Clim EMPOWER

INTRODUCTION TO CLIMATE RISK ASSESSMENT

Part of ClimEmpower educational library

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Coordinator:	Denis Havlik, Scientist <denis.havlik@ait.ac.at> AIT Austrian Institute of Technology Giefinggasse 4, 1210 Vienna, Austria
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Deliverable details	
Report name	**Introduction to Climate Risk Assessment**
Target audience	Regional Planners, Policymakers, Resilience Officers, and Consultants
Description:	Part of the ClimEmpower Educational Library. This introductory guide presents the IPCC risk framework and the ClimEmpower methodology, moving beyond technical risk calculations to build a conceptual understanding of climate risk and highlight the role of social equity in adaptation planning.
Reading time	~45 Minutes
Learning level	Learning level: ☒ Introductory – assumes no previous knowledge ☐ Intermediate – assumes basic understanding ☐ Advanced – assumes professional knowledge
Prerequisites	**Core Framework:** Basic understanding of adaptation planning. **Social Equity:** Awareness of social vulnerability and marginalized populations. **General:** Basic interest in climate adaptation.
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Author(s):	Godos, K., Havlik, D., AIT Austrian Institute of Technology, Austria

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Date	Version	Contributor/Reviewer	Description
28/08/2026	Initial release	Katarzyna Godos and Denis Havlik	First public release

Legal Disclaimer

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List of Acronyms

CIC	Climate interaction context
IPCC	Intergovernmental Panel on Climate Change
SPI-12	Standardized Precipitation Index (12-month)
NDMI	Normalized Difference Moisture Index
FWI	Fire Weather Index
GIS	Geographic Information System
KISS	Keep It Simple and Straightforward
FAIR	Findable, Accessible, Interoperable, and Reusable

Glossary

Climate impacts	The consequences of realized risks on natural and human systems, where risks result from the interactions of climate-related hazards (including extreme weather and climate events), exposure, and vulnerability. Impacts generally refer to effects on lives; livelihoods; health and well-being; ecosystems and species; economic, social and cultural assets; services (including ecosystem services); and infrastructure (based on IPCC, 2018)
Hazard	A climate-related event (e.g., drought, heatwave) with potential to cause harm.
Exposure	The presence of people, assets, or ecosystems in hazard zones.
Vulnerability	The susceptibility of exposed elements to suffer harm or loss.
Risk	The potential for adverse consequences, calculated as Hazard × Exposure × Vulnerability.
Equal-Weighting	A method where variables within a component contribute equally to the score to ensure transparency.

About this document

This document is part of ClimEmpower educational library and associated with project deliverable D4.2 “Educational materials for increased regional Climate Change resilience v2”.

*ClimEmpower’s key ambition is to **prove beyond doubt that CC-resilience should, and can, be an integral part of regional development** everywhere in EU and beyond it. That is, we anticipate that the regional stakeholders will recognise that CC-resilient development pathways offer multiple benefits to them, including but not limited to **higher quality of life and reviving economy**, and that these can be understood using available **data, tools, and services**. Second key ambition of the project is to **help the regions address the CC resilience** in key community systems addressed in five ClimEmpower trials.*
*Underlying philosophy of the project is to “**help the regions to help themselves**”. This will be achieved through various mechanisms, including co-creation and mediation of the regional “Communities of Practice”, provision of the Climate Change -resilience training materials, as well as in provision and training in use of the user-centric data and services – including those that have already been made available through previous research projects and EU initiatives.*

This material is part of the ClimEmpower educational library, related to Deliverable D4.2 and available at ClimEmpower web site and Zenodo: https://climempower.eu/, https://zenodo.org/communities/climempower .

It introduces **climate risk assessment** using the **IPCC framework** and **ClimEmpower methodology**. It is designed to help readers **understand, explain**, and **apply** the principles of climate risk assessment to inform adaptation planning.

Intended target audience is: (i) Regional planners and disaster management authorities, (ii) Consultants advising on climate resilience strategy, and (iii) Policymakers interpreting risk maps for decision-making

After reading this material, you will be able to:

- **Understand** the key concepts and challenges of climate risk assessment.
- **Explain** how the IPCC risk framework works and why it is relevant for adaptation planning.
- **Apply** the framework to real-world scenarios at conceptual level.

1 Introduction

1.1 Why should I read this document?

Climate change is not just an environmental issue; it is a serious societal disruptor. While some regions are more prone to hazards, the impacts are felt most acutely by the most vulnerable parts of the population—including women, children, the elderly, the sick, and the impoverished. This document will help you:

- **Assess climate risks** using a structured, science-based approach.
- **Identify "hidden" vulnerabilities** within your population to ensure a more just and equitable society.
- **Prioritize adaptation measures** based on evidence to prevent the erosion of trust in authorities and avoid severe outcomes like depopulation or food insecurity

Who will benefit?

- **Regional planners** needing to protect marginalized communities.
- **Consultants** advising on equitable risk reduction.
- **Policymakers** ensuring that adaptation investments reach those who need them most

1.2 The Challenge

Climate hazards are increasing in severity, but their impact is uneven. A heatwave does not affect every citizen the same way; a person living in a well-insulated home with air conditioning faces a different risk than an elderly person living in a top-floor apartment in a concrete urban centre with no access to green space.

When we ignore these social nuances, we risk creating "one-size-fits-all" solutions that leave the most vulnerable behind. These citizens have the lowest ability to help themselves too. This can lead to increased social inequality and a breakdown in the relationship between the state and its citizen.

1.3 What will I learn?

After reading this document, you will be able to:

- **Understand** the IPCC risk framework and its components.
- **Explain** how climate risks are conceptually calculated and mapped.
- **Apply** the framework to identify high-risk areas and population groups in your region

2 Concepts, methods, and approaches

2.1 IPCC Risk Framework

2.1.1 The basic formula

The IPCC risk framework describes climate risk through the interaction of three components:

Risk = Hazard × Exposure × Vulnerability

- **Hazard (H):** The potential occurrence of a climate-related event or trend that may cause harm, such as a flood, heatwave, drought, or wildfire.
- **Exposure (E):** The presence of people, infrastructure, ecosystems, economic assets, or other elements in places that could be adversely affected.
- **Vulnerability (V):** The predisposition of exposed elements to be adversely affected, including their sensitivity and capacity to cope with or adapt to the hazard.

Considering all three components helps distinguish between the occurrence of a climate hazard and the risk resulting from that hazard.

Example: “Assess wildfire risk to critical infrastructure" or "Evaluate drought risk to agricultural productivity."

Key Question: *What specific risk are we assessing, and for whom?*

2.1.2 Define the risk

Purpose: Establish the scope and focus of the risk assessment.

First, define the specific risk that will be assessed by selecting:

- A hazard, such as flood, heatwave, drought, or wildfire.
- A domain or element at risk, such as population, agriculture, infrastructure, ecosystems, or tourism.

For example:

- Assess wildfire risk to critical infrastructure.
- Evaluate drought risk to agricultural productivity.
- Assess heatwave risk to the urban population.

Key question: *What specific risk are we assessing, and for whom or what?*

2.1.3 Identify Components

Purpose: Determine the variables for Hazard (H), Exposure (E), and Vulnerability (V).

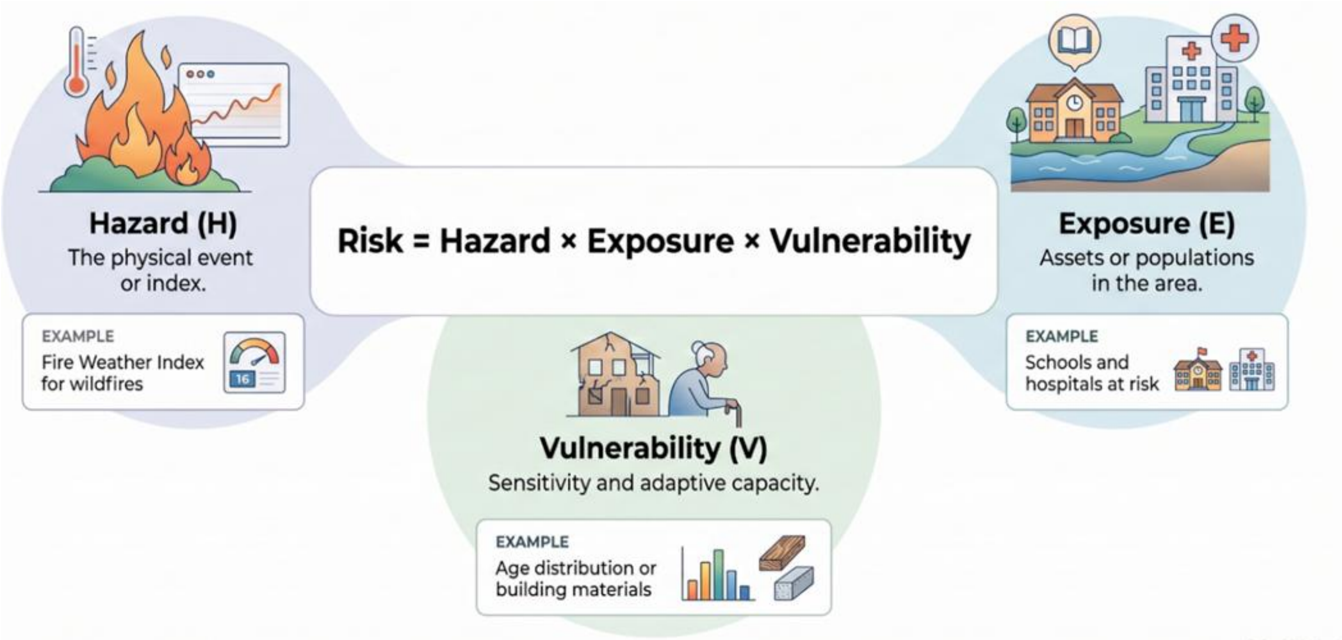

Figure 1: Risk calculation (AI-generated illustration)

2.1.4 The choice of data sets

Key Question: *What data do we need to measure hazard, exposure, and vulnerability for this specific risk?*

A large and growing collection of pan-European datasets exists and can be used to rapidly perform baseline risk assessments for all European city or region. Some examples of required data are shown in Table 1: Examples for data sources. More information is available in D2.1.

Table 1: Examples for data sources

Component	Example indicators	Possible pan-European source
Hazard	River-flood extent / return period	Copernicus CEMS / EFAS, JRC Risk Data Hub
	Drought severity/frequency	Copernicus CEMS / European Drought Observatory
	Heatwaves / extreme temperature	Copernicus C3S Climate Data Store
	Wildfire hazard / fire danger	EFFIS / Copernicus CEMS
	Landslide susceptibility	JRC Risk Data Hub
	Coastal flooding	Copernicus / JRC
Exposure	Population exposed to flood, heat, wildfire etc.	JRC Risk Data Hub, GHSL
	Built-up area / buildings	Copernicus GHSL
	Critical infrastructure	JRC Risk Data Hub / Copernicus, supplemented by national data
	Agricultural land / crops	CORINE Land Cover / Copernicus, Eurostat
	Economic assets / GDP	Eurostat, JRC
Vulnerability	Elderly population, poverty, unemployment	Eurostat regional statistics
	Social vulnerability / deprivation	JRC Risk Data Hub, Eurostat
	Economic vulnerability	GDP, income, employment structure — Eurostat

	Environmental vulnerability	Land degradation, soil, ecosystem indicators — Copernicus / EEA / JRC
	Capacity to cope/adapt	Health, governance, infrastructure, services — JRC Risk Data Hub / Eurostat

For more accurate assessment, local data is essential because it:

- **Adds missing parameters**: Local data can disaggregate exposure (e.g., identifying exactly where nursing homes are located), which pan-European data cannot do.
- **Improves quality**: Local sensors provide higher accuracy than coarse regional models.
- **Offers projections:** Local urban plans can show where future exposure will increase due to new construction.

However, such data is often difficult to procure.

2.1.5 Interpret and Act

A risk map is the starting point, not the not the end of the assessment. The next step is to understand what the results mean and how they can support action.

***Purpose**: Use the risk assessment to identify priorities and support adaptation planning.*

2.1.6 Where is the risk highest?

Identify areas, people, or assets with particularly high risk. Compare the results with local knowledge, historical events, or observations where possible.

***Key question:** Does the result reflect what we know about the area?*

2.1.7 What is driving the risk?

Look separately at the three components:

- **Hazard:** Is the climate hazard particularly severe or frequent?
- **Exposure:** Are many people, buildings, ecosystems, or other assets affected?
- **Vulnerability:** Are the exposed elements particularly susceptible to harm?

The same overall risk level can have different causes in different locations.

***Key question:** Is the risk mainly driven by hazard, exposure, vulnerability, or a combination of them?*

2.1.8 What can be done to mitigate the risk?

Use the identified risk drivers to explore appropriate adaptation measures. Different risk drivers may require different responses.

Table 2: Adaptation measures

If risk is mainly driven by…	What could be done?	Example
Hazard	Reduce or manage the impacts of the hazard	Create **urban green spaces and shade** to reduce local heat; restore **floodplains** to help manage flooding
Exposure	Reduce exposure or protect exposed people and assets	Avoid **new construction in flood-prone areas**; establish **firebreaks around settlements** exposed to wildfires
Vulnerability	Reduce sensitivity and strengthen coping or adaptive capacity	Provide **heatwave warning systems and cooling centres** for vulnerable populations; improve **building insulation and shading** to reduce indoor heat

Note: *Risk mitigation is called "adaptation" in the context of Climate Change.*

Adaptation measures should reflect the local context, available resources, and needs of affected groups.

Adaptation measures should reflect:

- local context
- available resources
- needs of affected groups

Key question: *Which actions could address the main drivers of risk?*

2.2 Baseline risk calculation method

In baseline ClimEmpower methodology, each layer is represented with exactly one data set. All data layers are treated as dimensionless, and the risk is calculated as a three-step process introduced hereafter.

In the first processing step, all data layers are converted to a dimensionless number between 1 and 10[1], using the following formulas:

2.2.1 Conversion Formulas

For data where higher values = higher risk (e.g., temperature, population density):

$$\text{Score} = \left(\frac{\text{Your Value} - \text{Minimum Value}}{\text{Maximum Value} - \text{Minimum Value}}\right) \times 9 + 1$$

Example:

- **Hazard:** Land Surface Temperature (LST) ranges from 20°C (min) to 60°C (max).
- **Your Value:** 45°C.
- Score: $\left(\frac{45 - 20}{60 - 20}\right) \times 9 + 1 = 6.625$ (rounded to 7/10).

For data where lower values = higher risk (e.g., SPI-12, where negative values indicate drought):

Inverted version:

$$\text{Score} = 10 - \left(\frac{\text{Your Value} - \text{Minimum Value}}{\text{Maximum Value} - \text{Minimum Value}} \times 9\right)$$

Example:

- **Hazard:** SPI-12 ranges from –3 (extreme drought, max risk) to +3 (wet conditions, min risk).
- **Your Value:** –1.5 (moderate drought)
- Score: $\mathbf{10} - \left(\frac{\mathbf{-1.5 - (-3)}}{\mathbf{3 - (-3)}} \times \mathbf{9}\right) = \mathbf{10} - (\mathbf{0.25} \times \mathbf{9}) = \mathbf{7.75}$ (rounded to 8/10)

In the second step, risk is calculated by multiplying the values of hazard, exposure and vulnerability for each map pixel. Thanks to initial scale conversion, the resulting risk map will always have a 1-1000 range.

[1] Alternatively, data layers could also be converted to a dimensionless number between 0 and 10. For this, the conversion formulas would need tob e slightly adjusted.

Example: If H = 8, E = 7, and V = 6, then Risk = 8 × 7 × 6 = 336

In the third step, the risk values are associated with a meaning. One possibility to do so is illustrated in Table 3.

Table 3: Risk score range

Risk Score Range	Risk Level	Interpretation	Recommended Action
0–200	Very Low	Minimal risk; hazard, exposure, or vulnerability is negligible.	Monitor trends; no immediate action required.
200–400	Low	Limited risk; one or two components are moderate.	Implement low-cost, no-regret measures (e.g., awareness campaigns, early warning systems).
400–600	Moderate	Noticeable risk; all components are present but not extreme.	Prioritize targeted interventions (e.g., urban greening for heatwaves, drought-resistant crops).
600–800	High	Significant risk; hazard, exposure, and vulnerability are all elevated.	Urgent action required (e.g., flood barriers, evacuation plans, cooling centers).
800–1000	Very High	Extreme risk; all components are at or near maximum levels.	Immediate, large-scale interventions (e.g., relocate vulnerable populations, upgrade critical infrastructure).

Practical note: *The minimum and maximum values used for standardization, and the thresholds used to classify risk scores, are not universal. They should be chosen according to the purpose of the assessment and, where possible, based on observed data ranges, established thresholds, or expert knowledge. Poorly chosen values can* ***overestimate, underestimate, or obscure important differences in risk****. The assumptions should therefore be documented and, where appropriate, tested through sensitivity analysis.*

2.3 Exercise 1: Understanding Map Overlaps

Observe the following three simple 3×3-pixel maps, representing the **hazard, exposure and vulnerability** layers of an imaginary risk assessment (Figure 2). In this exercise, the maps have already been scaled to 0-10 range and a meaning associated to values.

0	0	0
0	10	0
0	0	0

10	0	0
10	0	0
10	0	0

0	0	0
0	0	0
0	0	10

Figure 2: 3x3 hazard (left), exposure (centre) and vulnerability (right) maps

- **Hazard Map:** Only the centre pixel has a value of 10 ("High"), all other pixels have a value of 0.
- **Exposure Map:** left column has a value of 10 ("High"), all other pixels have a value of zero.
- **Vulnerability Map:** only the bottom-right pixel has a value of 10 ("High"), all other pixels have a value of zero.

Question: Calculate the 3×3 risk map, assuming that risk is calculated by multiplying the corresponding hazard, exposure, and vulnerability values. Which pixel has the highest risk?

Answer: None. Every pixel has a risk value of zero because there is no pixel where **hazard, exposure, and vulnerability are all simultaneously greater than zero**.

This illustrates an important principle of risk assessment: **high hazard and high vulnerability do not automatically result in high risk.** Risk arises only where a hazard affects exposed elements that are also vulnerable. In other words, a high hazard in one location and high vulnerability in another do not create risk unless they coincide with exposure in the same location.

Practical note: *Even a relatively small 10 × 10 km² study area can contain a very large number of cells. At a resolution of 100 × 100 m, each map layer contains* ***10,000 cells****. Real-world risk assessments may involve much larger areas, finer resolutions, and several additional data layers. Managing and combining such datasets manually quickly becomes impractical. Specialised tools such as* ***QGIS, ArcGIS, or Jupyter Notebooks*** *can simplify these operations and make the results easier to analyse and visualise.*

2.4 Exercise 2: From Urban Data to a Heat-Risk Map

2.4.1 Scenario: Heat in Horký Hradov

You are a city planner in **Horký Hradov**, a fictional mid-sized Central European city. Summers are becoming hotter, and the city wants to identify neighbourhoods where extreme heat poses the greatest risk to residents.

Horký Hradov has a pronounced **urban heat island**. Dense areas with little vegetation become considerably hotter than greener surroundings, while higher parts of the city close to woodland remain cooler.

The city is also socially uneven. Some neighbourhoods have spacious, well-maintained housing and abundant green space. Others contain dense, older housing, few trees and a larger share of low-income and elderly residents.

Your task is to construct a simple heat-risk map and identify areas that should receive priority for adaptation.

To keep the exercise manageable, Horký Hradov is represented by **nine 1 km² cells**. The data are synthetic, but resemble information that could realistically be obtained from Copernicus, Eurostat, national statistics and municipal datasets.

The important point is that **you are not given ready-made hazard, exposure and vulnerability maps**. You first must construct them from the available information.

2.4.2 The city

The nine cells have the following characteristics:

Table 4: The city plan of Horký Hradov

North-west	North-centre	North-east
Low-density, wealthy residential, detached houses, gardens, abundant vegetation; about 300 m higher than the city centre	Business district, mixed offices, commercial buildings and apartments; relatively little vegetation	Low-density, wealthy residential, detached houses, gardens, abundant vegetation; about 300 m higher than the city centre
Centre-west	**Centre-centre**	**Centre-east**
Dense, lower-income residential, older apartment buildings, few trees	Business district, mixed offices, shops and apartments; heavily paved	Dense, middle-income residential apartment buildings, moderate vegetation
South-west	**South-centre**	**South-east**
Dense, lower-income residential older apartment buildings, very few trees	Business district, commercial and office buildings with apartments	Dense, middle-income residential apartments buildings, moderate vegetation

Large offices, shopping centres and other major commercial buildings generally have air conditioning. Indoor conditions can therefore be considerably better than outdoors. However, people walking outside, waiting for public transport, working outdoors, or living in apartments within the business district can still experience considerable heat.

2.4.3 The climate

Horký Hradov is fictional, but its climate reflects conditions found in parts of Austria, Czechia, Slovakia, and Hungary. Long-term observations from Vienna are therefore used to provide a realistic climatic reference for the exercise.

Practical note: *A **summer day** (Sommertag) reaches at least 25°C, while a **hot day** (Hitzetag) reaches at least 30°C.*

Table 5: Historical summer days and hot days in Vienna per decade (average, min and max values, compiled from https://www.wien.gv.at/statistik/eis-hitze-tage)

Decade	Summer days ≥25°C	Hot days ≥30°C
1950s	~48 (37-61)	6 (1-13)
1960s	~49 (34-60)	10 (2-17)
1970s	~50 (38-59)	~7 (0-15)
1980s	~55 (30-77)	~10 (4-21)
1990s	~62 (45-75)	~15 (3-28)
2000s	~73 (54-102)	~19 (8-40)
2010s	~80 (56-113)	~28 (13-42)
2020-24	~90 (76-102)	~30 (21-45)

Despite year-to-year variability, long-term data indicate a steady warming trend, with hot days becoming increasingly common.

Practical note: *This systematic warming is further evidenced by a record-hot 2026, during which Vienna experienced temperatures exceeding 40°C for the first time in history, and this across all three summer months of June, July, and August.*

For this exercise, assume that

1) Horký Hradov currently experiences around **30 hot days in a typical year and 40-45 or more in particularly hot years**.
2) **Heat waves typically last 3 to 7 days**, though prolonged summer heat waves can extend up to 18 days during peak months like July and August.
3) During a severe heatwave, assume an **average daytime temperature across the city of approximately 35°C, with maximum temperatures occasionally exceeding 40°C**.

Conditions within the city are not uniform:

- the **wealthy northern residential areas are approximately 3°C cooler** because they are about 300 m higher, close to woodland and have abundant vegetation.
- the **dense, lower-income residential areas are approximately 2°C warmer** because of the urban heat-island effect and lack of vegetation.
- the **business district is approximately 2°C warmer outdoors** because of dense development, extensive paved surfaces and little vegetation.
- the dense, **middle-income residential areas are approximately 1°C warmer** than the city average.

2.4.4 The people and buildings

The densest residential neighbourhoods contain approximately **10,000 inhabitants per km²**.

The following simplified information is available:

Table 6: People and buildings in Horký Hradov

Cell	Permanent population	Population over 70	Median income*	Main housing/buildings
North-west	2,400	12%	€3,200	Detached houses
North-centre	4,500	18%	€2,300	Offices + apartments
North-east	2,100	10%	€3,300	Detached houses
Centre-west	9,800	22%	€1,500	Older apartments
Centre-centre	5,000	20%	€1,900	Offices + shops + apartments
Centre-east	8,700	16%	€2,300	Apartments
South-west	10,200	25%	€1,400	Older apartments
South-centre	4,500	24%	€1,800	Commercial buildings + apartments
South-east	8,900	17%	€2,200	Apartments

(*) Income is included as a simplified indicator of socio-economic conditions and does not represent an actual statistical threshold. For improved transferability, income should be interpreted as **purchasing power parity (PPP)-adjusted income**.

The business district also attracts a substantial **daytime population**. During a typical working day, approximately 2,000 additional people are present in the north-centre cell, 3,500 in centre-centre and 2,500 in south-centre.

2.4.5 What happens during heatwaves?

Municipal health records show that heat does not affect everyone equally.

During recent heatwaves:

- **people aged over 70** were considerably more likely to require medical assistance;
- **residents of older apartment buildings** reported greater problems with high indoor temperatures, particularly at night;
- lower-income households were more likely to live in housing with poorer thermal performance;
- residents of greener and less densely built neighbourhoods generally experienced lower temperatures.

Most residential buildings in Horký Hradov, as in much of Central Europe, do **not** have air conditioning. Large offices and commercial buildings are more likely to have mechanical cooling.

The ability to cope with heat can therefore depend on factors such as building quality, shading and ventilation, access to green and cool spaces, income, age and health.

Practical note: *Urban heat transitioned from a minor seasonal discomfort into a documented public health crisis and critical policy problem in Vienna during the landmark 2003 European heatwave. In 2018 another tipping point occured, as heat-related deaths in Austria, for the first time, surpassed traffic fatalities (Vienna heat action plan).*

You now have quite a lot of information.

You do **not**, however, have three neat maps labelled *Hazard*, *Exposure* and *Vulnerability*.

2.4.6 Construct the hazard map

Hazard describes a, potentially harmful, physical climate event or phenomenon.

Select hazard index

In this exercise, we will use the citywide temperature distribution as our hazard index.

Methodological Note (Risk vs. Impact): *Strictly speaking, this calculation will generate an* ***impact map*** *rather than a true* ***risk map****. This is because we have chosen a* ***representative temperature during a specific heatwave*** *as our hazard, rather than a statistical, probabilistic unit, such as the annual frequency of days exceeding a certain threshold.*

- ***Risk*** *inherently indicates the probability that an adverse event will occur, which requires statistical, frequency-based data.*
- ***Impact*** *indicates the severity of consequences under one specific, deterministic climate scenario (in this case, our chosen heatwave temperature).*

While we will proceed with this temperature-based hazard as a practical simplification for this exercise, it is important to keep this distinction in mind: you are mapping the direct, scenario-based consequences of a specific heatwave event rather than a probabilistic risk."

This illustrates an important point: **even before calculating risk, the analyst has already made modelling choices.** Some of these choices can drastically alter the final results.

Construct the hazard index map

In the next step, the hazard index map must be constructed. This can be as simple as downloading a ready-to-use index from Copernicus climate data server or require more work. Typically, this step involves calculation of a high-resolution data from several inputs – some of them having low spatial resolution (“downscaling”).

In this exercise, we will start with the city-wide heatwave temperature of 35°C and use the information about elevation, vegetation and urban form to estimate the average daytime temperature in each cell.

Your temperature map

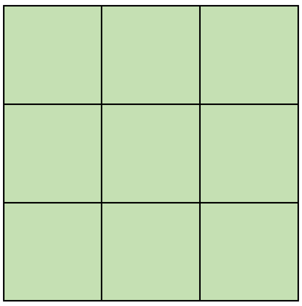

Figure 3: Your temperature map

Check your result

There is not necessarily one uniquely correct answer. One reasonable interpretation gives:

32°C	37°C	32°C
37°C	37°C	36°C
37°C	37°C	36°C

Figure 4: Example temperature map

Discussion: *How similar/how different is your map? Where did you make different assumptions? How important are these differences for a city planner? What data could be used as a hazard, to construct a real risk map, rather than an impact map? What would this change for a city planner or for a risk manager?*

Normalise the hazard layer

We now convert temperature into a common **1–10 scale**.

For indicators where higher values mean higher risk:

Score = ((Value – Minimum) / (Maximum – Minimum)) × 9 + 1

For this exercise, use:

- Minimum = **30°C**
- Maximum = **40°C**

For example, for 37°C:

((37 – 30) / (40 – 30)) × 9 + 1 = 7.3 → 7

Round all values to the nearest whole number.

Your hazard map

Figure 5: Your hazard map

Check your result

3	7	3
7	7	6
7	7	6

Figure 6: Example hazard map

We have transformed measurements in degrees Celsius into a relative **hazard score**.

The 1–10 values were not present in the original temperature data. **We created them through normalisation.** The choice of 30°C and 40°C as reference values is therefore part of the model.

2.4.7 Construct the exposure layer

Exposure describes the people or assets located where the hazard occurs.

Select exposure index

For this exercise, we use permanent population density as the exposure indicator. Since every cell on our 3x3 map represents **1 km²,** the population figures in Section 4 can be treated directly as population densities.

We assume that **10,000 inhabitants/km²** represents the upper end of the population density we want to consider.

Normalise the exposure layer

Convert population to a 1–10 exposure score:

- Exposure score = ((Population – 0) / (10,000 – 0)) × 9 + 1

Round to the nearest whole number. Values slightly above the reference maximum, such as 10,200 inhabitants/km², are capped at 10.

The population figures are the raw exposure data. The resulting values are the normalised exposure layer.

Your exposure map

Figure 7: Your exposure map

Check your result

3	5	3
10	6	9
10	5	9

Figure 8: Example exposure map

This is a modelling choice, not a universal rule.

2.4.8 Construct the vulnerability layer

Vulnerability describes the susceptibility or sensitivity of those exposed people or assets to the hazard.

Select vulnerability index

A person may be vulnerable because of age, health, income, social isolation or housing conditions. A building can also increase or reduce the vulnerability of its occupants.

For this exercise, we shall use two vulnerability indicators rather than one:

- share of residents over 70;
- housing and socio-economic conditions.

Age vulnerability

Convert the percentage of residents over 70 to a 1–10 score:

- Age score = ((Percentage over 70 − 10) / (25 − 10)) × 9 + 1

For this exercise, 10% represents the lower reference value and 25% the upper reference value.

Calculate the age vulnerability score for each cell.

Housing and socio-economic vulnerability

There are a many ways of translating housing and socio-economic conditions into a vulnerability score. A detailed assessment could consider building age, insulation, floor level, roof characteristics, shading, ventilation, renovation status, household income, access to green space and many other variables.

At some point, however, an assessment has to be pragmatic.

For this exercise, use the following simple expert judgement:

Table 7: Housing/neighbourhood type

Housing/neighbourhood type	Vulnerability score
Wealthy, low-density housing with gardens	2
Mixed commercial/residential buildings	4
Middle-income apartment areas	5
Older, lower-income dense housing	8

These scores are **not natural properties of the neighbourhoods**. They are informed modelling assumptions. In a real assessment, the method should be appropriate to the available data and purpose of the analysis, and the assumptions should be documented.

Combine two vulnerability indicators

We now have two vulnerability indices: age and housing/socio-economic conditions.

For this exercise, we will calculate the combined vulnerability as a **simple average of the two vulnerabilities**, with each index having equal weight:

- Compound Vulnerability = (Age score + Housing score) / 2

Round the result to the nearest whole number.

Practical note: *averaging over several hazard, exposure or vulnerability layers is convenient and transparent, but it can also be dangerous. It implicitly assumes that both indicators are equally important and can compensate for one another. This may not be appropriate if one factor is particularly critical or if several indicators measure essentially the same underlying vulnerability. A real assessment should therefore justify both* ***which indicators are combined, how they are combined and how they are weighted****. In some cases, calculating several risk indicators and only then constructing a compound risk map will be more appropriate.*

Your vulnerability map

Figure 9: Your vulnerability map

Check your result

A reasonable result is approximately:

2	4	2
8	5	5
9	6	5

Figure 10: Example vulnerability map

2.4.9 Calculate and classify risk

We started with temperature information, population statistics, demographic data and descriptions of neighbourhoods and buildings. Only after making several decisions did we arrive at the three maps required for the risk calculation.

Hazard

3	7	3
7	7	6
7	7	6

Exposure

3	5	3
10	6	9
10	5	9

Vulnerability

2	4	2
8	5	5
9	6	5

Figure 11: Example final 3 layer (Hazard x Exposure x Vulnerability)

Now—and only now—can we calculate the risk map.

Calculate the risk

For each cell:

- Risk = Hazard × Exposure × Vulnerability

For example, south-west has:

- Hazard = 7
- Exposure = 10
- Vulnerability = 9

Therefore:

- Risk = 7 × 10 × 9 = 630

Calculate the risk for all nine cells.

Your risk map

Figure 11: Your risk map

Check your result

18	140	18
560	210	270
630	210	270

Figure 12: Example risk map

Classify the risk

For this exercise, use the following illustrative classification:

Table 8: Risk score

Risk score	Risk level
1–200	Very Low
201–400	Low
401–600	High
601–1000	Very High

This gives:

Very Low	Very Low	Very Low
High	Low	Low
Very High	Low	Low

Figure 13: Example for the risk score application

These thresholds are **illustrative rather than universal**. Different thresholds could produce a different-looking map.

Critically assess the results

At this point, we have a mathematically valid risk map. But is it a good risk map?

Practical note: *A mathematically correct calculation can still produce a poor representation of real-world risk.*

The **south-west dense, lower-income neighbourhood** has the highest calculated risk. Several factors coincide there:

- high temperature;
- very high population density;
- a large proportion of elderly residents;
- older, poorer-quality housing.

The northern residential areas contain exposed and vulnerable people too, but their cooler environment and lower population density substantially reduce the calculated risk.

The business district is more complicated. It is hot and has a substantial permanent population.

Some of those residents are relatively elderly and less affluent, particularly in the central and southern parts of the district. At the same time, many offices and larger commercial buildings are actively cooled. This lowers the risk indoors, but may further increase outdoor temperatures.

Our map also ignores thousands of workers, shoppers and visitors who enter the district during the day.

Practical Note: *is common thresholds are used to normalise the hazard, exposure and vulnerability layers for different regions, common risk classification may return misleading results for a particular city or region. Local expertise can help to improve the classification and make the final risk map useful for the region without having to re-calculate it.*

Consider whether the results correspond reasonably well with the story of the city. If a result appears implausible, do not automatically assume that the calculation is wrong—or that reality is wrong. Examine the **input data, standardisation, assumptions, weights and classification thresholds**.

Practical Note: *if a common thresholds are used to normalise the hazard, exposure and vulnerability layers for different regions, common risk classification may return misleading results for a particular city or region. Local expertise can help to improve the classification and make the final risk map useful for the region without having to re-calculate it.*

The matter of future

Now consider the future.

For this simplified scenario, assume that by **2055 average temperatures are approximately 2°C higher**, while heatwaves also become more frequent and longer.

First perform a very simple experiment:

1) Add **2°C** to every cell in your temperature map.
2) Repeat the hazard standardisation.
3) Recalculate the risk map while keeping today's exposure and vulnerability unchanged.

Does the ranking of neighbourhoods change? Which neighbourhoods experience the largest increase in calculated risk? Does the dense, lower-income area remain the highest-risk area?

Also consider an important limitation of this calculation: simply adding 2°C does not capture changes in the **frequency or duration of heatwaves**. If Horký Hradov experiences more hot days and longer periods without nighttime relief, the change in heat hazard may be considerably more important than the temperature increase alone suggests.

A more realistic future assessment

In reality, we should not simply take today's city and make it 2°C warmer.

By 2055, population distribution may change. Buildings may be renovated, demolished or replaced. New housing may be constructed. Trees planted today may provide substantial shade. The city may create parks, shaded public spaces and cool refuges or implement other heat-adaptation measures. Socio-economic conditions and the age structure of the population may also change.

A realistic future risk assessment should therefore consider **anticipated changes in hazard, exposure and vulnerability**, including planned adaptation measures.

2.4.10 Alternative heat risk calculation methods

For this exercise, we made a pragmatic choice:

- **Hazard =** daytime outdoor temperature distribution during a heatwave
- **Exposure** = how many permanent residents are present.
- **Vulnerability** = how susceptible those residents are to harm.

We also decided to use two vulnerability indices and combine them in a specific way. Moreover, we made assumptions that affected the normalisation of input layers and the presentation of the final map. All of this affects the result. Let us look at some possible alternatives.

Alternative hazard indices

For simplicity, this exercise uses **temperature on a representative hot day as the spatial hazard indicator, technically resulting in an impacts map, rather than a risk map**. An obvious alternative would be to use the probability of days with temperatures exceeding certain threshold as the hazard index. Another alternative would be to use frequency and duration of heatwave as the hazard index. A more sophisticated assessment might combine temperature, the number of hot days, nighttime temperature and heatwave duration into a compound hazard indicator.

Practical note: *temperature is not the only characteristic of a heatwave. A temperature of 35°C lasting for one day is clearly different from the same temperature persisting for a week.*

Alternative exposure indices

Look at the business district.

Centre-centre has **5,000 permanent residents**, but another **3,500 people** may be present during a normal working day. Which population should we use?

We could use permanent population, daytime population, or create separate assessments for daytime and nighttime heat risk.

There is another possibility. Instead of counting everybody equally, we could calculate the number of **particularly vulnerable people** in each cell—for example, residents over 70—and use this directly as exposure. We could also assign higher exposure weights to particular groups.

These approaches are also possible, but they start to blur the distinction between **exposure** and **vulnerability**.

Alternative vulnerability indices

Look again at the vulnerability calculation.

We combined age with housing and socio-economic conditions. But we could have constructed the model differently.

For discussion:

- Should elderly residents be represented in the **vulnerability layer**, or should we calculate their number and include them as a special category of **exposure**?
- Should poor-quality housing be vulnerability, or does it modify the **heat hazard actually experienced indoors**?
- Should daytime workers be included in exposure?
- Should office workers, outdoor workers and residents have different vulnerabilities?
- Should office buildings and residential buildings be assessed separately?
- Should income be included directly, or only through measurable consequences such as housing quality?
- Should a small population with extremely high vulnerability receive more attention than a large population with moderate vulnerability?

These are not merely technical questions. They are **choices about how we conceptualise risk**.

Practical note: *There is no universal rule saying that a particular indicator must belong in one particular layer. The important thing is that the choices are practical, explicit, consistent, documented, defensible, and most importantly useful for the task at hand.*

Vulnerability functions vs. vulnerability maps

So far, we have treated a vulnerability as another map layer. This is yet another design choice, not a universal rule. For example, we could have chosen the average heat wave duration as a hazard and population distribution as exposure.

Even better, we could have chosen a set of maps representing the frequency or probability of a heat wave with duration of 2, 3, 4 and more days as a hazard and a distribution of “population at risk of poverty” or “population over 70” as exposure layer.

In this case, the vulnerability could be a single function, indicating how this population is affected by the heat wave, as a function of the heat wave duration and not a map. As an optional exercise, you can try to construct a vulnerability function and the complete risk calculation method grounded in heat wave duration, using the following **Heat Wave Timeline:**

- **Day 2 (The Immediate Shock):** when daily temperatures spike for just **two consecutive days**, ambulance calls rise by **10%**. Children and respiratory patients are hit first.
- **Day 3 (The Mortality Surge):** daily death rates rise three-fold to four-fold in heat waves of **three or more consecutive heat days**.
- **Day 4+ (Saturation):** By the fourth consecutive day of sustained heat, the global "added effect" of independent heat stress peaks. The human body fails to shed core heat, and the city's concrete infrastructure begins trapping daytime radiation, creating an artificial furnace.

This list should be taken as a simplified model, roughly aligned with actual experience in the region of Vienna and surrounding regions in Austria, Czechia, Slovakia and Hungary. For better data, please consult regional experts and publications.

Practical note: *the adverse effects of heat waves are initially mitigated by thermal capacity of the buildings and the fitness of the population. As house walls and even cellars gradually heat and the effects of fatigue accumulate, the daily morbidity and mortality rates start climbing before platooning after ~4 days.*

3 Practical considerations and lessons learnt

3.1 Conceptual vs. actual risk calculation

Risk calculation equation is, in principle extremely simple:

- Risk = Hazard × Exposure × Vulnerability

You do not need to be an environmental scientist, a GIS expert or even have access to any data sets to understand how the risk is calculated. Certainly, real data sets and GIS tools are necessary to perform actual calculations for a specific region, at a reasonably high resolution. However, this is merely a technical hurdle. Certainly, real datasets and GIS tools are necessary to perform actual calculations for a specific region at a reasonably high resolution. However, this is merely a technical hurdle. Several more significant challenges are discussed below.

Conceptual ambiguity

Key conceptual issue is that no “right” or even “obvious” choices of data sets representing hazard, exposure and vulnerability exist and that a choice of a specific dataset therefore affects not only the numerical result, but also what the resulting risk measure represents (Table 9).

Table 9: Two examples of heat health risk calculation

Component	Data set 1	Data set 2
Hazard	number of days with T_{max} > 35°C;	Heatwave duration
Exposure	Total population	Population exposed to the heatwave
Vulnerability	Share of elderly people	Multidimensional social vulnerability index
Result	Measure of risk for the elderly population	Measure of risk across different population groups.

The need for data preparation

Key practical consideration is that these data sets do not come as three perfectly aligned 1–10 maps, at a right spatial resolution for the problem at hand. Instead, they come as a mix of satellite-derived temperature data, demographic statistics, building databases, income statistics, land-cover information, elevation data, health records and surveys—often collected at different times and represented using different spatial units. A further challenge is that datasets representing different components may contain overlapping information. Ideally, each dataset should represent a clearly defined component of the risk chain. In practice, this is often difficult to achieve.

To calculate a risk map reflecting a real world, someone must decide not only which three data layers to conceptually combine but how to transform available data into normalised hazard, exposure and vulnerability layers. This requires expert knowledge and time, as different approaches need to be tested and discussed with intended users of the risk maps.

The problem of correlated data

Consider agricultural drought. A possible hazard dataset could describe soil moisture deficits, while exposure could be represented by the area of agricultural land affected. Vulnerability could then be represented by the share of drought-sensitive crops. However, other datasets may already combine some of these characteristics. A crop-specific drought index, for example, may incorporate both soil moisture and crop sensitivity. Using such an index as the hazard while separately including crop sensitivity as vulnerability would therefore partly count the same information twice.

This illustrates why choosing datasets requires more than simply finding one suitable indicator for each component. **The datasets must also be examined for what they already contain and how they relate to each other.**

When one data set per layer is not enough

Finally, it is often necessary to **consider more than one dataset per layer when calculating risk.** For example, we may need to combine an exposure layer representing land cover with another representing buildings and roads to calculate total flood exposure. Likewise, we may decide to combine heatwave duration and maximum daily temperature into a single hazard layer. **Deciding how exactly to combine these datasets is itself a methodological choice that can significantly affect the resulting risk measure.** The datasets may need to be normalised, weighted or otherwise transformed before they can be combined, and there is often no single objectively correct approach.

3.2 Social Equity in Adaptation

Adaptation is not just about engineering; it is about justice. Some population groups, such as elderly and single mothers, are often both more vulnerable to natural hazards and living in an area with higher hazard occurrence. Due to their lower purchasing power, these citizens also have the lowest ability to help themselves (Table 10: Conceptual interaction of Hazard, Exposure, and Vulnerability.).

Table 10: Conceptual interaction of Hazard, Exposure, and Vulnerability.

Component	Variable	Low Risk Scenario	High Risk Scenario
Hazard	Air Temperature	35°C	42°C
Exposure	Location	Suburban area	Dense city centre
Vulnerability	Demographics	Healthy adult	Elderly person with chronic illness
Coping capacity	Disposable income	high	low

Practical consideration: *If we decide to protect the "highest value" assets (e.g., the financial district, affluent residential areas) first, vulnerable population groups will suffer disproportionally. This can lead not only to higher morbidity and mortality, but* *also to loss in trust in the governance, with negative consequences ranging from the rise of populism to social unrests.*

A resilient region is, therefore, one where the most vulnerable citizens are protected first.

~~3.2~~3.3 Common Pitfalls

Table 11: Common pitfalls and solutions

Pitfall	Solution	Component
Treating burnable vegetation as vulnerability	Classify burnable vegetation as a hazard factor	Hazard
Averaging exposure across asset types	Calculate risk by asset class, then sum results	Exposure
Using unjustified equal weighting	Use sector-specific indicators and justify weights	Vulnerability
Ignoring local vulnerability data	Include municipal-level data where available	Vulnerability
Overlooking risks from nearby critical infrastructure	Include hazardous/critical infrastructure in vulnerability assessment	Vulnerability
Combining datasets at different spatial resolutions	Resample to a common resolution and document trade-offs	Data Downscaling
Using outdated static datasets	Validate against recent local data or state temporal limitations	Data Downscaling
Not documenting assumptions and limitations	State data gaps, assumptions, and uncertainties	Uncertainty Management
Ignoring stakeholder feedback	Validate indicators and results through CoP engagement	Stakeholder Engagement

4 Key messages and next steps

4.1 Key messages

Remember:

- **Risk is a multiplicative function of hazard, exposure, and vulnerability.** High risk only materializes when all three factors coincide: a physical climate event (hazard), people or assets located in the hazard zone (exposure), and a susceptibility to harm based on factors like age, income, or housing quality (vulnerability).
- **Risk maps are constructed models, not objective discoveries.** The final output is shaped by methodological choices, including data selection, standardization ranges (e.g., 1–10 scales), and the weighting of indicators. Consequently, assumptions must be transparently documented to avoid distorted prioritization.
- **Equity must be central to risk assessment to avoid "one-size-fits-all" solutions.** Vulnerability is socially constructed and spatially uneven; marginalized groups often face disproportionate risks. Assessments must use local data to identify hidden vulnerabilities—such as the urban heat island effect in low-income neighbourhoods—to ensure resources are allocated fairly.
- **Future risk projections require dynamic analysis of all components.** Simply increasing hazard intensity (e.g., +2°C) is insufficient. Realistic future scenarios must also account for shifting exposure and vulnerability, such as aging populations or the impact of new urban greening and building retrofits.
- **The process of assessment is more critical than the final numerical score.** Practitioners should prioritize understanding the "why" behind the data. This includes conducting sensitivity analyses to test assumptions and performing plausibility checks against local qualitative narratives to ensure the map aligns with real-world conditions.

4.2 What can you do next?

Regional Planners

Identify vulnerable groups in your region (e.g., elderly, low-income). Audit existing risk maps to check if they exclude key exposures (e.g., daytime workers) or vulnerabilities (e.g., poor housing quality). Use GIS tools to create tailored risk maps.

Policymakers

Review existing risk maps for gaps in representation of marginalized populations. Ensure that budget allocations for adaptation are prioritized based on the intersection of high hazard, high exposure, and high vulnerability.

Consultants

Apply the IPCC risk framework to provide evidence-based advice to regional governments. Test alternative vulnerability indicators to avoid oversimplification and ensure that risk assessments are grounded in local socio-economic data.

4.3 Further resources

Table 12 shows the recommended platforms for further reading and access to related project resources.

Table 12: recommended platforms

Source platform	Short definition	Relevant materials
ClimEmpower Project Results — climempower.eu/results/	Official ClimEmpower platform for project results and outputs	Project deliverables; resilience recommendations; risk-map information; project tools and software; scenarios; data and knowledge assessments; stakeholder engagement results
ClimEmpower Educational Library — climempower.eu/knowledge-hubs/	ClimEmpower collection of educational materials and selected knowledge resources	Educational materials; reports and guidance; presentations; learning resources; climate-hazard and sector resources; target-group resources; external knowledge resources
CORDIS — cordis.europa.eu	European Commission platform for EU-funded research and innovation	Project descriptions; public deliverables and reports; publications; project partners; project results and outputs
Climate-ADAPT — climate-adapt.eea.europa.eu	European platform for climate change adaptation knowledge and practice	Adaptation strategies and policies; case studies; climate risks and impacts; adaptation options; tools; indicators; research and innovation projects
ClimEmpower Zenodo Community — zenodo.org/communities/climempower	Open repository for ClimEmpower research outputs and project materials	Datasets; journal publications; conference papers and posters; educational materials; other project outputs

The following short list identifies key resources that complement this report:

Climate Risk and Resilience: A Practical Introduction

- **What is it?** A ClimEmpower educational resource providing an accessible overview of climate risk and resilience concepts.
- **Why is it highly relevant?** It complements the methodology by reinforcing the IPCC framework for climate risk assessment and supporting the understanding of hazard, exposure, and vulnerability.
- **Access:** https://zenodo.org/communities/climempower

Using Climate Risk Maps for Regional Planning

- **What is it?** A ClimEmpower educational material focused on the application of climate risk maps in regional planning contexts.
- **Why is it highly relevant?** It aligns with the methodology's emphasis on spatial resolution and stakeholder engagement, offering practical guidance on integrating risk maps into adaptation planning.
- **Access:** https://zenodo.org/communities/climempower

From Climate Risk Assessment to Adaptation Measures

- **What is it?** A ClimEmpower educational resource that bridges climate risk assessment and the design of concrete adaptation measures.
- **Why is it highly relevant?** It supports the methodology's focus on turning indicators into actionable policies, ensuring that assessments lead to measurable outcomes and institutional responsibility.
- **Access:** https://zenodo.org/communities/climempower

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