
Tsunami
Volcano

Hazard	Severity	Expected annual loss (% p.a.)[2]	Return period (years)	PML (%)[3]	PML (EUR)
Riverine flood	No risk	0.0000	200 100	0.00 0.00	0 0
Coastal flood	No risk	0.0000	250 100	0.00 0.00	0 0
Heavy rain [4]	Very low	0.0276	250 100	6.23 2.98	62,301 29,841
Hail	Very low	0.0001	200 100	0.00 0.00	0 0
Storm	No risk	0.0000	200 100	0.00 0.00	0 0
Tornado	Very low	0.0002	200 100	0.06 0.03	559 279
Earthquake	Very low	0.0099	475 100	0.80 0.46	8,049 4,556
Volcano	No risk	0.0000	-	-	-
Tsunami	No risk	0.0000	475	0.00	0

Legend

The following risk labels are applied for increasing expected annual loss.

-	<0.05%	0.05% - 0.1%	0.1% - 0.4%	0.4% - 0.7%	0.7% - 1%	>1%
No risk	Very low	Low	Medium	Medium high	High	Very high

Footnotes

[1] **Flood defense target** Many areas have flood protection measures in place to counteract flood events, such as walls or embankments. The number refers to the return period (in years) of the flood event up to which the protection is effective. In case the user does not provide the flood protection level, VIDA estimates the flood protection level based on a established dataset.

[2] **Expected annual loss (%p.a.)** Estimation of the percentage of the total value of the asset destroyed per year by the corresponding hazard.

[3] **PML (%)** Probable Maximum Loss is the estimated loss to an asset in case an event with the specified return period occurs. The PML is given as a percentage of the total asset value as well as in the currency specified by the user.

[4] **Heavy rain** Heavy rain is a hazard which is partially already included in riverine flood. Furthermore, the hazard is not derived from a hydrological model. As a result, this hazard is supplementary and its value not used for the total estimated risk.

Sources are omitted on this report for brevity. For the list of datasets used, please see the long report.

Riverine flood

Riverine flood occurs when a river's water level rises and overflows. It can be caused by heavy rain, snowmelt and intensified by deforestation, urban and agricultural development. Riverine flood can weaken foundations, shift structures, and damage walls, floors, and electrical systems.

Expected annual loss

0.0000% No risk

Risk figures

Flood defense target (return period) 100-year

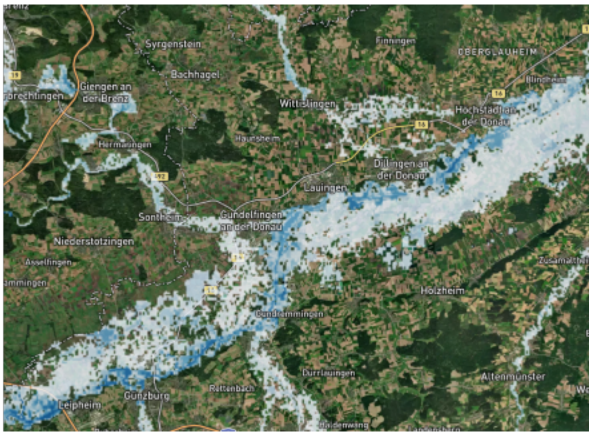
Return period	10-year	20-year	50-year	100-year	200-year	500-year
Flood depth (undefended)	0 m	0 m	0 m	0 m	0 m	0 m
PML (undefended)	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Flood depth (defended)	0 m	0 m	0 m	0 m	0 m	0 m
PML (defended)	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

Methodology

- The flood risk is based on the European/Global river flood hazard maps developed by the European Joint Research Centre (JRC) driven by the European and Global Flood Awareness Systems (EFAS and GloFAS) of the Copernicus Emergency Management Service (Baugh et al.).
- Unless a flood protection level is given by the user, it is estimated based on the FLOPROS database by Scussolini et al. We estimate the corresponding protected flood depth and then only consider the overflow.
- A buffer with a radius of ~150 meters around the location is considered, and the maximum flood depth within this area used for the analysis. This approach accounts for potential discrepancies between flood models and incorporates the spatial context of the building.

Vulnerability curves

- The curves are sourced from Huizinga et al. from the JRC. They provide average vulnerabilities for residential, commercial, and industrial buildings for all continents. To adapt the curves to multi-storey buildings, we assume equal cost per floor and scale the curves accordingly.



Example image of the undefended riverine flood hazard map by JRC over parts of Germany.

Coastal flood

Coastal flooding occurs when high tides, storm surges and/ or waves push seawater towards the coast. It is generally exacerbated by rising sea levels. Floodwaters can weaken foundations, cause structural shifts and degrade building materials. Interior walls, floors and electrical systems may also be damaged.

Expected annual loss

0.0000% No risk

Risk figures

Flood defense target (return period) 100-year

Return period	100-year	250-year
Flood depth (undefended)	0 m	0 m
PML (undefended)	0.00%	0.00%
Flood depth (defended)	0 m	0 m
PML (defended)	0.00%	0.00%

Methodology

- The Deltares flood inundation map is used to assess coastal flood risk for return periods of up to 250 years.
- The model is forced by extreme water levels containing surge and tide from the Global Tide Surge Model (GTSM).
- The same flood protection levels are applied as for riverine flood.

Vulnerability curves

- The curves are sourced from Huizinga et al. from the JRC. They provide average vulnerabilities for residential, commercial, and industrial buildings for all continents. To adapt the curves to multi-story buildings, we assume equal cost per floor and scale the curves accordingly.

Example image of the undefended coastal flood hazard map.

Heavy rain

Flooding occurs when heavy rainfall exceeds the ability of the ground or drainage system to absorb water. Floodwaters can weaken foundations, cause structural shifts and degrade building materials. Interior walls, floors and electrical systems may also be damaged.

Expected annual loss

0.0276% Very low

Risk figures

Return period	100-year	250-year
Flood depth	0.15 m	0.31 m
PML	2.98%	6.23%

Methodology

- Pluvial flood risk is determined by analyzing extreme precipitation events using ECMWF's ERA5 reanalysis data and fitting a Generalized Extreme Value distribution to estimate return levels up to 500 years. ERA5 provides comprehensive global coverage of data of multiple sources, from weather stations to satellite measurements of precipitation and other climate variables.
- Runoff generation is modelled using the Curve Number method, with excess rainfall beyond a 5- year design threshold converted into runoff and used to estimate flood damages by applying the vulnerability curves.
- Heavy rain is a hazard which is partially already included in riverine flood. Furthermore, the hazard is not derived from a hydrological model. As a result, this hazard is supplementary and its value not used for the total estimated risk.

Vulnerability curves

- The curves are sourced from Huizinga et al. from the JRC. They provide average vulnerabilities for residential, commercial, and industrial buildings for all continents. To adapt the curves to multi-story buildings, we assume equal cost per floor and scale the curves accordingly.

Hail

Hail forms during storms when water droplets are carried into extremely cold regions of the atmosphere, where they can grow to several centimeters in diameter. It has the potential to damage exterior parts of buildings, such as roofs and windows, as well as surrounding structures, vehicles, and pose a risk to people.

Expected annual loss

0.0001% Very low

Risk figures

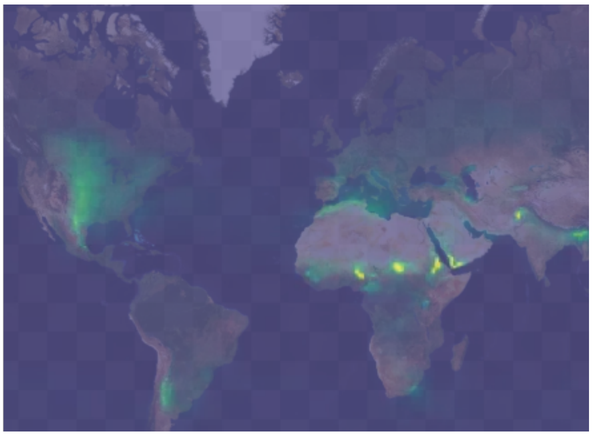
Return period	100-year	200-year
Hail size	3.52 cm	3.87 cm
PML	0.00%	0.00%

Methodology

- The global hail climatology from Prein et al. is used to calculate the global hail occurrence rate.
- Historical US hail size measurements are used to correlate hail occurrences with hail size and calculate return periods for different hail sizes globally.

Vulnerability curves

- It is assumed that hail damage predominantly impacts roofs (see Pucik et al.)
- Furthermore, the impacts of hail on two different types of roofs is considered (see Li et al. Class 2 roof for residential buildings, class 4 roof for commercial buildings), along with the assumption that the roof makes up 15% of the total cost of the asset.



Global hail potential.

Storm

Strong winds from storm events can strip roofing materials, break windows, and damage facades, especially in buildings not designed for such conditions. Strong winds can also impact nearby structures, vehicles, and people.

Expected annual loss

0.0000% No risk

Risk figures

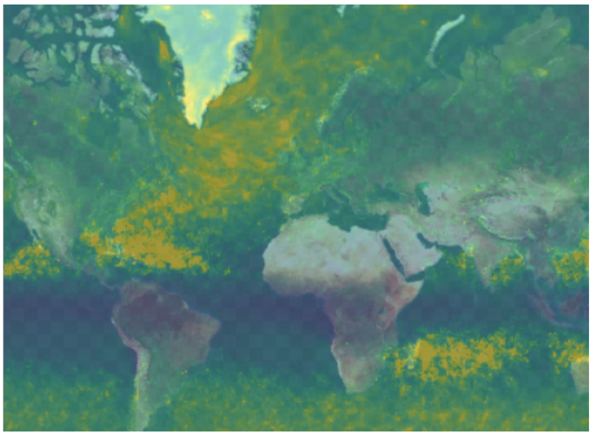
Return period	100-year	200-year
Wind speed	36.06 m/s	39.48 m/s
PML	0.00%	0.00%

Methodology

- The last 30 years of ERA-5 data is used to calculate the max wind gust speeds in m/s at a 0.25° resolution (~27km). Reanalysis data combines multiple types of observations and data, hence it is deemed the best dataset in this case.
- A generalized extreme value distribution is fitted to the dataset to calculate the max wind gust speed at different return periods.

Vulnerability curves

- The damage curves are based on a publication by Feuerstein et al. from the European Sever Storms Laboratory on the impact of wind gust speed on different building materials (weak brick/strong brick/concrete).



Global max wind gust speed distribution (100 year return).

Tornado

Tornadoes are destructive, funnel-shaped vortices of rotating winds formed when warm, humid air meets cold, dry air during a thunderstorm. Although rare, if they do occur they can cause significant structural damage or complete destruction of assets.

Expected annual loss

0.0002% Very low

Risk figures

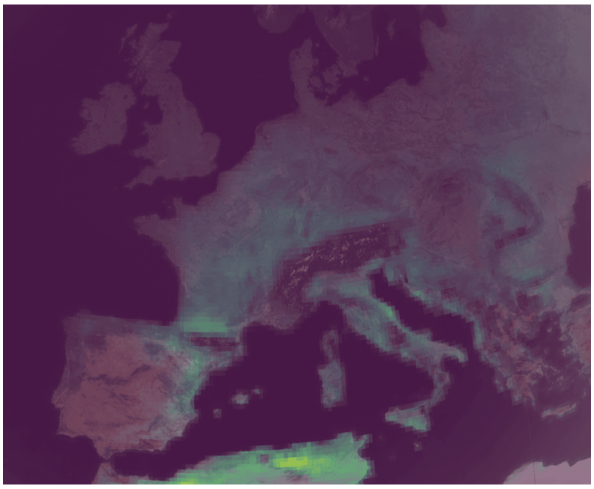
Return period	100-year	200-year
Expected tornado potential	0.02	0.04
PML	0.03%	0.06%

Methodology

- Hail is used as a proxy to predict tornadoes given their heavy correlation. A model is trained to predict tornadoes with >EF-3 from the hail dataset over the USA using the the Tornado Archive.
- A dampening is applied based on terrain roughness, accounting for the fact that tornadoes mostly form in flat lands (Grieser et al.)
- Applying this methodology to Europe would overestimate strong tornado occurrence in Europe. To correct for this, the tornado occurrence is dampened by 85% based on the fact that Europe has about 15% of tornados in the USA according to Grieser et al.
- The expected tornado potential shown in the table above represents the number of expected tornadoes within the given time period.

Vulnerability curves

- The damage curves are identical to the ones used for storm.
- A weighted average of the wind speeds of tornado occurences is assumed for each tornado, resulting in a weighted average of 71 m/s.



Estimated probability of tornado occurrence.

Earthquake

Earthquakes occur when tectonic plates shift along a fault, causing damage from structural collapse to cracking and wall failures. Equipment, furniture, and windows may be damaged, and internal systems like HVAC (heating, ventilation, and air conditioning) and plumbing can be impacted.

Expected annual loss

0.0099% Very low

Risk figures

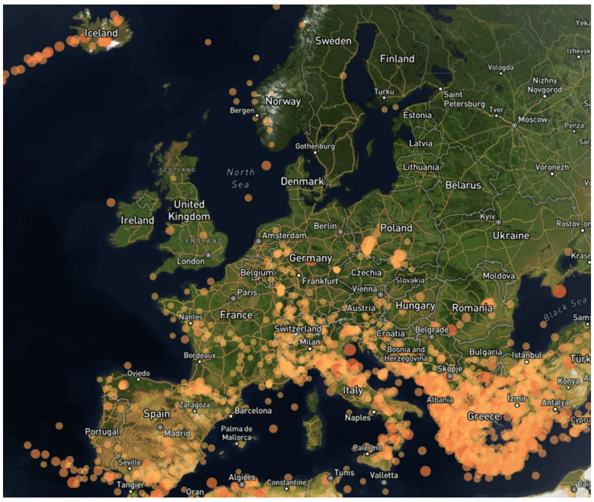
Return period	50-year	100-year	200-year	475-year	500-year	1000-year
Magnitude	5.34	5.73	6.12	6.61	6.64	7.03
PML	0.39%	0.46%	0.56%	0.80%	0.82%	1.25%

Methodology

- The database of historic earthquakes by the U.S. Geological Survey (USGS) Earthquake Hazards Program (EHP) is used.
- For each location, earthquakes within a radius of 150km are considered.
- Given the low frequency of earthquakes compared to other natural hazards, higher return periods, including a 475- year earthquake event (6% chance during a 30 year period) are considered.

Vulnerability curves

- The magnitude- vulnerability curve is developed based on estimations for different soil conditions from the fragility curves in Grigoriu et al.



Recorded earthquakes from the USGS database.

Volcano

Eruptions are rare but can cause damage ranging from complete building destruction to damage to roofing and facades.

Expected annual loss

0.0000% No risk

Risk figures

Showing up to 8 nearest volcanoes.

Volcano name	Years since first eruption	Estimated recurrence (years)	Distance from the site (m)
-	-	-	-

Methodology

- The Volcanoes of the World Database by the Smithsonian Institution is used to collect volcanic eruptions since the Holocene.
- An area with a 300 km radius around each location is considered, and every record of an eruption is collected to determine the probability of an eruption event.
- Destructive effects are assumed to decrease by half every 24 km.
- No PML is provided for volcanoes due to the difficulty in calculating a relevant return period for this hazard.

Vulnerability curves

- Vulnerability at a given point is the cumulative vulnerability from all volcanoes in the area of interest, capped at 100%, representing full asset destruction.

Recorded volcanic eruptions from the Smithsonian Institutions Volcanoes of the World Database.

Tsunami

Tsunamis are caused by sudden displacements in the ocean, typically resulting from earthquakes, landslides, or volcanic activity. They can cause widespread damage to buildings, including structural collapse, degradation of materials, and extensive interior damage.

Expected annual loss

0.0000% No risk

Risk figures

Return period	475 year
Mean inundation depth (meters)	0
PML	0.00%

Methodology

- Tsunami risk is estimated using historical data from FEMA (for the US), NEAMTHM18 (for Europe and North Africa), and the NOAA hazard database for other regions.
- The 475-year event risk is used as an indicator for each location.

Vulnerability curves

- The curves are sourced from Huizinga et al. from the JRC. They provide average vulnerabilities for residential, commercial, and industrial buildings for all continents. To adapt the curves to multi-story buildings, we assume equal cost per floor and scale the curves accordingly.

Sources

Riverine flood

Hazard maps

- Baugh, Calum; Colonese, Juan; D'Angelo, Claudia; Dottori, Francesco; Neal, Jeffrey; Prudhomme, Christel; Salamon, Peter (2024): Global river flood hazard maps. European Commission, Joint Research Centre (JRC) [Dataset] PID: http://data.europa.eu/89h/jrc-floods-floodmapgl_rp50y-tif , CC-BY 4.0 licence
- Baugh, Calum; Colonese, Juan; D'Angelo, Claudia; Dottori, Francesco; Neal, Jeffrey; Prudhomme, Christel; Salamon, Peter (2024): River flood hazard maps for Europe and the Mediterranean Basin region. European Commission, Joint Research Centre (JRC) [Dataset] doi: 10.2905/1D128B6C-A4EE-4858-9E34-6210707F3C81 PID: http://data.europa.eu/89h/1d128b6c-a4ee-4858-9e34-6210707f3c81, CC-BY 4.0 licence

Flood protection standards

- Scussolini, P., Aerts, J. C. J. H., Jongman, B., Bouwer, L. M., Winsemius, H. C., De Moel, H., & Ward, P. J. (2016). FLOPROS: an evolving global database of flood protection standards. Natural Hazards and Earth System Sciences, 16, 1049-1061. https://doi.org/10.5194/nhess-16-1049-2016

Vulnerability curves

- Huizinga, J., De Moel, H. and Szewczyk, W., Global flood depth-damage functions: Methodology and the database with guidelines, EUR 28552 EN, Publications Office of the European Union, Luxembourg, 2017, ISBN 978-92-79-67781-6, doi:10.2760/16510, JRC105688

Coastal flood

- Deltares (2021), hosted by Microsoft Planetary Computer, CDLA-Permissive-1.0 licence
- Flood protection standards and vulnerability curves: See riverine flood above.

Heavy rain

- Hersbach, H., and Coauthors, 2020: The ERA5 global reanalysis. Q.J.R. Meteorol. Soc., 146, 1999-2049, https://doi.org/10.1002/qj.3803.
- USDA-SCS (1986) Urban Hydrology for Small Watersheds. Technical Release No. 55 (TR-55). USDASCS, Washington DC.
- Vulnerability curves: See riverine flood.

Hail

Hazard map

- Prein, Andreas & Holland, Greg. 2018. Global estimates of damaging hail hazard. Weather and Climate Extremes. 22. 10.1016/j.wace.2018.10.004.
- Storm Events Database, NOAA / National Centers For Environmental Information, https://www.ncdc.noaa.gov/stormevents/

Vulnerability curves

- Yao Li, Keith Porter, Katsuichiro Goda, Hail hazard modeling with uncertainty analysis and roof damage estimation of residential buildings in North America, International Journal of Disaster Risk Reduction, Volume 113, 2024, 104853, ISSN 2212-4209, https://doi.org/10.1016/j.ijdrr.2024.104853.
- Púčik, T., C. Castellano, P. Groenemeijer, T. Kühne, A. T. Rädler, B. Antonescu, and E. Faust, 2019: Large Hail Incidence and Its Economic and Societal Impacts across Europe. Mon. Wea. Rev., 147, 3901–3916, https://doi.org/10.1175/MWR-D-19-0204.1.

Storm

Hazard map

- Hersbach, H., and Coauthors, 2020: The ERA5 global reanalysis. Q.J.R. Meteorol. Soc., 146, 1999-2049, https://doi.org/10.1002/qj.3803.

Vulnerability curves

- Bernold Feuerstein, Pieter Groenemeijer, Erik Dirksen, Martin Hubrig, Alois M. Holzer, Nikolai Dotzek, Towards an improved wind speed scale and damage description adapted for Central Europe, Atmospheric Research, Volume 100, Issue 4, 2011, Pages 547-564, ISSN 0169-8095, https://doi.org/10.1016/j.atmosres.2010.12.026.

Tornado

Hazard maps

- Prein, Andreas & Holland, Greg. (2018). Global estimates of damaging hail hazard. Weather and Climate Extremes. 22. 10.1016/j.wace.2018.10.004.
- Maas, M., Supinie, T., Berrington, A., et al. (2023). The Tornado Archive: Compiling and Visualizing a Worldwide, Digitized Tornado Database. Bulletin of the American Meteorological Society, 105(7), E1137-E1152.
- Grieser, J.; Haines, P. Tornado Risk Climatology in Europe. Atmosphere 2020, 11, 768. https://doi.org/10.3390/atmos11070768
- Vulnerability curves: See Storm.

Earthquake

- U.S. Geological Survey (USGS). Earthquake Hazards Program (EHP). Retrieved from https://earthquake.usgs.gov/earthquakes
- M. Grigoriu, A. Radu, Are seismic fragility curves fragile?, Probabilistic Engineering Mechanics, Volume 63, 2021, 103115, ISSN 0266-8920, https://doi.org/10.1016/j.probengmech.2020.103115.

Volcano

- Global Volcanism Program, 2024. [Database] Volcanoes of the World (v. 5.2.5; 23 Dec 2024). Distributed by Smithsonian Institution, compiled by Venzke, E. https://doi.org/10.5479/si.GVP.VOTW5-2024.5.2

Tsunami

- NGDC/WDS Global Historical Tsunami Database, doi:10.7289/V5PN93H7
- Basili, R., et a. (2018) NEAM Tsunami Hazard Model 2018 (NEAMTHM18): online data of the Probabilistic Tsunami Hazard Model for the NEAM Region from the TSUMAPS-NEAM project. Istituto Nazionale di Geofisica e Vulcanologia (INGV); https://doi.org/10.13127/tsunami/neamthm18 , CC-BY 4.0 licence
- Vulnerability curves: See riverine flood.

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