Institute for Environmental Policy

Identifying climate risk levels of Slovak municipalities

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Economic analysis 14

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Ministry of Environment of the Slovak Republic

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This analysis summarises the results of the study by IEP and OECD “Adaptation measurement: Assessing municipal climate risks to inform adaptation policy in the Slovak Republic”. The work received guidance from Mikaela Rambali, Maike Kirsch and Catherine Gamper (OECD Environment Directorate).

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Abbreviations

DEA	Data Envelopment Analysis
EEA	European Environmental Agency
IHA	Institute of Health Analysis
MF SR	Ministry of Finance of the Slovak Republic
MARD SR	Ministry of Agriculture and Rural Development of the Slovak Republic
MoE SR	Ministry of Environment of the Slovak Republic
NRRP	National Recovery and Resilience Plan
SEA	Slovak Environment Agency
SPEI	Standardized Precipitation Evapotranspiration Index

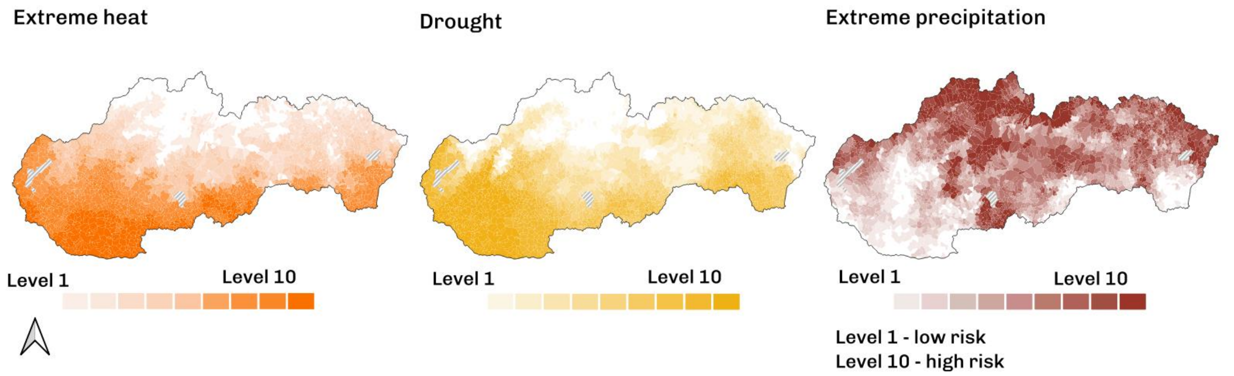
Summary

Adapting to the impacts of climate change will be a major social, economic and political challenge in the coming decades. Adaptation aims to reduce the vulnerability of human and ecological systems to upcoming changes. Effective implementation of adaptation measures is a complex process and requires joint efforts of various sectors and stakeholders. Since the impacts of climate change will vary across the regions of Slovakia, the measures will have to reflect the specificities of the individual territories of the country. This will require cooperation at all levels of public administration.

Climate change and its manifestations will have fundamentally negative impact on Slovakia. Rising temperatures, a decrease in soil moisture, changes in climate variability, longer and more intense periods of drought, or changing trends in annual precipitation totals across the country will affect the territory of the Slovak Republic in varying degrees. This will have consequences for the economy, human health and ecosystems, and will also exacerbate existing social inequalities.

This analysis determines risk levels of municipalities with regards to three climate hazards - extreme heat, extreme precipitation and drought. Municipalities are divided into ten categories according to the risk posed by individual threats – the higher the level, the higher the potential negative impacts of climate change. The risk levels take into account climate, socioeconomic and landscape specificities of individual areas.

Figure 1: Municipality risk levels by climate hazard



Source: IEP

The south of Slovakia, including the capital Bratislava, is most at risk of extreme heat. The districts with the highest risk are Bratislava I, Komárno and Nové Zámky, but Šaľa, Lučenec and Rimavská Sobota are also vulnerable. This is mainly determined by the current number of tropical days and nights and expected future temperature changes. Districts with low availability of healthcare and a high proportion of children under the age of four were also rated as significantly at risk. More than 16% of Slovakia's population live in areas with the highest risk of extreme heat.

Droughts represent a significant risk for districts in the southwest of the country, including Žitný ostrov. Žitný ostrov is an important agricultural area and the largest reservoir of drinking water in Slovakia, so droughts threaten water supply and food security. The districts with the highest risk level are Bratislava II, Senec and Bratislava V. The current situation and forecasts of future changes in the incidence of drought have the greatest influence on determining the risk level, followed by the share of households without access to public water supply.

The threat of extreme precipitation is mainly concentrated in the north of the country, a particular risk is posed in areas with marginalized Roma communities. The high-risk districts are Tvrdošín, Dolný Kubín and Kysucké Nové Mesto. These areas have been exposed to heavy rains in the past and are also highly prone to landslides, which increases their vulnerability. According to forecasts, the occurrence of precipitation will also increase significantly in the vicinity of Veľký Krtíš district. Extreme precipitation has significant social consequences, especially in areas where minorities live without sufficient protective infrastructure, which can lead to particularly tragic consequences. In 1998, extreme rains and floods in Jarovnice (Sabinov district) claimed 50 lives and caused other serious damage.

Slovakia's adaptation policy is built on a framework of strategies and plans, but this complex structure is not aligned with the system of financing measures. Most of the funds intended for adaptation come from foreign sources, and the investments do not reflect the priorities set out in the strategic documents. Until now, the resources allocated to adaptation measures were focused primarily on anti-flood measures. At the same time, the defined goals and priorities are not binding for the actors.

Financing of adaptation measures should be concentrated in the most affected areas of the country. The results and methodology developed as part of this study should serve as a starting point for decision-making processes related to the financing and implementation of adaptation measures. An important source of funds in the coming years will be the EU scheme Operational Programme Slovakia 2021-2027, which significantly increases the allocation of resources for water retention measures in settlements and the country.

Projecting climate threats into municipal spatial plans will help strengthen the commitment of adaptation. At the same time, this study can serve as a guide for improving the quality of methodologies for developing local adaptation strategies. Municipalities that are defined as high risk in this study should, in their own interest, consider developing their own adaptation strategies with the aim of integrating them into the spatial plan, in order to prevent such construction and changes to landscape structures as a preventive measure, which may worsen the future impacts of climate change. Serving as examples of good practice are the municipalities which have already developed their adaptation strategies and implementation plans. However, so far only a small number of municipalities have done so.

Introduction

Climate change has significant global negative impacts. Heat, floods, forest fires and droughts are increasingly frequent phenomena. As average global temperatures are predicted to increase further due to human activities and the long-term persistence of greenhouse gases in the atmosphere, these phenomena will intensify. According to the medium scenario of the Intergovernmental Panel on Climate Change, by the end of the century the average temperature on Earth should be 2.1 to 3.5 °C higher than in the years 1850-1900 (IPCC, 2021).

The effects of climate change can already be seen in Slovakia today and the situation is expected to deteriorate. Higher air temperatures have been recorded in the country in recent years (MoE SR, 2018). There has been a decrease in total precipitation in the south and an increase in the north of the country. In addition, we have witnessed a reduction in relative humidity in southern Slovakia. Snow cover in places up to 1,000 m above sea level has become scarcer. Since 1993, gradual desertification has been occurring, especially in the south, due to long-lasting dry periods with very low precipitation during the growing season (MoE SR, 2017). In addition, the occurrence of heat waves as well as cold waves has increased. All observed impacts of climate change in Slovakia exceeded their predictions in terms of frequency and intensity. Climate conditions recorded between 2001 and 2017 were originally predicted to occur around 2030 (MoE SR, 2017). It is expected that the average air temperatures will gradually increase by 2 to 4 °C compared to the averages in the years 1961 - 1980 (MoE SR, 2018).

The changing climate will have an impact on the daily lives of the Slovak residents who will need to adapt to the new conditions. Droughts threaten agriculture, food security and ecosystems. Extreme rainfall damages infrastructure and threatens human lives. High air temperatures are a risk to the health of the most vulnerable groups of the population. Therefore, it is not enough to consistently reduce greenhouse gas emissions, but it is also necessary to adapt the landscape and settlements to the coming changes. The goal of adaptation is not only to reduce vulnerability and possible negative consequences, but also to use the positive effects of climate change and the opportunities it brings. For example, increased temperatures can be devastating for crops that are grown in Slovakia now, but also an opportunity for growing other species.

The aim of this publication is to identify the risk levels based on the impacts of climate change for individual municipalities of the Slovak Republic, namely for three main areas: extreme heat, drought and extreme precipitation. The consequences of climate change differ in individual districts or even municipalities in Slovakia. All regions will feel these changes, but some will be more exposed or vulnerable. It is necessary to identify the most threatened areas, which should be adapted first, and thus prevent irreversible damage. The risk assessment presented in this study is intended to help local governments, regions and the state as a whole to more effectively allocate resources and attention so that we can achieve the best possible preparedness for climate change.

This analysis summarizes the results of a joint study by the Institute for Environmental Policy (IEP) and the Organization for Economic Cooperation and Development (OECD), which was published in English under the title "Adaptation measurement: Assessing municipal climate risks to inform adaptation policy in the Slovak Republic". Among other things, it also contains an appendix with a detailed methodology, description and visualization of all indicators. The study is accompanied by the data layers published at the National Geoportal, which interactively displays the risk levels of individual municipalities **https://geoportal.geocloud.sk/maps/climate-change-risks/.**

1 How we adapt to climate change

The aim of adaptation measures is to minimize the vulnerability of human and ecological systems to climate change (IPCC, 2022). By adapting to the negative impacts of climate change on the country and society, these impacts can be prevented or at least limited. Slovakia is a signatory country to the Paris Agreement, which obliges states to reduce their vulnerability to climate change. The EU climate change adaptation strategy, in turn, aims to shift the emphasis from adaptation planning to actual implementation (European Commisson, 2021). Increasingly ambitious plans and investments will be needed to reduce the impacts of climate risks, so it is important to consider where and what measures will be implemented.

The main pillars of state policy in the area of adaptation to climate change are defined in the Environmental Policy Strategy of the Slovak Republic until 2030 (MoE SR, 2019). Legislative changes are outlined as the main measures, which should ensure the obligation to prepare adaptation strategies at the level of regions and cities. These should contain specific actions and allocated financial resources and, above all, should lead to their subsequent implementation in spatial plans. The MoE of the Slovak Republic coordinates policies, it is responsible for implementation, monitoring and reporting on progress and evaluates the effectiveness and sustainability of the approach to adaptation. Due to the complexity of the issue, multiple departments or public administration bodies share the responsibilities regarding planning and implementation tasks.

The main sectoral strategic documents are the Climate Change Adaptation Strategy of the Slovak Republic (2018) and the subsequent Action Plan for Implementation (2021). The main goal of the Slovak Republic in the field of adaptation is to reduce the risk and increase the adaptive capacity of systems to the current or expected negative consequences of climate change (MoE SR, 2018). By the end of 2025, the Ministry of the Interior of the SR has an obligation to submit a new, updated Strategy. The Action Plan for implementation following the Strategy sets out 6 cross-cutting strategic priorities, 45 specific measures and 169 tasks, the implementation of which is necessary for the fulfilment of the goals. The Ministry of the Interior of the Slovak Republic is obliged to continuously inform the government about progress in the area of adaptation. Information on the progress achieved in the implementation of adaptation measures in the Slovak Republic was approved by the Slovak government in March 2023. The Ministry of the Interior of the Slovak Republic will also inform the Slovak government of the progress in achieving the short-term goals of the plan by June 30, 2024. Working group for adaptation led by the Ministry of the Interior of the Slovak Republic is in charge of the monitoring and evaluation of progress in adaptation to climate change. In the coming years, more resources will be available for adaptation, including EU funds, and therefore an economically efficient distribution of funds will be key.

The phenomena associated with climate change have different intensity and frequency, therefore it is necessary that implemented measures reflect local climate threats and socioeconomic conditions. The adaptation process requires the involvement of a wide range of actors. It requires extensive scientific, technical and economic expertise and cooperation in the public and private sectors, including the involvement of local governments, which are responsible for the implementation of measures at the local level. Local governments and self-governing regions do not have a formal obligation to develop adaptation strategies and plans, but various tools motivate them to do so. This primarily involves the requirement to develop an adaptation plan if municipalities wish to apply for Norwegian Grants. At the sub-national level, 16 plans and strategies were adopted, and four of the eight self-governing regions created their own adaptation strategies.

Table 1: List of entities with adaptation plans or strategies

Self-governing regions	Bratislava, Košice, Prešov, Trnava
Cities	Bratislava, Hlohovec, Kežmarok, Košice, Prešov, Trenčín, Trnava, Zvolen, Žilina
City districts	Bratislava - Karlova Ves, Košice – západ
Municipalities	Spišská Teplica
International cooperation	district Michalovce and Sobrance together with Uzhhorod district (Ukraine)
Other areas	Horná Ondava

Source: SEA

Adaptation to climate change is also addressed in the Recovery and Resilience Plan. Landscape planning reform can ensure the binding nature of adaptation through the reflection of adaptation priorities in landscape planning documentation. The reform aims to establish adequate protection against disturbance of landscape structures. The component dedicated to adaptation to climate change also includes water management reforms and the reform of national parks. Investments envisaged in the Recovery and Resilience Plan amount to 159 million euros and include adaptation measures such as renaturation of watercourses, land purchases for the purpose of expanding non-intervention areas and tourism development projects in two national parks.

The main financial source for investments in adaptation measures are the EU funds, especially the European Structural Funds and the Common Agricultural Policy. Until now, the LIFE Program of the European Union and the EEA or Norway Grants have been a partial source of funding for adaptation to climate change. The LIFE program supported the development of local adaptation strategies, adaptation in urban areas, etc. The EEA and Norway Grants support, among other things, building of green and blue infrastructure and soft measures for raising awareness about climate change mitigation and adaptation. In total, the SK-Climate Programme financed by the EEA and Norwegian Grants has so far supported projects in the amount of 19.81 million euros. The implementation of the program will last until 2024.

In the new program period, an increased attention will be directed towards water retention measures. In 2022, the European Commission approved the Operational Programme Slovakia 2021-2027, where more than 239 million euros are allocated for adaptation measures and strengthening resilience. Finances are aimed, among other things, at the definition of starting points for the implementation of measures, as well as at the actual implementation at the national, regional and local level. In the past, adaptation in Slovakia mainly focused on anti-flood measures, while investments in water retention measures in cities were relatively insignificant. Nowadays, in addition to anti-flood measures, finances are now also allocated separately for water retention measures in settlements and in the countryside. More than 127 million euros are intended to be spent on such investments.

Table 2: Selected adaptation financing programmes until 2021[1]

Programme	Adaptation measures	Number of projects	Allocated resources for the whole period (mil. euros)	Note
European structural and investment funds (2014-2020)	Water retention in urban areas	88	18,2	Water retention measures, rain gardens
	Flood protection measures	29	124,6	Grey and green flood protection measures
Common agricultural policy (2015-2020)	Reforestation	12	0,2	
	Prevention and elimination of damage caused by forest fires, natural disasters and events	15	58,1	
	Restoration of forests damaged by forest fires, natural disasters	143	29,9	
	Improving the resilience and environmental value of forest ecosystems	255	4,3	
	Restoration, protection and strengthening of ecosystems related to agriculture and forestry	2	139,7	
Environmental Fund (2020)	Air quality	30	2,8	Building green infrastructure in accordance with legislation on non-native and invasive species
	Access to drinking water	36	4,5	Construction or reconstruction of public water supply
	Flood protection	2	0,3	Measures on the river or watershed
Municipalities		NA	NA	Miscellaneous; e.g. planting trees and capturing water in urban areas
LIFE (2014-2020)	Climate resistance of residential buildings and support of biodiversity in urban areas, climate-smart forestry measures Raising awareness of green urban infrastructure	2	5	Priority area: Adaptation to climate change
			0,2	Priority area: Management and informatization of climate change
	Raising awareness about urban green infrastructure	1	0,2	Priority area: Management and informatization of climate-related activities
EEA and Norway Grants (SK-Climate) (2014 – 2021)	Energy saving, E-mobility, green and blue infrastructure, increasing soil infiltration capacity, reducing waste production and its further reuse, restoration of degraded wetland ecosystems	49	19,8	Combination of mitigation and adaptation measures, continuity of wetlands and inundations (repeatedly flooded areas) with surface flow, management of wetlands and management of wetland biotopes, flood potential of wetlands, hydrological regime of wetlands

Source: IEP; based on data from MoE and MARD SR

[1] There is no comprehensive database of all adaptation financing at the moment

2 Defining risk levels

The costs of adaptation measures will increase in the near future. Given the limited resources, it is necessary to establish priorities on the basis of which the funds will be redistributed in order to maximize the benefit. This requires an assessment of the degree of climate risks throughout Slovakia and the identification of the most threatened areas. Methods, procedures and criteria for evaluating investments for adaptation are summarized in the Prioritization of investment projects prepared by the Ministry of Environment of the Slovak Republic (MoE SR, 2021).

The current assessment of investments does not take into account the diversity of climate threats and it also omits smaller municipalities. The document focuses only on settlements with more than 5,000 inhabitants. It then defines priority investment areas for adaptation as a whole. In practice, however, it is often not possible to prepare adaptation measures that would respond to all climate threats at once. While shade and the ability to cool down are important for cities in the heat, these measures may not be the most effective for the drought that plagues farmers, and they will not help with torrential rains. Therefore, it is necessary to assess the three biggest threats separately - extreme heat, extreme precipitation and drought[2].

Extreme heat is a challenge for cities and especially for vulnerable groups of residents living there. The built environment of urbanized areas is susceptible to formation of a heat island when the city is unable to cool down sufficiently. Green and blue infrastructure in the form of parks and water features can help alleviate this phenomenon. However, if the city consists mainly of impermeable surfaces and heat-accumulating materials, particularly vulnerable groups of the population - for example, children and seniors – may be exposed to a higher risk of heat-related health issues. The worst effects can still be averted by good availability of healthcare, but this should not replace sensible urban planning solutions aimed at preventing heat.

Extreme rainfall is the biggest problem in areas with increased susceptibility to erosion and landslides. Unstable soil can loosen due to extreme rainfall and cause significant damage to property and endanger the inhabitants of the affected areas. In an urbanized environment with an excessive occurrence of impervious surfaces, torrential rains can also temporarily cause problems such as paralyzing traffic or damage to infrastructure.

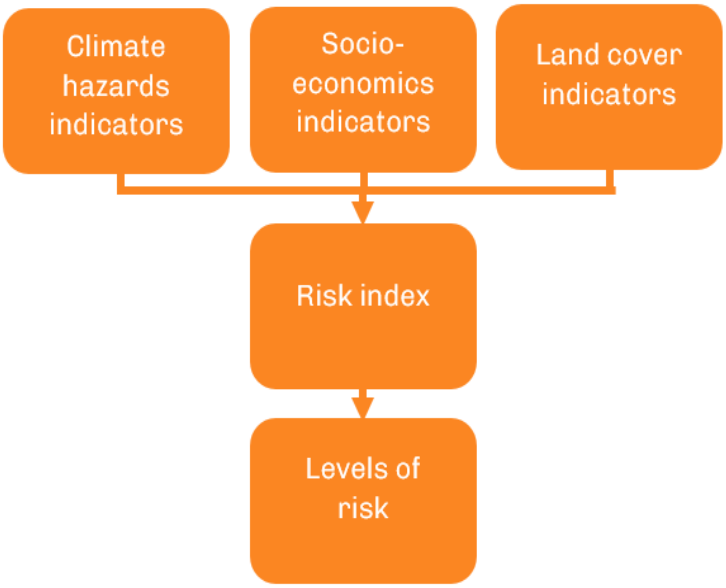
The adverse effects of drought are most noticeable on agricultural land and production. The current way of managing agricultural land has caused its reduced ability to retain water, while many areas were deliberately drained in the past using hydrotechnical infrastructure. In addition to the country, households that are not connected to the water supply can also be significantly affected by the drought, because a long-term drought also adversely affects the abundance of water resources.

Three groups of indicators were used to assess vulnerability - climatic, socioeconomic and physical environment indicators. The indicators were chosen based on the literature (e.g. Ludena et al. (2015)), expert consultations and data availability. Each of the three indices - for extreme heat, drought and extreme precipitation - uses a selection of indicators to be relevant to a given type of threat. Groups of indicators allow us to

[2] In addition to the above, floods are another challenge for the country. Prioritization in the given area is based on the assessment of flood risks covered by the Concept of the water policy, the update of which is currently being prepared by the Ministry of the Interior of the Slovak Republic. If it is necessary to assess the vulnerability of the territory with regard to other climatic threats, this methodology can serve as a basis for further analyses.

capture various aspects of climate change in a specific context, which reflects the complexity of potential adaptation activities.

Figure 2: Levels of risk development process



Source: IEP

Current and future climate indicators are the most important part of the assessment. Indicators regarding climate threats are based both on average values measured over the past three decades, and also on climate development predictions modelled for the whole of Europe until 2050. By combining current and future threats, we can identify regions that are already suffering from the consequences of climate change with those that will be affected later on. Due to insufficient investment in adaptation measures, it will be necessary to both make up for the resulting deficit and actively respond to forecast challenges.

The impacts of climate change can be significantly affected by the physical character of the natural, but also the human-built environment. The heat will be more bearable in cities where trees provide shade and cool the air in the surrounding public space. Similarly, bodies of water may not only be used for recreation, but also for thermoregulation in overheated locations. Even untouched nature in protected areas represents a potentially resilient space where vegetation and soil have not lost their natural water-retaining properties. On the contrary, in settlements where nature does not mitigate the impacts sufficiently, the built infrastructure in the form of water pipes or hospitals helps to compensate for the adverse effects.

In order to minimize the negative impact on people, densely populated settlements should be adapted as a priority. Municipalities with a high share of vulnerable population are most at risk. A separate challenge is the adaptation of marginalized Roma communities who already live in unsatisfactory conditions. Climate change has the potential to deepen social inequalities. However, poverty (captured in the indicators using the unemployment rate) is also present outside Roma communities, making it impossible for residents to carry out adaptation measures on their own. In such cases, greater involvement of the public sector is needed, whether at the local or national level.

Table 3: Indicators

Area	Indicator	Extreme heat	Extreme precipitation	Drought
Climate threats	Future extreme heat - climatological definition	x		
	Future extreme heat - medical definition	x		
	Current heat - tropical days	x		
	Current heat - tropical nights	x		
	Future drought - number of consecutive days of drought			x
	Future drought - total number of days of drought			x
	Current drought (SPEI index)			x
	Future extreme precipitation		x	
	Current extreme rainfall		x	
Socio - economic indicators	Population density	x	x	x
	Vulnerable population - children under four years of age	x	x	x
	Vulnerable population - seniors over 70 years old	x	x	x
	Availability of hospitals	x		
	Unemployment rate	x	x	x
	Financial resources of the municipality (per capita)	x	x	x
	Access to drinking water (waterworks)			x
	Percentage of segregated inhabitants of Roma communities	x	x	x
Physical environment	Percentage of area covered with trees (entire territory of the municipality)		x	x
	Percentage of territory with impervious surfaces (entire territory of the municipality)		x	x
	Percentage of territory with grass surfaces (entire territory of the municipality)		x	x
	Percentage of territory with water bodies (entire territory of the municipality)		x	x
	Percentage of territory covered by trees (inhabited territory, weighted by the number of inhabitants)	x	x	
	Percentage of territory with impervious surfaces (inhabited territory, weighted by the number of inhabitants)	x	x	
	Percentage of territory with grass surfaces (inhabited territory, weighted by the number of inhabitants)		x	
	Percentage of territory with water bodies (inhabited territory, weighted by the number of inhabitants)	x	x	
	Share of agricultural land		x	x
	Average degree of protection	x	x	x
	The share of the territory threatened by soil erosion		x	
	Area threatened by landslides		x	

Source: IEP

We divide municipalities into ten risk levels reflecting the negative consequences of climate change. This way, we define the priority areas in which assistance with the financing of adaptation measures should be prioritized. The methodology for creating the composite index reflects the fact that municipalities operate in different climatic, landscape and socioeconomic contexts and eventual resilience to climate change can be achieved in different ways. Each municipality has its own significant indicators that are the most effective for achieving resilience.

The index is created as the sum of the contributions of the input indicators, which are multiplied by the automatically assigned weights. For especially relevant indicators, the lower limit of their share in the resulting index is expertly determined. The lower limit is implemented for all groups of climate variables for the three indices. Similarly, the importance of indicators related to soil stability in case of extreme precipitation or share of agricultural land and water access in case of drought is built into the model. On the contrary, we set an upper limit for least relevant indicators. The index is created using the Data Envelopment Analysis (DEA) method, which is described in more detail in Box 1.

Box 1: Methodology of the composite index

Composite indices allow us to encapsulate complex information into a simple summary metric. Often, individual input indicators are simply averaged or multiplied by expert weights and summed to the resulting index. The results of such an approach depend to a great extent on the subjective opinions of the authors. In case of inappropriate selection of input indicators, they may attribute more importance to less relevant factors. At the same time, these approaches do not allow the specific context of individual entities (municipalities) to be incorporated, but they determine the same conditions for everyone across the board. These problems are solved by more advanced approaches that automatically create weights for indicators using a mathematical model. Such methodologies ensure greater objectivity of the results, which are not based only on expert estimates.

Data envelopment analysis (DEA) is based on the idea that individual units, in our case municipalities, operate in different contexts and achieve their efficiency in different ways. Therefore, each municipality gets its own set of weights, which will allow it to achieve the best possible result in its specific conditions. Thus, the municipality can compensate for any deficiencies in one area with better performance in another. The advantage of DEA is the possibility to include expert boundaries for the share of indicators on the resulting index and thus highlight the influence of important indicators.

Our analysis is based on the methodology described in the manual from OECD (2008), where the composite index CI_e is defined as the ratio of the performance of the investigated municipality *e* to the performance of the benchmark:

$$CI_e = \frac{\sum_{q=1}^{Q} I_{qe} w_{qe}}{\sum_{q=1}^{Q} I_{qe}^{*} w_{qe}}$$

Where I_{qe} is normalized score of the q^{th} indicator (q=1,...,Q) for municipality e (e=1,...,M), w_{qe} is the corresponding weight and I* is the value for the hypothetical municipality that maximizes the total performance with respect to an unknown set of weights *w*. A benchmark is a solution to a maximization problem

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

We obtain the set of optimal weights as a result of the optimization task for all municipalities e=1,...,M:

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

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

Index values range between 0 and 1, with a higher value indicating better efficiency. We do not limit the weights directly, but we set a limit for the share of the product of the weight and the indicator in the index:

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

In our case, we chose the following restrictions for all three indexes:

- Current climate threats (total) – min. 40%
- Current climate threat (each separately) – min. 10%
- Future climate threats (total) – min. 15%
- Each indicator (other than climate threat) – max. 30%

Restrictions for the Extreme Precipitation Index:

- Seniors over 70 - max. 2%
- Hospital availability – max. 2%
- Erosion + landslides – min. 15%

Restrictions for the Drought Index:

- Seniors over 70 – max. 2%
- Children up to four years old - max. 2%

- Availability of drinking water + share of agricultural land - min. 15%

Based on the *CI* values, the municipalities are divided into 10 quantiles indicating the level of risk, where low values correspond to a high degree of risk. For better interpretation, the risk levels are inverted in the next step so that a higher value means a higher risk. The number of municipalities with a given level is the same for each level, only in the case of the same values are the municipalities divided into the same group.

DEA is standardly used to create KI in various fields from education (Stumbriene, et al., 2020), to environment (Rogge, 2012) or social responsibility of firms (Oliveira, et al., 2019). Vulnerability to climate change is assessed by e.g. Huang et al. (2019) or Huang et al (2011) but by default a smaller number of units (mostly countries) are included. Our analysis thus exceeds the usual range of previous analyses by the amount of data.

3 Where are the most severe impacts of climate change?

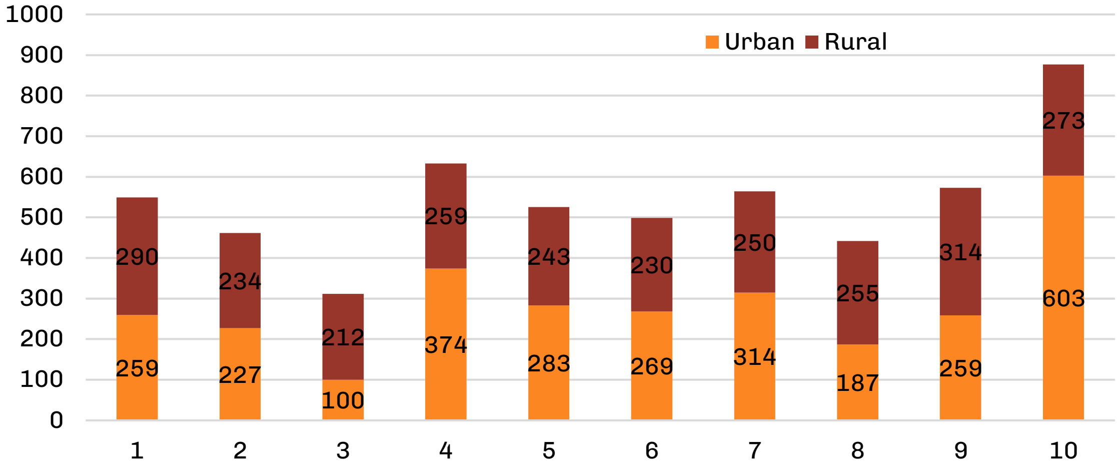
Climate change risk indices determine which municipalities are among the most threatened by the impacts of climate change, and therefore should be given special attention when implementing adaptation measures. Individual municipalities are assigned risk levels from 1 (the lowest risk) to 10 (the greatest risk). This is done separately for each of the three main climate threats. The results show that most of the municipalities facing the risk of extreme heat are located in the south of Slovakia. Municipalities exposed to the risk of drought are mainly concentrated in the southwest, and extreme rainfall is a threat mainly to municipalities in the north and east.

The indices include data on climate hazards, socioeconomic indicators, as well as land cover status. In this way, we can take into account several factors relevant to the capacity of a municipality to face climate change. For example, some municipalities are particularly at risk due to their lack of resources and conditions to increase resilience to climate threats (e.g. those with marginalized Roma communities). Other municipalities may be better equipped compared to others, but the climate hazard affects them more. This is the case for Bratislava, which is economically resilient, but will also face intense heat and drought due to strong urbanization.

3.1 Extreme heat

More than 16% of Slovakia's population lives in areas with the highest extreme heat risk level. Among the most threatened areas are the city of Bratislava and the districts of Komárno, Nové Zámky, Šaľa, Bratislava IV, and Bratislava V. Threatened regions are concentrated in the southwest of the country around the capital and Žitný ostrov, but also in the south of central Slovakia. At the same time, the districts of Bratislava I, Komárno and Nové Zámky are currently among the places with the highest average number of tropical days per year.

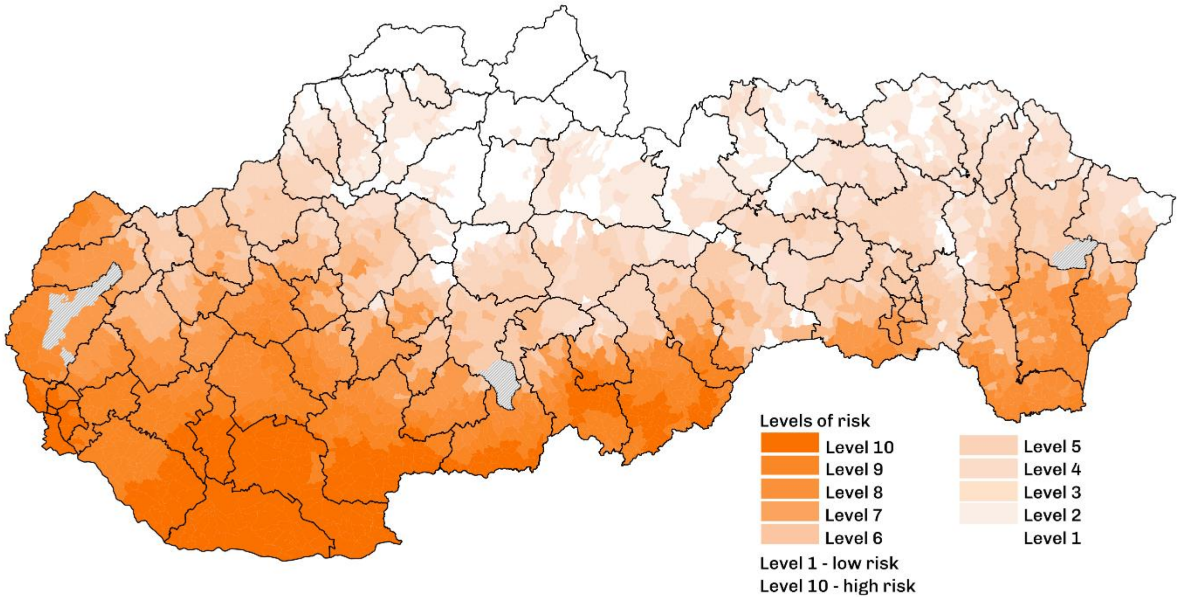
Figure 3: Number of inhabitants by level of risk (in thousands)



Source: IEP

Larger, more densely populated and built-up cities tend to be more at risk. In the past, Bratislava I was affected by frequent tropical nights, during which the air temperature did not drop below 20 °C. Such nights are characteristic of urbanized places, because buildings and roads in cities accumulate heat, which slows the cooldown during the nights. Bratislava - Staré Mesto is a municipality with a high share of impermeable surfaces, which in general contribute to the creation of heat islands in cities. It is also a densely populated part of the city, which means that the effects of the heat are felt by a large number of residents concentrated in one place.

Figure 4: Extreme heat levels of risk

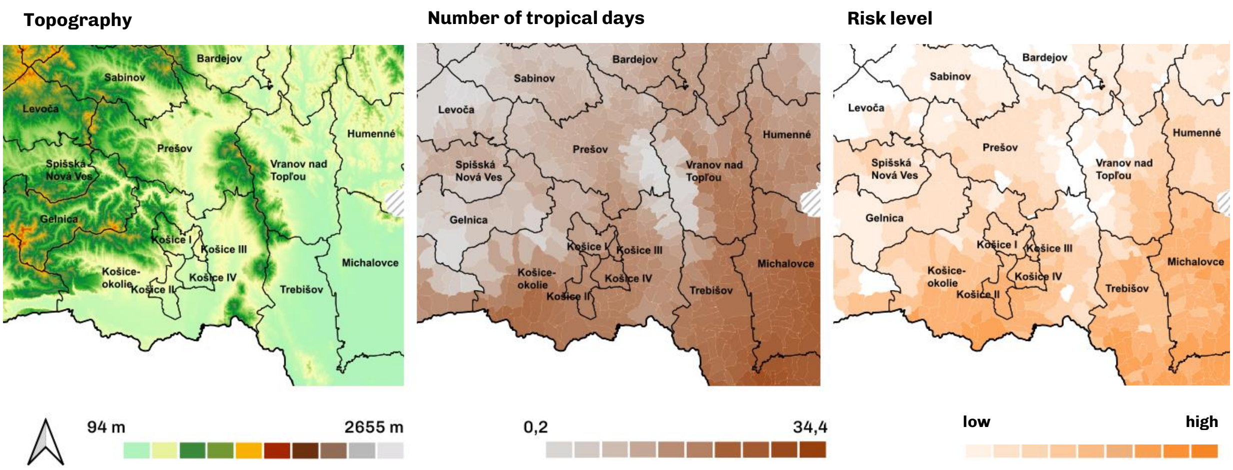


Source: IEP

The districts of Komárno and Nové Zámky record the highest average number of tropical days per year. In the town of Hurbanovo in the district of Komárno, the highest recorded temperature in Slovakia was also measured at 40.3 °C. At the same time, these districts are relatively vulnerable, as they have a large population of elderly people who have relatively poor access to health care. In some municipalities in Nové Zámky, the minimum travel time to the nearest hospital or polyclinic is at least 50 minutes. During extreme heat, the population is therefore more vulnerable.

Municipalities located at higher altitudes are less exposed to heat. The north of the country is more mountainous than the south, which means on average the number of tropical days and nights is significantly lower in that area. The importance of the altitude can be seen near Levoča, which has experienced only four tropical days a year on average in recent years, while in Prešov it was more than 11 days. The topographic map (Figure 5) shows the Levočské and Slanské vrchy mountain ranges, whose surroundings are less threatened. This is also why the least threatened districts are Námestovo, Tvrdošín and Čadca in the north of the country. This is also evidenced by the temperatures recorded so far, as well as forecasts for the future, despite the fact that some municipalities in the Námestovo district, such as Novoť and Oravská Lesná, have relatively low access to health care.

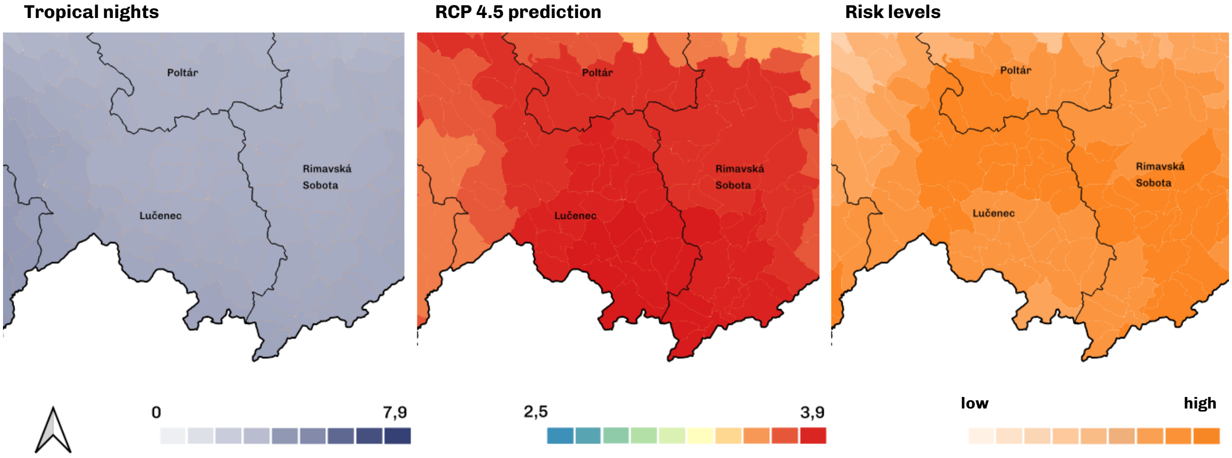
Figure 5: Relationship between altitude, climate and risk level



Source: IEP based on data from the Statistical Office; MF SR; Atlas of Roma Communities; IHP; Copernicus Land Monitoring Service; Copernicus Climate Change Service; SMHI; MoE SR, State Geological Institute Dionýz Štúr; National Agricultural and Food Centre; State Nature Protection of the Slovak Republic; The United States Geological Survey

In the future, a sharper rise in temperatures is expected in some districts, such as Lučenec. So far, Lučenec has not recorded such a high number of tropical days and nights as, for example, in Nové Zámky or Komárno, but as a result, the level of threat in Lučenec is comparable to the high-risk districts (Figure 6). This is due to forecasts that indicate an increase in day and night temperatures. The situation in the district is also influenced by socio-economic factors that increase vulnerability, as some municipalities have a relatively high share of the vulnerable population, e.g. children up to four years old. At the same time, there is a higher number of concentrated Roma communities in Lučenec, which often do not have access to the infrastructure that is crucial for protection against the effects of extreme heat.

Figure 6: The effect of climate predictions on risk levels



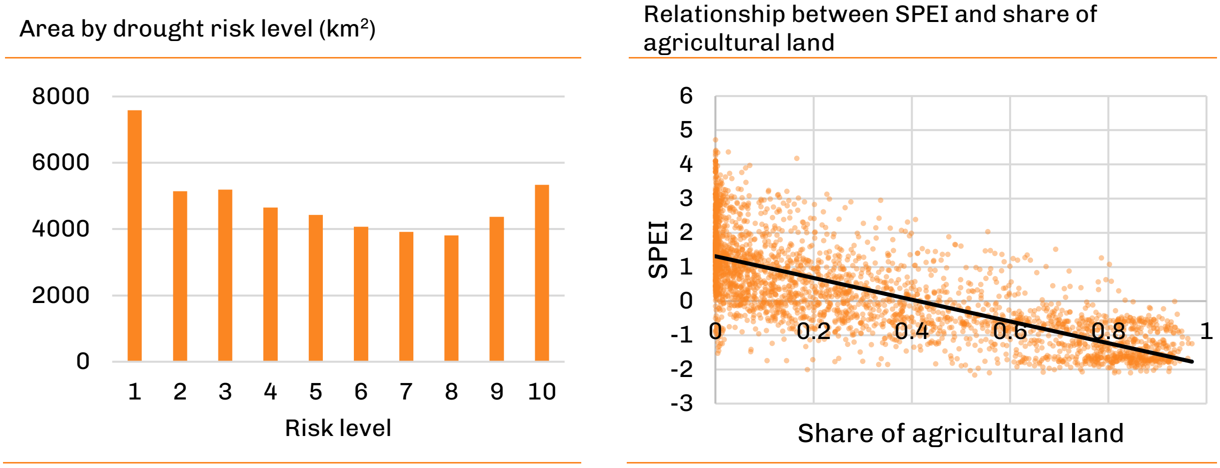
Source: IEP based on data from the Statistical Office; MF SR; Atlas of Roma Communities; IHP; Copernicus Land Monitoring Service; Copernicus Climate Change Service; SMHI; MoE SR, State Geological Institute Dionýz Štúr; National Agricultural and Food Centre; State Nature Protection of the Slovak Republic; The United States Geological Survey

The risk levels are mainly affected by the extreme temperatures measured so far. The resulting degrees greatly affect the number of tropical nights (when the temperature does not drop below 20 °C at night) per year, which most affected Bratislava. In some parts of the city more than 7 tropical nights were recorded per year. Another important factor is tropical days - that is, the average number of days during which more than 30 °C were measured. The highest number of such days was recorded in Nové Zámky. While the Slovak average was approximately 18 days, residents in Nové Zámky witnessed 34 such occasions. Other important indicators include the share of children, forecasts of future temperature changes, availability of health care, and population density.

3.2 Drought

Drought will have a significant impact on agricultural production, and that is why Žitný ostrov is one of the most threatened regions of Slovakia. Žitný ostrov is an extremely important agricultural area and the largest reservoir of drinking water in Slovakia. Its territory is the largest river island in Europe and is largely deforested due to agricultural activity, which increases the level of vulnerability. Agricultural areas in Slovakia are concentrated at lower altitudes and mainly in southern, warmer areas. Conversely, the more mountainous northern regions are characterized by more frequent rainfall and lower soil quality. In addition to the presence of agricultural land, access to the public water supply is also an important aspect.

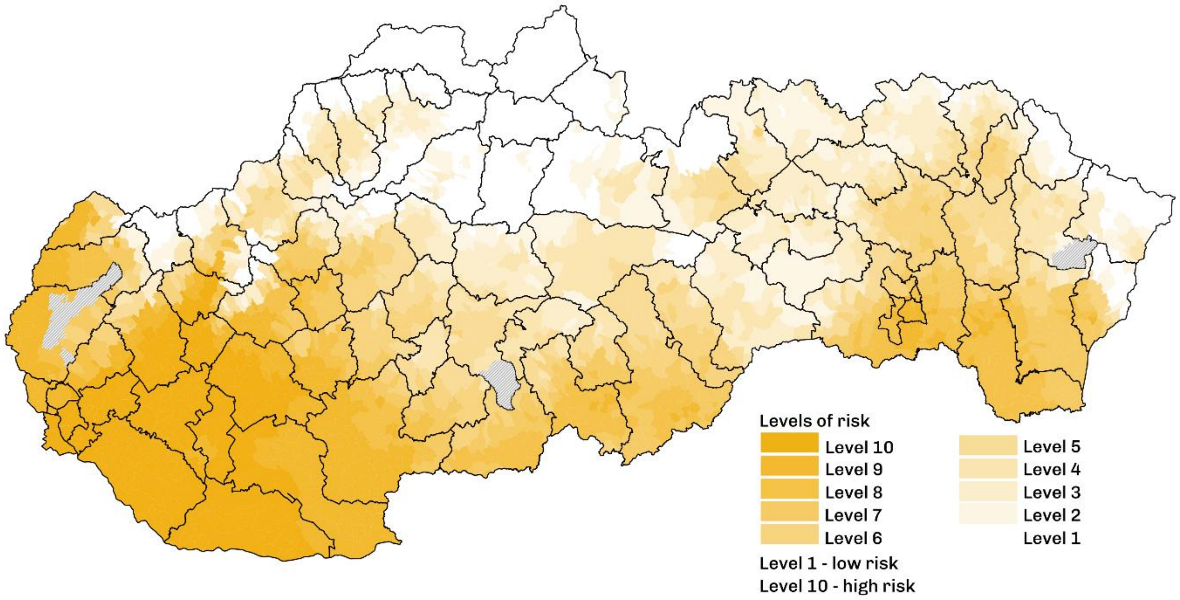
Figure 7: Drought risk



Source: IEP

The districts with the highest risk of drought include Bratislava II, Senec and Bratislava V. The droughts recorded so far in these areas contribute the most to the final result. A large part of Senec's territory is used as agricultural land, which increases the risk of drought. Another group of risky districts, although not as endangered as in the southwest, is located in the southeast of Slovakia in the vicinity of Trebišov and Košice. The south of central Slovakia (Gemer) is threatened by a lack of water resources, which is aggravated by geological factors that prevent water accumulation.

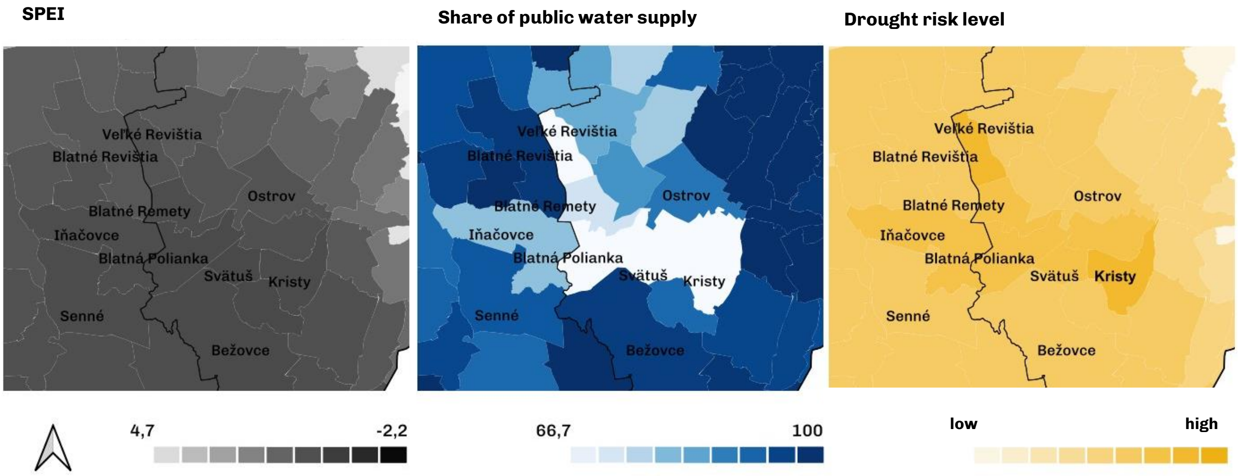
Figure 8: Drought risk levels



Source: IEP based on data from the Statistical Office; MF SR; Atlas of Roma Communities; IHP; Copernicus Land Monitoring Service; Copernicus Climate Change Service; SMHI; MoE SR, State Geological Institute Dionýz Štúr; National Agricultural and Food Centre; State Nature Protection of the Slovak Republic; The United States Geological Survey

Municipalities that have limited access to public water supply are more at risk from the effects of drought. The share of households connected to the public water supply thus affects the degree of threat to municipalities. This is visible, for example, in the neighbouring villages of Kristy and Svätuš in the Sobrance district, which lack this type of infrastructure compared to the surrounding area (see Figure 7).

Figure 9: The effect of public water supply and current drought on drought risk level



Source: IEP based on data from the Statistical Office; MF SR; Atlas of Roma Communities; IHP; Copernicus Land Monitoring Service; Copernicus Climate Change Service; SMHI; MoE SR, State Geological Institute Dionýz Štúr; National Agricultural and Food Centre; State Nature Protection of the Slovak Republic; The United States Geological Survey

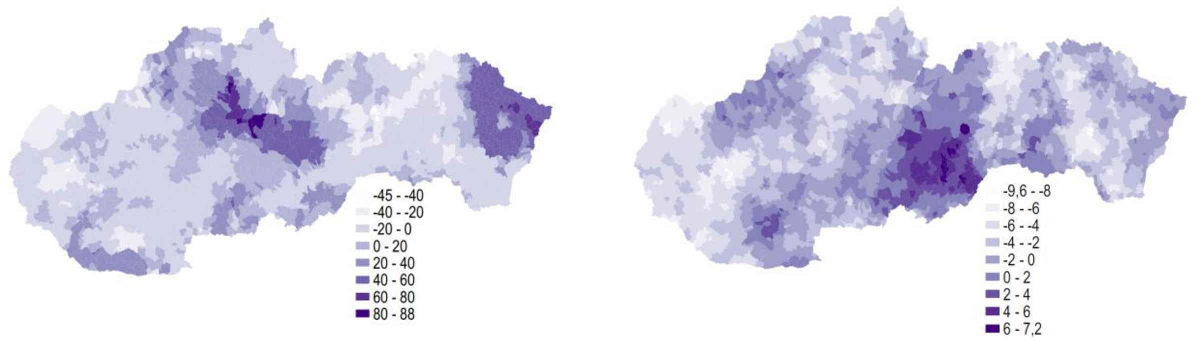
The least threatened are the districts in the north of Slovakia, namely Námestovo, Dolný Kubín and Čadca. This is greatly influenced by the previous measurements, but also by forecasts for this region, which indicate that they will be less exposed to droughts compared to other parts of the country. Although access to public water supply in the municipalities of Námestovo is not as high as in some of the high-risk districts (e.g. Bratislava II), the proportion of grassland and blue infrastructure, which have a positive effect on reducing the vulnerability of municipalities, lead to the fact that this district belongs to among the least threatened by drought.

The resulting risk levels are primarily influenced by the current drought, but predictions show that in the future, other regions will be affected by drought than today (Figure 8). The impact of forecasts of the longest periods of drought is significant for the districts of Medzilaborce and Snina. For example, the village of Brezovec in Snina district is expected to record more than 70 consecutive days of drought in the future. The highest number of dry days per year is expected in the districts of Revúca, Poltár and Rimavská Sobota. Investments should therefore be reoriented over time to the eastern part of Slovakia and the regions around the Low Tatras and Malá Fatra national parks.

Figure 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

Number of dry spells – change in number of dry periods

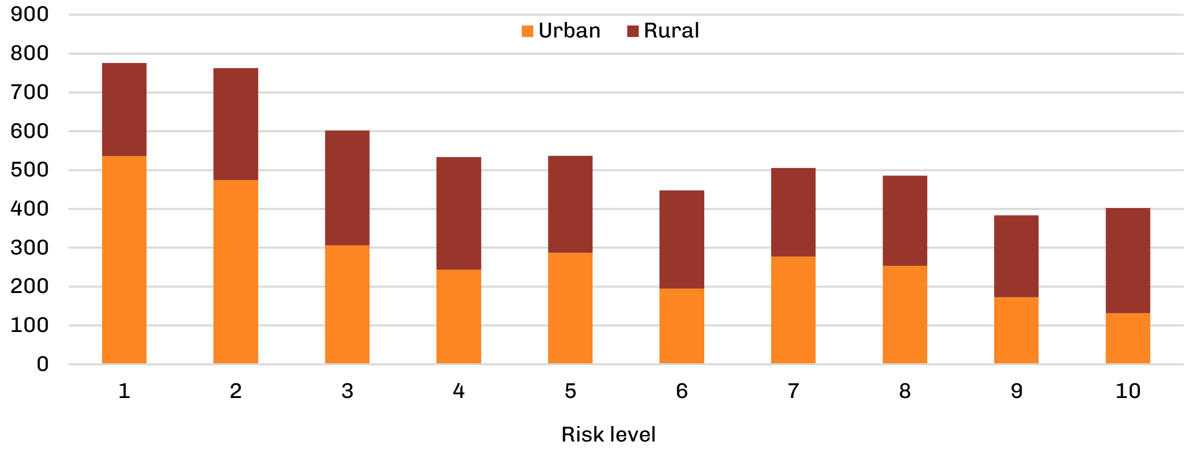


Source: Copernicus Climate Change Service

3.3 Extreme precipitation

Although the population of the SR is relatively less affected by extreme precipitation than by heat and drought, municipalities with marginalized Roma communities are extremely vulnerable due to insufficiently developed infrastructure. This applies, for example, to the municipalities of Ostrovany, Chminianske Jakubovany and Jarovnice, which are among the most threatened by extreme rain. This has already been shown in the past. In 1998, Jarovnice (Sabinov district) was hit by extreme rains and subsequent floods, which claimed 50 lives and caused considerable damage to the infrastructure.

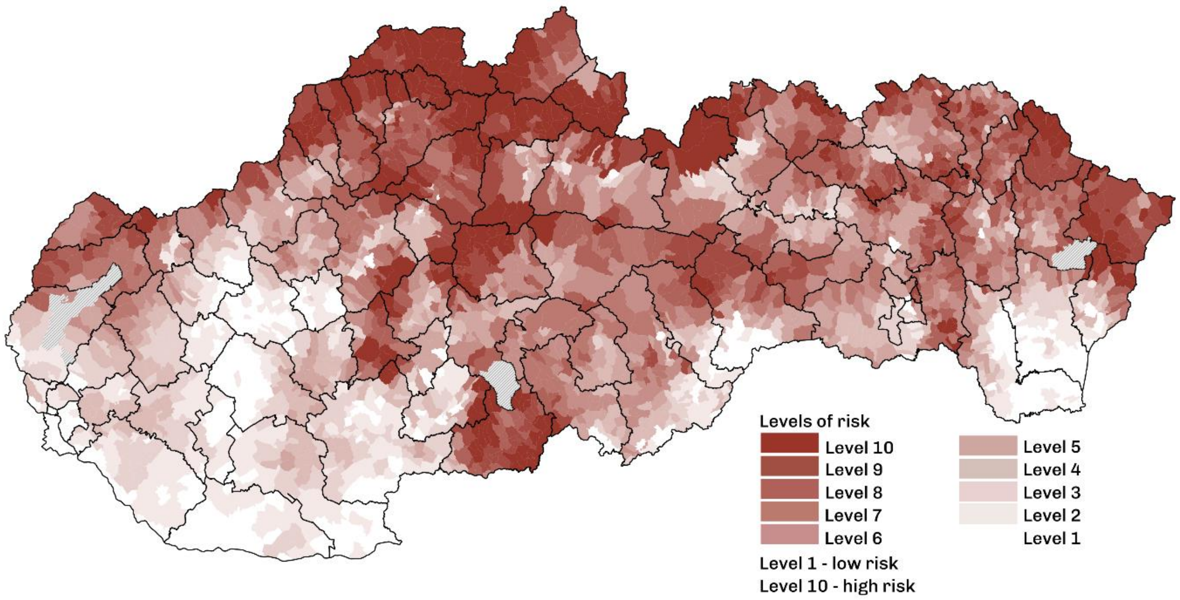
Figure 11: Residents count per risk level of extreme precipitation (in thousands)



Source: IEP

The districts of Tvrdošín, Dolný Kubín and Kysucké Nové Mesto are most at risk of extreme rainfall. These districts have been suffering from heavy rains over the past 30 years and are predicted to continue to be affected in the future. The Tvrdošín district recorded an average of almost 10 days with precipitation ≥ 20.0 mm per year and is also prone to landslides. Soil stability is also an issue the Dolný Kubín district. Although Kysucké Nové Mesto was not affected by extreme precipitation like Tvrdošín, according to forecasts, this area will be more exposed to them in the future than it is today. The settlements with the highest degree of risk of extreme precipitation are also Čadca, Dolný Kubín, Handlová and Snina. On average, Banská Bystrica recorded the most days with extreme rain - up to 9.9 days per year.

Figure 12: Extreme precipitation risk levels

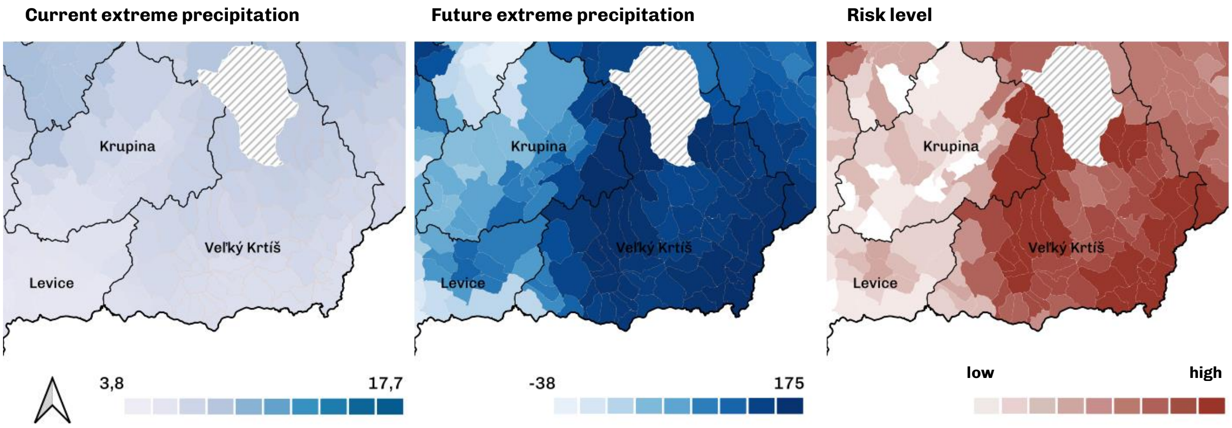


Source: IEP based on data from the Statistical Office; MF SR; Atlas of Roma Communities; IHP; Copernicus Land Monitoring Service; Copernicus Climate Change Service; SMHI; MoE SR, State Geological Institute Dionýz Štúr; National Agricultural and Food Centre; State Nature Protection of the Slovak Republic; The United States Geological Survey

Extreme precipitation is currently affecting mainly the north and east of Slovakia. The area around the High Tatras, Orava and the regions around the Vihorlat mountain range and the Poloniny National Park are usually exposed to heavy rains. In the most affected districts, as well as in neighbouring Žilina and Martin, precipitation is generally observed mainly in the winter season. Vihorlat and Poloniny are often affected by supercell storms, which typically come to the area from the north. Threatened areas such as Skalica, Myjava, Senica and Veľký Krtíš experience predominantly September rainfall. According to forecasts, their further increase is expected, while the danger levels for the Veľký Krtíš district are conditioned mainly by predicted future changes in precipitation events.

The threat index is primarily influenced by the precipitation recorded so far and future forecasts. For example, Tatranská Javorina in the Poprad district recorded the most precipitation in the country, on average more than 17 days with rain ≥ 20.0 mm per year. According to forecasts for the future, the precipitation situation will worsen the most in the Veľký Krtíš district (Figure 13). The districts of Bratislava I, Bratislava II and Bratislava V are the least risky districts, as these areas have not experienced more significant rainfall compared to other districts in the past, and this should not be the case in the future either. On average, approximately 6 days with precipitation ≥ 20.0 mm per year were recorded there.

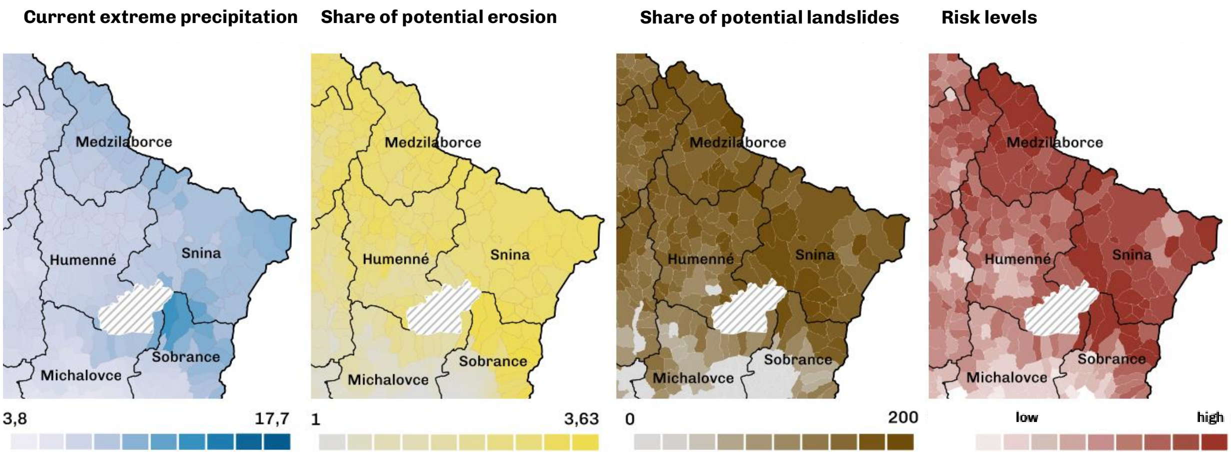
Figure 13: The effect of extreme precipitation predictions on risk levels



Source: IEP based on data from the Statistical Office; MF SR; Atlas of Roma Communities; IHP; Copernicus Land Monitoring Service; Copernicus Climate Change Service; SMHI; MoE SR, State Geological Institute Dionýz Štúr; National Agricultural and Food Centre; State Nature Protection of the Slovak Republic; The United States Geological Survey

Among the socioeconomic and landscape indicators, susceptibility to landslides, the unemployment rate and the proportion of the tree cover contribute the most to the resulting index. Even in municipalities where extreme rainfall has not been frequent, it may happen that due to poor preparedness and vulnerability, they will be affected more than other, more exposed municipalities. In some municipalities in the districts of Snina and Sobrance, where extreme rains are not common, but have high unemployment rates and are prone to landslides, rainfall can cause more serious damage (see Figure 14).

Figure 14: The effect of soil erosion and landslides on risk levels



Source: IEP based on data from the Statistical Office; MF SR; Atlas of Roma Communities; IHP; Copernicus Land Monitoring Service; Copernicus Climate Change Service; SMHI; MoE SR, State Geological Institute Dionýz Štúr; National Agricultural and Food Centre; State Nature Protection of the Slovak Republic; The United States Geological Survey

Box 2: Review of literature on adaptation measures

Extreme heat

One of the most effective adaptation measures against the heat in cities is the strengthening of green infrastructure. Carefully planned placement of trees and green infrastructure can reduce the heat island effect and cool the air by 2°C to 8°C (Doick a Hutchings, 2013). The cooling effect of green spaces without trees is 2 to 4 times lower than the cooling effect of urban tree cover (Schwaab et al, 2021). If the building of green infrastructure is properly designed, green corridors, parks with shade trees and vegetation in general can improve urban ventilation (Climate ADAPT, 2015).

An analysis of US land cover data (Ziter et al., 2019) showed that daily temperatures decreased significantly as tree canopy cover increased. In areas where there was more than 25% impervious surfaces (i.e., urban areas), the greatest cooling occurred when tree cover was greater than 40% within a given radius. Impervious surfaces have been shown to be more important than tree canopy cover for night-time temperatures because such surfaces store significant amounts of heat that is radiated back during the night. The most effective adaptation measures to high night temperatures in urban areas include modifications to green and gray infrastructure, i.e. j. increase in canopy cover and decrease in impervious surfaces (ibid).

Another alternative to heat adaptation measures, although less effective, involves the increased use of cool materials on surfaces. Cool surfaces are usually white and have a high albedo effect, i.e. j. the ability to reflect solar radiation back into the atmosphere. A study in Chicago compared green roofs with dark roofs and showed that the surface temperature of green roofs ranged between 33 and 48 °C, while dark roofs were significantly higher at 76 °C (EPA, 2008). Green roofs also reduce the transfer of heat through the roof of the building, and thus have the ability to improve thermal comfort in the interior. An experiment in Taipei showed that although green roofs have little insulating effect in winter, they have a significant cooling effect in summer, when they can reduce the indoor temperature by 4 °C compared to normal roofs (Lei et al., 2019). Lower indoor temperatures can also be effectively achieved by applying blinds and solar blinds to buildings.

The implementation of action plans against heatwaves and the establishment of meteorological early warning systems can effectively improve public health and reduce mortality rates. The goal is to raise public awareness of the potential danger of extreme temperatures and heat (Climate ADAPT, 2019). For example, the Austrian Heat Protection Plan, which has been operational since 2017, provides early warnings that trigger a response at national and local level (ibid).

Drought

Adaptation measures should focus primarily on reducing the demand for water and its consumption and efficient use and retention of water. In agriculture, this is, for example, the cultivation of drought-resistant crops, the application of agrochemicals, changing the planting time, the cultivation of early maturing crops, the location of farms in river areas, the use of drip irrigation techniques, biobelts, draws, etc.

One of the most effective drought adaptation measures is the transition from conventional irrigation systems to the use of drip irrigation systems. According to Fader et al. (2016), Mediterranean countries could save 35% of water by using drip irrigation. Drip irrigation systems can save 80% of water and increase water use efficiency by 38% (Rakibuzzaman et al., 2018). On US farms, the use of a drip irrigation system reduced farm water use by up to 60% and increased crop yield by 90% (Chu, 2017)

Forests are also prone to drought. One of the most effective adaptation measures in forests is their restoration. Reforestation is a direct possibility to control the species and composition of stands. For regeneration to have the desired adaptive effects, it is necessary to increase genetic diversity (Spathelf, et al., 2018). Emphasis should therefore be placed on changing the species composition, i.e. j. higher proportion of species tolerant to drought (Hlásny et al., 2014). Expanding no-interference zones and forest protection are other effective measures. Together with their complex root systems, forests play an important role in the water recharge cycle (de Jager, et al., 2022). Uninterrupted areas are more resilient because they are able to recover from drought with almost no change in species composition (Convention on Biological Diversity, 2009).

Droughts increase the risk of forest fires. According to a study by Kolstrom et al (2011), effective adaptation measures include, for example, changes in forest structure; fuel economy; prioritizing forest types that have the ability to regenerate after fires and increasing genetic diversity with species that have lower flammability; and implementing policies to limit the abandonment of burned areas and measures to prevent the spread of invasive species in burned areas.

Adaptation measures in urban areas typically include water demand management, stormwater management, wastewater reuse and desalination. In urban areas, raising awareness to reduce water use and demand has been effective in Barcelona, where water use decreased by approximately 10% between 2006 and 2011 following water conservation awareness campaigns (March et al., 2013). Wastewater from households or sewage treatment plants is an alternative water source that can be used to irrigate gardens, public spaces, parks and clean streets. It is considered a relatively reliable source of water supply, as it is independent of drought and weather variability (European Commission, 2019).

Extreme precipitation

Impervious surfaces and lack of vegetation in urban areas reduce the ability to capture, retain and infiltrate rainwater (EEA, 2020). A study from Munich demonstrated that trees and green roofs significantly increase water storage capacity and thereby reduce surface runoff (Zolch et al., 2017). As a result of climate change, the intensity of precipitation will increase, and thus, according to the study, the regulatory potential of vegetation and green roofs will decrease, as their capacity to retain water is limited. If no additional vegetation and green roofs are added, a maximum surface runoff reduction of 2.4% can be achieved compared to the baseline scenario. If the vegetation and permeable areas are substantially increased, a reduction of up to 14.8% can be achieved by greening all roof surfaces.

Another adaptive measure is the disconnection of impermeable surfaces. Results of a modeling study in Ontario indicate that a 40% reduction in runoff volume and peak flow compared to future estimates can be achieved by disconnecting roof downspouts from the sewer system (Waters et al., 2003). The study also suggested increasing surface water accumulation. For example, open spaces such as parks, schoolyards, etc. can be used to temporarily store water during heavy rains.

Draws and bio-belts on fields capture water and slow down surface runoff. Evidence from a UK study suggests that stands of deciduous trees placed on grazed land can reduce the risk of flooding (Donnison, 2012). In Wales, two years after the planting of broad-leaved tree draws, infiltration rates were 60 times higher than in areas without draws.

Forests play an important role in retaining water and reducing surface runoff. Forests that are degraded and deforested retain a significantly lower volume of water. As a result, extreme rainfall can wash away the soil in such forests and cause flooding (EEA, 2015) Based on a study in Europe, the reduction of surface runoff is only apparent when the forest cover in small sub-basins is higher than 30%. Furthermore, surface water retention in forests is 25% higher when forest cover increases from 30% to at least 70%. Protection of forested areas and afforestation are therefore necessary adaptation measures against extreme precipitation events.

A structured review of the literature on the effectiveness of adaptation measures can be found in the appendix.

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Appendix

Table 4: Review of the literature on the impacts of adaptation measures (extreme heat)

Adaptation measure	Impact	Example	source
Green infrastructure and vegetation	Lowering the air temperature	Between 2°C and 8°C	Doick and Hutchings(2013)
		Coolest when tree cover is above 40%	Ziter and others (2019)
		Cooling effect 2 to 4 times more effective in urban areas with rows of trees	Schwaband others (2021)
		Increasing the proportion of vegetation by 10%, in those parts of cities where this proportion is low, will ensure maintaining the temperature at the level of 1961-1990 even in 2080	Handleyand others (2007)
Use of bright and reflective materials	Lowering the air temperature	cooling surfaces of roads and buildings can reduce the ambient temperature by 1.5 °C and the surface temperature by 11.5 °C	Kyriakodis and Santamouris (2017)
Green roofs	Lowering the air temperature	The surface temperature of green roofs was 28 °C to 43 °C lower than the surface temperature of dark roofs	EPA (2008)
		Reduction of the air temperature above the green roof by approx. 4 °C	
	Improving internal thermal comfort	Internal temperatures can be reduced by approx. 4 °C	Lei and others (2019)
Vegetation facades	Improving internal thermal comfort	an unshaded facade can heat up to 40 °C in summer, while the temperature of the wall under the green cover can be more than 15 °C lower	Pérez and others (2011)

Table 5: Review of the literature on the impacts of adaptation measures (drought)

Adaptation measure	Impact	Example	source
Raising awareness about water conservation	Reducing water consumption	In Barcelona, water consumption fell by up to 10 %	March and others (2013)
Using drip irrigation systems	Reducing water losses	Saves 80% of water and increases the efficiency of water use by 38%	Rakibuzzaman and others (2018)
		Using a drip irrigation system reduced farm water use by up to 60% and increased crop yield by 90%	Huh (2017)
Cultivation of drought resistant crops	Reduction of sensitivity to dryness		Mushore and others (2021)
Construction of reservoirs for water collection	Water reservoir for irrigation and industrial use	It increases the availability of water for irrigation during droughts and water shortages	Staccione and others (2021)
Green infrastructure	Restoration of natural ecosystems, water retention, improvement of water management and water availability		Ghofrani and others (2017)
Forest restoration	Heterogeneous forests are more likely to adapt to changes in livelihoods environment	This can be achieved by increasing the genetic diversity in the seedling population	Hlazny and others (2014)
Biobelts near soil blocks	Reduction of wind speed and evapotranspiration losses	Wheat yields increased by 3.5% or more in the dry season in buffer zone fields	Donnison (2012)

Table 6: Review of the literature on the impacts of adaptation measures (extreme precipitation in cities)

Adaptation measure	The effect
Rain gardens	Rainwater collection
Storage blocks	Storage of underground water ; infiltration
Drainage ditches	Reducing runoff and increasing groundwater recharge
Green roofs and vegetation in urban areas	Storage of rainwater drainage
Retention ponds	Reduction of surface runoff, water accumulation

Source: Ramos et al. (2017)

Table 7: Review of the literature on the impacts of adaptation measures (extreme precipitation)

Adaptation measure	Impact	Example	source
Green infrastructure	Increasing water retention, capture and infiltration	A reduction of 14.8% is achieved with green roofs It supports sustainable drainage systems	Zolch and others (2017)
Disconnection of impermeable surfaces	Reduction of surface runoff	A 40% reduction in outflow volume and maximum flow can be achieved	Waters and others (2003)
Landslide protection		Management of settlements in areas at risk of landslides Reinforcement of the slope by vegetation Mechanical strengthening of the slope Avoiding building houses in areas with steep slopes that are prone to landslides	Oktorie (2017)
Blue and green infrastructure		Regional wetlands, retention basins, seasonal storage and rainwater harvesting	Ghofrani and others (2017)
Biobelts near soil blocks	Water retention, protection against erosion		Donnison (2012)
Protection and restoration of forests	Water retention		EEA (2015)