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* This designation is without prejudice to positions on status and is in line with UNSCR 1244/199 and the ICJ opinion on the Kosovo* declaration of independence.

Western Balkans Investment Facility Infrastructure Project Facility Technical Assistance 7 (IPF 7)

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Detailed Design and Environmental and Social Impact Assessment For Motorway A4, Skopje - Blace. Section: Interchange Stenkovec-Blace Border Crossing Point (12.5 km)

Climate resilience report

January, 2022

The Western Balkans Investment Framework (WBIF) is a financing facility launched in December 2009 by the European Commission, together with the Council of Europe Development Bank (CEB), the European Bank for Reconstruction and Development (EBRD), the European Investment Bank (EIB), Bilateral Donors, and Western Balkans countries with the purpose to deliver funding for strategic investment projects in beneficiary countries. Eligible sectors include infrastructure development in the environment, energy, transport, social and digital sectors as well as private sector development. KfW and the World Bank subsequently joined the Framework. In July 2017, the KfW became a partner organisation.

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Table of Content

List of tables

List of figures

1. INTRODUCTION

Climate change is the result of the mutual influences of multiple causes and consequences. The primary reason is the imbalance in the greenhouse gases that are emitted in an atmosphere that causes systemic and cyclical change in normal atmospheric processes which in turn causes changes in world weather. Such rapid changes in weather also affect regional and local landscapes / ecosystems / biological diversity. This is because local systems are struggling to adapt and evolve with that in mind the unpredictability of extreme weather events caused by climate change.

Global climate changes lead to extreme climate events, including prolonged periods of high temperatures and droughts, followed by high air temperatures, intensive short periods of precipitation and the appearance of cold waves and negative temperatures, snowfall and precipitation periods. Extreme climate events have negative effects on the health of humans and animals, on agriculture and water resources, and an imbalance in heat and energy.

Republic of North Macedonia is a non-Annex I country to the UNFCCC, it is also a candidate country for European Union (EU) membership, and thus must adhere to EU Climate and Energy Policy, which actually assumes the commitments of Annex I countries. The legal framework on climate change currently falls under the Law on Environment, including the details for the development of national GHG inventories. As a Non-Annex I Party to the UNFCCC, Republic of North Macedonia has been compiling an inventory of anthropogenic emissions by sources and removals by sinks of greenhouse gases (GHGs) since the year 2000.

The Republic of North Macedonia ratified the UN Framework Convention on Climate Change (UNFCCC) in December 1997 and the Kyoto Protocol in 2004. Responding to the obligations incurred by signing the Framework Convention as a non-Annex I Party, the country prepared and submitted the First National Communication on Climate Change in 2003, Second National Communication in 2008 and Third National Communication in 2013. Within these National Communications, GHG inventories were developed, applying the Tier 1 method (i.e., the simplest method) for most sectors. Tier 2 methods were partially applied in the Energy sector as being a key source of CHCs, accounting for over 70% of all emissions. In the framework of the Third National Climate Change Plan (2013) scenarios for temperature changes and precipitation in the country affected by climate change have been prepared. The Fifth Intergovernmental Panel on Climate Change Report identifies four so-called Representative Concentration (RCP) scenarios for future global greenhouse gas concentrations: RCP8.5, RCP6.0, RCP4.5 and RCP2.6. These scenarios represent possible changes in the concentrations of greenhouse gases in the atmosphere in the period 2006-2100.

The country has signed the Paris Agreement in September 2016 and delivered the Intended National Determined Contributions (INDCs) to reduce the CO_2 emissions from fossil fuels combustion for 30%, that is, for 36% at a higher level of ambition, by 2030 compared to the business as usual (BAU) scenario. The Macedonian Parliament adopted the Law on ratification of the Paris agreement in 2017. It is important to underline that the objective of the Republic of Macedonia is to incorporate as much as possible the reporting principles accepted by the European Union (EU) member states (as a candidate country for full membership into the EU), going far beyond reporting requirements as developing non-Annex I country under the UNFCCC.

However, it is becoming increasingly clear that in order to avoid dangerous climate change, it is necessary to reduce greenhouse gas emissions not only in industrialized but also in developing countries. Globally, the transport sector is one of the sectors that significantly contribute to increasing greenhouse gas emissions[1]. In 2005, 23 % of world greenhouse gas emissions came from the transport sector, and the share of OECD countries was 30 %[2]. Because of this, the transport sector has progressively reached the top of the agenda for climate change mitigation in Europe, as well as in other parts of the world.

With a predicted 30-40 year lag time between the emission of greenhouse gases into the atmosphere and the effect being seen in our climate, as well as the uncertainties in natural cycles, estimating

[1] Brannigan C, Gibson G, Hill N, Dittrich M, Schroten A, Essen VH, Grinsven VA. Greenhouse gases in transport in the European Union: Roads to 2050? Develop a better understanding of the scope of associated benefits associated with GHG reduction policies in the transport sector. Final draft text from February 16, 2012.

2 OECD. Reduction of greenhouse gas emissions, trends and data in transport. 2010

what climatic changes might occur is a complex science. However, this inertia that exists in our climate means that past greenhouse gas emissions will result in the Earth undergoing a certain inevitable level of climate change.

Key IPCC (Intergovernmental Panel on Climate Change) projections are that:

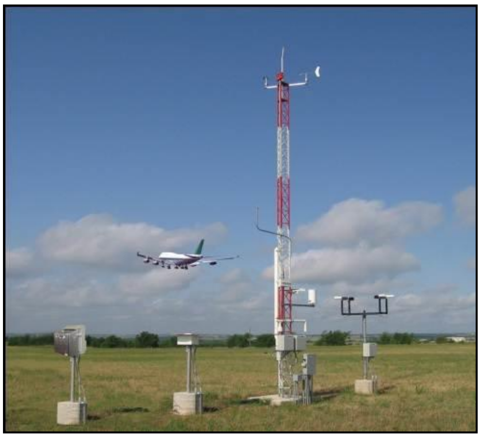
- The Earth will become warmer;
- Some regions will become wetter overall and some will become drier;
- Sea levels will rise and storm surge height will increase;
- Snow cover and the extent of sea-ice will reduce; and,
- The frequency and severity of extreme weather events (such as storms, heat waves, drought and periods of prolonged and heavy precipitation) will increase.

These changes are set to have significant impacts on the design, construction, maintenance and operation of global road infrastructure. For example, drier and hotter weather will lead to more incidences of infrastructure subsidence and heat damage to pavements and structures, more frequent heavy precipitation events will result in increased incidences of flooding in low-lying areas and floodplains and sea level rise may make some networks and assets temporarily or permanently inaccessible. These impacts will lead to disruption to services and increased operational, maintenance and emergency repair costs. Communities, businesses and localities that rely on the networks will be impacted if part of a network becomes inaccessible as a result of the impacts of climate change or an extreme weather event. Therefore, in order to networks, assets and services to be resilient to in the face of a changing climate, effective and targeted action must be taken to minimize this disruption, damage and cost. This is the main aim why the preparation of this Climate resilience report is of crucial importance for the new motorway A4 Blace – Skopje (interchange Stenkovec).

The Hydrometeorological Administration is a body within the Ministry of Agriculture. The Hydrometeorological Administration, according to the Law on Free Access to Public Information, as a legal entity, publishes hydrological, meteorological, climatological and agrometeorological information, provides analysis and weather forecast through their meteorological stations placed on several locations through the whole country. The closest meteorological stations to the project area are the stations in Skopje Zajcev Rid and Skopje Petrovec, which have 24 hour observations, seven days a week.

The location of these representative stations are the following: Zajcev Rid is λ=21°24’00”, φ=42°01’00” and Hs=301m, and for GMS Skopje Petrovec λ=21°37’17”, φ=41°57’42” and Hs=239 m.

GMS Skopje Zajcev Rid



GMS Skopje Petrovec

Today, the stations perform continuous measurements of all meteorological elements and phenomena, through visual observations and measurements with modern automatic instruments.

2. NATIONAL FRAMEWORK

The environmental protection and climate change requirements are still not sufficiently integrated into relevant sector policies of the Country. The Strategic goal of the Country is to ensure approximation of the EU acquis and its implementation. Even though there is no national Law on Climate Change in force, there are framework documents that provide a basis for further regulation activity. In the following table are presented all relevant legislations to climate change management.

Table 1 National relevant legislations to climate change management

Legislation	Description
Draft Law on Climate Action (or LCA) - (not enacted – in drafting process)	The Draft Law will regulate the framework for climate action in the RNM (Republic of North Macedonia). When enacted, the Law will serve as an umbrella low for all climate mitigation and adaption considerations in the country. The draft Law on Climate Action provides an enabling environment for overarching policy coordination processes, defines the legal mechanism for national sustainable development pathway.
Law on environment ("Official Gazette of RM" no. 53/05, 81/05, 24/07, 159/08, 83/09, 48/10, 124/10, 51/11, 123/12, 93/13, 187/13, 42/14, 44/15, 129/15, 192/15, 39/16, 99/18)	This Law aims at ensuring protection and improvement of the environment, for the purpose of exercising the right of citizens to a healthy environment. Protection objectives include the ozone layer and anthropogenic impacts on the climate. The document charges the relevant ministry to develop a National Environmental Action Plan notably containing guidelines for climate change mitigation. The Fund for the programme shall include projects related to the climate. A National Plan for mitigation of climate change shall further be adopted. Article 187 refers to the National Plan for Climate Change Mitigation, and Article 188 refers to the National Inventory of GHG Emissions. Article 188-a, Article 189 refers to Action plan.
Law on Vehicles (Official Gazette of the RM no. 140/08, 53/11, 123/12, 70/13, 164/13, 138/14, 154/15, 192/15, 39/16)	The purpose of this law is to ensure a high degree of safety of road traffic and in the performance of agricultural and forestry works, protection of life and health, protection of the environment and nature and energy efficiency.
Energy Law (Official Gazette of the RM no. 96/2018, 96/2019)	This Law regulate: the objectives and the manner of implementing the energy policy; the construction of energy facilities; the status and competence of the Energy and Water Supply Regulatory Commission of the RNM; electricity, natural gas, heat energy markets, as well as the crude oil, oil derivatives and transport fuels market; the manner and procedure for determining and fulfilling the obligations for providing a public service on the electricity, natural gas and heat energy markets, as well as the rights and obligations of the energy consumers and the users of the energy systems; the manner and conditions for encouraging the use of renewable energy sources.
Law on waters ("Official Gazette of the Republic of Macedonia" No. 87/08, 6/09, 161/09, 83/10, 51/11, 44/12, 23/13, 163/13, 180/14, 146/15, 52/16, 151/21)	This law regulates issues related to: surface waters, permanent or temporary watercourses, lakes, reservoirs, springs, groundwater, coastal land, water habitats and their management, including water distribution, protection and conservation of water, as well as protection against the harmful effects of water; water management facilities and services; organizational structure and financing of water management; conditions, manner and procedures under which water can be used or discharged.
Law on crisis management ("Official Gazette of the Republic of	This law regulates the crisis management system: organization and functioning, decision-making and use of resources,

Macedonia" No. 29/05, 36/11, 41/14, 104/15, 39/16, 83/18)	communication, coordination and cooperation, assessment of threats to the security, planning and financing.
Law on hydro-meteorological activities ("Official Gazette of the Republic of Macedonia" No. 103/08)	This law regulates the bases of the functioning of hydrometeorological activity in North Macedonia
Law on local self-government ("Official Gazette of the Republic of Macedonia" No. 05/02)	This law regulates the competencies of the municipality; direct participation of citizens in decision-making; organization and affairs of municipal bodies, acts of municipal bodies; property - subsistence in the municipality; supervision over the affairs of municipal bodies; mechanisms of cooperation between the municipality and government, protection of local self-government, establishment of official languages, etc.
Law on water economy ("Official Gazette of the Republic of Macedonia" No. 51/15)	This law regulates the operation, use, operation and maintenance of hydro systems, irrigation systems and drainage systems. The purposes of this law are: ensuring economical management; use, operation and maintenance of hydro systems, irrigation systems and drainage systems; defining the scope of services provided to water users by the water operator; establishment of conditions for normal and successful operation of the performer of the water economy activity and use of its services by the water users, and establishment of a state-owned joint stock company Water Economy of the Republic of Macedonia.
Law on urban planning ("Official Gazette of the Republic of Macedonia" No. 32/20)	This law regulates the system, goals and principles of spatial and urban planning, the content of urban plans, conditions for performing urban activities, procedures for preparation, adoption and implementation of urban plans, supervision of law enforcement, etc.
Law on Protection and Rescue ("Official Gazette of the Republic of Macedonia" No. 36/04, 49/04, 86/08, 124/10, 18/11, 41/14, 129/15, 71/16, 106/16, 83/18)	This law regulates the system for protection and rescue of people, environment, material goods, natural resources, animal and plant world and cultural heritage from natural disasters and other accidents in peace, state of emergency and state of war.
Law on Ratification of the United Nations Framework Convention on Climate Change ("Official Gazette of the Republic of Macedonia" No. 61/97); **Law on Ratification of the Kyoto Protocol to the United Nations Framework Convention on Climate Change (Official Gazette of the Republic of Macedonia No. 49/2004);** **Law on Ratification of the Paris Agreement (Official Gazette of the Republic of Macedonia No. 161/2017);** **Law on Ratification of the Doha Amendment to the Kyoto Protocol to the United Nations Framework Convention on Climate Change (Official Gazette of the Republic of Macedonia No. 152/2019 dated**	Laws by which the Republic of North Macedonia ratified the Kyoto Protocol and the UNFCCC, Doha Amendment to the Kyoto Protocol, Kigali Amendment to the Montreal Protocol on Substances that Deplete the Ozone Layer, and the Paris Agreement The Republic of North Macedonia has signed (2015) and ratified (January 2018) the Paris Agreement, with the following contribution to the global efforts for GHG emissions reduction (Macedonian NDC): "To reduce the CO2 emissions from fossil fuels combustion for 30%, that is, for 36% at a higher level of ambition, by 2030 compared to the business as usual (BAU) scenario." North Macedonia became the twenty-third country in the world that submitted its Intended Nationally Determined Contributions for Climate Change (INDC).

25.07.2019); **Law on Ratification of the Kigali Amendment to the Montreal Protocol on Substances that Deplete the Ozone Layer (Official Gazette of RSM No. 34/2020)**	

3. IDENTIFICATION OF SCOPE, VARIABLES, RISKS AND DATA

3.1. Scope and aims

The main aim of this Climate resilience report is to ensure and enhance the resilience of the proposed construction of the new motorway A4 Blace – Skopje (Stenkovec) to the effects of climate change and extreme weather events. Other key elements which will contribute to the overall aim of the project are:

- to meet national climate change legislation;
- to understand how asset design standards need to be adapted;
- to understand the road network vulnerability to climate change;
- to prioritise assets and operations for adaptation.

In order to present and assess as most appropriate the climate change impacts on construction and operation of the new motorway A4 Blace Skopje, the following data were analyzed and taken into consideration:

- annual temperature data for the region;
- annual precipitation data for the region;
- predicted changes in temperature;
- predicted changes in precipitation;
- intensive rainfalls in the region;
- floods;
- droughts;
- Landslides.

In order to fulfill the requests, the team started by reviewing all of the relevant national legal and strategic documents in the Republic of North Macedonia. The following list of documents was taken into account:

- Climate extreme scenarios - Climate extreme scenarios are covered in each National Communication on Climate Change. For our purposes Third National communication to the UNFCCC was analyzed;
- Macedonian third biennial update report on climate change, August 2020;
- Technical assistance preparation of climate resilience design guidelines for the Public Enterprise for State Roads in North Macedonia, July 2019;
- Draft Law and Long-term Strategy on Climate Action;
- SEA Climate Strategy;
- Action Plan for the 1st Stage of Implementation of the Strategy and Law;
- Study for erosion and action plan for City of Skopje, 2017;
- Risk management and protection plan from floods on the Lepenec river basin;
- Data for intensive rainfalls from Hydro Meteorological Institute;
- Resilient Skopje – Climate change strategy.

After assessment scope, aims and objectives have been defined, the team has begun to consider the assets, climatic variables and impacts which will be scoped into their assessment. In order to do this, information is provided upon the following aspects which will help to determinate which variables to include within an assessment:

- assessing vulnerability levels of different assets and locations, based on exposure and sensitivity levels;
- assessing existing levels of adaptive capacity and how these affect vulnerability; and
- assessing and using climate change projections and scenarios to understand future climatic conditions and the impact of vulnerability.

3.2. Historical overview of climate data

Temperature

Within the Third National communication to the UNFCCC, analysis of extreme temperatures heat and cold waves has been prepared for the country including City of Skopje. Analysis of heat waves and warm weather in the period 1961–2012 is given for the 11 meteorological stations of Skopje, Bitola, Prilep, Stip, Demir Kapija, Gevgelija, Strumica, Kriva Palanka, Berovo, Ohrid and Lazaropole.

In the following table are presented the average annual air temperature from 2011 – 2020. Source of data is Open Weather Map (https://home.openweathermap.org/history_bulks)

Table 2 Average annual air temperature

Month	Year									
	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Jan	0.00	-1.36	1.49	3.48	0.26	0.54	-5.47	2.10	-1.72	0.58
Feb	1.50	-2.77	4.25	6.25	2.75	7.80	4.25	2.76	3.41	4.59
Mar	6.55	7.55	6.94	8.76	5.58	7.59	9.88	6.91	9.30	6.87
Apr	11.37	11.83	12.78	11.30	9.95	14.32	11.35	15.63	12.22	10.80
May	15.16	15.81	17.47	15.38	17.45	15.11	16.27	18.14	14.56	15.64
Jun	20.09	22.78	20.01	19.64	19.54	21.52	21.58	19.95	21.62	19.26
Jul	23.00	25.99	22.32	22.02	24.83	23.13	24.05	22.20	22.61	22.54
Aug	23.64	24.67	24.04	22.63	23.93	21.51	24.03	22.95	24.42	21.89
Sep	21.13	20.08	17.38	16.97	19.50	17.28	18.25	18.46	18.85	19.32
Oct	10.32	14.29	12.72	11.91	12.30	11.78	11.90	13.75	14.40	12.67
Nov	3.46	8.57	8.21	8.46	7.88	5.72	6.14	7.39	10.70	6.04
Dec	1.80	-0.26	0.51	2.65	2.21	-0.39	2.83	0.86	3.36	4.83

Analysis of heat waves and warm weather in the period 1961–2012 is given for the 11 meteorological stations of Skopje, Bitola, Prilep, Stip, Demir Kapija, Gevgelija, Strumica, Kriva Palanka, Berovo, Ohrid and Lazaropole. This analysis is based on the following climate parameters:

- The Heat Wave Duration Index (HWDI): maximum duration of heat waves, interval of at least 6 successive days with Tx>Txavg+ 5°C.
- The number of heat waves;
- The monthly and annual frequency of heat waves;
- The frequency of heat wave occurrences in the warm and cold parts of the year;
- Summer days: days with a maximum air temperature of Tx >25 °C;
- Tropical nights: days with minimum air temperature of Tn >20 °C.

On the basis of maximum daily air temperature values, it can be concluded that the frequency of heat waves decreases in correlation to the length of their duration, with the most frequently occurring heatwaves being those of the shortest duration—i.e., no more than 6 days in succession. For the period 1961–2012, the number of heat waves of 6-day duration for Skopje was 25 and the single occurrences of heat waves of longer duration were 16.

Figure 1 shows the number of heat waves with determined duration for the meteorological station of Skopje.

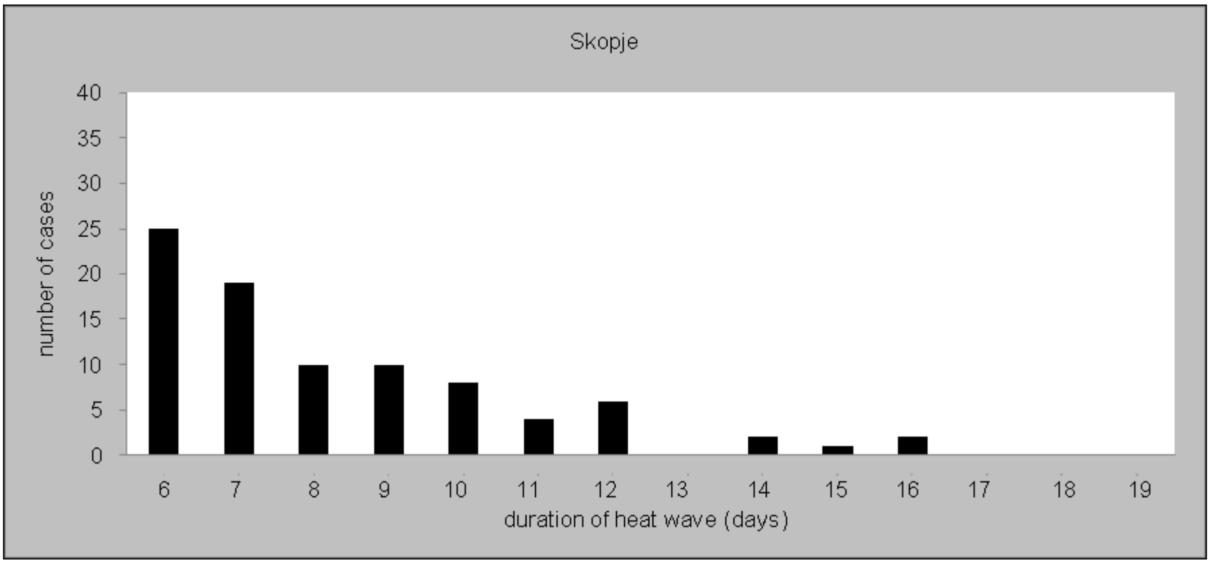


Figure 1 Number of heat wave occurrences in the period 1961–2012 in Skopje[3]

Analyzing the annual frequency of heat waves, it can be remarked that the total number of recorded waves were not evenly distributed throughout the years. As can be seen in Figure 2, the annual frequency of heat waves increases in the second half of the analyzed period, that is, the frequency of occurrences increases from 1987 onwards. And in contrast to the first half of the period, a heat wave is recorded almost every year from 1987. It can also be noted that the greatest frequency of heat waves occurred in the last ten years, with maximum occurrences in 2012 and 2007. During 2012, 8 heat waves were recorded in Skopje, Stip, Lazaropole and Demir Kapija, 7 in Gevgelija and Berovo, 6 in Bitola, 5 in Strumica and Prilep and 3 in Ohrid.

[3] Source: Analysis of extreme temperatures heat and cold waves, Third National communication to the UNFCCC

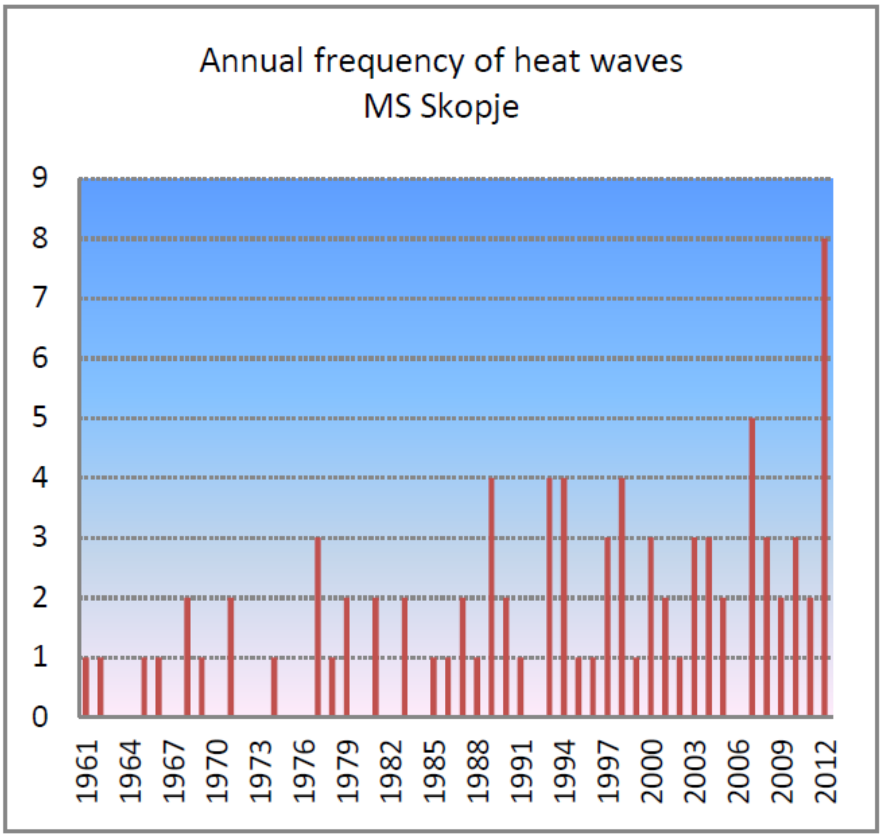


Figure 2 Annual frequency of heat waves in the period 1961–2012[4]

2012 is a specific year with heat waves with most heat waves in the summer period for the analyzed period, but the greatest deviation was recorder in the spring and fall period. Figure 3 show the occurrences of heat waves in the measuring site of Skopje.

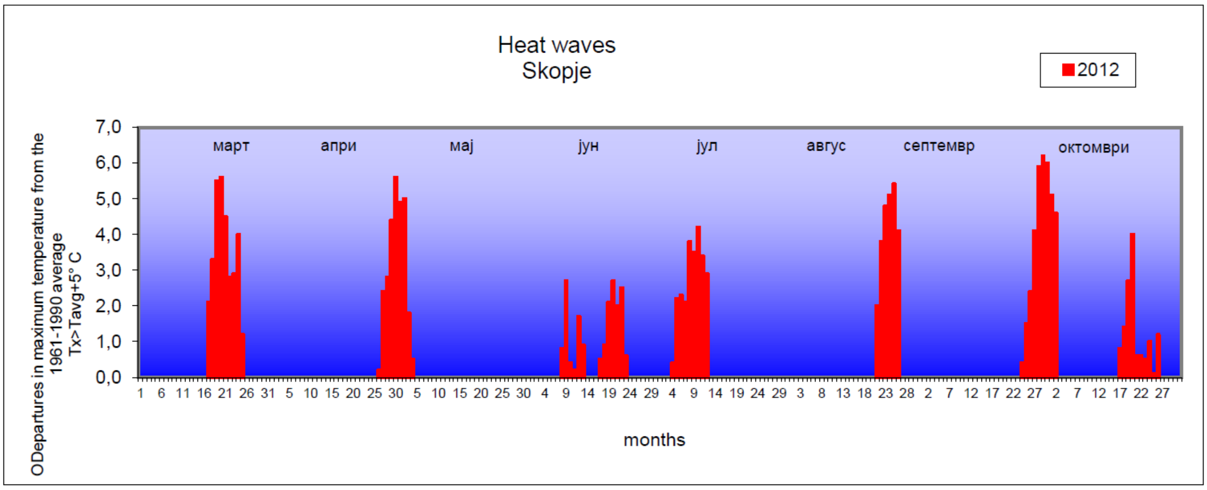


Figure 3 Heat waves in 2012 in Skopje[5]

Heat waves did not occur with regular frequency during the year by months. March stands out as the month with the greatest number of cases of heat waves. The frequency of heat waves in Skopje is 22 cases. It can be concluded that the least frequency of heat waves at the greatest number of stations is recorded in March (Figure 4).

4 Source: Analysis of extreme temperatures heat and cold waves, Third National communication to the UNFCCC
5 Source: Analysis of extreme temperatures heat and cold waves, Third National communication to the UNFCCC

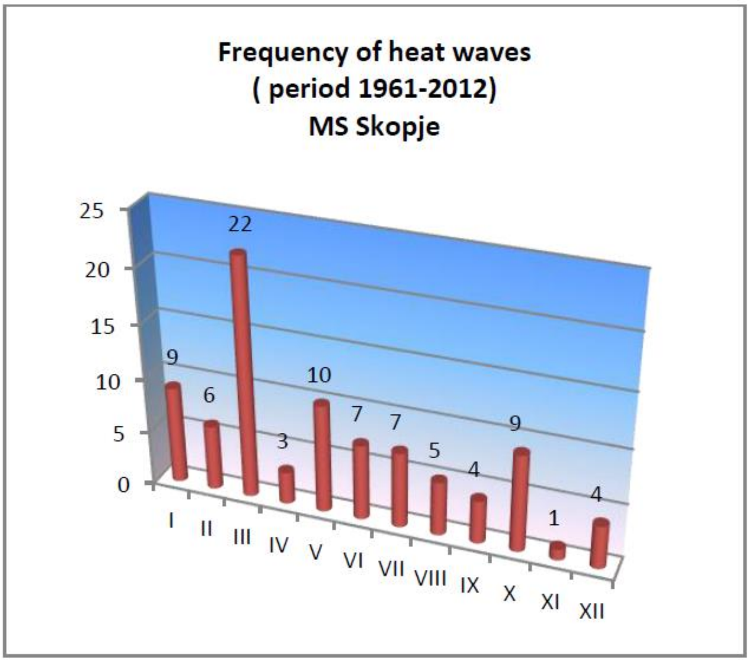


Figure 4 Frequency of heat waves by month in the period 1961–2012[6]

Referring to the pattern of heat waves in the warm and cold part of the year, analysis shows (Figure 5) that the percentage of recorded heat waves cases compared to the multi-year average, is greater in the cold part of the year (November–April) than in the warm part of the year (May-October).

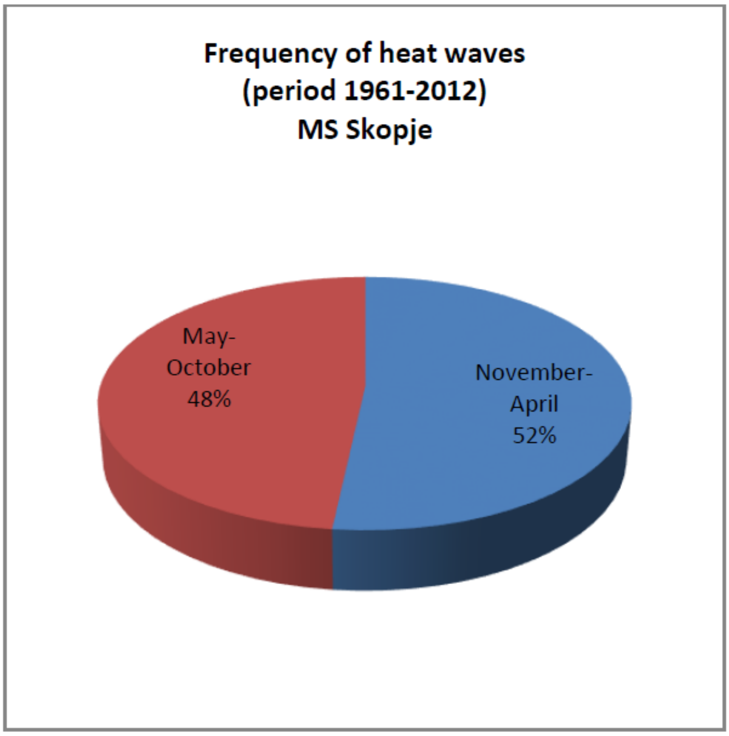


Figure 5 Frequency of heat waves in the warm and cold parts of the year in the period 1961–2012[7]

The maximum durations of heat waves have been determined on the basis of analysis of the Heat Wave Duration Index (HWDI). Of all recorded cases of heat waves, the most characteristic ones occurred in the warm part of the year in May 2003, July 2007, July and October 2012.

[6] Source: Analysis of extreme temperatures heat and cold waves, Third National communication to the UNFCCC
[7] Source: Analysis of extreme temperatures heat and cold waves, Third National communication to the UNFCCC

One of the heat waves of longest duration to have occurred, especially in the warm part of the year, was the heat wave distributed over the whole territory of the Republic of North Macedonia in the period from 29 April 2003 to 15 May 2003. The maximum duration of heat waved in Skopje was 16 days. Although of shorter duration (from 8 to 15 days), the heat wave in the period from 16 to 25 July 2007 is also notable. In that period the highest values of maximum air temperature were recorded at most stations in the Republic of North Macedonia. Year 2012 was one of the most characteristic years in terms of the frequency and pattern of heat waves, mainly in the warmer part of the year. On the following table is given the heat wave occurrences in Skopje for periods: from 29 April 2003 to 15 May 2003, from 16 July 2007 to 25 July 2007, from 30 June 2012 to 12 July 2012, from 24 September 2007 to 7 October 2012.

Table 3 Heat wave occurrences in Skopje[8]

First -last day	29 April 2003 to 15 May 2003	16 July 2007 to 25 July 2007	30 June 2012 to 12 July 2012	24 September 2007 to 7 October 2012
Duration (days)	16	8	9	9

One characteristic of heat waves is a number of days with a maximum air temperature of Tx>25 °C (summer days), as shown in Figure 6, which was developed with GIS-technology for the period 1971–2000. It can be seen that in the project area the number of summer days in period from 1971 – 2000 is in range from 80-120 days.

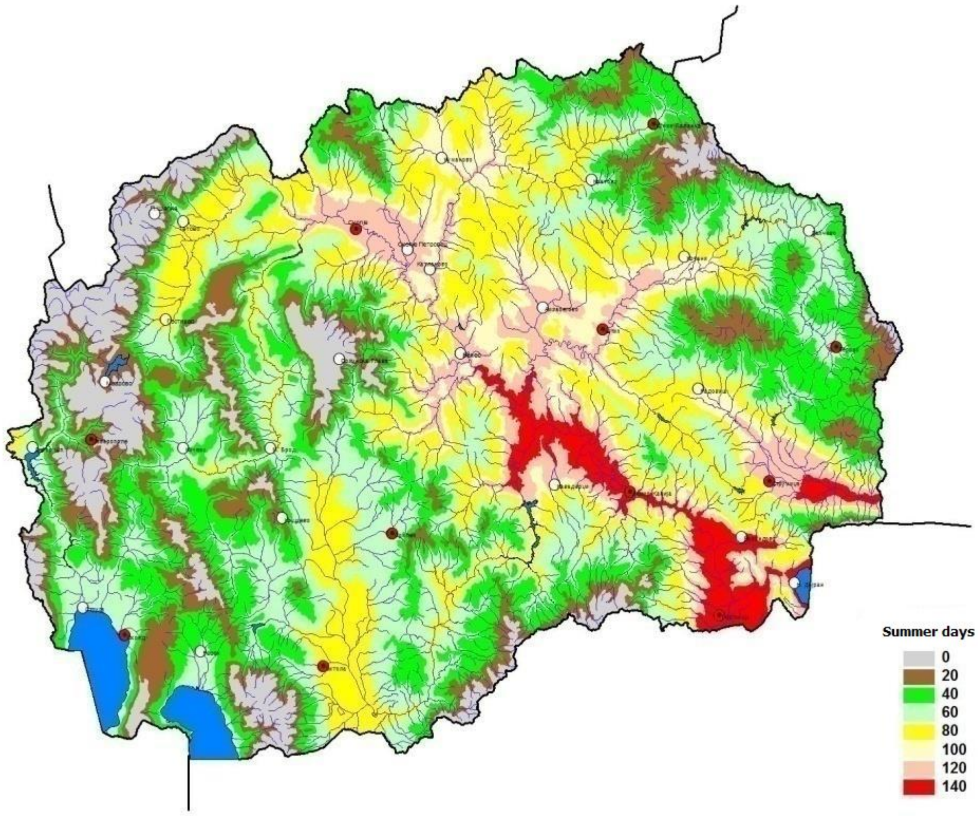


Figure 6 Average annual number of summer days (days with a maximum air temperature of Tx >25 °C) in the period 1971–2000[9]

Figure 7 and Figure 8 show the number of summer days by years recorded at the main meteorological station of Skopje for the period 1961 to 2012, illustrating the changes in the number of summer days and tropical nights per year in this period. The number of summer days and tropical

[8] Source: Analysis of extreme temperatures heat and cold waves, Third National communication to the UNFCCC

[9] Source: Analysis of extreme temperatures heat and cold waves, Third National communication to the UNFCCC

nights has significantly increased in recent years as compared to the number at the beginning of the analyzed period.

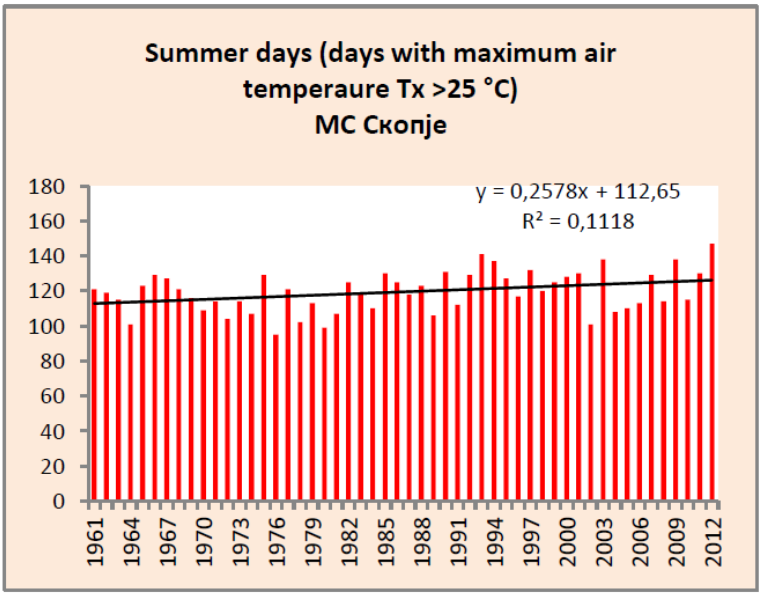


Figure 7 Summer days (days with a maximum air temperature of Tx >25 °C) in the period 1961–2012 [10]

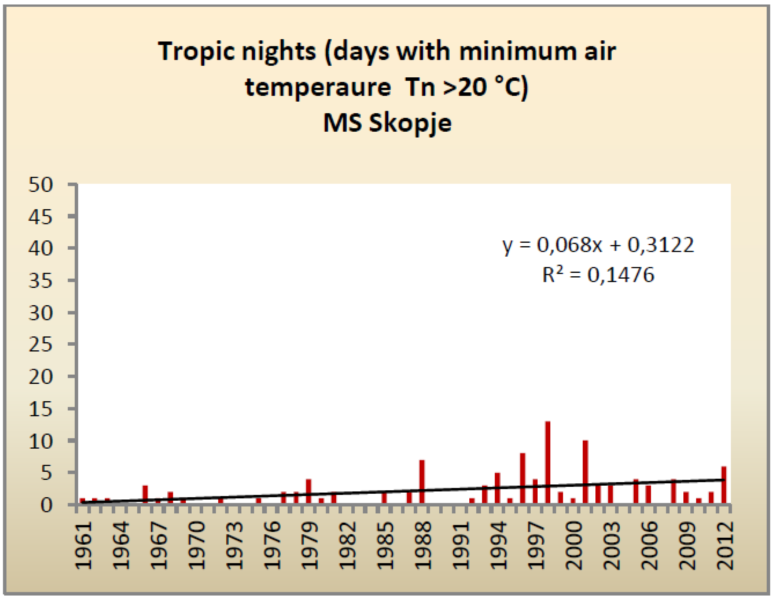


Figure 8 Tropical nights (days with a minimum air temperature of Tn >20 °C) in the period 1961–2012[11]

Analysis of cold waves and cold weather is made on the basis of the following climate parameters:

- The Cold Wave Duration Index (CWDI): (maximum length of cold wave with an interval of at least 6 successive days with Tn < Tnavg - 5°C);
- Number of heat wave occurrences;
- Monthly and annual frequency of cold wave occurrences;
- Frost days: days with a minimum air temperature of Tn <0 °C;
- Ice days: days with a maximum air temperature of Tx <0 °C.

[10] Source: Analysis of extreme temperatures heat and cold waves, Third National communication to the UNFCCC
[11] Source: Analysis of extreme temperatures heat and cold waves, Third National communication to the UNFCCC

On the basis of statistical processing of daily minimum air temperature values, it can be concluded that the most frequently occurring cold waves are those of the shortest duration, i.e. of six days. For example, 7 cold waves of six-day duration were recorded in Skopje. Cold waves of longer duration occurred with less frequency in the period analyzed. Cold waves occur much less frequently than heat waves. For example, a total number of 27 cold waves were recorded in Skopje in the period 1961–2012. 1991 and 1967 are years as characteristic years, with the greatest annual number (4 cases) of cold waves. As can be noted from Figure 9, the cold waves did not occur with equal frequency in each month; rather, they occurred with highest frequency in the cold part of the year, especially in January and February, and with lowest frequency in the warm part of the year.

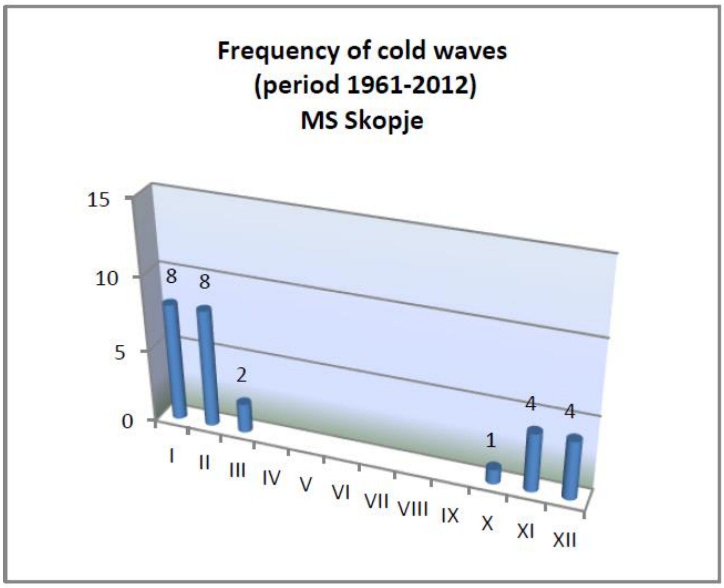


Figure 9 Frequency of cold waves by months in the period 1961–2012[12]

The frequency of cold waves in the periods from 22 January to 2 February 1963 and 12-27 February 1985 have been presented separately as being the most characteristic of all recorded cases. Cold waves of the longest duration were recorded in these periods throughout the whole territory of the Republic of Macedonia. Cold waves of the longest duration with a maximum length of 22 days are recorded in Skopje (in the period from 17 December 2001 to 7 January 2002 and 21 days in Bitola in the period from 4 January 1993 to 24 January 1993) presented in the following table.

Table 4 Cold wave occurrences in Skopje[13]

First - last day	22 January 1963 to 2 February 1963	12 February 1985 to 27 February 1985
Duration (days)	11	15

The spatial arrangement of these extreme climate parameters of air temperatures (average number of frost and iced days) for the territory of the Republic of Macedonia is shown in the following map. It can be seen that in the project area the number of frost days are in around 10 days.

[12] Source: Analysis of extreme temperatures heat and cold waves, Third National communication to the UNFCCC
[13] Source: Analysis of extreme temperatures heat and cold waves, Third National communication to the UNFCCC

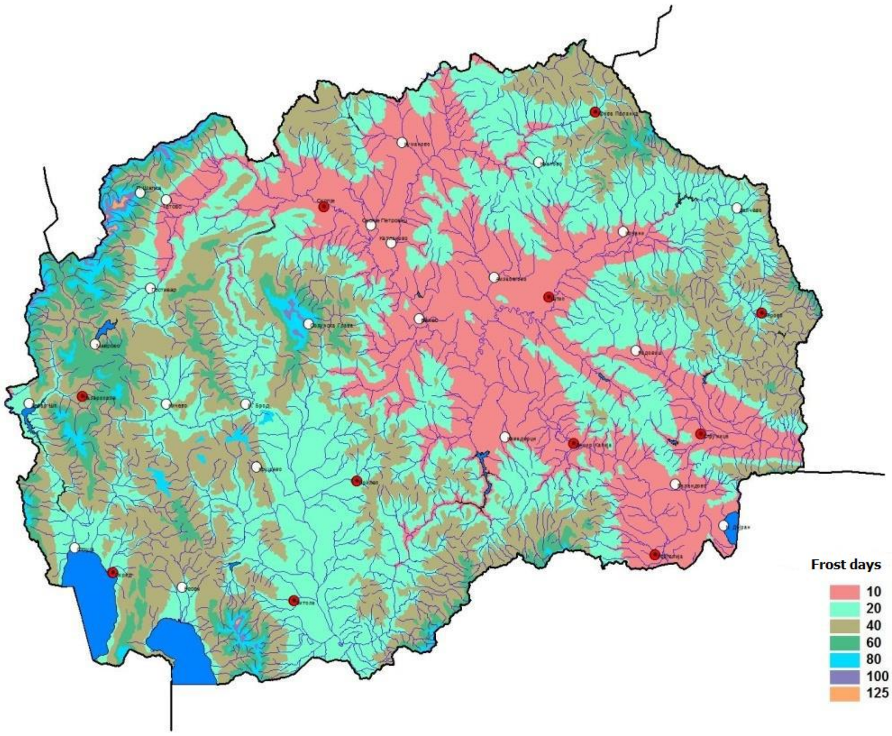


Figure 10 Average annual number of frost days (days with a minimum air temperature of Tn <0 °C) in the period 1971–2000[14]

On the following figure is given number of frost days with minimum air temperature Tn <0 °C (period 1961-2012).

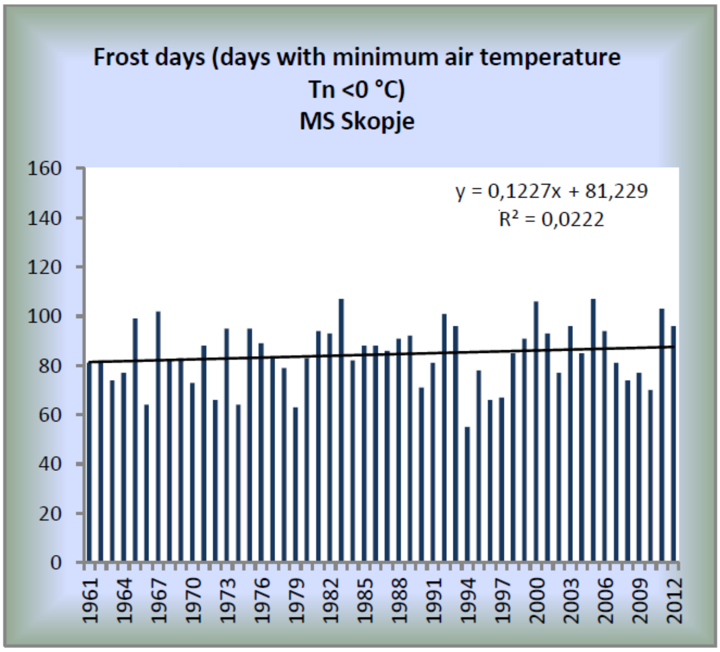


Figure 11 Frost days (days with minimum air temperature Tn <0 °C (period 1961-2012)[15]

The average number of cold days on the territory of the Republic of North Macedonia varies from 5 to 60 days, depending on height above sea level. In the project area the number of frost days varies from 5 to 10. On the following figure are given the average annual number of cold days.

[14] Source: Analysis of extreme temperatures heat and cold waves, Third National communication to the UNFCCC
[15] Source: Analysis of extreme temperatures heat and cold waves, Third National communication to the UNFCCC

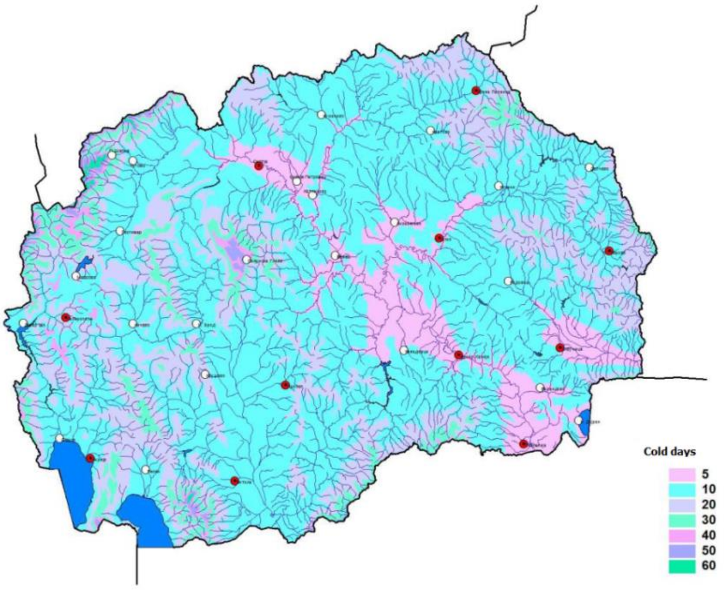


Figure 12 Average annual number of cold days – (days with minimum air temperature Tx <0 °C (period 1971-2000)[16]

On the following figure is given number of ice days – days with a maximum air temperature of Tx <0 °C in the period 1961–2012.

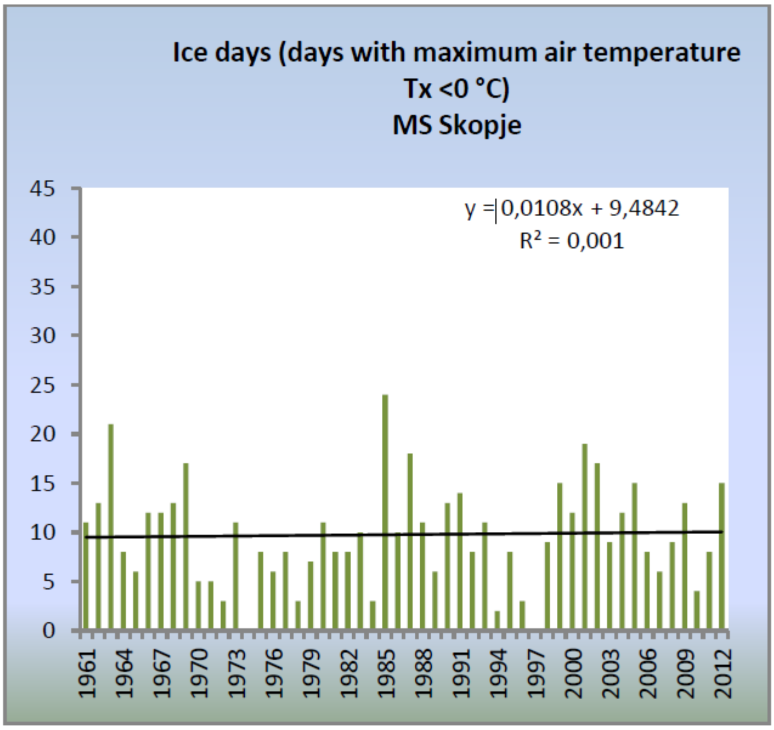


Figure 13 Ice days – days with a maximum air temperature of Tx <0 °C in the period 1961–2012[17]

I. ***Rainfall***

As a result of the influence of the continental and Mediterranean climate, the precipitation in the Republic of North Macedonia is unevenly distributed by space and time. Current trend of precipitation in North Macedonia, and the precipitation for the baseline period, suggests that there is a strong

16 Source: Analysis of extreme temperatures heat and cold waves, Third National communication to the UNFCCC
17 Source: Analysis of extreme temperatures heat and cold waves, Third National communication to the UNFCCC

discrepancy between the central and western part of the country, as total annual rainfall increases dramatically, with approximately 400 mm/year in the centre and over a 100 mm/ year in the western part of the country. For the maximum 24 hours of precipitation, the latest data series from 1961 up to 2017 for 13 stations were used. The daily precipitation maxima is clustered in the western half of the country, in the hilly area, reaching approximately over 150 mm/ day, while the eastern part is relatively steady with approximately 40-70 mm/ day. This reflects the extreme events, which are generally expected and historically occurred more in the western hilly areas. Figure below summarizes both the continuous and extreme rainfall trend. The main A1 road route along the Vardar valley, apparently do not suffer neither of these two effects, but A2 is affected, together with the associated road lower-level roads (R1 and R2).

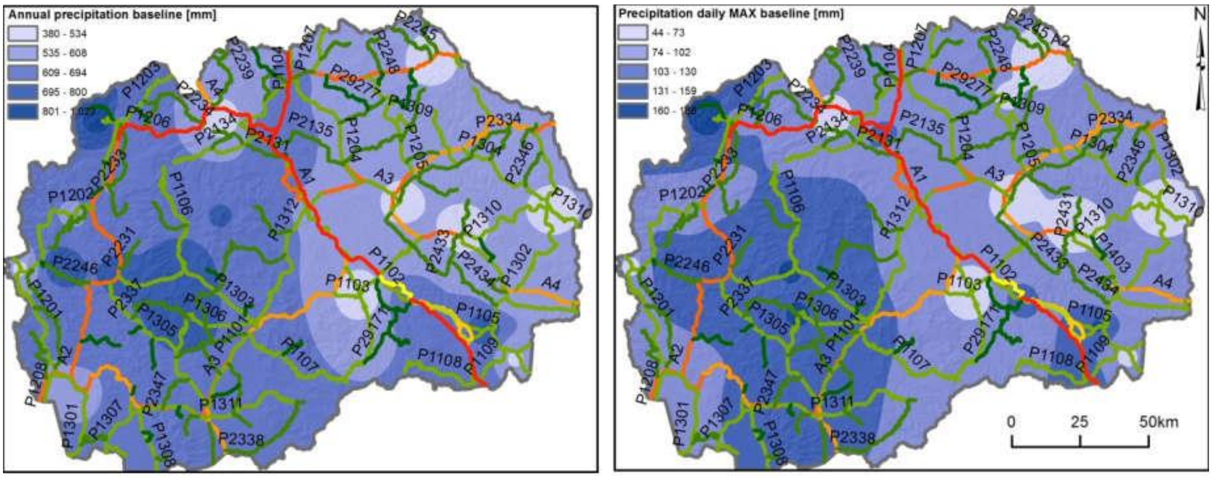


Figure 14 Rainfall baseline map

In Skopje, the amount of annual precipitation in 2017 compared to the average annual amount of precipitation for the period 1981-1990, slightly increased by 5% of the average. The highest amount of annual precipitation of 782.9 mm was in 2014. This year was the biggest deviation from long-term average rainfall in the period from 1981 to 1990, and is 76%. On the following table are presented the quantities of annual average rainfall for the period 1990 – 2017.

Table 5 Annual average rainfall for the period 1990 – 2017[18]

		Unit	1990	1995	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
1	Average rainfall quantity for 1990 – 2017	mm	445.4																			
2	Annual rainfall quantity for Skopje	mm	309.9	585.7	296.4	297.9	726.5	563.3	532.0	573.1	511.4	527.7	445.8	656.6	704.1	329.2	412.7	464.8	782.9	526.3	682.9	468.3
3	Deviation from the average amount of precipitation	%	69	131	67	67	163	113	119	129	115	118	100	147	158	74	93	104	176	118	153	105
4	Maximum monthly rainfall quantity	mm	97.9	98.8	57.7	89.4	155.9	118.2	63.2	101.7	96.7	140.0	78.4	104.3	143.9	88.2	108.2	66.1	167.5	138.1	130.7	93.3
5	Minimum monthly rainfall quantity	mm	4.4	0.2	2.1	1.3	14.7	1.7	16.1	21.2	13.2	1.2	0.8	10.2	3.5	2.3	4.2	15.7	6.7	0	0	7.52

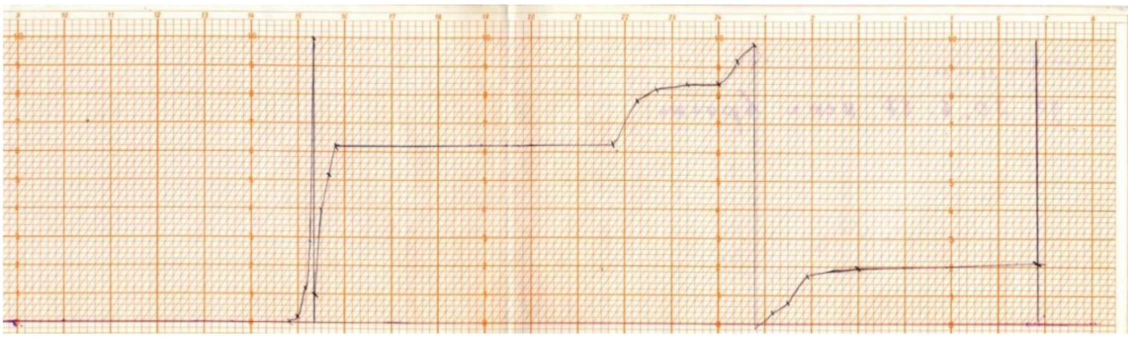
[18] Source: Risk management and protection plan from floods on the Lepenec river basin

Measurements of rainfall intensity and duration are performed with one-day, seven-day or monthly pluviographs. The one-day pluviographs mostly use German instruments from the company Lambreht and R.Fruess as well as the Russian type P-2 (with forced discharge). The most common of the seven-day and monthly pluviographs are the German instruments from the company Lambrecht.

Given the technical means available for pluviogaf precipitation monitoring, the measurements were performed only in the warm period of the year (April to November). In the winter, the so-called pluviographs with heaters were used (to prevent freezing at negative temperatures), but then not a one-day pluviographic tape was used, but a seven-day one. Such records are unusable for determining the amount of precipitation for the duration of rainy episodes less than 60 minutes.

This study presents the results of the processed pluviographic diagrams from GMS Skopje Petrovec from previous studies (Intensive precipitation in the Republic of Macedonia, Faculty of Civil Engineering - Institute of Hydrotechnics, Skopje, 1993) for the period 1956-75; 1978-1980; 1982-84 and 1986-88.

The processing is supplemented with the latest thirty-year series of data regarding the measuring point Skopje Zajcev Rid for the period 1991-2020. Thereby, the reading of the pluviographic diagrams is done in two ways: manually and automatically. As the two methods in individual cases do not give identical results, the expert assessment is that when choosing the annual maximum precipitation for a certain duration should be taken into account for further processing the higher value.



Processing of pluviographs for 27.06.1987					Highest values		
Time (h.min)	Rainfall quantity (mm)		$\Delta t = t_{i+1} - t_{i(min)}$	Hi/ Δt	Interval Δt(min)	Start and end of interval	Selected rainfall Hi(MM)
	Σ h_i	Hi					
1	2	3	4	5	6	7	8
14^{50}	0.0	0.2	10	0.020	5	15^{15}-15^{20}	7.10
15^{00}	0.2	1.0	10	0.100	10	15^{15}-15^{25}	10.00
15^{10}	1.2	1.7	5	0.340	20	15^{10}-15^{30}	12.80
15^{15}	2.9	7.1	5	1.420	40	15^{10}-15^{50}	15.00
15^{20}	10.0	4.0	10	0.400	60	14^{50}-15^{50}	16.20
15^{30}	14.0	2.2	20	0.110	90	14^{50}-16^{20}	16.20
15^{50}	16.2	0.0	295	0.0	150	14^{50}-17^{20}	16.20
21^{45}	16.2	1.6	30	0.53	300	14^{50}-19^{50}	16.20
22^{15}	17.8	0.4	25	0.016	720	14^{50}-02^{50}	21.90
22^{40}	18.2	0.2	40	0.005	1440	(960) 14^{50}-06^{50}	22.10

The pluviographic diagrams determined the largest amounts of precipitation H (mm) for the designated durations of time t (5, 10, 20, 40, 60, 90, 150, 300 and 720 minutes and 24 hours) for the stations Skopje Petrovec and Skopje Zajcev Rid .

The obtained values for the annual maximum amounts of precipitation for the specified durations are further used for statistical processing.

Tables 4 and 5 show the calculated values of the maximum amounts of precipitation. Due to the consistency and possibility for comparability with the previous calculations of intensive precipitation for Skopje-Petrovec, also the data from Zajcev Rid for the period 1991-2020 are analyzed with Gumbel distribution. In addition, the Kolmogorov-Smirnov and Chi-square tests were used to assess the suitability of the theoretical distribution with the empirical data. For all levels of test significance, there is no justification for rejecting the selected statistics.

The distribution of the probability of occurrence of maximum amounts of precipitation in millimeters calculated for Skopje Petrovec for the period 1956-1988, is graphically shown for different time intervals (graph 1a and 1b), and for Skopje Zajcev Rid for the period 1991-2020 on graph 2a and 2b.

Table 6 Calculated maximum amount of precipitation in mm with given duration for different probabilities (return period) in% (years) for Skopje Petrovec

P (%)	5 '	10 '	20 '	40 '	60 '	90 '	150 '	300 '	720 '	24h	T (year)
50	6.6	10.2	14.3	17.5	19.0	20.2	22.8	25.5	30.0	32.3	**2**
20	9.5	15.2	21.0	25.7	27.8	29.1	31.8	35.6	43.8	45.8	**5**
10	11.4	18.5	25.5	31.2	33.6	35.0	37.9	42.3	53.0	54.8	**10**
4	13.7	22.7	31.2	38.1	40.9	42.5	45.5	50.8	64.5	66.1	**25**
2	15.5	25.8	35.3	43.2	46.3	48.0	51.1	57.1	73.1	74.6	**50**
1	17.2	28.9	39.5	48.3	51.7	53.5	56.7	63.4	81.6	82.9	**100**
0.1	23.0	39.2	53.2	65.0	69.5	71.6	75.2	84.1	109.8	110.5	**1000**

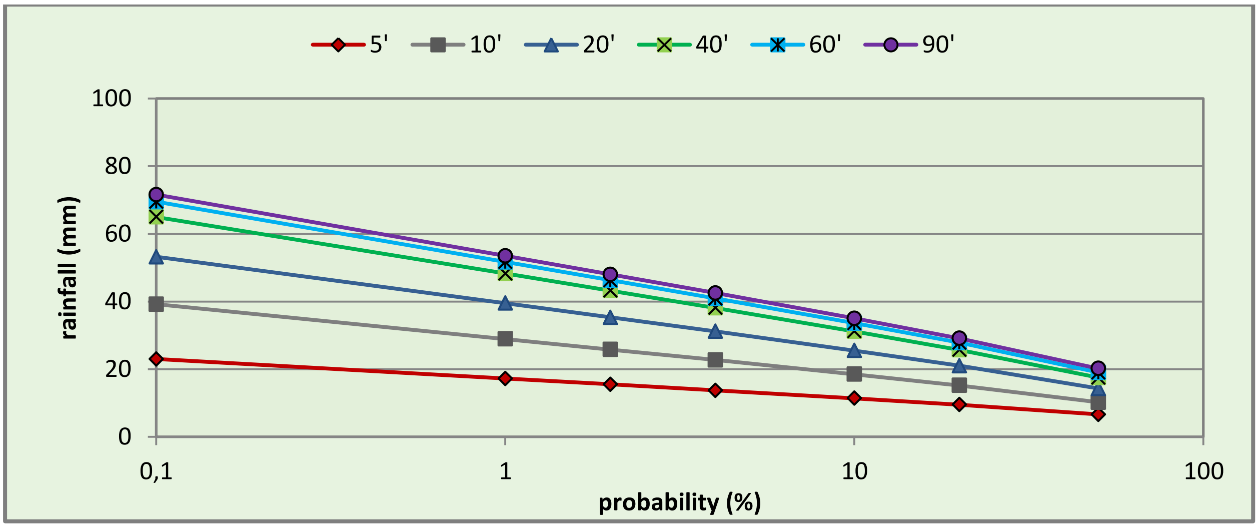


Figure 15 Distribution of the probability of maximum precipitation for 5, 10, 20, 40, 60 and 90 minutes for Skopje Petrovec

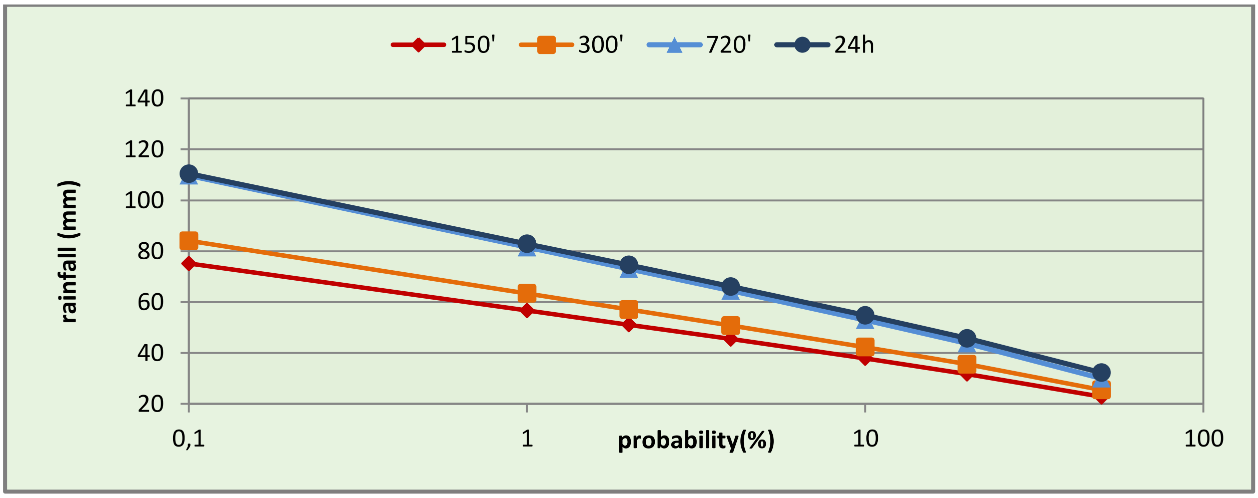


Figure 16 Distribution of the probability of maximum precipitation for 150, 300 and 720 minutes and 24 hours for Skopje Petrovec

Table 7 Calculated maximum amount of precipitation in mm with given duration for different probabilities (return period) in% (years) for Skopje Zajcev Rid

P (%)	5 '	10 '	20 '	40 '	60 '	90 '	150 '	300 '	720 '	1440 '	24h	T (year)
50	4.8	7.4	10.6	14.0	16.4	18.5	21.0	27.0	34.3	43.76	41.7	2
20	7.3	10.9	15.5	20.6	24.3	27.7	30.1	40.1	49.5	58.83	56.0	5
10	9.0	13.3	18.7	24.9	29.5	33.8	36.2	48.7	59.6	68.80	65.5	10
4	11.0	16.3	22.7	30.4	36.1	41.5	43.8	59.6	72.3	81.40	77.6	25
2	12.5	18.5	25.7	34.5	41.0	47.2	49.4	67.7	81.7	90.75	86.5	50
1	14.1	20.7	28.7	38.5	45.9	52.8	55.0	75.8	91.1	100.03	95.3	100
0.1	19.1	27.9	38.5	51.9	62.0	71.5	73.6	102.3	122.1	130.69	124.5	1000

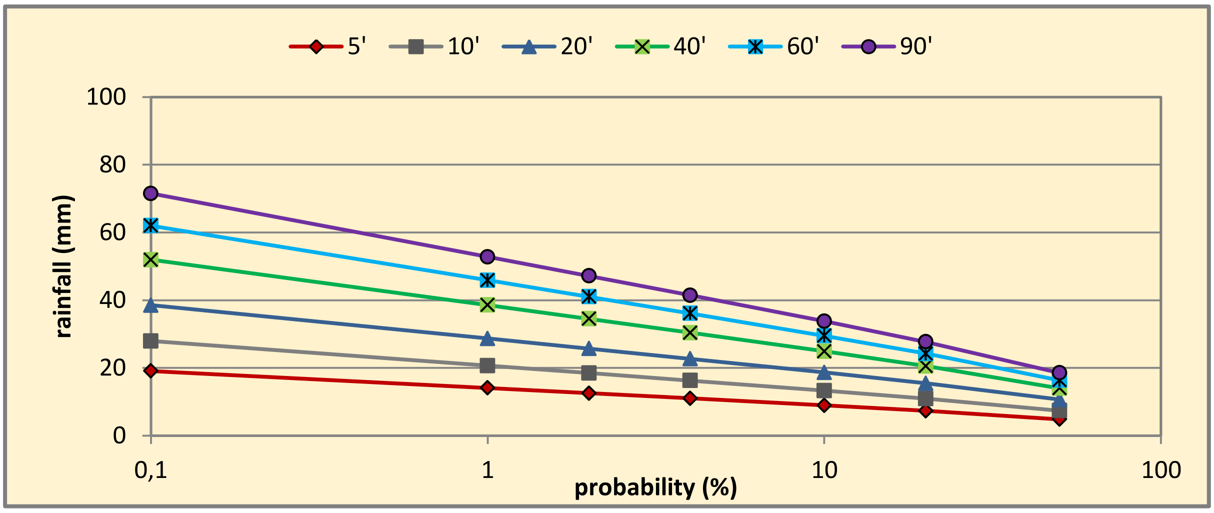


Figure 17 Distribution of the probability of occurrence of maximum precipitation for 5, 10, 20, 40 and 60 minutes for Skopje Zajcev Rid

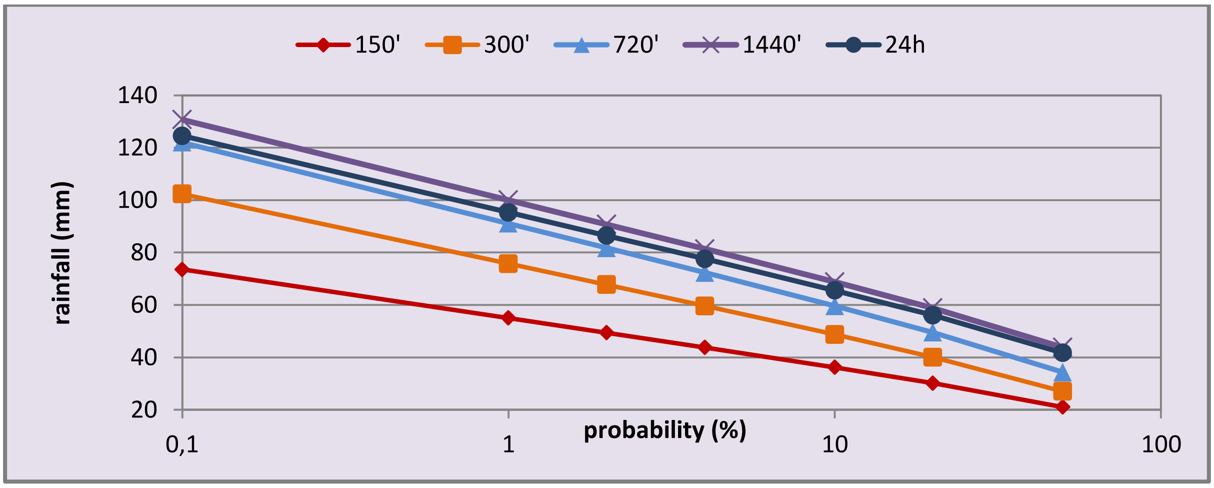


Figure 18 Distribution of probable occurrence of maximum precipitation for 90, 150, 300, 720 and 1440 minutes and 24 hours for Skopje Zajcev Rid

II. ***Landslide***

Landslides occur when the stability of the slope changes from stable to unstable. The change in the stability of the slope can be caused by a number of factors, acting mutually or independently of each other. On the following table are given the causes for landslides.

Geological reasons	**Anthropogenic causes**
• Decomposition materials • Intertwined materials • Joints or cracks • Unfavorably oriented discontinuities • Permeable contrasts • Material contrasts • Rain and snow • Earthquakes	• Deforestation • Excavation • Embankment • Water management (groundwater extraction and water leakage) • Land use (for example, construction of roads, houses, etc.) • Mining and quarrying • Vibration
Physical causes	**Morphological reasons**
Topography • Slope and slope exposure *Geological factors* • Discontinuity factors *Tectonic activity* • Seismic activity, volcanic eruption *Physical decay* • Defrosting, freezing-warming, soil erosion *Hydrogeological factors* • • Heavy rain, rapid snowmelt, prolonged rainfall, groundwater changes, runoff.	• Angle of inclination • Raising land • Landing • Fluvial erosion • Abrasive erosion • Glacial erosion • Lateral erosion • Underground erosion (suffocation) • Artificial slopes • Change of vegetation

Source: Study for erosion and action plan for City of Skopje, 2017

In the City of Skopje, 13 landslides were registered, 2 in urban areas, 3 along the road and 8 in uninhabited areas. All landslides that endanger infrastructure or facilities have been repaired. The biggest landslide is in the section Kisela Voda - Teferic and this landslide has protective measures and is under monitoring. Outside the City of Skopje, 31 landslides were registered, 1 in a populated area (Rakotinci), 5 along the road and 25 in uninhabited areas. All 7 landslides that endanger the infrastructure or facilities have been repaired, and 3 landslides are under monitoring. In the project area there aren't any significant landslides which occurred in the past.

On the following figure is given a map of the registered landslides in City of Skopje including the project area.

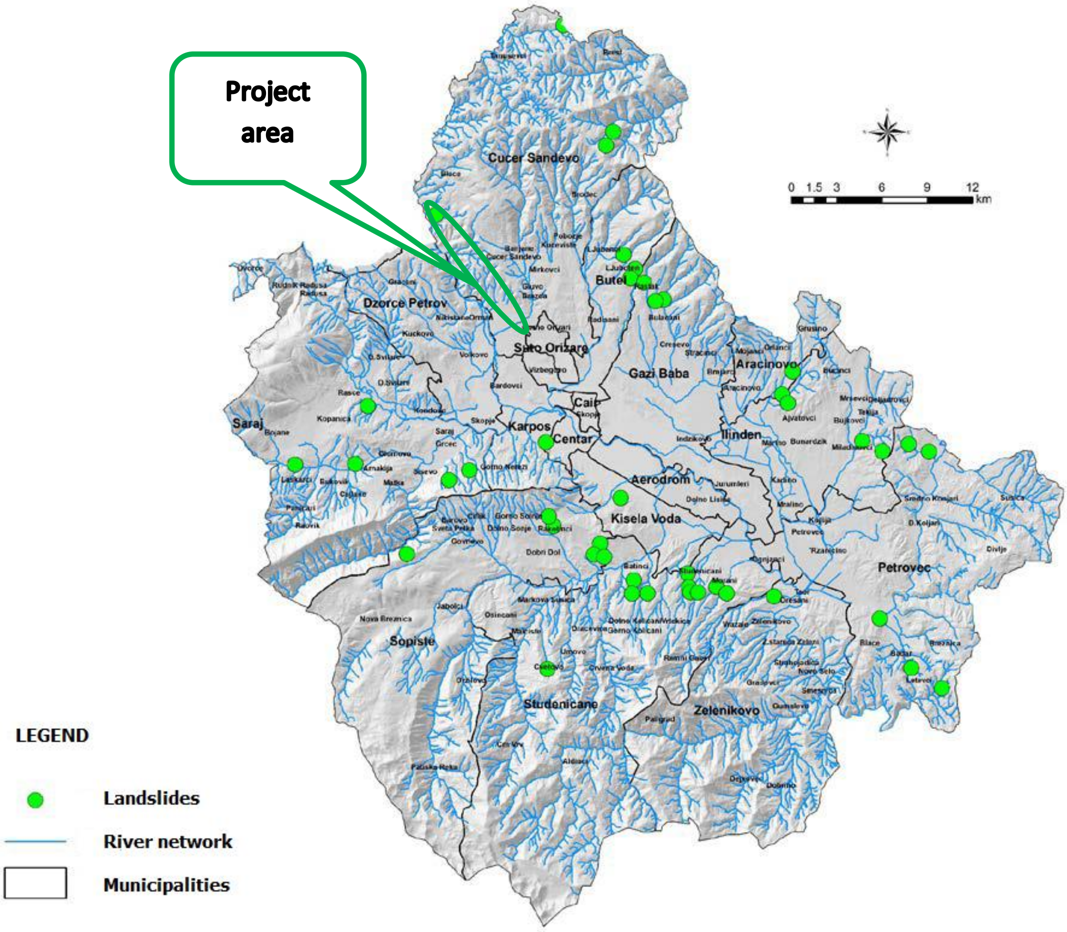


Figure 19 Landslides in Skopje region including project area[19]

III. ***Floods***

River floods represent the most frequent and expensive natural disaster affecting most of the countries around the world. Main factors that contribute to river floods are: heavy rains at river sources, snow melting and land-use change (such as deforestation and urbanization). Runoff after heavy precipitation is the principal reason for river floods, and as urbanization increases, impervious areas increase as well, leading to higher rates of runoff.

In the frame of the project Technical assistance preparation of climate resilience design guidelines for the Public Enterprise for State Roads in North Macedonia, the project team has conduct flood analysis in order to be developed flood hazardous map for the whole regional and magisterial roads in the country. Flood hazard map, based on analytic hierarchy process (Figure 19) produced in GIS environment shows a pattern of flood influenced strongly by rainfall intensity parameters due to high weight assigned during the multi criteria assessment procedure of analytic hierarchy process. The spatial pattern of the flood hazard map has been categorized in five levels of hazard classes namely very low, low, medium, high and very high flood hazard. On the following figure is presented the flood hazardous map for the whole country.

[19] Source: Study for erosion and action plan for City of Skopje, 2017

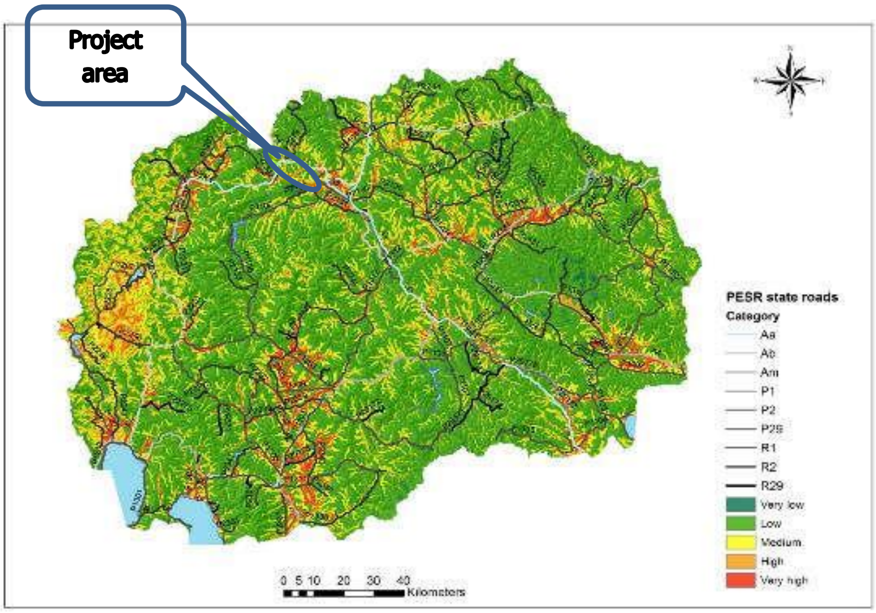


Figure 20 Flood hazardous map[20]

Verification of the resulting flood hazard map is completed using several past flood information where infrastructural damage is evident (for these guidelines, from 2015). The results (Table 6) shows those almost all past flood events were located in hazard classes' medium to very high.

Table 8 Classes of flood hazard and number of historical flood events[21]

FLOOD HAZARD	NUMBER OF EVENTS
Very low	6
Medium	12
Nigh	9
Very high	13

Furthermore, a visual inspection where infrastructural damage is evident was conducted and an assessment of the obtained hazard map was performed by comparing it to a flood zone map developed on national level. Satisfying matching between the two maps was observed even though the flood zones map is fairly coarse and on small scale (1:200,000) and has the shortcoming that is developed only for alluvial lowlands of the major rivers (minor tributaries and torrents are not included). Results are shown in the figure below.

[20] Source: Part B: Methodology statement: Technical assistance Preparation of Climate resilience design guidelines for the Public Enterprise for Public Roads in North Macedonia

21 Source: Part B: Methodology statement: Technical assistance Preparation of Climate resilience design guidelines for the Public Enterprise for Public Roads in North Macedonia

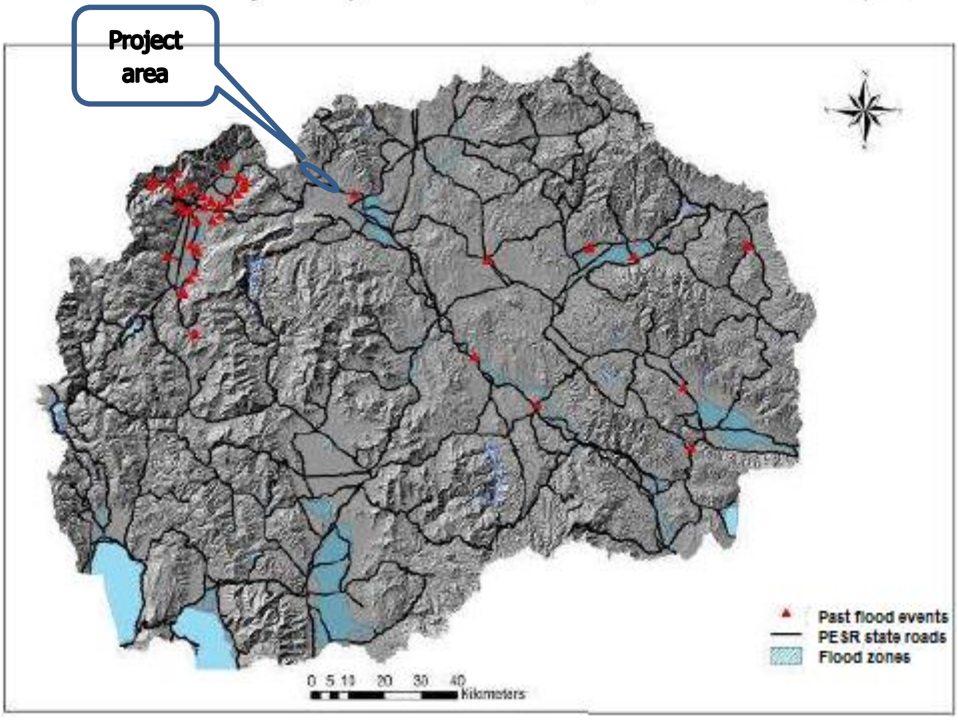


Figure 21 Flood Zones and Past Flood Events[22]

The waters of the river Treska, the upper course of the river Vardar and the lower course of the river Lepenec, combine and can create a high discharge into the river Vardar. The combination of intense autumn rainstorms, the confluence of the three listed rivers and drainage area, offering little resistance to floodwaters from floods have caused large and sudden floods in Skopje in the past. The City of Skopje and the downstream river valley were flooded in 1876, 1895, 1916, 1935, 1962,1979 and 2016. In May 1916, the river Vardar overflowed from both banks, entering the streets and houses with a large amount of water. Waters poured right from the riverbed of Vardar reached the old railway station.

Only twenty years later, two more floods occurred, and for them, for the floods of 1935 and 1937, there is much more specific information about the flows measured at the hydrological station Skopje-Iron Bridge, as well as at the hydrological station in Shisevo. The main reason for the two floods, as well as the flood that occurred on November 16, 1962, were the intense rains in the upper course of River Vardar, basin of the River Treska and the basin of the River Lepenec. In the flood that occurred on November 16, i.e. between November 16 and 20, 1962 year, which is considered to be the largest in the recent history of Skopje, did not exist victims, but 5,000 houses were flooded and great material damage was caused. According to the information published in the newspaper "Nova Makedonija", only with the first wave of floods, between 16 and 17 November 1962, the water collapsed around 1,000 houses and about 4,000 families were left homeless.

The flood in 1979 affected a large part of Skopje and the Skopje region Valley, starting from Gjorce Petrov to Belimbegovo, leaving behind huge material damage, but, fortunately, without direct human casualties. In Madzari, Hippodrom and surrounding villages, 1,400 houses were flooded, and 20 were demolished to the ground, while 5,000 residents were evacuated.

General observations are that in conditions of intense rainfall and snow melting, the water flows from the riverbed of the River Lepenec in the Republic of North Macedonia starting immediately after the Kachanica Gorge until the inflow into the River Vardar. Based on the Draft Analysis Report of the Lepenec River, it has been determined that 124 ha were flooded in 1979 in the plain along the Lepenec River. At the same time, it is estimated that 50% of the area in the Skopje region exposed to floods, estimated at 8730 ha according to the Assessment of the threat to the City of Skopje from natural disasters and other accidents, is due to the water level of the River Lepenec and its

[22] Source: Part B: Methodology statement: Technical assistance Preparation of Climate resilience design guidelines for the Public Enterprise for Public Roads in North Macedonia

unregulated flow and lack of water protection facilities that would control the flow of the River Lepenec.

Based on recorded data from automatic precipitation measuring stations in municipalities Gazi Baba and Karposh, over 100.00 mm/m^2 of rainwater fell in approximately two hours, which is roughly three times the average monthly sum, or nearly equal to the maximum recorded precipitation for the entire month of August in Skopje. Compared to records of rainfall in the region for the period 1978 to 2010, the storm is categorized as an event with 0.1% (1 in 1000 years) probability of occurrence. The storm affected a wider area of 15 municipalities around the capital of Skopje. However, most severe consequences were caused in the north-east part of the region at the foothill of Skopska Crna Gora Mountain, i.e. municipalities of Gazi Baba and Arachinovo, where rapid and substantial increase of water level in torrential streams running from the peaks of the mountain to the Vardar river created devastating effects to several suburban settlements and villages. Although, as a result of the terrain topographic characteristics, accumulated rainwater drained relatively quickly, urban, industrial and rural areas in the most affected region were completely submerged under water and mud/debris, cut off without electricity or communications, and with damage to roads and transport facilities. Consequently, a vast number of houses were damaged or left underwater, leading to a significant number of displaced households. In addition, substantial damages at two locations were also caused on the Skopje ring road, as rainwater from torrential streams running from the mountain surged over the highway. Overall the flood affected some 1 million people living in 15 municipalities located in the wider Skopje region. At least 21 people have died.

The annual average population affected by flooding in Macedonia is about 70,000 and the annual average affected GDP about $500 million. For most regions, the 10 and 100 year impacts do not differ much, so relatively frequent floods have large impacts on these averages (Source: World Bank).

Also, in the last few years, Macedonia has black statistics regarding the floods (Centre for Research on the Epidemiology of Disasters - CRED). Both in 2015 and 2016, Macedonia is among the top 10 countries, with the greatest economic damages and mortality also, as a result of the floods:

- 6th of top 10 countries in terms of disaster mortality in 2016 (1.06/100.000)
- 3th of top 10 countries by damages in 2016 (0.55% of GDP)
- 8th of top 10 countries by damages in 2015 (0.85% of GDP)

IV. ***Droughts and fires***

Drought is a common phenomenon in Macedonia. Drought-related meteorological elements are P-average annual precipitation [mm], PET - potential evapotranspiration [mm], AI - aridity index, 0.05 <AI <0.65 - regions prone to desertification, Md - deficit of humidity [mm], DI - Drought Index by De Martone, PF - Rainfall factor by Lang, G - climatic designation according to Gracanin, (a) - ariden, (sa) - semi-ariden and Na, Nsa - number of arid/semi-arid months in the year.

Arid areas exist because the annual water loss (evaporation) exceeds the annual rainfall. Therefore, these regions have a permanent water deficit. Based on the calculation of the aridity index (Ai=ΣH/ PET) on an annual basis, where ΣH is the Precipitation, and PET is the Potential Evapo-Transpiration and the criteria for the RVD Region Subject to Region (Vulnerable to Desertification) according to UNCCD, a map was prepared with designated climatic stations and the aridity index (based on older data 1961-1990). On the following figure is presented the map with climatological stations and aridity index.

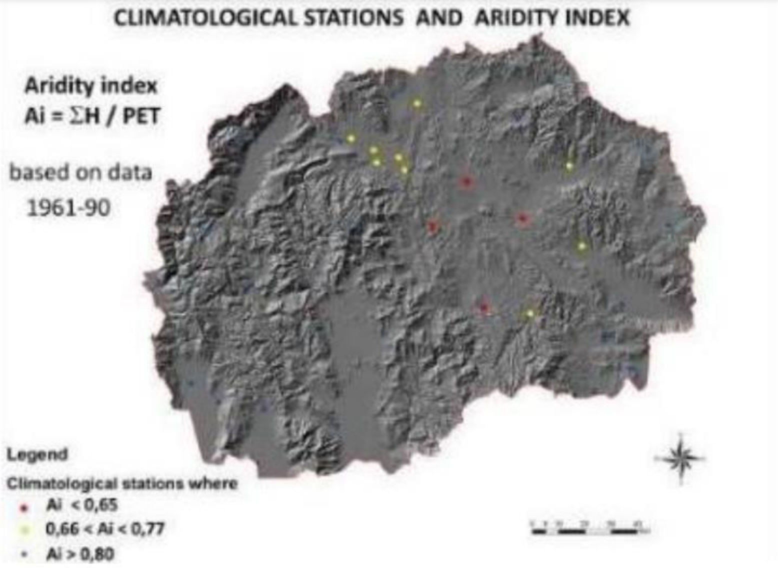


Figure 22 Climatological stations and aridity index[23]

The aridity index for Skopje region is 0,69[24]. Detailed research on the desertification in the Republic of Macedonia, i.e. the marking of the regions subject to desertification, has not been done yet.

On the project area, in the period between 2015 and 2020, two major forest fires were recorded by the PE National Forests from Skopje, the first one on Stenkovec locality, cadastral municipality (CM) Gluvo-Brazda, where 5.61ha of Austrian pine young forest was set on fire and the second one in the forest sections 25a, 26a, 27a and 28a of the forest management unit "Skopska Crna Gora" on Blace locality in CM Blace, where 220,00 ha of oak forest area were burned.

3.3. Climate change projections and scenarios

The mentioned and many other data indicate that there is a high probability that the increase of the average air temperature, increase of the sea level, change of the spatial and temporal wind patterns, the appearance of intense extra-tropical storms, long-lasting heat waves and etc. are due to the impact of human activities primarily on increasing the amount of greenhouse gases in the atmosphere. This is supported by the results of numerous mathematical models used to simulate - predict the future state of the climate. Although natural processes and factors are too complex to be good enough described with these models, the results unequivocally indicate the impact of greenhouse gases that are a product of human activities on climate change.

These mathematical models are known as Global Circulation Models (GCM) or Atmosphere-Ocean Global Circulation Models (AOGCM) generally cover two components that affect climate change. One component is the natural factors: solar radiation, the processes of water circulation in the atmosphere, periodic (daily, seasonal and annual) changes in the atmosphere and storms, volcanic eruptions, desert dust and the like. These quantities and their changes are expressed through real measured values - parameters or by mathematical functions.

The second component is the presence of greenhouse gases expressed through: the intensity of their discharge in the atmosphere, their composition, total and partial quantity. This component describes with the so-called "Emissions scenarios." These emission scenarios were developed by the IPCC and described in Special Emission Scenario Report (SRES). They describe different conditions of the show and the total quantity of GHG in period to 2100 year and together with scenarios (predictions) for the

[23] Source: Part B: Methodology statement: Technical assistance Preparation of Climate resilience design guidelines for the Public Enterprise for Public Roads in North Macedonia
[24] National action plan for fight against desertification in the Republic of Macedonia (2017-2023)

future economically, technological, demographic and sociological development of different parts of our planet are inputs data on the models used to make forecasts for the future climate.

Prediction of climate change in Macedonia is implemented with the help of the software package MAGICC / SCENGEN version 5.3. This adheres to the basic recommendations of the IPCC and the results presented in the last, Fourth Assessment Report (AR4), as follows:

- Non-existence of one favored ("best") scenario, i.e. advocating for the use of several scenarios which would provide a range of probable results and no single values,
- Use of the three most likely values (optimal and limit values) for climate sensitivity: 2.0, 3.0 and 4.5°C.
- Selection of scenarios valid for the observed space.

Estimation of changes in temperature and precipitation are made in comparison with the period 1961-1990 who is taken as a reference and initial. According to the recommendations in MAGICC / SCENGEN software, though generate scenarios for a certain year, in fact for the elimination of the annual fluctuations and uncertainties, those data represent an average situation in a period of thirty years for which the selected year is central year. For example the year 2025 is representative for the period 2011 - 2040. In doing so, in the selection of the year 2100 for the generation of scenario, there is slight inconsistency in relation to the former. Because the scenarios defined in SRES describe the situation with emission of the GHG until 2100, the results for the change of temperature and precipitation for 2100 present the period 2086 - 2100.

The assessment is made for four characteristic years:

- 2025, central year for 2011 - 2040,
- 2050, central year for 2036 - 2065,
- 2075, central year for 2061 - 2090
- 2100, represents the period 2086 - 2100.

Climate models and future projections

Temperature and precipitation are considered to be crucial climate parameters since greenhouse gas emissions are beyond the scope, even though they are the principal cause of the changes and are tightly associated with temperature change and indirectly to the precipitation. It is globally accepted that temperatures are rising, and there are different variants of temperature increase depending on the gas emission scenario (from optimistic to pessimistic). On the other hand, the precipitation is globally dropping, but with higher frequency and intensity of localized rainfall extremes. The onset of the climate change is confirmed by observing the past couple of decades, wherein the climatic parameters are changing rapidly, with rates much higher than they were in the past 100 years. According to some projections, in next 40 years amount of temperature rise will be equal to the rise for previous 100 years. Also, some scenarios predict that the frequency of droughts and extreme rainfall will double, which might cause irreversible changes to the bio-systems on Earth, including also human environment, urban fabric, infrastructure, etc. In following sub-chapters are presented projections for specific climate parameters for the Republic of North Macedonia.

Temperature projections

The predicted changes in air temperature are calculated for the period 2025, 2050, 2075 and 2100 for all four seasons (winter, summer, autumn and spring) on annual level. On the following table are given the changes of average air temperature.

Table 9 Predicted changes in air temperature for: 2025, 2050, 2075 and 2100, for four seasons (winter, spring, summer, autumn) and annually (Year)[25]

	Winter				Spring				Summer				Autumn				Year			
	2025	2050	2075	2100	2025	2050	2075	2100	2025	2050	2075	2100	2025	2050	2075	2100	2025	2050	2075	2100
High	1.1	2.4	3.8	5.0	1.4	3.0	4.6	6.2	2.4	4.8	7.9	10.6	1.5	3.0	5.0	6.7	1.6	3.3	5.3	7.1
Average high	0.9	1.9	3.0	3.9	1.1	2.4	3.6	4.8	1.9	3.8	6.2	8.2	1.2	2.4	3.9	5.2	1.3	2.6	4.2	5.5
Average	0.8	1.5	2.2	2.7	1.0	1.8	2.7	3.3	1.7	3.0	4.6	5.8	1.1	1.9	3.0	3.7	1.2	2.0	3.1	3.9
Average low	0.7	1.0	1.5	1.7	0.9	1.3	1.9	2.1	1.6	2.1	3.4	3.9	1.0	1.3	2.2	2.5	1.1	1.4	2.2	2.5
Low	0.5	0.8	1.1	1.1	0.7	0.9	1.4	1.4	1.2	1.5	2.4	2.7	0.7	1.0	1.6	1.8	0.8	1.0	1.6	1.7

It is obvious that all the values are positive, which means that in the period 2025 -2100 is overlooks increase in air temperature. Changes to the temperature are given below. The value before the parentheses is the mean change and the values in bracket are: the maximum (absolutely the highest) and the minimum (absolutely the lowest) change.

The results are the following:

Winter season (December, January, February):

- 2025 year - change 0.8 [0.5 – 1.1] ℃,
- 2050 year – change 1.5 [0.8 – 2.4] ℃,
- 2075 year - change 2.2 [1.1 – 3.8] ℃,
- 2100 year - change 2.7 [1.1 – 5.0] °C.

This is presented in chart 1.

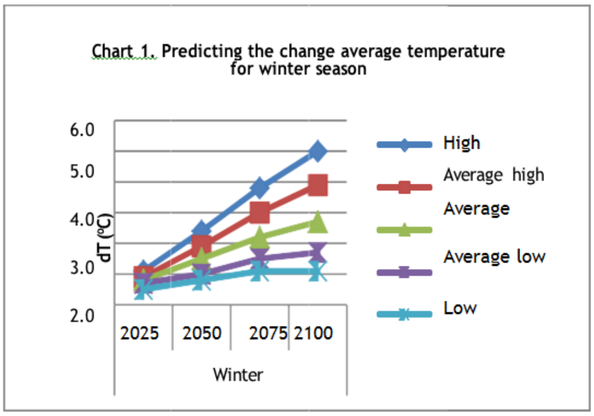


Chart 1 Predicting the change average temperature for winter season

Spring season (March, April, May):

- 2025 year - change 1.0 [0.7 – 1.4] °C,
- 2050 year – change 1.8 [0.9 – 3.0] °C,
- 2075 year - change 2.7 [1.4 – 4.6] °C,
- 2100 year - change 3.3 [1.4 – 6.2] °C.

This is presented in chart 2.

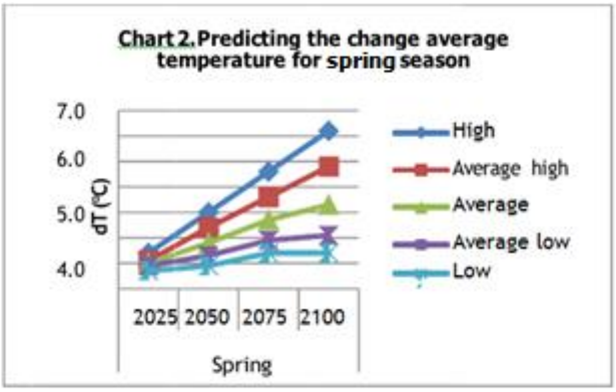


Chart 2 Predicting the change average temperature for spring season

Summer season (June, July, August):

[25] Source: Climate change scenarios for Macedonia, 2012

- 2025 year - change 1.7 [1.2 – 2.4] °C,
- 2050 year – change 3.0 [1.5 – 4.8] °C,
- 2075 year - change 4.6 [2.4 – 7.9] °C,
- 2100 year - change 5.8 [2.7 – 10.6] °C.

This is presented in chart 3.

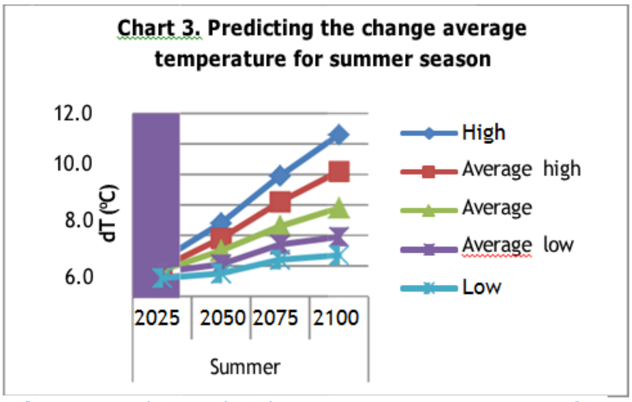


Chart 3 Predicting the change average temperature for summer season

Autumn season (September, October, November):

- 2025 year - change 1.1 [0.7 – 1.5] °C,
- 2050 year – change 1.9 [1.0 – 3.0] °C,
- 2075 year - change 3.0 [1.6 – 5.0] °C,
- 2100 year - change 3.7 [1.8 – 6.7] °C.

This is presented in chart 4.

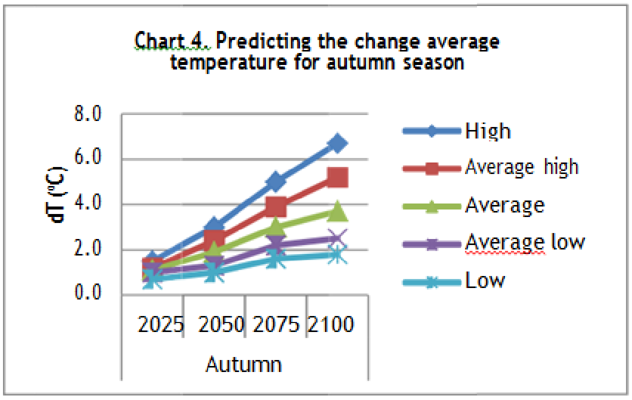


Chart 4 Predicting the change average temperature for autumn season

On annual level:

- 2025 year - change 1.2 [0.8 – 1.6] °C,
- 2050 year - change 2.0 [1.0 – 3.3] °C,
- 2075 year - change 3.1 [1.6 – 5.3] °C,
- 2100 year - change 3.9 [1.7 – 7.1] °C.

This is presented in chart 5.

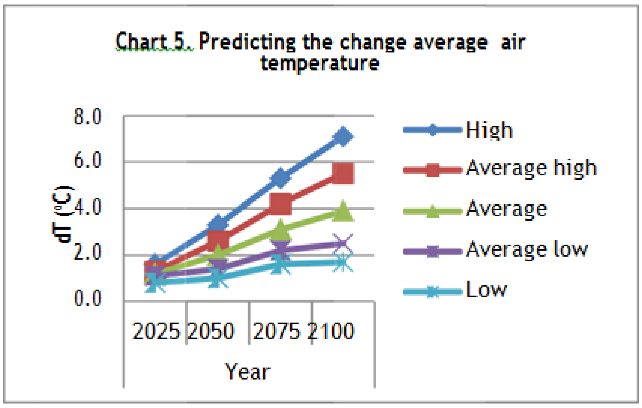


Chart 5 Predicting the change average air temperature

From the above it follows that:

- It is likely that in the period 2025 - 2100 there will be a continuous rise in temperature;
- Compared to the period 1961-1990, the projected changes are most intense in the warm part of the year. The summers would be warmer and the temperature rise more pronounced. An increase in air temperatures in the cold part of the year is forecast, but with lower intensity;
- The transition from winter to spring is probably the approach and equalization of the average monthly temperatures in this period.

On the following figure are presented the temperature projections based on the worst climate change scenario RCP8.5 for the analyzed period.

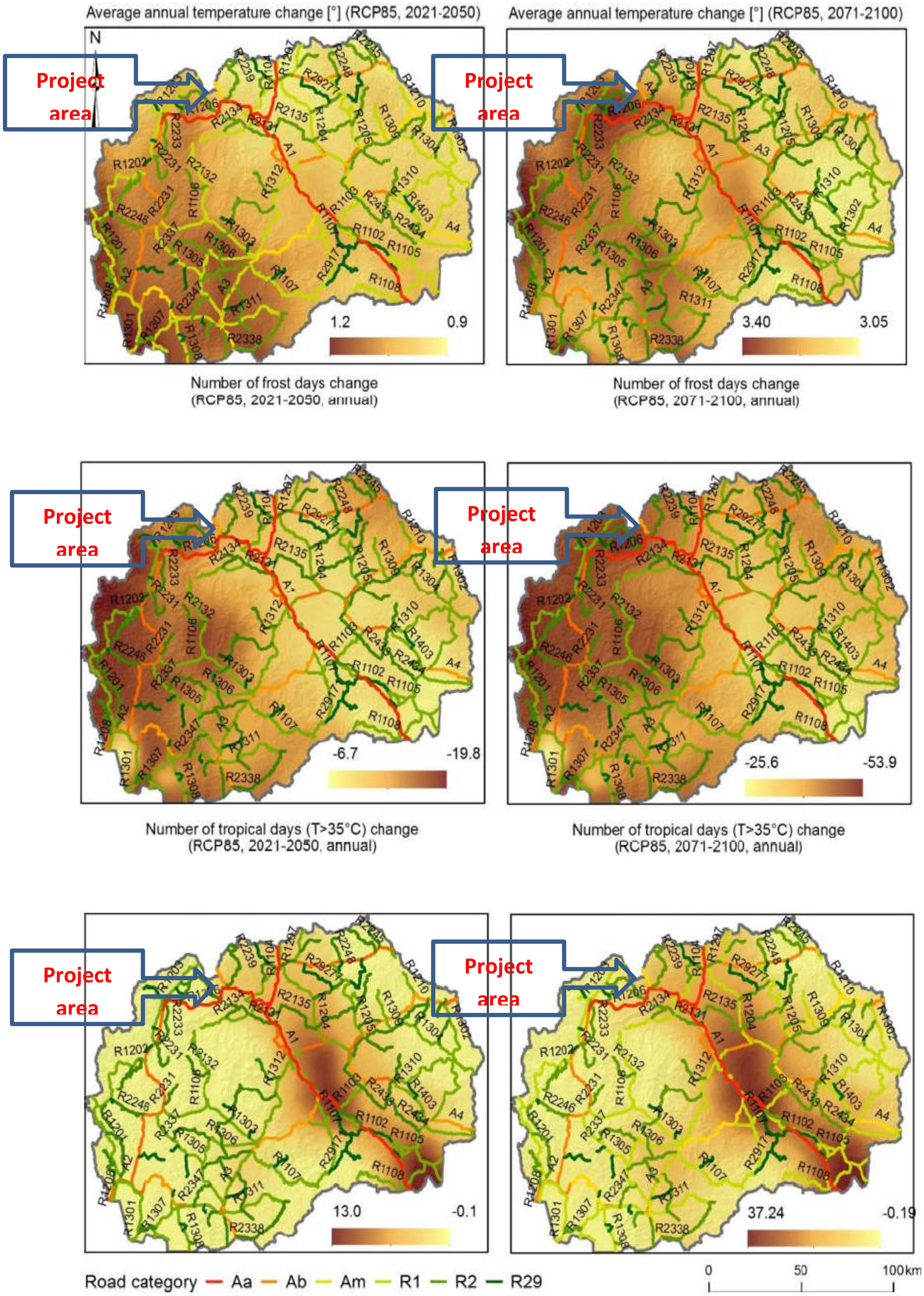


Figure 23 Temperature projections based on the worst climate change scenario RCP85 for the analyzed period [26]

[26] Technical assistance preparation of climate resilience design guidelines for the Public Enterprise for State Roads in North Macedonia, July 2019

Rainfall projections

The predicted changes in rainfall quantities are calculated for the period 2025, 2050, 2075 and 2100 for all four seasons (winter, summer, autumn and spring) on annual level. On the following table are given the changes of average rainfall quantities.

Table 10 Predicted changes in rainfall quantities for: 2025, 2050, 2075 and 2100, for four seasons (winter, spring, summer, autumn) and annually (Year)[27]

	Winter				Spring				Summer				Autumn				Year			
	2025	2050	2075	2100	2025	2050	2075	2100	2025	2050	2075	2100	2025	2050	2075	2100	2025	2050	2075	2100
Low	-1	-3	-2	-1	-2	-5	-7	-9	-4	-12	-29	-36	-1	-5	-8	-9	-2	-6	-8	-8
Average low	-1	-4	-3	-2	-2	-6	-10	-12	-6	-15	-38	-47	-1	-7	-10	-13	-3	-8	-10	-12
Average	-3	-6	-7	-9	-3	-8	-13	-17	-13	-25	-46	-57	-2	-9	-14	-20	-4	-10	-15	-19
Average high	-4	-8	-11	-16	-4	-9	-17	-23	-20	-38	-54	-66	-4	-11	-21	-27	-5	-11	-21	-27
High	-5	-10	-14	-20	-5	-12	-21	-29	-25	-48	-68	-80	-5	-14	-25	-34	-6	-14	-25	-33

It is noticed that all values are negative, which means that in the period 2025 - 2100 a decrease in precipitation is overlooked. The value before the parentheses is the mean change and the values in parentheses are: the maximum (absolutely the biggest) and the minimum (absolutely the smallest) change. The results are as follows:

Winter season (December, January, February):

- 2025 year - change -3 [-1/-5] %,
- 2050 year – change -6 [-3/-10] %,
- 2075 year - change -7 [-2/-14] %,
- 2100 year - change -6 [-1/-20] %.

This is presented in chart 6.

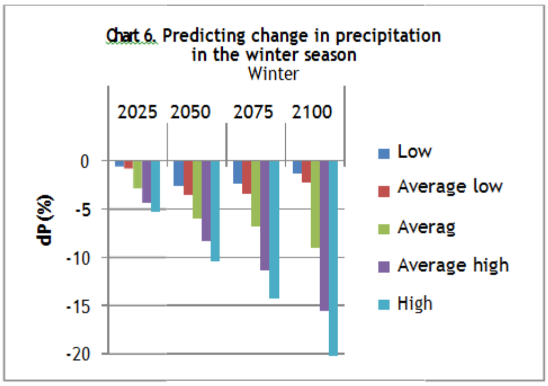


Chart 6 Predicting change in precipitation in winter season

Spring season (March, April, May):

- 2025 year - change -3 [-2/-5] %,
- 2050 year – change -8 [-5/-12] %,
- 2075 year - change -13 [-7/-21] %,
- 2100 year - change -17 [-9/-29] %.

This is presented in chart 7.

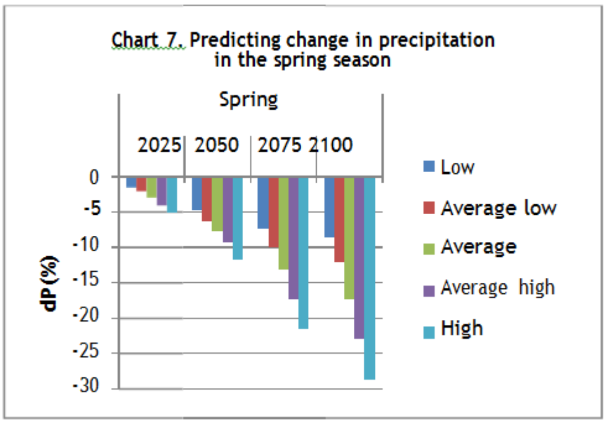


Chart 7 Predicting change in precipitation in spring season

[27] Source: Climate change scenarios for Macedonia, 2012

Summer season (June, July, August):

- 2025 year - change -13 [-4/-25] %,
- 2050 year – change -25 [-12/-48] %,
- 2075 year - change -46 [-29/-68] %,
- 2100 year - change -57 [-36/-80] %.

This is presented in chart 8.

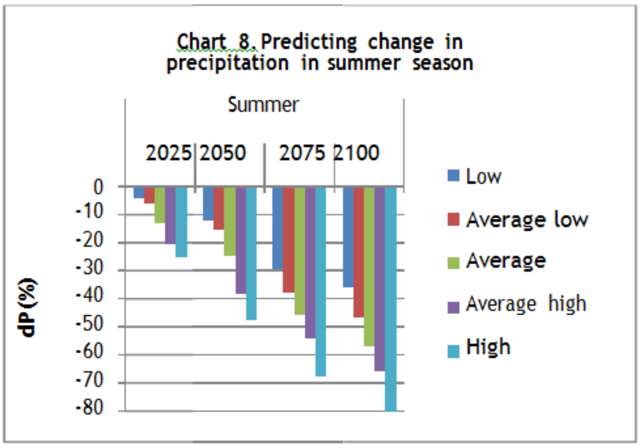


Chart 8 Predicting change in precipitation in summer season

Autumn season (September, October, November):

- 2025 year - change -2 [-1/-5] %,
- 2050 year – change -9 [-5/-14] %,
- 2075 year - change -14 [-8/-25] %,
- 2100 year - change -20 [-9/-34] %.

This is presented in chart 9.

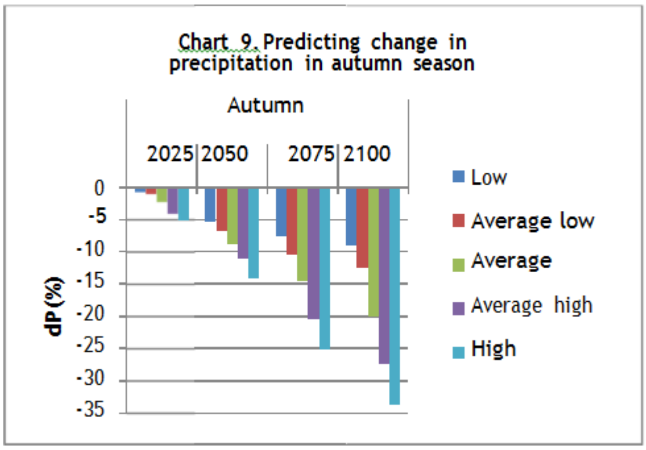


Chart 9 Predicting change in precipitation in autumn season

On annual level:

- 2025 year - change -4 [-2/-6] %,
- 2050 year – change -10 [-6/-14] %,
- 2075 year - change -15 [-8/-25] %,
- 2100 year - change -19 [-8/-33] %.

This is presented in chart 10.

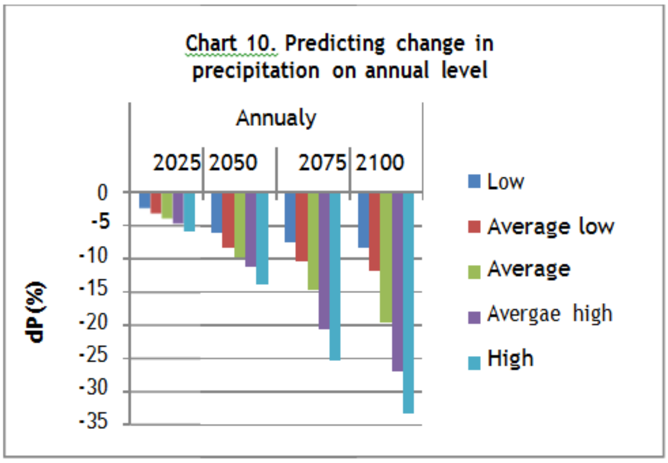


Chart 10 Predicting change in precipitation on annual level

In all seasons and annually there is a decrease in rainfall, with a maximum in the summer season. The graphs show the following:

- For all selected years, generally all changes in precipitation are negative, i.e. there is a decrease in the average amounts of precipitation,
- The intensity of the changes is greatest in the warm part of the year, so in July and August it can reach 80%, so it is likely that there will be no precipitation at all in those months,
- In the cold part of the year, reductions of between 20% and 34% of the average monthly quantities are predicted.
- Reduction of the average amount of precipitation,
- For all years (2025 - 2100) and intensity of changes (high, medium low) there is a maximum reduction of precipitation in the summer season (June, July, August),
- In the summer season the reduction of precipitation will be much bigger and faster than in the other seasons,
- In the cold part of the year the reductions are more moderate.

From the above it follows that:

- It is probable that in the period 2025 - 2100 there will be a continuous decrease in the amount of precipitation,
- The predicted changes are most intense in the warm part of the year, so the summers would be drier and it is likely that some summer months (July, August) will be without precipitation. In the previous period for which there are data there were months without precipitation.
- There is probability a decrease in precipitation in the cold part but with less intensity.

The return period of occurrence of maximum precipitation with short duration can be represented in liters per second per hectare (l / (sek * ha)). The values for Skopje Petrovec for the period 1956-1988 are presented in Table 9 and graphically shown in Figure 22. The values for Skopje Zajcev Rid for the period 1991-2020 are presented in Table 10 and graphically shown in Figure 23.

Table 11 Return period of occurrence of maximum precipitation with short duration for Skopje Petrovec (l/sec *h)

T (year)	5 '	10 '	20 '	40 '	60 '	90 '	150 '	300 '	720 '	24h	P (%)
2	220.0	170.0	119.2	72.9	52.8	37.4	25.3	14.2	6.9	3.7	**50**
5	316.7	253.3	175.0	107.1	77.2	53.9	35.3	19.8	10.1	5.3	**20**
10	380.0	308.3	212.5	130.0	93.3	64.8	42.1	23.5	12.3	6.3	**10**
25	456.7	378.3	260.0	158.8	113.6	78.7	50.6	28.2	14.9	7.7	**4**
50	516.7	430.0	294.2	180.0	128.6	88.9	56.8	31.7	16.9	8.6	**2**
100	573.3	481.7	329.2	201.3	143.6	99.1	63.0	35.2	18.9	9.6	**1**
1000	766.7	653.3	443.3	270.8	193.1	132.6	83.6	46.7	25.4	12.8	**0.1**

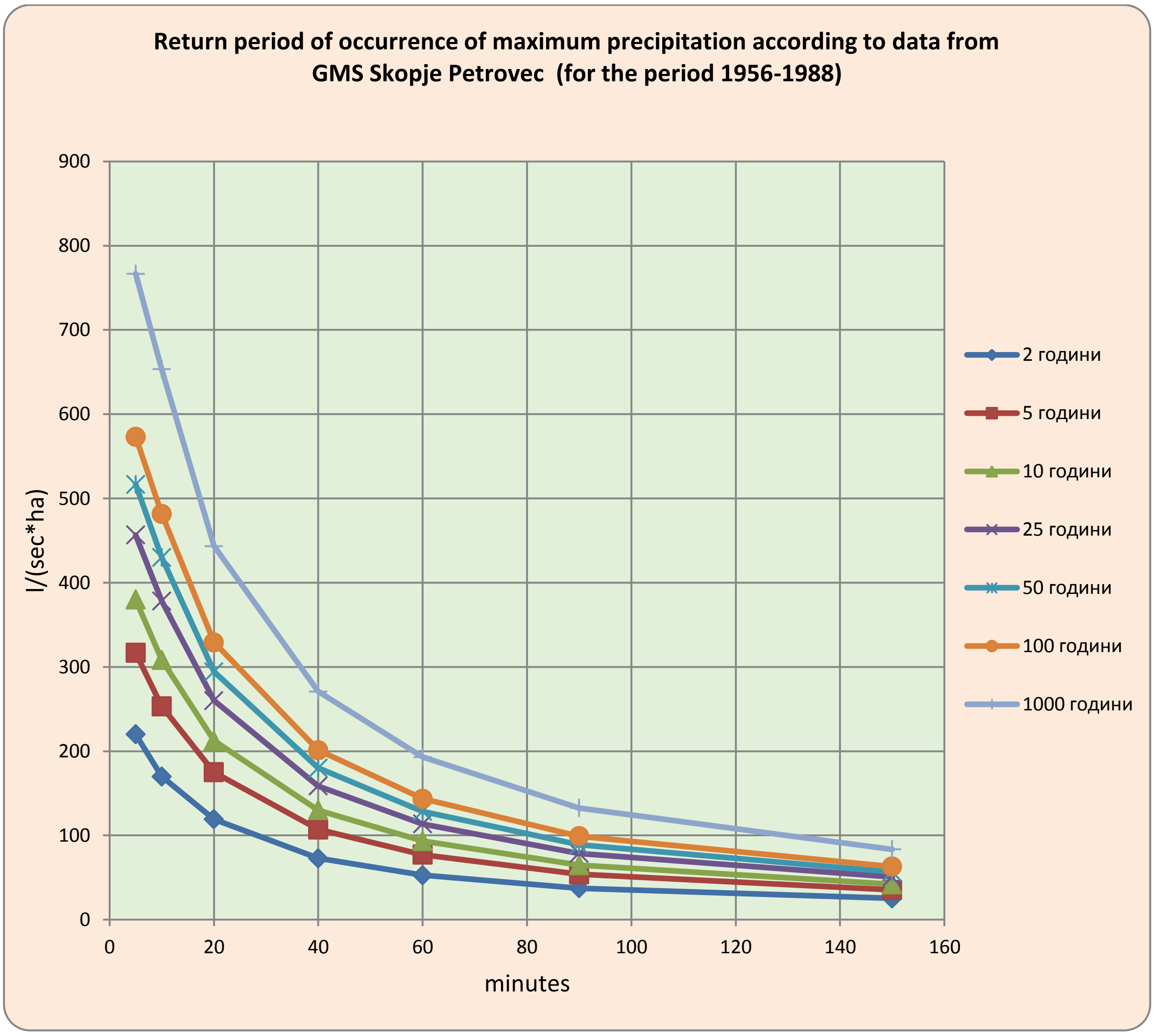


Figure 24 Return period of occurrence of maximum precipitation with short duration for Skopje Petrovec

Table 12 Return period of occurrence of maximum precipitation with short duration for Skopje Zajcev Rid (l/sec*h)

T (year)	5 '	10 '	20 '	40 '	60 '	90 '	150 '	300 '	720 '	1440 '	24h	P (%)
2	161.6	122.9	88.5	58.3	45.4	34.3	23.4	15.0	7.9	5.1	4.8	**50**
5	243.9	182.3	128.8	85.7	67.4	51.3	33.5	22.3	11.5	6.8	6.5	**20**
10	298.3	221.6	155.5	103.8	81.9	62.6	40.2	27.1	13.8	8.0	7.6	**10**
25	367.2	271.2	189.3	126.7	100.3	76.8	48.6	33.1	16.7	9.4	9.0	**4**
50	418.2	308.1	214.3	143.7	113.9	87.3	54.9	37.6	18.9	10.5	10.0	**2**
100	468.9	344.6	239.1	160.6	127.5	97.8	61.2	42.1	21.1	11.6	11.0	**1**
1000	636.4	465.5	321.2	216.4	172.2	132.4	81.7	56.9	28.3	15.1	14.4	**0.1**

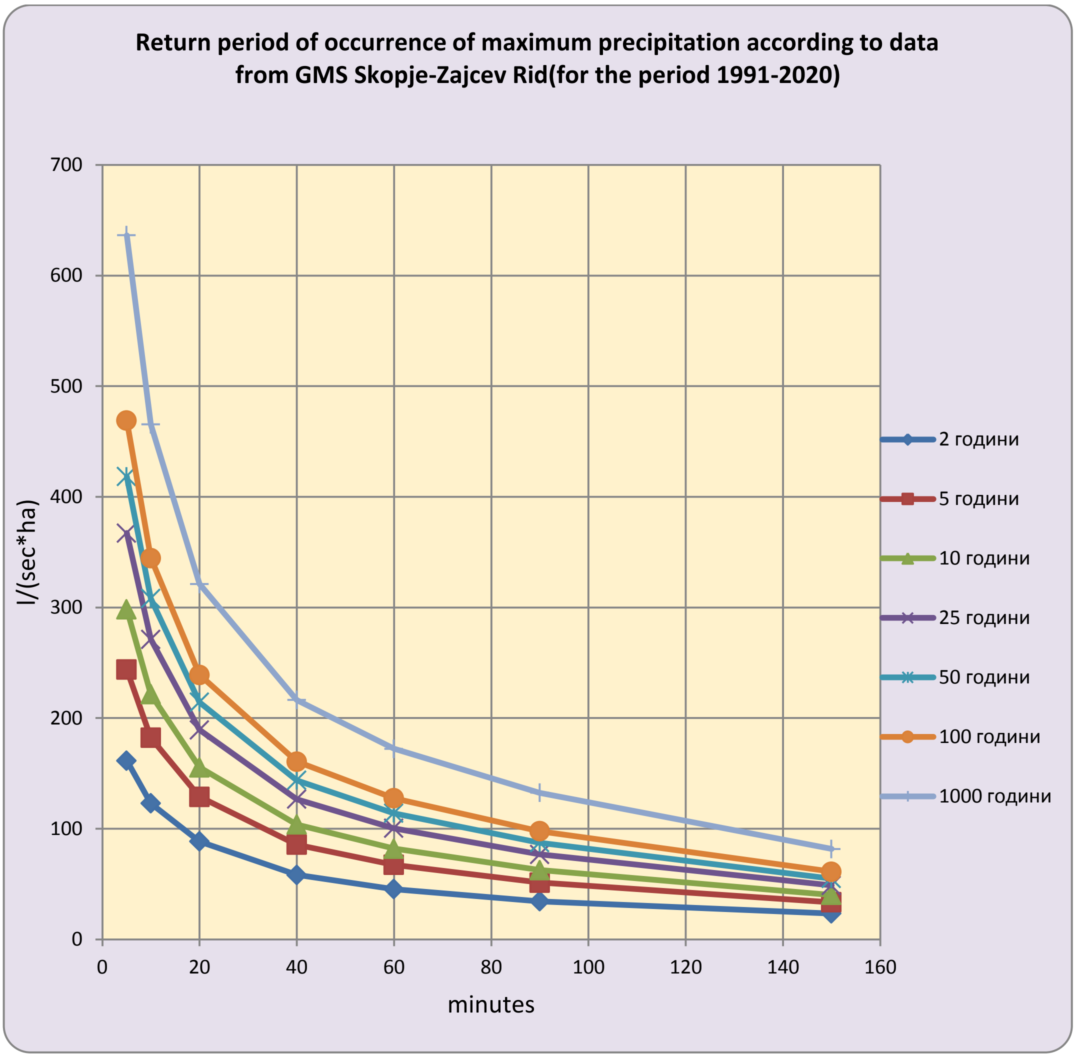


Figure 25 Return period of occurrence of maximum precipitation with short duration for Skopje Zajcev Rid

Based on the performed calculations for the return period of occurrence of maximum precipitation with short duration for Skopje, can be concluded that in the future we will expect more frequent precipitations presented through torrents, which will have very short time duration but with bigger quantities of precipitations.

On the following figure are presented the rainfall projections based on the worst climate change scenario RCP8.5 for the analyzed period.

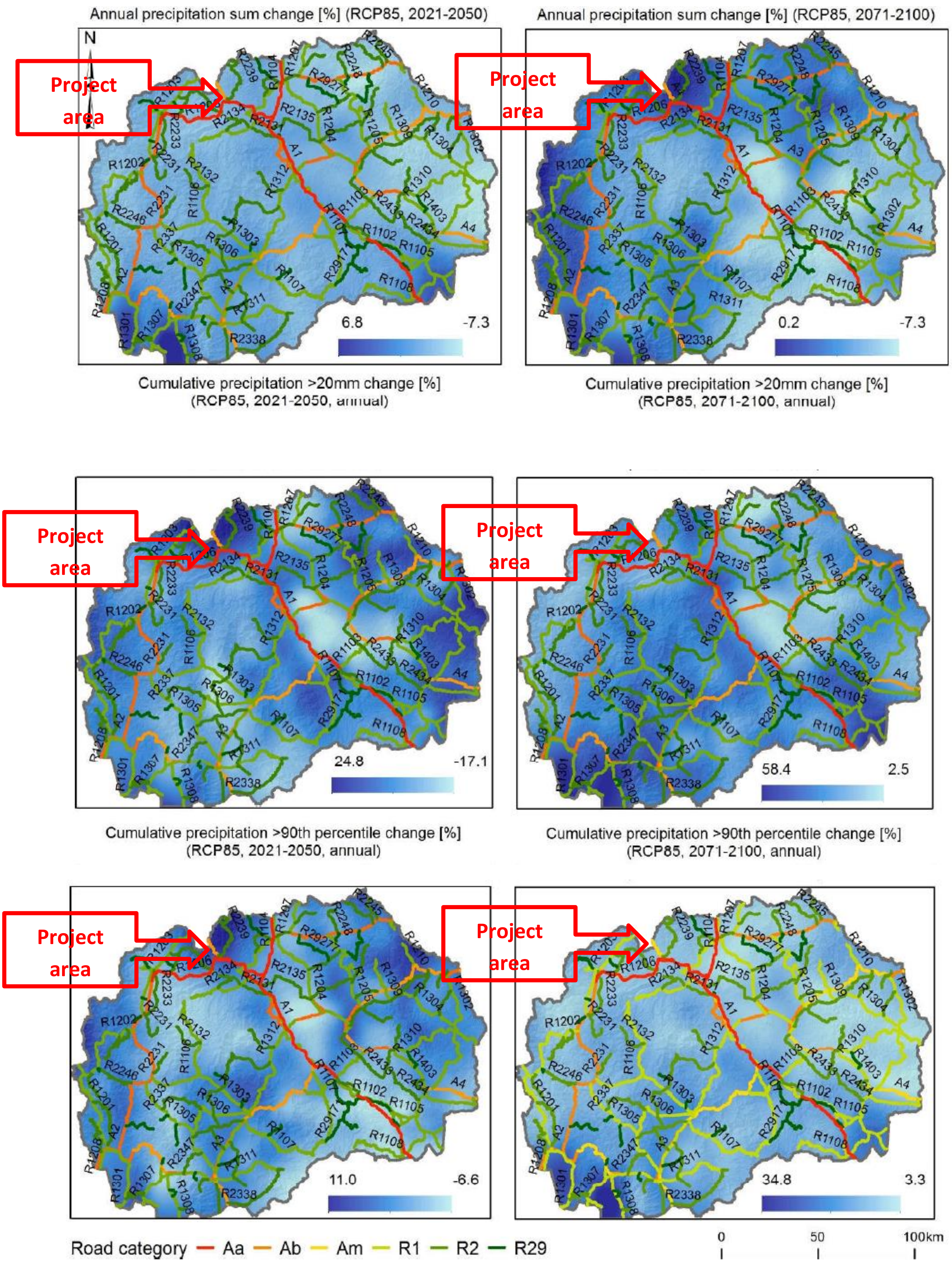


Figure 26 Rainfall projections based on the worst climate change scenario RCP85 for the analyzed period[28]

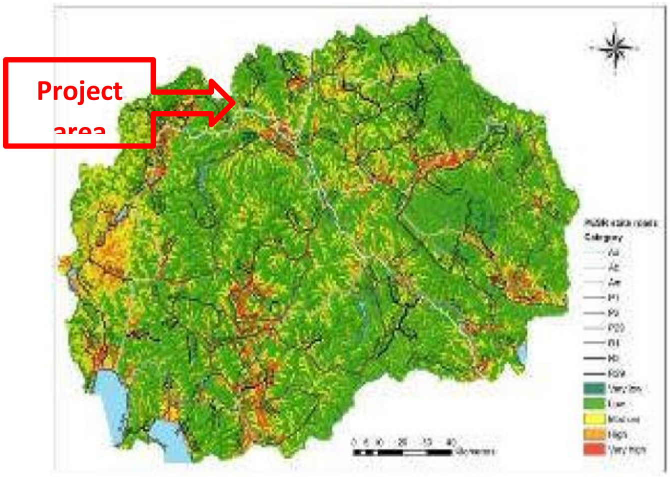
[28] Technical assistance preparation of climate resilience design guidelines for the Public Enterprise for State Roads in North Macedonia, July 2019

Flood projections

In order to assess the flood vulnerability on national level due to climatic changes two precipitation parameter (annual sum change and change of cumulative precipitation >90th percentile) are selected to simulate the effect of climate changes. Both parameters are related to the rainfall parameters obtained for the baseline (annual precipitation sum). The second parameter reflects a situation with very intense and very rapid rainfall that is unlikely to happen (probability lesser than 10%); the worst-case scenario. All climatic parameters belong to the RCP8.5 scenario, with the highest estimated gas emissions, i.e. the most severe climate changes. The Resulting Baseline Flood Vulnerability Map reveals that in vicinity of all rivers there is relatively high vulnerability to floods, especially of major rivers. Almost all river basins are critical in terms of flood vulnerability, especially in lowland parts.

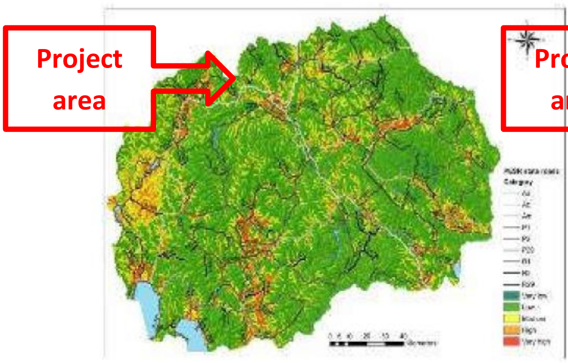
The project area where the new motorway A4 is planned to be constructed the risk of floods with the worst climate change scenario is assessed as low.

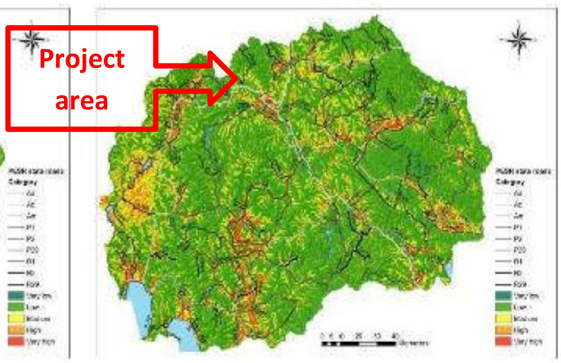
On the following figure are presented flood projections based on the worst climate change scenario RCP85 for the analyzed period.



Annual precipitation sum change [%]
(RCP85 2021-2050)

Annual precipitation sum change [%]
(RCP85 2051-2100)





Cumulative precipitation >90th percentile change [%]
(RCP85 2021-2050)

Cumulative precipitation >90th percentile change [%]
(RCP85 2051-2100)

Figure 27 Flood projections based on the worst climate change scenario RCP85 for the analyzed period[29]

[29] Technical assistance preparation of climate resilience design guidelines for the Public Enterprise for State Roads in North Macedonia, July 2019

There are no significant changes compared with baseline for the short term and long-term vulnerability projection based on annual sum change of rainfall. The change is intense for the short-term and long-term vulnerability projection with rainfall that is unlikely to happen (probability lesser than 10%), as demonstrated in figure above.

The flood projections in the project area for long term period are assessed as low at the upper part of the project area and with moderate to high risk close to interchange Stenkovec in low land which can be seen in the figure bellow.

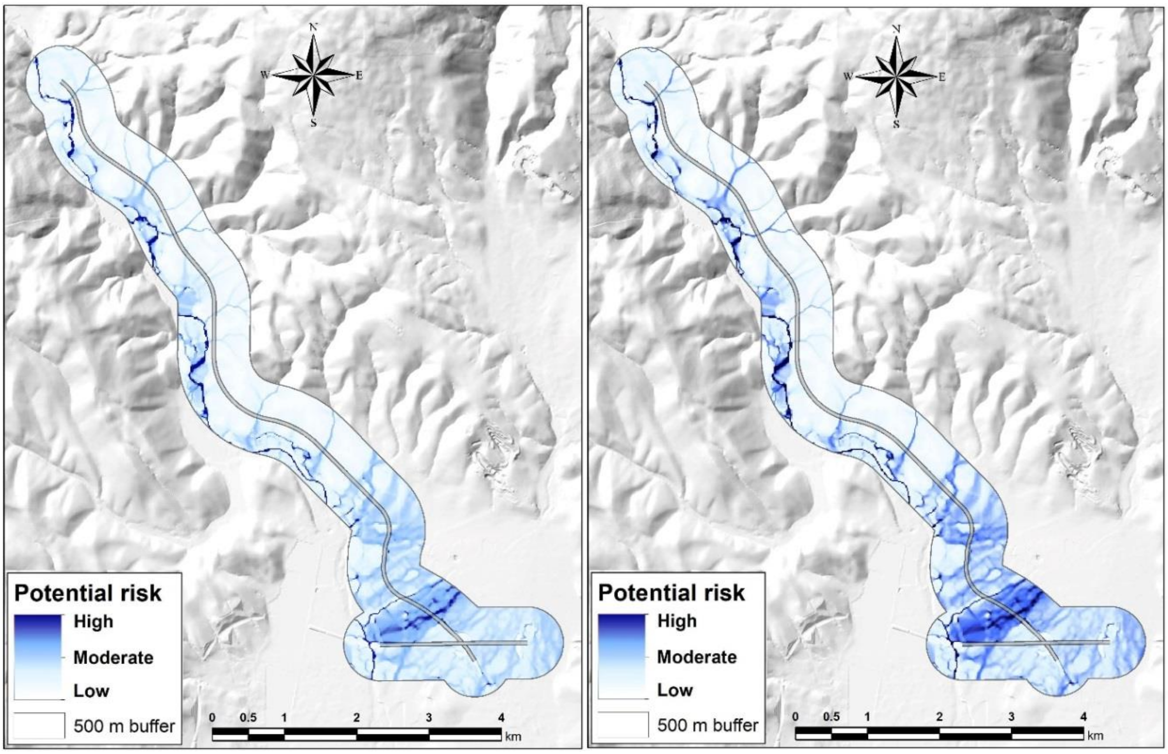


Figure 28 Flood projections for the project area: current situation (left); worst case climate change scenario (right)

Landslide susceptibility assessment

Landslide susceptibility is developed using a statistical and expert-based approach (Milevski et al. 2019), wherein, typical geological, morphometric and environmental parameters were combined. Each parameter was represented as a raster model that was subjected to a typical GIS raster processing. This included their reclassification into appropriate intervals, weighting of the importance of each class, and finally, addition of each raster into a final Landslide susceptibility model.

The susceptibility model represents a distribution of the natural potential to develop landslides, depicted by very high to very low susceptibility classes. From what is presented on the following figure, the project area has low risk of landslide in the lower part of the alignment close to interchange Stenkovec and medium to high in the beginning of the alignment based on the worst climate change scenario RCP85 for the analyzed period.

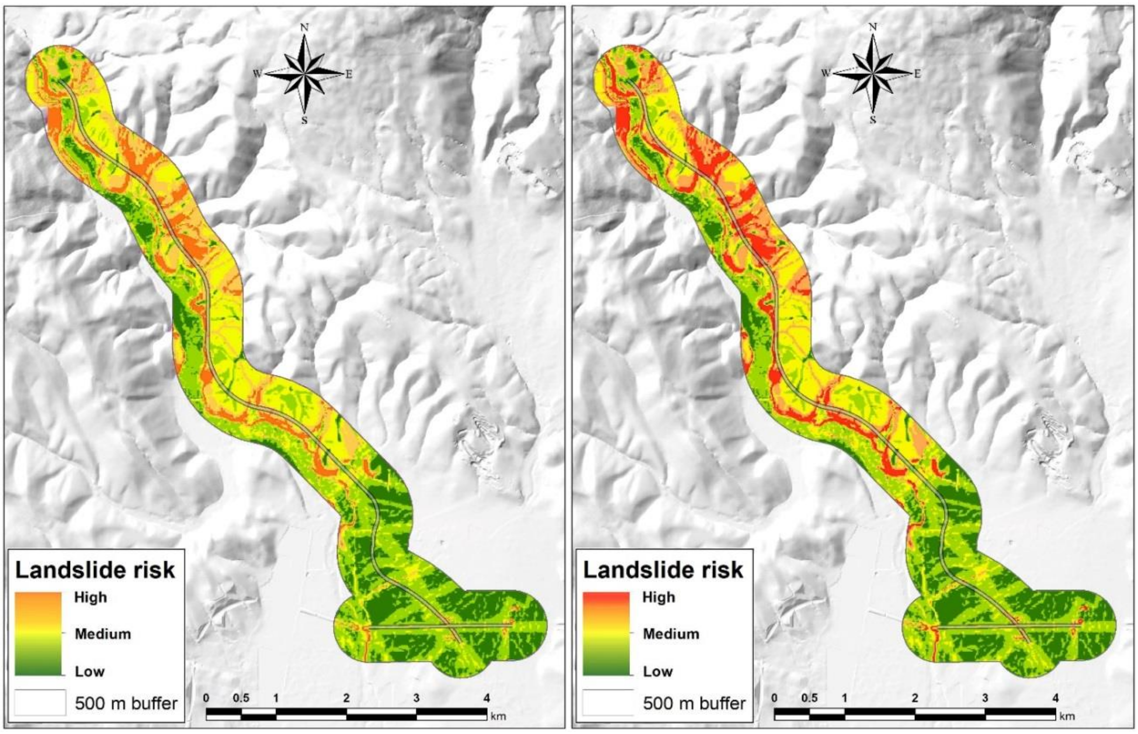


Figure 29 Landslide susceptibility map (left) and projected one (right) based on the worst climate change scenario RCP85 for the analyzed period

3.4. Assessment of vulnerability

Vulnerability is the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variables and extremes. Vulnerability, in the context of this framework, is a function of the character, magnitude and rate of climate change and variation to which a system is exposed (its exposure); and the degree to which something is affected, either adversely or beneficially, by climate-related stimuli (its sensitivity). Vulnerability is also determined by the type of asset, location or operation's adaptive capacity, and essentially the system's ability to cope and adapt to existing climatic variability and future changes.

The steps below provide a suggested approach to assessing vulnerability, which parts of the network, assets and operations are likely to be most at risk from climate change.

Selection of assets and/or locations for inclusion in the assessment

The assessment of the vulnerability will cover both phases of the project i.e. construction and operational phase of the motorway A4. Due to that, different assets and locations for assessment were identified.

In the construction phase the following assets and locations were identified:

- Construction site including access roads to it;
- Storage of materials and waste;
- Construction mechanization, equipment and vehicles;
- Work force.

In operational phase the following assets and locations were identified:

- Alignment of the motorway A4;
- Tunnels (11);
- Bridges (9);
- Underpasses (10);
- Retaining walls (10);
- Culverts (16).

The location of each structure along the alignment is presented in the following table.

Table 13 Locations of the structures along the alignment of the motorway

Structure	CH.FROM	CH.TO
Tunnels	2+569,94	2+856,65
	2+630,63	2+860,00
	3+315,79	3+596,27
	3+351,00	3+630,00
	6+494,90	7+499,76
	6+805,01	7+530,00
	7+776,21	8+500,00
	8+000,00	8+150,21
	8+259,90	8+510,00
	8+829,81	9+035,77
	8+876,53	9+028,00
Bridges	2+145,03	2+327,10
	2+145,42	2+328,62
	2+415,08	2+563,14
	3+045,00	3+290,00
	6+292,00	6+434,00
	6+308,82	6+395,79
	6+666,07	6+710,00
	11+185,44	11+225,44
	11+200,00	11+240,00
Underpasses	3+913,29	3+928,53
	4+687,05	4+694,00
	5+367,04	5+374,94
	7+589,55	7+626,25
	8+670,20	8+693,98
	9+681,08	9+710,40
	10+244,98	10+249,13
	10+474,40	10+480,33
	10+875,05	10+863,29
	11+809,01	11+827,57
Retaining walls	2+327,10	2+415,08
	2+477,00	2+525,00
	3+027,40	3+045,00
	4+635,90	4+681,40
	6+434,00	6+519,68
	6+640,00	6+666,00
	6+711,30	6+750,00
	9+156,20	9+226,00
	11+731,70	11+900,00
	11+891,56	12+040,20
Culverts	2+891,71	2+897,47
	3+174,40	3+187,17
	3+285,01	3+283,10
	3+668,66	3+704,86
	3+899,22	3+909,83
	4+339,06	4+341,19
	4+704,02	4+706,55
	5+012,35	5+018,20
	5+400,51	5+403,80
	5+513,48	5+517,50
	5+979,03	5+983,64
	7+636,80	7+670,97
	Tunnel left	7+954,09

	Tunnel left	8+200,82
	8+688,12	8+713,95
	9+443.37	9+462.09

Assessing exposure

Once all assets and locations have been defined, the next step is to assess the exposure to climate change impacts. The assessment of the exposure is done through assessing the existing exposure levels based on historical and recent event and observations, local and technical knowledge and existing research and/or on expected future exposure levels to different climate change effects. In order to identify the exposure of specific assets and/or locations, the matrix presented in table below was used. For the construction phase the projections for 2025 year were taken into consideration and for the operational phase the projections for 2050, 2075 and 2100 year were considered.

Exposure is scored as follows:

- X = No or negligible exposure now and/or in the future
- 1 = Low exposure now and/or in the future
- 2 = Medium exposure now and/or in the future
- 3 = High exposure now and/or in the future

Table 14 Exposure matrix for construction phase

Phase	Assets/location	Extreme heat	Mean heat	Drought	Mean rainfall	Storms/extreme rainfall
Construction phase	Construction site including access roads	1	x	x	x	1
	Storage of materials and waste	2	X	x	x	2
	Construction mechanization, equipment and vehicles	1	X	x	x	2
	Work force	1	x	x	x	x

Table 15 Exposure matrix for operational phase

Phase	Assets/location	Extreme heat			Mean heat			Drought			Mean rainfall			Storms/extreme rainfall		
		2050	2075	2100	2050	2075	2100	2050	2075	2100	2050	2075	2100	2050	2075	2100
Operational phase	Alignment of the motorway A4	1	2	3	1	2	3	1	2	3	1	2	3	1	3	3
	Tunnels	x	1	1	x	x	1	x	x	1	x	1	1	x	1	1
	Bridges	1	2	2	x	1	2	x	x	1	1	2	3	1	2	3
	Underpasses	x	x	1	x	x	1	x	x	x	x	2	2	1	2	2
	Retaining walls	x	x	1	x	x	1	x	x	x	x	1	2	1	2	2
	Culverts	x	x	1	x	x	1	x	x	x	1	2	2	1	2	2

Assessing sensitivity

In order to assess the vulnerability of the project to climate changes, despite of exposure matrix, sensitivity matrix is also needed to be established. Sensitivity is the degree to which a system is affected, either adversely or beneficially, by climate-related stimuli. Sensitivity can be assessed using:

- Recent and historical events;
- Geographical location;
- Condition and design life of defined assets.

The following sensitivity matrix was used in our assessment. There are 4 levels of sensitivity i.e. negligible, low, medium and high. On the table below is presented each sensitivity level with it's description related to infrastructure.

Table 16 Sensitivity scale

Level of sensitivity		**Description of Sensitivity Level to Infrastructure**
3	High	Permanent or extensive damage requiring extensive repair
2	Medium	Widespread infrastructure damage and service disruption requiring moderate repairs. Partial damage to local infrastructure
1	Low	Localized infrastructure service disruption. No permanent damage. Some minor restoration work required.
0	Negligible	No infrastructure service disruption or damage.

Calculating vulnerability levels

Through combining the exposure and sensitivity ratings, it is possible to identify whether the asset is vulnerable, to what degree, and to which climate variables. Assets having high exposure and sensitivity will have a higher vulnerability to the climate variable than those with a low exposure and low sensitivity. Those with low vulnerability to the climate variable are less likely to require adaptation strategies to be put in place to protect them. The Vulnerability Matrix shown in the table below provides how exposure and sensitivity can be used to determine overall vulnerability level.

Table 17 Vulnerability matrix

Exposure	**Sensitivity**		
	Low	Medium	High
High	4 (medium)	5 (high)	6 (extreme)
Medium	3 (low)	4 (medium)	5 (high)
Low	2 (very low)	3 (low)	4 (medium)

The following categories of the level of vulnerability will be used:

- **Extreme Vulnerability**: The network or asset is extremely vulnerable, immediate adaptation and/or mitigation will be required to prevent loss;
- **High Vulnerability**: The network or asset is highly vulnerable; adaptation and/or mitigation will be required to prevent loss;
- **Medium Vulnerability**: The network or asset is moderately vulnerable, adaptation and/or mitigation will be required to prevent damage;
- **Low Vulnerability**: The network or asset is less vulnerable, adaptation and/or mitigation would be beneficial;
- **Very Low Vulnerability**: The network or asset is not vulnerable, adaptation and/or mitigation is very unlikely to be necessary.

According to the vulnerability matrix presented above, for the purpose of the project, vulnerability level for each defined assets in construction and operational phase was assessed. According to the dynamic plan of the Public Enterprise for State Roads (PESR), the project is planned to be started in the 4th quartile of 2022. The construction of the motorway is planned to be realized in period of 3 years with possible extension of 1 year. The climate change projections for assessment of the project in construction phase were taken for the period 2025 year (central year for 2011 – 2040). For operational phase the climate change projections were taken for the period up to 2075 if we assume that the lifespan of the motorway is 50 years. In the following tables are presented the obtained vulnerability levels for construction and operational phase of the project.

Table 18 Vulnerability assessment for construction phase of the motorway A4

Assets	Climate change	Exposure	Sensitivity	Vulnerability
Construction site including access roads	Extreme heat	Medium	Medium	Medium
	Mean heat	Low	Negligible	Very low
	Drought	Negligible	Negligible	Very low
	Main rainfall	Low	Negligible	Very low
	Storms/extreme rainfall	High	Medium	High
Storage of materials and waste	Extreme heat	Medium	Medium	Medium
	Mean heat	Medium	Negligible	Low
	Drought	Medium	Negligible	Low
	Main rainfall	Low	Negligible	Very low
	Storms/extreme rainfall	High	Medium	High
Construction mechanization, equipment and vehicles	Extreme heat	Medium	Low	Low
	Mean heat	Low	Negligible	Very low
	Drought	Negligible	Negligible	Very low
	Main rainfall	Negligible	Negligible	Very low
	Storms/extreme rainfall	High	Low	Medium
Work force	Extreme heat	Medium	Low	Low
	Mean heat	Low	Negligible	Very low
	Drought	Negligible	Negligible	Very low
	Main rainfall	Low	Negligible	Very low
	Storms/extreme rainfall	Low	Low	Very low

Table 19 Vulnerability assessment for operational phase of the motorway A4

Assets	Climate change	Year	Exposure	Sensitivity	Vulnerability
Alignment of the motorway A4	Extreme heat	2050	Low	Low	Very low
		2075	Medium	Medium	Medium
		2100	High	Medium	High
	Mean heat	2050	Low	Negligible	Very low
		2075	Medium	Medium	Medium
		2100	High	Medium	High
	Drought	2050	Low	Low	Very low
		2075	Medium	Low	Low
		2100	High	Low	Medium
	Main rainfall	2050	Low	Low	Very low

Assets	Climate change	Year	Exposure	Sensitivity	Vulnerability
		2075	Medium	Low	Low
		2100	High	Low	Medium
	Storms/extreme rainfall	2050	Low	Low	Very low
		2075	High	Medium	High
		2100	High	Medium	High
Tunnels	Extreme heat	2050	Negligible	Negligible	Very low
		2075	Low	Low	Very low
		2100	Low	Low	Very low
	Mean heat	2050	Negligible	Negligible	Very low
		2075	Low	Low	Very low
		2100	Low	Low	Very low
	Drought	2050	Negligible	Negligible	Very low
		2075	Negligible	Negligible	Very low
		2100	Low	Low	Very low
	Main rainfall	2050	Negligible	Negligible	Very low
		2075	Low	Low	Very low
		2100	Low	Low	Very low
	Storms/extreme rainfall	2050	Negligible	Low	Very low
		2075	Low	Low	Very low
		2100	Low	Medium	Low
Bridges	Extreme heat	2050	Low	Low	Very low
		2075	Medium	Medium	Medium
		2100	Medium	High	High
	Mean heat	2050	Negligible	Low	Very low
		2075	Low	Low	Very low
		2100	Medium	Medium	Medium
	Drought	2050	Negligible	Negligible	Very low
		2075	Negligible	Negligible	Very low
		2100	Low	Low	Very low
	Main rainfall	2050	Low	Low	Very low
		2075	Medium	Low	Low
		2100	High	Medium	High
	Storms/extreme rainfall	2050	Low	Low	Low
		2075	Medium	Medium	Medium
		2100	High	Medium	High
Underpasses	Extreme heat	2050	Negligible	Low	Very low
		2075	Negligible	Low	Very low
		2100	Low	Medium	Low
	Mean heat	2050	Negligible	Negligible	Very low
		2075	Negligible	Low	Very low
		2100	Low	Low	Low
	Drought	2050	Negligible	Negligible	Very low

Assets	Climate change	Year	Exposure	Sensitivity	Vulnerability
		2075	Negligible	Low	Very low
		2100	Negligible	Low	Very low
	Main rainfall	2050	Negligible	Low	Very low
		2075	Medium	Low	Low
		2100	Medium	Low	Low
	Storms/extreme rainfall	2050	Low	Low	Low
		2075	Medium	Low	Low
		2100	Medium	Medium	Medium
Retaining walls	Extreme heat	2050	Negligible	Low	Very low
		2075	Negligible	Low	Very low
		2100	Low	Medium	Low
	Mean heat	2050	Negligible	Low	Very low
		2075	Negligible	Low	Very low
		2100	Low	Low	Low
	Drought	2050	Negligible	Negligible	Very low
		2075	Negligible	Low	Very low
		2100	Negligible	Low	Very low
	Main rainfall	2050	Negligible	Low	Very low
		2075	Low	Low	Low
		2100	Medium	Low	Low
	Storms/extreme rainfall	2050	Low	Low	Low
		2075	Medium	Low	Medium
		2100	Medium	Medium	Medium
Culverts	Extreme heat	2050	Negligible	Negligible	Very low
		2075	Negligible	Low	Very low
		2100	Low	Low	Low
	Mean heat	2050	Negligible	Negligible	Very low
		2075	Negligible	Low	Very low
		2100	Low	Low	Low
	Drought	2050	Negligible	Negligible	Very low
		2075	Negligible	Low	Very low
		2100	Negligible	Low	Very low
	Main rainfall	2050	Low	Low	Low
		2075	Medium	Low	Low
		2100	Medium	Low	Low
	Storms/extreme rainfall	2050	Low	Low	Low
		2075	Medium	Low	Low
		2100	Medium	Medium	Medium

4. ASSESSING AND PRIORITISING RISKS

Based on the established vulnerability assessment for the defined assets in construction and operational phase of the motorway, assessment and prioritization of risk is the next step to be conducted in order to identify where the most significant risks are expected to occur and which adaption measures need to be applied and when. For assessment and prioritization of risk of the defined assets, only those with medium and high vulnerability will be taken into considerations which are vulnerable to climate change impacts. On the following table is presented a summary of the assets which will be subject of analysis.

Table 20 Assets vulnerable to climate change impacts in construction phase

Assets	Climate change	Vulnerability
Construction site including access roads	Extreme heat	Medium
	Storms/extreme rainfall	High
Storage of materials and waste	Extreme heat	Medium
	Storms/extreme rainfall	High
Construction mechanization, equipment and vehicles	Storms/extreme rainfall	Medium

Table 21 Assets vulnerable to climate change impacts in operational phase

Assets	Climate change	Year	Vulnerability
Alignment of the motorway A4	Extreme heat	2075	Medium
		2100	High
	Mean heat	2075	Medium
		2100	High
	Drought	2100	Medium
	Main rainfall	2100	Medium
	Storms/extreme rainfall	2075	High
		2100	High
Bridges	Extreme heat	2075	Medium
		2100	High
	Mean heat	2100	Medium
	Main rainfall	2100	High
	Storms/extreme rainfall	2075	Medium
		2100	High
Underpasses	Storms/extreme rainfall	2075	Medium
		2100	Medium
Culverts	Storms/extreme rainfall	2100	Medium

4.1. Assessing impact probability

Impact probability relates to the likelihood of an impact occurring within a given timeframe. Due to the uncertain nature of climate change, assessing probability of impacts occurring can be difficult. However, approximations can be made using climate change projections, evidence of past events, proposed design of the project in the Preliminary Design, vulnerability levels and other conclusions presented in 3.2. Historical overview of climate data .

Probability should be scored for a specified point in time or timeframe. A process for assessing and scoring the likely probability of climate change risks facing the future motorway A4 is presented in the following table.

Table 22 Impact probability scoring

Probability of effect	Definition	Score
Almost certain	More likely to happen than not (probability close to 100%)	5
Likely	Fairly likely to occur (probability greater than 50%)	4
Unlikely	Possible it may occur (probability less than 50%)	3
Rare	Low, but not impossible (low, but noticeably greater than zero)	2
Highly unlikely	Very low, close to zero	1

Based on the defined impact probability scoring, in the following table are presented the scores of each identified asset in construction and operational phase.

Table 23 Impact probability scores of defined assets in construction phase of the motorway

Assets	Climate change	Vulnerability	Probability/Scores
Construction site including access roads	Extreme heat	Medium	Unlikely - 3
	Storms/extreme rainfall	High	Rare - 2
Storage of materials and waste	Extreme heat	Medium	Unlikely - 3
	Storms/extreme rainfall	High	Rare - 2
Construction mechanization, equipment and vehicles	Storms/extreme rainfall	Medium	Rare - 2

Table 24 Impact probability scores of defined assets in operational phase of the motorway

Assets	Climate change	Year	Vulnerability	Probability/Scores
Alignment of the motorway A4	Extreme heat	2075	Medium	Likely – 4
		2100	High	Likely - 4
	Mean heat	2075	Medium	Almost certain - 5
		2100	High	Likely - 4
	Drought	2100	Medium	Likely - 4
	Main rainfall	2100	Medium	Likely - 4
	Storms/extreme rainfall	2075	High	Likely - 4
		2100	High	Likely - 4
Bridges	Extreme heat	2075	Medium	Unlikely - 3
		2100	High	Likely - 4
	Mean heat	2100	Medium	Likely - 4
	Main rainfall	2100	High	Likely - 4
	Storms/extreme rainfall	2075	Medium	Likely - 4
		2100	High	Likely - 4
Underpasses	Storms/extreme rainfall	2075	Medium	Unlikely - 3
		2100	Medium	Unlikely - 3
Culverts	Storms/extreme rainfall	2100	Medium	Unlikely - 3

4.2. Assessing impact severity

Severity relates to a judgment about the severity of an impact (such as flooding of a road, heat damage to a bridge, a landslide in a particular location etc.) if it were to be realized, regardless of the probability of occurrence. Severity is assessed by the user on the basis of knowledge, estimation and evidence of past similar events (at a similar scale, at the same of similar asset, or at the same or similar location) and can be scored using the Severity Scale presented below. The assigned overall Severity Score for each asset should be that corresponding to the highest rated criterion. So, for example, if the Service criterion is scored as 5 (Very High) and all other criterion are scored as 4 (High), then the overall Severity Score should be 5 (Very High).

Table 25 Impact severity scale

Score / Criteria	1 (Very low)	2 (Low)	3 (Medium)	4 (High)	5 (Very high)
Population and communities	Less than 1% of the population affected	Between 1-2 % of the population affected	Between 2-5 % of the population affected	Between 5-10 % of the population affected	More than 10 % of the population affected
Economic impact	< 5% of annual maintenance budget or negligible budget value of the project	Asset damage > 5% but < 10% of annual maintenance budget or 1% of budget value of the project	Asset damage > 10% but < 25% of annual maintenance budget or 5% of budget value of the project	Asset damage 50%+ of annual maintenance budget or 25 % of budget value of the project	Asset damage > annual maintenance budget or 75 % of budget value of the project
Asset Damage	No infrastructure damage	No permanent damage / Some minor restoration work required	Damage recoverable by maintenance and minor repair / Partial loss of local infrastructure	Extensive infrastructure damage requiring extensive repair / Permanent loss of local infrastructure services	Permanent damage and/or loss of infrastructure
Society	Local disruption of essential services, social practices and events	Regional disruption of essential services, social practices and events	Regional disruption of essential services, social practices and events	National disruption of essential services, social practices and events	International disruption of essential services, social practices and events
Stakeholders and Supply Chain	One stakeholder or element of supply chain affected	More than one stakeholder or element of supply chain affected	One group of stakeholders or elements of supply chain affected	More than one group of stakeholders or element of supply chain affected	All stakeholder or supply chain elements affected

On the following tables are presented the impact severity scale for each identified asset in construction and operational phase.

Table 26 Impact severity scale of defined assets in construction phase of the motorway

Assets	Climate change	Population and communities	Economic impact	Asset Damage	Society	Stakeholders and Supply Chain	Overall Severity Score
Construction site including access roads	Extreme heat	1	1	1	1	2	**2**
	Storms/extreme rainfall	2	1	2	2	3	**3**

Storage of materials and waste	Extreme heat	1	1	1	1	1	**1**
	Storms/extreme rainfall	2	1	2	1	3	**3**
Construction mechanization, equipment and vehicles	Storms/extreme rainfall	1	1	2	1	2	**2**

Table 27 Impact severity scale of defined assets in operational phase of the motorway

Assets	Climate change	Year	Population and communities	Economic impact	Asset Damage	Society	Stakeholders and Supply Chain	Overall Severity Score
Alignment of the motorway A4	Extreme heat	2075	1	1	2	1	2	**2**
		2100	2	2	3	1	3	**3**
	Mean heat	2075	1	1	1	1	1	**1**
		2100	1	1	2	1	1	**2**
	Drought	2100	1	1	1	1	1	**1**
	Main rainfall	2100	1	1	1	1	1	**1**
	Storms/extreme rainfall	2075	1	1	2	1	2	**2**
		2100	2	1	3	2	3	**3**
Bridges	Extreme heat	2075	1	1	2	1	1	**2**
		2100	1	2	3	1	2	**3**
	Mean heat	2100	1	1	2	1	1	**2**
	Main rainfall	2100	1	1	2	1	1	**2**
	Storms/extreme rainfall	2075	1	1	2	1	2	**2**
		2100	1	2	3	2	3	**3**
Underpasses	Storms/extreme rainfall	2075	1	1	1	1	2	**2**
		2100	1	2	2	2	2	**2**
Culverts	Storms/extreme rainfall	2100	1	2	2	2	2	**2**

4.3. Establishing of risk scores

Risk can be seen as a combination of probability and severity. By multiplying together the score for these two criteria, a 'Risk' score of between 1 and 25 is calculated. Based on this numerical score, each risk can be graded and color coded as shown in table below from 1 (Low) to 25 (Extreme). The resulting score will be assigned one of four levels of risk: Low <5, Medium ≥ 5, High ≥ 12 and Extreme ≥ 20. From this scoring, levels of action and attention will be determined.

Table 28 Risk score matrix

Likelihood	**Severity**				
	1	**2**	**3**	**4**	**5**
1	1	2	3	4	5
2	2	4	6	8	10
3	3	6	9	12	15
4	4	8	12	16	20
5	5	10	15	20	25

The definition of each risk level is presented in the following table.

Table 29 Risk categories and responses

Level of risk	Definition
Extreme ≥ 20	• Extreme risks demand urgent attention at the most senior level and cannot be simply accepted as a part of routine operations without executive sanction. • These risks are not acceptable without treatment
High ≥ 12	• High risks are the most severe that can be accepted as a part of routine operations without executive sanction but they are to be the responsibility of the most senior operational management and reported upon at the executive level. • These risks are not acceptable without treatment.
Medium ≥ 5	• Medium risks can be expected to form part of routine operations but they will be explicitly assigned to relevant managers for action, maintained under review and reported upon at the senior management level. • These risks are possibly acceptable without treatment.
Low < 5	• Low risks will be maintained under review but it is expected that existing controls will be sufficient and no further action will be required to treat them unless they become more severe. • These risks are can be acceptable without treatment.

Based on the established risk score matrix and risk categories, the final step would be the assessment of risks on each defined assets in construction and operational phase of the project, and it's prioritization. On the following table is presented the risk score of construction and operation of the motorway A4 Blace – Skopje (Stenkovec).

Table 30 Risk score of defined assets in construction phase of the motorway

Assets	Climate change	Probability score	Severity Score	Risk Score
Construction site including access roads	Extreme heat	3	2	**6**
	Storms/extreme rainfall	2	3	**6**
Storage of materials and waste	Extreme heat	3	1	**3**
	Storms/extreme rainfall	2	3	**6**
Construction mechanization, equipment and vehicles	Storms/extreme rainfall	2	2	**4**

Table 31 Risk score of defined assets in operational phase of the motorway

Assets	Climate change	Year	Probability/Scores	Severity Score	Risk Score
Alignment of the motorway A4	Extreme heat	2075	4	2	**8**
		2100	4	3	**12**
	Mean heat	2075	5	1	**5**
		2100	4	2	**8**
	Drought	2100	4	1	**4**
	Main rainfall	2100	4	1	**4**
	Storms/extreme rainfall	2075	4	2	**8**
		2100	4	3	**12**
Bridges	Extreme heat	2075	3	2	**6**
		2100	4	3	**12**
	Mean heat	2100	4	2	**8**
	Main rainfall	2100	4	2	**8**

Assets	Climate change	Year	Probability/Scores	Severity Score	Risk Score
	Storms/extreme rainfall	2075	4	2	**8**
		2100	4	3	**12**
Underpasses	Storms/extreme rainfall	2075	3	2	**6**
		2100	3	2	**6**
Culverts	Storms/extreme rainfall	2100	3	2	**6**

5. IDENTIFYING IMPACTS AND SELECTING ADAPTION MEASURES

Based on the performed risk assessment for the future motorway A4 Blace – Skopje (Stenkovec) as a result of climate change projections, identification of impacts and adaptation measures for each risk and impact needs to be proposed. In the following sub – chapters are presented the assessed impacts and adaptation measures for each identified assets in construction and operational phase of the motorway.

5.1. Identification of impacts and adaptation measures in construction and operational phase

Construction phase

The most affected assets in the construction phase will be:

- Construction site including access roads;
- Storage of materials and waste;
- Construction mechanization, equipment and vehicles.

Based on the performed risk assessment, these assets are vulnerable to extreme heat and storms/extreme rainfall. As a result of the extreme heat and storms/extreme rainfall in the following table are presented the possible impacts and adaptation measures for each asset in construction phase:

Table 32 Impacts and adaptation measures in construction phase

Assets	Climate change impact	Impact on assets	Adaptation measures
Construction site including access roads	Extreme heat	• Drying and cracking of construction land; • Increased dust emissions; • Forest fires may occur; • Extreme heat can limit construction activities, which may increase the cost and duration of construction and maintaining activities.	• Stopping the work during extreme temperatures according to the recommendations by the governmental institutions; • Supply the construction site with sufficient technical water; • Spraying the construction site and access roads with water in order to reduce the dust emissions; • Install ventilation systems in ground facilities; • Review of the Preliminary Design and Main Design to evaluate design measures and materials specification in light of the anticipated climate change forecasts and projections over the lifetime of the Project; • Prepare and implement Emergency

			Preparedness and Response Plan (EPRP); • Development and implementation of emergency and resilience plans and changes of working practices and policies.
	Storms/extreme rainfall	• Accumulation of water or complete flooding of the construction site and the access to it; • Excess erosion and sedimentation, landslides activation.	• Review capacity of pump equipment; • Install drainage system for collection of storm water and torrential flows from the bigger catchment areas i.e. installation of open channels, pipelines and culverts; • Technical protection measures on location with possibility of landslide.
Storage of materials and waste	Extreme heat	• Risk of fires as a result of storage of flammable substances on construction site;	• Improved coverage of fire-fighting equipment; • Store flammable materials in special heat-resistance containers; • Development and implementation of emergency and resilience plans and changes to working practices and policies
	Storms/extreme rainfall	• Flooding of the stored material; • Drainage of the piles of temporary stored excavated material;	• Use waterproof materials and materials that are less affected by water; • Using water capture and storage systems; • Install drainage system for storm water; • Build reservoirs and retaining ponds to buffer the water.
Construction mechanization, equipment and vehicles	Storms/extreme rainfall	• Reduce visibility for the drivers of vehicles; • Turning the ground into mud which poses its own risks to the health and safety of site workers which are operating the mechanization; • Ignition of equipment containing hazardous substances; • Damage of construction equipment (melting); • In case of complete flooding of	• Stopping the work during intensive rainfalls; • Installation of drainage on the construction site for the storm water; • Parking the mechanization and equipment on stable terrains.

		the construction site, the mechanization, equipment and vehicles can not be used.	

Operational phase

In operational phase of the motorway A4 Blace – Skopje (Stenkovec) the following assets will be affected by the climate change:

- Alignment of the motorway A4;
- Bridges;
- Underpasses;
- Retaining walls;
- Culverts.

Based on the performed risk assessment, these assets are vulnerable to extreme heat and storms/extreme rainfall for the upcoming period. As a result of the extreme heat and storms/extreme rainfall which are expected to happen in the next period as described in the Chapter climate change projections and scenarios, in the following table are presented the possible impacts and adaptation measures for each asset in operational phase:

Table 33 Impacts and adaptation measures in operational phase

Assets	Climate change impact	Impact on assets	Adaptation measures
Alignment of the motorway A4	Extreme heat	• Higher temperatures and solar radiation can increase the rate of degradation of pavements leading to higher maintenance costs; • Softening and expansion of pavements which can lead to rutting and pavement cracking.	• Confirm capability of current heat-resistant road and track materials and if necessary use more heat tolerant binders and materials; • Use lighter color paving materials (i.e. concrete) or reflective coatings for asphalts; • Maintain and implement vegetation management practices that minimize fire risk.; • Prepare Operational Emergency Preparedness and Response Plan; • Control water leakage, to prevent its disappearance in extremely dry periods, which can cause land subsidence; • Restrict the movement of vehicles transporting dangerous substances during periods of high temperatures; • Establish an appropriate program of regular control maintenance and inspection of road infrastructure • Regularly control the state of fires in the project area by visual

			inspection and monitoring of news in local media; • Install fire extinguishers in tunnels.
	Storms/extreme rainfall	• Damage to roads from landslides, flooding, and ground movement can restrict access to essential emergency services, food supplies, and access to markets and other economic opportunities; • Flooding of the road and surface damage;	• Build dams, reservoirs and retaining ponds to buffer the water; • Build flood walls to protect the road from flooding; • Construction of (temporary) flood barriers along road; • Regular cleaning of drain pipes; • Tree planting to reduce run-off rates across a catchment.
Bridges	Extreme heat	• Sensitive to high temperatures that affect thermal expansion of the joints and increase the earth pressure; • Degradation of the material (concrete, wood).	• Use more heat tolerant binders and materials; • Use lighter color paving materials (i.e. concrete) or reflective coatings for asphalts.
	Storms/extreme rainfall	• Flooding and undermining of supporting structures; • Demolition of pillars.	• Cleaning out watercourses and structures of flood prone areas ahead of predicted heavy rainfall; • Use corrosion-resistant or waterproof materials (adapting different pavement mixture design can improve resistance to water damage – compared with concrete pavement, asphalt pavement material is generally less resistant to water damage).
Underpasses	Storms/extreme rainfall	• Demolition of underpasses; • Closure of underpass with vegetation and stones;	• Regular cleaning and removal of vegetation; • Tree planting to reduce run-off rates across a catchment.
Retaining walls	Extreme heat	• Drying the vegetation which will result with destabilization of the slope; • Occurrence of wild fires which reduce vegetation cover contributing to increased run-off and the potential for flooding or landslides;	• Maintenance of the planted vegetation on slopes; • Maintain and implement vegetation management practices that minimize fire risk.
	Storms/extreme rainfall	• Increased risk of landslides, excess erosion and deposition; • Cracking the retaining walls as a	• Drainage of road embankment for fast lowering of

		result of increased rainfalls.	groundwater table after flood retreats; • Use vegetation for improving slope stability and erosion protection; • Use geo-synthetics for improving slope stability and erosion protection;
Culverts	Storms/extreme rainfall	• Storm water drainage systems have been designed based on historic precipitation data. It is possible that they will not withstand more intense and frequent events, thereby leading to road washouts and flooding of assets; • Closure of culverts with vegetation and stones;	• Inspect and clean drainage systems regularly; • Keeping the road drainage in good condition; • Prevent the clogging of pipes/culverts on connecting roads

6. CONCLUSION

The main aim of this Climate resilience report is to ensure and enhance the resilience of the proposed construction of the new motorway A4 Blace – Skopje (Stenkovec) to the effects of climate change and extreme weather events.

The prescribed measures in the Climate resilience report as well as in the ESIA study needs to be fully implemented in order the project to be adopted and resilient on a future climate change projections for the region. The proposed measures will be implemented in the Detailed Design in order the future Contractor and Operator to manage and monitor the successful implementation of the measures and to be avoid future hazards as a result of the climate change.

Despite of the climate change mitigation and adaptation measures, this Project itself has other environmental benefits. On the following table are presented the benefits on each environmental media and area as a result of the implementation and operation of the motorway and the disadvantages in case of do nothing scenario.

Table 34 Benefit and disadvantages in case of implementation of the project and do nothing

No.	Environmental media and area	Do nothing	Implementation
1.	Air quality and climate change	Increase emission of dust, exhaust gasses and GHG as a result of increased traffic on the road, traffic jams etc	Reduced dispersion of pollutants as a result of free traffic on the motorway, no traffic jams and availability of more vehicles to use the motorway as well as installation of charging station for electric vehicles which will increase the flow of this type of vehicles in the project area
2.	Surface and ground water	Free discharge of pollutants in the soil and surface and ground water bodies without any treatment as a result of leakages and incidents	Constructed and installed drainage infrastructure and oil captures for collection of storm water on the motorway and eliminate waste oils
3.	Soil	Possible risks of landslides and soil pollution	Reduced risks of landslides with stabilization of slopes and construction of retaining walls and avoidance of soil contamination as a result of constructed drainage infrastructure and installed oil captures
4.	Biodiversity	Increasing the number of mortality of animals due to the lack of fencing and corridors for movement of the animals	Reduced number of mortality of animals as a result of installation of fence on the motorway, construction of tunnels, underpasses and high bridges for movement of animals etc.

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