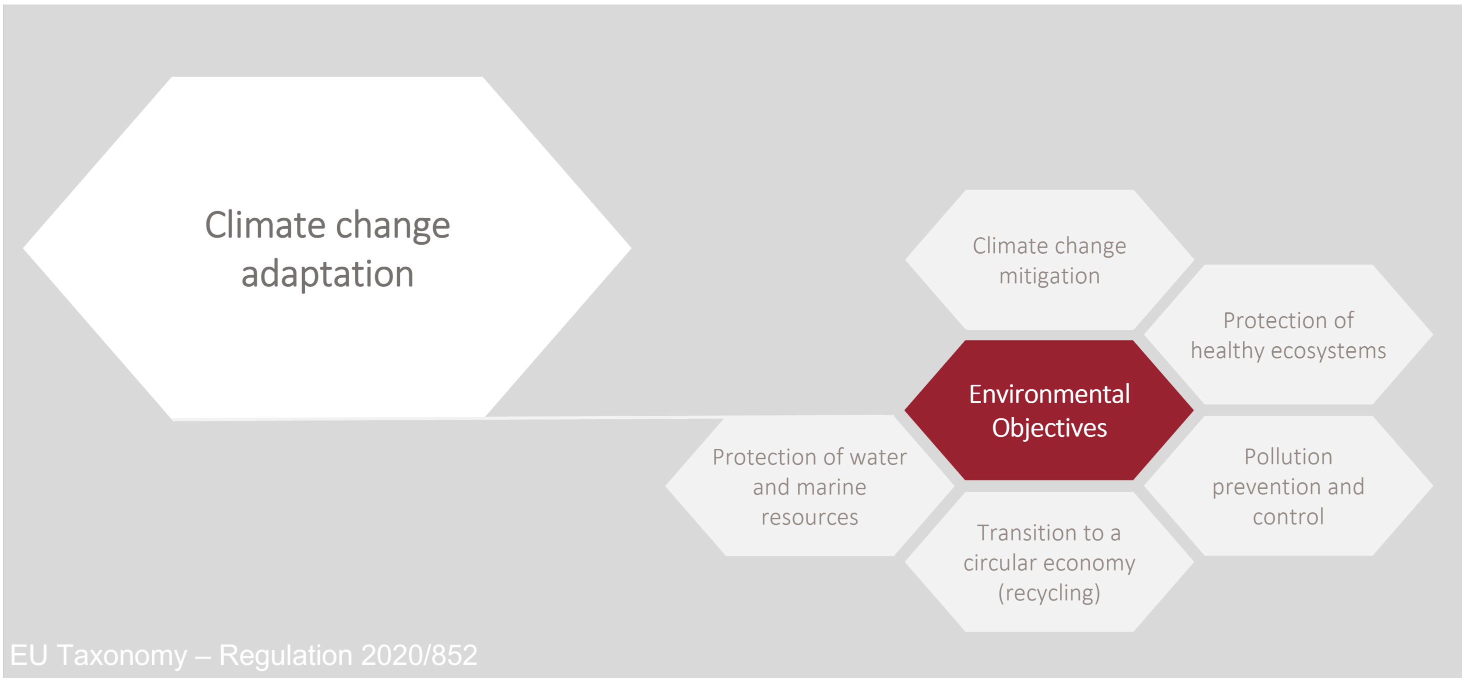
KA Köln.Assekuranz Agentur

Ein Unternehmen der ERGO

K.A.R.L.® Climate Risk and Vulnerability Analysis

Assessment of physical risks within the framework of the environmental objective 2 "Adaptation to climate change" from the EU Taxonomy Regulation (2020/852).



Site information

Address: Demo Location, Germany
Latitude: 51.xxx
Longitude: 7.yyy
Elevation (m a.s.l.): 300.00

Object type

K.A.R.L.®-vulnerability:
Shopping-Center
Simplified vulnerability:
Real Estate

Order information

Date of the analysis: 12.09.2023
Customer: Customer X
Taxonomy-Version: 1.2.0.1

Overview of the climate risk assessment

Site information: Demo Location, Germany (51.xxx / 7.yyy)

Object type: Real Estate (Shopping-Center)

	Climate-related hazards (EU Taxonomy 2020/852)	**Current* risk**	**Future** worst-case risk**	**Chapter**
Temperature	Changing temperature *(chronic)*	not relevant	not relevant	1.1
	Heat stress *(chronic)*	not relevant	low	1.2
	Temperature variability *(chronic)*	not relevant	not relevant	1.3
	Permafrost thawing *(chronic)*	excluded	excluded	1.4
	Heat wave *(acute)*	not relevant	low	1.5
	Cold wave/frost *(acute)*	not relevant	not relevant	1.6
	Wildfire *(acute)*	low	medium	1.7
Wind	Changing wind patterns *(chronic)*	not relevant	not relevant	2.1
	Cyclone, hurricane, taifun *(acute)*	excluded	excluded	2.2
	Storm (including snow-, dust- and sandstorms) *(acute)*	low	low	2.3
	Tornado *(acute)*	low	low	2.4
Water	Changing precipitation patterns and types (rain, hail, snow/ice) *(chronic)*	not relevant	not relevant	3.1
	Precipitation or hydrological variability *(chronic)*	not relevant	not relevant	3.2
	Ocean acidification *(chronic)*	excluded	excluded	3.3
	Saline intrusion *(chronic)*	excluded	excluded	3.4
	Sea level rise *(chronic)*	excluded	excluded	3.5
	Water stress *(chronic)*	not relevant	not relevant	3.6
	Drought *(chronic)*	not relevant	not relevant	3.7
	Heavy precipitation (rain, hail, snow/ice) *(acute)*	low	low	3.8
	Flood (coastal, fluvial, pluvial, groundwater) *(acute)*	not relevant	not relevant	3.9
	Glacial lake outburst *(acute)*	excluded	excluded	3.10
Solid mass	Coastal erosion *(chronic)*	excluded	excluded	4.1
	Soil degradation *(chronic)*	not relevant	not relevant	4.2
	Soil erosion *(chronic)*	not relevant	not relevant	4.2
	Solifluction *(chronic)*	excluded	excluded	4.3
	Avalanche *(acute)*	excluded	excluded	4.4
	Landslide *(acute)*	excluded	excluded	4.5
	Subsidence *(acute)*	low	low	4.6

**The current risk refers to the hazard of the near past (1985 to 2014) and depends on the sensitivity of the object under investigation. **The "worst case" risk is the highest risk across all scenarios and time periods.*

Notes on the evaluation

This document presents the results of a climate risk and vulnerability analysis conducted by KA Köln.Assekuranz Agentur GmbH for a chosen object. The present analysis fulfils all requirements from the EU-Taxonomy Regulation for a robust climate risk analysis, which are required for the environmental objective 2 ‘climate change adaptation‘.

As a part of the present analysis 28 both chronic and acute natural hazards were analysed on a site-specific basis. The aim is to identify all significant risks for the object under investigation, both under current and future climate conditions. For this the hazards were analysed not only on basis of observational data but also using an ensemble of 20 climate models, considering the prescribed emission scenarios (SSPSSP1-2.6, SSP2-4.5, SSP5-8.5) for four time periods (around 2000, 2030, 2050, 2085).

The result is a risk assessment for each natural hazard according to a four-level, quantitative classification system (traffic light colours). The meaning of the individual risk classes in terms of potential damage and the development of adaptation measures are presented in the following table.

Risk classification	Damage	Adaption measures
○ excluded	The occurrence of the natural hazard at the site or any adverse effect on the object under investigation can be **ruled out**.	Adaptation measures are not necessary.
● not relevant	Potential damage is **negligible**.	Adaption measures are not necessary.
● low	Potential damage is **low**. No substance damage.	In individual cases, an inspection of the site is advisable. Adaptation measures may be useful in exceptional cases.
● medium	Damage of a **medium extent** is possible or substance damage cannot be ruled out in extreme cases.	An on-site examination of the situation is strongly recommended. Adaptation measures must be decided on a case-by-case basis.
● high	A **significant risk** has been identified. Substance damage is possible.	Effective adaptation measures are required to reduce the risk (taxonomy compliance).

All significant risks are identified using appropriate and officially recognized data and methods, which are described in detail to users in a separate manual.

It is explicitly pointed out that part of the present analysis is based on partially not yet validated results.

The K.A.R.L. Climate and Vulnerability Analysis presented here was automatically generated and has not been reviewed by experts of the KA Köln.Assekuranz Agentur GmbH. If you have any questions about the results or see further explanations, we offer consultation with our experts at favourable terms.

Team K.A.R.L. (team.karl@koeln-assekuranz.com)

Detailed description of the perils

1 Temperature-related risks

1.1 Changing temperature (chronic)

The present analysis addresses the effects resulting from a slow and continuous change in the annual mean temperature. Extreme events are not considered in this analysis. The risk assessment is based on the annual mean temperature and its adverse effects on the object under investigation (vulnerability).

Note: *Only the change in air temperature is analyzed. Changes in water temperatures are usually not relevant for the object under investigation.*

Current conditions In the reference period (1985-2014), the annual mean temperature at the site is **9.8 °C**. During this period, the annual mean temperature has increased by **0.046 °C** every year.

Based on the selected vulnerability, **no adverse effect** on the object under investigation is to be expected from the mean annual temperature. This results in **no relevant risk**.

Climate outlook Table 2 lists possible future changes in the annual mean temperature, which were calculated based on an ensemble of 20 climate models for the site under investigation. A maximum change in annual mean temperature is projected for scenario **SSP5-8.5** and time period **2070-2099** with **increase** of **+4.42 °C** compared to the reference period.

For the maximum projected annual mean temperature, **no adverse effect** on the object under investigation is to be expected based on the selected vulnerability. This results in **no relevant risk**.

			Changes compared to 1985-2014		
	Reference 1985-2014	Scenario	short-term 2015-2044	medium-term 2035-2064	long-term 2070-2099
Annual mean temperature $^{\circ}C$	9.8	SSP1-2.6	+0.95	+1.3	+1.35
		SSP2-4.5	+1	+1.38	+2.23
		SSP5-8.5	+1.09	+1.97	+4.42

Table 2: Projected changes in annual mean temperature for three 30-year periods and scenarios determined based on the model ensemble (CMIP6). The values of the reference period were derived from the ERA5 reanalysis data.

General impacts Changes in the annual mean temperature primarily affect agriculture, forestry, and fisheries. They also influence other ecosystem-related activities, such as ecosystem restoration, tourism, and water used for cooling. Rising temperatures can additionally lead to health problems, as disease vectors (i.e., tiger mosquitoes, ticks, etc.) increase or allergy seasons lengthen.

1.2 Heat stress (chronic)

Heat stress is defined as the exposure of humans and the environment to persistently high temperatures. The risk assessment is based on a heat stress index developed by KA and the associated adverse effects on the object under investigation (vulnerability).

The heat stress index primarily relates to the duration of heat waves, which pose a particular threat due to persistently high temperatures both during day and night. Index values range from 0 to 10, with 0 representing no heat stress and 10 representing extremely stressful and frequently recurring situations with high temperatures.

Current conditions With a current heat stress index of **2.4**, the site under investigation is located in an area with **a low exposure** of heat stress.

Based on the selected vulnerability, **no adverse effect** on the object under investigation is to be expected from heat stress. This results in **no relevant risk**.

Climate outlook Table 3 lists possible future heat stress indices, which were calculated based on an ensemble of 20 climate models for the site under investigation. A maximum heat stress of **5.1** is projected for scenario **SSP5-8.5** and time period **2070-2099**. This corresponds to **an increased exposure**.

For the maximum projected heat stress, **a low adverse effect** on the object under investigation is to be expected based on the selected vulnerability. This results in **a low risk**.

			Projected heat stress-indices		
	Reference 1985-2014	**Scenario**	**short-term** 2015-2044	**medium-term** 2035-2064	**long-term** 2070-2099
Heat stress-indices	2.4	SSP1-2.6	2.7	2.9	2.9
		SSP2-4.5	2.7	3	3.4
		SSP5-8.5	3	3.5	5.1

Table 3: Projected heat stress indices for three 30-year periods and scenarios determined based on the model ensemble (CMIP6). The values represent sums from the values of the reference period (ERA5) and the mean anomalies of the model ensemble. The values of the reference period were derived from the ERA5 reanalysis data.

General impacts Heat stress can impair physical and mental performance, especially in non-air-conditioned rooms or when working outdoors. Heat can also damage materials (e.g., by deformation), leading to the deterioration of means of production and infrastructure. Furthermore, an elevated heat stress can pose serious risks to human health ranging from a reduction of the workforce productivity to heat-related fatalities. The effects of heat stress are likely to increase in urban areas.

1.3 Temperature variability (chronic)

Temperature variability is the fluctuation in temperatures over the course of the day or year. This is a chronic hazard which results from a slow change in the climatic mean.

The risk assessment is based on the average difference between the daily maximum and minimum temperature and its impact on the object under investigation (vulnerability).

Current conditions In the reference period (1985-2014), the mean daily temperature difference at the site is **6.64 °C**.

Based on the selected vulnerability, **no adverse effect** on the object under investigation is to be expected from the daily temperature difference. This results in **no relevant risk**.

Climate outlook Table 4 lists possible future changes in daily temperature differences, which were calculated based on an ensemble of 20 climate models for the site under investigation. A maximum change in the daily temperature difference is projected for scenario **SSP5-8.5** and time period **2070-2099** with **increase** of **+0.48 °C** compared to the reference period.

For the maximum projected fluctuation in the daily mean temperature, **no adverse effect**on the object under investigation is to be expected based on the selected vulnerability. This results in **no relevant risk**.

			Changes compare to 1985-2014		
	Reference 1985-2014	Scenario	short-term 2015-2044	medium-term 2035-2064	long-term 2070-2099
Daily mean temperature difference $^{\circ}C$		SSP1-2.6	+0.3	+0.02	+0.05
	6.64	SSP2-4.5	+0.02	-0.02	+0.14
		SSP5-8.5	+0.24	+0.23	+0.48

Table 4: Projected changes in the daily mean temperature difference for three 30-year periods and scenarios determined based on the model ensemble (CMIP6). The values of the reference period were derived from the ERA5 reanalysis data.

General impacts Changes in temperature variability have similar effects as the mean temperature increase (see 1.1), i.e., agriculture, forestry and fisheries are primarily affected. Extreme temperature differences, especially during the day, can have a negative impact on building materials or infrastructure, such as roads or rails. The adverse effect on buildings is rather low. However, in regions with high daily and seasonal temperature fluctuations, materials (e.g., cladding, window frames, seals) are subjected to greater stress and can therefore become more susceptible to e.g., hail damage (skylights).

The increase in average temperatures is often accompanied by temperature extremes and an increase in the temperature variability. That is to say, in regions with a strong increase in average temperatures, the temperature variability will also increase (e.g., in the Mediterranean region in Europe).

1.4 Permafrost thawing (chronic)

Permafrost are permanently frozen soils that occur in polar regions and mountains. The soils must be permanently frozen for at least two consecutive years. However, the surfaces of permafrost soils can thaw to a depth of about half a meter during summer.

The present analysis uses permafrost simulations to assess the hazard. These give the extent of permafrost in percentage for the past climate (1960- 1990) and for different warming scenarios (from +1 °C to +6 °C).

These warming scenarios include all temperature increases modeled in the typically used emission scenarios.

Current and future conditions Due to its location, it can be **excluded** that the site under investigation is located in a permafrost region. Since all considered emission scenarios lead to an increase in global temperatures in the coming decades, it can also be **excluded** that permafrost will be present at the site in the future.

General impacts Thawing permafrost can impact the local landscape, infrastructure, economy, and population. The melting of irregularly distributed ice can lead to uneven subsidence of the land surface, which can cause roads, railways, runways, buildings, and oil and gas pipelines to subside, among other things. Permafrost thawing can affect the global climate and the entire ecosystem through feedback effects by releasing more greenhouse gases which consequently accelerate global warming.

1.5 Heat wave (acute)

A heat wave is a period of unusual hot weather that is particularly stressful for people and the environment. In the present analysis, a heat wave refers to a period of at least three consecutive days with a maximum daytime temperature greater than 30 °C ("Hot Days") and nighttime temperatures above 20 °C ("Tropical Nights"). The risk is assessed based on the average number of heat wave days per year at the site and their adverse effects on the object of investigation (vulnerability).

Note: *In many regions, including Central Europe, very low values (< 1) are calculated for the referenced period, which seem to contradict the definition of a heat wave as well as the personal experience. Several factors are responsible for this: The averaging required for the climate statement is of major importance. For example: a heat wave with a value of 0.5 corresponds to a total of 15 heat wave days within the 30-year reference period. Years without heat waves (in terms of the definition!!) are included in the averaging with a value of 0. The reference period (1985 – 2014) was not yet so strongly influenced by climate change, therefore the probability of heat waves was lower. Local temperature phenomena (e.g., urban heat islands, which are also governed by urban planning) cannot be adequately captured by the climate models, which can lead to small local deviations from the observations.*

Current conditions During the reference period (1985-2014), an annual average of **0 heat days** were recorded at the site under investigation which were part of a heat wave.

Based on the selected vulnerability, **no adverse effect** on the object under investigation is to be expected from heat waves. This results in **no relevant risk**.

Climate outlook Table 5 lists possible future changes in heat wave days, which were calculated based on an ensemble of 20 climate models at the site under investigation. A maximum change is projected for scenario **SSP5-8.5** and time period **2070-2099** with **increase** of **+11.4** heat wave days in average compared to the reference period.

For the maximum projected heat wave days, **a low adverse effect** on the object under investigation is to be expected based on the selected vulnerability. This results in **a low risk**.

			Changes compared to 1985-2014		
	Reference 1985-2014	**Scenario**	**short-term** 2015-2044	**medium-term** 2035-2064	**long-term** 2070-2099
Heat wave days *Days per year*	0	SSP1-2.6	+0.4	+0.7	+0.8
		SSP2-4.5	+0.3	+0.7	+2
		SSP5-8.5	+0.7	+2.5	+11.4

Table 5: Projected changes in heat wave days for three 30-year periods and scenarios determined based on the model ensemble (CMIP6). The reference period values were derived from the ERA5 reanalysis data.

General impacts Heat waves primarily impair physical and mental performance as well as the well-being, especially in non-air-conditioned rooms or when working outdoors. In addition, heat waves can lead to a deterioration in air quality. Heat can also damage materials (e.g., by deformation), leading to the deterioration of means of production and infrastructure.

1.6 Cold wave/ frost (acute)

A cold wave is a period of unusual cold weather. In the present analysis, the risk from cold waves is assessed based on the number of annual frost days (daily minimum temperature < 0 °C) and their adverse effects on the object under investigation.

Current conditions During the reference period (1985-2014), an annual average of **56 frost days** were recorded at the site.

Based on the selected vulnerability, **no adverse effect** on the object under investigation is to be expected from **cold waves**. This results in **no relevant risk.**

Climate outlook Table 6 lists potential future changes in annual frost days, which were calculated based on an ensemble of 20 climate models at the site under investigation. A maximum change is projected for scenario **SSP5-8.5** and time period **2070-2099** with **decrease** of **-37.92** frost days in average compared to the reference period.

For the maximum projected frost days, **no adverse effect** on the object under investigation is to be expected based on the selected vulnerability. This results in **no relevant risk**.

			Changes compared to 1985-2014		
	Reference 1985-2014	**Scenario**	**short-term** 2015-2044	**medium-term** 2035-2064	**long-term** 2070-2099
Frost days *Days per year*	56	SSP1-2.6	-9.62	-14.24	-15.68
		SSP2-4.5	-9.63	-14.9	-22.94
		SSP5-8.5	-12.6	-19.59	-37.92

Table 6: Projected changes in annual frost days for three 30-year periods and scenarios determined based on the model ensemble (CMIP6). The values of the reference period were derived from the ERA5 reanalysis data.

General impacts Extreme cold temperatures can have negative effects on materials and production processes as well as on human health. Late frost poses a risk for fruit-growing, especially at the time of fruit blossom. In regions with prevailing cold climates, it is assumed that buildings are adapted to the cold temperatures. Therefore, the impact of low temperatures is generally low. A decrease in cold snaps has already been observed in Europe and is expected to intensify as climate change progresses. In contrast, the risk of late frosts has increased in Europe in recent years.

1.7 Wildfire (acute)

Forest- and wildland fires (referred as wildfire hereafter) are fires that occur in forests, grasslands, and agricultural land. They are initiated intentionally, accidentally or by natural causes after a prolonged dry period. The risk for the occurrence of a wildfire depends on the climatological conditions on site and on the amount of combustible vegetation in the immediate vicinity of the site. Therefore, this risk analysis is based on two variables that describe these conditions:

1. The **wildfire potential** is calculated from various, predominantly climatological parameters (relative humidity, drought stress, prevailing wind speed, etc.) that can influence the occurrence of wildfires. Therefore, the probability that a wildfire occurs and their intensity (e.g., duration, spatial extent) increases with the potential. The wildfire potential is given as a unitless index number with values between 0 and 10, where 10 refers to an extremely high wildfire potential due to the prevailing climatological conditions.
2. The four-level **combustibility index** derived from the land use data indicates whether and how much combustible vegetation (e.g., the combustibility is high for closed forests and low for grasslands) is present in the vicinity of the site.

The resulting risk is highest when climatological conditions favor the emergence of wildfires and at the same time sufficient combustible materials exist in the surrounding.

Current conditions Based on the prevailing climatological conditions at the site during the reference period (1985-2014), the wildfire potential is **low (3.2)**. According to the land use data, **a low proportion** of vegetation is assumed to be present at the site under investigation. This results in **a low risk** based on the selected vulnerability.

Note: *Due to potential inaccuracies in the land use data, it is strongly recommended that vegetation in the immediate vicinity of the site is examined.*

Climate outlook Table 7 lists possible future wildfire potentials, which were calculated based on various climate simulations. The maximum wildfire potential is **high (4.7)** and is projected for scenario **SSP2-4.5** and time period **2070-2099**.

Based on the selected vulnerability and assumption that the proportion of combustible vegetation components does not change, there will be at most **a medium risk** in the future.

			Projected wildfire potential		
	Reference	**Scenario**	**short-term**	**medium-term**	**long-term**
	1985-2014		2015-2044	2035-2064	2070-2099
Wildfire potential	3.2	SSP1-2.6	3.2	3.2	3.2
		SSP2-4.5	3.5	4.1	4.7
		SSP5-8.5	3.5	3.8	4.7

Table 7: Projected future wildfire potentials for three 30-year periods and scenarios determined based on the model ensemble (CMIP6). The values of the reference period were derived from the ERA5 reanalysis data.

Note: *Since predictions or possible future projections about the development of vegetation conditions are currently not available, the risk assessment is based on current land use data.*

General impacts Wildfires pose a significant hazard to social, economic, or ecological values. Fires can not only completely destroy properties, but also release pollutants (e.g., particulate matter and dioxins) that pose a threat to human health. Increasing periods of heat and drought due to climate change contribute to the expansion of fire-prone areas and the extension of the wildfire season. Wildfires exacerbate global warming through the release of greenhouse gases.

2 Wind-related risks

2.1 Changing wind patterns (chronic)

Changing wind patterns describe slow and chronic changes in the mean wind speeds, while extreme events are not considered. The risk assessment is based on modeled trends in mean wind speeds at 10 m above the ground surface and their adverse effects on the object under investigation (vulnerability).

Current conditions In the reference period (1985-2014), the **mean wind speed** at the site is **16.231 km/h**.

Based on selected vulnerability, **no adverse effect** on the object under investigation is to be expected. This results in **no relevant risk**.

Climate outlook Table 8 lists possible future changes in mean wind speeds, which were calculated based on an ensemble of 20 climate models for the site under investigation. A maximum change in mean wind speed is projected for scenario **SSP2-4.5** and time period **2070-2099** with **decrease** of **-0.86 km/h** compared to the reference period.

For the maximum projected change in mean wind speed, **no adverse effect** on the object under investigation is to be expected based on the selected vulnerability. This results in **no relevant risk.**

			Changes compared to 1985-2014		
	Reference 1985-2014	Scenario	short-term 2015-2044	medium-term 2035-2064	long-term 2070-2099
Mean wind speed km/h	16.231	SSP1-2.6	-0.5	-0.72	-0.76
		SSP2-4.5	0	-0.14	-0.86
		SSP5-8.5	-0.04	-0.22	-0.29

Table 8: Projected changes in mean wind speed for three 30-year periods and scenarios determined based on the model ensemble (CMIP6). The values of the reference period were derived from the ERA5 reanalysis data.

General impacts Changing mean wind speeds primarily affect the wind energy sector as well as the industries and populations that depend on it. In addition, changes in wind patterns (sometimes in combination with other climatological phenomena, such as drought) also affect several other sectors. Stronger winds, for example, can exacerbate drought and intensify the wildfire season. Weaker winds can increase air pollution in cities. Wind also plays an important role in nature, as it e.g., influences the growth, reproduction, and distribution of plants.

2.2 Cyclone, hurricane, typhoon (acute)

Cyclones (Northern Indian Ocean), hurricanes (Atlantic Ocean), and typhoons (Pacific Ocean) are tropical storms that occur in different regions of the world. All tropical storms form over tropical waters (usually between 20° N and 20° S) with a sea surface temperature of at least 26 °C as a violent low-pressure vortex that can reach diameters of 1,000 km. Tropical storms can cause enormous damage due to high wind speeds, storm surges and intense precipitation.

Current and future conditions The site under investigation is not located in the area where tropical cyclones occur. Therefore, the occurrence of tropical storms can currently be **excluded**. Whether and how the spatial extent of the areas of tropical cyclones will change in the future cannot be assessed due to a lack of data. According to current knowledge, it can be assumed that the occurrence of tropical storms can also be **excluded** in the future. The possible future risks from tropical cyclones are part of the storm analysis in the following chapter.

General impacts Tropical cyclones can cause catastrophic destruction over large areas due to high wind speeds, landslides, and flooding. This, among other things, can lead to severe damage to residential buildings in an entire region. Tropical cyclones can endanger shipping at sea due to storms and high swells. If wind-induced waves run up onto the coastline, they can cause flooding and erosion.

2.3 Storm (acute)

Storms are defined as strong wind events with wind speeds of at least 75 km/h, since the first damage can usually occur from this wind speed. The analysis of the storm risk is carried out with the natural hazard model K.A.R.L.. The calculations for the reference period are based on the evaluation of wind data from many weather stations worldwide. Future trends are estimated by using an ensemble of 20 climate models.

K.A.R.L. does not distinguish between tropical and extratropical storms. Additionally, the digital elevation model is used to capture local wind effects.

The calculated risk in percent per year (% p.a.) by K.A.R.L. corresponds to the expected mean annual loss. This is the loss that occurs on a long-term statistical average per year due to the natural hazard under consideration.

Current conditions The storm risk (based on the year 2023) calculated by K.A.R.L. based on the selected vulnerability is **0.0544 % p.a.**. This results in **a low risk**.

Climate outlook Table 9 lists potential future storm risks (% p.a.), which were calculated using the K.A.R.L. model based on the selected vulnerability and an ensemble of 20 climate models for the site under investigation.

The maximum projected storm risk is **0.0568 % p.a.** and was simulated for the time period **2015-2044** and scenario **SSP2-4.5**. This results in **a low risk** in the future.

			K.A.R.L. storm risk		
	Reference 1985-2014	Scenario	short-term 2015-2044	medium-term 2035-2064	long-term 2070-2099
Storm risk $\%p.a.$	0.0544	SSP1-2.6	0.0278	0.0332	0.0333
		SSP2-4.5	0.0568	0.0563	0.0312
		SSP5-8.5	0.0387	0.0504	0.0372

Table 9: Projections of the K.A.R.L. storm risk (% p.a.) for three 30-year periods and scenarios determined based on the model ensemble (CMIP6) and the selected vulnerability. The values of the reference period were derived from many worldwide observations.

General impacts The wind pressure and strong gusts resulting from storms with sustained high wind speeds can cause severe damage to infrastructure and buildings, such as blown off roofs and slapped trees or power poles. Furthermore, falling or flying objects can cause personal injuries.

2.4 Tornado (acute)

A tornado is a relatively small but very intense storm system with wind speeds that are significantly higher than other storms, occasionally exceeding 400 km/h.

The analysis of the tornado risk is carried out with the natural hazard model K.A.R.L. It is assumed that significant damage will only occur if a tornado directly hits a site under investigation. If hit by a tornado, a total loss should be assumed. However, since this rarely occurs even in areas with a high tornado hazard (due to their small size), the calculated risks are generally relatively low compared to other natural hazards.

The calculated risk in percent per year (% p.a.) by K.A.R.L. corresponds to the expected mean annual loss. This is the loss that occurs on a long-term statistical average per year due to the natural hazard under consideration.

Current conditions The tornado risk (based on the year 2023) calculated by the K.A.R.L model based on the selected vulnerability is **0.0110 % p.a.**. Consequently, there is **a low risk**.

Climate outlook Table 10 lists potential future tornado risks (% p.a.), which were calculated using the K.A.R.L. model based on the selected vulnerability and an ensemble of 20 climate models for the site under investigation. The maximum projected K.A.R.L. tornado risk is **0.0115 % p.a.** and was simulated for the time period **2070-2099**and scenario **SSP1-2.6**. This results in a maximum **a low risk** in the future.

			K.A.R.L. tornado risk		
	Reference 1985-2014	Scenario	short-term 2015-2044	medium-term 2035-2064	long-term 2070-2099
Tornado risk $\%p.a.$	0.0110	SSP1-2.6	0.0111	0.0113	0.0115
		SSP2-4.5	0.0112	0.0114	0.0112
		SSP5-8.5	0.0112	0.0112	0.0087

Table 10: Projections of the K.A.R.L. tornado risk (% p.a.) for three 30-year periods and scenarios determined based on the model ensemble (CMIP6). Reference period values were derived from ERA5 reanalysis data.

General impacts Although the damage of tornados is limited to a relatively narrow extent, the very high wind speeds, and wind shear (rapid change in direction or speed) pose a high risk even to massive structures.

3 Water-related risks

3.1 Changing precipitation patterns and types (rain, hail, snow/ice) (chronic)

Changing precipitation patterns describe slow changes in accumulated precipitation or the seasonal occurrence, while extreme events are not considered.

The risk assessment is based on the average annual precipitation amounts and their adverse effects on the object of study (vulnerability).

Note: *No distinction is made between the different types of precipitation. In general, there will be less precipitation in frozen form due to the long-term warming of the atmosphere. However, it cannot be ruled out that in some limited regions local phenomena may also lead to more hail or snowfall. These topics are discussed in chapter 3.8.*

Current conditions In the reference period (1985-2014), the annual precipitation amount at the site is**1101.6 mm** per year. Based on the selected vulnerability, **no adverse effect** on the object of study is to be expected from annual rainfall. This results in **no relevant risk**.

Climate outlook Table 11 lists possible future changes in annual precipitation, which were calculated based on an ensemble of 20 climate models for the site under investigation. A maximum change in annual precipitation is projected for scenario **SSP1-2.6** and time period **2015-2044** with **increase** of **+30 mm** compared to the reference period.

For the maximum projected annual precipitation, **no adverse effect**on the object under investigation is to be expected based on the selected vulnerability. This results in **no relevant risk**.

			Projected changes compared to 1985-2014		
	Reference 1985-2014	Scenario	short-term 2015-2044	medium-term 2035-2064	long-term 2070-2099
Annual precipitation mm		SSP1-2.6	+30	-3.7	+17.7
	1101.6	SSP2-4.5	+21.1	-0.8	+15.6
		SSP5-8.5	+1.4	+0.6	-0.8

Table 11: Projected changes in annual precipitation for the three 30-year periods and scenarios determined based on the model ensemble (CMIP6). The values of the reference period were derived from the ERA5 reanalysis data.

General impacts Changing precipitation has an impact on water management and ecosystems, as well as on agricultural and forestry production. This is also relevant for other activities related to water use, such as tourism and inland navigation.

The change in average precipitation has no direct or only a minor adverse effect on a building. The indoor climate can only be affected by persistent moisture, which can promote mold growth. Moreover, a prolonged drought can lead to a decline in groundwater and consequently to ground subsidence, which in extreme events can have a negative impact on building structures.

3.2 Precipitation or hydrology variability (chronic)

Precipitation variability describes the slow and chronic change in precipitation variability (fluctuations) that does not include individual extreme events. Strong fluctuations in precipitation influence the availability of water and water levels and can lead to extreme events such as drought (see e.g., chapters 3.6, 3.7).

The risk assessment is based on fluctuations of the annual precipitation amounts (standard deviation of the annual precipitation) and their adverse effects on the object under investigation (vulnerability). A high standard deviation of the annual precipitation indicates that very strong precipitation fluctuations occur from year to year.

Current conditions In the reference period (1985-2014), the standard deviation of the annual precipitation at the site is **122.5 mm**.

Based on the selected vulnerability, **no adverse effect** on the object under investigation is to be expected from precipitation variability. This results in **no relevant risk**.

Climate outlook Table 12 lists possible future change in precipitation variability, which were calculated based on an ensemble of 20 climate models at the site under investigation. A maximum change in precipitation variability is projected for scenario **SSP2-4.5** and time period **2015-2044** with **increase** in precipitation variability of **+13.4 mm** compared to the reference period.

For the maximum projected change in precipitation variability, **no adverse effect** on the object under investigation is to be expected based on the selected vulnerability. This results in **no relevant risk.**

			Projected changes compared to 1985-2014		
	Reference 1985-2014	Scenario	short-term 2015-2044	medium-term 2035-2064	long-term 2070-2099
Precipitation variability mm	122.5	SSP1-2.6	+0.6	+3.5	-1
		SSP2-4.5	+13.4	+4.8	-3.8
		SSP5-8.5	+7.3	+12.2	+8

Table 12: Projected changes in precipitation variability (standard deviation of the annual precipitation) for three 30- year periods and scenarios determined based on the model ensemble (CMIP6). The values of the reference period were derived from the ERA5 reanalysis data.

General impacts The variability of precipitation mainly affects the availability of water and water levels. It impacts various water users, such as water management and ecosystems, as well as all economic sectors that rely on water (e.g., fisheries, tourism, inland navigation, manufacturing, cooling, and purification). Precipitation variability tends to have no direct impact on buildings, apart from associated acute hazards (e.g., flooding in chapter 3.9), which are addressed separately. However, the quality of life and living conditions of occupants in a building can be affected through long-term changes in water availability (see chapter 3.6).

3.3 Ocean acidification (chronic)

Ocean acidification involves the uptake of (primarily anthropogenic) carbon dioxide (CO_2) by the oceans, which leads to a chemical change in seawater. When carbon dioxide reacts with seawater, carbonic acid is formed, which lowers the pH value of the oceans, causing a gradual acidification of the ocean. The pH value is a measure of the acidity and has decreased by 0.1 since the beginning of the industrial age, i.e., seawater has become more acidic.

Current and future conditions The object under investigation is located on land and is therefore not directly affected by ocean acidification. Consequently, negative effects at the site can be **excluded** currently and in the future.

General impacts Ocean acidification has negative impacts on ecosystems and the biodiversity of the oceans. The loss of biodiversity can affect millions of people who depend on fishing, aquaculture, or natural coastal protection such as coral reefs or mangroves. Ocean acidification can affect the corrosion of objects, although pH variations between 7.8 and 8.2 are not believed to cause significant changes.

3.4 Saline intrusion (chronic)

Saline intrusion is the intrusion of saltwater into coastal aquifers and surface waters. Regions with high population density are usually affected by saline intrusions due to excessive groundwater extraction.

The present analysis considers sites located at a maximum distance of 150 km from the coast. The risk assessment is based on a potential for saline intrusion and its adverse effects on the study object (vulnerability). The potential is calculated from the population density and the distance to the coast. For example, the closer a site is located to the coast and the higher the population density, the higher is the probability (or potential) that a saline intrusion may occur.

Current and future conditions The distance to the coast is **more than 150 km**. Therefore, the occurrence of a saline intrusion at the site under investigation can be **excluded** currently and in the future.

General impacts Saline intrusion poses a major threat to the drinking water supply of coastal areas. About 40 % of the world's population lives within 100 km of the coast. More than 100 countries and coastal regions around the world are currently affected by saline intrusion. Especially drinking water management and production in agriculture and forestry are affected by saline intrusion. The impact on ecosystems can also influence the tourism industry. Moreover, intruding salt can cause damage to buildings because of corrosion.

3.5 Sea level rise (chronic)

As a result of global warming, the sea levels around the world have risen, currently about 20 cm (global average) compared to pre-industrial times. The main causes of seal level rise are the thermal expansion of the oceans and the melting of ice and glaciers. This process will continue in the future, especially if global warming continues.

The projected sea level rises are used to identify if the object under investigation could be affected by the sea level rise. For this, sea level rise data are compared with the site's altitude and distance from the coast. The risk assessment considers the susceptibility of the object under investigation (vulnerability).

Current and future conditions The site is located **more than 10 km** from the coast. Therefore, negative impacts from sea level rise at the site can be **excluded** currently and in the future.

General impacts Sea level rise can lead to permanent flooding, making coastal areas uninhabitable. It can also cause coastal flooding, coastal erosion, and the intrusion of saltwater into groundwater reservoirs and agricultural soils. These effects can result in unusable agricultural land and drinking water reservoirs but also damage infrastructure, industries, and buildings.

3.6 Water stress (chronic)

Water scarcity or water stress refers to the chronic situation in which there is a shortage of water of sufficient quality required for humans and the environment. The risk assessment is based on the annual water availability at the site and its adverse effects on the object of study (vulnerability). The water availability is calculated from the difference between the annual precipitation and the effective evapotranspiration. In theory, this amount of water can be used as surface water, or it supplements the groundwater supply through infiltration. If an annual **threshold of 200 mm** per year is exceeded, a long-term water shortage is not to be expected.

The water availability values analyzed here are calculated using the K.A.R.L. natural hazard model.

Current conditions The site under investigation is located in an area with a current water availability of **566.0 mm per year**.

Based on the selected vulnerability, **no adverse effect** on the object under investigation is to be expected. This results in **no relevant risk**.

Climate outlook Table 13 lists possible future water availability, which were calculated with K.A.R.L. based on the selected vulnerability and an ensemble of 20 climate models for the site under investigation. A maximum water stress is projected for scenario **SSP5-8.5** and time period **2070-2099** with **452.0 mm per year** at the site.

For the minimum projected water availability, **no adverse effect** on the object under investigation is to be expected based on the selected vulnerability. This results in **no relevant risk**.

			Projected water availability		
	Reference 2023	**Scenario**	**short-term** 2015-2044	**medium-term** 2035-2064	**long-term** 2070-2099
Water availability $mm/year$		SSP1-2.6	575.0	558.0	570.0
	566.0	SSP2-4.5	578.0	544.0	531.0
		SSP5-8.5	558.0	534.0	452.0

Table 13: Projected water availability for three 30-year periods and scenarios were calculated using K.A.R.L..

General impacts Water stress has various consequences for the society such as contaminated drinking water, parched fields and an associated enhanced risk of a food crises, the spread of diseases, flight, or political and social conflicts. In addition, water shortages have ecological consequences, such as an increase in extreme droughts, declining groundwater levels and the drying up of rivers and lakes, which in turn can have a negative impact on businesses and industries.

Water stress does not have a direct adverse impact on real estate, but long-term groundwater depletion can cause subsidence, which can negatively impact the structure of a building.

3.7 Drought (acute)

Drought defines an exceptional period of water shortage due to low rainfall, high temperatures, and/or wind. The drought stress is analyzed in the present analysis using a drought stress index defined by the KA. This index includes precipitation-related parameters such as the annual precipitation, the duration of a drought, and the mean annual maximum temperature. The index values range from 0 to 10, with 0 representing no stress and 10 representing extreme and frequently recurring stress.

Current conditions With a current drought stress of **1.9**, the site under investigation is located in an area with **a low stress**.

Based on the selected vulnerability, **no adverse effect** by drought on the object of investigation is to be expected. This results in **no relevant risk**.

Climate outlook Table 14 lists possible future drought stress indices, which were calculated based on an ensemble of 20 climate models for the site under investigation. A maximum drought stress of **2.8** is projected for scenario **SSP5-8.5** and time period **2070-2099**. This corresponds to **a low stress**.

For the maximum projected drought stress, **no adverse effect** on the study object is to be expected based on the selected vulnerability. This results in **no relevant risk**.

			Projected drought stress indices		
	Reference 1985-2014	Scenario	short-term 2015-2044	medium-term 2035-2064	long-term 2070-2099
Drought stress	1.9	SSP1-2.6	1.9	2.1	2
		SSP2-4.5	1.9	2.1	2.2
		SSP5-8.5	1.9	2.2	2.8

Table 14: Projected drought stress indices for three 30-year periods and scenarios determined based on the model ensemble (CMIP6). The values represent sums from the values of reference period (ERA5) and the mean anomalies of the model ensemble. The values of the reference period were derived from the ERA5 reanalysis data.

General impacts Droughts have a significant impact on agriculture causing crop failures and increased incidence of plant diseases. They endanger the life and health of humans and cause property damage and business interruptions. Industrial sectors, such as shipping or the energy industry, are also affected when river water levels drop, or power plants have to be shut down due to a lack of river water cooling. The risk of wild- and bushfires may also be exacerbated.

3.8 Heavy precipitation (rain, hail, snow/ice) (acute)

Precipitation is water from the atmosphere that reaches the earth's surface in liquid or solid form. Rain, hail, and snow are three types of precipitation that pose a substantial hazard if they occur as extreme events. A risk analysis is carried out for each of these three types of precipitation.

3.8.1 Rain

Heavy rain is defined as heavy, cloudburst-like rainfall in which very high amounts of precipitation fall in a short period of time. In contrast to continuous rain, heavy rain is a more localized phenomenon in which the amount of precipitation exceeds the seasonal average for the locality. Heavy rain often occurs during the summer season in conjunction with thunderstorms.

The natural hazard model K.A.R.L. is used to calculate the risk of heavy rain. The impact of heavy rain depends to a large extent on the absorption capacity of the local sewage systems. These sewage systems are normally designed for a 3 to 10-year rainfall event (design rainfall). If the design rainfall is exceeded, overflow and leakage of sewer water at the ground surface will occur which can cause consequential damage. For the risk assessment of K.A.R.L. it is decisive by how much the design rainfall is exceeded and with which return periods.

The calculated risk in percent per year (% p.a.) by K.A.R.L. corresponds to the expected mean annual loss. This is the loss that occurs on a long-term statistical average per year due to the natural hazard under consideration.

Current conditions The risk of heavy rainfall (based on the year 2023) calculated by K.A.R.L. based on the selected vulnerability is **0.0014 % p.a.**. This results in **a low risk**.

Climate outlook Table 15 lists potential future heavy rain risks (% p.a.), which were calculated using the K.A.R.L. model based on the selected vulnerability and an ensemble of 20 climate models for the site under investigation. The maximum projected K.A.R.L. heavy rain risk is **0.0076 % p.a.** and was simulated for scenario **SSP5-8.5** and time period **2070-2099**. This results in **a low risk**.

			K.A.R.L. heavy rain risk		
	Reference 1985-2014	Scenario	short-term 2015-2044	medium-term 2035-2064	long-term 2070-2099
Heavy rain risk $\%p.a.$	0.0014	SSP1-2.6	0.0015	0.0022	0.0017
		SSP2-4.5	0.0013	0.0016	0.0022
		SSP5-8.5	0.0017	0.0026	0.0076

Table 15: Projections of the K.A.R.L. heavy rain risk (% p.a.) for three 30-year periods and scenarios determined based on the model ensemble (CMIP6). The values of the reference period were derived from the ERA5 reanalysis data.

General impacts Heavy rain can trigger flash flooding, which can cause flooding in areas at a distance to the location where the heavy rainfall event occurs. Flooding can be also triggered by backwater from the sewage system, which can impact the infrastructure. The intrusion of water can damage buildings, vehicles and means of transport, while the ingress of water can occur in basements and underground garages.

3.8.2 Hail

Hail is frozen precipitation with a diameter of at least 0.5 centimeters. Hail is observed mainly in the summer months and in the mid-latitudes. First hail damage usually occurs from a hailstone size of 1.5 cm (e.g., damage to plants, varnish damage to cars).

The risk is assessed by the hail model integrated in K.A.R.L.. The model is based on the calculation of a worldwide hail potential, which incorporates various regional climate parameters (e.g., temperature, height of the zero-degree line, lightning frequency), which either favor or prevent the occurrence of hail.

The calculated risk in percent per year (% p.a.) by K.A.R.L. corresponds to the expected mean annual loss. This is the loss that occurs on a long-term statistical average per year due to the natural hazard under consideration.

Current conditions The hail risk (based on the year 2023) calculated by K.A.R.L. based on the selected vulnerability) is **0.0032 % p.a.**. This results in **a low risk**.

Climate outlook Table 16 lists potential future hail risks (% p.a.), which were calculated using the K.A.R.L. model based on the selected vulnerability and an ensemble of 20 climate models for the site under investigation. The maximum projected K.A.R.L. hail risk is **0.0035 % p.a.** and was simulated for scenario **SSP1-2.6** and time period **2070-2099**. This results in a **a low risk**.

			K.A.R.L. hail risk		
	Reference	**Scenario**	**short-term**	**medium-term**	**long-term**
	1985-2014		2015-2044	2035-2064	2070-2099
		SSP1-2.6	0.0033	0.0033	0.0035
Hail risk $\%p.a.$	0.0032	SSP2-4.5	0.0033	0.0034	0.0033
		SSP5-8.5	0.0033	0.0033	0.0023

Table 16: Projections of the K.A.R.L. hail risk (% p.a.) for three 30-year periods and scenarios determined based on the model ensemble (CMIP6). The values of the reference period were derived from the ERA5 reanalysis data.

General impacts The possible damage caused by hail varies in severity and mostly depends on the size of hailstones. Even small hailstones can cause considerable damage to plants and other susceptible objects. Larger hailstones often lead to damage to vehicles, solar systems or even buildings. Drainage systems on roofs or in streets can become clogged by hail, causing backwater and localized flooding.

3.8.3 Snow

Heavy snowfalls are events in which large amounts of snow fall in a short period of time. Regions that experience more heavy snowfalls are less prone to damage for the same amounts and times of snow.

The structural design of a building should consider the maximum possible snow load that can accumulate on the roof. This snow load differs depending on the region and altitude of the site (climatological factors) and the design of the building (especially the roof).

The snow loads used in the present analysis, are calculated with the natural hazard model K.A.R.L. based on globally available climate data. The modeling approach was calibrated against numerous specific local recommendations and building regulations from different climatic zones and topographic elevations worldwide. The risk calculation does not take into account the design of a building (e.g., roof).

The snow loads given here are values that relate to an extremely rare event (> return period 100). From a risk management perspective, these values are interesting, but they are not suitable as a basis for the structural design of buildings. For this purpose, please use the official standard values. These standardized snow loads are usually much lower than the values given in the present study.

Current conditions The mean snow load (based on the year 2023) is **214.3 kg/sqm** .

Based on the selected vulnerability, **a low risk** due to snow load is to be expected.

Climate outlook Table 17 lists possible future snow loads calculated with K.A.R.L. considering the selected vulnerability and based on an ensemble of 20 climate models for the site under investigation. A maximum snow load at the site is projected for scenario **SSP2-4.5** and time period **2015-2044** and is **217.6 kg/sqm**.

For the projected maximum snow load, **a low adverse effect** on the object under investigation is to be expected based on the selected vulnerability. This results in **a low risk**.

			K.A.R.L. snow load		
	Reference 1985-2014	Scenario	short-term 2015-2044	medium-term 2035-2064	long-term 2070-2099
Snow load kg/sqm	214.3	SSP1-2.6	189.0	207.2	195.0
		SSP2-4.5	217.6	189.8	155.8
		SSP5-8.5	201.1	181.1	69.5

Table 17: Projections of the K.A.R.L. snow loads (kg/m^2 p.a.) for three 30-year periods and scenarios determined based on the model ensemble (CMIP6). The values of the reference period were derived from the ERA5 reanalysis data.

General impacts Heavy snowfalls result in large amounts of snow in a short time, which can cause significant damage. The weight of the snow not only damages trees, power lines and buildings, but also impairs the usability of transport infrastructures (road, rail, air), which can lead to supply bottlenecks. Furthermore, large amounts of snow and ice can also be significant for agriculture and forestry as well as for the tourism and event industry.

3.9 Flood (coastal, fluvial, pluvial, groundwater) (acute)

In the present analysis, floods are divided into coastal floods, i.e., storm surges, and general floods. The latter refers to floods that are exclusively caused by a temporary excess of water. It can be caused by river floods (fluvial), but also by heavy rainfall events (pluvial). Groundwater flooding (flooding or infiltration of water by groundwater) is not considered in this analysis.

3.9.1 Coastal flooding (storm surge)

A storm surge is an unusual high rise of water along the coasts and in tidal rivers that exceeds the normal tidal range. High-water levels occur especially when a storm surge occurs during a spring tide. Storm surges occur when strong winds (storms and hurricanes) across the ocean push water towards the shore and pile it up.

Current and future conditions Due to the sufficiently large distance to the coast of **more than 30 km**, there is no need for investigations. **A relevant risk** can be **excluded** based on human discretion.

General impacts Storm surges can cause extreme flooding in coastal areas and hence damage buildings, infrastructure, or protective measures (e.g., levees). Storm surges can cause property damage to boats and ships in harbors and contribute to beach erosion. In estuaries and bays, seawater can penetrate inland during a storm surges resulting in the salinization of groundwater reservoirs, which can have negative consequences for the water supply.

3.9.2 River flood

River flood is the rise in the water level of rivers or streams caused by heavy precipitation, often also associated with snow melt. Flooding of major river systems often results from extensive and long-lasting heavy precipitation in the upper river basin that leads to flooding. In smaller river systems, local heavy precipitation is often sufficient to cause localized flooding.

The risk of river floods (also referred to as inundation) is assessed using the flood model integrated in K.A.R.L.. The flood model first determines the flood hazard (e.g., is the site in a depression or does it have good drainage?) of the site by examining the terrain profile (elevation model) of the site and its surrounding. Consequently, climatological, hydrological, and geographic factors are used to estimate water levels and return periods.

Current conditions The location under survey is in an area not endangered by surge. However, following extreme precipitation and given unfavourable circumstances, water can penetrate into buildings and especially flood underground spaces such as cellars.

The flood risk (based on the year 2023) calculated by K.A.R.L. based on the selected vulnerability is **0.0000 % p.a.**. This results in **no relevant risk**.

Climate outlook Table 18 lists potential future flood risks (% p.a.), which were calculated using the K.A.R.L. model based on the selected vulnerability and an ensemble of 20 climate models for the site under investigation.

Assuming no change in geography at the site, the maximum projected K.A.R.L.flood risk is **0.0000% p.a.** and was simulated for scenario **SSP1-2.6** and time period **2015-2044**. This results in **no relevant risk**.

			K.A.R.L. flood risk		
	Reference 1985-2014	Scenario	short-term 2015-2044	medium-term 2035-2064	long-term 2070-2099
Flood risk $\%p.a.$		SSP1-2.6	0.0000	0.0000	0.0000
	0.0000	SSP2-4.5	0.0000	0.0000	0.0000
		SSP5-8.5	0.0000	0.0000	0.0000

Table 18: Projections of the K.A.R.L. flood risk (% p.a.) for three 30-year periods and scenarios determined based on the model ensemble (CMIP6). The values of the reference period were derived from the ERA5 reanalysis data.

General impacts River floods can inundate areas close to rivers and cause damage to infrastructure, buildings, vehicles, and agricultural land, among other things. Flooding, e.g., in urban areas, can release pollutants that contaminate water bodies, groundwater and soils.

3.10 Glacial lake outburst (acute)

Glacial lake outbursts are floods caused by the release or overflow of glacial lakes. Glacial lakes are naturally occurring lakes dammed by ice and moraines that are located within, on top of, or at the edge of glaciers. Glacial lake outburst occurs either when the lake overflows or when damage occurs to the dam. Due to the global increase in temperature and the melting of glaciers, a more frequent occurrence is expected temporarily in areas where glaciers are still present.

Current and future conditions There is **no** known current glacier within a radius of 30 km around the site under investigation. Consequently, negative effects from glacial lake outburst at the site can be **excluded** currently and in the future.

General impacts When glacial lakes fail, enormous amounts of water and debris are released within a very short time. These floods can be catastrophic with serious consequences for any life in the valley below. Therefore, glacial lake outbursts can cause a high number of fatalities. Although predicted widespread deglaciation may stop most outbreaks in the long term, global warming will contribute to earlier and more frequent glaciel lakes outburst in the short term. In total, about 15 million people worldwide are now at risk from these floods.

4 Soil-mass-related risks

4.1 Coastal erosion (chronic)

Coastal erosion is the gradual change of the coast by tides and weather influences (e.g., wind, precipitation). Natural events such as hurricanes, earthquakes, storm surges and tsunamis, just as human actions (e.g., construction of a dam) contribute to coastal erosion. In addition, ports and infrastructures can obstruct the natural transport path of sand, making the coastal zone vulnerable to erosion.

Due to data availability, only erosion of sandy coasts is considered in the present analysis. Although erosion can alter any type of shoreline, the effects are greatest for soft material (e.g., sand, silt, clay).

Current and future conditions The distance to the coast is **more than 2 km**. Therefore, negative effects from coastal erosion at the site under investigation can be **excluded** currently and in the future.

General impacts Coastal erosion can reduce habitual human space and destroy infrastructure or commercially used land. As a result of coastal erosion and the landward retreat of the shoreline, salt water can penetrate the groundwater reservoir and cause salinization. Tourism is also negatively affected by coastal erosion, as e.g., beaches can no longer be used accordingly. In addition, the natural habitats of flora and fauna in the coastal land and in the sea change as erosion progresses, which can result in the loss of biodiversity.

4.2 Soil erosion (chronic) and soil degradation (chronic)

Soil degradation describes the degradation of soils up to irreversible destruction, for example through nutrient loss, acidification, or decalcification. Soil erosion is the most problematic and widespread form of soil degradation. Soil functions such as soil fertility or storage capacity can decrease due to erosion until the entire soil substance is destroyed. Soil erosion is mostly caused by water, with heavy rainfall being the main cause. Human actions, such as deforestation, urbanization, agricultural tillage, and fertilization, can also contribute to soil erosion and degradation.

Current conditions At the site under investigation, **no hazard** of soil erosion or soil degradation is to be expected. Based on the selected vulnerability, this results in **no relevant risk**.

Climate outlook For the maximum projected erosion rates, **no hazard** is to be expected for the object under investigation. Based on the selected vulnerability, this results in **no relevant risk**.

			Projected hazard assessment		
	Reference	Scenario	short-term	medium-term	long-term
	1985-2014			2070	
Soil erosion, soil degradation	not relevant	SSP1-2.6	n/A	not relevant	n/A
		SSP2-4.5	n/A	not relevant	n/A
		SSP5-8.5	n/A	not relevant	n/A

Table 19: Hazard assessment of soil erosion. n/A = not available: No data is currently available for this period.

General impacts Soil degradation and soil erosion have severe consequences for agriculture. Soil degradation can reduce the quality of the soil to such an extent that it can no longer be used for agriculture. This can lead to food shortages for the growing world population. In addition, the soil loses its ability to store water, which results in an increasing risk of flooding. Soil erosion removes the protective vegetation cover, leaving the soil defenseless against natural processes. If the rainwater runs off, the fertile soil (top layers) as well as the nutrients that are still present are flushed out. Furthermore, the removed soil material (sediments) can be deposited on neighboring areas, roads or in bodies of water.

4.3 Solifluction (chronic)

Solifluction (earth flow, soil flow) is a slow, down-slope flow movement of water-saturated rock and soil material of the topsoil. Solifluction often occurs in the layers where permafrost thaws and additionally requires some slope of the terrain. When the surface of the permafrost thaws, water can accumulate on top of the frozen ground as it cannot percolate into the frozen ground. Consequently, this water flows downslope and transports overlying loose rock and solid material.

Since solifluction and the associated risk can only occur in the vicinity of permafrost, the present analysis examines whether a site is located in a permafrost area or in the immediate vicinity of it. Therefore, the basis of this risk assessment is analogous to the approach used to assess the risk for permafrost thawing (see 1.4).

Current and future conditions It can be **excluded** that the site under investigation is currently or will be in the future located in a permafrost region. Therefore, negative effects from solifluction at the site can be **excluded** currently and in the future.

General impacts Solifluction affects the erosion of sediments and therefore the morphology of the mountain landscape. Within or in the proximity of the area where solifluction occurs, slope stabilization measures and infrastructures, as well as hiking trails and buildings, may be at risk from flow movements.

4.4 Avalanche (acute)

An avalanche describes a mass of snow or ice that detaches from mountain slopes and descends into the valley. It usually occurs on slopes with an inclination of 30 degrees or more. Natural triggers can be loosely accumulated fresh snow, rising temperatures and violent gusts of wind. However, avalanches are often triggered by human actions (e.g., skiing).

Current and future conditions Due to the location of the site under investigation, the occurrence of avalanches can be **excluded** currently and in the future.

General impacts The hazard associated to avalanches is governed by the enormous masses of snow and other objects carried along (e.g., trees and stones) but also by the enormous pressure wave generated by the avalanche. If a building is hit, the resulting effects vary depending on the strength of the pressure, ranging from deformed and cracked walls to a destroyed roof or even in the complete destruction. Avalanches can also affect tourist activities as well as infrastructure.

4.5 Landslide (acute)

A landslide refers to the downslope movement of material, which can fall, tumble, slide, flow, and spread, depending on the underpinning geological conditions. The triggers for such movements are various, while precipitation and earthquakes play a major role. Human activities can also trigger landslides.

The landslide susceptibility classification of the site used for the present analysis is based on a Global Facility for Disaster Reduction and Recovery (GFDRR) data set from 2021, which incorporates precipitation and earthquakes as driving forces behind landslides. The site does not necessarily have to be located in the area of the landslide itself but may be damaged by incoming material.

Current and future conditions The site under investigation is not located in an area where landslides occur. Therefore, negative effects at the site can be **excluded** currently and in the future.

General impacts Landslides can have serious consequences. They can swallow houses and roads, and transport large amounts of debris into the valley damaging people, ecosystems, and infrastructure. Increasing urbanization and climate change are expected to further increase the risk from landslides. It is not uncommon for landslides to lead to homelessness, food loss or, in the worst case, to fatalities.

4.6 Subsidence (acute)

Ground subsidence, or subsidence, is the lowering of the soil. This can be caused by natural geological processes, such as erosion or earthquakes, whereas human actions dominate. Groundwater depletion (e.g., by sustained groundwater extraction) is particularly crucial and is therefore considered in the present analysis.

The present analysis is based on a data set that describes the probability of subsidence for the year 2010 (representing the current conditions) and the evolution for the year 2040. The data set is based on many different variables such as land use, climate, population density, and groundwater storage.

Current conditions At the site under investigation, **low hazard** of subsidence is to be expected. Based on the selected vulnerability, this results in **a low risk**.

Climate outlook Different from the other climate risk analyses, **scenario SSP2-8.5** was used for the future projection, which assumes a steady population growth as well as increasing greenhouse gas emissions. In the future, **low hazard** of subsidence at the site under investigation is to be expected based on the selected vulnerability. This results in **a low risk**.

General impacts Subsidence poses a gradual threat to people and the environment. Possible consequences of subsiding ground include water stress and an increased risk of flooding, especially in coastal areas. Furthermore, subsidence can damage buildings and infrastructure (e.g., power supply).

Preliminary references and links for further reading*

**References will be updated and verified when the automation is finalized.*

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