Adaptation measurement: Assessing municipal climate risks to inform adaptation policy in the Slovak Republic

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Authorised for publication by Jo Tyndall, Director, Environment Directorate.

Abstract

Climate change presents a major social, economic and political challenge for the Slovak Republic. The majority of municipal administrations are unaware of the potential climate risks they face today and in the coming years. Identifying risks posed by climate change and its inevitable impacts is an essential part of developing adaptation policies. While national adaptation policies have historically been formulated in an *ad hoc* manner, an evidence-based approach that relies on data is increasingly informing policy decisions. This paper provides an overview of the country's adaptation policy context and presents a methodology – and the results of its application – for measuring climate change risks with respect to heat, drought and extreme precipitation. The results aim to inform future budget allocation decisions for climate change adaptation.

Keywords: climate change adaptation, data envelopment analysis, climate hazards

JEL codes: C60, Q54, Q58

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Acronyms

AHP	Analytic hierarchy process
APVV	Slovak Research and Development Agency (Agentúra na podporu výskumu a vývoja)
BAP	Budget allocation process
CA	Conjoint analysis
CCC	Climate Change Committee
CI	Composite Index
D	Drought
DEA	Data envelopment analysis
DEFRA UK	Department for Environment, Food and Rural Affairs
EC	European Commission
EEA	European economic area
EGD	European Green Deal
EH	Extreme heat
EP	Extreme precipitation
EPA	European Protection Agency
ERDF	European Regional Development Fund
ESIF	European Structural and Investment Funds
EU	European Union
GGA	Global Goal on Adaptation
GHG	Greenhouse gas
IEA	International Energy Agency
IEP	Institute for Environmental Policy
IPCC	Intergovernmental Panel on Climate Change
IVAVIA	Impact and vulnerability assessment of vital infrastructures and built-up areas
LULUCF	Land use, land-use change, and forestry
MoE	Ministry of Environment of the Slovak Republic

MRE	Monitoring, Reporting, and Evaluation
NAP	National Adaptation Plan (the Action Plan)
NAS	National Adaptation Strategy
NC	National Communication (under the UNFCCC framework)
NDCs	Nationally Determined Contributions
NEHAP	Action Plan for the Environment and Health of the Population of the Slovak Republic
NGOs	Non-governmental organisations
NI	Northern Ireland
NSRMS	National Security Risk Management Strategy of the Slovak Republic
MSL	Mean sea level
PIP	Prioritisation of Investment Projects
RRP	Recovery and Resilience Plan
SHMI	Slovak Hydrometeorological Institute (SHMÚ)
SPEI	Standardised Precipitation-Evapotranspiration Index
UCM	Unobserved components model
UNFCCC	United Nations Framework Convention on Climate Change
VEGA	Scientific Grant Agency (Vedecká grantová agentúra)

Executive summary

Climate change will negatively impact Slovakia in the coming decades, and preparing for its effects is a difficult social, economic, and political challenge. This requires efforts on all levels and sectors of government. Adaptation is becoming a key issue addressed by policy-makers, and this complex task requires integrated strategies and tools to ensure efficient implementation. Climate change adaptation is context-specific and the effectiveness of adaptation measures depends on a number of factors, including the local environmental and geographical circumstances and socio-economic conditions.

Evaluating risks posed by climate change can guide potential adaptation measures. The country's governance is increasingly shifting from a project-oriented towards more integrated strategies, which prioritise data-driven, multi-scalar co-operation across levels of government and its policy domains**.**

This study presents the country's approach to adaptation and formulates a methodology for measuring climate change risks at the municipal level for better adaptation policies. It maps ongoing adaptation policy development processes, and then divides municipalities into ten categories according to the levels of climate risk of three prevalent climate hazards: heat, drought and extreme precipitation. The dissemination of the results can help scale-up adaptation in individual municipalities, districts and regions. Administrations are encouraged to invest in implementation and outline their own adaptation plans, which should reflect the risks identified in this study.

Data-driven adaptation policies and processes can guide implementation and allocation of finance.

The National Adaptation Plan (NAP) identifies key sectors and actors responsible for adapting to the effects of climate change. It is based on the latest National Adaptation Strategy (NAS), which establishes the country's key adaptation objectives to become a climate-resilient country. Together, they laid the grounds for ensuring an effective implementation of adaptation measures. Additional policy-makers, such as municipalities, have formulated their own adaptation strategies and plans. This paper aims to help both national as well as local policy-makers to steer adaptation policies.

There is currently no cost-benefit assessment methodology for adaptation finance allocation in Slovakia. The current priorities for environmental funding are defined in the Ministry of Environment's Prioritisation of Investment Projects, which assesses only the drought and heat risks and does not consider all municipalities in Slovakia. Although the National Adaptation Strategy states that adaptation measures with positive effects on public health should be prioritised, there is scope to define criteria under which adaptation finance should be allocated and which areas and measures should be emphasised.

While policy strategies address diverse aspects of adaptation, currently adaptation priorities do not align with funding.

Adaptation in Slovakia is funded from multiple sources, including domestic national and local funds, international finance and private funding. Overall, most funding from any source allotted to adaptation in Slovakia have been designated for preventive flood protection measures. No clear, comprehensive list of past adaptation funding has been developed yet. One of the notable sources for adaptation in the coming years is the EUR 2.3 billion assigned towards green economy within the Recovery and Resilience Plan, out of which EUR 159 million are to be allocated to adaptation measures and adaptation-related reforms. Additionally, within the latest EU Programming period for 2021-2027, over EUR 239 million are assigned to several types of adaptation measures, including legislative reforms.

There is a critical need for a practical alignment between funding and policy, which would aim to address adaptation in a targeted and impactful manner. There are several, rather complex policy strategies and methodologies for addressing adaptation processes in Slovakia, and yet, funding frameworks are not completely aligned with adaptation plans. A simplified policy framework, closely tied to an effective funding system could tackle adaptation more directly. As past investments in adaptation have mostly from outside sources, and focused on tackling some impacts more than others, there is scope for the upcoming National Adaptation Strategy to focus on the necessity of allocating finance towards other adaptation measures. The risk assessment method presented in this paper can serve as the basis for this framework and showcase the needs of individual districts across Slovakia.

Regions with the highest level of climate risk need to prioritise enhancing their resilience to climate change impacts.

The risk assessment in this paper divides municipalities into 10 levels of risks for three climate hazards. Risk levels are assigned according to municipalities' values for each composite index**.** By identifying a set of indicators, which include socio-economic, land cover and both observed and projected climate hazard factors, the methodology considers each municipality's levels of risk, exposure and coping capacity. Indicators were chosen based on expert recommendations and data availability. While the three hazards used as indices are estimated to be the most prevalent in the country's future, this methodology is adaptable and can be extended to account for more hazards, or to account for other indicators of different weights.

The results show that districts at the highest risk of extreme heat impacts are located in the south of Slovakia including the capital of Bratislava. Rimavská Sobota and Lučenec in the south are at risk as well. This index is conditioned by the data for the number of tropical heat days and heat nights, as well as projected future scenarios. Districts with low access to healthcare and high proportion of children aged below four years old were assessed as more at risk. More than 16 % of the Slovak population lives in the areas with the highest prevalence of heat hazard.

Droughts pose notable risks to districts in the southwest of the country, namely Bratislava and the areas of Žitný ostrov. Žitný ostrov is a critical agricultural land and has the biggest drinking water reservoir in the country. Potential droughts present a severe risk to water supply and food security. While the current and the past drought-related situation was used to evaluate the risks, access to public water supply plays a major role in territories' risk level.

Extreme precipitation presents a risk to districts in the north – Tvrdošín, Dolný Kubín and Kysucké Nové Mesto in particular. These areas have historically been exposed to heavy rains, while being significantly affected by landslides, which plays a factor in their exposure. Additionally, Veľký Krtíš in the south and its adjacent districts are at risk as well, based on future precipitation projections. The impacts of extreme precipitation have significant social implications, as several municipalities with a high share of Roma populations like Ostrovany, Chminianske Jakubovany and Jarovnice have the highest level of risk of extreme precipitation. In 1998, extreme rainfall led to floods in Jarovnice (district of Sabinov) that resulted in 50 deaths and grave property damages.

1 Introduction

The effects of climate change are already being observed and experienced in all regions of the world. The occurrence of extreme weather events such as heatwaves, floods, and wildfires, is expected to become more frequent and intense under the continued climate change. By the end of this century, the average global temperature is very likely to increase by 1.0°C to 1.8°C, considering a low greenhouse gas emissions (GHG) emission scenario[1], potentially even by 2.1°C to 3.5°C, if an intermediate emissions scenario[2] is assumed, compared to the average temperature between 1850 – 1900 (IPCC, 2021[1]).

The Slovak Republic (hereinafter Slovakia) is already being negatively impacted by climate change, and the effects are expected to multiply and further deteriorate. The effects of climate change, such as the increasing atmospheric temperatures are currently observed throughout all regions (Ministry of the Environment of the Slovak Republic, 2019[2]). These are likely to negatively impact water balance, thereby affecting economic sectors such as agriculture, forestry and fisheries, as well as increasing biodiversity threats and risks to human health.

Since 1881, Slovakia has experienced several changes in climate conditions due to increasing GHG concentrations in the atmosphere. A substantial rise in the average annual air temperature, which increased by 1.73 °C, was observed. Precipitation has decreased by up to 10 % in the South and has increased by up to 3 % in the north and northeast (Ministry of Environment of the Slovak Republic, 2017, p. 23[3]). Furthermore, a decrease of up to 5% in relative humidity was observed in the South of Slovakia. Snow cover reduction has been recorded at levels up to 1 000 m above mean sea level (MSL). almost throughout all of Slovakia. On the other hand, higher altitudes (above 1000 m) have experienced an increase in snow cover.

The frequency of changes in climate variability, particularly between extremely dry and wet intervals within a short period, have significantly increased. Since 1993, severe daily precipitation has caused a considerable increase in flash floods. At the same time, the country has suffered from gradual desertification as a result of prolonged dry periods, with very low precipitation rates during growing seasons (April to September), which have been particularly salient in the southern regions (ibid). In addition, both the occurrence of heat waves as well as cold waves has increased. All the observed climate change impacts in Slovakia exceeded their respective projections in terms of frequency and intensity. In fact, between 2001 and 2017, some impacts reached climate conditions projected for 2030[3] (Ministry of Environment of the Slovak Republic, 2017, p. 23[3]).

There is an urgent need to adapt to the risks posed by climate change. While emissions mitigation can limit the extent of climate impacts, they will continue to unfold in the short term, with some impacts found to be irreversible. Adaptation measures have the potential to limit the damages to society. Adaptation to climate

1 SSP1-1.9 is an illustrative emissions scenario established by the IPCC; it describes an optimistic future scenario with very low and low GHG emissions and CO_2 emissions and in decline to net zero around or after 2050

2 SSP2-4.5 is an illustrative emissions scenario established by the IPCC; it described a future scenario with intermediate GHG emissions

3 These were estimated with regard to climate change scenarios in Slovakia

change is therefore a key area, which is becoming integral to Slovakia's sectoral policies and continues to be addressed by policymakers on all levels of governance.

Many policymaking authorities in Slovakia, including local governments have begun mainstreaming adaptation to climate change into other sectoral policies. The National Adaptation Strategy (NAS), namely the *Adaptation Strategy of the Slovak Republic on Adverse Effects of Climate*, and National Adaptation Plan (NAP), namely the *Action Plan for the Implementation of the Strategy for Adaptation of the Slovak Republic to Climate Change*, are key policy documents which outline the objectives and the implementation of adaptation measures in a number of social and economic areas. A section of the Prioritisation of Investment Projects (PIP) (Ministry of Environment of the Slovak Republic, 2021[4]), which outlines the strategic priorities for environmental funding in Slovakia, is devoted to adaptation. A part of the adaptation section in PIP entails an evaluation of priority areas across the country, based on climate risk data. However, the PIP is a limited tool for risk evaluation at an urban level, as it overlooks less populated areas of the country. Developing local-level adaptation strategies is a challenging task faced by municipal authorities. Although climate change is a global issue, its impacts are location-specific and vary across regions. As the climate hazards and their effects on the social and economic sectors vary across the country, adaptation processes must be addressed in a manner specific to the needs of each location.

The objective of this paper is to assist these efforts and build on relevant data to assign each municipality according to their risk levels, and consequently, to assess which municipalities in Slovakia face high risk of climate change impacts. This paper develops an assessment of climate risks in all municipalities to formulate a comprehensive risk assessment throughout all areas of the country to support municipalities, districts and regional administrations in making data-informed decisions regarding resource allocation and appropriate adaptation strategies.

To provide a detailed assessment of the levels of climate risks across the country and to estimate which areas are more endangered than others, this paper formulates a climate risk evaluation, which incorporates data for all municipalities in Slovakia. The widespread approach to risk evaluation so far has been to develop a complex framework encompassing a number of relevant indicators, such as from the climate change impact assessment (Céza et al., 2019[5]). Similarly, the UK set out to track its adaptation policy progress through a comprehensive framework, using indicators related to adaptation actions, risk factors and impacts of climate change (OECD, 2022 forthcoming[6]). Instead, this paper proposes composite indices to comprise all the relevant dimensions into one metric, with weights endogenously generated for more objective results.

This paper applies one of the most frequently used methodologies for data-driven creation of composite indices – Data Envelopment Analysis (DEA). While the DEA model has been used for the construction of several composite indicators, such as Human Development Index (Despotis, 2005[7]) or Environmental Performance Index (Zanella, Camanho and Dias, 2013[8]), it is not usually used to create an index for as many entities as are considered in this paper. Thus, the number of units used in this work exceeds the usual scope of previous works, and has not been widely used in the context of climate change adaptation. As such, it provides additional challenges in the complexity and sensitivity of the task.

2 Adaptation policy and institutional contexts

In Slovakia, climate change mitigation and adaptation follow different policy development processes. Mitigation policy is closely tied to the European Union's (EU) climate change frameworks, and therefore its underlying goals are aligned within the country and within the EU. Slovakia's climate change mitigation strategy has been coordinated by the EU's 2020 climate and energy package and its main mitigation instrument is the Fit for 55 plan.

Adaptation measures in Slovakia are formulated and adopted at the national level by the Ministry of Environment. As both mitigation and adaptation are equally important, it is crucial that their respective policies do not undermine, but complement each other. Identifying and harnessing prospective synergies between the two in a coordinated approach can increase cost-effectiveness and bring about win-win outcomes (Wreford, 2012[9]).

2.1 National policy framework relevant to adaptation

The Ministry of Environment of the Slovak Republic (MoE) is the coordinating body for developing and implementing adaptation policies[4], as well as for the monitoring and evaluation thereof. The responsibilities for policy and implementation lie with different ministries and with sub-national level administrations (Figure 2.1). As responsibilities are distributed horizontally as well as vertically, the MoE plays a very important consulting role in coordinating strategic and legislative issues.

Figure 2.1. The position of the Ministry of Environment in adaptation policy-making

Note: Other ministries include the Ministry of Economy, Ministry of Finance, Ministry of Transport and Construction, Ministry of Interior, Ministry of Defence, Ministry of Justice, Ministry of Foreign and European Affairs, Ministry of Labour, Social Affairs and Family; and other national actors include the Slovak Academy of Sciences, Slovak Environmental Agency, Public Health Office of the Slovak Republic, State Geological Institute of Dionýz Štúr, State Nature Conservancy of the Slovak Republic, National Forest Center, Soil Science and Conservation Research Institute, and non-governmental organisations such as Carpathian Development Institute.

[4] Order as per the codex of the law 575/2001 Z. z. o organizácii činnosti vlády a organizácii ústrednej štátnej správy (about the organisation of government operations and of the central state governance)

Source: Institute for Environmental Policy

Since 2020, the MoE has been the presiding body of the Council of the Government of the Slovak Republic for the European Green Deal (EGD), of which the EU Strategy on Adaptation is a subordinate initiative. The Council of the Government is an advisory body authorised to implement measures in line with the EGD's goals and advise on and coordinate issues concerning, in particular, but not exclusively, the European Green Agreement. Meanwhile, ministries and regional governing bodies have their own individual competencies, and are responsible for developing policies, including actions plans and strategies, which incorporate adaptation objectives endorsed by the MoE. Therefore, the role of the MoE is to promote and mainstream adaptation across other across ministries and other levels of governance.

In 2021, the MoE started the implementation phase of Slovakia's first National Adaptation Plan (NAP) based on the National Adaptation Strategy (NAS) (see chapter 2.3.1). The main goal of the NAP is to increase Slovakia's resilience to the adverse effects of climate change. The MoE must submit information on the progress achieved in meeting the short-term objectives of the National Action Plan to the Slovak Government in the coming months.

The NAP recommends that the Chairmen of self-governing regions, the President of the Association of Towns and Municipalities of Slovakia, the President of the Union of Slovak Cities, the President of the Office for the Regulation of Network Industries and the Governor of the National Bank of Slovakia support achieving the objectives of the NAP and in the respective regional and local adaptation strategies. Similarly, other ministries are listed as cooperating bodies to the adaptation implementation.

The sub-national governments do not have a formal obligation to develop adaptation strategies and plans. Instead, the NAS is intended to guide their policies. However, there are some instruments in place to incentivise sub-national governments to develop and implement their own adaptation strategies, such as funding incentives. For example, Slovak municipalities are eligible for accessing Norwegian Funds if they have developed an adaptation plan.

Additionally, the Slovak Hydrometeorological Institute (SHMI) is responsible for gathering climate change data, including adaptation-relevant information. It provides hydrological, climatological and meteorological data, operates a climatological information system and conducts research aimed at assessing the impacts of climate change. The SHMI has helped in assessing exposure, vulnerability and adaptive capacity to climate risks in Slovakia.

Thus far, in Slovakia, adaptation measures have been implemented on an *ad-hoc* basis following extreme weather events, rather than systematically as *ex-ante* measures (Ministry of Environment of the Slovak Republic, 2018[10]). Progress in the implementation of adaptation measures is not measured directly, because it is very complex. The MoE does not have an overview of all adaptation projects in Slovakia, although prospective plans to increase oversight of the implementation of adaptation measures are envisioned.

As a response to the increasingly apparent adverse impacts of climate change in Slovakia, as well as in light of ongoing developments in the wider European and international contexts, Slovakia has adopted several documents (Table 2.1) which aim to improve and enhance the efficiency of adaptation processes. Notably, it has adopted its National Adaptation Strategy (2018[10]).

Table 2.1. Strategic documents and lead institutions

Document	Lead institution	Year of adoption
The Adaptation Strategy of the Slovak Republic on Adverse Effects of Climate Change (i.e. NAS)	Ministry of Environment	2018
Low – Carbon Development Strategy of the Slovak Republic until 2030 with a view to 2050	Ministry of Environment	2020

The Strategy of the Environmental Policy of the Slovak Republic until 2030	Ministry of Environment	2019
Action plan for the implementation of the Strategy for Adaptation of the Slovak Republic to Climate Change (i.e. NAP)	Ministry of Environment	2021
Prioritisation of investment projects	Ministry of Environment and other ministries	2021
Slovakia's Recovery and Resilience Plan	Ministry of Environment	2021
The Value is water: Action plan to address the consequences of drought and water shortages	Ministry of Environment	2018
The concept of water policy until 2030 with a view to 2050	Ministry of Environment	2022
Water plan of Slovakia	Ministry of Environment	2021
The concept of the urban development in the Slovak Republic by 2030	Ministry of Transport and Construction	2017
National Security Risk Management Strategy of the Slovak Republic	Ministry of Defence	2022
The Action Plan for the environment and health of the population of the Slovak Republic	Public Health Office	2018

One of the fundamental documents that guide environmental policy in Slovakia is the Strategy of the Environmental Policy of the Slovak Republic until 2030 (Environmental Strategy or Greener Slovakia) (Ministry of Environment of the Slovak Republic, 2019[11]), adopted in 2019. The previous Environmental Strategy was first approved in 1993 and, until 2019, the only document determining environmental policies in Slovakia. The Environment strategy 2030 is an updated version that addresses currently relevant and up-to-date environmental challenges. It recognises the NAS as the primary policy setting out the implementation of adaptation measures in specific sectors. Analyses carried out by the Institute of Environmental Politics, public consultations and working groups carried out with around 160 experts served as the bases for this policy.

The Environmental Strategy's primary objective is to set out a long-term vision and a strategic pathway, of which adaptation is an important component, intended to guide Slovakia's environmental policies. It is the key document paving the way towards improved environmental quality and more sustainable economy. The strategy formally recognises that adaptation measures have to be carried out at regional and local levels to respond to specific needs and demands of individual regions (Ministry of Environment of the Slovak Republic, 2019[11]). While the Environmental Strategy outlines larger objectives for environmental policies, the NAS broadens its scope related to adaptation and sets priorities in terms of adaptation in more detail.

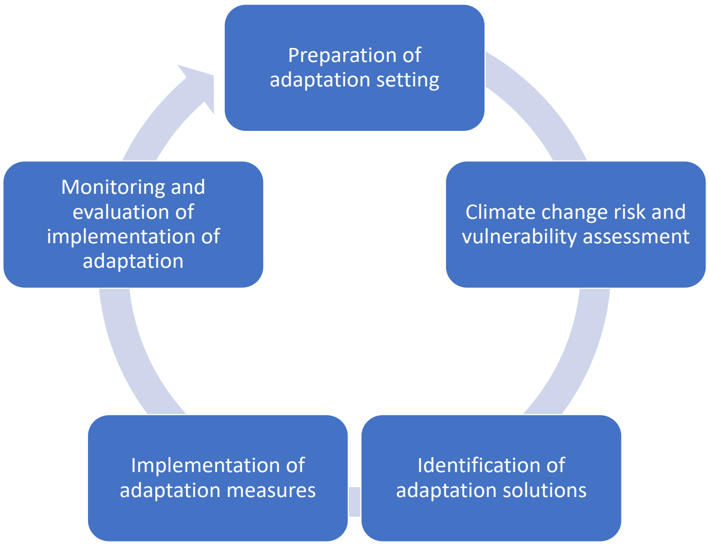
Subsequent to the adoption of the Environmental Strategy, the government developed the Low-carbon Development Strategy of the Slovak Republic until 2030 with a view to 2050 (Low-carbon Strategy) (Ministry of Environment of the Slovak Republic, 2020[12]). It identifies a comprehensive set of measures to achieve carbon neutrality in Slovakia by 2050 and calls to develop a climate change law that addresses both mitigation and adaptation (ibid).

Chiefly, the Low-carbon Strategy sketches out adaptation finance opportunities. In addition to state and local budgets, six potential financial mechanisms are identified. The Low-carbon Strategy includes a chapter outlining adaptation policies and measures, referring to the Adaptation Strategy as well as the National Adaptation Action Plan. Furthermore, the document outlines adaptation measures that exhibit synergies between adaptation and mitigation specifically in the agricultural and land-use, land-use change and forestry (LULUCF) sectors.

2.2 The National Adaptation Strategy and Plan

The NAS aims to improve Slovakia's readiness to face the adverse effects of climate change and calls to establish an institutional framework and coordination mechanism to ensure effective implementation of adaptation measures at all levels and in all areas. It aims at reducing vulnerability and increasing the adaptive capacity of natural and man-made systems to the present and future impacts of climate change, alongside strengthening societal resilience by fostering public awareness to climate change and building a knowledge foundation to strengthen more efficient adaptation (ibid). The strategy specifically identifies adaptation measures that either directly or indirectly contribute to achieving its main goals. It is based on a proactive adaptation approach (Figure 2.2).

Figure 2.2. Proactive adaptation process



Note: "Preparation of adaptation setting" involves establishing a coordination structure and involving stakeholders in adaptation policy-making
Source: (Ministry of Environment of the Slovak Republic, 2018[10])

An integrated adaptation approach and assessment of the proposed measures across different sectors is essential because of the cross-cutting nature of adaptation. The NAS recognises that the conceptual and legislative frameworks for adaptation must take an integrated approach incorporating all considered adaptation-relevant areas, including (*ibid*):

- geological environment
- natural environment and biodiversity
- water regime and water management
- settlements
- population health
- agriculture
- forestry
- transport
- tourism
- industry
- energy
- other areas of business (e.g. insurance)
- risk management and emergency management.

The NAS aims to establish an institutional framework and a coordination mechanism to ensure effective implementation of adaptation measures across government levels and areas, as well as to raise awareness of the need to adapt (Ministry of Environment of the Slovak Republic, 2018[10]). The corresponding actions are outlined in the Action Plan for the Implementation of the Strategy for Adaptation of the Slovak Republic to Climate Change - the National Adaptation Plan (NAP), adopted in 2021. The NAP defines:

- Six strategic priorities listed below and five cross-cutting measures comprising 18 specific tasks.
- 45 specific measures in seven key areas and 169 tasks determining their implementation.

The six strategic priorities are listed as follows:

1. Support adaptation as a strategic priority of the Slovak Republic in the political and legal frameworks and strengthen adaptation in existing and forthcoming national and sectoral plans and programmes.
2. Strengthen the implementation of adaptation policies and legislation, reduce the bureaucratic burden limiting the implementation of measures and improve law enforcement through transparency, improved competencies and the strengthening of control and sanction mechanisms.
3. Build and develop an effective, feasible and well-functioning system for adaptation, based on the principle of subsidiarity and joint efforts of relevant stakeholders and the public.
4. Develop the knowledge and a database as well as a monitoring system and conduct research related to data dissemination and information. Support the dissemination of data by systemising open data.
5. Promote climate change education and solutions through the means of education at all levels. Contribute to the raising of public awareness about adaptation.
6. Promote and develop a multi-source financing system for adaptation.

The NAP identifies short-term and medium-term adaptation measures for the 2021-2023 and 2024-2027 periods and distinguishes seven distinct policy domains that are associated with specific principles, objectives, and specific measures (see

Table 2.2).

Table 2.2. Seven domains of the NAP and examples of their measures

Domain	Number of measures	Example of measures
Water protection, management and use	7	Water retention in the country and in settlements; Improving land protection and integrated landscape management
Sustainable agriculture	6	Measures to increase water retention in the soil; Adaptation of crop production to changed climatic conditions
Adapted forestry	8	Modification of forest wood composition to increase their stability and drought resistance and reduce vulnerability to biotic and abiotic factors
Natural environment and biodiversity	7	Water supply for nature, biodiversity and landscape; Protection and adaptation of forests in protected areas
Health and healthy population	6	Strengthening immunisation programmes
Residential environment	6	Strengthening financial framework to support adaptation measures in settlements
Technical, economic and social measures	5	Support for adaptation in sediment environment and geology sectors; Supporting the businesses regarding of adaptation

Note: only examples of measures are included, not all of them
Source: Action plan for the implementation of the Strategy for adaptation of the Slovak Republic to climate change (Ministry of Environment of the Slovak Republic, 2021[13])

The NAP summarises the situation in the key areas, delineates the tasks to achieve the objective of the respective priority measure, and outlines the responsible actors for implementing the tasks as well as implementation deadlines. To review the extent to which these adaptation measures have been implemented, the NAP recommends the adoption of an evaluation system and to monitor the relationship between adaptation costs and adaptation benefits (Ministry of Environment of the Slovak Republic, 2021[14]). However, Slovakia has neither developed a specific methodology or indicators to monitor and evaluate the extent to which these have been implemented, nor a framework that sets out the measurement of progress. Further, no methodology is yet available to identify the costs, benefits and impacts of the proposed adaptation measures that could ultimately help prioritise them.

Information on the progress made in the implementation of adaptation measures in Slovakia, which is soon to be submitted by the Government of the Slovak Republic, will inform an updated NAS due to be developed by 2025. This information will provide a picture of the obligations of the Ministry of Environment of the Slovak Republic and other relevant ministries in fulfilling the objectives of the NAS and NAP.

2.3 Mainstreaming adaptation into sectoral policies and at the local level

While the NAS is the primary policy document defining objectives and priorities, different regions need custom adaptation strategies that consider their individual vulnerabilities, which may vary depending on a region's geographical conditions and socio-economic factors. Several regions and municipalities in Slovakia have developed their own adaptation strategies to address the specific needs of their respective jurisdiction (Ledda et al., 2020[15]).

In Slovakia, 16 adaptation plans and strategies have been adopted at sub-national levels (Table 2.3). In addition, four out of eight administrative regions have their own adaptation strategies. Local adaptation plans are usually not complex, but rather concrete set of proposals aimed at addressing specific climate risks that the municipality will face as a result of climate change.

Table 2.3. Slovak jurisdictions with adaptation plans and strategies

Regions	Bratislava, Košice, Prešov, Trnava
Cities	Bratislava, Hlohovec, Kežmarok, Košice, Prešov, Trenčín, Trnava, Zvolen, Žilina
City Boroughs	Karlova Ves, Košice – západ
Towns	Spišská Teplica
Cross-border	Districts of Michalovce and Sobrance together with district of Uzhorod in Ukraine
Country Territory	Horná Ondava

Source: Slovak Environment Agency[5]

The majority of municipality adaptation plans assessed the level of risk at their municipality level in terms of: 1) vulnerability to climate impacts; 2) exposure to different hazards; and 3) the sensitivity and adaptive capacity thereto. The risk assessments were based on research conducted by the Slovak Hydrometeorological Institute, domestic and foreign academic literature, and other relevant documents. Based on this, the specific objectives and priorities of adaptation measures in individual municipalities were defined.

[5] https://www.sazp.sk/zivotne-prostredie/starostlivost-o-krajinu/zelena-infrastruktura/adaptacne-a-mitigacne-opatrenia-adaptacne-strategie-na-zmenu-klimy-a-akcne-plany-publikacie.html

Box 2.1. Adaptation to climate change in the Capital City of Bratislava

In Bratislava, Slovakia's capital city, one of the goals of the *Action Plan for Adaptation to the Adverse Consequences of Climate Change in Bratislava for the years 2017-2020* (Capital City of the Slovak Republic Bratislava, 2017[16]) is to assess the region's climate risks and its vulnerability. As a response, in 2020, the city has developed a risk and vulnerability assessment, the *Atlas of assessment of vulnerability and risks of adverse effects of climate change* (Chief Architect's Department of Bratislava, the Capital of Slovak Republic, 2020[17]).

The underlying collection of data on the city's climate risk and vulnerability was unprecedented. Specifically, Bratislava employed an Impact and vulnerability assessment of vital infrastructures and built-up areas (IVAVIA), a methodology based on current IPCC requirements. IVAVIA consists of 7 modules that entail qualitative and quantitative assessment phases, and one presenting its outcomes to relevant stakeholders (ibid). The assessment identified approximately 90 different attributes of climate hazards and their impacts, as well as aspects of the city's sensitivity and capacity to cope with these.

The quantitative assessment in Bratislava's Action Plan, on the other hand, established representative indicators that would help fill impact chains with specific data, based on which the observed phenomena, conditions or trends are quantified. Indicators are normalised on a scale from 0 to 1, aggregated and have been assigned weights based on their significance determined in statistical testing. This enables the creation of visual outputs (e.g. graphs, maps) showing sensitivity to and capacity to cope with the impacts of climate change, vulnerability of the evaluated system and levels of risk focusing on the impacts of extreme heat and intense rainfall on the population, buildings and road infrastructure at the level of city districts and cadastral areas.

As the impacts of climate change are transboundary, Slovakia cooperated with its neighbouring country Ukraine on adaptation-related matters. Several municipalities on the Slovak-Ukrainian border have developed a joint adaptation strategy, which is Slovakia's first regional adaptation strategy and serves as an example framework to incorporate a global threat such as climate change into local level planning (Jarošová et al., 2018[18]).

As the private sector will also be affected by climate change, it is necessary to create formalised public-private partnerships for the preparation and implementation of the adaptation strategy and action plan as the private sector is, according to the NAS, co-responsible for its implementation (Ministry of Environment of the Slovak Republic, 2018[10]). The implementation of adaptation measures may also provide new business and investment opportunities for the private sector and create new market opportunities and jobs, especially in the energy, agricultural technologies, protection and sustainable use of ecosystems, construction, water management and insurance sectors (ibid). Currently however, the role of private companies in climate adaptation in Slovakia is very limited.

As adaptation is a complex and cross-cutting process, a number of actors are involved in reducing the risks posed by the impacts of climate change, notably the national government, individual ministries and their associated organisations, regional governments, non-governmental organisations (NGOs) and other organisations. May of the aforementioned actors have developed their own strategic adaptation-related documents as part of their individual agendas. Whilst the documents are not necessarily specifically addressing adaptation per se, they implicitly follow up on Slovakia's Environment Strategy and Adaptation Strategy.

Policy documents focused on various sectors of the economy which formally mention adaptation include water management, urban development, health, and others. For example, *The concept of water policy until 2030 with a view to 2050* (Ministry of Environment of the Slovak Republic, 2022[19]) recognises that water resources and their sustainable development and protection are essential to adaptation. *The concept of urban development in the Slovak Republic by 2030* (Ministry of Transport and Construction, 2017[20]) stresses the importance of a systemic approach to adaptation in Slovakia's cities. According to this document, the cities in Slovakia have an obligation to create and implement several types of local concepts and strategies aimed at addressing specific areas, including adaptation. The *Action Plan for the Environment and Health of the Population of the Slovak Republic (NEHAP)* (Public Health Office of the Slovak Republic., 2018[21]) acknowledges that implementation of adaptation measures in the health sector is essential for addressing present and future impacts of climate change.

Adaptation is integral to Slovakia's Resilience and Recovery Plan (RRP), which outlines a comprehensive package of reforms (European Comission, 2021[22]). One of its components is dedicated to adaptation. The goal is to increase the resilience of ecosystems as well as human settlements to the impacts of climate change through reforms, and the RRP foresees funds to be allocated to adaptation measures to finance reforms in several areas. The main reforms set out in the plan are the Landscape Planning reform, reforms in water management and a recent reform of National Parks.

The aim of the upcoming Landscape Planning reform is to link and coordinate between spatial and landscape planning to preserve and protect existing landscape structures in the country, that significantly contribute to mitigation of and adaptation to climate change, and the loss of which would impede the country's adaptive capacity. This will be done by developing a zoning plan of the country, which can be tied to the risk assessment in this document to determine which areas will be vulnerable or exposed to the impacts of climate change. The water management reform creates better conditions for achieving a more sustainable state of watercourses and increase the ability to retain water and ensure flood protection of settlements. Renaturation of watercourses and wetlands and the strengthening of their retention capacity will contribute to minimising the risk of water scarcity.

The reform of national parks has intended to consolidate the management of protected areas, especially in national parks and protected landscapes, as part of nature protection in order to minimise different approaches and conflicts between nature conservationists and foresters. The goal of the reform is the development of national parks and a higher level of quality of life for residents in the affected regions. The approved parliamentary amendment has led to the transfer of state-owned land management to the Ministry of Environment (Ministry of Interior of the Slovak Republic, 2022[23]).

2.4 Funding

The NAP recognises the following as the primary sources of funding for adaptation measures in the country (Ministry of Environment of the Slovak Republic, 2021[14]):

- domestic public finance: state and local governments budget
- international public finance: EU funds and the common agricultural policy (including their compulsory national co-financing); additional resources (such as the Environmental Fund, LIFE, EEA and Norway grants etc.); funding from science and research (Horizon 2021-2027, VEGA and others)
- private finance.

There is currently no overview of past investments in adaptation in Slovakia, and many projects cannot be traced back as some projects do not solely address adaptation. Thus far, no clear comprehensive list of projects could be developed. Previously, adaptation measures, or adaptation-related projects had been financed by many different sources including the EU funds, the Common agricultural policy, national and local budgets and the Slovak Environmental fund managed by the MoE, as illustrated in Table 2.4.

One of the sources of finance for adaptation measures in the future will be provided through the *Recovery and Resilience Plan of the Slovak Republic* (RRP) prepared as a joint response of the EU countries to a sharp economic downturn following the COVID-19 pandemic. In the context of adaptation, planned investments will mainly help to facilitate renaturation of water courses, land purchases in protected areas and projects for the development of tourism in two national parks. The NAP is linked to RRP, which defines a financing strategy for the green transition, wherein adaptation is considered.

The RRP intends to allocate EUR 2.3 billion towards green economy. Two segments of the plan specifically address adaptation. The first segment refers to the renovation of buildings. Adaptation will be enhanced by the construction of new energy-efficient public hospitals and schools and the renovation of existing public and private buildings, including 30 000 family homes, with an emphasis on improving thermal insulation, replacing inefficient heat and hot water sources and application of climate change adaptation measures. The plan allocates EUR 528 million to support the thorough renovation of family houses with a target to achieve primary energy savings of at least 30%. Part of the building renovation focusses on surroundings to ensure space for green spaces providing shadows, storage and the use of rain water, which will also be promoted through green roofs. The second segment specifically addresses adaptation allocating 159 million euro to nature protection and biodiversity development to ensure the long-term sustainable adaptation of ecosystems through, for instance, flood and drought prevention.

In the past, one of the key sources for adaptation measures was the EC's *Operational Programme Quality of Environment 2014-2020*, where adaptation-related projects focused primarily on water retention measures in urbanised landscapes and were allocated a total of EUR 44 million, and preventive flood protection measures were allocated EUR 155.14 million in total. The implementation of measures from the programming period 2021-2017 will proceed as part of the Programme Slovakia 2021-2027.

One of the sub-programmes of the European Programme on Environment and Climate Action LIFE (2014-2020) is focused on Climate Action. The sub-programme for Climate Action covers three priority areas: *Climate Change Mitigation*, *Climate Change Adaptation* and *Climate Governance and Information*. Total allocation for projects under the Climate Action sub-programme for the 2014-2017 period was EUR 431.5 million, while the allocation for projects within the period of 2018-2020 was EUR 401.9 million. The following types of projects were supported: climate change mitigation actions in land use sector and agriculture, energy intensive industries, recovery of the ozone layer, fluorinated greenhouse gases, land use, land use change and forestry (LULUCF).

Climate Change Adaptation is one of the priorities of the sub-programme and had been focused on funding the development of local adaptation strategies, innovative adaptation technologies in urban areas, including in the water, energy and construction sectors. Additionally, projects which promote and develop green and blue infrastructures in cities to strengthen the resilience of infrastructure, and apply ecosystem-based approaches to adaptation, promote the sustainable management of water, agriculture, forestry and tourism sectors were prioritised as well. Under the *Climate Governance and Information* priority, projects contributing to the development of climate and energy strategies were supported, as well as projects focused on climate policy monitoring, assessment and *ex-post* evaluation. This was intended to help raise awareness about adaptation and its related processes.

The EEA and Norway Grants (2014 – 2021) had supported adaptation projects in Slovakia through the *Climate Change Mitigation and Adaptation* programme (SK-Climate). The funded projects introduced adaptation measures in order to reduce vulnerability to climate change. Measures supported through these funds included energy saving initiatives, such as the use of renewable energy sources, the building of green and blue infrastructures, restoration of degraded wetland ecosystems and others. Additionally, the grants had funded soft measures for formal as well as informal education of students and the public on climate change mitigation and adaptation. Overall, the SK-Climate Programme has so far supported projects by EUR 19.81 million in total. The implementation of the SK-Climate Programme will last up until 2024.

In 2022, the European Commission has approved the Slovakia Operational Programme of the latest EU Programming period for 2021 – 2027, where over EUR 239 million have been assigned to adaptation measures and the strengthening of resilience. This funding targets several adaptation-related development areas, including conceptual policy steps towards the implementation of adaptation measures at the national, regional and local levels, water retention measures, prevention measures against floods, and others.

In the past, adaptation funding in Slovakia had focused mainly on flood protection measures. While floods are a prevalent risk and must continue being addressed, funding of adaptation measures against the impacts of other climate risks is important. The upcoming NAS should reflect the need for a more targeted approach to funding through a strategy, which embraces adaptation priorities and aims to incite more investment towards other adaptation measures as well. Additionally, the majority of adaptation-related projects are funded from outside sources. This manifests the need for a comprehensive prioritisation, which addresses the local character of adaptation. Designing a more programmatic funding structure is critical to ensure efficient allocation of finance.

Table 2.4. Past funding of the climate adaptation projects in Slovakia

Funding programme and period	Adaptation Measure	Number of projects	Total approved grant (milion EUR)	Comment
European structural funds (2014-2020)	Water catchment in urban areas	88	18.2	Raingardens, water retention tanks
	Flood control management	29	124.6	Grey and green flood measures
Common agricultural policy (2015-2020)	Afforestation	12	0.2	
	Prevention and remediation of damage caused by forest fires, natural disasters, and catastrophic events	15	58.1	
	Restoration of forests damaged by forest fires, natural disasters, and catastrophic events	143	29.9	
	Improvement of the resilience and environmental value of forest ecosystems	255	4.3	
	Restoration, conservation and strengthening of ecosystems related to agriculture and forestry	2	139.7	
Environmental fund (2020)	Air quality	30	2.8	Green infrastructure building in accordance with legislation on non - native invasive species
	Water supply	36	4.5	Building or reconstruction of public water supply
	Flood measures	2	0.3	Measures on the river or in the catchment area
Municipalities		Not known	Not known	Different projects, such tree planting and water catchment in urban areas
LIFE (2014-2020)	Climate resilience of residential buildings and biodiversity promotion in urban areas, climate-smart forestry measures	2	5	Priority area: Climate Change Adaptation
	Awareness raising on urban green infrastructure	1	0.2	Priority area: Governance and Information in Climate Action
EEA and Norway Grants (2014 – 2021)	Energy saving, E-mobility, Green and blue infrastructure, Increasing the infiltration capacity of land, Reduction of waste production and its further re-use, restoration of degraded wetland ecosystems	49	19.8	Combination of various measures on climate change mitigation and adaptation (hard, soft), lateral continuity of wetlands and inundations with surface flow, wetland management and management of wetland biotopes, wetland flood potential, hydrological regime of wetlands

Source: Institute for Environmental Policy; based on data from Ministry of Environment of the Slovak Republic and Ministry of Agriculture and Rural Development of the Slovak Republic

3 Assessing climate change risks at the municipal level

Due to climate change, the occurrence and the intensity of many extreme weather events such as floods, extreme heat and droughts will increase in many parts of the world, which will have adverse effects on the economy, health, environment, and other important aspects of the society (Jacob, Valois and Maxime, 2022[24]). Adapting to the impacts of climate change is essential and must be adjusted to the specific challenges that each region faces. It is thus important that each region sets its own adaptation priorities and objectives that are context specific.

Adaptation measures will require increased funding in the near future. The majority of adaptation-related measures will be covered from public sources. Public sources aiming to help with adaptation are and will be limited, and it is therefore vital to set policy priorities across geographical levels, to ensure an effective and efficient allocation of funding to maximise the benefits. This process will require climate risk assessment, to determine which areas will be affected and to which hazard are they endangered by.

3.1 Status quo of objectives and priorities setting

Slovakia has not yet developed any methodologies for assessing the costs and benefits of adaptation measures for all municipalities. Analyses defining methodologies or criteria for setting priorities in adaptation are currently lacking, which is affirmed in the NAS as well (Ministry of Environment of the Slovak Republic, 2018[10]). However, the MoE has developed the PIP (Ministry of Environment of the Slovak Republic, 2021[4]), which outlines a methodology for a funding prioritisation of adaptation which calls for a formalised estimation of adaptation needs in urbanised areas to inform funding allocation. The PIP assesses climate risks in municipalities of over 5000 inhabitants and, based on the results, determines which municipalities should be prioritised. As a tool for prioritisation at an urban scale, the PIP is limited, as it does not consider all municipalities in the country.

This study aims to create a climate risk assessment to help inform adaptation policies based on a district's or region's exposure, socio-economic vulnerability and adaptive capacity to the risks of climate change impacts. It strives for a fair, equitable approach by including socioeconomic factors, to ensure that areas which are particularly vulnerable are not overlooked.

This study formulates three separate indices to differentiate between different types of impacts and relevant indicators. This detailed prioritisation will cater to decision makers across the country on the national, regional and municipal levels. This study covers extreme heat, extreme perception and drought, based on the key risks identified in the NAS. Floods and other climate hazards relevant to Slovakia could be added as indices in the future. Flood prioritisation is already being developed as a part of Slovakia's Water Plan (Ministry of Environment of the Slovak Republic, 2021[13]) (see Box 3.1). The climate risk assessment builds on the example of the United Kingdom (OECD, 2022 forthcoming[6]).

Box 3.1. Flood protection prioritisation

Slovakia started assessing and quantifying flood risks in 2011 as a response to the EU Directive 2007/60/EC. The prioritisation of flood protection measures is formed based on this assessment. In the first Preliminary Flood Risk Assessment, the aim was to identify flood risk-prone areas. These were selected on the basis of flood event statistics from previous years. Flood risk maps were subsequently created for the selected areas, analysing the possible extent, depth and speed of the flood wave.

In 2015, Flood Risk Management Plans were produced through the integration of the Preliminary Flood Risk Assessment and the Flood Risk Maps. The Plans assess 588 selected vulnerable areas. New Flood Risks Management Plans are being developed in 2022 for the following six-year period.

The Flood Risk Management Plan ranks flood protection measures in all vulnerable areas based on the sum of the values of eight specific criteria. The order of the evaluated geographical area according to the given criterion is determined by the number of points that are allocated to each geographical area.

The following eight criteria were evaluated:

1. The number of inhabitants at risk in a given area
2. The number of sensitive economic objects
3. The number of environmentally and strategically sensitive objects
4. The number of cultural heritage sites
5. The number of river basin management plan measures
6. The amount of damage prevented
7. The total implementation and maintenance costs over the lifetime
8. The ratio of damages prevented to the cost of the measure

The upcoming Flood Risk Management Plan is expected to consider the future impacts of climate change. The recommendation for funding practice is to support projects with the highest priority according to the resulting classification and at the same time to support only projects identified in the Flood Risk Management Plan. If there is a need to build flood infrastructure outside the plans, it will automatically have a low priority.

The new Plan will also include the compliance of the measure with the environmental objectives, the evaluation of which will be part of the prioritisation. It is recommended that the new prioritisation realistically assess the alternatives for dealing with flood protection measures, also with regard to environmental objectives.

3.2 The climate risk index construction

To assess the risks posed by climate change impacts, it is necessary to define relevant sets of factors, which help paint a better picture about the circumstances of each area. Further, it is essential to delineate a feasible methodology, which allows for an evaluation of these factors. This study assigns all municipalities in Slovakia their respective climate risk levels for three climate hazards: extreme heat, drought and extreme precipitation. The climate risk levels of each municipality are determined by their results for climate risk composite indices (CI) (Figure 3.1), which are a result of data evaluation through a DEA model for a set of relevant indicators.

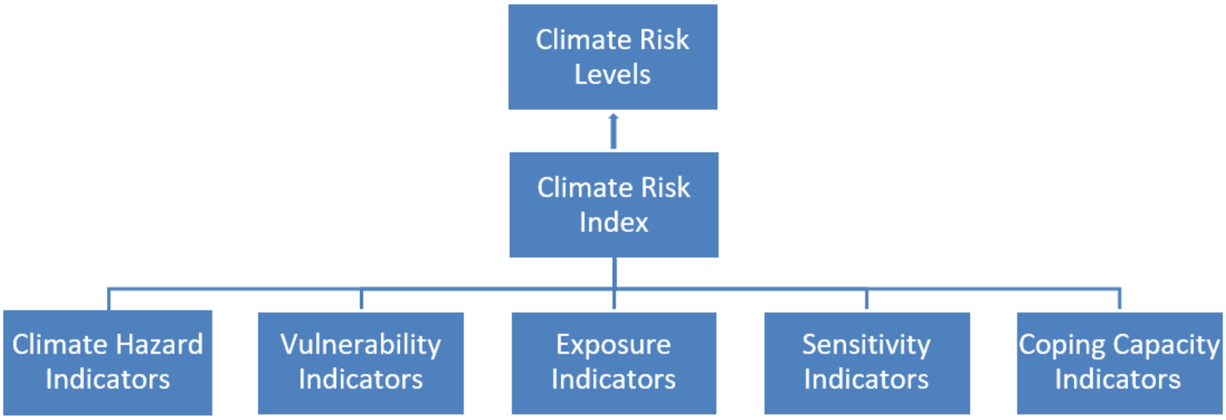
The resulting values of the CI were divided into ten risk levels. Each risk level contains the same number of municipalities, except for the cases when the value of the CI was the same for multiple municipalities. In such a situation, municipalities with the same value fall into the same risk category. Municipalities with low risk level have CI equal or close to one, and conversely, high risk level is associated with CI values close to zero.

Each index is comprised of indicators related to a climate hazard, and of exposure, coping capacity, sensitivity and vulnerability indicators.

- Climate hazards are a set of climatic phenomena that affect Slovakia today and in the future.
- Exposure refers to the nature and degree to which a system is exposed to climate change.
- Vulnerability refers to the propensity or predisposition to be adversely affected by climate change.
- Sensitivity is the degree to which the systems and species of fauna and flora are affected, whether unfavourably or favourably, by climate variability or climate change and the effect may be direct or indirect.
- Coping capacity refers to the ability of the people, institutions, organisations and systems using the available experiences, values, beliefs, resources and opportunities, address, manage and overcome adverse climate change impacts.

It is important to note that risks and vulnerabilities depend in part on specific aspects of sensitivity and adaptive capacity which are difficult to measure and cover by proxy indicators alone.

Figure 3.1. Climate Risk Index composition



Note: Indices have been developed by the Ministry of Environment
Source: Ministry of Environment

The indicators are composed of information on climate hazard, socio-economic factors and environmental land cover factors (see more details in Table A A.1. Extreme heat climate hazard indicators). These indicators were chosen based on expert recommendations and data availability to assess the specificities of and differences between municipalities in Slovakia. While climate hazards set basis for observed and projected hazards indicators, socio-economic indicators help indicate which areas are more vulnerable and capable of coping with the impacts. Lastly, land cover indicators such as the ratio of impervious surfaces establish levels of exposure and vulnerability (see the Annexes for an overview of all indicators).

The climate risk indices are created by a DEA (data envelopment analysis) model, which is enriched by expert judgement. In essence, the DEA model selects the best set of weights for each municipality based on values of provided indicators. The model generates climate risk levels for each municipality, all the while taking into account the situation in all other municipalities. It allows for a certain degree of flexibility by allowing each municipality to compensate the shortcomings in some areas by better performance in others. At the same time, the DEA model allows to incorporate additional information based on expert judgment. For a more detailed methodology and weighing description see Annex B.

All the data used in this study accounted for all municipalities and were selected based on relevance, accuracy, and sufficient granularity. Any data with insufficient granularity (regional, national or international level) were excluded, as the aim is to achieve comparisons between all municipalities. Data granularity level can be outlined as following:

- Gridded data of different resolutions from 10x10 meters to 0.1° x 0.1° was aggregated at the municipal level.
- Municipal data input for all 2925 municipalities.

Table 3.1. List of indicators used in the indices

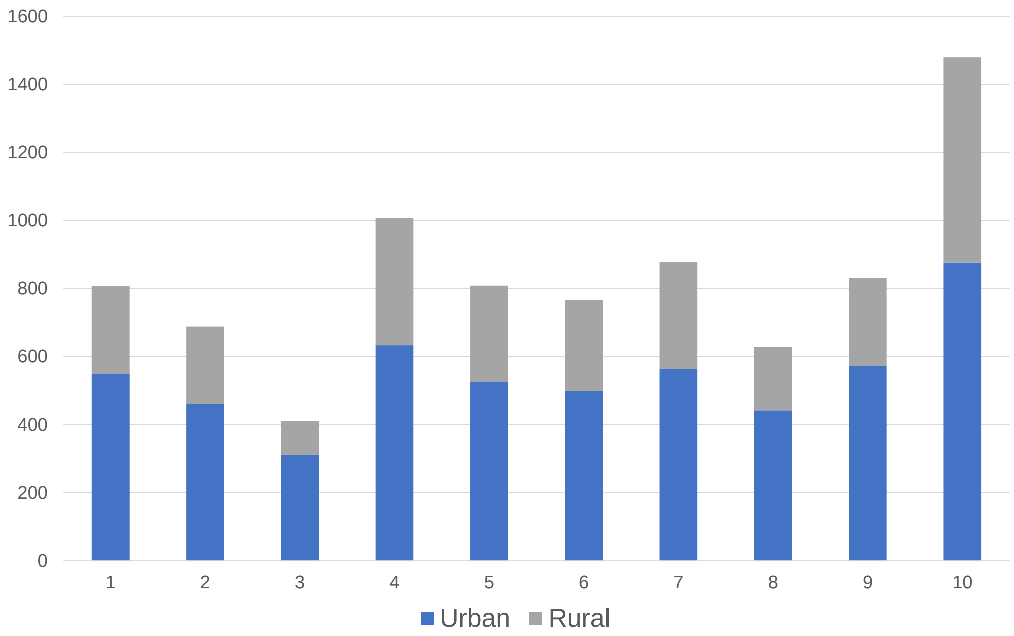
Climate risk component	Indicator	Extreme Heat	Drought	Extreme Precipitation
Climate hazards	Climatological definition RCP 4.5 scenario	x		
	Health definition RCP 4.5 scenario	x		
	Tropical Days	x		
	Tropical Nights	x		
	Consecutive days RCP 4.5 scenario		x	
	Number of days RCP 4.5 scenario		x	
	Drought hazard measures by SPEI (Standardised Precipitation-Evapotranspiration Index)		x	
	High precipitation RCP 4.5 scenario			x
	Present precipitation hazard			x
Socio-economic indicators	Population density	x	x	x
	Vulnerable population aged ≤ 4	x	x	x
	Vulnerable population aged ≥ 70	x	x	x
	Polyclinics and hospitals	x		
	Registered unemployment rate	x	x	x
	Municipal Income	x	x	x
	Share of population supplied from public water supply system		x	
	Percentage of concentrated Roma communities	x	x	x
Physical indicators	Share of Tree cover density in whole area of municipality	x	x	x
	Share of Imperviousness in whole area of municipality	x	x	x
	Share of Grasslands in whole area of municipality	x	x	x
	Share of Water and wet cover in whole area of municipality	x	x	x
	Share of croplands area within municipality		x	x
	Areas under environmental protection	x	x	x
	Soil erosion - share of unstable soil			x
	Landslide hazard areas			x

3.3 Climate risk indices results

3.3.1 Heat risk index

More than 16 % of the Slovak population resides in areas assigned the highest risk of extreme heat (Figure 3.2). Primarily of urban residence, these include the capital city Bratislava and the municipalities of Komárno, Nové Zámky, Šaľa, Lučenec, or Rimavská Sobota, of which the latter two lie in some of the least economically developed regions of Slovakia (Figure 3.3). The most heat-prone areas are clustered around the capital of Bratislava as well as around the Žitný ostrov region and in the south of central Slovakia. Overall, the districts most at risk are Bratislava I, Komárno and Nové Zámky, which are presently among the most affected by tropical heat days.

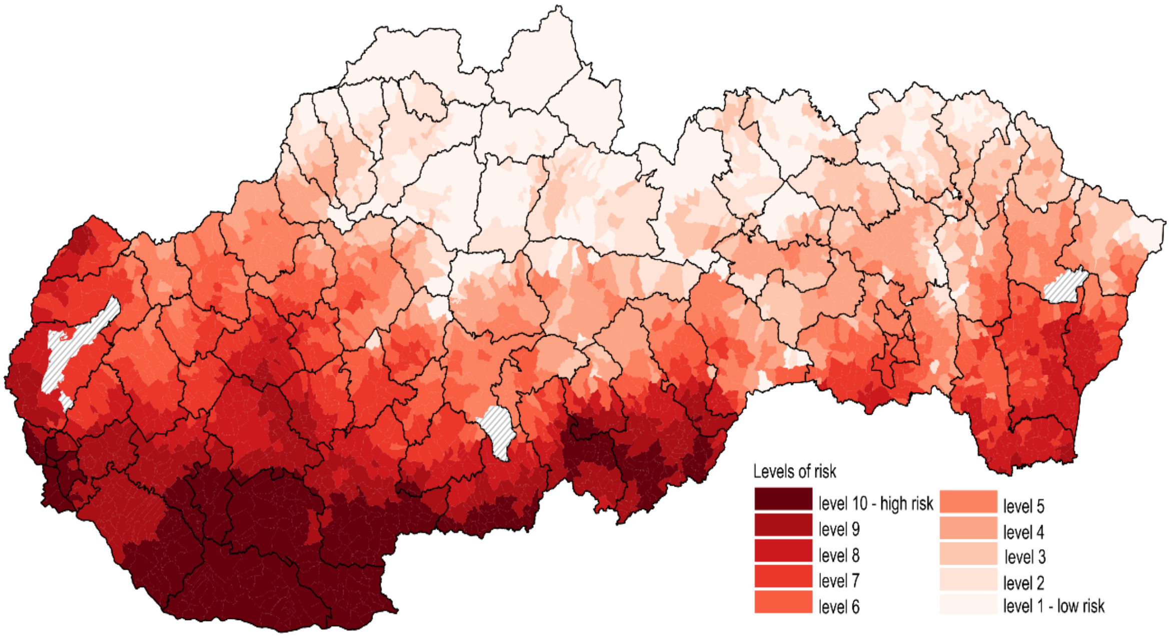
Figure 3.2. Residents count per risk level of heat (in thousands)



Note: Risk level of heat is represented on the x-axis (1 to 10).
Source: Institute for Environmental Policy

While the current situation in these districts is, according to forecasts, expected to deteriorate, there are other factors which add to their future exposure and vulnerability. For example, Staré Mesto is the sole municipality of Bratislava I, and its urban landscape is the second most impervious in the country. Simultaneously, it is one of the most densely populated municipalities, which makes it particularly vulnerable to the effects of extreme heat. Additionally, Bratislava I is one of the areas most affected by tropical heat nights (see Annex A). Tropical heat nights are characteristic of highly urbanised places like Staré Mesto, as buildings and roads in cities accumulate heat, slowing temperature drops during the nights.

Figure 3.3. Heat risk levels at municipal scale

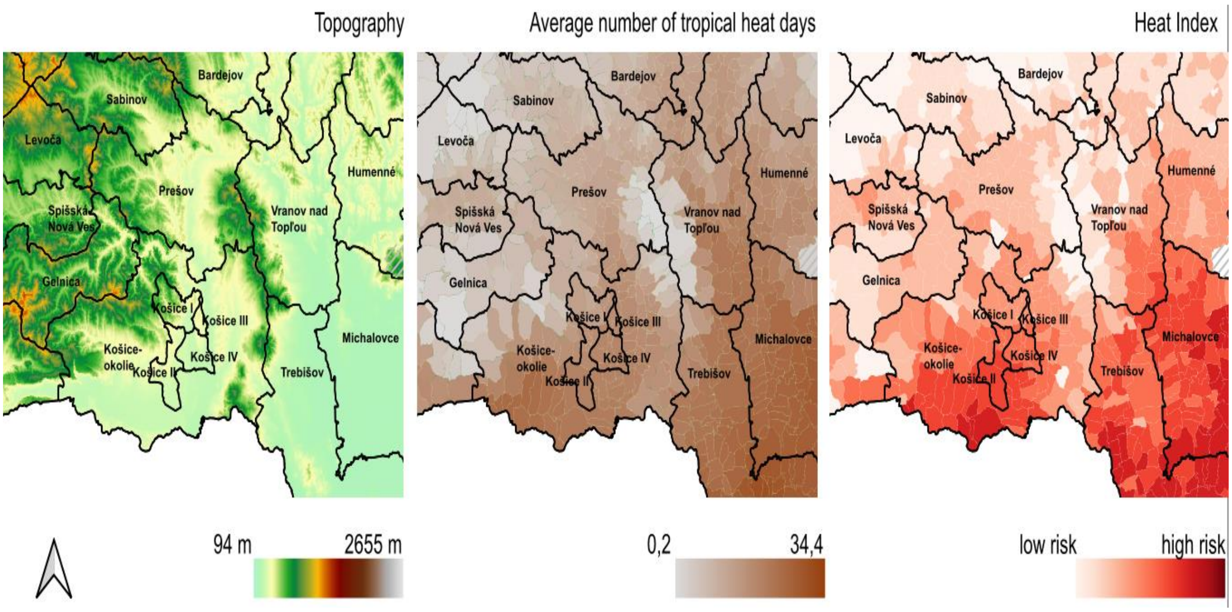


Note: The map is based on data from the Statistical Office of the SR, Ministry of Finance of the Slovak Republic, Atlas of Roma communities, Institute for Healthcare Analyses, Copernicus Land Monitoring Service, Slovak Hydrometeorological Institute, Copernicus Climate Change Service, The 2021 Population and Housing Census, Ministry of Environment, State Geological Institute of Dionýz Štúr, National Agricultural and Food Centre, State Nature Protection of the Slovak Republic
Source: Institute for Environmental Policy

Komárno and Nové Zámky, located in the south, experience the highest number of tropical heat days per year, respectively, even though they are not as highly impacted by tropical heat nights. The highest temperature that has ever been recorded has been measured in Hurbanovo, a municipality in the district of Komárno, with a value of 40,3 °C. Conversely, they are not as likely to be within the top most affected by heat according to future prediction scenarios. Instead, these districts are relatively vulnerable, as they have large older populations above the age of 70, and notably, residents of both have poor access to healthcare, with the minimum time to a hospital or a polyclinic in some municipalities in Nové Zámky being over 50 minutes. This finding highlights that vulnerability to a hazard can pose a high risk compared to hazard exposure itself.

The geographical location of the districts with the lowest extreme heat risk demonstrates a correlation between topography and heat-related risks, as the least heat-prone municipalities are located in the north of the country, which is characteristically more mountainous than the south. This is, however, the case for almost all municipalities located in higher altitudes. For example, Figure 3.4 shows the mountain ranges of Levočské and Slanské vrchy in a topography map to link how locations situated in higher altitudes or in their proximity experience lower numbers of tropical heat days. While the municipality of Levoča located just below Levočské vrchy experiences an average of around 4 tropical heat days per year, Prešov sees over 11 days.

Figure 3.4. The effects of topography on the heat index

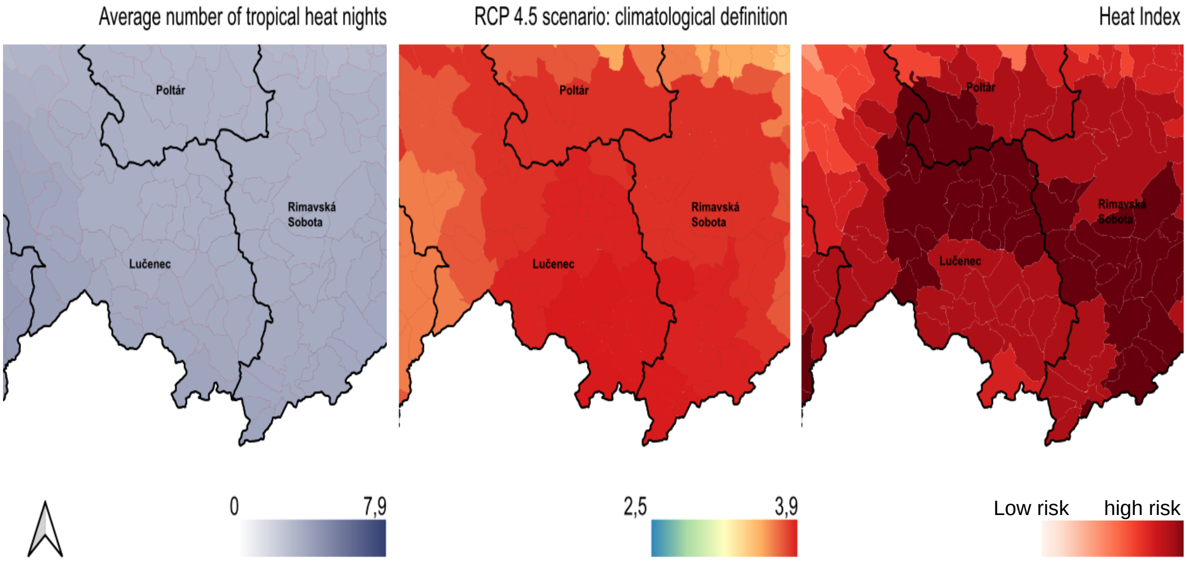


Note: The maps are based on data from the Statistical Office of the SR, Ministry of Finance of the Slovak Republic, Atlas of Roma communities, Institute for Healthcare Analyses, Copernicus Land Monitoring Service, Slovak Hydrometeorological Institute, Copernicus Climate Change Service, The 2021 Population and Housing Census, Ministry of Environment, State Geological Institute of Dionýz Štúr, National Agricultural and Food Centre, State Nature Protection of the Slovak Republic, The United States Geological Survey
Source: Institute for Environmental Policy

According to the resulting index for heat, the least risky are the Námestovo, Tvrdošín and Čadca districts, with both the current temperatures as well as future predictions being mild compared to their southern counterparts. Although some municipalities in districts like Námestovo have relatively low access to healthcare, such as Novoť and Oravská Lesná, these municipalities currently experience the lowest numbers of heat days and nights. Having a cooling effect on its surroundings, the presence of waterbodies is a factor which can influence a territory’s coping capacity and help decrease air temperatures. For example, the Torysa river and the stream of Tablový potok flow through the municipality of Seniakovo, which lowers the risks of heat-related hazard.

According to forecasts, multiple districts around the country that are currently not as exposed to heat are expected to experience a rapid increase in temperatures in the future, such as the Lučenec district (figure 3.5). It is not currently as impacted by tropical heat days and nights as Nové Zámky and Komárno, yet the resulting index values are comparable to some the most high-risk districts. Simultaneously, the indices for these municipalities are shaped by socio-economic indicators which increase their vulnerability, like the relatively high ratio of population below the age of four in some municipalities, and the presence of concentrated Roma populations in others.

Figure 3.5. The effect of forecast indicator on the heat index: Lučenec



Note: Maps are based on data from the Statistical Office of the SR, Ministry of Finance of the Slovak Republic, Atlas of Roma communities, Institute for Healthcare Analyses, Copernicus Land Monitoring Service, Slovak Hydrometeorological Institute, Copernicus Climate Change Service, The 2021 Population and Housing Census, Ministry of Environment, State Geological Institute of Dionýz Štúr, National Agricultural and Food Centre, State Nature Protection of the Slovak Republic, The United States Geological Survey
Source: Institute for Environmental Policy

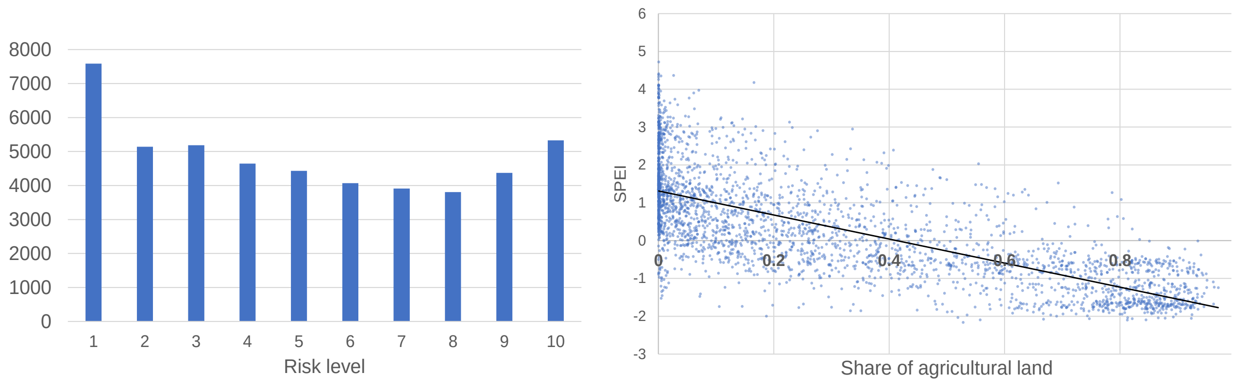
The levels of risk are most notably driven by an observed heat hazard variable - the number of tropical heat nights, a phenomena characteristic of urbanised localities. Districts of Bratislava are impacted the most, with some parts experiencing more than 7 tropical nights a year night on average between 1991 and 2020. Another significant driver is the number of tropical heat days, which accounts for the average number of days with temperatures over 30 in the years between 1991 and 2020, with a number of municipalities in the Nové Zámky district leading with over 34 days, while the overall average in Slovakia is just below 18 days. Followed by the share of the population below four years old, municipalities with high values for this indicator were spread across the country, yet when weighed in the model have proven most significant in Bratislava.

3.3.2 Drought risk index

The places most at risk of drought are located in the southwest of the country (Figure 3.7). Žitný ostrov, a critical agricultural land and the biggest drinking water reservoir in the country is at a severe risk of drought, endangering the country's key croplands. Agricultural land is concentrated in lower altitudes, in the warmer, southern areas. Meanwhile, the more mountainous northern regions with greater rainfall are characteristic of having lower soil quality. Poor access to public water supply increases an area's vulnerability to the hazard of drought.

Figure 3.6. Drought risk

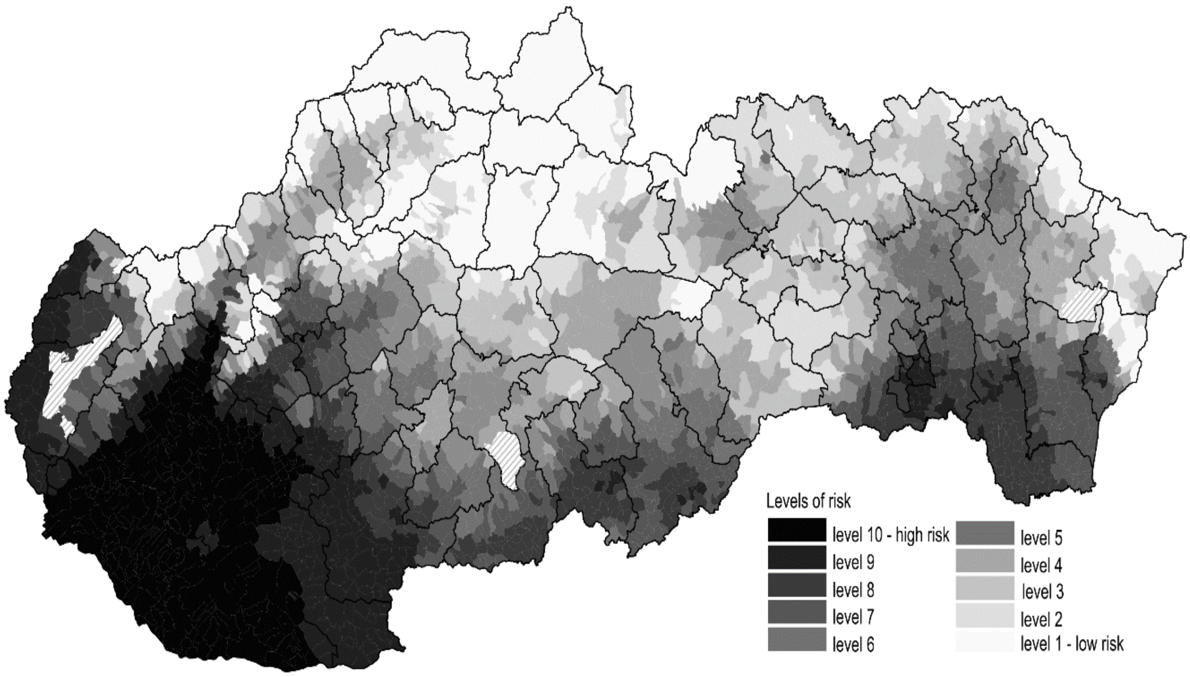
Area by drought level of risk (km2) (left); Relation between Standardised Precipitation-Evapotranspiration Index and share of agricultural land (right)



Source: Institute for Environmental Policy

Bratislava II, Senec, and Bratislava V are the areas with the highest level of risk, mainly due current situation regarding droughts. Senec is characterised by its large share of agricultural lands what increases the level of risk of drought. A cluster of high-risk districts, although not as threatened as the southwest cluster is located in the southeast around Trebišov and Košice. The south of central Slovakia (the Gemer area) is at risk due to its lack of water resources; ongoing water shortages are accelerated by geological factors, which prevent water accumulation.

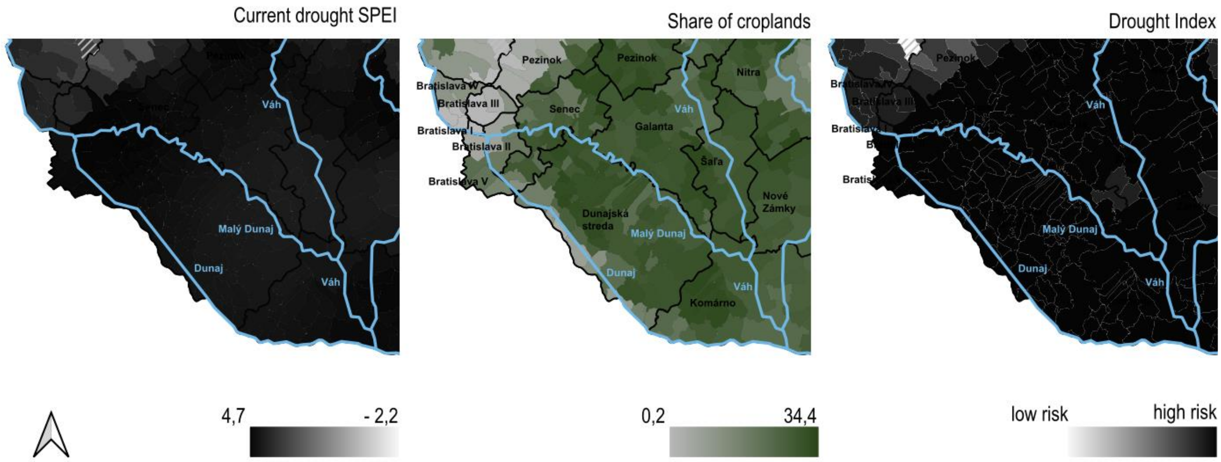
Figure 3.7. Drought risk levels at municipal scale



Note: Map is based on data from the Statistical Office of the SR, Ministry of Finance of the Slovak Republic, Atlas of Roma communities, Institute for Healthcare Analyses, Copernicus Land Monitoring Service, Slovak Hydrometeorological Institute, Copernicus Climate Change Service, The 2021 Population and Housing Census, Ministry of Environment, State Geological Institute of Dionýz Štúr, National Agricultural and Food Centre, State Nature Protection of the Slovak Republic, The United States Geological Survey
Source: Institute for Environmental Policy

Žitný ostrov, which is a critical agricultural land well-suited for crop production and equipped with the biggest drinking water reservoir in the country, is at a significant risk (Figure 3.8). It is a key area between the rivers of Danube, Little Danube and Váh, and it is the largest river island in Europe, which has been largely deforested due to agricultural activities in the region. The indices for drought hazard consider the share of agricultural lands in a municipality to determine the risk to an exposed area. The more croplands a municipality consists of, the more is it likely to be negatively affected by the hazard.

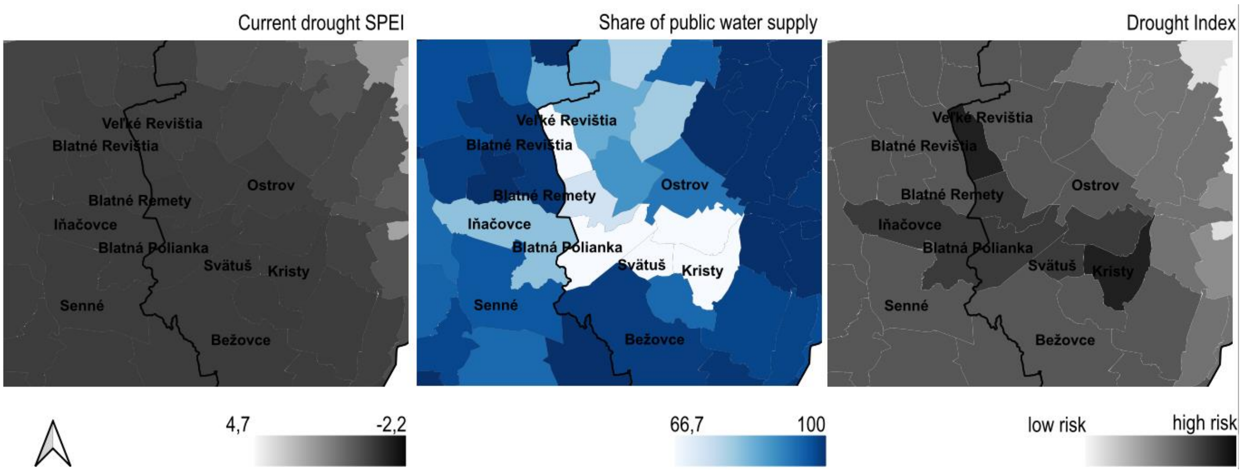
Figure 3.8. Drought risk and share of croplands in Žitný Ostrov



Note: The maps are based on data from the Statistical Office of the SR, Ministry of Finance of the Slovak Republic, Atlas of Roma communities, Institute for Healthcare Analyses, Copernicus Land Monitoring Service, Slovak Hydrometeorological Institute, Copernicus Climate Change Service, The 2021 Population and Housing Census, Ministry of Environment, State Geological Institute of Dionýz Štúr, National Agricultural and Food Centre, State Nature Protection of the Slovak Republic, The United States Geological Survey
Source: Institute for Environmental Policy

Municipalities which have poor access to public water supply are more at risk of the effects of drought-related impacts. Therefore, the share of households connected to public water supply influences the overall index, which is the case for a number of neighbouring municipalities of Kristy and Svätuš in the district of Sobrance, which, relative to other municipalities, lack this type of infrastructure (Figure 3.9).

Figure 3.9. The effect of public water supply access on drought index



Note: The maps are based on data from the Statistical Office of the SR, Ministry of Finance of the Slovak Republic, Atlas of Roma communities, Institute for Healthcare Analyses, Copernicus Land Monitoring Service, Slovak Hydrometeorological Institute, Copernicus Climate Change Service, The 2021 Population and Housing Census, Ministry of Environment, State Geological Institute of Dionýz Štúr, National Agricultural and Food Centre, State Nature Protection of the Slovak Republic, The United States Geological Survey
Source: Institute for Environmental Policy

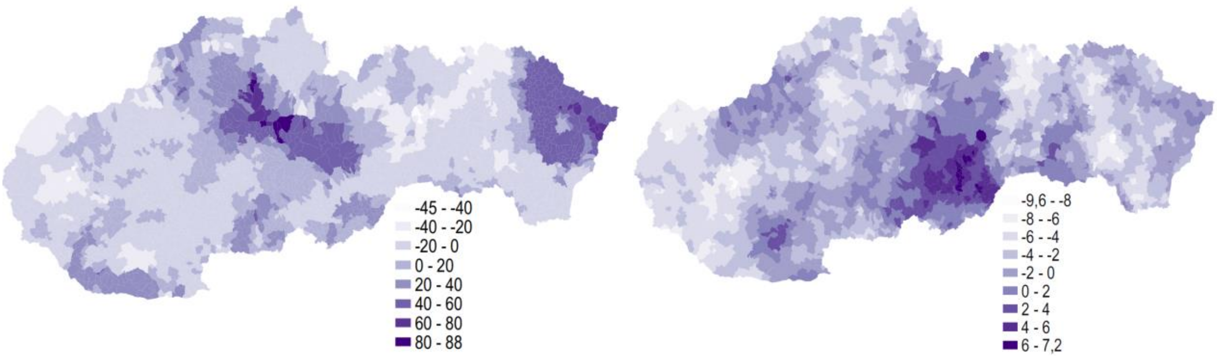
In contrast, northern regions of the country are less likely to be affected by this hazard. The most drought-proof districts - Námestovo, Dolný Kubín, and Čadca - are located in the northernmost part of Slovakia. Beyond the current situation regarding drought in this region, this index is also influenced by the future 4.5 RCP scenarios, which are, relative to other regions, less deteriorating. For example, although the access to public water supply in Námestovo is not as widespread as it is in some of districts with the highest risk (e.g. Bratislava II), the share of grasslands and water and wetness degree in combination with the current drought hazard and forecasts mean that this district is the one at the least risk to droughts.

The risk levels are significantly conditioned by present-day droughts measured by SPEI, a multiscalar drought index based on climatic data, where Bratislava II is ranked the driest district. Another hazard indicator which impacts the index predicts the longest dry spells, which is notable in some districts in eastern Slovakia, such as Medzilaborce and Snina. For example, the municipality of Brezovec in Snina is expected to experience over 70 consecutive days of dry spells in the future. As for the overall number of dry days, this forecast variable indicates that districts such as Revúca, Poltár and Rimavská Sobota are to face an increase in drought risk as well.

The drought index is mainly driven by current situation regarding droughts, but the forecast indicators (Figure 3.10) predict that in the future different regions will be hit by the drought than it is now. Therefore, over the coming years, the investments need to refocus on eastern part of Slovakia and the regions of national parks Nízke Tatry and Malá Fatra.

Figure 3.10. Change in drought between years 2041-2070 and reference period 1971-2000 for RCP 4.5 scenario

Longest dry spells definition – change in number of days (left); Number of dry spells – change in number of dry periods (right)

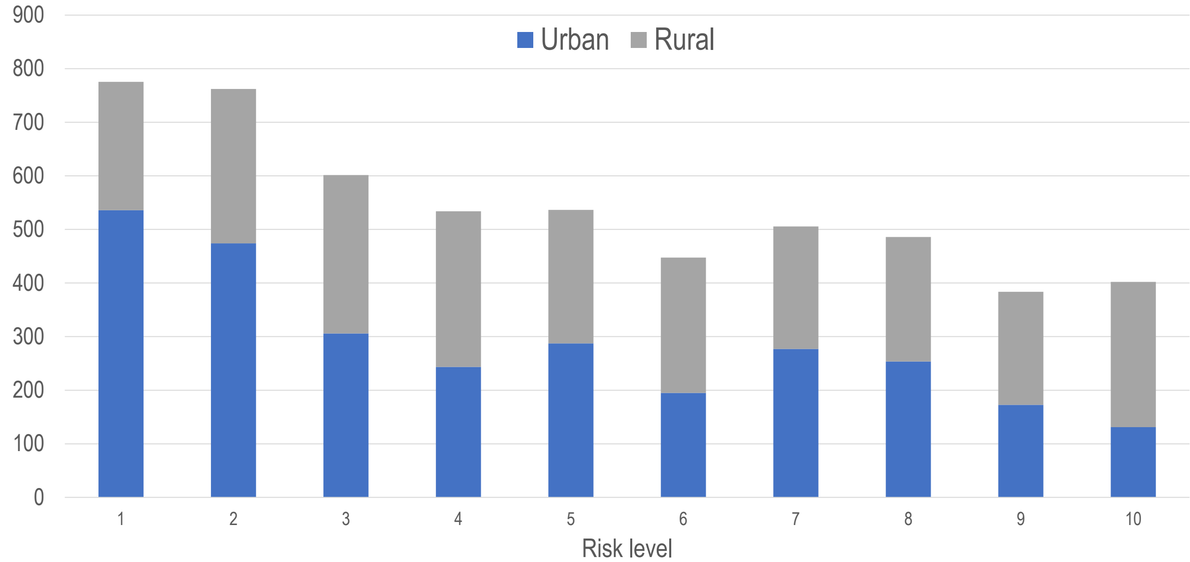


Source: Copernicus Climate Change Service

3.3.3 Extreme precipitation risk index

The population is relatively less affected by extreme precipitation, however, among the areas with the highest level of risk are several municipalities with high share of Roma population like Ostrovany, Chminianske Jakubovany or Jarovnice (Figure 3.11). In 1998, Jarovnice (the district of Sabinov) was hit by extreme rain that led to flood which resulted in 50 dead people and infrastructural damages. Čadca, Dolný Kubín, Handlová and Snina are the most significant urban areas with the highest level of risk of extreme precipitation.

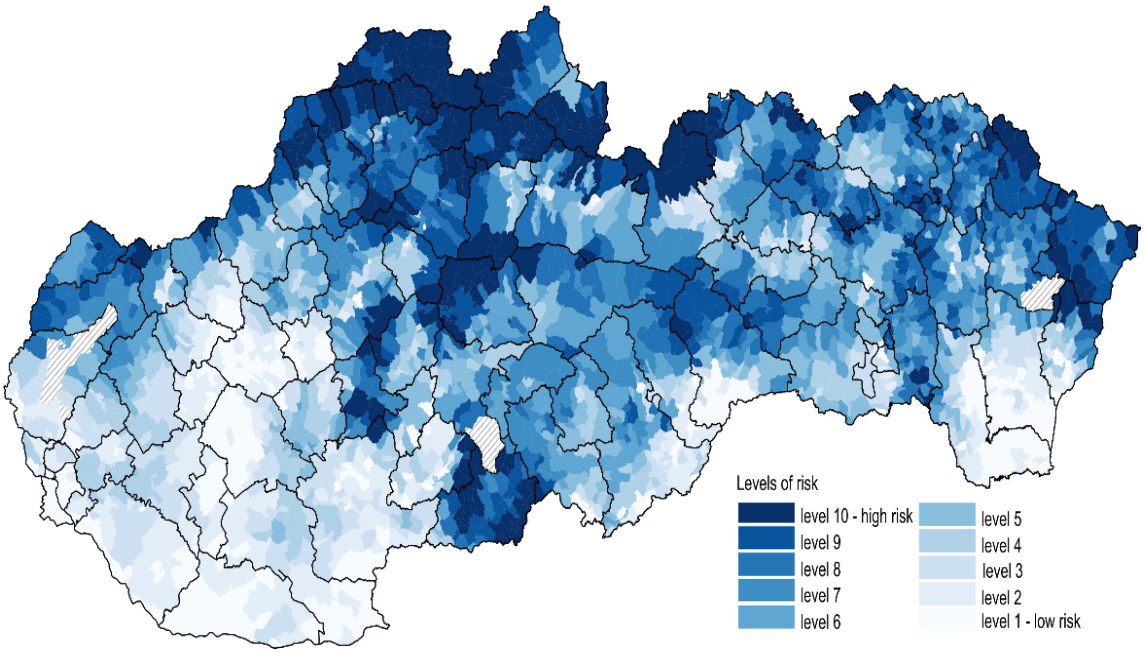
Figure 3.11. Residents count per risk level of extreme precipitation (in thousands)



Note: Level of extreme precipitation risk is displayed in the x-axis (0 to 10)
Source: Institute for Environmental Policy

Tvrdošín, Dolný Kubín and Kysucké Nové Mesto are the districts at the greatest risk to extreme precipitation, as all of these districts have been highly impacted by heavy rains over the past 30 years, and according to forecasts, they are expected to be impacted by high precipitation in the future. The district of Tvrodšín had experienced as many as 9,8 days of precipitation of over 20 mm a day per year on average and is prone to landslides. Dolný Kubín district is the one most susceptible to landslides. Meanwhile, Kysucké Nové Mesto is not as impacted by past and current precipitation as Tvrdošín, yet forecasts predict this area will be more endangered in the future. Banská Bystrica has been the district most affected by heavy rains in the country with an of average 9.9 days annually.

Figure 3.12. Extreme precipitation risk levels at municipal scale

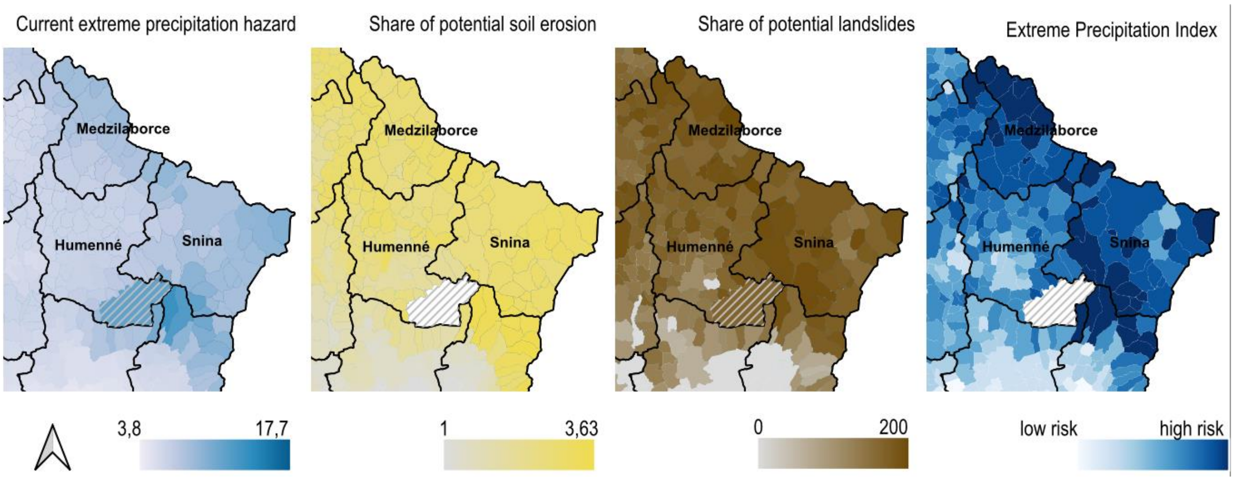


Note: The map is based on data from the Statistical Office of the SR, Ministry of Finance of the Slovak Republic, Atlas of Roma communities, Institute for Healthcare Analyses, Copernicus Land Monitoring Service, Slovak Hydrometeorological Institute, Copernicus Climate Change Service, The 2021 Population and Housing Census, Ministry of Environment, State Geological Institute of Dionýz Štúr, National Agricultural and Food Centre, State Nature Protection of the Slovak Republic, The United States Geological Survey
Source: Institute for Environmental Policy

Overall, the current extreme precipitation is salient mainly in the north around Vysoké Tatry and Orava, and in the east near the Vihorlat and Poloniny national parks (Figure 3.12). Precipitation in the most affected district, just as in their adjacent Žilina and Martin has generally been observed in wintertime. The cluster of Vihorlat and Poloniny is affected by supercell storms, which typically approach the area from the north. As for the north-western cluster of Skalica, Myjava and Senica, and the Veľký Krtíš district in the south, the bulk of precipitation in these areas usually occurs in September, and rainfalls are expected to increase. The results for Veľký Krtíš are mainly conditioned by the results are caused by the predicted future changes in high precipitation events.

The districts least risky to extreme precipitation the Bratislava I, Bratislava II, and Bratislava V districts respectively. Relative to other districts, these areas are less prone to increase in precipitation in the future, nor had they experienced frequent or heavy rainfalls in the past years. With not more than approximately 6 days of ≥ 20.0 mm precipitation in the past, while having low unemployment rates, these districts are well-equipped to cope with the hazard. On the other hand, some districts had not experienced heavy rainfalls, nor are they among the areas which are at high risk according to forecasts. However, socioeconomic and land cover indicators determine that their level of risk is rather high, and if they were to become affected by precipitation, they would be in risk. For example, the district of Snina has high unemployment rates and is susceptible to landslides, which effects the precipitation index (Figure 3.12).

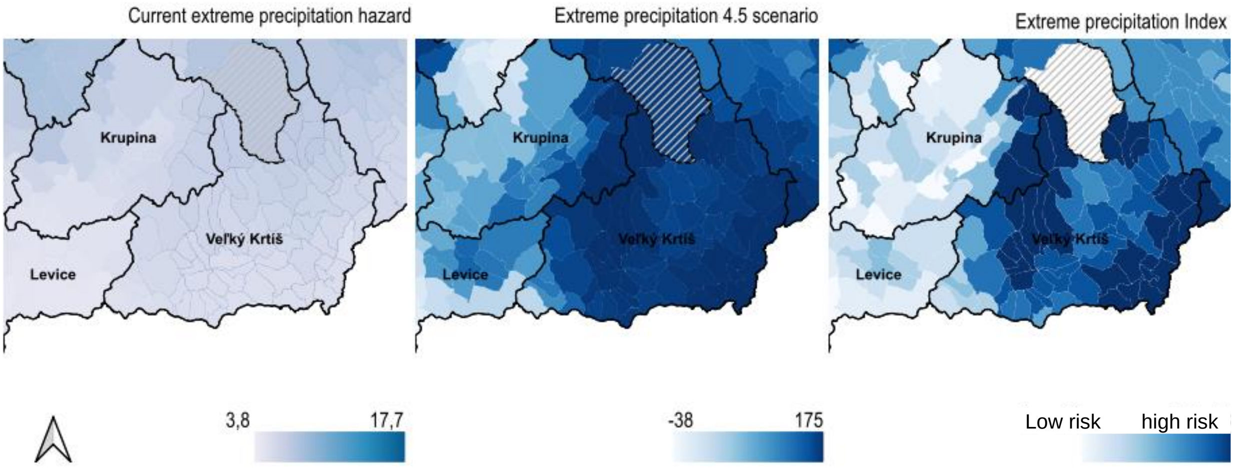
Figure 3.13. The effects of a indicators on the drought index in Snina



Note: The maps are based on data from the Statistical Office of the SR, Ministry of Finance of the Slovak Republic, Atlas of Roma communities, Institute for Healthcare Analyses, Copernicus Land Monitoring Service, Slovak Hydrometeorological Institute, Copernicus Climate Change Service, The 2021 Population and Housing Census, Ministry of Environment, State Geological Institute of Dionýz Štúr, National Agricultural and Food Centre, State Nature Protection of the Slovak Republic, The United States Geological Survey
Source: Institute for Environmental Policy

The results of this index are driven predominately by the present-day precipitation hazard, followed by future prediction scenarios (Figure 3.14). For example, Tatranská Javorina in the Poprad district had experienced the highest precipitation in the country, an average of over 17 days of rains of ≥ 20.0 mm, while future predictions determine that Veľký Krtíš is at risk the most (Figure 3.13). Even though socioeconomic and land cover indicators do not exceed 0.3 (30%) of the overall index value, some significant indicators that influence the model are the share of landslide-prone areas, the unemployment rates, and the share of tree cover. Dolný Kubín, one of the riskiest areas, is affected both by erosion, and it is the district most prone to landslides.

Figure 3.14. The effects of hazard forecasts on the extreme precipitation index



Note: The maps are based on data from the Statistical Office of the SR, Ministry of Finance of the Slovak Republic, Atlas of Roma communities, Institute for Healthcare Analyses, Copernicus Land Monitoring Service, Slovak Hydrometeorological Institute, Copernicus Climate Change Service, The 2021 Population and Housing Census, Ministry of Environment, State Geological Institute of Dionýz Štúr, National Agricultural and Food Centre, State Nature Protection of the Slovak Republic, The United States Geological Survey
Source: Institute for Environmental Policy

3.4 Ex-post measurement and implementation

The risk assessment outlined in this paper informs regional and municipal administrations of their risk level. The results are disseminated with the help of an interactive online map[6] integral to this risk assessment. It facilitates its use by local-level administrations to support adaptation efforts in each region. The risk assessment can help local authorities to strategically plan adaptation actions relevant to their area. Higher-priority municipalities should be preferred when adaptation interventions are planned, and adaptation measures need to reflect the type of climate risks threatening the area.

State and local budgets can endorse this list to allocate finance in an efficient and targeted manner. A distributive framework for future public or other funding based on this study can support strategically allocating finance and need to be applied by the Ministry itself. This study widens the scope of the previous prioritisation outlined in the PIP (Ministry of Environment of the Slovak Republic, 2021[4]) to set a new, more robust, methodology for territorial prioritisation in risk assessments.

The upcoming Landscape Planning reform, which aims to preserve and protect landscape structures in Slovakia, could benefit from the data-driven approach to adaptation established in this study (see section 2.3). The study can help identify high-risk areas, which needs to be prioritised to strengthen their coping capacities. A successful implementation of the reforms would bring benefits not only from the climate point of view but strengthen biodiversity as well.

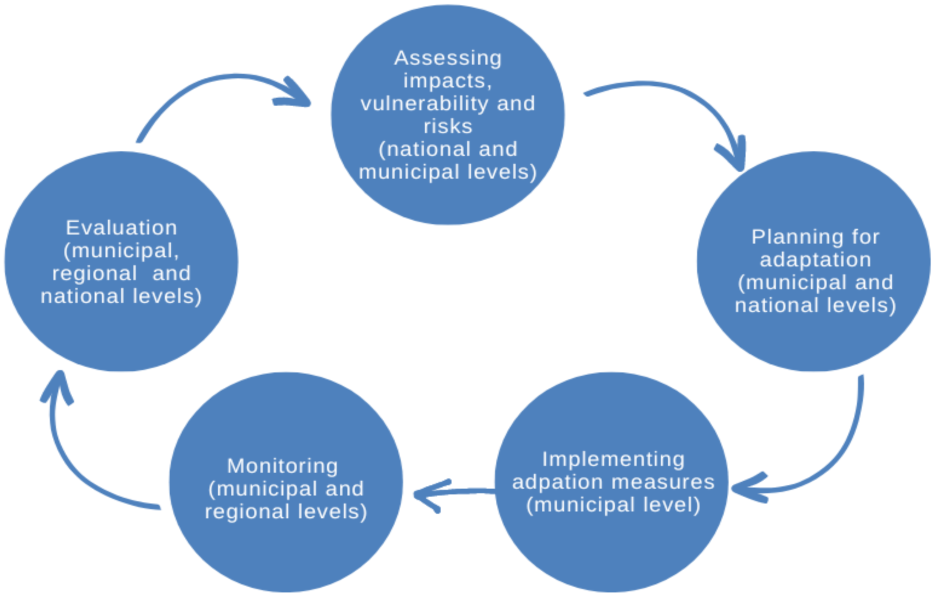
Monitoring Progress

A monitoring-evaluation framework works as an iterative policy and implementation process, which consists of an impact assessment, and an evaluation of the results (Vallejo, 2017[25]; EEA, 2020[26]). The former requires tracking and reporting on specific indicators, while the latter means indicators are reviewed in combination with other relevant information to examine implementation efficiency, and levels of

[6] geoportal.stage.geocloud.sk/maps/climate-change-risks

progress, and accommodate future revisions. Additionally, tracking progress can disseminate these insights at several government levels and improve accountability.

Figure 3.15. Monitoring-evaluation framework



Source: Adapted from Vallejo, 2017

Relevant data on adaptation progress must be gathered and supplied to provide the basis for progress evaluation and future prioritisation analyses. Indicators can quantitatively monitor measurable changes in climate before and after adaptation measures are implemented. Additionally, continued monitoring of indicators used in this study will ensure climate trends are followed on the national level. The SHMI should continue to track future trends in indicators used for the prioritisation, which is essential for subsequent progress evaluations.

Extending the existing monitoring framework in place by integrating indicators used in this study could provide a common metric for progress evaluation. The National Adaptation Plan sets out to monitor progress on three levels: strategic priorities, specific goals and tasks. Monitoring indicators help describe implementation progress and details about undertaken projects and measures. Each task, whether it be ‘soft’, qualitative measures or interventions relating to blue, grey and green infrastructures, is assigned a monitoring indicator.

Municipalities construct their adaptation plans and/or report to regional administrations. Reporting mechanism on adaptation could be implemented through extending existing reporting schemes between municipalities and the Ministry to avoid additional reporting responsibilities (e.g. the flood protection reports submitted by municipalities semi-annually could also serve to inform on adaptation). Additionally, reporting may boost regional and local adaptation efforts.

Regional administrations’ reports on progress needs to specify what measures were implemented, their description and their effects, or other implementation actions, including legislative changes. Municipalities have deep knowledge and understanding of local issues that state-level policy-making benefits from. Additionally, municipalities are encouraged to consult adaptation plans and interventions with experts and the wider public. While participation is in its beginnings in Slovakia, a growing number of municipalities are integrating participative activities into their inner processes (e.g. Bratislava has published its participation manual, see (MIB, 2021[27]).

Box 3.2. Example of measuring progress in adaptation: the UK case study

The UK has implemented a Monitoring, Reporting, and Evaluation (MRE) process to assess its progress on adaptation (EEA, 2020[26]). However, based on the Climate Change Committee's (CCC) evaluation of the UK's second NAP, the Adaptation Committee has failed to integrate clear and measurable priorities for the adaptation plan. Under the 2008 Climate Change Act, the Adaptation Committee presents the UK government's progress on adaptation to the Parliament every other year. Additionally, the Parliament also undertakes reports from the Department for Environment, Food and Rural Affairs (Defra). Reporting authorities from different sectors supply reports on progress in adaptation to Defra.

Between 2008 and 2010, all English local authorities were required to report their progress in process-oriented reviews (OECD, 2022 forthcoming[6]). In these reports, local authorities were required to self-report their adaptations actions. These are no longer required, and as of today, there is no UK-wide adaptation reporting required of local authorities. Thus, even though the UK has a reporting process in place, it does not ensure the measurability of progress in adaptation on local levels (EEA, 2020[26]). Therefore, there is a disconnect between local-level adaptation plans and national-level ones. This highlights the importance of a progress measuring framework which includes a common metric and connects local and regional adaptation actions.

Meanwhile, Northern Ireland included local governments and civil society in the process of adaptation as well as tracking progress. The Civil Society and Local Governments Adapt (Climate Northern Ireland, 2019[28]) aims to outline the work on adaptation planned by civil society and raise awareness of the necessity to adapt. Additionally, it developed an online platform which demonstrates climate change adaptation work undertaken by local authorities. Local Governments report on adaptation through online submission forms that list the methods, forms and outcomes of adaptation actions in Northern Ireland (OECD, 2022 forthcoming[6]).

Evaluating Progress and Future Improvement

Evaluating adaptation implementation helps assess progress towards policy goals, actions and impacts, their effectiveness and consistency, and refine existing processes. It is intended to answer larger questions about the country's preparedness for future climate change impacts and its resilience. Evaluation is based on data and experience gathered through monitoring progress. While some municipalities evaluate progress on adaptation in their own local adaptation plans, nation-level evaluations bridge these plans to national plans by assessing and compiling data from the regions. Larger evaluations based on cross-level and cross-sectoral data thus bridge the gaps between existing adaptation plans.

The NAP working group, responsible for evaluations, could benefit from implementing the risk levels assessed in this document as a methodology for adaptation implementation and evaluations. The group, led by the MoE, is responsible for gathering information about progress and its evaluation. Consisting of experts and stakeholders from various governmental sectors, its purpose is to coordinate and assess action towards implementation periodically. It periodically reports progress on adaptation to the UNFCCC (via NCs), the European Commission, and the Government of the Slovak Republic.

The climate risk assessment analysis framework in this study can be reapplied in the future. Re-evaluating and re-determining municipalities' risk levels based on updated data gathered through continued monitoring can ensure strategic revision of implementation processes.

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Annex A. List of indicators

This annex provides an overview of all indictors used in this study to shed light on the way the methodology for this analysis was constructed, and to outline the relevance of each factor accounted for. Indicators are divided into three categories: climate hazards, socio-economic factors and land cover factors. Indicators of each category have different weights but all are significant to the prioritisation. The UK has developed a comprehensive indicator framework that is already being used to track progress in adaptation policy-making (OECD, 2022 forthcoming[6]). Final set of indicators is a combination of indicators from the UK study and indicators recommended by local experts.

A.1 Climate hazards

Climate hazards are the expected risks of the future impacts of climate change. Extreme heat, drought and extreme precipitation are considered to be relevant phenomena in Slovakia. All of the data used were available in the gridded format from the Copernicus data store or were provided by the SHMI. The values for each phenomenon in individual municipalities were assigned based on the QGIS *Zonal statistics* analytical tool.

The future impacts of heat, precipitation and drought are assessed from the climate change projections. All projected hazard indicators were assessed based on the relative change between future period in the mid-21st century, and reference period in the present. This is dependent on the data format. Alternative approach to future projections would be using currently observed climate information on the three climate hazards. As adaptation measures need to be focused mainly to cope with the future expected impacts of climate change, this analysis applied the former.

Extreme heat

Two indicators based on two definitions of heatwaves are used to evaluate extreme heat — climatological and health related definition. In both cases, RCP 4.5 as well as RCP 8.5 projected scenarios are available. But, as a RCP 4.5 is an intermediate scenario and therefore more likely to occur, it is applied in the analysis. For individual municipalities, the differences in the number of heatwave days between decades 2016-2025 and 2046-2055 were evaluated and averaged based on this scenario.

The number of tropical days and tropical nights are indicators used to track the present heat conditions. Tropical days are defined as the days when the temperature of the air reaches at least 30 degrees Celsius, while tropical nights are the nights with the air temperature not falling below 20 degrees. The average number of tropical days or nights per year between 1991 and 2020 for each municipality is formulated into a comprehensive indicator to account for the present heat conditions.

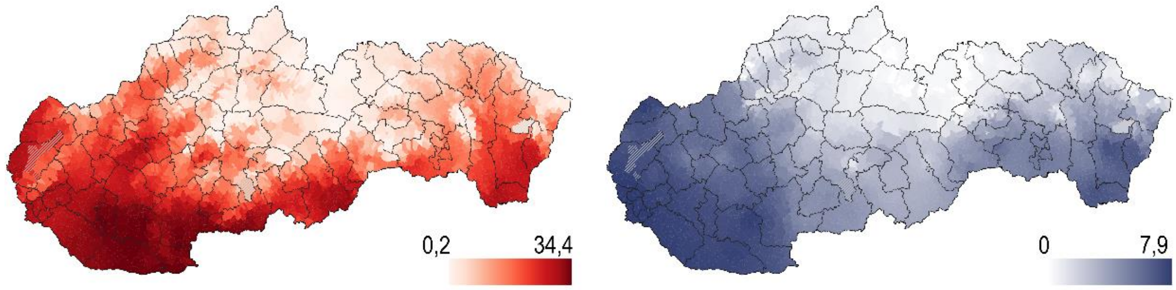
Table A A.1. Extreme heat climate hazard indicators

Type of data	Definition	Indicators	Data information	Data transformation
Climatological definition	Based on the EURO-CORDEX project - heat wave is considered as a period of at least three consecutive days on which the daily maximal temperature exceeds the 99th percentile of the daily maximal temperatures of the May to September season of the control period of 1971 to 2000.	RCP 4.5 ensemble members average	Horizontal resolution: 0.1° x 0.1°	QGIS zonal statistics per municipality; Average of annual data projections per decade; Normalisation
Health related definition	Health-related EU-wide definition relies on the results of the EUROheat project (Michelozzi et al. 2007; WHO 2009). For the summer period of June to August, heat waves were defined as days in which the maximal apparent temperature (Tappmax) exceeds the threshold (90th percentile of Tappmax for each month) and the minimum temperature (Tmin) exceeds its threshold (90th percentile of Tmin for each month) for at least two days. The apparent temperature is a measure of relative discomfort due to combined heat and high humidity, developed on the basis of physiological studies on evaporative skin cooling. It can be calculated as a combination of air and dew point temperature (Steadman 1979).	RCP 4.5 ensemble members average	Horizontal resolution: 0.1° x 0.1°	QGIS zonal statistics per municipality; Average of annual data projections per decade; Normalisation
Tropical heat days	Tropical heat days as defined by the SHMI are the days on which the air temperature between 7AM and 9PM exceeds 30 degrees Celsius.			
Tropical heat nights	The SHMI defines tropical heat nights as those with air temperature not falling below 20 degrees Celsius.			

Source: Copernicus Climate Change Service

Figure A A.1. Average number of tropical heat days and nights in the period 1991 – 2020

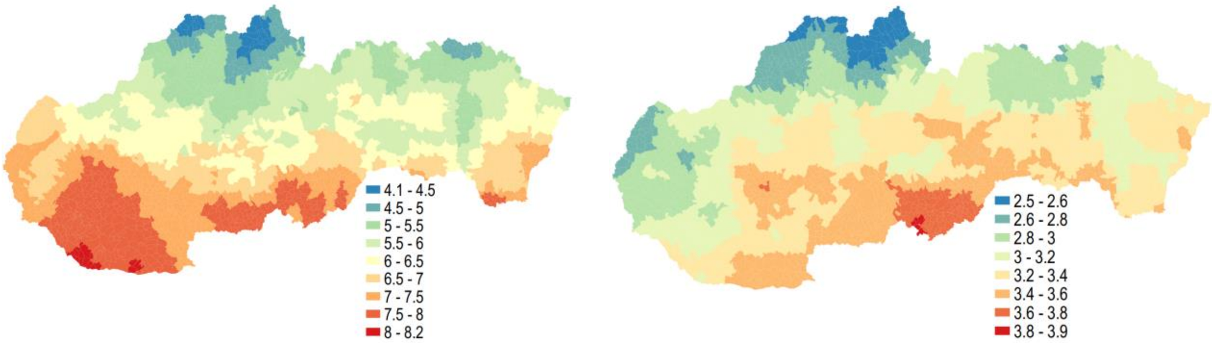
Tropical heat days (left); Tropical nights (right)



Source: Slovak Hydrometeorological Institute

Figure A A.2. Average heat increase in days between decades (2016-2025) and (2046-2055) in RCP 4.5 scenario by heat definition

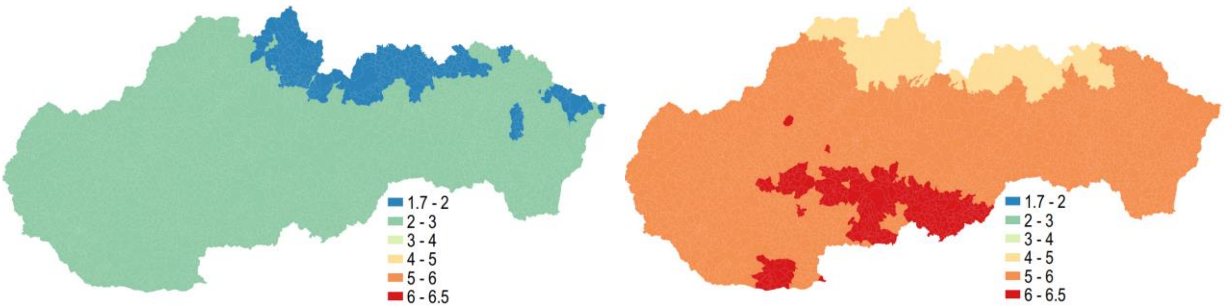
Health definition (in degrees Celsius) (left); Climatological definition (in degrees Celsius) (right)



Source: Copernicus Climate Change Service

Figure A A.3. Average heat days number in decades by climatological definition of heat in RCP 4.5 scenario

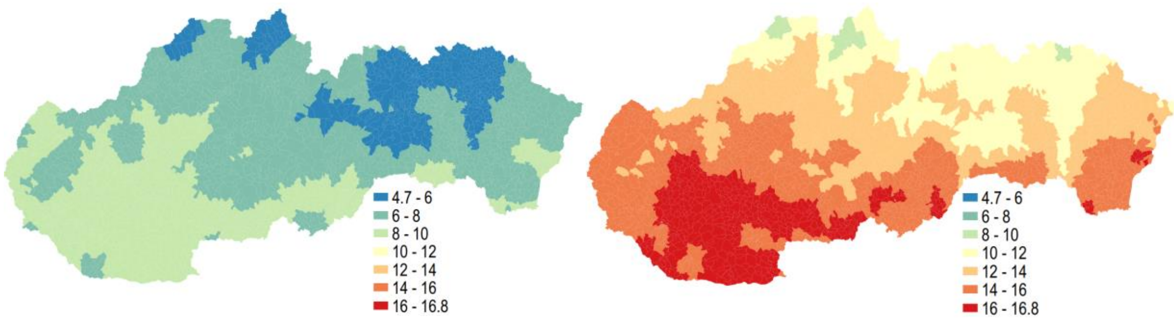
2016 – 2025 (in degrees Celsius) (left); 2046 - 2055 (in degrees Celsius) (right)



Source: Copernicus Climate Change Service

Figure A A.4. Average heat days number in decades by health definition of heat in RCP 4.5 scenario

2016 – 2025 (in degrees Celsius) (left); 2046 – 2055 (in degrees Celsius) (right)



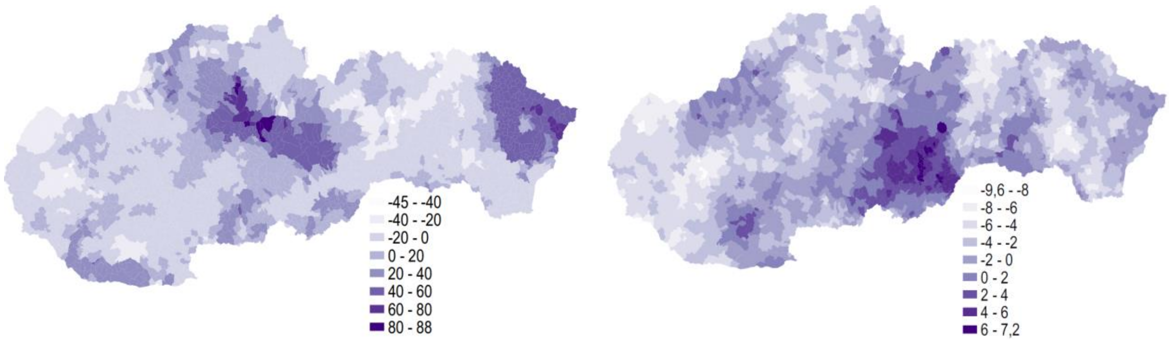
Source: Copernicus Climate Change Service

Drought

The current situation regarding droughts is accounted for through the Standardised Precipitation-Evapotranspiration Index (SPEI) The data used for this indicator account for the average values for the period of 1991-2020. Next, drought prediction assessment is a composition of two indicators based on two different definitions of droughts - Longest dry spells and Number of dry spells. In both cases, only RCP 4.5 scenario was used although there are RCP 2.6., RCP 4.5 and RCP 8.5 scenarios available, as RCP 4.5 scenario is the most probable. For individual municipalities, the data from period 2041-2070, which represents the difference to the reference period in 1971-2000 were evaluated based on RCP 4.5 scenario.

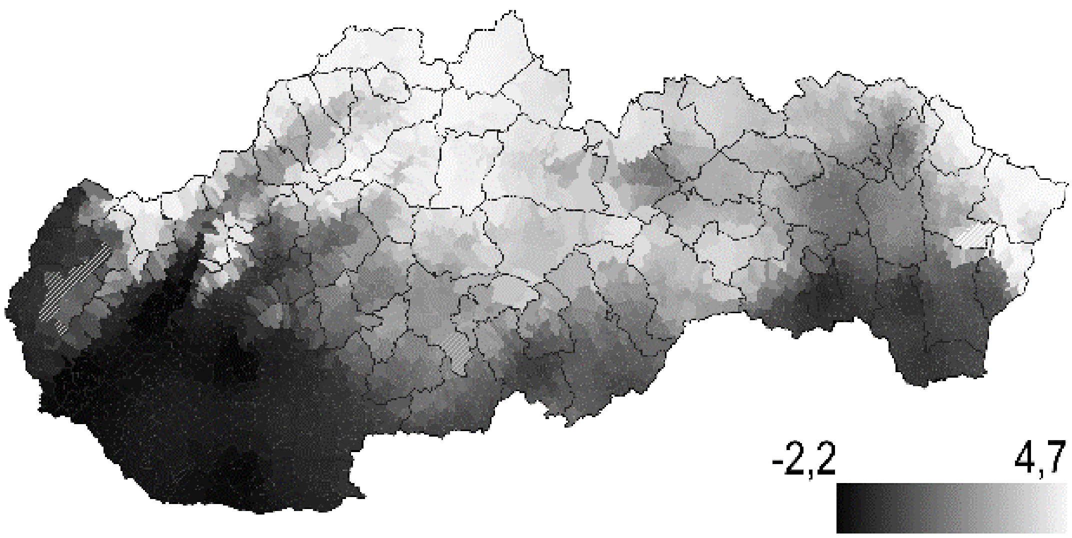
Figure A A.1. Change in drought between years 2041-2070 and reference period 1971-2000 for RCP 4.5 scenario

Longest dry spells definition – change in number of days (left); Number of dry spells – change in number of dry periods (right)



Source: Copernicus Climate Change Service

Figure A A.2. Current drought (SPEI Index)



Source: Slovak Hydrometeorological Institute

Table A A.1. Drought climate hazard indicators

Type of data	Definition	Indicators	Data information	Data transformation
Longest dry spells	Longest dry spells is defined as the maximum number of consecutive dry days (dry day: daily precipitation < 1mm) over a 30 year period. For future periods the indicator is given as a relative change against the reference period (1971-2000). Data used were bias corrected, based on CCLM4-8-17 (CLM-Community, EU) regional and EC-EARTH (ICHEC, Ireland) global climate model for the period between 2041-2070	RCP 4.5	Horizontal resolution: 5 x 5 km	QGIS zonal statistics per municipality; Normalisation
Number of dry spells	Number of dry spells is defined as the number of dry periods (dry day: daily precipitation < 1mm) of more than 5 days for a 30-year period. For future periods the indicator is given as a relative change against the reference period (1971-2000). Data used were bias corrected, based on CCLM4-8-17 (CLM-Community, EU) regional and EC-EARTH (ICHEC, Ireland) global climate model for the period between 2041-2070	RCP 4.5	Horizontal resolution: 5 x 5 km	QGIS zonal statistics per municipality; Normalisation
Drought (SPEI)	The Standardised Precipitation-Evapotranspiration Index (SPEI) expresses relative deviations from the long-term mean value for a simple water balance of precipitation and evapotranspiration. Evapotranspiration is a process that includes evaporation from the earth's surface and transpiration (release of water vapor from vegetation).	SPEI		

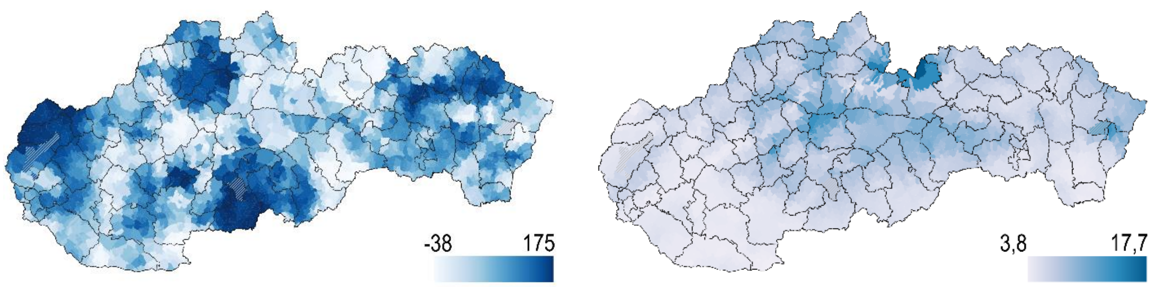
Source: Copernicus Climate Change Service, Slovak Hydrometeorological Institute

Extreme precipitation

The number of days with atmospheric precipitation total of ≥ 20.0 mm in the 1991 – 2020 period was averaged to formulate an indicator, which expresses the current precipitation-related situation in each municipality. Next, precipitation forecast indicator is based on a definition of extreme precipitation - Highest 5-day precipitation amount. As RCP 4.5 is the most probable RCP scenario, only that one was used as indicator, though the RCP 2.6., RCP 4.5 and RCP 8.5 were available. For individual municipalities, the data from period 2041-2070, which represents the difference to the reference period in 1971-2000 were evaluated and averaged based on RCP 4.5 scenario.

Figure A A.1. Change in high precipitation between years 2041-2070 and reference period 1971-2000 for RCP 4.5 scenario

Change in high precipitation between years 2041-2070 and reference period 1971-2000 for RCP 4.5 scenario (average number of days) (left); Current precipitation trend (Average number of days with precipitation total ≥ 20,0 mm in the normal period 1991 – 2020 (right)



Source: Copernicus Climate Change Service

Table A A.1. Extreme precipitation climate hazard indicators

Type of data	Definition	Indicators	Data information	Data transformation
Highest 5-day precipitation amount	Highest five-day precipitation amount is defined as the maximum of 5-day precipitation totals. The value is given as a maximum over a 30-year period. For future periods the indicator is given as a relative change against the reference period (1971-2000). Data used were bias corrected, based on CCLM4-8-17 (CLM-Community, EU) regional and EC-EARTH (ICHEC, Ireland) global climate model for the period between 2041-2070	RCP 4.5	Horizontal resolution: 5 x 5 km	QGIS zonal statistics per municipality; Normalisation
Precipitation ≥ 20.0 mm	Average annual number of days with atmospheric precipitation total ≥ 20.0 mm for the 1991-2020 period.			

Source: Copernicus Climate Change Service

A.2 Socio-economic context – sensitivity and coping capacity

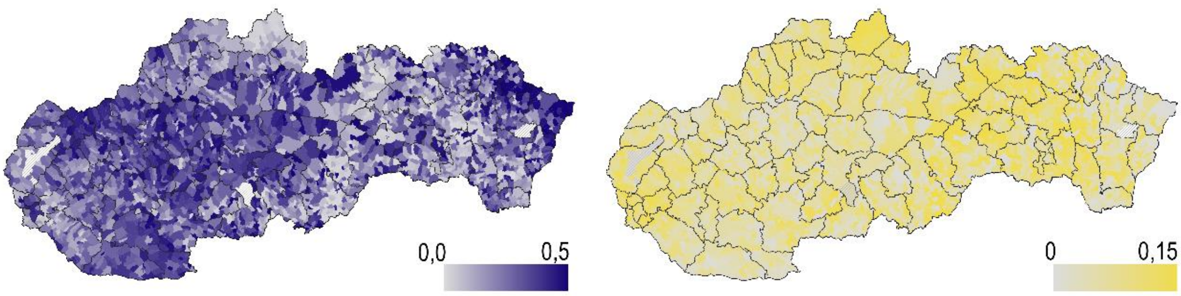
The extent and the intensity of climate change effects is not dependent solely on the nature of climatic hazards and the resilience of the environment, but on the socio-economic factors as well (UNFCCC, 2008[29]). Risks are not isolated, they are intricately linked to social, economic and demographic factors and ongoing transformations (Ludena et al., 2015[30]).

Population: This study considers population dynamics to estimate each area‘s climate vulnerability. In this analysis, population densities across the country were determined using a GIS method by noting the number of inhabitants per address. A grid of 100 x 100 meters was applied, and the inhabitants per address data was assessed for each cell. The results were subsequently reflected in the final evaluation of each settlement. The children up to four years old and 70 or older (Figure A2.1) populations were singled out as these groups are highly vulnerable to the effects of extreme heat (Fouillet, 2006[31]).

Health: To estimate access to specialised healthcare in each region, the minimum distance from a polyclinic or a hospital in minutes was included as an indicator in the analysis (Figure A2.1). While all communities are vulnerable to climate risks, some are better equipped to manage the impacts. Urban population with well-developed by health facilities are more likely to deal with weather extremes compared to less developed settlements (UNFCCC, 2008[29]). Therefore, access to services such as healthcare contribute to the levels of both vulnerability and adaptive capacity of individual territories.

Figure A A.2. A selection of socio-economic indicators

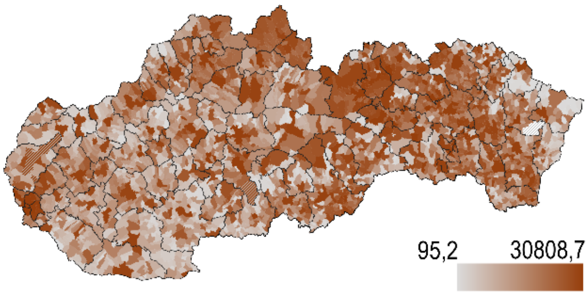
Vulnerable population aged ≥ 70 (%); Vulnerable population aged ≤ 3 (%) (right)(left)

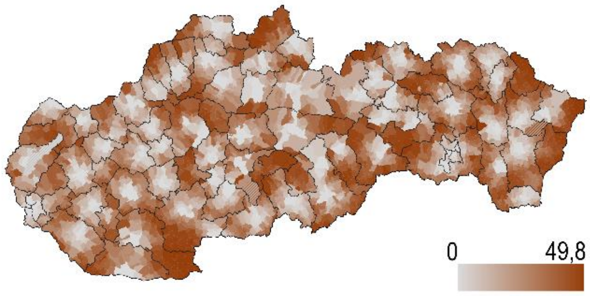


Source: Statistical Office of the Slovak Republic

Figure A A.3. A selection of socioeconomic indicators

Population Density (per ha) (left); Minimum travel time to hospitals and polyclinics (minutes) (right)





Source: Statistical Office of the Slovak Republic, Institute for Financial Policy (Ministry of Finance of the SR); Institute for Healthcare Analyses

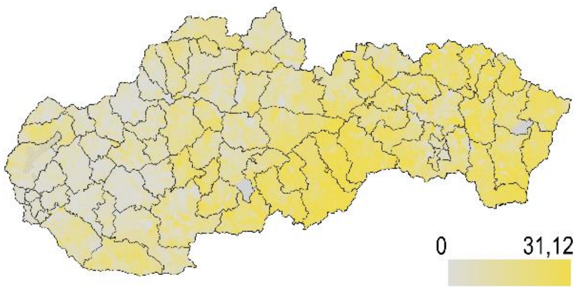
Employment: Registered unemployment rate and municipal income per capita (Figure A2.2) indicate the society's resilience and its ability to cope with the effects of climate change. Wealthier, high-income societies have lower climate vulnerability (Asumadu Sarkodie, Ahmed and Owusu, 2022[32]) and are generally better prepared for the negative impacts of climate change. Meanwhile, the unemployment rate speaks to the ratio of people without the stability of regular income or with no or precarious income.

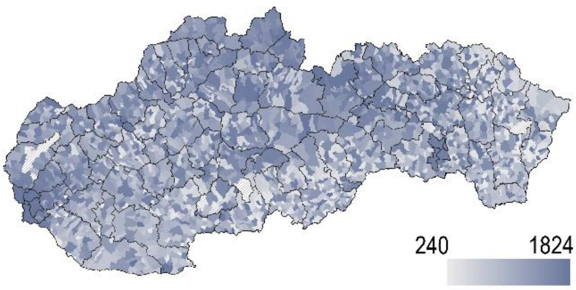
Water: A socio-economic indicator used to calculate the drought index is the share of population supplied by the public water supply system per municipality (Figure A2.2). Municipalities or areas without access to public water could be negatively affected by long-term droughts, as they can potentially cause a decrease in the water supply.

Social: The percentage of concentrated Roma communities in a given municipality is linked to its capacity to cope with the adverse effects of climate change (Figure A2.2). Social exclusion of the Roma population has many socio-economic effects; for example, more than half the Roma inhabitants in Slovakia live in segregated settlements characterised by a lack of fundamental infrastructure (Filčák and Škobla, 2016[33]). Racialised constructions of environmental segregation deepen climate risks, as the influence of the communities on decision-making-processes is often circumscribed (Harper, Steger and Filčák, 2009[34]). For example, studies have shown that Roma communities often have low access to water and a clean environment, and this condition is related to social practice and discrimination, as well as structural, institutional, and economic challenges (Filčák, Szilvasi and Škobla, 2018[35]).

Figure A A.4. A selection of socio-economic indicators

Unemployment rate (%) (left); Municipal Income per capita (EUR) (right)





Source: The 2021 Population and Housing Census, Statistical Office of the Slovak Republic; Ministry of Finance of the Slovak Republic

Table A A.2. Socio-economic indicators

Indicator	Index used	Data information and transformation
Population density	EH, D, EP	Grid 10x10 meters created by pop. living on addresses adjusted by pop. count in municipality.
Vulnerable population aged < 4	EH, D, EP	
Vulnerable population aged ≥ 70	EH, D, EP	
Minimum travel time to the nearest hospital	EH, EP	
Registered unemployment rate	EH, D, EP	
Municipal income	EH, D, EP	
Share of population supplied from public water supply system	D	
Percentage of concentrated Roma communities	EH, D, EP	Share of population living in segregated marginalised Roma communities.

Source: Institute for Environmental Policy

A.3 Environmental conditions relevant to adaptation

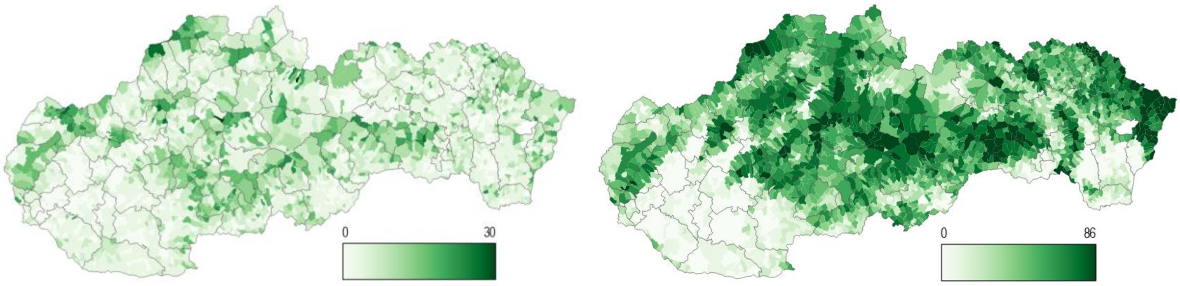
Land cover indicators speak to the effects the physical environmental conditions have on climate change exposure. While some conditions have positive effects on the coping capacity, others are more likely to aggravate climate impacts. Additionally, areas under the environmental protection, such as national parks, are better equipped to deal with hazards. The information for land cover indicators was measured both in inhabited areas by creating a 100x100 meters grid for all areas of at least 1 inhabitant and in the whole municipality. The data for inhabited areas were weighted by population. The data for evaluating land use were obtained from the EU Copernicus Land Monitoring Service website (Copernicus, 2022[36]) in raster layers with a resolution of 10x10 meters. The result is the share of the surveyed land cover layers in the municipality, which was then normalised from 0 to 1.

Tree cover density: Trees can cool the air by 2°C to 8°C (Doick and Hutchings, 2013[37]) and reduce urban heat islands. Additionally, forests can control rainfall and prevent landslides and soil runoff. Therefore, areas with concentrated forests outside the urban area are better prepared to cope with the effects of climate change, while trees in urban areas, while not as effective as forests, can help reduce temperatures in cities and towns as well. Tree cover density was assigned values from 0 to 100, based on the percentage of tree cover per cell.

Imperviousness: Materials that cover the soil with impervious materials as a result of urban and industrial development are more likely to be negatively affected by the impacts of climate change. Posing problems to biodiversity and soil functions, they increase the pressure on adjacent permeable soil surfaces. Locations with a high proportion of impermeable surfaces are problematic since the area is more likely to be impacted by heat islands. The indicator was calculated using the overall share of imperviousness in whole area of municipality. Depending on the percentage of imperviousness on the grid, values between 0 and 100 were assigned to each cell.

Figure A A.5. A selection of land cover indicators

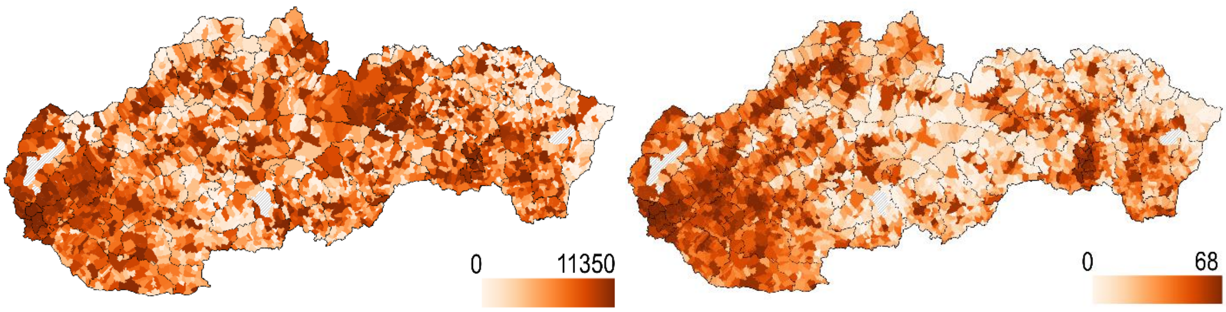
Tree cover density per inhabited area weighted by population (index) (left; Tree cover density per municipality area (percent) (right)



Source: Copernicus Land Monitoring Service

Figure A A.6. A selection of land cover indicators

Imperviousness density per inhabited area weighted by population (index) (left); Imperviousness density per municipality area (percent) (right)



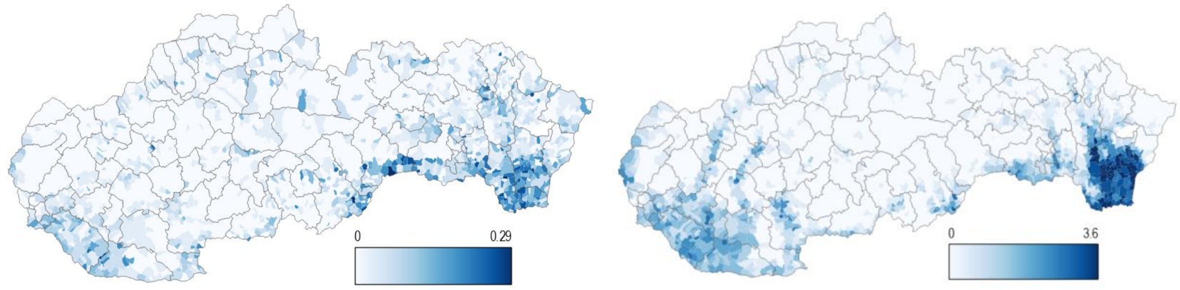
Source: Copernicus Land Monitoring Service

Water and Wetness: Water and Wetness buffer against extreme climate hazards, by absorbing access water and precipitation. Areas with concentrated presence of water such as wetlands have an enormous adaptive capacity, prevent floods and have positive effects on its surroundings. Individual cells were weighted with a value of 0 (no water), or 1 (temporary wetting), 2 (permanent wetting), 3 (temporary water), and 4 (permanent water) to create a single index.

Grasslands: Compared to urban areas, grasslands are more likely to cope with precipitation, heat and drought hazards and prevent soil runoff. Each cell was assigned a valued of 0 or 1 depending on whether the area off the cell is covered in grass or not.

Figure A A.7. A selection of land cover indicators

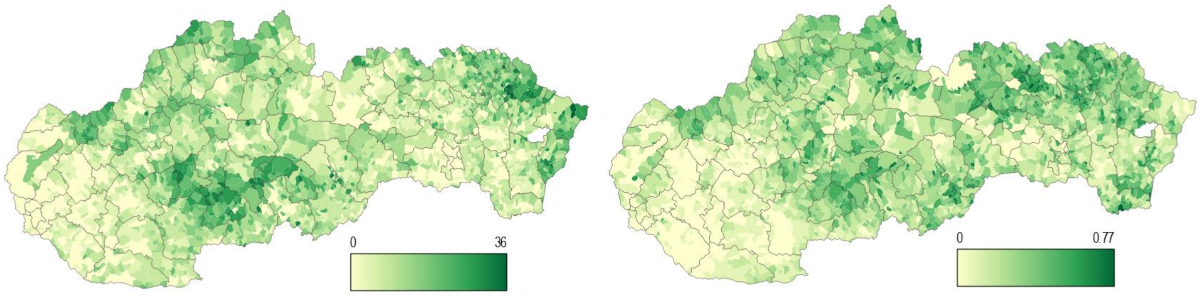
Water and wetness per inhabited area weighted by population (index) (left); Water and wetness per municipality area (index) (right)



Source: Copernicus Land Monitoring Service

Figure A A.8. A selection of land cover indicators

Grassland density share per inhabited area weighted by population (index) (left); Grassland density share per municipality area (index) (right)



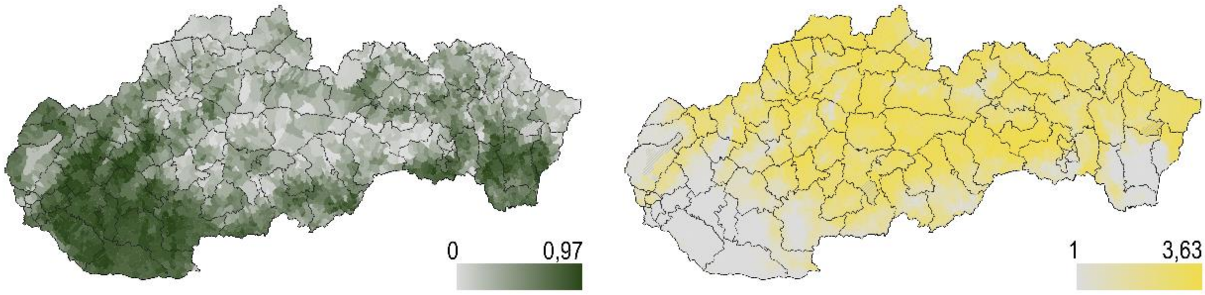
Source: Copernicus Land Monitoring Service

Share of croplands: Agriculture is a key sector which is highly exposed and vulnerable to the effects of climate hazards and therefore needs to be protected. Therefore, the share of croplands per municipality was included as an indicator to determine the vulnerability of every grid cell. Each cell was given a value between 0 and 1 depending on the share of croplands in the whole of a municipality.

Potential Soil Erosion: Areas prone to soil erosion are more likely to be negatively impacted by extreme precipitation. The share of unstable erosion-prone soil was calculated by assigning each cell a value between 1-4, which represent the degree of proneness to erosion, where 1 is no risk of erosion and 4 stands for extreme erosion risks.

Figure A A.9. A selection of land cover indicators

Share of croplands per municipality area (left); Share of potential soil erosion areas per municipality (right)



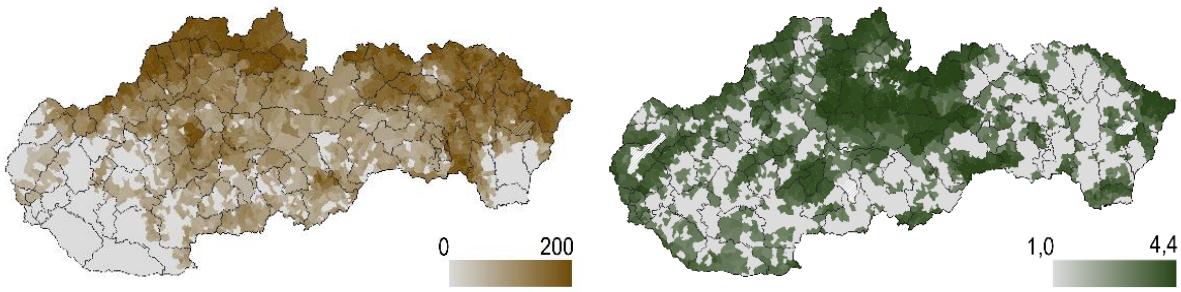
Source: The United States Geological Survey; National Agricultural and Food Centre

Landslides: This indicator indicates the presence of landslide-prone areas on the grid. Landslides can be triggered by specific events, like heavy precipitation. Increasing frequency and intensity of rains may lead to more landslides in landslide-prone areas. The values used in the analysis consider areas prone or potentially prone to landslides to formulate a variable for each cell. The average landslide risk is based on the share of unstable and potentially unstable slopes in every municipality.

Areas under Environmental Protection: Protected areas, such as national parks, reservations, protected landscapes and others belong to areas under environmental protection. These areas generally combine many of the elements which improve adaptive capacity of land, such as forests, wetlands and others. Therefore, these are more likely to remain more resilient as climate impacts worsen. Levels of protection between 1 (general protection) and 5 degrees (high protection) for each cell were normalised to achieve values input for the final analysis.

Figure A A.10. A selection of land cover indicators

Share of potential landslides areas per municipality (left); Average levels of environmental protection (right)



Source: State Geological Institute of Dionýz Štúr; State Nature Protection of the Slovak Republic

Table A A.3. Land

Indicator	Index used	Data information and transformation
Share of Tree cover density	EH, D, EP	Density of Tree cover per inhabited area within municipality and per whole municipality area
Share of Imperviousness	EH, D, EP	Density of Imperviousness per inhabited area within municipality and per whole municipality area
Share of Grasslands	EH, D, EP	Grassland cover per inhabited area within municipality and per whole municipality area

Indicator	Index used	Data information and transformation
Share of Water and wet cover	EH, D, EP	Water and wetness cover index per inhabited area within municipality and per whole municipality area
Share of croplands area within municipality	D, EP	Cropland share per whole municipality area
Areas under environmental protection	EH, D, EP	Average nature protection degree in municipality on scale from 1 to 5, where 1 is land where general protection is applied and 5 is area with highest protection
Soil erosion - share of unstable soil	EP	Average erosion risk on cropland area in municipality on scale from 1-4, where 1 is least vulnerable and 4 is most vulnerable
Landslide hazard areas	EP	Average landslide risk based on share of unstable and potentially unstable slopes in municipality

Source: Institute for Environmental Policy

Annex B. Ensuring the robustness of the results: methodology

Adaptation to climate changes is a complex phenomenon which cannot be captured with a single indicator. One way of dealing with this is to introduce a composite index (also known as composite indicator). A composite index is created when several indicators are combined into a single index on a basis of an underlying model (OECD, 2008[38]). On the one hand, composite indices are simpler for interpretation than a group of separate indicators. On the other hand, composite indices need to be constructed well if their policy message shall be reliable.

It is necessary to apply suitable weighting to ensure the composite index used in this study is well-constructed. Weights refer to the "explicit importance" that is related to every criterion in a composite index (Greco et al., 2019[39]). Different selection of weights may significantly impact the entities ranked. Although expert opinion reflects better policy priorities, data driven methods better capture the nature of data. The proposed method combines these two approaches. Namely, at its core it is a data driven DEA model, which is enriched by expert opinion through the setting of boundaries which limit the influence of a particular indicator or groups of indicators.

DEA is a well-established and widely used non-parametric technique which derives objective weights for use (Zhou, Ang and Poh, 2007[40]). DEA has also gained popularity in CI construction (Zhou, Ang and Poh, 2007[40]), mainly due to the desirable properties of the endogenously calculated differential weighting with each entity choosing its own weights in such a way as to maximise its performance (Greco et al., 2019[39]). As Greco et al. point out, this helps dismiss any potential conflicts such as the chosen weights not favouring any entity.

In the application of the DEA method, just as the OECD (2008[38]), composite indicator are defined as the ratio of an entity's actual performance to its benchmark performance:

$$CI_e = \frac{\sum_{e=1}^{M} I_{qe} w_{qe}}{\sum_{e=1}^{M} I_{qe}^{*} w_{qe}}$$

where I_{qe} is the normalised score of the qth individual indicator (q=1,…,Q) for entity e (e=1,…,M), w_{qe} is the corresponding weight and I* is the score of the hypothetical entity which maximises the overall performance given the unknown set of weights w (OECD, 2008[38]). The benchmark is obtained as a solution to the following maximisation problem:

$$I^{*} = I^{*}(w) = \underset{I_k, k\in\{1,\dots,M\}}{\operatorname{argmax}} \left(\sum_{q=1}^{Q} I_{qk} w_q \right)$$

The set of optimal weights is obtained as a result of the following optimisation procedure for e=1,...,M:

$$CI_e^{*} = \underset{w_{qe}, q=1,\dots,Q}{\operatorname{argmax}} \frac{\sum_{q=1}^{Q} I_{qe} w_{qe}}{\max_{I_k, k\in\{1,\dots,M\}} \left(\sum_{q=1}^{Q} I_{qk} w_{qe} \right)}$$

$$s.t.\ w_{qe} \geq 0 \ \ where \ \ q = 1,2,\dots,Q.$$

As (OECD, 2008[38]) states, the resulting composite index will have its values between zero (worst possible performance) and one (the benchmark).

It should also be noted that bounds limiting influence of indicators based on expert judgements can be easily added. Instead of limiting weights directly, “proportion constraints” are used. This restriction of flexibility of weights is incorporated in the model if there are some practical considerations with respect to the weight (Wong and Beasley, 1990[41]):

$$L_q \leq \frac{I_{qe} w_{qe}}{\sum_{q=1}^{Q} I_{qe} w_{qe}} \leq U_q \ \ where \ \ q = 1,2, \dots, Q.$$

As (Cherchye et al., 2009[42]) argue, in general it is easier to ask experts to determine the constraints on the weights than to let them determine the weights themselves.

During the process of data preparation, the authors have ensured that all indicators have been modified to such a form that the higher value of indicator corresponds to a better preparedness. This is important as DEA requires that variables have ‘the same direction’ for the optimisation to work properly. The authors have also conducted normalisation. As the last step, correlation analysis and expert judgement lead to final selection of indicators for each composite index.

The DEA model constructed for this study incorporated several expert judgements in form of constraints on shares of different variables (see Table B.1). The authors have limited the share of each socio-economic and land cover indicator to contribute 30% at most to the overall scores for each municipality. At the same time, each indicator related to current hazard are required to bring at least 10% (only applicable for heat) and all current hazard indicators should together cover at least 40 % of the overall scores. Future hazards bound is set to a minimum of 15%.

Several additional restrictions are applied for the precipitation and drought indices. Especially relevant variables such as landslides and erosion are set to contribute by at least 15% in the case of precipitation. Similarly, access to water and share of croplands are important factors that affect droughts, and their shares are adjusted in the same fashion. Even though vulnerable population aged 70+ is an indicator relevant primarily in the case of heat, this indicator has been deemed by experts somewhat relevant to drought and extreme precipitation as well, yet its share is limited to maximum 2%. For the same reason, travel time to hospitals and vulnerable population aged up to 4 years are also limited to 2% in the case of precipitation or drought, respectively. These bounds are still not too restricting and can be strengthened or relaxed based on further expert judgement.

Table A B.1. Constraints on indicators in the DEA model

All indices	
Hazard indicators current state (together) – min. 40%	
Hazard indicator current state (each) – min. 10%	
Hazard indicators future prediction (together) – min. 15%	
Every indicator (other than hazard) – max. 30%	
Precipitation	**Drought**
Residents aged 70+ - max. 2%	Residents aged 70+ - max. 2%
Travel time to the nearest hospital – max. 2%	Children up to 4 years – max. 2%
Erosion + landslides – min. 15%	Access to water + share of croplands – min. 15%

Source: Institute for Environmental Policy

Adaptation measurement: Assessing municipal climate risks to inform adaptation policy in the Slovak Republic

Climate change presents a major social, economic and political challenge for the Slovak Republic. The majority of municipal administrations are unaware of the potential climate risks they face today and in the coming years. Identifying risks posed by climate change and its inevitable impacts is an essential part of developing adaptation policies. While national adaptation policies have historically been formulated in an *ad hoc* manner, an evidence-based approach that relies on data is increasingly informing policy decisions. This paper provides an overview of the country's adaptation policy context and presents a methodology – and the results of its application – for measuring climate change risks with respect to heat, drought and extreme precipitation. The results aim to inform future budget allocation decisions for climate change adaptation.

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