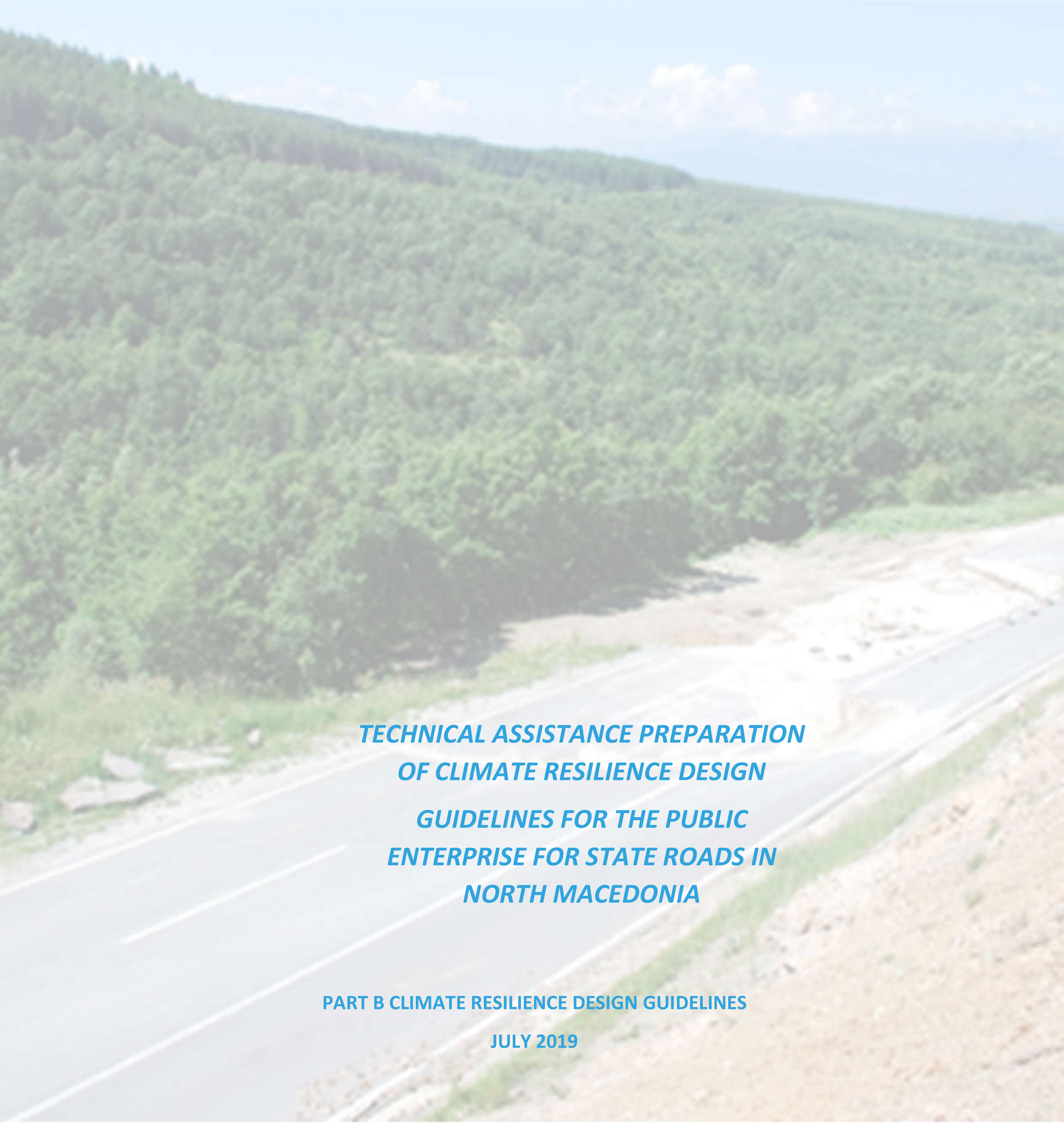

TECHNICAL ASSISTANCE PREPARATION OF CLIMATE RESILIENCE DESIGN

GUIDELINES FOR THE PUBLIC ENTERPRISE FOR STATE ROADS IN NORTH MACEDONIA

PART B CLIMATE RESILIENCE DESIGN GUIDELINES

JULY 2019

Client: Republic of North Macedonia – Public Enterprise for State Roads Project financed by the World Bank

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1 Methodology for the Assessment of Hazard, Vulnerability and Risk from Landslides and Floods

1.1 Terminology

Terminology is important to follow assessment process and these Guidelines follow that adopted by the IPCC AR5. The basic concepts and terms used are explained below.

Natural hazards - are naturally occurring physical phenomena caused either by rapid or slow onset events which can be geophysical, hydrological, climatological and meteorological.

Geological Hazards*:* Geological process or phenomenon that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage. Geological hazards include internal earth processes, such as earthquakes, volcanic activity and emissions, and related geophysical processes such as mass movements, landslides, rockslides, surface collapses, and debris or mud ows. Hydro-meteorological factors are important contributors to some of these processes.

Hydrological hazards - process or phenomenon of atmospheric, hydrological or oceanographic nature that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage.

Landslides[1] - In the broadest sense, landslides are the movement of rock, debris or earth down a slope over stable surfaces under the influence of gravity.

Landslide Susceptibility[2] – Spatial probability of an event (e.g. landslide) in an area expressed in qualitative terms (scale from low to high susceptibility) or quantitatively.

Landslide Hazard - In general terms, a space-time probability of occurrence of an event, substance, human activity or condition that can lead to loss of life, injury or other health impacts, property damage, loss of livelihoods and work, social and economic disturbances and damage to the environment. Landslide hazard is a probability of processes in a certain area of a specified magnitude / intensity in a given time period.

Conditioning Factors - Factors inducing hazards by creating favourable conditions for their development, such as unfavourable geological settings, unfavourable morphology of the terrain, poor physical and mechanical parameters of rock masses making up the terrain, unfavourable hydrological conditions, inappropriate land use, etc. A set of unfavourable conditioning factors makes specific area a subject to the event.

Triggering Factors – Factors such as heavy rainfall, rapid snowmelt, dynamic impacts (e.g. earthquakes), which directly lead to hazardous event.

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[1] According to international terminology, it is noteworthy that *Landslides* in English encompasses the entire group of gravitational processes of different mechanisms of movement that do not imply only sliding as a process or landslides as an event. A closer general term, also frequently used is “mass movements”. Macedonian language has no sufficiently precise and comprehensive linguistic terms except for sliding, falling and flowing.

[2] In the spirit of local language, the term *Susceptibility* can be translated as sensitivity, proneness.

Flood - is a temporary covering by water of land normally not covered by water. This shall include floods from rivers, mountain torrents, and floods from the sea in coastal areas, and may exclude floods from sewerage systems.

Flash floods occur when excessive water fills normally dry creeks or river beds along with currently flowing creeks and rivers, causing rapid rises of water in a short amount of time. They can happen with little or no warning and combine the destructive power of a flood with incredible speed and unpredictability.

Flood risk - is the combination of the probability of a flood event and of the potential adverse consequences to human health, the environment and economic activity associated with a flood event.

Flood hazard maps shows areas which could be flooded according to three probabilities (low, medium, high) complemented with: type of flood, the flood extent; water depths or water level where appropriate; where appropriate, flow velocity or the relevant water flow direction.

Flood risk maps indicate potential adverse consequences associated with floods under several probabilities, expressed in terms of: the indicative number of inhabitants potentially affected; type of economic activity of the area potentially affected; installation which might cause accidental pollution in case of flooding.

Flood plain maps indicate the geographical areas which could be covered by a flood (from all sources except sewerage systems – see above definition of flood) according to one or several probabilities: floods with a very low probability or extreme events scenarios; floods with a medium probability (likely return period >=100y); floods with a high probability, where appropriate.

Elements at risk - People, assets, systems or other elements present in hazard zones that are affected or subject to potential losses.

Vulnerability - Characteristics and conditions of exposed elements that make them susceptible to the harmful effects of danger. Vulnerability is expressed as the potential extent of the loss of value of a given element or set of elements exposed to geological and climate-related hazards of a corresponding intensity or magnitude.

Risk - The combination of the probability of a hazardous event and its negative consequences on the exposed elements over time. It is assumed that is combination of hazard, and vulnerability of exposed elements.

Risk Assessment - The methodology for determining the nature and extent of risk by analysing potential hazards and the assessment of the existing conditions of vulnerability that together could cause damage to exposed persons, property, services, living conditions and environment that the population is dependent on.

Landslide risk - a combination of the likelihood of a landslide-related hazard event and its adverse effects on exposed elements over time. It is assumed to be a combination of hazard and vulnerability to exposed elements.

Resilience - The ability of a system, community or society exposed to hazards to resist, absorb, and respond to the effects of hazards in a timely and efficient manner and to recover, including the preservation and restoration of its essential basic structures and functions.

Road Link (also referred to as segment) - a section of road between clearly defined points.

Road infrastructure asset – a distinct structure within the road corridor. Examples include a drainage structure (e.g. culvert), bridge, retaining wall and other supportive structures. These structures tend to enhance the resilience of the road corridor and reduce the vulnerability of the road network as specific locations.

Road element. This is a distinct part of the road corridor or road infrastructure asset. For example, this could be a bridge abutment, embankment or road pavement.

1.2 Introduction

The Guidelines provide detailed and practical instructions on how to conduct a climate change and natural hazard road network vulnerability and risk assessment. The process is structured into a series of tasks. These tasks together will guide users in how to manage step by step, hazard, vulnerability and risk assessment through additional expert support. The individual tasks build on each other to provide the overall analysis.

The Guidelines are designed to generate the answers to a series of practical questions, namely:

1. What parts of the road network cross areas with high climate related hazard(s) zones;
2. What is the relative level of risk to the road infrastructure, from increased natural hazards across the road network;
3. What level of socio-economic impacts could potentially be generated due to hazard events on particular roads;
4. What are the appropriate treatments for each hot spot identified?
5. What are the priorities for future road interventions? This applies to both current climate conditions and for future climate change projections;
6. What are the estimated budgets for the work required to prioritise mitigation and resilience measures with respect to climate and natural hazard events?

It is re-emphasised that these Guidelines are designed for Technical Staff to follow the Methodology whilst using specialist inputs to generate the outputs from the work.

We expect that the user will have the ability to adapt the data inputs including the use of proxy data (where specific original data is unavailable). The user should also be familiar with the work of post-processing of data in GIS environment and managing short timeframe series of records or different return periods for different hazardous phenomena.

Each logical process within the methodology is formulated as a module, defined by the algorithm/ assessment approach and specific inputs and outputs. With such an approach, each module can independently be adapted to a specific country case, as long as it completes the assigned logical task in the chain of steps and provides the desired outputs in the format required. As the sector in a country develops, the more data and capacity will become available, allowing for refinement and/ or improvement of the algorithm/ assessment approach within each module. In this respect, and under each module, the algorithm/ assessment approach suited for limited data availability and capacities is used. Nevertheless, tested algorithms/ assessment approaches are also complemented with descriptions and advancement recommendations to be used once the conditions are met. Ultimately, due to a modular structure of the methodology each user has full freedom to elaborate the way, i.e. algorithm, upon which each modular step will be analysed and calculated.

The methodology distinguishes between two main groups of actions: i) risk impact assessment, and ii) identification and prioritisation of engineering/ non-engineering solutions for risk reduction/ mitigation. The identification of road sections under the most critical need for intervention (in relation to natural hazards) is performed through four steps incorporating 9 tasks spanning across three layers: Hazard, Risk, and Engineering Screening. In addition is the planning layer - Data Layer as a common one for all the other layers that represents the baseline data prepared for PESR with the hydromet data, climate projections and historic data hazard maps.

Introduction of layers reflects the modular structure of the approach and brings about a logical clustering of tasks/ modules in the overall process of application. In addition, it acknowledges the main purpose of each task/ module and prescribes the main skills and data processing requirements for the accomplishment of the actions within. Baseline Layer requires good GIS and overall data processing and management skills. Under the Hazard Layer, ideally a team of engineers with specific knowledge on hazards (e.g. geologists, geotechnical, hydrologists, etc.) is needed. The engineers with the knowledge on hazards, but supported by road/ transport specialists, will have a key role under the Risk Layer. The remaining layers are much more transport-specific, with a slight difference that in the Engineering Screening Layer there is a need for civil engineers and transport planners/ economists, while the Engineering Planning Layer needs civil, road/ transport and geotechnical engineers with knowledge on road design, operation, maintenance and costs. Both Engineering Layers also represent areas/ tasks that should be primarily integrated within RAMS and, in some cases, could be extracted directly from RAMS.

The main steps of this methodology are:

- Step 1. Climate modelling and hazard analysis to create layers at a national scale for input into GIS, to inform the identification of hot spot areas;
- Step 2. Create CVRA model in GIS environment to produce hotspot maps to identify priority road sections for further study and interventions;
- Step 3. Use CVRA output and field studies to select engineering and non-engineering interventions; and
- Step 4. Prioritise measures on an economic basis and develop an investment plan.

These are set out in more detail as follows (Fig 1):

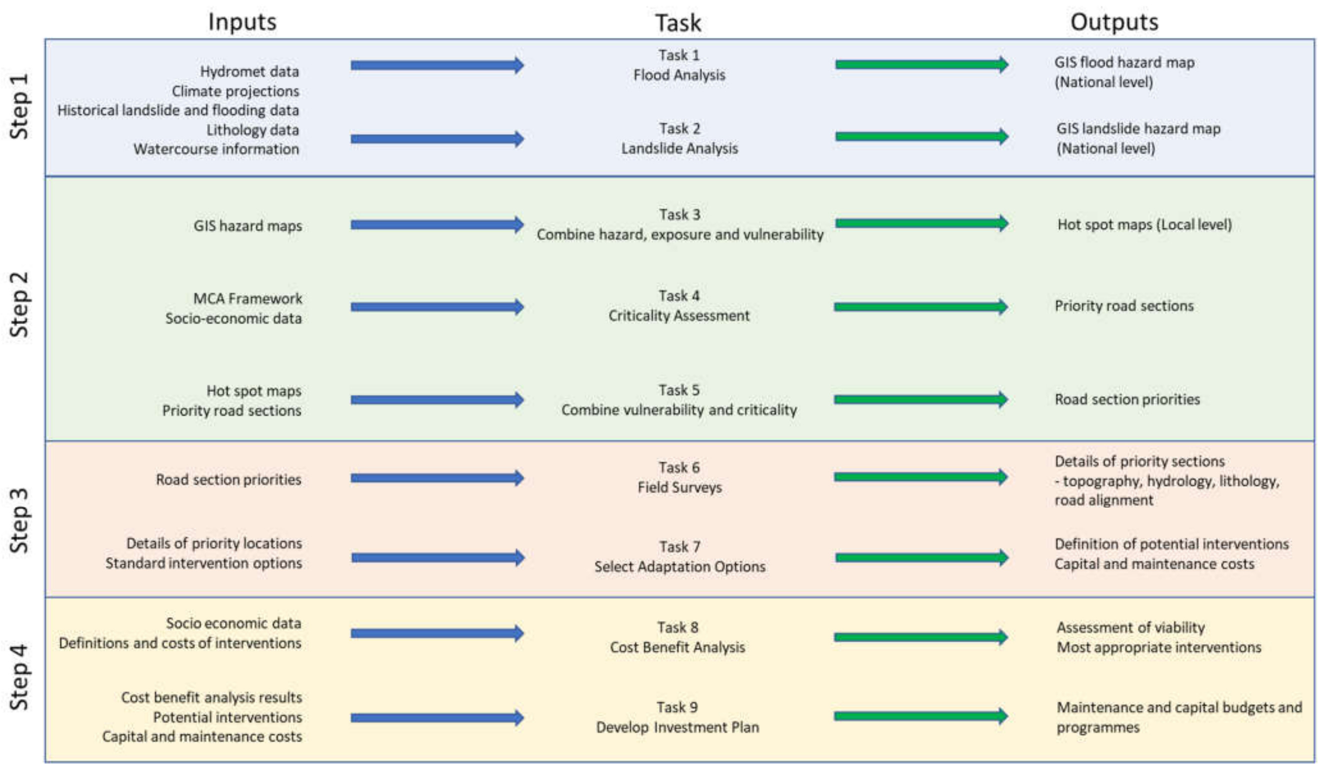


Figure 1 Summary of Key Steps and Tasks

Step 1. Climate modelling and hazard analysis to create layers at a national scale for input into GIS, to inform the identification of hot spot areas;

2 Application in the Republic of North Macedonia

2.1 Baseline climate characteristics for North Macedonia– climate modelling and hazard analysis

Baseline climate data is crucial in describing and forecasting the current climate most likely to be experienced at a given location. It also serves as a benchmark against which recent or current observations can be compared, including providing a basis for many anomaly-based climate datasets (e.g. global mean temperatures).

Baseline climate data is based on historical records, with mean values for successive 30 years periods being the most frequently used statistical normal parameter and a requirement of the United Nation's World Meteorological Organization (WMO). In North Macedonia, the National Hydrometeorological Service holds long-term daily and monthly records.

Although it is a small country, the Republic of North Macedonia has a diverse climate. The following, more homogeneous climate regions and sub-regions, are differentiated as in description below and presented in the Figure 2.

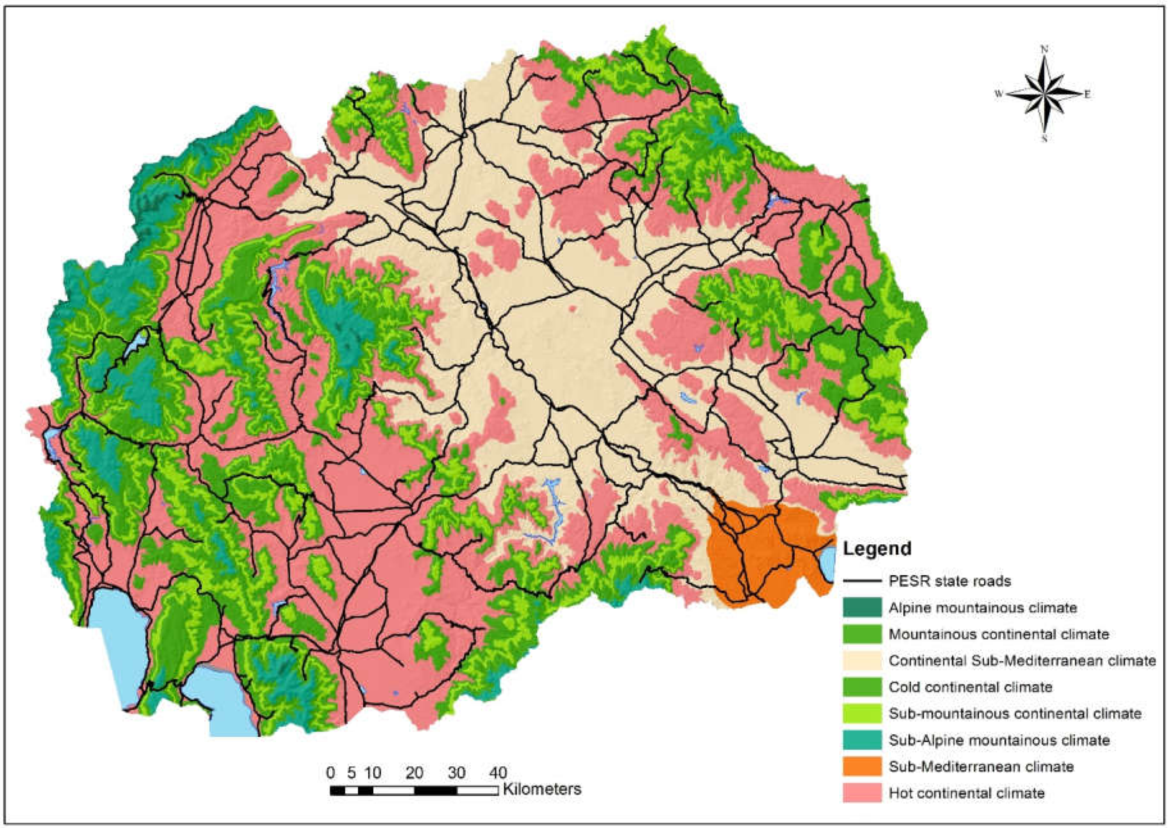


Figure 2 Climatic regions in Republic of North Macedonia

The list of climatological and meteorological stations, which are used to define climate parameters, according to the climate zone and location is presented on Figure 3.

For basic climate elements (annual rainfall amounts, maximum and minimum air temperatures and others), series of data from 1961-2015 were used. The data from the national water strategy were used as source. For the maximum 24 hours of precipitation, series data from 1961-2017 for 13 stations were used. For intense rainfall with short duration and different return period, the latest HMS data was used. Innovation of the IDF curves was carried out by HMS for six main meteorological stations.

Nº	Station	Climate Type	Altitude	Latitude	Longitude
1	Gevgelija	Sub-Mediterranean	59	41° 09'	22°30'
2	Valandovo	Sub-Mediterranean	100	41° 19'	22° 34'
3	Demir Kapija	Sub-Mediterranean	125	41° 25'	22° 15'
4	Nov Dojran	Sub-Mediterranean	180	41° 13'	22° 43'
5	Veles	Moderate continental Sub-Med	175	41° 25'	22° 15'
6	Strumica	Moderate continental Sub-Med	224	41° 26'	22° 39'
7	Skopje-Petrovec	Moderate continental Sub-Med	232	41° 57'	21° 38'
8	Amzabegovo	Moderate continental Sub-Med	250	41° 49'	22° 00'
9	Kavadarci	Moderate continental Sub-Med	260	42° 26'	22° 02'
10	Katlanovo	Moderate continental Sub-Med	260	41° 54'	21° 42'
11	Skopje-Zajcev Rid	Moderate continental Sub-Med	301	42° 01'	21° 24'
12	Stip	Moderate continental Sub-Med	326	41° 45'	22° 11'
13	Kumanovo	Moderate continental Sub-Med	338	42° 08'	21° 43'
14	Kocani	Moderate continental Sub-Med	345	41° 55'	22° 25'
15	Radovis	Moderate continental Sub-Med	380	41° 38'	22° 27'
16	Tetovo	Hot continental	462	42° 00'	20° 58'
17	Gostivar	Hot continental	525	41° 48'	20° 55'
18	Makedonski Brod	Hot continental	545	41° 31'	21° 13'
19	Bitola	Hot continental	586	41° 03'	21° 22'
20	Kicevo	Hot continental	620	41° 31'	20° 58'
21	Delcevo	Hot continental	630	41°58'	22° 46'
22	Kratovo	Hot continental	640	42° 05'	22° 09'
23	Prilep	Hot continental	673	41° 20'	21° 34'
24	Debar	Hot continental	675	41° 31'	20° 32'
25	Kriva Palanka	Hot continental	691	42° 12'	22°20'
26	Struga	Hot continental	695	41° 20'	20° 41'
27	Ohrid	Hot continental	760	41° 07'	20° 48'
28	Berovo	Cold continental	824	41° 43'	22° 51'
29	Resen	Cold continental	881	41° 05'	21° 01'
30	Krusevo	Sub-forest-continental-mountainou	1230	41° 22'	21° 15'
31	Mavrovo	Forest-continental mountainous	1240	41° 42'	20° 45'
32	Lazaropole	Forest-continental mountainous	1332	41° 32'	20° 42'
33	Popova Sapka	Sub-alpine mountainous	1750	42° 01'	20° 53'
34	Solunska Glava	Alpine mountainous	2540	41° 42'	21° 25'

Figure 3 List of climatological and meteorological stations

<u>Road classification according to climate regions</u>

According to the topographic characteristics and the size of the climate regions, most of the road transport infrastructure in the Republic of North Macedonia is located in the hot continental climate (43% of state road network) and the Continental Sub-Mediterranean climate (39%), Table 1. The rest of the road transport infrastructure is evenly distributed in other climatic regions. More detailed statistics are given in the annexes section.

Table 1 Road classification based on climatic regions

Climate type	Length of roads in km	Ratio
Mountainous continental climate	80	1.7%
Continental Sub-Mediterranean climate	1.796	38.6%
Cold continental climate	373	8.0%
Sub-mountainous continental climate	205	4.4%
Sub-Alpine mountainous climate	8	0.2%
Sub-Mediterranean climate	202	4.3%
Hot continental climate	1.988	42.7%
TOTAL	**4.653**	**100%**

2.1.1 Climate change – North Macedonia Scenarios

Temperature and precipitation are considered to be crucial climate parameters required in these Guidelines, 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 baselines and projections for specific climate parameters for the Republic of North Macedonia.

2.1.2 Rainfall baseline

Current trend of precipitation in North Macedonia, and the precipitation for the baseline period, suggests that there is a strong 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 data of maximal daily precipitations are provided from National Hydro-Meteorological Service. 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 4 below summarises both the continuous and extreme rainfall trend for the baseline period. 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). The maps are created by Inverse Distance Interpolation of National Hydrometeorological Service weather station data.

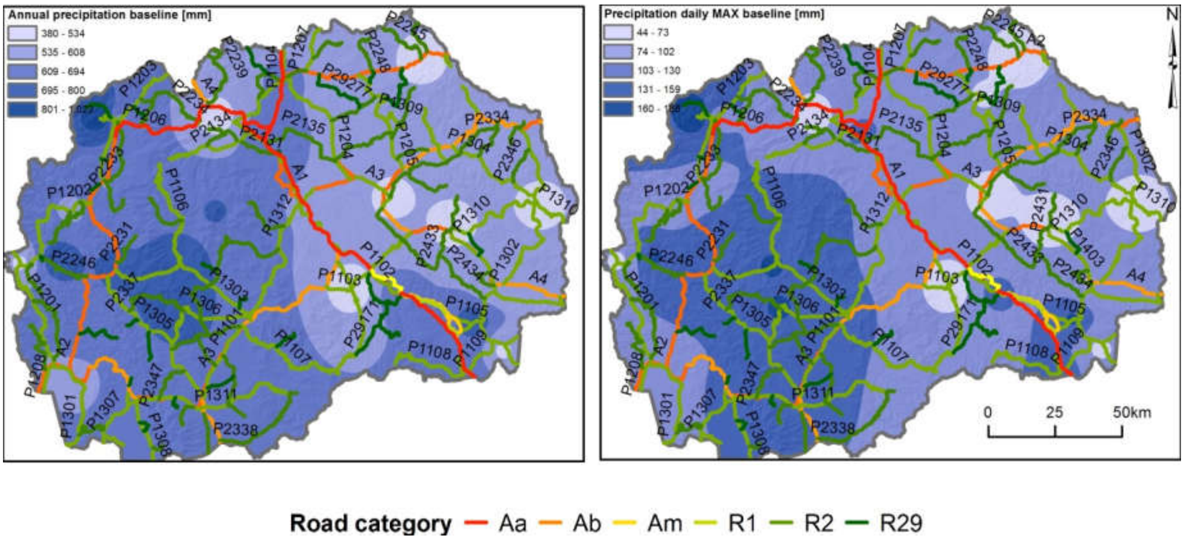


Figure 4 Rainfall baseline map

Rainfall projections

Based on the worst climate change scenario **RCP85 explained in chapter 1.7,** in the following Figure 5 are presented the obtained rainfall projection maps for the Republic of North Macedonia.

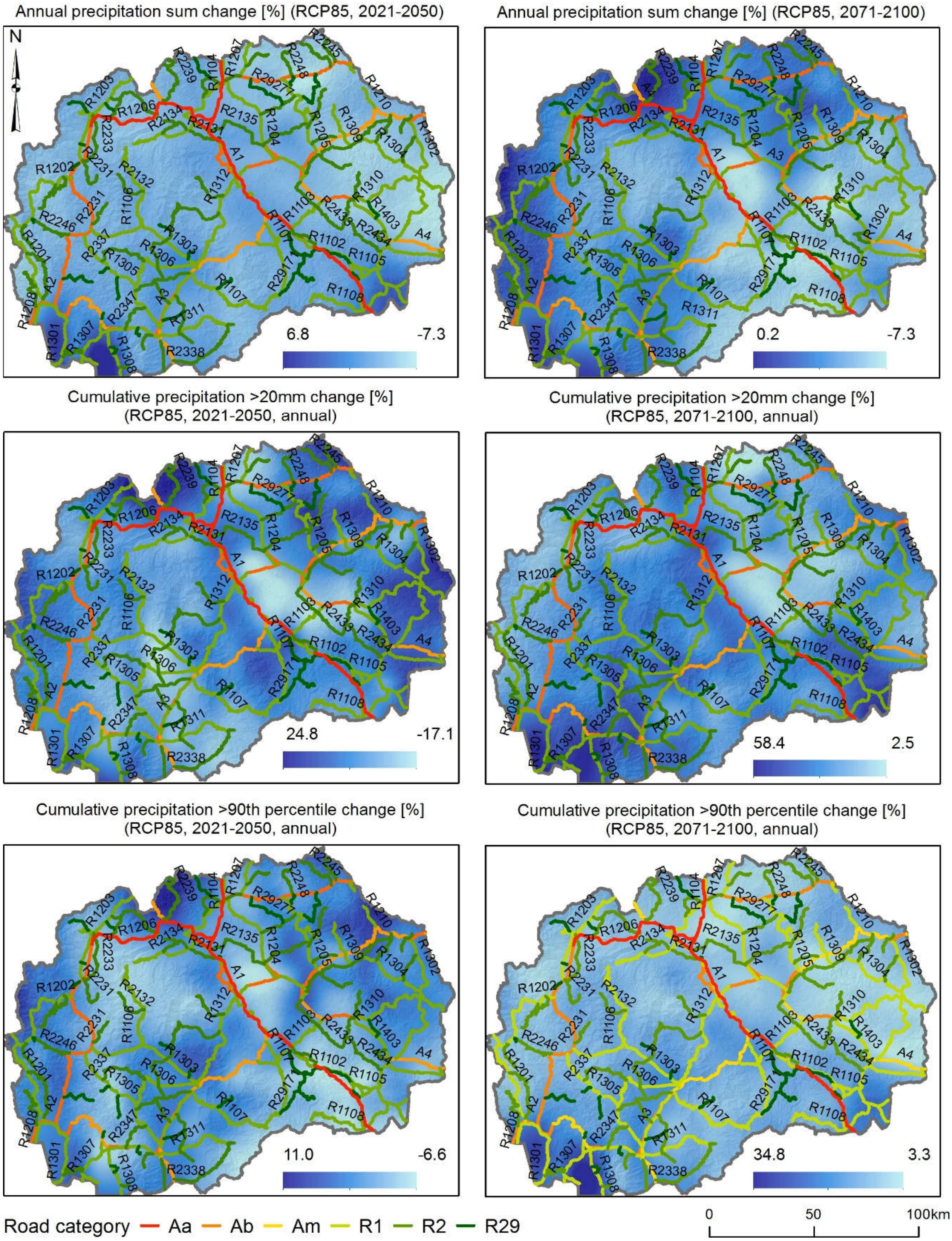


Figure 5 Rainfall projection maps

The rainfall parameters are obtained at 10 x 10 km resolution, which can be considered fair level of detail given the size of the country and available climatic data density, even though the display seems tiled-pixelated. For a better visualization, these were subsequently transformed into points and then spline-interpolated, which gives slightly better visual impression of the minima-maxima distribution but does not entail a higher quality data. However, this form is also more suitable for the subsequent landslide hazard assessment.

The chosen precipitation parameters (annual sum change, change of cumulative precipitation >20 mm and change of cumulative precipitation >90th percentile) are related to the rainfall parameters obtained for the baseline (annual precipitation sum and daily maximum) and can be regarded as relevant because of their tight connection to the landsliding mechanism, particularly debris flows and shallow slides. These are both sensitive to a general increase of water content which is reflected by increased annual precipitation sum change (% of change in respect to the baseline period). On the other hand, cumulative precipitation greater than 20 mm reflects the influence of moderately intense rainfall over a short period of time (one to several days). Such events are likely to cause local concentration of percolated water and eventually, lead to saturation of the ground, which has been confirmed as a failure scenario in the wider region in massive landsliding in 2014. The last parameter reflects a situation with very intense and very rapid rainfall that are unlikely to happen (probability lesser than 10%), which is the worst-case scenario. All climatic parameters belong to the RCP85 scenario, with the highest estimated gas emissions, i.e. the most severe climate changes. Other scenarios, e.g. RCP45 can locally indicate significantly different effects, such as decrease instead of increase etc. but this is usually limited to a pixel or two per map. In any case, we decided to use the worst-case scenario, RCP85, which is generally more severe regarding climate change effects than any other scenario for the target area.

2.1.3 Temperature baseline

The main outputs of this analysis include changes in mean temperature, mean daily maximum/minimum temperature, temperature of the warmest/coldest day/night, precipitation (including on the wettest day)

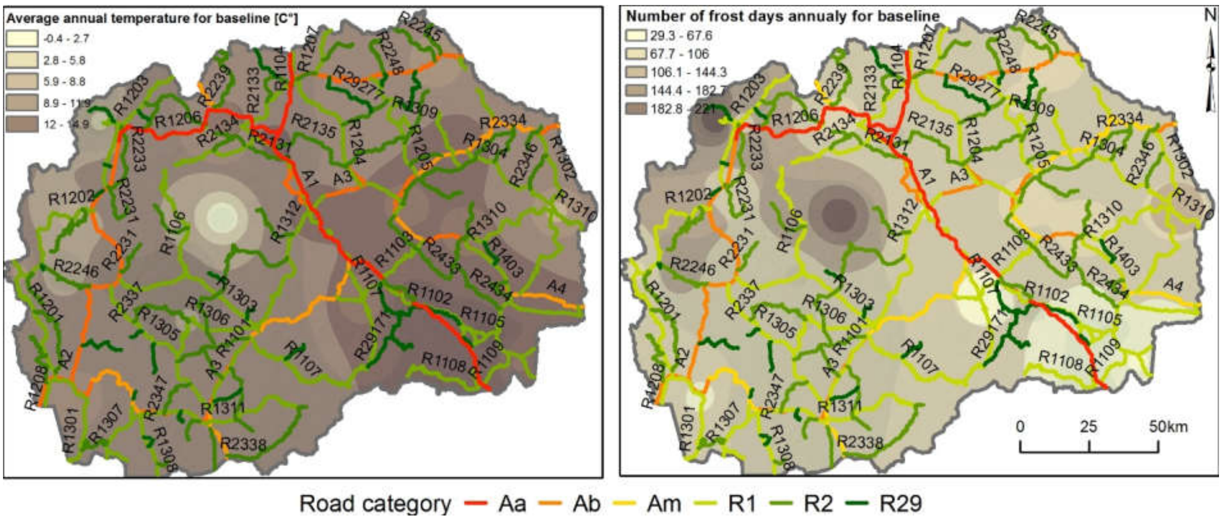


Figure 6 Temperature baseline maps

2.1.3.1 Temperature projections

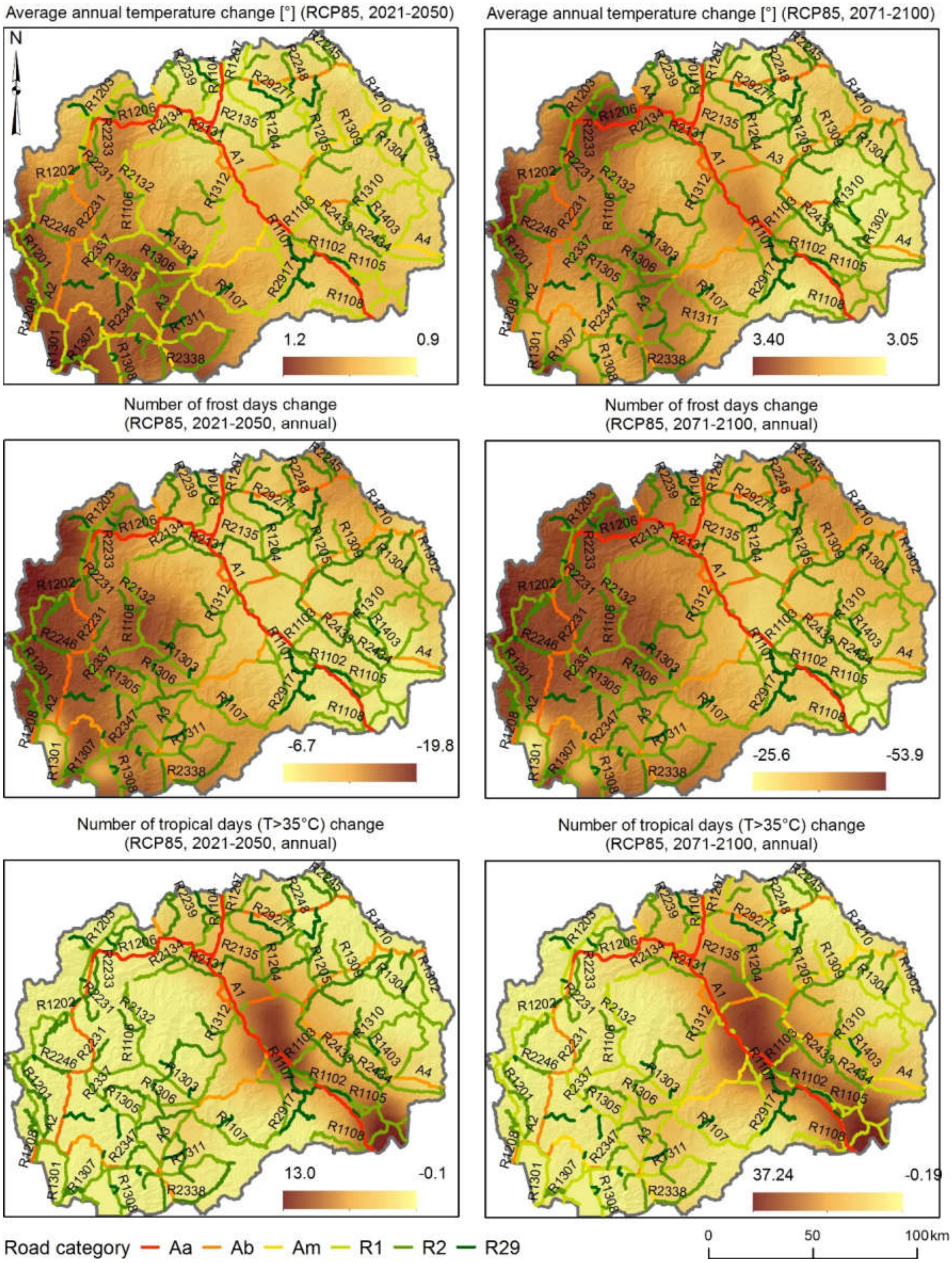


Figure 7 Temperature projection maps

2.1.4 Overlapping the state road network

The baseline maps are overlapped with the road network to identify sections of the network to produce natural hazard maps. These are used for initial identification of the areas to be further investigated as they reveal where is the potential of the road sections to be under risk. Overlapping the state road network with the rainfall projection maps reveals interesting findings and comparisons.

In comparison to annual baseline precipitation, there is no significant change in short-term, 2021-2050, projection except for a subtle increase around SW area (Ohrid) and SE area (Demir Kapija) reaching approximately +7%. Whereas, central and especially eastern parts suffer decrease of total precipitation, as low as -7%. This is even further highlighted in the long-term, 2071-2100, projection, which also has no significant overall change, but the decreasing trend is apparent, especially in the central part (as low as -7%). This mean that wet areas will keep getting wet at first, but will receive lesser and lesser amounts of rainfall, while dry areas will become even dryer. This is an expected and well-known trend at mid-latitudes for Europe. Interestingly, the drying domain is concentrated along the A1 highway route.

Moderately intense rainfall (>20 mm) will keep falling with the same rate in the central parts, along the A1 route, but significant increase will affect lower category roads, away from the central parts, especially in the far north and east. The distribution is very similar in both projections, except for the Ohrid area, which is more affected in the long-term projection, but in the long-term projection the effect is generally amplified, and reaches nearly +60% change, which is 2-3 times more than in the short-term case. It is indicative that these areas will face the saturation problem as encompassed geological formations will be cumulatively/ continuously weakened.

Cumulative extreme events, i.e. continued extreme precipitation (lasting for several days, for instance), shows significantly different distributions in the short and long run. The short-term projection predicts clustered cub-maxima on the northern and NE parts, locally in the central area (here and there). The long-term projection however, marks Ohrid and Demir Kapija area as the most critical, while the rest of the country shares similar trend. Also, in the short-term the changes are not as high (from -7% to +11%) as in the long-term projection, where they exceed 30% in comparison to the baseline. The A1 road is therefore, affected, particularly at the border-crossing to Greece, while all R1 level roads around Ohrid are heavily affected.

Generally, the hypothesis is that we are facing decades of smaller annual rainfall sums, but more frequent moderate and extreme rain surges is confirmed in the case of North Macedonia. Drying areas will get dryer, while wet areas will become wetter. These drying areas will spread from east to central part, including most of the A1 route. The extreme events will be more frequently hitting those dryer areas, which is even more inconvenient (drying and oversaturating cycles will increase the rock weathering and deterioration of rock strength). Inconveniently, these zones coincide with most of the routes of the highest category roads (A, R1 and R2).

Step 2. CVRA model in GIS environment to produce hotspot maps to identify priority road sections for further study and interventions

2.2 Flood and Landslide vulnerability and risk analysis

For the purposes of this assignment we have developed methodologies for landslides and floods on different scales: on the country level and on the local scale. The methodology for the landslide CVRA and the floods CVRA are taking different parameters up to Module 4, then are combined with the results of the rest of the modules to provide PESR with the tools to make informed decision that incorporates climate impact on their road assets.

For the local scale application, we have used Polog region as the Study Area. We have developed maps that will guide PESR through the process and Study Area will be used as the case study in the capacity building and field survey study with the PESR beneficiaries and relevant stakeholders.

The Polog region is located in the northwest part of North Macedonia. This region covers ~2420 km^2 including the densely populated towns of Tetovo and Gostivar (parts of which were developed on rugged hilly terrain). It includes many villages on the steep Mt. Shar Planina, and important infrastructure including railways, a highway, well developed network of regional and local roads (mostly in the mountains), ski centers, and a very important hydro-energy system consisting of 130 km of water distribution channels accompanied by 167 km of service roads.

In a geological context, the study area belongs to a larger regional tectonic unit called the Western North Macedonian Zone (WMZ). In this unit rock masses from the Palaeozoic, Mesozoic, Pliocene and Quaternary periods are represented. Igneous rock masses include granodiorites, granites, diorites, rhyolites, serpentinites, gabbros, diabases etc. The Palaeozoic is represented by a thick complex of metamorphic rocks, rarely igneous rocks. The rocks from the Devonian age are the commonly occurring ones in the area, and here belong the phyllitic schists, meta-conglomerates, metasandstones, quartzites, quartz-chlorite schists, carbonate schists and marbles. It is important to note that most landslides in the study area have been reported to occur at the contact of the weak schist type rocks and the soil debris which covers them.

On 3 August 2015, a severe storm and intense rainfall in the Polog region affected more than 85,000 people causing 6 casualties and inflicting € 30 million in damages.

2.2.1 Flood analysis to create GIS flood hazard map

2.2.1.1 Hydrotechnical analysis at national level

Hydrotechnical analysis is conducted to support the design of bridges and large culverts for road projects. The flood hazard mapping based on GIS and multi-hazard analysis is a valuable tool for estimating flood hazard with little data requirements, helping planners and decision makers to focus on specific flood prone areas, where further detailed assessment of flood risk (e.g. through the use of hydrological and hydraulic models) can be conducted, if needed.

Data requirements

Most, if not all, of the climate data required to conduct hydrotechnical analysis are used indirectly. Design values such as water levels, flow rates are the results of climate parameters: precipitation, snowpack and temperature. When considering the impacts of climate and climate change, future values may change from historical values. Modelling climate change impacts for every infrastructure design project may not be required, since the roads are not in the hot spot area. Hydrologic models that reflect potential climate change might have been completed for selected watersheds, but the results might be too coarse at this time, both temporally and spatially, to be of use in design projects.

Since the hydrotechnical analysis involves design considerations for a small number of key components (e.g. bridge or culvert) interacting with a small number of climate parameters (e.g. rainfall, flash floods), less time may be spent on the risk assessment (i.e., listing components and evaluating interactions). Thus, bigger focus is on adaptive design approach that considers anticipated effects of climate change on site hydrology and how modified hydrology affects the structure performance.

The most prone to flooding are alluvial lowlands of the major rivers and their tributaries within the basins, as well as hilly areas with high rainfall intensities. The actual data requirements for a road project are very extensive. The data is grouped at different levels on different scales.

- At the National scale, alignment can be carried out with national and regional scale data, existing maps and national river networks can show water crossing points and a national and areas with potential significant flood risk.
- At catchment scale (local scale) an understanding of the character of the area that drains to the crossing point is required by the hydrologist: the character of the catchment area, to allow a hydrologist to provide an estimation of the expected flows at the crossing.
- Finally, at the detailed scale, more detailed topographical survey data is required to carry out the detailed design for a crossing as exact levels and sizes are need for construction. The table below shows what kinds of data are used at what scales (Roads in flood affected areas)[3].

Table 2 Data requirements at different scales

SCALE\DATA TYPES	TOPOGRAPHIC	HYDROLOGY	HYDRAULICS	OTHER
	(Elevations and terrain)	(flows and catchment characteristics)	(water levels and flood extents)	(Auxiliary information)
NATIONAL (1:100.000, 1:50.000)	National elevation contours or digital elevation model (DEM) to identify steep and flat areas.	Vulnerability assessment, Preliminary flood risk assessment. Areas with potential significant flood risk, River networks. Spatial variation in rainfall. Climate context.	General catchment slopes to identify backwater areas. Location of other surface water bodies.	Environmentally protected or sensitive areas. Urban areas that may be affected, including downstream.
LOCAL (1:25.000, 1:10.000)	National DEM or local DEM (e.g. LiDAR) to define catchment and topography slope.	Flood hazard and risk maps, Flood Risk Management Plans. Catchment rainfall-runoff modelling, river network, land use types, catchment specific gauged flow data.	DEM and river networks to identify flow paths and processes.	Catchment characteristics; geology, soil types etc., other catchment issues related to water, e.g. dams, abstractions, management plans.
DETAILED (1:1.000 AND LARGER)	LiDAR DEM or Detailed topographic survey. For	Locally measured flows at site. Historical flood data, frequency, IDF	Locally measured water levels at site. Photographs or	Waterway structure details, types & dimensions.

3 *Roads in flood affected areas*.

	river channel and road embankment geometry.	curves, eye-witness accounts of mechanisms.	wrack marks from past events. Detailed local hydraulic model of channel and structure.	

To assess the vulnerability to floods on existing or new roads, vulnerability maps at the national level available to PESR are used.

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.

Methodology for flood hazard assessment

Given the increase in flood events in recent years, accurate flood vulnerability assessment is an important component of flood mitigation in Republic of North Macedonia. Due to the lack of flood vulnerability assessment on national level, the methodology further explained is developed to assess the vulnerability to flood hazard. The hazard maps created use GIS and multi-criteria analysis along with the application of Analytical Hierarchy Process methods to define and quantify the optimal selection of weights for the criteria that contribute to flood hazard[4].

The outcome of this methodology is to show the spatial distribution of flood hazard along with its intensity level, ranging from very high to very low. In MCDM, there are different methods for assessing criterion weights: entropy, ranking, rating, trade-off analysis, and pairwise comparison, among others. The (AHP) proposed by Saaty is one of the most common MCDM methods, and it has been widely applied to solve decision-making problems related to water resources[5]. The purpose of AHP is providing decision makers with the best decision, among different alternatives, compares two criteria at a time through a pairwise comparison matrix, in which values of relative importance from one criterion over another criterion are assigned. This is GIS-based approach, that requires the spatial layers of the parameters that contribute to the flood hazard. The result is a reliable flood hazard map with a relatively low monetary and time investment to identify only areas that need further detailed assessment. Also, it is easy to update and is flexible in terms of which criteria are included. The methodology consists of the following steps:

1. Defining the Problem
2. Identification of key experts and stakeholders in the decision-making process and the definition of criteria for assessing susceptibility to floods;
3. Collection and preparation of data (statistical analysis, etc.) and creation of raster data for each factor;
4. Classification of data sets and forming the susceptibility map for each factor;
5. Establish a matrix of criteria for decision making and evaluation;
6. Calculation of weighted factors of the criteria;
7. Weighting of maps and their summing up in the map of vulnerability;

[4] J. Paquette and J. Lowry, "Flood hazard modelling and risk assessment in the Nadi River Basin, Fiji, using GIS and MCDA," *The South Pacific Journal of Natural and Applied Sciences*, pp. 33–43, 2012.

[5] N. Kazakis, "Assessment of flood hazard areas at a regional scale using an index-based approach and Analytical Hierarchy Process: Application in Rhodope–Evros region, Greece," *Sci. Total Environ.*, vol. 538, pp. 555–563, Dec. 2015.

To each of the criteria different score (rank) on a scale of 1 (not susceptible to floods) to 5 (most prone to floods) was assigned in accordance with the limitations, the experts opinion involved in the evaluation and international literature.

Table 3 Criteria scoring

Criteria	Distance to stream (m)					Height above river (m)					Terrain Slope (*)					Rainfall (mm) annual					Curve Number (CN)				
Description	0-100	100-300	300-500	500-1000	>1000	<2	0-5	5-8	8-10	>10	0-10	10-20	20-30	30-50	>50	<500	500-750	750-850	850-900	>900	<40	40-50	50-70	70-90	>90
Grade	5	4	3	2	1	5	4	3	2	1	5	4	3	2	1	1	2	3	4	5	1	2	3	4	5

The **measure of distance to streams** plays an important role in defining areas susceptible to flooding. The zones closest to rivers are the most affected by floods. To obtain these distances, the Euclidean Distance tool was used. The reclassification was based on assigning a rank value of 1 to areas farthest from streams, and a rank value of 5 to areas near streams (as shown in Table 3).

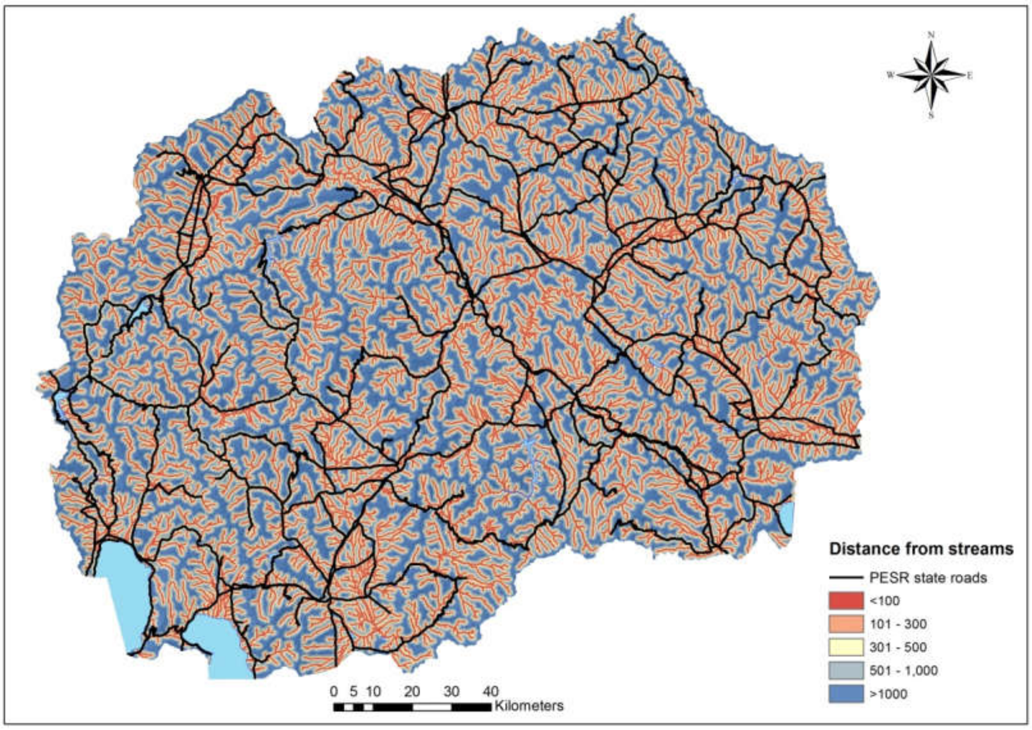


Figure 8 Distance from streams factor

The **Hight above nearest river** (HANR) has influence in flood susceptibility, since low-lying land adjacent to streams is more susceptible to be flooded than higher land. The map was produced with the DTM and the Streams layer as inputs. When reclassifying, lower values of HANR were assigned to a higher class, and higher values were assigned to a lower class, as shown in Table 3.

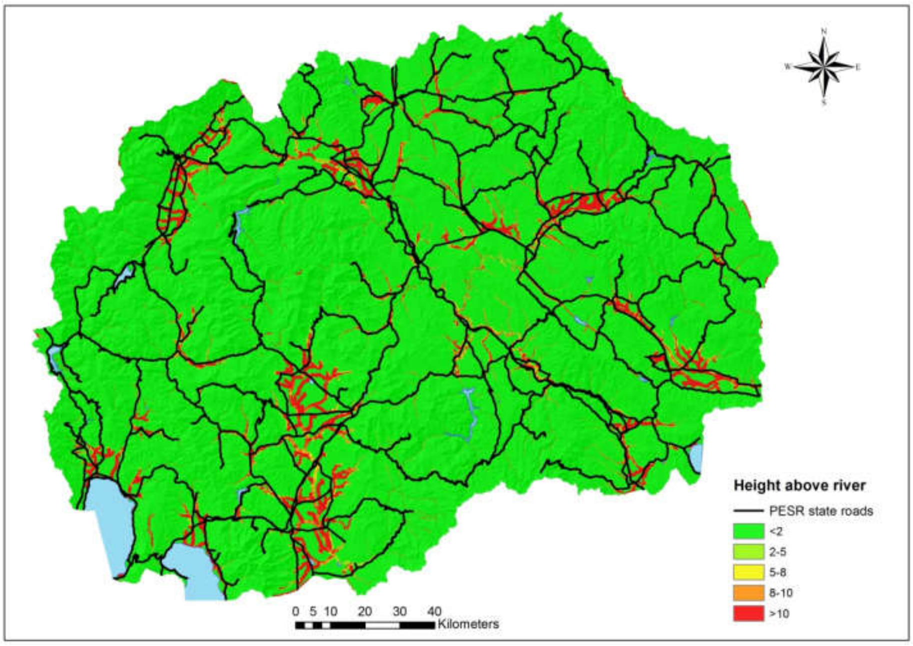


Figure 9 Height above nearest river factor

The **terrain slope** affects the velocity in which the water is conveyed through the drainage channel and the watershed. Additionally, the steeper the slopes, the higher the runoff will be, and consequently, higher peak discharges will be generated from sloped terrain. The slope layer was derived from the DTM, with a resolution of 5m x 5m. It was reclassified in a scale from 1 to 5, where a value of 5 was given to lower slopes and 1 was given to higher value of slope.

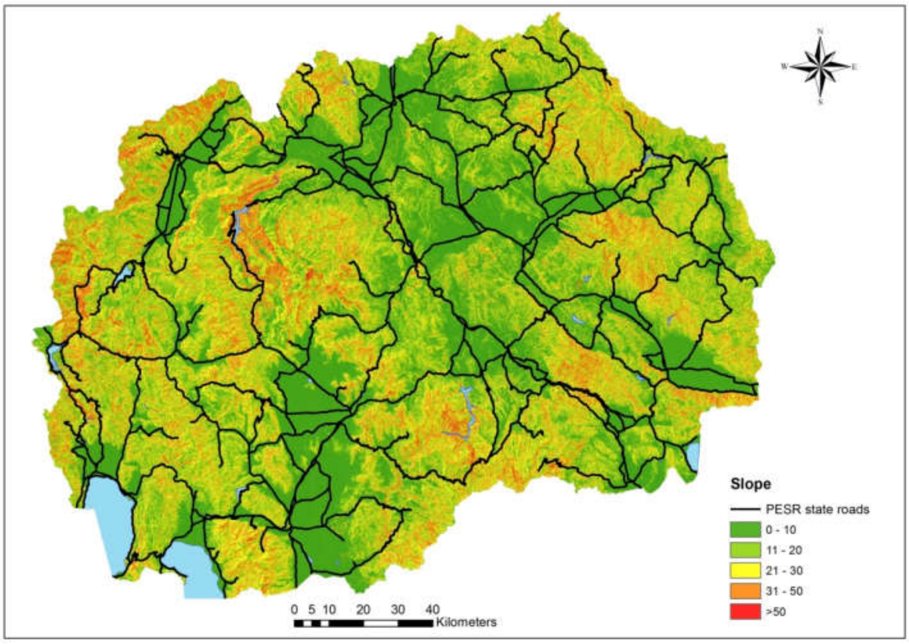


Figure 10 Slope factor

Precipitation is the major cause of river floods. Heavy rainfall can lead to flooding when the streams can no longer convey excess water. As runoff is related to the amount of precipitation, a higher precipitation increases the amount of runoff. Annual precipitation data from four rain gauge stations, was used to create the precipitation-isohyet map by interpolation using the inverse distance weighted (IDW) interpolation method. The rainfall map was reclassified on a scale from 1 (for low values) to 5 (for high values), as shown in Table 3.

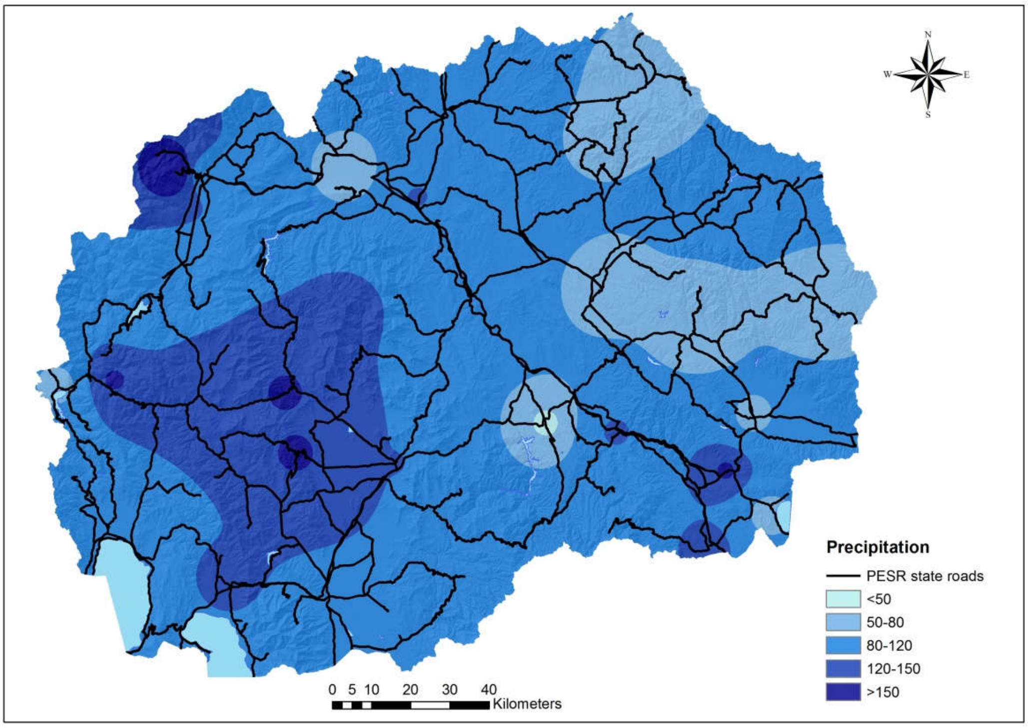


Figure 11 Rainfall factor (mm/y)

The Curve Number (CN) is an empirical parameter by the Soil Conservation Service (SCS) used in hydrology for predicting direct runoff or infiltration from rainfall excess. It considers the characteristics of land use and soil texture type. The values of CN ranged from 100 for impermeable surfaces to 30 for very permeable soils with low runoff potential. The CN map was obtained using both the land-cover type data and the soil texture type.

The map with soil textural classes of 1:200.000 was used to derive the soil hydrology group (SHG) and land cover was derived from CORINE LC[6] by overlaying these two maps the map for CN was produced. CN values are published by the SCS for different land uses and soil types. As a high CN means high runoff and low infiltration and a low CN means low runoff and high infiltration, high values of CN where assigned to a scale of 5, and low values for CN were assigned to a scale of 1 (details are provided in Table 11).

[6] Saaty, T.L., "Decision making with the analytic hierarchy process," *Int. J. Services Sciences*, vol. 1, 2008.

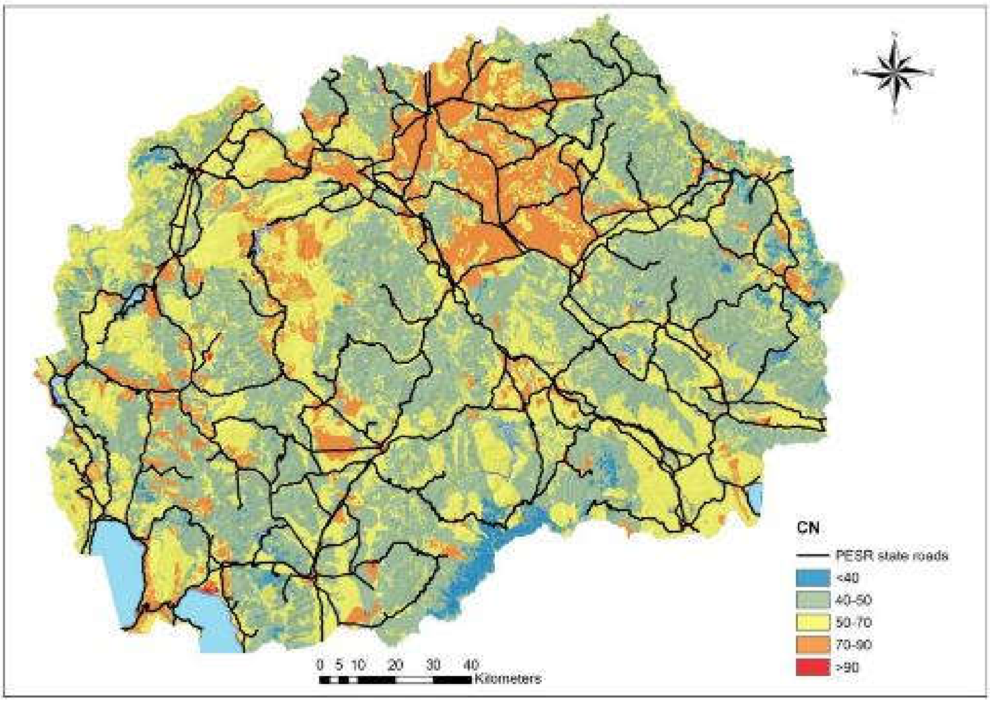


Figure 12 CN factor

The analytic hierarchy process (AHP) method is an effective approach to extract the relative importance weights of the factors[7]. The AHP is based on pairwise comparisons, which are used to determine the relative importance of each factor.

Table 4 The Saaty Rating Scale

Level of importance	Definition	Explanation
1	Equal importance	Two factors contribute equally to the objective
3	Somewhat more important	Experience and judgement slightly favors one over the other.
5	Much more important	Experience and judgement strongly favors one over the other.
7	Very much more important	Experience and judgement very strongly favors one over the other. Its importance is demonstrated in practice.
9	Absolutely more important.	The evidence favoring one over the other is of the highest possible validity.
2,4,6,8	Intermediate values	When compromise is needed

[7] International Bank for Reconstruction and Development / The World Bank, "Methods in Flood Hazard and Risk Assessment-technical notes." 2016

These pairwise comparisons are carried out for all factors to be considered, and the matrix is a completed Pairwise Comparison Matrix (PCM). The next step is the calculation of the relative weights, importance, or value, of the factors which are relevant to the problem in question (technically, this list is called an eigenvector). The estimation of the right principal eigenvector of the PCM can be approximated using the geometric mean of each row of the PCM (by multiplying the elements of each row and then taking the nth root, where n is the number of criteria). This mode is known as multiplicative AHP and is used in this methodology guideline. The calculated geometric means are then normalised and the relative importance weights are extracted. The final stage is to calculate a Consistency Ratio (CR) to measure how consistent the judgements is relative to large samples of purely random judgements. If the CR is higher than 0.1, the judgements are unreliable because they are too close for comfort to randomness and the exercise must be repeated. Based on the results shown in the following table, it is confirmed that the Rainfall factor can be seen as the most important factor comparing to other factors in flood vulnerability estimation.

Values of degree of consistency, named as consistency ratio (CR) for all comparisons are calculated and have a value of less than 0.1, indicating the consistency of the obtained results. Matrix comparisons and weight value elements are shown below and in the following order: Criterion (C1-C5) and weight (W). Firstly, pairwise comparison is between factors;

Table 5 Matrix comparisons with rate value for factors and their relative importance

	Distance to streams	Height above river	Slope	Rainfall	CN
Distance to streams	1	1	2	1/3	2
Height above river	1	1	2	1/3	2
Slope	1/2	1/2	1	1/3	3
Rainfall	1	1	3	1	4
CN	1/2	1/2	1/3	1/4	1

Table 6 Matrix comparisons with rate value for criteria and their relative importance

Secondly the corresponding weight is calculated for each criterion.

		Criteria	Weight
7A	C1	Distance to streams	0.211
	C2	Height above river	0.211
	C3	Slope	0.154
	C4	Rainfall	0.328
	C5	Curve number (CN)	0.097

Table 8 Weight value of criteria

The selected five factors have been weighted to be used in Flood hazard evaluation (distance to stream, height above river, slope, rainfall and curve number). Flood hazard map based on AHP (Fig.13) produced in GIS environment shows a pattern of flood influenced strongly by rainfall intensity parameters due to high weight assigned during the MCA procedure of AHP. 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.

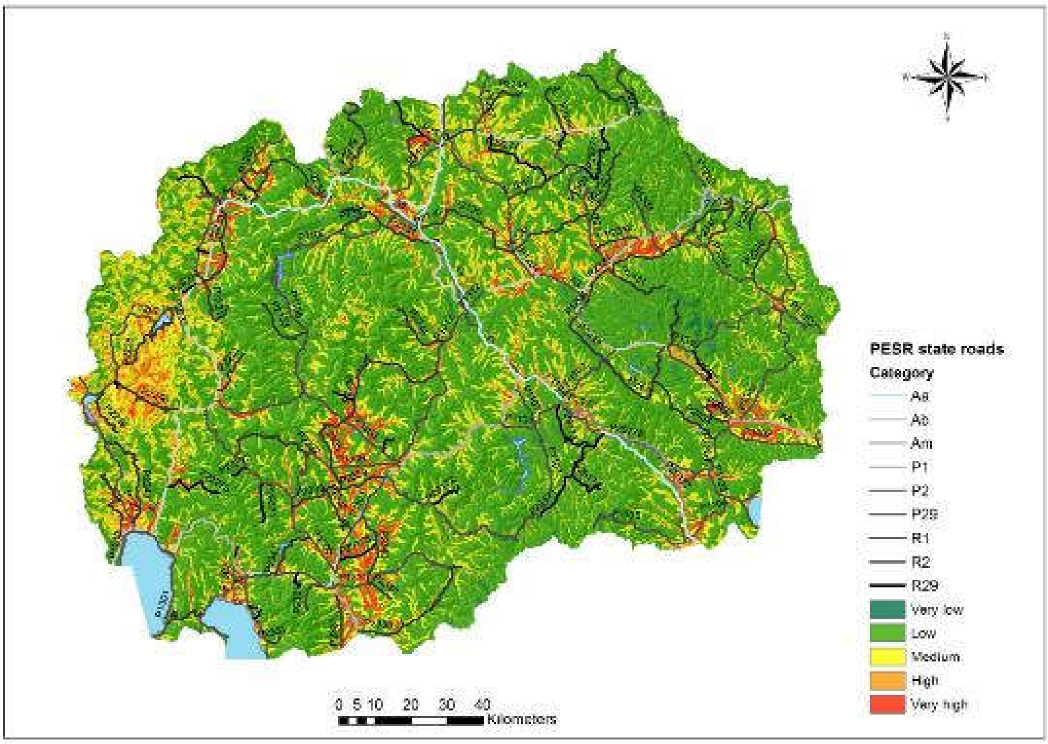


Figure 13 Flood hazard map

Verification of the resulting flood hazard map[8] is completed using several past flood information where infrastructural damage is evident (for these guidelines, from 2015). The results (Table 9) shows those almost all past flood events were located in hazard classes' medium to very high.

Table 9 Classes of flood hazard and number of historical flood events

FLOOD HAZARD	NUMBER OF EVENTS
VERY LOW AND LOW	6
MEDIUM	12
HIGH	9
VERY HIGH	13

[8] European Commission, "The EU Floods Directive, Directive 2007/60/EC."

Furthermore, a visual inspection and assessment of the obtained hazard map is 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 following Figure 14.

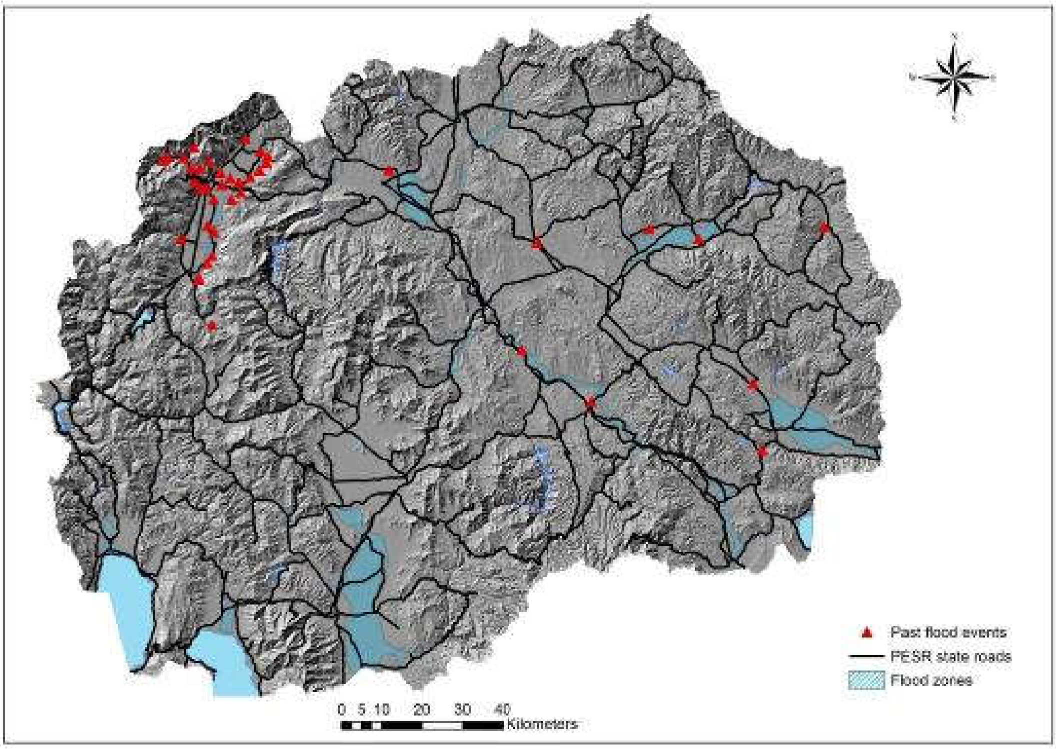


Figure 14 Flood zones and past flood events

Additionally, an analysis of affected PESR state roads was performed and results are represented as cumulative length per hazard class (Table 10).

Table 10 Classes of flood hazard and total length of PESR state roads

FLOOD HAZARD	LENGTH OF ROADS IN KM
VERY LOW	11
LOW	1681
MEDIUM	1708
HIGH	734
VERY HIGH	507

However, future work will be investigation on inclusions of other or improvement of the existing physical factors. In addition, the weighting of relative importance factors must be revised flexibly due to changes of relevant factors.

The GIS-aided methodology presented is flexible as far as the criteria determination is concerned. Thus, it is quite easy to expand and improve the methodology by taking into account other or include more parameters considering data availability.

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 RCP85 scenario, with the highest estimated gas emissions, i.e. the most severe climate changes.

The baseline vulnerability to flood map was prepared with the help of GIS and multi-criteria analysis along with the application of AHP methods to define and quantify the optimal selection of weights for the criteria that contribute to flood vulnerability (distance to stream, height above river, slope, rainfall parameter and curve number). The outcome of this methodology is to show the spatial distribution of flood vulnerability along with its intensity level, ranging from very high to very low.

Regarding the input climate change projection for the rainfall parameters; those are obtained at 10 x 10 km resolution which can be considered a fair level of detail given the size of the country and available climatic data density, even though the display seems tiled-pixelated. For a better visualization, these were subsequently transformed into points and then spline-interpolated, which gives slightly better visual impression of the minima-maxima distribution but does not improve the quality of the data. However, this form was also more suitable for the subsequent flood vulnerability assessment.

The Resulting Baseline Flood Vulnerability Map (figure 15) 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. Regarding the vulnerability of roads it can be concluded that parts of A2 road (Polog region), A4 (Skopje region), A3 (Pelagonija region), A1 (several parts along Vardar River), A3 (in Bregalnica River basin), A2 (Kumanovo area) and A4 (Strumica River basin) are heavily exposed, together with some R1 and R2 roads in the same areas and in the area of Mavrovo and Debar as well.

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 15 Climate flood vulnerability projection maps

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 15 above. The road sections that are already mentioned as vulnerable to floods are even more affected mainly with spreading of areas with high to very high class of vulnerability. This is particularly obvious if we take into account the total length of affected roads per vulnerability class for long-term projection 2071-2100 as shown in the following Figure 18 and Table 11.

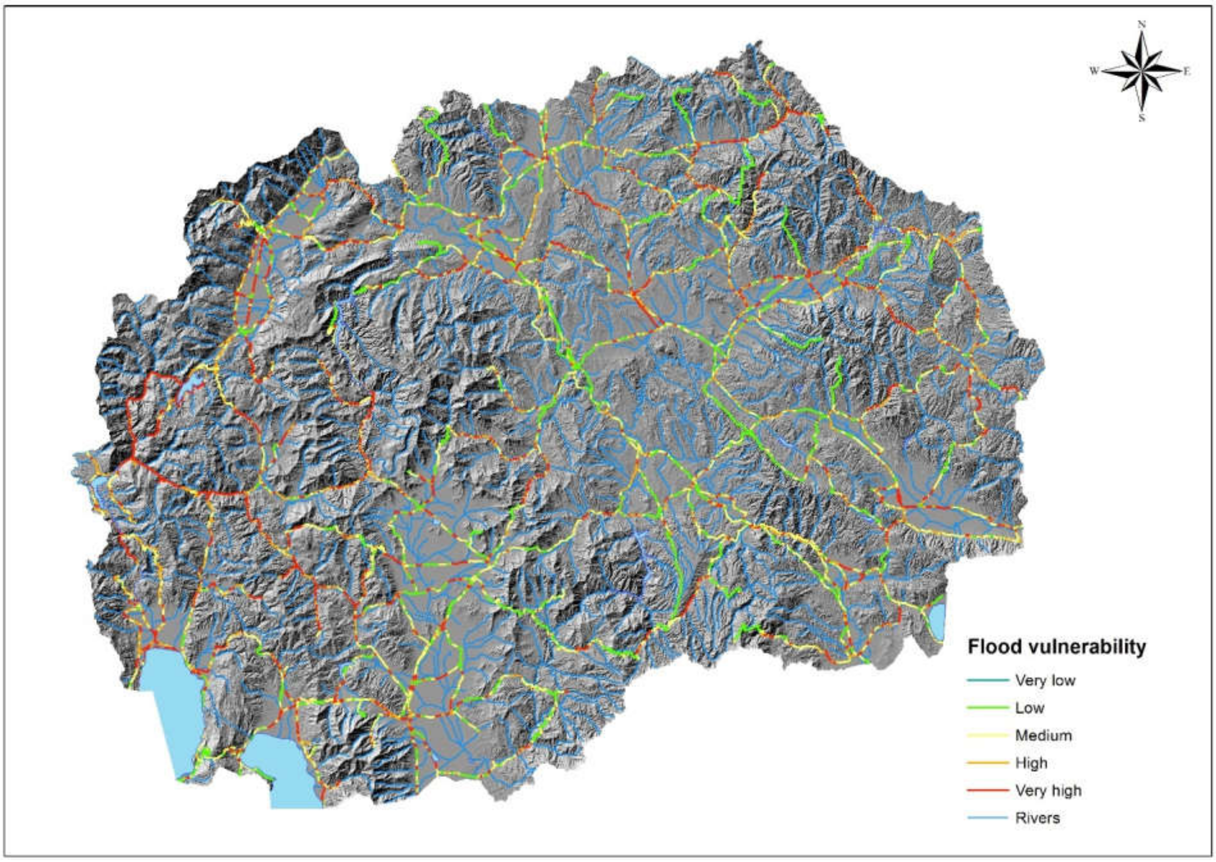


Figure 16 Increased vulnerability of roads due to climate change

Table 11 Increased vulnerability of roads due to climate change

FLOOD VULNERABILITY	LENGTH OF ROADS IN KM BASELINE	LENGTH OF ROADS IN KM CUMULATIVE >90TH PERCENTILE CHANGE 2071-2100
VERY LOW	11	7
LOW	1681	1418
MEDIUM	1708	1642
HIGH	734	923
VERY HIGH	507	652

For the identification of the areas with potential significant flood risk and potential adverse consequences of future floods, hydrologic and hydraulic modelling of the relevant watercourses in combination with a detailed analysis should be conducted.

There are many methodologies used worldwide to determine the flood risk at catchment scale. We have based our approach for the assessment of the risk of floods of road infrastructure, as a methodology to follow the recommendations of European Floods Directive 2007/60/EC. This Directive, introduced in October 2007, provided a new approach to managing flood risk on a catchment-wide scale. The Directive required 3 distinct preparatory stages:

1. Preliminary Flood Risk Assessment
   Article 4 of the Directive [6] required that each EU Member State undertook a Preliminary Flood Risk Assessment (PFRA) for their respective territories. In the PFRA, areas in RNM which have the most significant flood risk, known as Significant Flood Risk Areas (SFRAs), should be identified.
2. Flood Hazard and Risk Mapping
   Article 6 of the Directive required that each Member State should prepare Flood Hazard and Flood Risk Maps for significant flood risk areas
3. Flood Risk Management Planning

Article 7 of the Directive required each Member State to prepare Flood Risk Management Plans (FRMPs). The Flood Risk Management Plans highlight the flood hazards and risks in the most Significant Flood Risk Areas in RNM from flooding from rivers, canals, surface water and reservoirs. They identify the objectives and measures that will be undertaken to address flooding and they set out how the relevant authorities will work together with communities to reduce the flood risks.

Floods Directive[9] (Figure 17) processes are cyclical, and Article 14 requires reviews of each stage to be carried out on a rolling 6-year cycle (Figure 17).

[9] European Commission, "The EU Floods Directive, Directive 2007/60/EC."

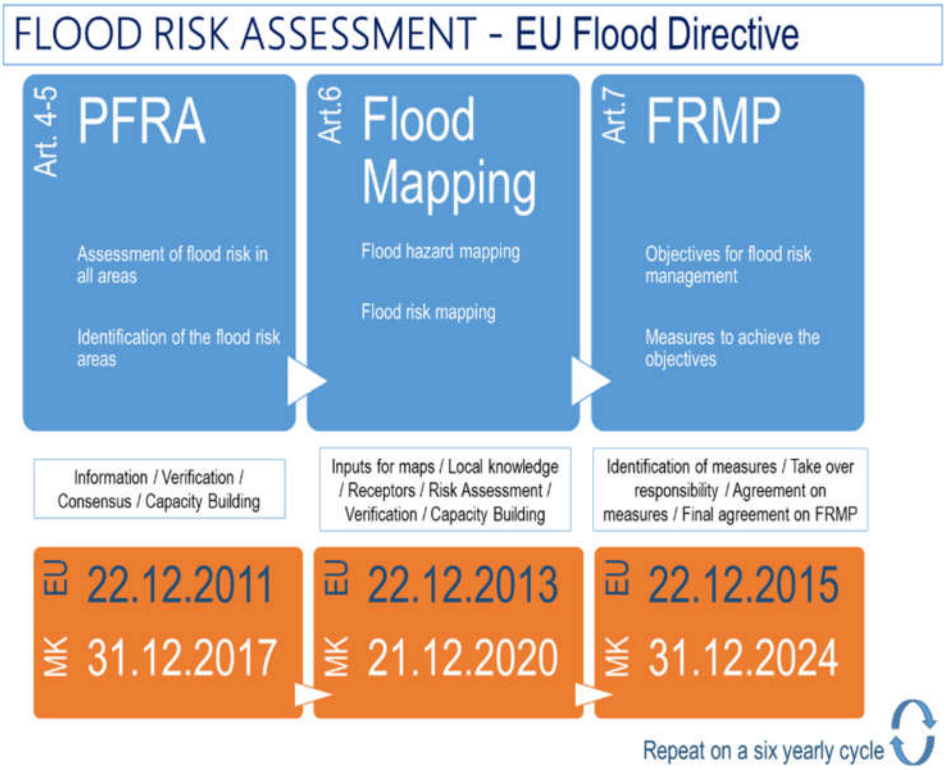


Figure 17 Flood Risk Assessment - EU Flood Directive

2.2.1.2 Modelling for flood hazard assessment at detailed scale

In the context of road networks, the damage caused by flooding, can include all the impacts addressed in the section on interactions between roads and floods.

The hydrologic model converts the rainfall over the watershed into runoff in the corresponding watercourse. The resulting flood hydrograph is then used as the input for the hydraulic model, in which he flow of the flood wave through the river channel is simulated.

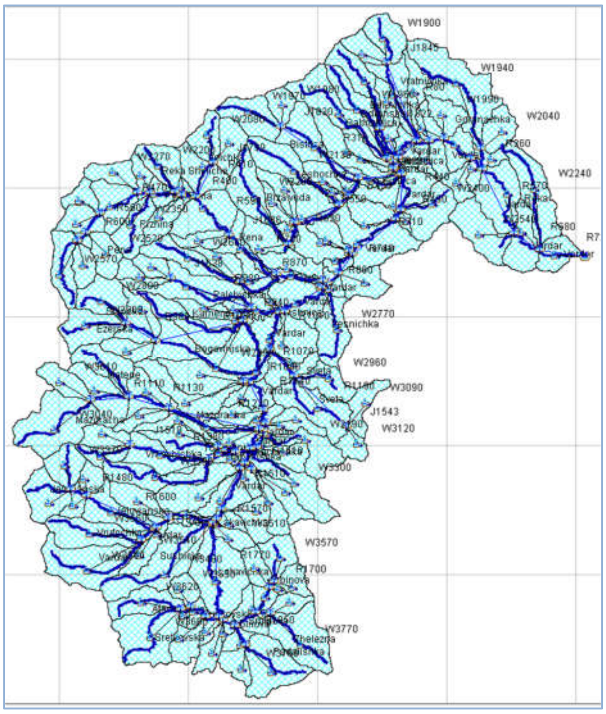


Figure 18 Hydrological Model of Upper Vardar (Polog Region)[10]

The successive step to define flood hazard is to perform a physically based hydrodynamic analysis of the river system, based on an input hydrograph. Two main approaches are available: one-dimensional (1-D) and two-dimensional (2-D) modelling.

Common engineering practices in North Macedonia use 1-D numerical models, that could be useful and particularly efficient in some particular contexts, e.g. engineering analyses, and mainly for highly artificialised rivers.

We are presenting another option, 2-D modelling , which is more common in the flood modelling that is practiced in the countries like UK, Germany and similar, becoming popular in other developed countries, due to the increasing availability of high resolution Digital Elevation Models (DEMs) of flood prone lands.

Also, good results can be achieved by combining 1-D/2-D modelling: flow in the riverbed is modelled in 1-D, while expansion in the floodplain caused by banks overflow is modelled in 2-D.

Figures 19/20 depict example of modelling flooding across a transportation network. They show the depth of the flood in meters, with the direction and velocity of the flood depicted with a vector field, output from 2D modelling. This methodology for the example is completed using HEC-RAS flood simulation system for modelling two-dimensional free surface flows. The system can model many conditions that occur in a floodplain, including flooding and drainage of the floodplain, embankment overtopping, and flow through hydraulic structures.

[10] *PRIRUČNIK ZA PROJEKTOVANJE PUTEVA U REPUBLICI SRBIJI, 2 GEOTEHNIČKA I HIDROLOŠKA ISTRAŽIVANJA I ISPITIVANJA*. 2012.

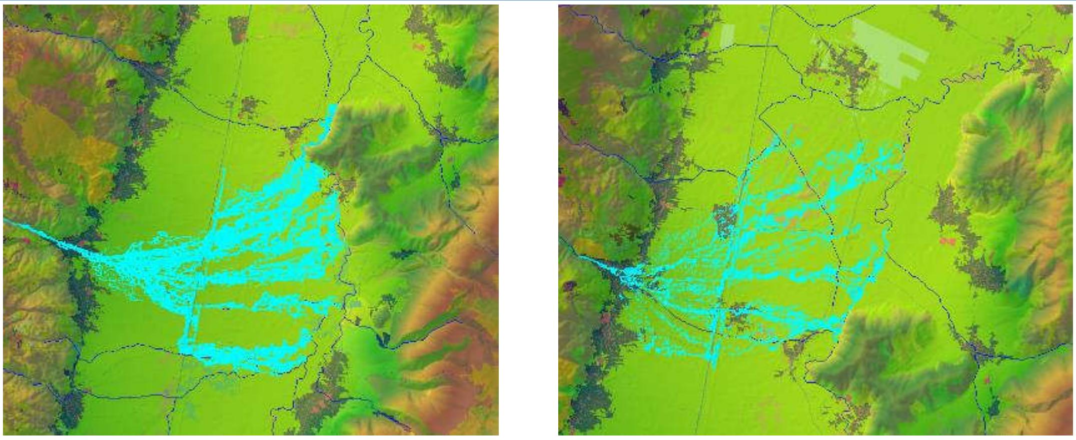


Figure 19 Hydraulic Model - sections of the road infrastructure at risk of flooding in Polog Region[11]

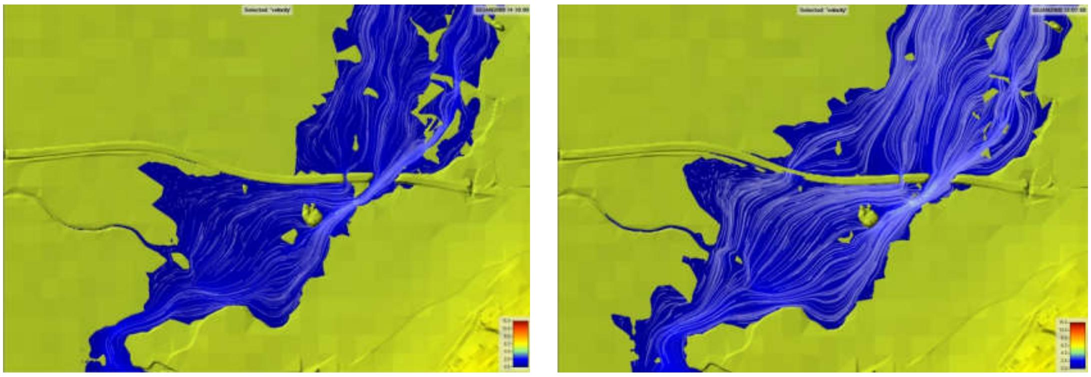


Figure 20 Hydraulic Model road sections at risk of flooding with medium (100 years) and low probability (500 years) of flooding events (River Vardar at Zelino)[12]

With this model, the extent of the flooded area is calculated and emphasises the exposure of the road to the flood hazard with different scenarios of flood occurrence (left is medium, and right is low probability of flood occurrence).

2.2.1.3 Flood risk mapping

From a scientific point of view, a flood risk map should comprise both a spatial and temporal description of the expected dynamic process modelled. In the case of flood modelling, the map must show where and when overflow conditions could happen, referring to events with a defined probability of occurrence. It should also show which areas could be inundated (estimating water levels and velocities), and how long the water is expected to remain in the system.

Flood risk maps shows areas at risk of flooding with low, medium and high probability, combined with type of flood, the flood extent; water depths or water level where appropriate or flow velocity. This is used for preparing maps to identify areas more suitable for development. Maps are essential for previewing and planning of land occupation extension, aiming to reduce damage and losses for the population and public authorities as a result of natural disasters. In cases where the areas are already

[11] *PRIRUČNIK ZA PROJEKTOVANJE PUTEVA U REPUBLICI SRBIJI, 2 GEOTEHNIČKA I HIDROLOŠKA ISTRAŽIVANJA I ISPITIVANJA*. 2012.

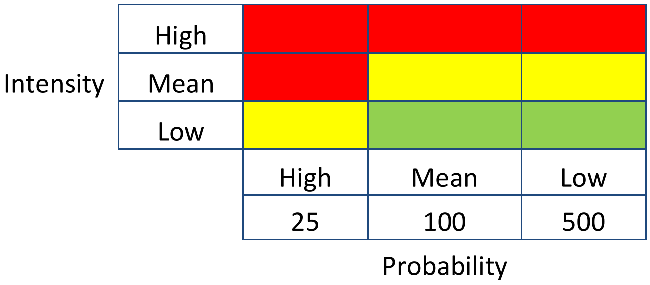
[12] *PRIRUČNIK ZA PROJEKTOVANJE PUTEVA U REPUBLICI SRBIJI, 2 GEOTEHNIČKA I HIDROLOŠKA ISTRAŽIVANJA I ISPITIVANJA*. 2012.

occupied e.g. the result could be useful for defining the necessary measures to address potentially damaging events.

Flood risk map is produced for return period of 100 years. By combining the probability and the intensity (magnitude), the latter expressed as flow velocity or depth, the flood risks class is obtained as indicated in the following Table 10.

Table 12 Flood risk class and criteria for classification

Process	Low intensity	Mean intensity	High intensity
Flooding (Torrents)	h > 0.5 m	0.5 m < h < 1.5 m	h > 1.5 m
Flooding (Lowland river)	h < 0.5 m	0.5 < h < 2 m	h > 2 m



The High risk zone mainly designates a prohibition domain (area where development is prohibited). The Moderate risk zone is mostly a regulation domain in which severe damage can be reduced by means of appropriate protective measures (area with restrictive regulations). The Low risk zone is mainly an alerting domain (area where people are notified of possible risk).

This overplayed with the road network, indicates the exposure of the road network that is at risk of flooding (Figure 21).

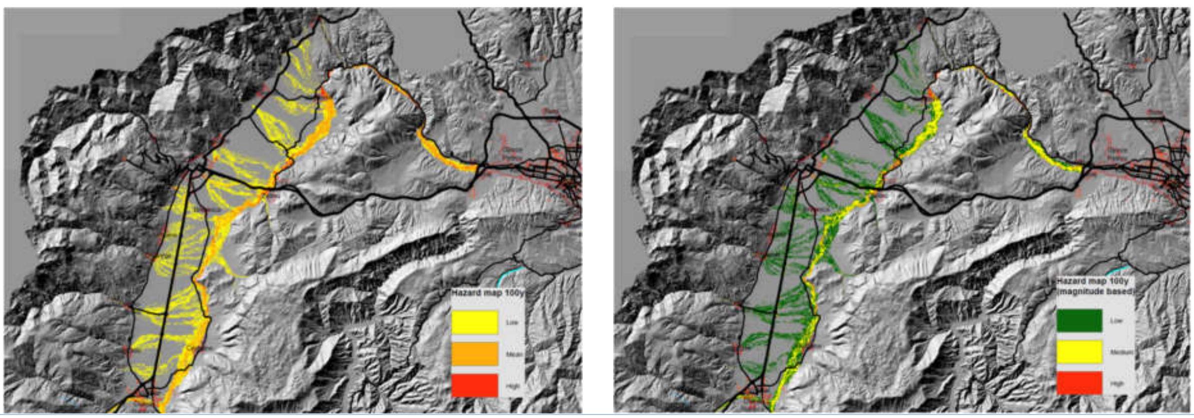


Figure 21 Flood risk maps Upper Vardar (100year)[13]

2.2.1.4 Flood criticality mapping

Criticality analysis is essential for planning and intervention in flood prone areas. As previously emphasized, for risk assessment, it is necessary to characterize both hazard and vulnerability. It is the combination of the probability of a flood event and of the potential adverse consequences to human health, the environment and economic activity associated with a flood event.

Flood management covers the complete and continuous assessment, evaluation and reduction of flood hazard and flood risks. As such flood management has three distinct goals:

1. To prevent the further build-up of risks through appropriate and risk-conscious development (i.e. development in safe places, appropriate forms of construction etc.)
2. To reduce existing risks through preventive and preparedness measures (e.g. construction of flood dikes and implementation of early warning systems)
3. To adapt to changing risk factors (e.g. climate change adaptation)

Flood criticality maps indicate potential adverse consequences associated with floods under specified probabilities (low, mean etc.), expressed in terms of the indicative number of residents or drivers potentially affected; type of economic activity of the area potentially affected; installations and other information that is useful to include.

Different risk concepts may turn out in different risk maps; despite that, it is opinion of the authors that the final ranking of the most critical areas should be comparable. An approach is proposed which includes the production of several complementary flood risk maps.

The following flood risk maps show (Figure 22 and 23):

- Indicative number of potentially endangered population (Figure 22)
- The type of economic activities that are potentially threatened in the area (Figure 22)
- Potential direct economic damage as a percent of GDP (Figure 23)
- Indicative number of potentially endangered passengers at the state road network (Figure 23)

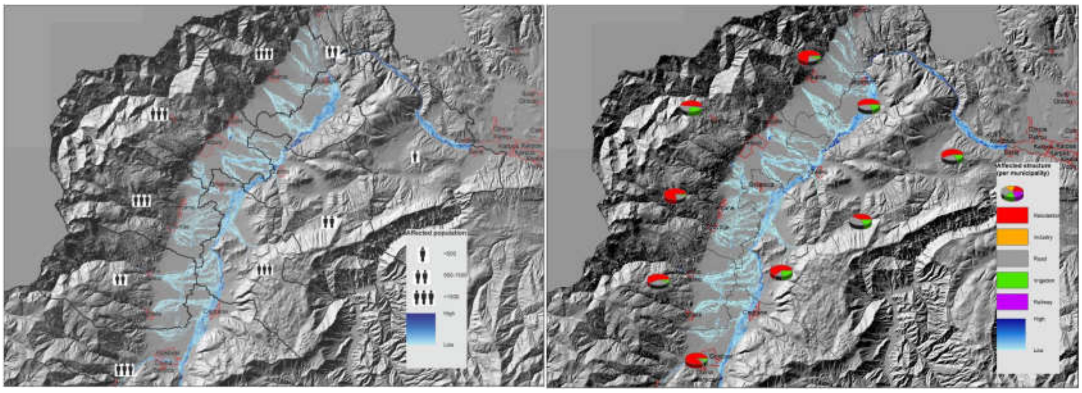


Figure 22 Flood damage as a percent of GDP (per municipality) and Affected passengers on State roads network, Upper Vardar (100year) [7]

[13] UNDP, "Reducing Flood Risk in the Polog Region."

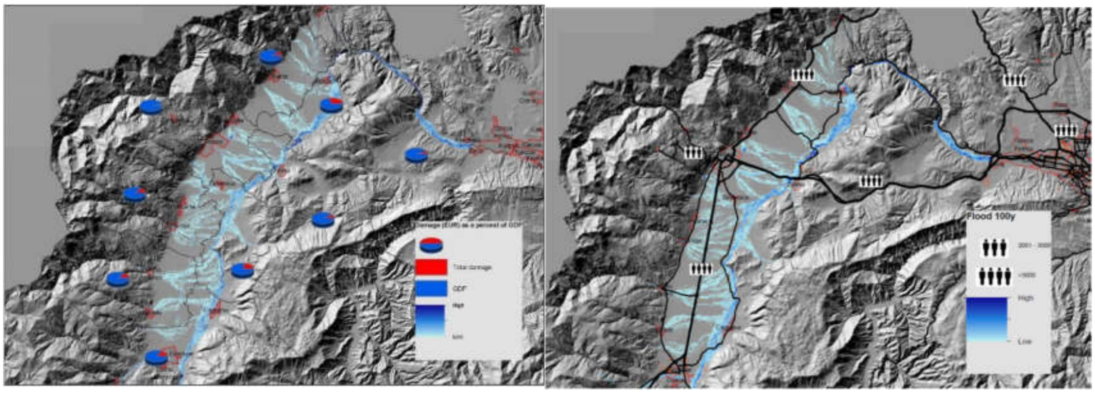


Figure 23 Affected population and Affected infrastructure (per municipality) Upper Vardar (100year)

These calculations and maps are then used for the MCA methodology for the assessment of the criticality based on multi-hazard assessment in Section 2.3.

2.2.1.5 METHOD OF APPLICATION OF FLOOD RISK ASSESSMENT AT DETAILED SCALE

In highway engineering, the diversity of drainage problems is broad and includes the design of pavements, bridges, culverts, siphons, and other cross drainage structures for channels varying from small streams to large rivers. It is often necessary to evaluate the impacts that future land use, proposed flood control and water supply projects, and other planned and projected changes will have on the design of the highway crossing. On the other hand, the designer also has a responsibility to adequately assess flood potentials and environmental impacts that planned highway and stream crossings may have on the watershed. The methodology for flood risk assesment at detailed scale was developed based on different sources from regional and international literature[14].

Step 1: Road alignment planning

Road alignment planning consists of identifying the crossing locations and geographical context of the road, identifying flooding areas and selecting design return periods.

Information about known flooding at these crossing locations can be gained from national flood hazard maps and historical flood records. A road can introduce a potential barrier to water flow and therefore become a major source of flood problems locally or have impacts on downstream areas.

The protection standard for the road and its watercourse crossings often are not clearly laid in national standards to ensure consistency of design. A design return period is often chosen based on the importance of the road and how much a particular standard of crossing will cost.

Table 13 Road alignment planning

Step 1: Road alignment planning		
Task:	**Input:**	**Design criteria:**
1a. Identify crossing locations and flooding areas	▪ National Flood (maps and records) ▪ Geographical maps ▪ Protected Areas (Environment)	▪ National Highway Standards
1b. Select design return periods	▪ National Flood (maps and records) ▪ Geographical maps ▪ Protected Areas (Environment) ▪ Road importance ▪ Economic criteria	▪ National Highway Standards
Result Step 1: Water crossing locations and design criteria		

[14] *Roads in flood affected areas*.
PRIRUČNIK ZA PROJEKTOVANJE PUTEVA U REPUBLICI SRBIJI, 2 GEOTEHNIČKA I HIDROLOŠKA ISTRAŽIVANJA I ISPITIVANJA. 2012.
U.S. Department of Transportation, Federal Highway Administration, *Highway Hydrology, Hydraulic Design*, 2nd ed. 2002.

Step 2: Hydrological analysis

Estimating peak discharges for various recurrence intervals is one of the most common engineering challenges faced by designers. The method of calculating the flow of large waters depends on the availability of flow monitoring data on the considered profile.

The problem can be divided into two categories:

- Gaged sites/basins – the site is at or near a gaging station and the streamflow record is of sufficient length to be used to allow statistical estimates of peak discharges. The calculation of the design discharges on the studied basins implies a statistical analysis of the observed maximum flow rates. As a result of the statistical analysis, the distribution of probability of maximum flows on the considered profile can be obtained. In the case of insufficiently studied basins, where at least short-term flow monitoring exists, it is sometimes possible to establish regression of the flows with the surrounding stations, and thus extend the sequence so that a statistical analysis can be carried out.
- Non-gaged sites/basins – the site is not near a gaging station and no streamflow record is available. In most of the cases of non-gaged basins (those which lack streamflow data due to absence, or other reasons) the transformation of rainfalls to discharge can be determined by using rainfall-runoff method.

Sites that are located at or near a gaging station, but that have incomplete or very short records represent special cases. For these situations, peak discharges for selected frequencies are estimated either by supplementing or transposing data and treating them as gaged sites; or by using regression equations or other synthetic methods applicable to non-gaged sites.

Step 2: Hydrological analysis

Table 14 Hydrological analysis

2.1. Hydrological analysis for Gauged Basins		
Task:	**Input:**	**Validation:**
Extreme Value Analysis	▪ River gauging station flow data	▪ Historical flood records
Output Step 2.1: Design flows		

- Extreme Value Analysis: (1) Statistical analysis of observation data on the considered profile, (2) Frequency distributions analyses (Normal, Log-Normal, Gumbel, Log-Pearson Type III, Distributions), (3) Risk assessment

Table 15 Hydrological analysis for Non-Gauged Basins

2.2. Hydrological analysis for Non-Gauged Basins		
Catchment characteristics		
Task:	**Input:**	**Result:**

Determine river network and connectivity	▪ National River Network	▪ Required flow locations
Delineate catchment/s	▪ Contours or Elevation Model	▪ Catchment boundary
Quantify catchment characteristics	▪ Land use, soils and geology data	▪ Catchment characteristics
(IDF) Rainfall Intensity Data		
Water Flows for Non-Gauged Basins		
Task:	**Input:**	**Validation:**
Empirical estimation methods	▪ Required flow locations ▪ Catchment boundary ▪ Catchment characteristics ▪ IDF (Rainfall intensity data)	▪ Historical flood records
Hydrological modelling (complex rainfall-runoff modelling)		
Output Step 2.2: Design flows		

- (IDF) Intensity-Duration-Frequency Curves: Three rainfall characteristics are important and interact with each other in many hydrologic design problems. For use in design, the three characteristics are combined, usually graphically into the intensity-duration-frequency (IDF) curve.
- Empirical estimation methods: (1) Regional analysis (extrapolation of data from nearby watersheds with comparable hydrologic and physiographic features is referred to as regional analysis and includes regional regression equations and index-flood methods), (2) SCS graphical peak discharge method, (3) Rational method, (4) Index flood method or (5) Peak discharge envelope curves.
- Hydrological modelling: (complex rainfall-runoff modelling by using software such HEC-HMS, HEC-GEOHMS EPA SWMM).

Step 3: Hydraulic analysis

To translate a design flow into a water level or velocity, some basic understanding of the geometry of the water course channel and crossing capacity is needed. The chosen method needs to be appropriate to the scale, importance, and watercourse complexity of the crossing.

Table 16 Hydraulic Analysis

Step 3: Hydraulic analysis			
Depending on complexity, terrain and scale			
Task:	**Input:**	**Result:**	**Validation:**
Simple: Steady state backwater calculation formula	▪ Design Flow	▪ Levels ▪ Velocity ▪ Duration	▪ Historical flood records

Complex: 1D Hydraulic Modelling	▪ Channel bathymetry ▪ Design Flow	▪ Flow paths	
Complex: 2D Hydraulic Modelling	▪ Channel bathymetry ▪ Detailed topography ▪ Design flow		
Output Step 3: Levels, velocity, duration and flow paths			

2.2.1.6 Empirical methods for the determination of hydrological parameters using new parameters

While using frequency approaches as the most appropriate means to determine a peak flow, at many stream crossings of interest to the highway engineer, there may be insufficient stream gaging records, or often no records at all, available for making a flood frequency analysis.

In the past in North Macedonia, there was a very detailed network of hydrological stations that were providing observation of hydrological parameters. Unfortunately, in the last few years, the number of gauging stations has been significantly reduced, which requires the Designers of hydro technical facilities to apply empirical methods for the determination of hydrological parameters.

Empirical methods include such widely applied techniques as the rational formula and the NRCS (formerly the SCS) graphical method. These methods employ empirical relationships between rainfall and runoff that allow estimation of design discharges on un-gaged watersheds by development of parameters describing the watershed.

The main input in empirical methods are intense rainfalls with a short duration and a return period. Three rainfall characteristics are important and interact with each other in many hydrologic design issues: rainfall intensity, duration, and frequency (IDF curves).

In the current practice of designing hydro technical facilities in North Macedonia, the IDF curves from the publication "Intensive Rainfall in the Republic of Macedonia" by Prof. Zivko Shkoklevski and Blagoja Todorovski were used. This publication is from 1993 and contains data on intensive rainfall until 1990. In order to improve the input data for the intensive rainfall needed for the design of the new hydro technical facilities, with the support of the PESR, data for the maximum 24 hour precipitation for 13 stations in North Macedonia are provided from National Hydro-meteorological Service. Besides them, the innovative IDF curves are provided for 6 stations.

Statistical analysis of maximal annual 24h precipitation data is applied to fit the selected theoretical distribution to both time periods (baseline 1961-1990) and the period from 2010 to the present, for Tetovo station. The analysis shows an increase in the intensity of this precipitation (increase of mean) at the Rainfall

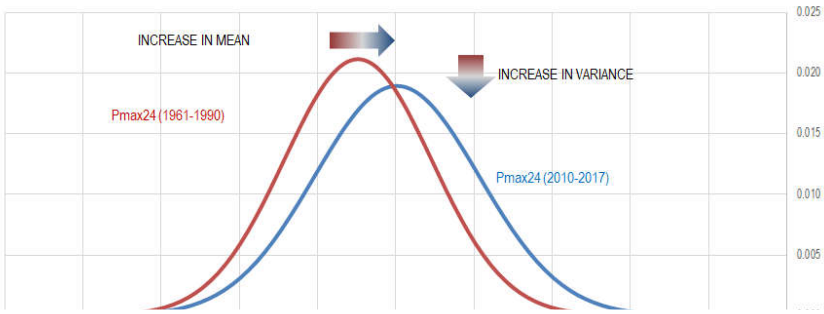


Figure 24 Normal distribution of max24h precipitations in RS Tetovo

Station in Tetovo and an increase in the variance. Also, from the analysis it can be noted that, compared to the base period, there is a decrease in the return period. Namely, the maximum annual 24h precipitation, which in the past was considered to be with a return period once in 100 years, the period from 1991 to the present has a lower probability of occurrence.

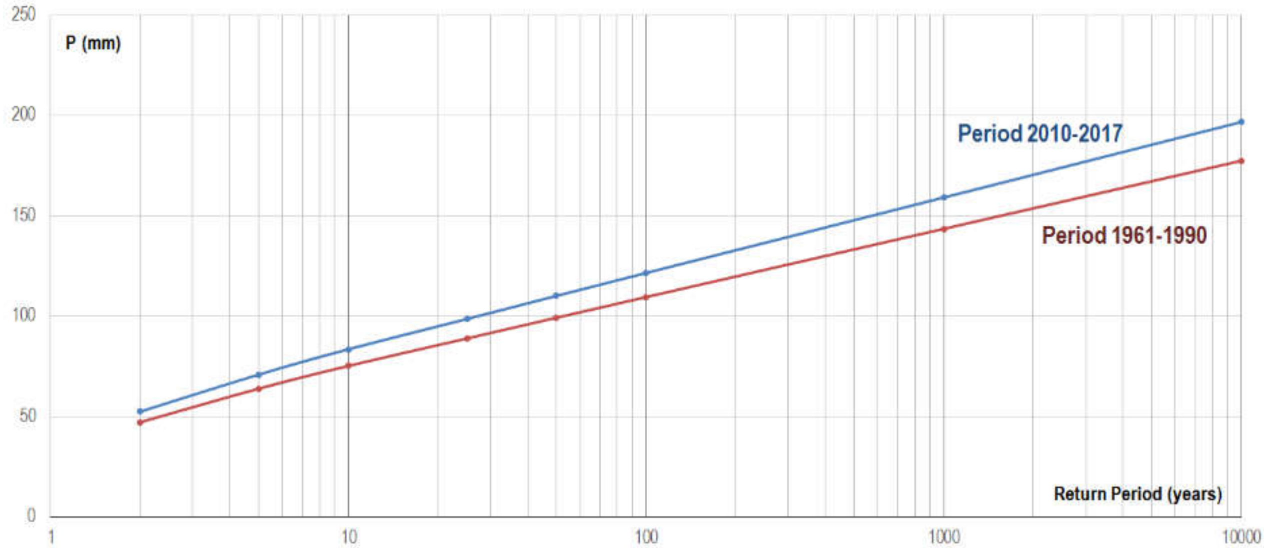


Figure 25 IDF curves for Tetovo Rainfall Station for two analysed periods

The final stage of the process involves taking the hydraulic dimensions required for the watercourse crossing and designing the structural detail to integrate this into the road alignment.

2.2.2 Landslide analysis to create GIS landslide hazard map

The overall objective of this task is to identify the relative levels of susceptibility, hazard, exposure, vulnerability/ risk to landslides that road network experiences under current climate condition and will experience in future climate scenarios. The output from the task is a series of according maps, covering a road section; the example given through the case study area in the Polog region. These relative levels need to be standardised into a normalized scale, typically ranging from 0 to 1. This task also needs to use climate change models to estimate how current levels are expected to change in the future. Using existing climate change projections, the output from the task should include three series of maps, one for each climate projection.

Herein, the most common landslide types in the country earth/ debris slide/ slumps/ flows are merged. Rock falls and other specific types should not be involved, due to the inconvenient scale, and would require different set of proxies than the former. Moreover, it is expected that PESR undertakes the assessment sequentially, by regions, and acquires access to existing landslide inventories covering according regions. Poorly covered (small number of landslides) regions will have to be mapped for landslides as proposed in the following methodology. The methodology works properly if at least 5-10% of the target territory is covered by landslides. It is sufficient to have point-based locations with additional essential attributes (size, depth, state of activity, level of confidence, etc.) but it is preferable to obtain polygonal geometry. It is possible to proceed only after compiling a decent landslide inventory of historical and recent landslides. In addition, it is advisable to have landslide instances (points/ polygons) evenly distributed across the target area (e.g. region), since clustered or aligned instances (e.g. along traffic corridors) can affect the model calibration/ evaluation.

2.2.2.1 Data requirements to complete analysis, together with clear definitions of the data

As a base for climate and climate change impact on infrastructure resilience, the road network and road asset data is crucial. All analysis is conducted according to the existing data. The vast majority of data is available in PESR. During field visits (site specific), the existing data should be updated locally.

- Road network map:
    - Road reference system;
    - Pavement surface conditions based on International Roughness Index and numbering;
    - Length, alignment, profile and width of road sections;
    - Road section surface type;
    - Data on surface condition and serviceability (deterioration, surface condition, roughness, speed limits);
    - Location (map) of the road interruptions and damages made by natural disasters (landslide, flood, erosion);
    - Data on traffic characteristics and volumes (annual average daily traffic –AADT);
    - Data on road section history (construction, rehabilitation and periodic maintenance data), information on road maintenance and repair strategy;
    - The costs of the repair or rehabilitation of road damage or interruptions (limited number of data); and
    - Location (map) of special works carried out, in particular sites especially prone to flooding or landslides, geographical position of bridges damaged by recent floods or erosion phenomena.
- Road asset data:
    - Location and information on bridge condition, ranking of importance of each bridge in the road network, (factors such as availability of alternate facilities, communication and economic impact, functional importance, replacement cost, etc.);
    - Location and information on tunnels and their condition;
    - Location (map) of culverts;

- Information on other road appurtenances: e.g. condition of road intersections, road signs, retaining walls and riverbanks defences.

All the above-mentioned data are available in the format of geo-referenced maps, shape files, Excel tables and text reports, sufficient to meet the demands.

Apart from the inventory, it is further necessary to collect various spatial data, triggering data, as well as an asset inventory (elements at risk). To summarize, it is required to obtain:

1. landslide inventory as point or polygon vector data (e.g. .shp file).[15]
2. environmental proxies as raster data (e.g. geotiff/ tiff) given in the table below
3. triggers (e.g. geotiff/ tiff)
4. road network as line vector data (e.g. .shp file) [16]

Spatial probability of landslide occurrence is related to the overall characteristic of the natural environment, i.e. geological, morphological and environmental conditioning factors or criteria. These reflect the natural potential of slopes to fail, without any artificial influence (road cuts, excessive loading, deforestation, disrupting natural drainage, excessive erosion in farming areas, mining – blasting). According to the proposed multi-hazard (criteria) based assessment, albeit heuristically or statistically approached, the relation between conditioning factors and historic landslides is a crucial link for devising a transferable model that can be then extrapolated over specified target area. In such context, adopted factors/criteria are proxies that control the landsliding process to some degree. The objective is then to model to what extent each of the adopted proxies influence the process. Only conditioning factors/criteria that are relevant for the target territory should be considered as proxies. Depending on the availability and chosen scale, the recommended proxies are, but not limited to those given in Table 16.

Table 17 Recommended proxies - landslide spatial probability

#	Conditioning factor	Proxy rationale	Recommended sources and formats
1	Lithological units	Landslides are predominantly hosted in looser rock masses, prone to weathering, with higher clayey content. An expert (group of experts) opinion or a simple statistical ratio (landslides vs. lithology) can be used to score more and less prone units on 0-1 scale.	Basic geological map of former Yugoslavia, 1:100.000, from the national geological survey, rasterized and/or digitised (.shp/.tiff)
2	Elevation	Potential energy is defined by elevation, so higher grounds have more energy to begin with and potentially host more destructive landslides, with long runout reach. Splitting of different elevation intervals their 0-1 scoring can be done automatically.	Digital Terrain Model (DTM) with 30m resolution, from national geodetic authority or open source variants (SRTM, ASTER, ALOS etc.), with standard raster format (.geotiff)
3	Slope angle	In loose rocks, steeper the slope, higher the potential of slope failure. An expert (group of experts) opinion or a simple statistical ratio (landslides vs. slope) can be used to score more and less prone units on 0-1 scale.	Derived from DTM in a GIS environment in raster format (.geotiff)

[15] This is currently not available in digital version. PESR has this information in various hard copy or electronic forms. The requirement for Landslide inventory mapping has been referenced in these Guidelines and for the purposes of this project, the existing maps with some information have been used and then study area Polog road section was verified/inspected. Alternative sources for analysis have been referenced

[16] Available from RAMS

4	Distance from stream	The streams local erosion basis dictates the lateral undercutting of the valley sides thereby destabilizing them. Closer to the stream, higher the potential of slope failure. Splitting of different distance intervals their 0-1 scoring can be done automatically.	Stream network is first derived from DTM and then the distance buffer from stream network lines is calculated in a GIS environment in raster format (.geotiff)
5	Land cover	In shallow landslides, the forest cover can provide an additional cohesion to the ground, coming from root suction, thereby additionally stabilizing the slope, but on the other hand, arable land is less resistant and therefore, more prone to landslides. An expert (group of experts) opinion or a simple statistical ratio (landslides vs. land cover) can be used to score more and less prone units on 0-1 scale.	From CORINE Land Cover Map 2012 or later, with 100m resolution (www.eea.europa.eu) in raster format (.geotiff).
6	Depth to bedrock	The topsoil is practically a weathering substrate of the underlying rock, and if it is thicker and contains more clayey components, it can host more destructive shallow slides and flows than the thinner soil cover. Splitting of different depth intervals their 0-1 scoring can be done automatically.	From SoilGrids open-source project (www.soilgrids.org), resolution 250 m raster of the Absolute depth to bedrock in cm [BDTICM], in raster format (.geotiff).

PESR should determine what other data is likely to be readily available from existing sources, what other region-specific data is reasonable to include, which will determine the new data that will need to be collected from the field. A balance needs to be established between what data would ideally be required to assess landslides vs. what is available.

As for the trigger data, it is assumed that multi-temporal landslide inventories are difficult to collect timely for an entire region, even more so on a national-level assessment. Therefore, trigger data (preferably rainfall, but possibly also earthquakes, floods, etc.), which are easily collected across various recent periods (e.g. past decade) incorporate the temporal dimension that is missing in the landslide inventory. These are usually available from national hydrometeorological/ seismological services for historic events, or future projections in raster format. Alternatively, the gauge/ ground station measurements are given as point-based vectors (or according tables can be converted to vectors) and interpolated over desired area, giving a raster output (e.g. geotiff format).

Finally, road network vector that will subsequently overlay all raster intermediate models (susceptibility/ hazard/ exposure) should consist of road links and nodes, with correct topology (no geometrical overlaps and gaps) and keep consistent road sector and road link identification reference. It is desirable that a single vector file in .shp format, or even better as a spatial database, hosts all necessary input attributes allocated per each individual road link. These attributes (road link reference, such as ID, beginning/ end chainage, length, etc.) should include, but not be limited to:

- Longitudinal evenness IRI or Average IRI: providing the basics for further vulnerability assessment (available for most of the network, but not for the lower category regional roads R2)
- Traffic accidents: for some possible correlations with our deliverables (presumably available)
- Average annual daily traffic: providing the basics for further criticality assessment (presumably available)
- Pavement distress: for further road vulnerability assessment (partially available)
- Pavement strength: for further road vulnerability assessment (limited/localized data)
- Transverse evenness Rut: for further vulnerability assessment (partially available)
- Skid resistance: for further road vulnerability assessment (limited/localized data)
- Texture depth: for further road vulnerability assessment (limited/localized data)

- Vertical points: for further criticality assessment – rerouting details about uphill-downhill driving mode (available for most of the network, but not for the lower category regional roads R2)
- Gradient: for further criticality assessment – rerouting details about uphill-downhill driving mode (available for most of the network, but not for the lower category regional roads R2)
- Speed limits: for further criticality assessment – rerouting details, as well as economic factors development (unavailable)
- EuroRap risk rating: for reference – result comparison (partially available)
- Investments: for scaling and scoring realistic remedial measurement costs and dynamic (partially available)
- Work programme or Road works plan: for scaling and scoring realistic remedial measurement costs and dynamics (available for most of the network, but not for the lower category regional roads R2)

2.2.2.2 Methodology for landslide hazard, vulnerability and risk assessment

Landslide assessment involves a sequence of susceptibility -> hazard -> exposure -> vulnerability -> risk analyses. Each step is an intermediate model that affects the succeeding one, in order to reach the final estimation, i.e. landslide risk over an element at risk, in this case, a road element. Herein, a brief explanation of these steps will be provided, with reference towards more elaborate instructions. Susceptibility, hazard, and intermediate exposure are conducted under raster modelling environment, whereas remaining part of the exposure, vulnerability, and risk have vector-based outputs.

1. Susceptibility represents a spatial probability of landslide occurrence over an area and relies on the analysis of the landslide vs. proxy relation. Particularly, the fact that landslides generally occur under similar conditions repeatedly is exploited to zone the areas that have similar characteristics as areas that host landslides. For regional and national levels, it is hereinafter recommended to use relatively simple multi-criteria heuristic approach, or alternatively, simple statistical implementation, to establish landslide vs proxy relation. The first would involve selection of relevant proxies, followed by their subjective splitting into intervals, finalized by subjective scoring of those intervals into 0-1 range (0 not susceptible, 1 highly susceptible). This is usually performed by an experienced landslide expert or group of experts. The existing landslide inventory should therein be used for visual check of the adopted scoring criterion, and fine calibration of the intervals and scores. Statistical approach, however, requires only the splitting into intervals and fine calibration of the intervals (by visual check against the landslide inventory), while the scores are calculated analytically. The simplest calculation would include landslide frequency within each class, i.e. a ratio of number of landslide instances and all instances within a class (with previously defined intervals, automatically or subjectively). In both approaches, the final model is additive, i.e. calculated by summing up all scored rasters into a single one, which after normalization falls within the 0-1 range of relative susceptibility to landslides.

2. Hazard assessment by definition, represents a spatio-temporal probability of landslide occurrence, and therefore relies on the information on landslide frequency within a specified return period (10, 20, 50 years, or as far as the landslide records can reach). However, it is seldom performed as such, because of a lack in temporal description in landslide reports (lack of multi-temporal inventories). Therefore, they can be approximated by some other quality, usually called a magnitude, which, apart from frequency, can include size, volume, or velocity of a landslide. Lately, there is another approach, which considers relating the frequency of the trigger (rainfall, earthquake) with the frequency of landslides. If one is certain that majority of expected landslides will be triggered by e.g. heavy rainfall it is sufficient to establish the threshold of the precipitation amount needed to activate landslides and then track-back the frequency of such rainfall events in the past. The historical rainfall and earthquake inventories are usually more systematic and tracked longer than the historic landslide inventories. However, it is not uncommon that even the said threshold cannot be confidently calculated. In such cases, which is actually the majority of cases, it is suggested to use the averaged values of the longest available antecedent period. These records can include (i) average annual rainfall, or even better, (ii) average annual heavy rainfall record (number of days >10 mm or >20 mm), which are usually presented per weather station (table or vector file). It is further needed to interpolate these values or make a combination of the rainfall index (e.g. multiply i and ii or devise

some other index) to reveal their spatial pattern in a raster file format. It should be finally normalized to 0-1 range. The landslide susceptibility raster, created in the first step, can then be overlapped with rainfall index raster to reveal areas that have both, a spatial potential to fail and a trigger of sufficient frequency and intensity. The output map is a quasi-hazard map, that discerns areas of higher vs lower spatio-temporal probability to fail using a relative, 0-1 scale.

Finally, it is required to establish specific hazard classes, usually five of them, ranging from very low to very high hazard. This step has several options, as raster with continuous numeric range 0-1 can be split into arbitrary number of classes with arbitrary intervals. However, it is generally suggested to split the classes by quantile proportion, so that each class has the same size (same number of pixels). It is, by all means, recommended to perform a validity check at this point by checking whether landslide instances fall well enough within high and very high class (using the inventory instances or a subsample of representative instances). Standard modelling performance metrics should be used for quantifying this (% of accuracy, predictive and success rates, etc.). The model should be modified until sufficient accuracy is achieved, typically over 70-80%.

Landslide assessment is herein depicted through the following steps: Landslide susceptibility -> Baseline landslide hazard ->Projected landslide hazard

Landslide susceptibility assessment

Landslide susceptibility is developed using a base from a model based on Analytical Hierarchy Process obtained from Milevski et al. (in press), 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. Details on this procedure are given in detail in the methodological part/annex.

The susceptibility model represents a distribution of the natural potential to develop landslides, depicted by very high to very low susceptibility classes (upper left of Figure 26). However, these are only spatially defined zones, and do not take into account the temporal variability of the landslide process. According to the adopted procedure, quasi-hazard can be simulated by substituting temporal dynamics of the landslide process by the temporal dynamics of its trigger, in this case, the rainfall factor. The latter is calculated by multiplying the normalized annual sum and normalized and normalized daily maximal precipitation. Obtained factor is within 0-1 range and highlights areas that have both, heavy rainfall extremes (daily) and high total rainfall throughout the year, i.e., the saturated areas. It was finally used to multiply previously created (AHP) landslide susceptibility raster to overlap these saturated areas with zones of high landslide potential. Such procedure allows relative hazard estimation, suitable for splitting hazard into very high to very low classes, indicated by the red-green colour ramp by using the Natural Breaks interval splitting method. Short and long-term projections of landslide hazard are generated by using the baseline hazard map and multiplying it with projected rainfall factor, i.e. a 1 + the product between according (short/ long-term) annual sum change and cumulative 90th percentile change, which are considered as rainfall parameters that best reflect those used for the baseline hazard.

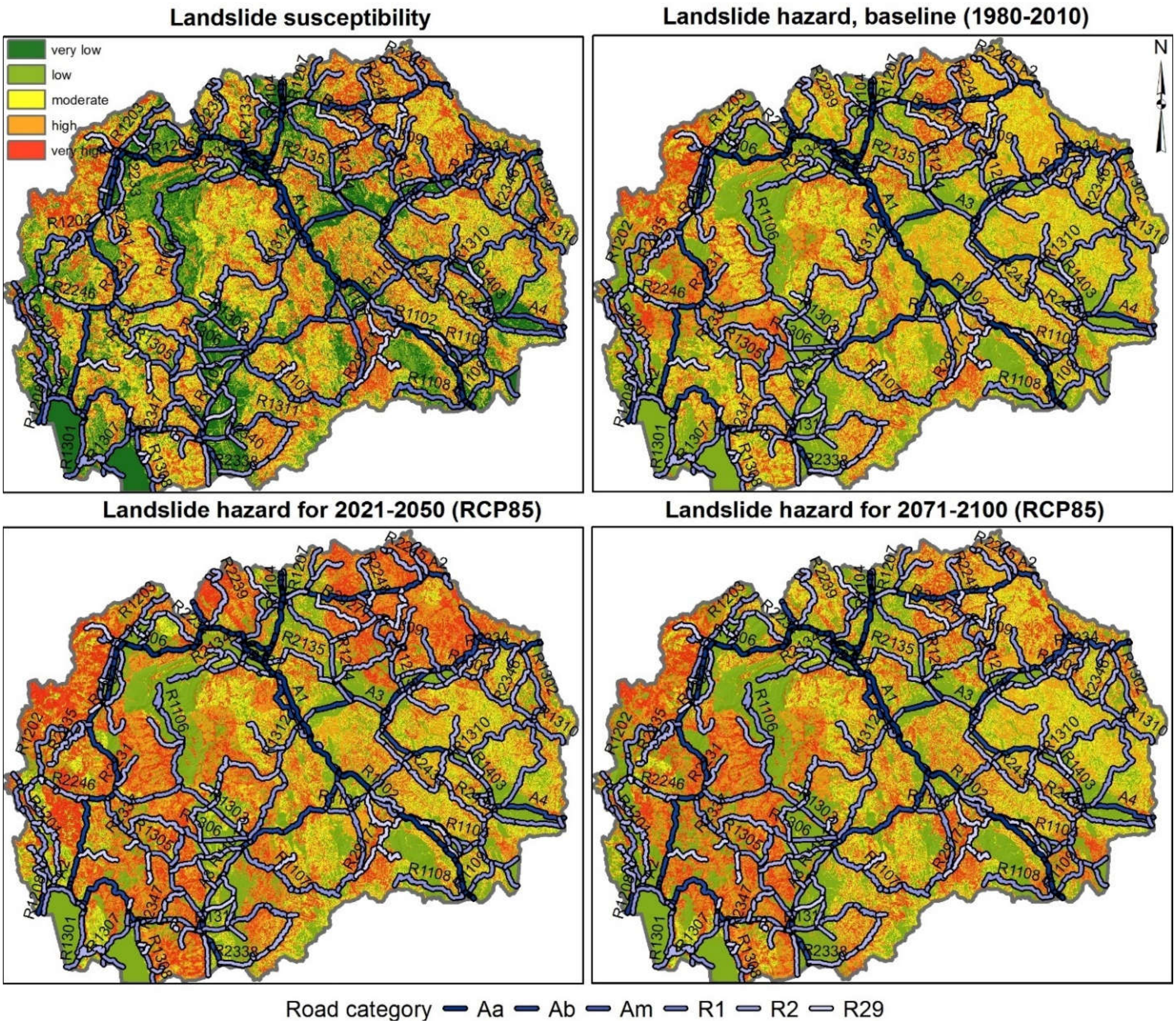


Figure 26 Baseline and projection landslide susceptibility and hazard maps

Resulting Baseline landslide hazard map (Figure 26 upper right) reveals that western and southernmost parts have very high landslide hazard, as well as the NE, and some smaller clusters within the central parts. The A2 road is heavily exposed, together with some R1 and R2 roads. However, the most severely affected areas are mainly away from the main state roads.

The change is dramatic for the short-term hazard projection, where most of the moderate to high hazard classes from the baseline shift towards high to very high i.e. for an entire class. Most of the A2 and A3 routes are highly exposed, while A1 is moderately exposed especially in the hilly areas. Most of the R1 and R2 roads along the west of the country also fall within high to very high hazard. Given that the rainfall trends for short-term projection are clustered all around the country, as previously discussed, such generic increase of landslide hazard is anticipated.

Long-term projection is more optimistic, as the landslide hazard is only somewhat more pronounced in comparison to the baseline. The main change is within the moderate class which tends to increase to high hazard, thereby increasing the exposure along the A2 route and associated R1/ R2 roads in the west. The strongest changes are around Ohrid area and Demir Kapija, which is in compliance with previously discussed anticipated changes of the extreme rainfall pattern for long-term rainfall projection.

3. Intermediate exposure is herein regarded as the zone of influence of previously defined very high hazard class. It is simply the calculation of distance of road asset from the very high hazard class, limited by an arbitrary landslide runout margin. If a future landslide starts on the very edge of the very high hazard zone its runout should not exceed this margin. This concept especially applies to flows, not as much to slides/slumps. The margin is established by field inspections, more detailed displacement modelling, or by analysing longest lengths/ runouts of the available historical landslides. The final intermediate exposure raster is created by normalizing the distance values to 0-1 range (1 being within the very high hazard zone or closest to it, while 0 means on the margin, i.e. the furthest away from the zone). It is a good concept that takes the spatial context of an element at risk to another level, as will be explained later.

According to the available insight into the stakeholder's road network database, the smallest road element is a road link, and all preceding models are to be reflected along road links. This means that road exposure, vulnerability and risk will be unique values along a link, albeit 10 m or 10 km long. Alternatively, these can be further split into regularly spaced segments (e.g. 500 m) to reflect the final risk output somewhat better, location-wise. Thus, there are two approaches at the very beginning of risk estimation (a) link-level, and (b) segment-level.

4. True exposure is allocated along the road link (a-case) or road segment (b-case). The values of intermediate exposure should be allocated to superimposed road network vector by averaging all intermediate exposure pixel values encountered along each link/segment. It is practically another attribute or another column in the road network attribute table (.shp format).

5. Vulnerability is an intrinsic feature of road network element that should describe its fragility when exposed to landslide hazard, i.e. to an actual landslide emergency. In other words, the roads with different vulnerability features will differently respond to the same magnitude of hazard. As such, it can be only linked to the road link level (a-case), as segments are arbitrarily divided and are not referent for carrying the official road link information. Vulnerability depends on the quality of the road on one hand, and quantity of traffic, i.e. possibility of affecting passengers. Additionally, the road sections are also vulnerable if their forming links are too long and require substantial rerouting in the case of emergency. Therefore, it is meaningful to use all available road network information about the road condition, geometry and traffic frequency. As exampled in the road data list in section 2.2.2.1, features such as roughness index or pavement condition, texture, link length, road category, etc. are all self-explanatory. For instance: the greater the frequency, greater the vulnerability; higher the length, more vulnerable the link; greater the roughness more vulnerable the link. These inputs should be appended to the road network vector, which already contains true exposure attribute, and normalized to a 0-1 range. The final vulnerability is calculated as a product of all normalized inputs.

6. Landslide risk is combined landslide exposure and vulnerability of element at risk. It should be depicted per each road link (a-case), as conditioned by the vulnerability, using the same line vector (preferably .shp format) as before. It is calculated by multiplying these two normalized values for each link, i.e. utilise the following formula:

   Risk = Hazard exposure of road assets x **Vulnerability of road assets**

   To validate the risk, it might be interesting to superimpose the information on traffic accidents (which is available in the stakeholder's database). However, the information on the cause of the accident is important, since all non-landslide caused cases are to be excluded. Otherwise, it is difficult to objectively validate the risk (especially for the future scenarios). In general, if the hazard/ exposure models are validated and show good fit, and there are no substantial logical flaws in vulnerability assessment, risk should inherit the good fit from the hazard/ exposure.

Having in mind all of the above, this procedure describes the current landslide hazard/ risk. It is further necessary to repeat the entire process from point 2-4 twice, for two according climate projections, since the rainfall index introduced at point 2 will likely differ in the future. It is safe to say that susceptibility model (Step 1) is more-or-less constant for the target (100-year) period. New hazard and exposure raster models should be represented by the according future projections, by substituting current rainfall factor with the first rainfall projection variant (e.g. expected rainfall index for the next 50 years) and the second variant (e.g. expected rainfall index for the next 100 years). Since intermediate exposure raster is affected, all succeeding steps will also be affected,. The problem therein is difficulty to confidently predict road conditions and traffic frequency in 50 or 100 years from now. Unforeseeable technological changes regarding vehicles and roads might affect any assumption, as well as other unpredictable impacts on traffic conduct (new settlements, new plants, new storage centres, service centres, shopping centres, building of entirely new roads etc.). It is therefore less harmful to keep the vulnerability constant and focus on the redistribution of hazard part of the risk for both future projections.

2.2.2.3 Approach and methodology for landslide risk assessment at detailed scale: The Polog study area landslide susceptibility, hazard and risk

Landslide susceptibility, hazard, and risk assessment at regional scale is demonstrated on Polog study area. All details of the approach are explained in Peshevski et al. 2019 (doi: 10.4154/gc.2019.03), but basics of the technique will be briefly explained hereinafter. Unlike for the national scale, the MCA – Multi Hazard is herein deployed with extensive fine-tuning and sensitivity analyses, based on very rich landslide inventory.

The Polog area spreads over 2400 km^2, with approximately 1200 registered landslides, which makes it convenient for any of the suggested approaches including MCA heuristic or statistical, Machine Learning or even deterministic. Even though the latter was not convenient due to a lack of available geotechnical properties over a wider region, it has was also included as a preliminary hazard model.

Multi factor approach to susceptibility and hazard assessment

The procedure includes selecting a set of predictors/ conditioning factors, which herein included:

- *Lithology*
- *Slope*
- *Land Cover*
- *Earthquake 100y/500y return period intensity*

These were subsequently ranged into appropriate number of classes, and appropriate score was assigned to each of the classes. The ranging and scoring procedure used a combination of statistical and empirical approaches, based on the available landslide inventory, i.e. based on the known distribution of numerous landslide examples. For instance, if the statistically based ranging and scoring would not produce apparently representative class within a predictor (low score for a class that encloses multiple landslides, or too narrow range of the class intervals), the experience-based ranging and scoring would replace it.

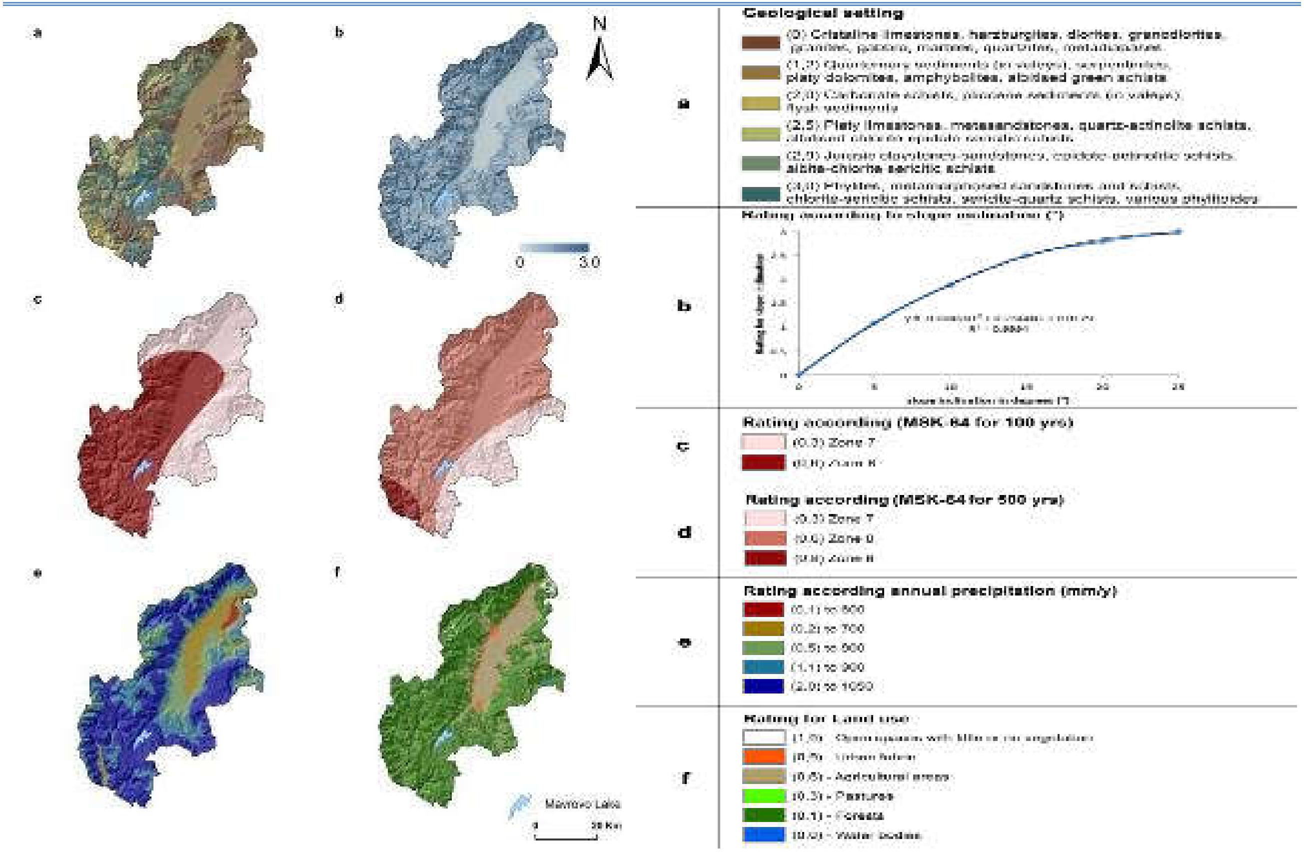


Figure 27 Conditioning factors (predictors) for landslide susceptibility and hazard assessment (Peshevski et al. 2019)

Eventually, all input predictors are shaped into the according rasters that can further be combined to reach the final additive model of Landslide Susceptibility (LS). Their combination and weighting can be fine-tuned and checked for sensitivity. The final optimal model included the following weight distribution:

LS = 0.3 x Lithology + 0.23 x (Slope + Land Cover + Earthquake_100)

Switching from susceptibility to Landslide Hazard (*LH*) required involvement of triggering process and its spatio-temporal influence, similarly as in the case of national scale. It was again based on interpolated rainfall measurements depicting conditions of severe rainstorms or periods of prolonged rainfall (maximal recorded daily values and annual totals, respectively) within a baseline period (*Rainfall*). The optimal model now included the rainfall:

LH = 0.3 x Lithology + 0.175 x (Slope + Land Cover + Earthquake_100 + Rainfall)

Finally, the Rainfall Factor (RF) normalized to 0-1 range, as described earlier for the national scale example (spline interpolated downscaling), was used to predict the hazard change in the future, for 2021-2050 and 2071-2100 period, respectively:

RF1 = 90th percentile rainfall x expected annual sum for 2021-2050
RF2 = 90th percentile rainfall x expected annual sum for 2071-2100

Both factors were introduced by using the worst climate change scenario, i.e., gas emission RCP85. Since it represents the factor of change of the baseline levels, it was introduced in the optimal model equation by using:

LH1 = 0.3 x Lithology + 0.175 x (Slope + Land Cover + Earthquake_100 + (1+RF1) * Rainfall)

and

$$LH2 = 0.3 \times Lithology + 0.175 \times (Slope + Land\ Cover + Earthquake\_100 + (1+RF2) * Rainfall)$$

LS model depicts that area is generally heavily affected by potential landsliding, covering 8.5 % by the Very low, 36% by the Low, 13% by the Moderate, 15% by the High and 27.5% by the Very high landslide susceptibility class. Affected road network primarily includes lower category roads, with only local connection importance. This model is relatively accurate for zoning landslides, with 73% of landslide instances mapped into High or Very high susceptibility class, but has a tendency of overestimating, especially the Very High hazard zone.

The LH model further penalizes those areas that are spatially susceptible to landsliding, while having a strong influence of *Rainfall* (a factor of prolonged and excessive precipitation). The distribution of classes, however, suggests a more balanced landsliding potential: 18% Very low, 19% Low, 18% Moderate, 16% High, and 27% Very high class. However, the High and Very high classes do not change significantly. There are no significant changes in respect to the road network. The model accurately predicts recorded landslides, as over 75% of landslide instances fall into High or Very high hazard class (wherein more than 55% fall within the Very high class). Overestimation is still present but with slight improvements.

The LH1 model shows decrease in Very high – High landslide hazard, as there will be less significant changes in the rainfall pattern in the short-term prediction period, which is partly in line with the climate change expectations on the national level, regarding the rainfall. The distribution of classes indicates a significant hazard decrease primarily on behalf of the Very high class: 23% Very low, 21% Low, 13% Moderate, 19% High, and 24% Very high class. There are no significant changes in respect to the road network. The model parallels the accuracy of the previous ones (73% of landslides in High or Very high class, i.e. 52% in Very high class), but has an obvious improvement, i.e. reduction of overestimation of landslide prone areas.

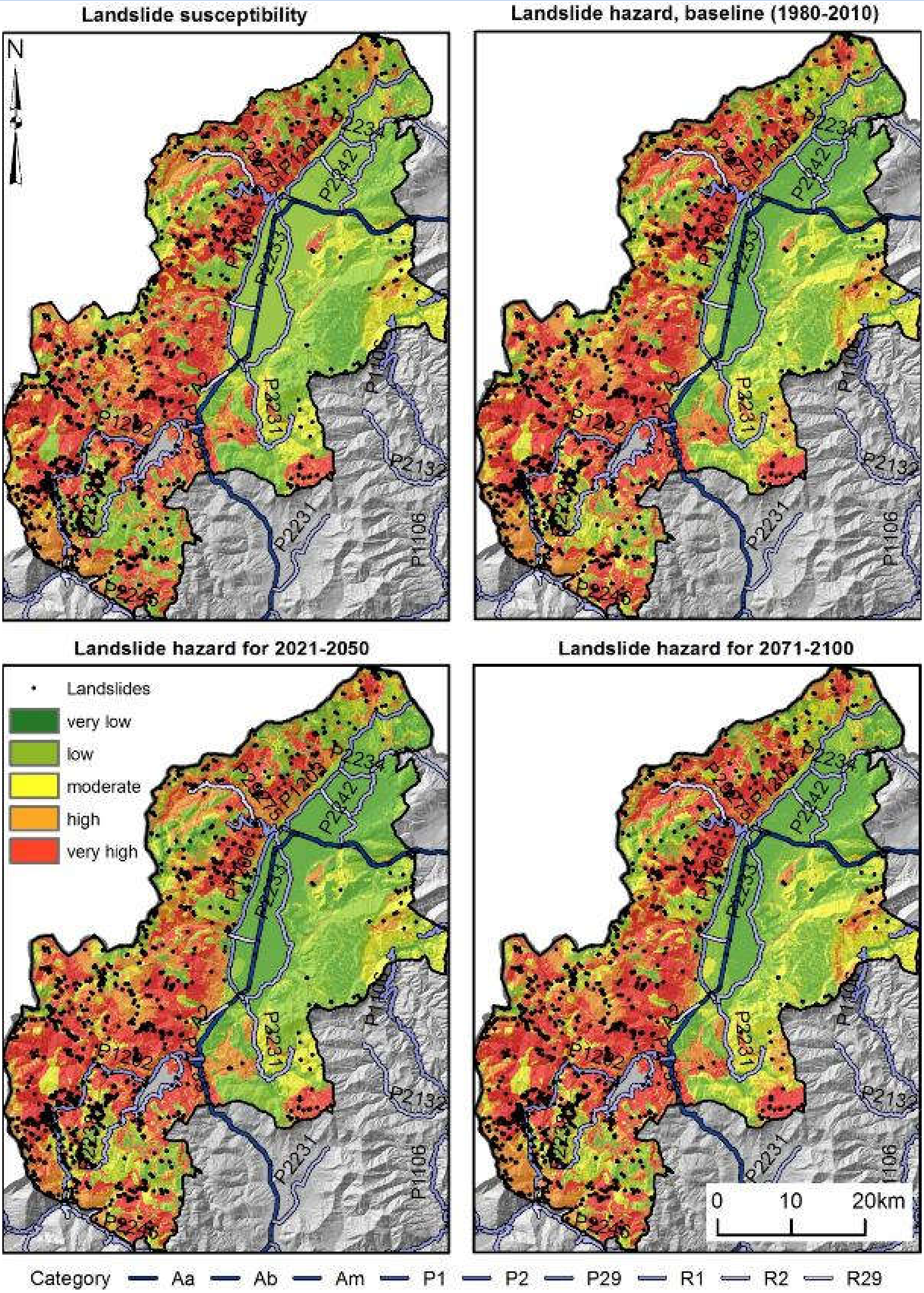


Figure 28 Landslide susceptibility and hazard models for respective periods

The LH2 model seemingly restores back the baseline hazard levels: 17% Very low, 19% Low, 18% Moderate, 17% High, and 29% Very high hazard class, except that High and Very high classes are slightly enlarged. There are no significant changes in respect to the road network. the model performs similarly well (75% of landslides fall into the High or Very high class, and 56% in Very high class) as its according predecessors.

Deterministic approach

The deterministic modeling included SINMAP (Stability INdex MAPping) – a shallow landsliding model based on infinite slope stability, coupled with a steady-state hydrologic model. Such simplification is reflected in the modeling performance but can be considered appropriate for regional scale. It outputs the stability index, i.e. Factor of Safety (FoS) with distributed probability, based on input data uncertainty. In that context it already incorporates direct hazard estimation, as it includes the magnitude (via FoS) of events while considering the influence of the primary trigger (percolated water). Factor of Safety is a convenient concept (well known in engineering and design), defined usually as a relation of resisting and driving forces (in this case strength of rock/ soil vs weight force components and pore pressures), and as such, can support decision making process.

The inputs include

- Digital Terrain Model at 30 m resolution (source SRTM)
- Landslide inventory
- Geotechnical and hydrologic parameters:
  - bulk density γ;
  - unit cohesion $C=c/\gamma$;
  - friction angle ϕ;
  - Transmissivity to Recharge soil ratio R/T (how much is the content of introduced water, e.g. rainfall, larger than the soil's capacity to percolate it)

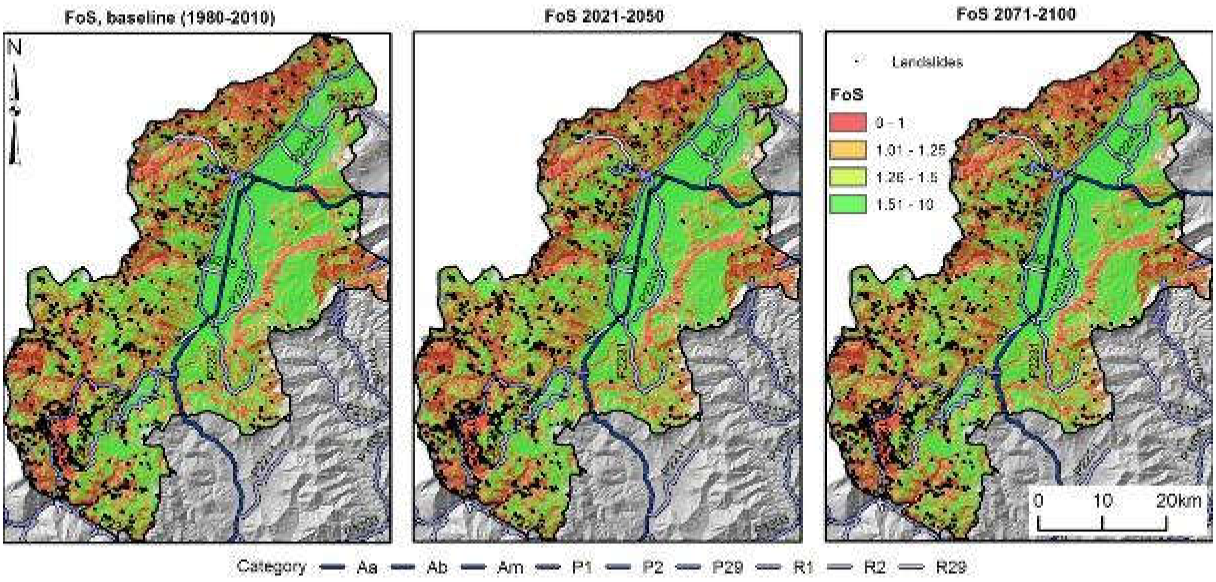


Figure 29 SINMAP models, delivering Factor of Safety as a proxy for landslide hazard

These inputs are estimated, since there is no wide-coverage geotechnical data available for the study area. Average values of C, ϕ and γ are estimated considering the units of the Lithological map. Hydrological parameter T is also estimated by considering the dominant lithology, whereas R is estimated by observing maximal/ extreme rainfall events in the area (baseline, and short/ long-term projections). The amount of change of the maximal/ extreme rainfall, available from both climate projections, is then used to multiply the initial R/T.

The first model, for the baseline period, suggests similar distribution of landslide affected zones to the one proposed by the MCA hazard model. There is a good match with the landslide inventory as well: 51% FoS<1, 16% FoS 1-1.25, 11% FoS 1.25-1.5 (FoS of 1.5 is usually considered as acceptable for slope design, so in total the model predicted almost 78% accurately), while remaining 22% were erroneous.

The second model addresses the short-term projection and suggests very slight variations in comparison to the baseline model. The same can be concluded for the third model, which addresses the long-term projection. In summary, the climate effects are not as evident as in the MCA models, but it needs to be highlighted again that these deterministic models are based on a great deal of approximation and averaging, due to a lack of detailed data.

Vulnerability and Risk assessment at local or site-specific location, Polog study area

The exposure to landslide hazard is calculated per each road link (predefined geometry). The baseline hazard values are projected onto the network, and maximal value picked up along the link is assigned for the entire link.

The Vulnerability is intrinsic road property and is based on its condition and setting. The criteria for estimating road Vulnerability includes road category (in the example, it is the same category along the road, so no influence), International Roughness Index (IRI, taken from RAMS portal visually), and road link length (node-to-node) as important factor of potential rerouting in case of emergency. These factors are collected along a road and normalized, to relative range (e.g. 0-1), as shown in the Figure 30. The final Vulnerability is obtained by multiplying individual factors.

The road risk is expressed on a relative 0-1 scale, as a product of Exposure and Vulnerability, and can further serve as a tool for deciding priorities and revealing the most critical parts of the road requiring attention.

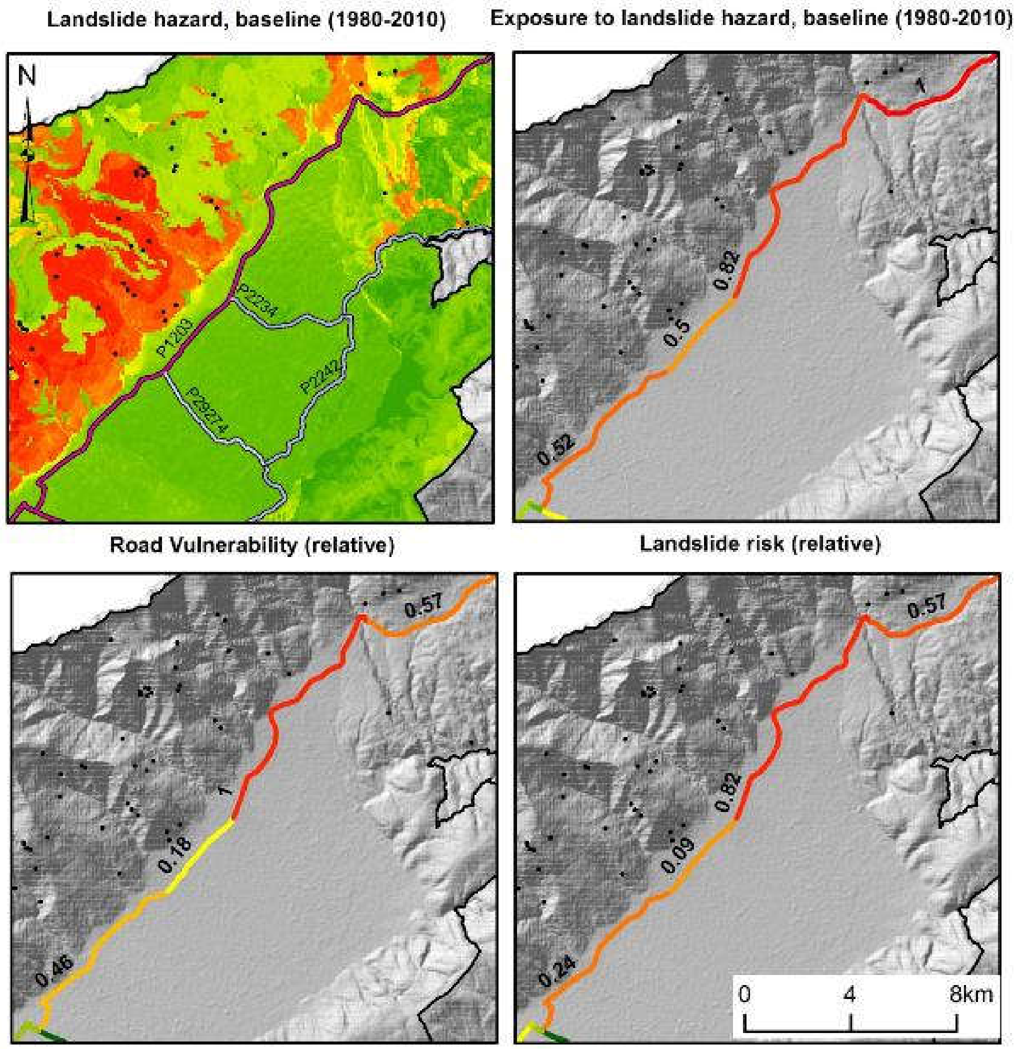


Figure 30 Example of calculation of road exposure, vulnerability and risk

2.2.2.4 Interpreting and using the hazard and hot-spot maps

Each raster model results in a map with delimited zones of high-low relative susceptibility/ hazard/ exposure. These are commonly colour-coded using a green-red colour ramp (green for 0 or low values, red for 1 or high values). Red indicates the areas where possibility of landslide event is greater than in other areas. Unless there is an impeccable landslide inventory (with magnitude, history and frequency of landslides) these raster models show only relative estimation. Instead of knowing how many landslides of what magnitude can be expected annually in a high hazard zone, we are simply left with the information that some places have higher probability than the others (sometimes it is exactly what decision-maker need, to prioritize between different parts).

Similarly, the true exposure, vulnerability and risk are also relative (0-1), as neither, hazard frequency nor exact element at risk value can be precisely determined, especially on regional/ national scale, so the risk cannot be expressed as a number of casualties/ injured/ endangered persons, or with monetary value, or by some other standard value (days of delay in services, km of rerouting, etc.).

As indicated before, there is a limited amount of information about traffic crashes held in PESR databases, but these need to be cautiously filtered before their implementation in landslide context. In other words, it is disputable if any of these had anything to do with landslides, but some correlation is possible.

PESR also keeps the record of planned work and their cost, which can be partly used in cost estimations per link. Lack of true hazard and exposure estimation would create difficulty in providing typical risk estimations, e.g. expected annual cost due to damage, or expected number of casualties per year. The problem of predicting the risk for the future is even more difficult as already addressed (uncertain and unconfident predictions of traffic along the network, wherein, the network itself is subjective to change). These have been addressed with the CBA methodology in the guidelines.

Still, these estimations represent valuable information, useful for planning, design, maintenance, emergency response etc. This is in fact, the ultimate preventive measure for road risk mitigation. For instance it can guide decision makers to focus the investments in maintenance (cleaning culverts and trenches, checking drains, scaling loose blocks, removing detached material, keeping effective vegetation cover, replacing damaged or expired protection elements, etc.) in highly exposed (red-painted) links or even better, link segments (b-case). Rainfall factor can serve also as a threshold estimation, and help in deciding when to promote the state of emergency in the cases of heavy rainfall (local threshold exceedance), which leads to establishment of an Early Warning System (EWS), which is practically, the ultimate objective of any landslide risk assessment.

Locations of the standard road signs for landslides can be updated, and some additional info panels can be installed at highly exposed parts (b-case). When planning new road routes, such zones need to be avoided or properly taken care of (by properly designed protection and prevention measures). Long links that have high vulnerability (due to long reroute), while also having high exposure to landslides, can be also clearly marked and provided with additional info panels on rerouting alternatives in case of emergency.

These outputs are precious for deciding on potential evacuation routes, finding alternative routes to ensure providing of essential services, prioritising which locations should be repaired first from a logistical point of view, restricting traffic (e.g. passenger vs cargo vehicles), etc. It is also important to overlap landslide exposure/risk maps with those of other types of hazards that might be simultaneously in progress due to the similar trigger (e.g. floods).

Further tools, i.e. other outputs that can be used to aid decision-making, are addressed in the Section 3. These are primarily intended for planning and investment, while the above is more dedicated to the practical short-term responds of decision-makers, equipped with the knowledge provided by the output maps (hazard, exposure, vulnerability, risk).

2.2.2.5 Using the hot-spot maps

One of the most important roles in decision-making includes directing of investments from available or planned budget. These decisions range from short- (e.g. annual) to long-term plans (e.g. 5-year, but rarely longer than that, due to political administrative and other reasons and uncertainties). Another part of decision-making is reflected through emergencies management, i.e. safeguarding population and property, ensuring continuity of providing services, etc. The latter is sufficiently supported by standard mapping products from previous sections, but some further tools are required for planning purposes, especially investments. Such tools would include calculation of criticality (Criticality Assessment – MCA described below), and prioritisation, together with its associated indices, i.e. prioritisation per km or per cost.

Prioritization combines all the outputs, i.e. vulnerability, risk, and criticality. The process of identifying the highest priority interventions takes the data from the previous stages and brings them together in a single analysis. This creates a single index, which can be used directly to rank interventions. The multi hazard combining Hazard, Vulnerability and Criticality to produce hot-spot map is described in Section 3

2.3 Criticality Assessment – Multi Criteria Assessment (MCA analysis of relevant parameters in GIS environment)

2.3.1 Background

In order to assess the criticality of the network exposed to the risk of floods and landslides, MCA analysis needs to be conducted prior to taking the next step, the site-specific survey. This will determine if the road link is critical enough to be further analysed and assessed and/ or the level of investment that will be required for mitigating the risk. Hence, the objective of this task is to identify the most important parts of the road network, that is under assessment. This enables the subsequent detailed assessment of their risks and specific interventions to be targeted on the most critical areas of the road network. The assessment is conducted after the Multi-Hazard Assessment, when it is determined that the road sections in the hot spot areas are of high importance, critical for the users and if critical assets are covered by this network.

Note that at this stage, the level of detail remains at a relatively high level. Thus, road sections, rather than specific sections or specific road assets, are being considered. However, this is considered to be the most appropriate approach as the criticality of any given asset should be assessed on the basis of its relationship with other assets on the same road section, as the integrity of the road section as a whole is the factor that provides utility (e.g. there is no point having a perfectly good bridge, if the roads either side are impassable).

The methodology for this task utilises a form of multi-criteria analysis, specifically the Weighted Arithmetic Aggregation Method, established by Intergovernmental Panel on Climate Change (IPCC) and others. This requires the calculation of a series of indices enabling the comparison of the criticality of different road sections, based upon a series of factors. This method is described further below.

The factors that should be included in the calculations are those which best reflect the socio-economic importance of a road section, the impact of a loss of connectivity in key areas, and the overall economic impact of dislocation/ rerouting.

Socio-economic data is very complex and structured in different ways, which has implications for the completion of this analysis. As shown below, data is often held by a variety of organisations, and reflects different collection dates, standards and levels of disaggregation. This has determined the methodology to be followed in these Guidelines.

2.3.2 Multi-criteria analysis

Multi-criteria analysis (MCA) is a methodology that provides a systematic approach for ranking decision options against a range of decision criteria; in this case, MCA should be used to rank different roads for investments in climate resilient improvements. The structured framework provided by MCA allows for the combination of expert knowledge and stakeholder preferences, thus being a useful tool for enabling the inclusion of stakeholders in decision-making.

Because MCA is able to consider both qualitative and quantitative information, it is particularly useful when such a combination of factors must be considered in the ranking of decision options. The actual measurement of indicators does not need to be expressed in monetary terms but is rather based on the quantitative analysis (through scoring, ranking and weighting) of a wide range of qualitative impact criteria. As such, criteria like social factors, traffic volume and road density can be accounted for within the same scoring system[17,18].

Each of the criteria is assigned a different weight that reflects its relative importance; these weights can be appropriately adjusted so as to match the policy priorities and investment goals of decision-makers. In the case of investing in the climate resilience of a road network, it might be that stakeholders wish to prioritise roads with small redundancy, and which would be stressed in case of a landslide or flood event. In other cases, traffic intensity might be the key factor to prioritise, or access to social services. After taking this into consideration when attributing weights to all the factors, the weighted sum of the different criteria is finally used to rank decision options.

2.3.3 Methodology

MCA should be used to assess the criticality of different segments of North Macedonia's road transport infrastructure. Infrastructure criticality is defined as the importance of specific sections of the road infrastructure regarding the provision of access to key locations (e.g. schools or hospitals). The bespoke methodology developed for this case includes what is served by each road in terms of traffic, availability of alternative routes, population, contribution to emergency response and overall resilience, and access to social services. The following criteria should be taken into consideration:

Table 18 Factors considered in the Multi-Criteria Analysis

Issue	Criteria	Rationale
Traffic intensity	Traffic using the road section	Traffic intensity is one clear measure of the importance of a road section
Availability of Alternative Routes	Density of road network in the area	Density of the road network is used here as a proxy for the availability of alternative routes
Population served	Number of people in different categories	Roads that serve higher levels of population are considered to be more important
Contribution to emergency response and overall resilience	Key infrastructure served	This includes centres used for coordination or emergency response, important infrastructure, and the places where people congregate during emergencies
Access to Social Services	Number of schools and hospitals served	Access to these facilities is important both for day to day life and during emergencies

Assessing road criticality involves setting up an MCA framework within the GIS system where the importance of each road link is established. By assigning a value to each of the factors in the Table 18 below, a score is then developed for each road section, allowing for the prioritisation of roads for climate resilient investments. This broadly follows the 'Weighted Arithmetic Aggregation' method proposed in the GIZ Vulnerability Sourcebook[19], although it uses a GIS-based approach rather than the more mathematical approach set out elsewhere. As far as possible, the methodology selected is designed to be as automated as possible, with

[17] Multi-criteria analysis: a manual (2009), UK Department for Communities and Local Government
[18] An Alternative Approach to Project Selection: The Infrastructure Prioritization Framework (2016), World Bank PPP Group
[19] Vulnerability Sourcebook (2014), GIZ

minimal human input required, once the system has been established and programmed and data input into the GIS.

Categories should be attributed the following scores:

Table 19 MCA scoring system

Factors	Categories	Score (in points)
Traffic using the road section	Per 1,000 vehicles	10
Density of road network in the area	Low density	100
	Medium density	50
	High density	0
Number of people in different categories	Per 1,000 children	2
	Per 1,000 adults	1
	Per 1,000 retired people	1
	Per 1,000 women	2
Key infrastructure served	Per electricity transfer station	10
	Per drinking water source	10
	Per religious building	10
	Per municipal office building	10
	Per fuel station	10
Number of schools and hospitals served	Per school served	10
	Per hospital served	10

Each road's criticality score should be combined with its score on exposure, hazard and vulnerability, with the goal of calculating a final score that allows for the ranking of road sections for climate resilient interventions.

An example of the use of this scoring system to assess criticality is shown below. As a case study, the MCA framework was used to assess the criticality of sections of the R1203 between Tetovo and Jazince. The results of this assessment show how different factors within the framework can affect the overall result, Table 19.

Table 20 Results of Case Study Assessment

Section	Traffic	Density	Population	Key infrastructure	Social infrastructure	Total
Gostivar 5 (Belichica) - Tetovo 3 (Brvenica)	129	0	277	220	160	786

Tetovo 2 (Dzhepchishte) - Leshok	79	50	1372	230	120	1851
Leshok - Tearce	79	100	189	150	50	568
Tearce - Vratnica (Orashje)	79	100	220	180	70	649
Vratnica (Orashje) - Drzhavna granica MK/KOS (Jazhince)	79	100	60	60	70	369

In order to derive the total MCA score, methodology based on GIS tools was applied. First, a buffer of 1.5km was created on the selected sections (from Gostivar to state border). Afterwards, the available data used for the different categories considered on the MCA – on traffic intensity (from PESR), road density (km/ km2), population served, key infrastructure and social infrastructure – were intersected with the selected buffer, in order to derive the exact population and infrastructure in the vicinity that was served by the selected road sections.

The GIS map with the total MCA score is presented on Figure 31, where red roads score highest and green roads score lowest in terms of MCA.

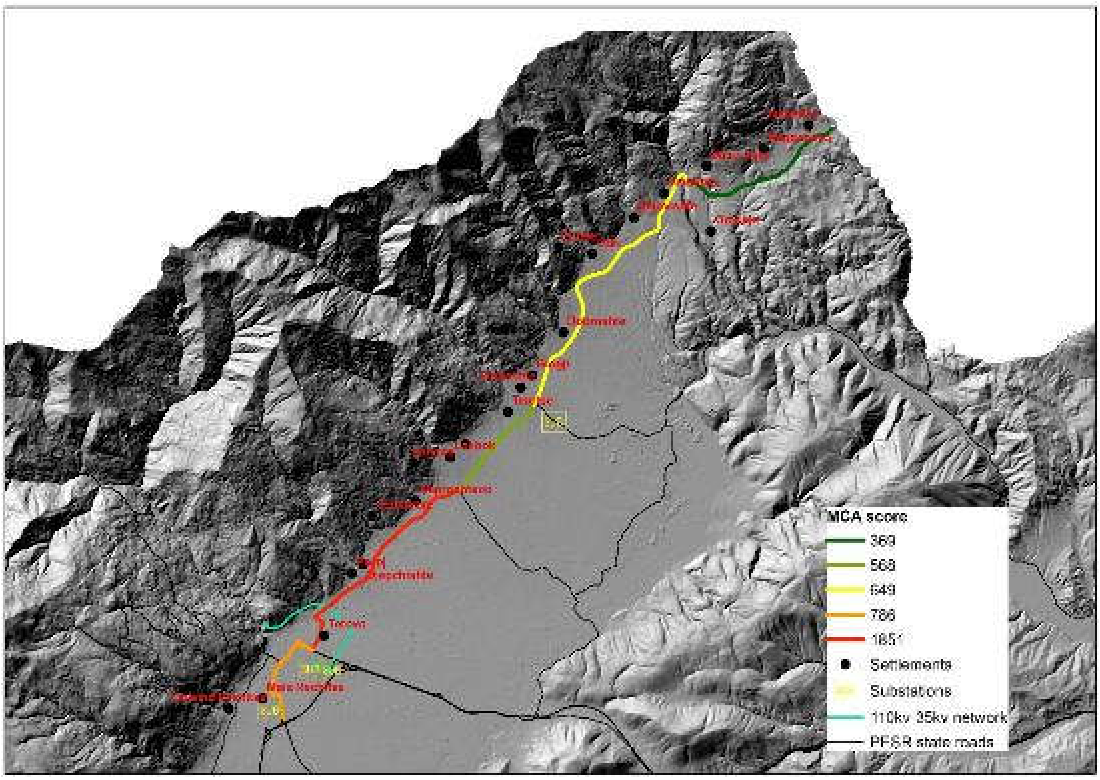


Figure 31 MCA Score represented in GIS

2.3.4 Data Sources

The methodology set out has been designed to use available data to PESR or publicly available data from the relevant institutions as outlined in Table 20. It is likely however, that extensive face to face meetings will be required with representatives of the relevant instituitons to ensure release of the data required, where this is not already in the public domain.

Table 20 below shows the data and respective sources used to perform this MCA:

Table 21 MCA data and sources

Data	Source
Traffic using the road section	PESR database (counting points)
Density of road network in the area	Calculated from GIS (road length per unit area)
Number of people in different categories	Census data, State statistical office
Key infrastructure served	Municipality data, OSM, Topographic map 1:25.000
Number of schools and hospitals served	Municipality data, Topographic map 1:25.000

2.3.5 Data considerations

Having access to relevant, up-to-date data is key to appropriately conducting the MCA scoring methodology, as well as to be able to carry out in-depth economic appraisals later on. The data recommendations presented here can serve as a reference to both national and local levels of governance for bridging data gaps in publicly available data, with the ultimate goal of building and maintaining high-quality socioeconomic and road network databases. As much as possible, we recommend the provision of complete, disaggregated and georeferenced data to the settlement and road levels.

Recommendations

- Detailed population and socioeconomic data, geocoded, age and gender-disaggregated at the settlement level. This should include factors like number of residents, population density, gender, age, number of people with disabilities and employment status;
- Detailed education data, geocoded, age and gender-disaggregated at the settlement level. This should include preschool, school and university network data, plus information on structure (number of pupils, number of teachers, etc.);
- Detailed health data, providing geocoded, age and gender-disaggregated at the settlement level. Health data should account for the number of hospitals and ambulance locations, number of doctors and nurses and average number of patients per hospital;
- Detailed data on other key infrastructure, geocoded at the settlement and road level. This should include electricity transfer stations, drinking water sources, religious buildings, municipal office buildings and fuel stations;
- Detailed local data on economic activities, geocoded and at the settlement level;
- Detailed local road network data, geocoded. This should include data about the traffic, road type, condition and any other characteristic of the local roads;
- Detailed and georeferenced database about all the hazards that affect the road network (usually done at the municipality level). Hazards should be recorded using standard forms with photo documentation.

2.3.6 Combining Hazard, Vulnerability and Criticality to produce hot-spot map

The process of identifying the highest priority sections takes the data from the previous stages of the process and brings them together in a single analysis.

- The first part of this activity is to group all of the vulnerability assessments by road section, in effect producing an average vulnerability, on a scale of 0 to 1.

- Secondly, it was necessary to similarly group the multi-hazard modelling by road section. This produces a measure of the average hazard rating for each road section.
- Finally, the criticality of each road section needed to be assessed, as described above.

These three indices are then combined. The road section definitions should be the same for each assessment. Using a simple formula, as described in the Box below, it is possible to calculate a 'unified index' which shows the priority road sections, based upon a combination of vulnerability and criticality.

The process of identifying the highest priority sections takes the data from the previous stages of the process and brings them together in a single analysis. A brief summary of these stages is described in the following list, with reference to the Polog example, illustrated in Figures 32, 33, 34 and 35.

- Firstly, each type of **hazard** was overlapped over the road network (Figure 32, 33, 34 , upper left), assigning averaged hazard level to each road link, on a scale of 0 to 1.
- Secondly, the MCA was used to define the socio-economic **criticality** based on various spatial data, so that scores, normalized to a scale of zero to one, can be assigned to each road link (Figure 32, 33, 34 , upper right).
- The third step is to group all of the vulnerability assessments by road link, in effect producing an average **vulnerability** along each considered link, on a scale of 0 to 1 (the data required to perform this, such as IRI, AADT, etc., is already collected and available in RAMS) (Figure 32, 33, 34 , lower left).
- Each of these three indices are combined into separate according risks, resulting in three according **risk** maps (flood, flashflood, landslide, Figures 32, 33, 34 , lower right) by multiplying hazard, criticality and vulnerability. Fine adjustments can be introduced at this level, by using multiplication **factors** if some of the three indices seem to be more important than the others (see the Box below).
- Finally, these three separate risks, or separate risk maps (Figures 32, 33, 34 , lower right) can be combined into a **multi-risk** map by summing up all values along the road link.

To make a more illustrative example, a road link is considered within the study road section in the Polog region. The link is affected by flood hazard as it picks up a flood hazard value of 0.72 (see Figure 32 A, upper left). Similarly, it is also exposed to average flash flood and a landslide hazard of 1.0. In comparison with the other links along this section, it is strongly affected by all three hazard types. In addition, its socio-economic criticality is not considerable, so in this regard it is given a lower score, due to lower population served by this route and the lack of presence of other relevant parameters, equaling 0.2 (see Figures 34, 35, 36, upper right). Its vulnerability score equals 0.57 (see Figure 34, 35, 36, lower left), which is average in the chosen section. The risk value can now be calculated as 0.72 x 0.2 x 0.57 = 0.082 for floods, or 0.034 and 0.112 for flash floods and landslides, respectively (using the same analogy). If combined, these three values give a multi risk of 0.082 + 0.034 + 0.112 = 0.228 ≈ 0.23, which makes it relatively lower priority link in the chosen section (Figure 35).

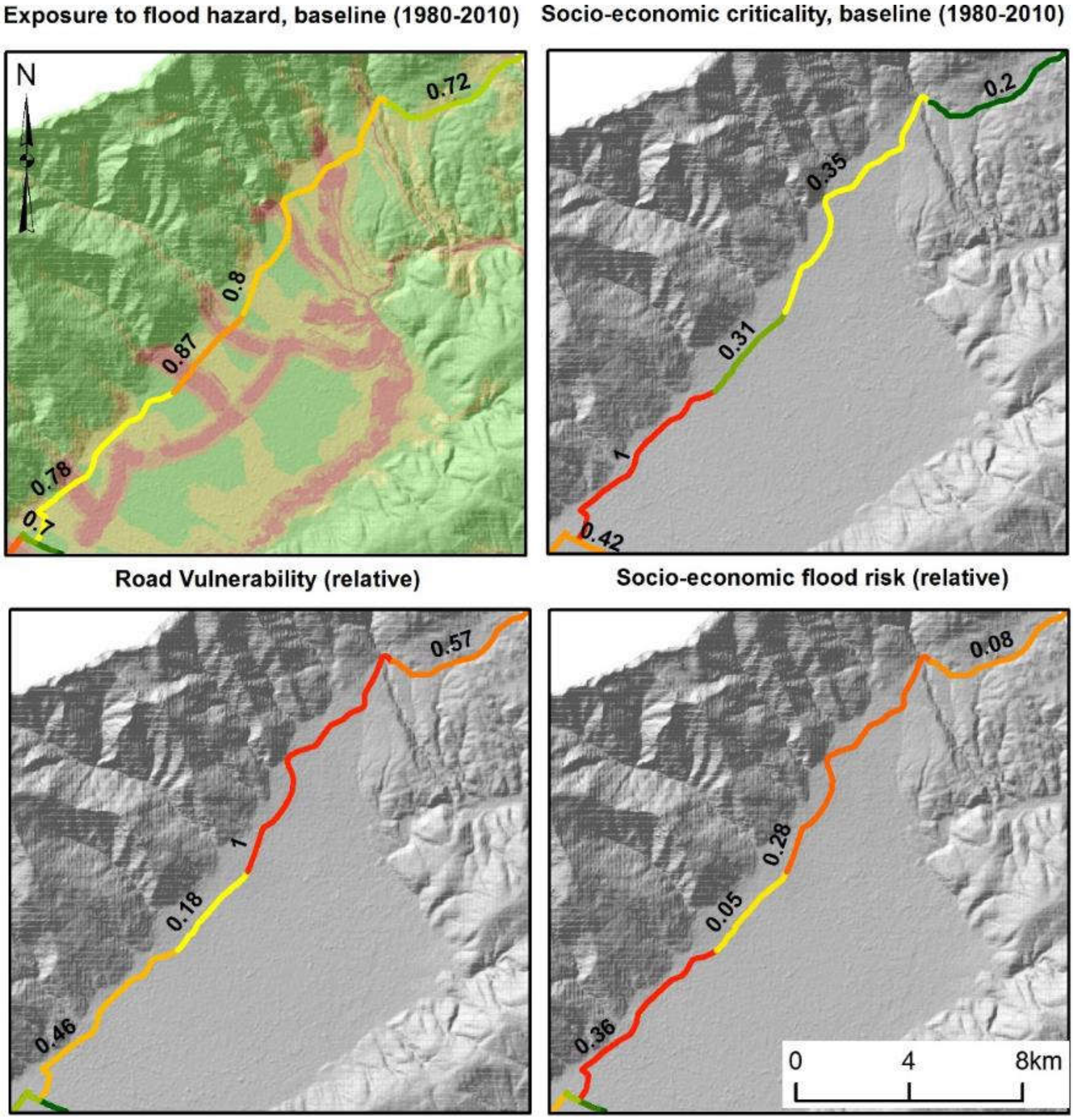


Figure 32 Flood risk map example for a road section in the study region (Polog)

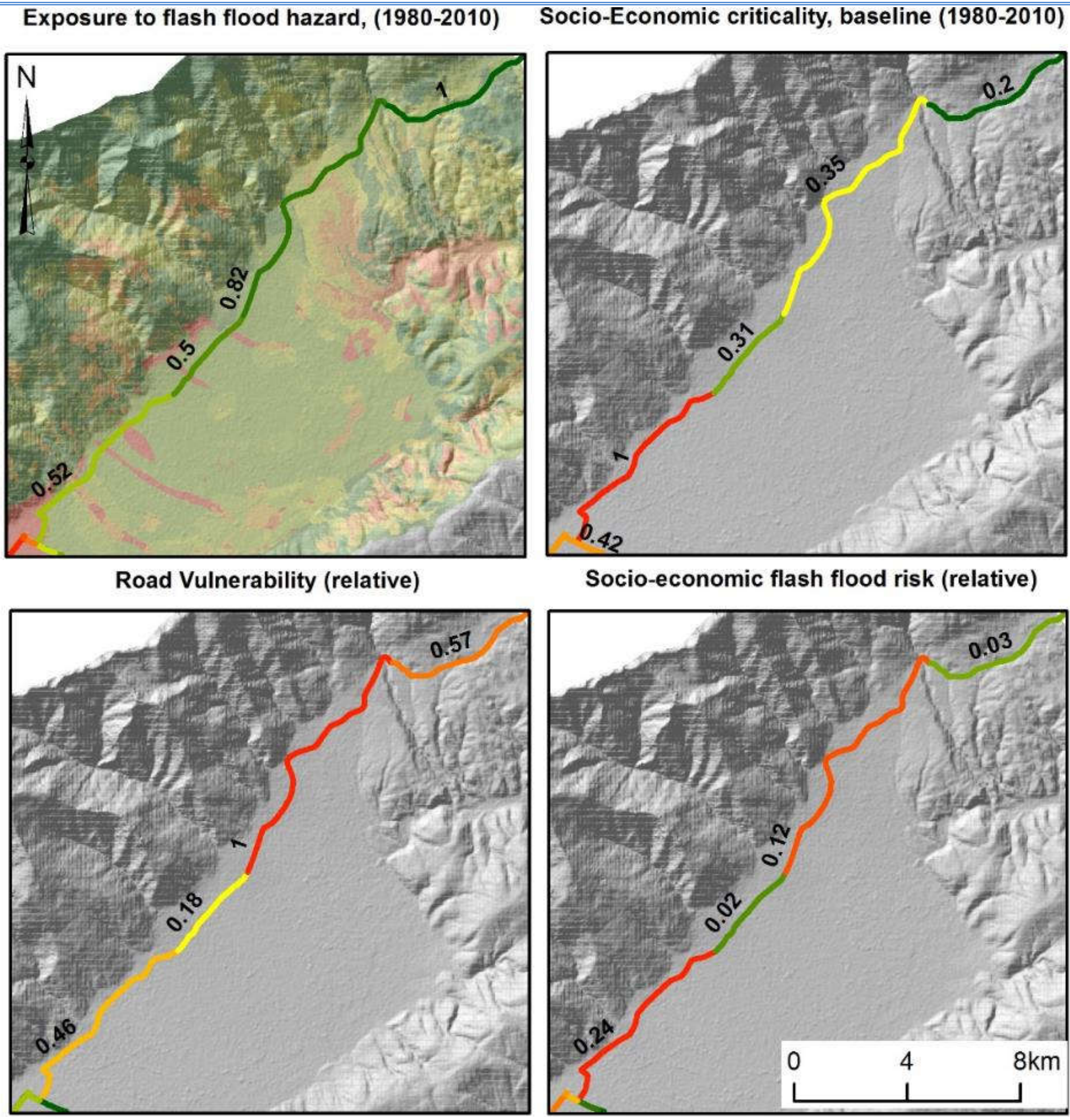


Figure 33 Flash flood risk maps example for a road section in the study region (Polog)

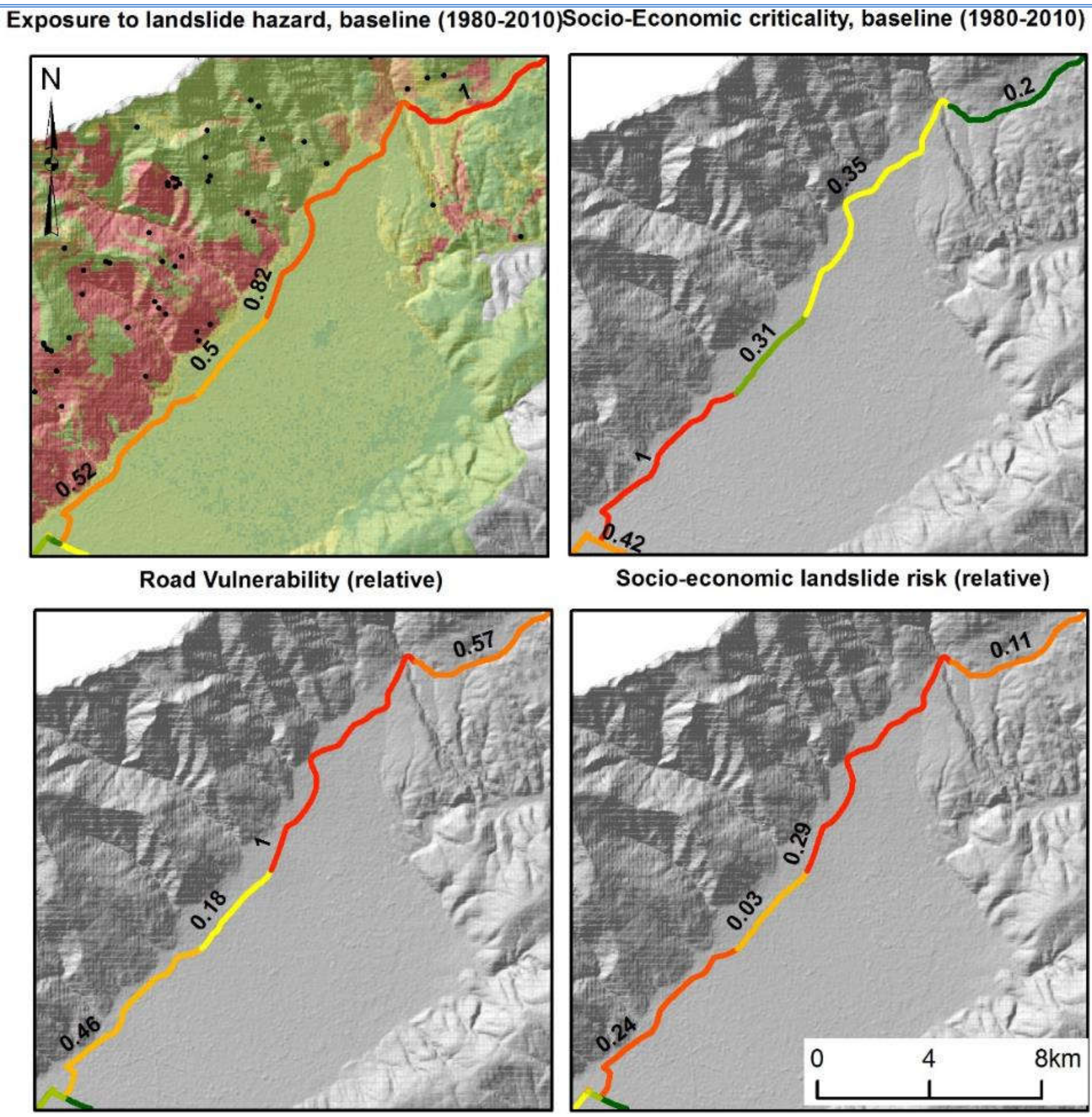


Figure 34 Landslide risk map example for a road section in the study region (Polog)

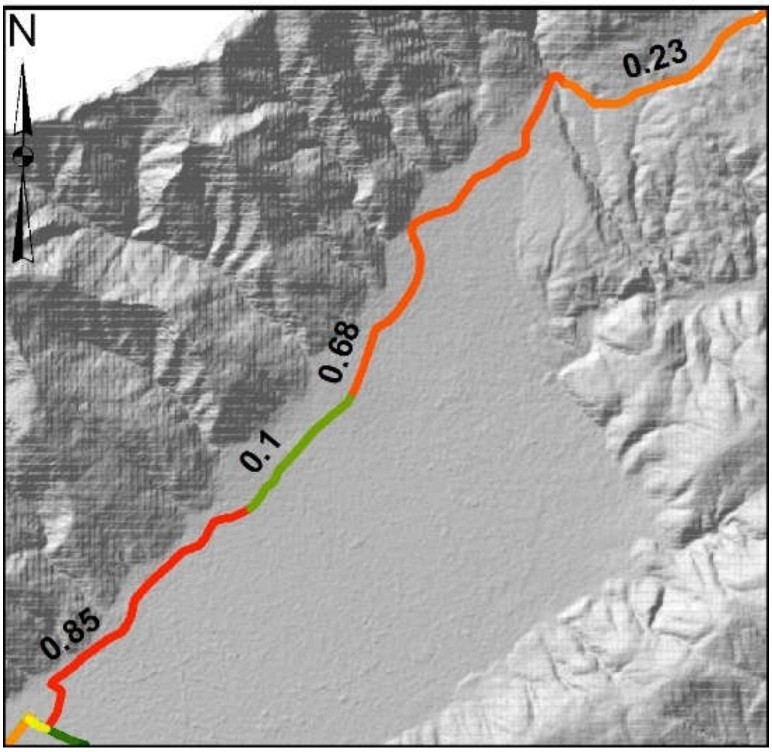


Figure 35 Multi-risk map example for road section (in the Polog region)

Using this algorithm (formula) embedded within the GIS environment, as described in the Box 1 below, it is possible to calculate a ‘unified index’ which shows the priority road sections from the risk perspective, based upon a combination of hazard, vulnerability and criticality and their relevance expressed through multiplication factors. In this case a value of 1.0 for each different aspect has been considered, but this could be varied following discussion with stakeholders, or allowed to be varied through the user within a more sophisticated tool within the GIS environment. In the case where their relevance is estimated as equal, then the multiplication factors are equal, too, e.g. 0.33. If one of the indices is considered more important, it can be assigned a higher multiplication factor on behalf of the other two indices. The sum of factors needs to add up to 1.0 or 100% (0.33 + 0.33 + 0.33 ≈ 1.0). It is further possible to use specific indices by adjusting the C value by the link length for example.

Define factors to apply to these indices to reflect their relative importance Unified Index (C) = 0.33 x Hazard x 0.33 Vulnerability x 0.33 Criticality Identify the length of the road section in km Unified Index per km (K) = C / length in km Unified Index per Euro (Denar) **(E)** = C/cost of investment

Box 1 Unified Index per km

Once the road has been determined to be critical for assessment, additional information is required to be collected from the specific site.

Step 3: Use CVRA output and field studies to select engineering and non-engineering measures

3 Field (site specific) survey and analysis of field data

Field surveys are crucial for collecting the additional data for the informed decision making. The above process up to this phase, will assist PESR to select the regions to be surveyed rather than going through the expensive process of surveying the whole network. The findings are then analysed by PESR and relevant engineers to select the appropriate mitigation measures.

3.1 Site specific survey

Based on the hotspot assessment, the survey can be focused on particular locations/ assets that are highly vulnerable and at risk of hazard and critical for the network, in this case flood and/ or landslide. This process essentially completes the hazard assessment process by relating the information considered thus far (which was either GIS, image/ data-based or a physical view from a remote location) to the ground itself. In practice the detailed site inspection comprised a walkover from road level and excursions up slope (or down where necessary) as required, but typically every 0.5km to 1.0km. Further entries are then made to the standardised inventory documents - data sheets provided in this Guidance and the scores obtained at this stage taken as final scores. Photographs are taken to illustrate both the features encountered on site and the decisions made, as appropriate.

3.1.1 Desk analysis

Once the region has been evaluated to be at risk, the site-specific field survey is planned to collect additional information and estimate the engineering and/or non-engineering measures that need to be enforced to prevent the damage of the climate impact on the assets.

The site-specific assessments are to supplement and validate the initial process by utilising high resolution aerial photography and initial site inspections from road level. More detailed inspection of any given site is to be subsequently conducted and needs to involve excursions from road level to the adjacent hillsides.

This information then enables those carrying out the inspections to familiarise themselves with the detail of the mapping, to reconcile the positioning of the object of surveying detail with the GIS-based assessment imagery and to examine the GIS-based assessment imagery with respect to detail features on the subject road mapping.

Historical events that have happened on the location, as well as historical remedy measures should be examined to give a base for the gap analysis for the future solutions. If any photographs are available, these need to be analysed, as well as aerial photographs.

3.1.2 Field Survey – Site specific inspection

The field work should be focused on inventorying processes on the existing roads – road sections (inspection of target climate change related hazards i.e. landslides/ rockfalls, floods, flash floods) and asset conditions (inspection in relation to specific hazards, such as floods and flash-floods). The inventory includes standard descriptors, but most importantly locations and the type of process and estimated impact on the assets. This is conducted to:

- Provide the base for calibration of the hazard models (fine-tuning of the class intervals in intermediate, i.e. slope, elevation, etc., and final models of target hazards, i.e. flood, flash flood, landslide);
- Provide the reference for validation of the target hazards final models;
- Assess the road asset conditions and assessment of possible engineering solution for improving road network (or site specific) conditions;
- Estimate damages, maintenance, potential long/short term measures as a base for prioritization;
- Update or check the existing historical records of climate related natural hazards (from all relevant sources); and
- General overview of the type, number and distribution of hazardous occurrences.

To collect all relevant information, from the field visit, standardised inventory documents - data sheets are created. The field data collection has to be systematic based on the predefined, standardized data sheets, the checklists in Annex 1. These have been designed for each hazard type and hazard-related asset separately (example in Figure 36 below).

1. ОПШТИ ПОДАТОЦИ ЗА ПАТОТ		
Ознака на патот *		
Локалност/делница*		
Датум на регистрација *		
Одговорен истражувач(и)*:		
Lat-Lon координати на почетната точка * (во правец на пораст на стационажата)		
Стационажа на почетната точка		
Lat-Lon координати на крајната точка * (во правец на пораст на стационажата)		
Стационажа на крајната точка		
Име на реката/потокот		

2. ИНФОРМАЦИИ ЗА ВОДОТОКОТ	
Постојан водоток	
Повремен водоток	
Водоток во кривина во однос на трасата	
Водоток во правец во однос на трасата	

3. СОСТОЈБА СО УРЕДЕНОСТ НА КОРИТОТО	
Коритото и обалата неуредени без вегетација	
Коритото и обалата неуредени со густа вегетација	
Коритото и обалата се уредени	
Коритото е регулирано	

4. ВИСИНА ОД ВОДОТОКОТ ДО НИВЕЛЕТАТА НА ПАТОТ (ЕДНА ОД ПОНУДЕНИТЕ)	
H ≥ 5 m	
5 m > H ≥ 2 m	
2 m > H ≥ 1 m	
H < 1 m	

6. ЕЛЕМЕНТИ НА ПАТОТ (ЕДЕН ОД ПОНУДЕНИТЕ)	
Насип со висина до 3 m	
Насип со висина преку 3 m	
Засек со висина до 3 m	
Засек со висина преку 3 m	
Траса во ниво на теренот	

5. ОДАЛЕЧЕНОСТ ОД ВОДОТОКОТ ДО НИВЕЛЕТАТА НА ПАТОТ (ЕДНА ОД ПОНУДЕНИТЕ)	
L ≥ 100 m	
50 m > L ≥ 100 m	
10 m > L ≥ 50 m	
L < 10 m	

7. ЗАГРОЗЕНОСТ НА ПАТОТ	
Ерозија на трупот на патот со подлокавање	
Плавење до ½ од висината на трупот на патот	
Плавење до висина на трупот на патот	
Плавење на коловозната конструкција	
Разорување на целата коловозна конструкција	

8. ПРЕКИН НА СООБРАЌАЈОТ (ЕДЕН ОД ПОНУДЕНИТЕ ДОКОЛКУ ПОСТОИ ПРЕКИН)	
Помалку од 1 ден	
Од 1 до 7 дена	
Од 7 до 14 дена	
Повеќе од 14 дена	
Не е познато	
Сообраќајот се одвива отежнато по една лента	

9. ДОПОЛНИТЕЛНИ КОМЕНТАРИ	**10. СКИЦА**

Figure 36 Data sheet for collection of data on floods

The final structure of the data sheets is aimed at relatively quick and effective data collection, using a checklist approach. The data sheets, whilst comprehensive, is created to be simple, to allow them to be used by other engineering or expert technical professionals. They should however be utilised by appropriate specialist with experience of the hazards identified in the field, especially mass movement related instabilities and flash floods i.e. civil, geotechnical or geological engineers.

The inventory consists of points identified along the road sections of selected area. It also considered relevant areas located below and above the road, especially regarding mass movement events and flash floods that could result in adverse impacts to the road. In addition to the inventory of the slope stability conditions (landslides, rockfalls), all streams and rivers and associated road assets (culverts and bridges, sections) should be inspected.

The common evidence of mass movement that could be examined during the field work should indicate possible slope instability. These includes indicators such as: head scarps, toe bulges, tension cracks, hummocky appearance of a slope surface, convex or concave slope appearance, misalignment of guardrail, power lines, or drainage pipes, tilting trees not associated with growth toward sunlight, cracking of surface drainage channel, expansion and/or closing of the bridge joints, loss of alignment of building foundation, patching of the roadway surface, longitudinal dips in pavement surface, water seepage on slope, debris blockage or poorly flowing ditches along the toe of the slope, discontinuities on the rock surface, rock fall material on the road surface or in the gutters, etc.

It should be emphasised that some of these conditions might not represent slope instability. This is because when slope instability is occurring multiple characteristics are observed. All inventory sites required the collection of data related to the location, hazard process and vulnerability. As part of the inventory, preliminary assessments for rehabilitation works must be performed at each site.

For example, the data collection can include the following:

- General Data (Road mark, Location, Coordinates etc.)
- General Data About Landslide (Type of movement, type of material, water content etc.)
- General Data About Terain and Position of the Road (Position, Height, Length etc.)
- Detailed Description of the Phenomenon (Shape, Geometry, Cause etc.)
- Physical Vulnerability of the Road (actual or potential damage of the roadway structure etc.)
- Recommendations (New design, Regular maintenance measures, Urgent maintenance measures, Monitoring etc.)

In addition to the slope conditions and slope/ cuts instabilities, stream and river erosion influence on road assets have to be recorded. The most vulnerable road assets are bridges and culverts, especially from torrential floods (flash floods) from streams and rivers, as well as riverine floods. The data sheet is similar to the landslide list and includes all necessary data to assess current conditions and propose engineering or non-engineering measures. Similarly, the hydrology assessment should include specialists that will collect details using the datasheets provided.

All the data from the field surveys have to be stored in analogue (paper form – the data sheets), photo documentation and in a database in a GIS environment. Every single observed point from the field must have unique data ID depending on the hazard type. Photo documentation is obligatory as part of the field data report.

Decision on the engineering and non-engineering measures is further discussed. The information on interventions (engineering and non-engineering, site-specific and generic/ institutional) should be collated in an “Options Summary Spreadsheet”. This will provide the information needed to allow an economist to carry out a cost-benefit analysis and then develop an investment plan (see next two sections).

The total cost of the interventions is produced by grouping interventions by road section. This way it is possible to identify the total cost of dealing with all the asset deficiencies along an entire section. This approach is consistent with the approach adopted in the RAMS which deals with links rather than individual assets. The advantage of this is that: it generally mirrors the procurement process for road maintenance; it serves to maintain the integrity of the road network; and it will increase the overall resilience of the network, as the resilience of whole links is improved.

By combining this with the unified index, it is possible to produce what might be called a cost effectiveness index. This is important, as it will promote road sections which are important, but where the required interventions are relatively low cost.

The road network in North Macedonia includes both short sections with a large number of required interventions, and long sections with relatively few required interventions. By factoring the unified index by the length of each section, it is possible to promote the latter road sections, where the resilience of a long section is jeopardised by a relatively short vulnerable section.

Once interventions have been assessed they should be categorised as to what, if any, intervention is required. This should consider where interventions should take place and where it may be more appropriate for an intervention to be deferred: for example, based on the remaining life of the asset against the cost of intervention for some measures. An example of this is where an improvement in road surfacing specification may be better addressed through uplift to design standards etc. or to be included in contract documents for the next planned road resurfacing, rather than additional works being undertaken immediately. A generic categorisation process is outlined in Table 22 below.

Table 22 Generic Adaptation Options[20]

Generic Option	Examples
Do minimum	Minimum actions necessary to maintain a safe and serviceable network. May include developing contingency plans, monitoring changes and, for assets, doing patch-and-mend repairs/ like-for-like replacements, as required.
Future-proof designs	Updating design requirements, including technical standards and specifications, to provide additional capacity/ functionality. These updated requirements could apply to all ‘designs’ e.g. designs for new structures or new roads, as well as to designs for maintenance, renewal and improvement works when these are implemented within the normal cycle for such activities. Typically, it will be appropriate to adopt a precautionary approach in future-proofing designs, so that the asset/ activity will perform satisfactorily throughout its life in the event of climactic changes towards the extreme predictions.
Retro-fit solutions	Proactively applying modifications to existing assets/ activities outside of the ‘normal’ cycle for renewal/ replacement. For example, proactively replacing/ fitting additional equipment or components or providing additional provision/ capacity to exiting assets. This option could be applied everywhere on the network, or just at high risk sites. Work could start now, or only once climate change effects meet certain threshold criteria.
Develop contingency plans	Development of a pre-planned response for when/ if climate change risks are realised so that their immediate effects can be managed. This option could apply where nothing can reasonably be done to mitigate an identified risk, during the period until other measures are put in place, or

[20] Highways England (2009) Climate Change Adaptation Strategy and Framework. http://assets.highways.gov.uk/about-us/climate-change/CCAF_Strategy_and_Vol_1_Rev_B_Nov.pdf

	where there is a residual risk, despite adaptation actions being employed. It should be included as standard within the 'do minimum' option.
Update operating procedures	Updating operating procedures to take account of the impacts of climate change. For example, updating the procedure for working in high temperatures.
Research	The main purpose of research is to reduce uncertainty, where this presents a barrier to determining preferred adaptation options with a reasonable level of confidence. It could be done to provide better understanding of the likelihood and consequences of a risk for the network. Alternatively, it could be done to help determine or refine appropriate adaptation options.
Monitor	Monitoring of the rate of climate change and/ or subsequent effects on a particular asset/ activity to increase confidence in the appropriate adaptation option, or to determine the appropriate point at which to implement some pre-determined action. An important part of this option would be to identify indicators of change and threshold 'triggers' for action.

This should lead to a short-list of invention options to be prioritised. This is expected to include both aspects that recur across the network (e.g. recurring road asset infrastructure issues such as road pavement design, standard culvert capacity, embankment stability - which may be similar across an area, but be prioritised for critical road links) and highly location specific options (e.g. options to enhance the resilience of critical assets such as a major bridge or culvert in vulnerable areas).

Some of these interventions will based on enhanced risk due to climate change (e.g. increasing the probability of a failure event or changing the failure mechanism to make failure catastrophic) whilst others may be required anyway due to the vulnerability of the network to existing natural hazards.

3.1.3 Calculating Per km or Per Denar Indices

The total cost of the interventions is produced by grouping interventions by road section. This way it is possible to identify the total cost of dealing with all of the asset deficiencies along an entire section. By combining this with the unified index, it is possible to produce what might be called a cost effectiveness index. This is important, as it will promote road sections which are important, but where the required interventions are relatively low cost.

As stated before, the road network in North Macedonia includes both short sections with a large number of required interventions, and long sections with relatively few required interventions. By factoring the unified index by the length of each section, it is possible to promote the latter road sections, where the resilience of a long section is jeopardised by a relatively short vulnerable section.

3.1.4 Ranking and grouping Interventions

After the field survey is completed (described in the next section) It is then possible to rank the interventions, grouped by road section, by any of C, K or E of the MCA (box 1). A further refinement to this process, which has been programmed into the GIS, is to allow the user to adopt alternative values for the factors that identify the relative importance each criteria, so that greater importance can be attributed to hazard, vulnerability or criticality.

Having prioritised the interventions, to assist the development of budget proposals, it is possible to sub-divide the list of interventions into:

- Maintenance or capital works

Further, it is possible to divide capital works into:

- Long term measures (extensive investigation and design is needed, more than 3 years away)
- Short term measures (no extensive investigation is needed, design optionally depending on type of measures, 1-3 years)

Maintenance works can be divided into:

- High maintenance measures and
- Regular maintenance measures (every year measures)

These groupings will allow the easy development of budgets for capital and revenue budgets.

Step 4. Prioritise measures on an economic basis and develop an investment plan.

4 Cost benefit analysis

4.1.1 Purpose and Introduction

Having identified the climate resilience hot spots through the vulnerability and criticality assessments, and assessed the options for mitigation of identified vulnerabilities at each location, it is next necessary to assess those options, against a policy of doing nothing, and each of the proposed do something options. The goal of the adaptation assessment is to identify and prioritize the most appropriate adaptation measures to incorporate into the project. This includes the identification of strategies to minimize damages caused by the changing climate and to take advantage of the opportunities that a changing climate may present.

The options considered can include maintenance, capital improvement and non-engineering measures in each location. The decision as to the most appropriate action in each location, is likely to be a trade-off between increasing levels of cost and increasing levels of resilience, with more costly interventions providing greater levels of resilience. The goal of the economic analysis of adaptation options is to provide decision makers with information pertaining to the expected costs and benefits of each technically feasible option and to rank these options according to the net total benefit (measured in present value terms) that each deliver.

It should be noted that options will fall into 3 general categories:

- Small investments, where cost benefit analysis is not required
- Investments on roads where a road is deemed to be of the highest criticality and the vulnerability is extreme, where action is essential and therefore cost benefit analysis is not required
- All other investments, where cost benefit analysis should always be undertaken.

These Guidelines should be used for the third category.

4.1.2 Methodology

Cost Benefit Analysis (CBA) is an economic appraisal method that can be used to compute the Internal Rate of Return (IRR) and Net Present Value (NPV) of the implementation of climate resilient investments in North Macedonia’s road transport network, as well as for investments along each individual road section. The CBA results can support decision-makers and guide discussion on what areas and infrastructure should be prioritised when faced with budget constraints.

The techniques used in this CBA should be incorporated into a bespoke spreadsheet-based framework, for which data inputs and parameter estimates may be sourced from national, multilateral, and non-governmental organizations. It is recommended that the appraisal should be completed for the expected life of the asset. So for road assets an appraisal should normally be completed for a 25 to 30-year period from the start of the programme. Recognising the reducing time value of money, it is recommended that a standard discount rate of 5% per annum, should be used.

The design of a CBA methodology into an RAMS should be tailored for a specific natural event and a specific location. For example, a synthetic guide for flood and landslides risk assessment exists for

Bosnia and Herzegovina, although the methodology only takes the housing sector into consideration[21]. Furthermore, the World Bank provides a useful guideline for asset management processes in the context of climate change on road infrastructure[22]. For a more general guidance, the UNDP has developed a guide to assess climate resilient infrastructure[23].

The Cost-Benefit Analysis of a climate resilient intervention i should be based upon the comparison between the costs in the Do Nothing scenario and the costs and benefits accrued in the Do Something scenario. This can be expressed by the formula below:

$$NPV^i = \left(\sum_{i=1}^{n} \frac{Direct\ costs^0 + Indirect\ costs^0}{(1+d)^{y-1}} \quad \frac{Direct\ costs^i + Indirect\ costs^i}{(1+d)^{y-1}} \right) \quad CI^i$$

Where i is the proposed intervention, n is the total years considered in the CBA, d is the discount rate, y is the years (going from 1 to n), CI^i is the capital cost of intervention i, and 0 is the base scenario where no investment takes place.

The appropriate $Direct\ costs$ and $Indirect\ costs$ categories to be considered in the CBA have been identified from the categories listed in the OECD paper *Improving the Evidence Base on the Costs of Disasters to Inform Better Policy Making for Disaster Risk Management* [24]. In the case of North Macedonia, the CBA should consider the direct and indirect cost categories defined below (Figure 37):

Direct costs	Cost of repairs to road infrastructure
	Emergency costs
Indirect costs	Economic activity costs
	Labour market costs
	Education costs

Figure 37 Direct and Indirect cost categories that should be included in the CBA

The methodology behind the CBA can be divided into several discrete steps, as discussed in the following sections.

4.1.3 Identify road sections

The first stage of the process is to identify which road sections will be the unit of the analysis. For consistency and to enable comparison, the CBA should use the same classification of road sections

[21] UNDP (2016). Floods and Landslides Risk Assessment for the Housing Sector in Bosnia and Herzegovina.
[22] World Bank (2017). Integrating Climate Change into Road Asset Management Technical Report
[23] UNDP (2011). Paving the Way for Climate-Resilient Infrastructure, Guidance for Practitioners and Planners
[24] OECD (2015). Improving the Evidence Base on the Costs of Disasters to Inform Better Policy Making for Disaster Risk Management: Toward a Framework for Accounting National Risk Management Expenditures and Losses of Disasters

considered in the MCA. In this case, unless good reasons exist to change this, the sections should be based upon the standard road sections defined in PESR's RAMS.

Sections should only be sub-divided where topography, road standard, traffic intensity or resilience risks, change markedly within a road section.

4.1.4 Identify climate resilient investments

The recommended measures to enhance the climate resilience of the road transport sector should be specified in this step. These should be based on the identification of hotspots and appropriate mitigation measures for each road section (capital improvements, maintenance works, etc.). This process is described in this guideline.

Two scenarios should be identified for the appraisal of each road section:

a) No investment scenario 0, where no climate resilient interventions are conducted on the road;
b) Investment scenario i, where the proposed climate resilient investment is carried out on the road.

This methodology also allows for the definition of additional scenarios to be tested, which can be built by combining different climate resilient investments. These Do Something scenarios can be compared both with the Do-Nothing scenario and the other Do Something scenarios.

4.1.5 Identify costs of climate resilient investments

The economic costs of each intervention are required as a key input to the CBA. As such, cost estimates need to be produced to reflect the full costs of the design, construction and maintenance of each intervention in each road section, in economic terms, excluding all taxes and duties.

These intervention costs should be based upon known costs in the country; where this option is unavailable, approximated costs should be identified from construction contracts elsewhere. For example, where a particular solution is new to the region, costs from contracts in other areas can be used, with suitable amendment, to reflect the most likely local cost rates. The result will be the indicator CI^i, the capital cost of intervention i.

4.1.6 Identify the severity and likelihood of weather events

The steps above are key to estimating the $Direct\ costs$ and $Indirect\ costs$ later on.

One of the main goals of climate resilient investments in road infrastructure should be to increase the resilience of North Macedonia's road network to extreme weather events, reducing the days of road closure for clean-up, repair and reconstruction efforts after the event. North Macedonia is considerably exposed to extreme weather occurrences, including floods and landslides of varying severity which can affect its road infrastructure.

Thus, to conduct a cost-benefit analysis of climate resilient investments it is necessary to **identify the existing magnitude and corresponding likelihood of the weather events affecting each road per year**. This methodology will mention flooding events as an example, although the framework allows for the consideration of any other weather events which may affect the road infrastructure.

The European Commission framework guideline[25] provides a standard classification for hazard level, based on its occurrence and severity. Severity ranges are classified in five levels according to their effects, from no effect to catastrophic effect. In the case of floods, this framework classifies events along five different severity levels[26]:

- **Very small floods (severity I):** no effect;
- **Minor floods (severity II):** minimal or no property damage, but possibly some public threat;
- **Moderate floods (severity III):** some inundation of structures and roads near stream. Some evacuations of people and/or transfer of property to higher elevations;
- **Major floods (severity IV):** extensive inundation of structures and roads. Significant evacuations of people and/or transfer of property to higher elevations;
- **Record floods (severity V):** flooding which equals or exceeds the highest stage or discharge at a given site during the period of record keeping.

Further, the framework classifies the likelihood of an extreme weather occurrence into five categories of probability:

- **Very unlikely:** 0-10% probability
- **Unlikely: (10–33 % probability)**
- **About as likely as not: (33–66 % probability)**
- **Likely: (66–90 % probability)**
- **Very likely: (90–100 % probability)**

Historic data should be used for identification of past patterns of floods and landslides for each road (or, alternatively, the region in which the road is integrated). Once past data on weather events is collected, it should be possible to infer the probability of occurrence of the event for each level of severity.

$$Probability\ of\ events\ for\ severity\ level\ I = \frac{Number\ of\ events\ for\ severity\ level\ I}{number\ of\ years}$$

Knowing the likelihood of each of these magnitudes of flooding will be very helpful to conduct a CBA, as this will allow the assessment of the economic benefits that will accrue from each scenario. The risk probability matrix can thus be drawn (Figure 38). This shows the combination of different levels of severity and probability and what these mean in terms of the acceptability of the level of risk.

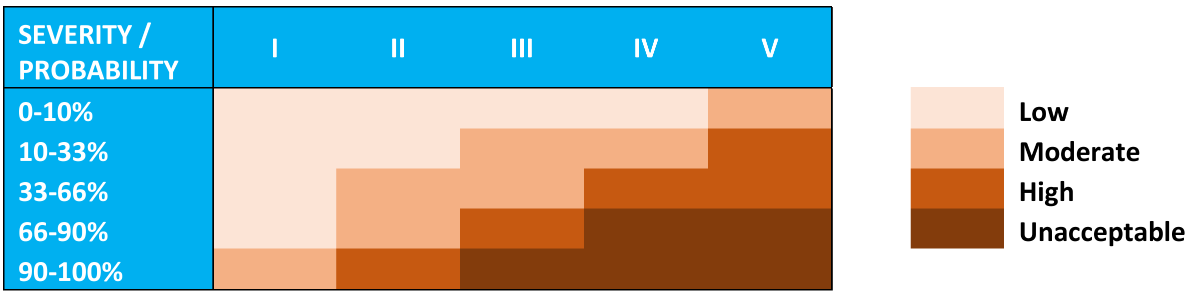


Figure 38 Risk probability matrix from oecd.org/gov/risk/issues-paper.pdf

[25] European Commission (2014). Guide to Cost-Benefit Analysis of Investment Projects, Economic appraisal tool for Cohesion Policy 2014-2020.

[26] Definitions from the US National Weather Service Glossary: w1.weather.gov/glossary

Each cell in the matrix represents a risk level with distinct damage and cost levels. The damage level can be split into four categories:

- **Low**: functionality of infrastructure not compromised;
- **Medium**: functionality compromised and resources to be fixed;
- **High**: elements severely damaged. Time and large resources are required for demolition and reconstruction work;
- **Unacceptable**: element completely damaged.

The goal is to understand where the road sits in the risk matrix for every level of severity. From there, we can infer the damage level to which the road is susceptible, and this information will be used to estimate the cost of repairs to the road in the case of an extreme weather event.

4.1.7 Estimate duration of road closure

Key to the CBA is to understand the difference in impacts in terms of road closure. The most important of these relates to the amount of time that a particular road would be closed as a result of a weather event. This difference in resilience should be expressed in the CBA as the difference between the duration of road closure for post-flood/landslide repairs. In the case where no investment in climate resilience occurs, the road is expected to stay closed for longer after an extreme weather event. If climate resilient investments are implemented, repairs to the road should take less time, as 'preventive' investments have been done from the start – e.g., if a road undergoes regular maintenance, the repairs after a flood/landslide will be quicker than a scenario where the road is not adequately maintained.

Thus, the implementation of climate resilient investments is expected to lower the duration of post-flood/landslide road closure, enabling the road to return to its normal functioning sooner.

For each flood severity category, PESR should identify (or estimate) the likely number of days the road is typically closed for clean-up, repair or reconstruction. This is the $Road\ closure$ if a flood/landslide occurs, for the no investment case, represented in the second column of Table 21 below. The $Road\ closure$ if a flood/landslide occurs, for the investment scenario, should depart from the numbers in the no investment case, and be derived by whoever is developing the climate resilient investments. This should be assessed on a case by case basis, depending on the investment that is being analysed.

The numbers presented here are examples, and PESR should undertake more analysis to establish appropriate rules of thumb for North Macedonia. In lieu of this analysis, the figures below can be used as proxy.

Table 23 Example of relationship between flood severity and duration of road closure

Flood severity	Road closure if flood occurs, no investment	Road closure if flood occurs, with minor investment	Road closure if flood occurs, with major investment
Very small floods/landslides (severity I)	Road does not close	Road does not close	Road does not close
Minor floods/landslides (severity II)	1 day	0.75 days	0.5 days

Moderate floods/landslides (severity III)	3 days	2 days	1 day
Major floods/landslides (severity IV)	10 days	7 days	5 days
Record floods/landslides (severity V)	20 days	15 days	10 days

The next step will be to calculate the $Road\ closure, per\ year$, for both the no investment and the investment cases. For the no investment case 0, this can be done using the formula below:

$$Road\ closure\ per\ year_0 = \sum_{s=1}^{n} Probability_s \quad Road\ closure_{0,s}$$

Where s is the severity of a flood/landslide, $Probability$ is the probability associated with severity s for the road, $Road\ closure$ is the number of days the road is typically closed for a given level of severity s in the no investment case 0, and n is the number of severity levels, from 1 to 5.

Similarly, for the investment case i:

$$Road\ closure\ per\ year_i = \sum_{s=1}^{n} Probability_s \quad Road\ closure_{i,s}$$

Where s is the severity of a flood/landslide, $Probability$ is the probability associated with severity s for the road, $Road\ closure$ is the number of days the road is typically closed for a given level of severity s in the investment case i, and n is the number of severity levels, from 1 to 5.

The result from this exercise should be the likely days of $Road\ closure\ per\ year$ for both no investment and investment cases. This difference should be used later on, to compare between the two scenarios: in a case where climate resilient investments are implemented, the road is expected to be closed for a shorter period of time; hence, the losses for economic activity, wages and education should be smaller than if no investment takes place.

4.1.8 Estimate direct costs

Cost of repairs

The most important costs to be considered in the CBA are the cost of potential repairs to the road if a flooding/landslide event does occur. These costs should be lower in the investment scenario, where climate resilient investments are implemented, as improving the resilience of the road infrastructure is expected to increase its ability to withstand extreme weather events. The data for repair cost to the roads should ideally be based upon known costs of repairs or improvements procured by PESR, or other agencies who are typically in charge of carrying out such works.

In the absence of this data, the repair costs can be approximated by the following rationale, where the damage levels previously defined will help estimate the cost of repairs to the road after an extreme weather event.

Each damage level – inferred from the severity and probability of events defined in Section 2.6 – should be associated with the respective level of repairs needed to cope with the damage. This is then used to estimate the cost of clean-up, repair or reconstruction works to the road after it is affected by an extreme weather event, where damages are costed as a percentage of the total reconstruction cost of the road in question (Table 22):

Table 24 Relationship between damage level and estimates for cost of repairs

Damage level	Description	Cost of repairs percentage
Low	When there is the need to conduct emergency cleaning of a road after a flood/landslide, such as clearing of debris.	2% of road reconstruction cost
Medium	Wherein a flood/landslide results in the need for minor repairs to the road infrastructure. These may include repairs to retaining walls, warning signs, and considerable clearing of debris and drains.	25% of road reconstruction cost
High	When major repairs to the road infrastructure are needed after a flood/landslide. Examples of major repairs are the replacement of key parts of the road infrastructure and/or equipment, such as bridge decks.	50% of road reconstruction cost
Unacceptable	When there is the need to replace major parts of the road infrastructure after a flood/landslide.	100% of road reconstruction cost

Given this, $Repair\ costs$ in a given year for road rd can be calculated as:

$$Repair\ costs_{rd} = \sum_{s=1}^{n} Probability_s \quad Cost\ percentage_{dl} \quad Road\ reconstruction\ cost_{rd}$$

Where s is the severity of a flood/landslide, $Probability$ is the probability associated with severity s for the road, $Cost\ percentage$ is the proportion of the total road reconstruction cost respective to damage level dl (as defined in Table 22 or 23), and $Road\ reconstruction\ cost$ is the total road reconstruction cost for road rd.

Emergency costs

Emergency costs associated with flooding should also be included. Where possible, these should be estimated based upon the costs of previous clear ups and be provided by the agency responsible for emergency efforts after extreme weather events.

In the absence of this data, it is possible to estimate emergency costs using one of the two rationales below:

- A study conducted in the UK quantifies emergency services at 10.7%[27] of total property damages;
- In mitigation, a study by the UK Environment Agency considered emergency costs equivalent to only 5.6%[28] of disaster damages.

This proportion can vary significantly across country and for different types of disaster. Nonetheless, this does suggest that emergency costs are significant.

4.1.9 Estimate indirect costs

Whilst indirect costs often account for a relatively 'small' portion of the total costs associated with an extreme weather event, if the damage is large enough, longer periods of time will typically be required to conduct repair – and sometimes, reconstruction – works on road infrastructure. In these scenarios, roads will stay closed for longer stretches of time. This is when indirect costs start to become significant, and when the impacts of extreme weather events become even wider, and potentially longer lasting.

The indirect costs considered for CBA should fall within one of the following groups:

- Economic activity costs, EC
- Labour market costs, LC

It is important to note that only two sources of indirect costs from decreased road access have been included in this CBA. Due to the limited availability of data and the dangers of double-counting benefits, only two types of economic loss should be included: economic activity losses and decreased wage income. This excludes a number of factors, which would contribute little in terms of benefits, but would introduce significant additional uncertainty. It is better to measure a small number of important factors accurately, rather than to try to measure less important factors erroneously. The economic costs of decreased access to economic activity and employment are significant sources of losses, but in taking such an approach it is important to be explicit about what is omitted.

Omissions include the lives saved and health benefits from improved access to hospitals and emergency care; the gain in welfare from greater access to leisure activities; lower transport costs and shorter delays for the movement of goods. Alongside increases in lifetime incomes, there are also other types of benefits deriving from education, which have been omitted. All of these omissions imply that this CBA most likely provides a lower-bound estimate of the potential benefits to the implementation of climate resilient investments in North Macedonia's road network.

Methods for estimating indirect costs are explained below.

Economic activity costs

One of the methods used to calculate yearly economic activity costs EAC caused by floods/landslides, combines a sector daily gross margin with the number of days of interruption:

[27] Penning-Rowsell et al. (2013). Flood and coastal erosion risk management: a manual for economic appraisal
[28] Chatterton et al. (2010). The costs of the summer 2007 floods in England, UK Environment Agency.

$$EC_0 = \sum_e GM_e \quad Road\ closure\ per\ year_0$$

Where GM is the daily gross margin of enterprise e, and $Road\ closure\ per\ year_0$ is the average yearly duration of road closure due to flooding/landslide in no investment case 0.

Similarly, we can calculate EC for the investment scenario:

$$EC_i = \sum_e GM_e \quad Road\ closure\ per\ year_i$$

Where GM is the daily gross margin of enterprise e, and $Road\ closure\ per\ year_i$ is the average yearly duration of road closure due to flooding/landslide in investment case i.

Daily gross margins should be estimated using value added data, table 23, for enterprises from the State Statistical Office of the Republic of North Macedonia. The statistics office provides data for value added at factor costs, as well as the number of enterprises for each sector, with data for 2017. By dividing the two, it is possible to obtain an approximate figure for gross margin per enterprise, which should then be multiplied by the number of official working days in the country.

Table 25 Daily value added per enterprise. Source: State Statistical Office of North Macedonia, 2017 data. Data for value added per enterprises and daily value added per enterprises is extrapolated.

Sector	Number of Enterprises	Value Added by Sector (denar million)	Value Added by Enterprise (denar million)	Value Added Enterprise per Day (denar million)
Mining and Quarrying	185	9436	51.0	0.2
Manufacturing	7444	69933	9.4	0.04
Electricity, Gas, Steam and Air-conditioning	163	16973	104.1	0.4
Water Supply and Sewerage	229	5333	23.3	0.1
Construction	4483	27618	6.2	0.02
Trade and Repair of Motor Vehicles	22279	61562	2.8	0.01
Transport and Storage	5466	21523	3.9	0.02
Accommodation and Food Service	4204	5940	1.4	0.01
Information and Communication	1684	18441	11.0	0.04
Real Estate Activities	554	3375	6.1	0.02

Professional, Scientific and Technical	6953	14125	2.0	0.01
Administrative and Support services	1214	7297	5.9	0.02
Repair of computers and household appliances	501	330	0.7	0.003

Labour market costs

The other indirect cost of extreme weather events is the loss of wage income due to decreased road access. Estimating labour market costs LC can be broken down into two steps:

1. **Identify road network users commuting to work in the region**

The goal of this step is to define the number of employees depending on the road network to commute to work. For this step, the number of workers in the region should be multiplied by the percentage of workers who commute to work (if not available, this percentage can be estimated through consulting the relevant agencies).

If the number of workers in the region is not known, it is possible to estimate it. First, the number of working age population in each region should be identified, as well as the regional employment and participation rates; the latest Census data should provide information on these parameters. Multiplying working age population by regional employment and regional participation rate should provide an estimate of the number of people working in the region.

2. **Identify daily wage income in the region**

Now that the workers living in each region are known, the wages earned by workers, in terms of mean daily wage by region should be identified.

Once both the number of workers commuting to work and the daily wage they earn are known for the region, we can calculate the labour market costs of the disruption caused by the extreme weather event in case there is no intervention:

$$LC_0 = \sum Number\ of\ commuters_r \quad Daily\ wage_r \quad Road\ closure\ per\ year_0$$

Where r is the region the road is situated in, $Number\ of\ commuters$ is the number of workers commuting in region r, $Daily\ wage$ is the average daily wage earned by workers in region r, and $Road\ closure\ per\ year$ is the likely number of days the road will be closed due to floods/landslides in a year, for the no intervention scenario 0.

Similarly, we can calculate labour market costs LC for the case where intervention i occurs:

$$LC_i = \sum Number\ of\ commuters_r \quad Daily\ wage_r \quad Road\ closure\ per\ year_i$$

Where r is the region the road is situated in, $Number\ of\ commuters$ is the number of workers commuting in region r, $Daily\ wage$ is the average daily wage earned by workers in region r, and

$Road\ closure\ per\ year$ is the likely number of days the road will be closed due to floods/landslides in a year, for the intervention scenario i.

4.1.10 Accounting for risk and uncertainty

While the overall framework presented above remains simple, a key issue is related to the treatment of risk and uncertainty in the CBA. While all cost-benefit analyses of any investment project are conducted in the presence of risk and occasionally uncertainty, this issue is felt to be particularly acute in the context of climate change.

Conducting any cost-benefit analysis implies looking into the future and asking what the “universe of interest” might look like without the project and with the project (the impacts of the project being the difference between these two scenarios). The exercise is fraught with incomplete information, risk, and uncertainty; this is true of all cost-benefit analyses, whether related to climate change or not. Hence, the same analytical tools currently available to account for risk and uncertainty in the conduct of a project cost-benefit analysis are of relevance in the context of assessing the costs and benefits of climate change adaptation options. The following two approaches may be applied to explicitly account for risk and uncertainty within the framework of the CBA.

Sensitivity analysis - The technique most widely applied to account for risk and uncertainty is known as sensitivity analysis (or sensitivity testing). For conducting a cost-benefit analysis of an adaptation option, this simple type of analysis involves changing the value of one or more variables at a time and recomputing the option’s net present value for each change. This exercise may be repeated as much as necessary. In sensitivity testing, switching values are often computed, where a switching value is the value of a specific variable that makes the net present value switch from positive to negative, or conversely. The purpose of such sensitivity testing is to raise the level of confidence when recommending the adoption or rejection of an adaptation option.

Probabilistic (or risk) analysis - Conducting a “probabilistic cost-benefit analysis” involves attaching a probability distribution for the possible value of any given specific cost or benefit component of the project instead of attaching a single deterministic value. Such probability distributions may be constructed using historical data. Probabilistic (or risk) analysis allows selecting multiple variables that can all be varied simultaneously according to the specific probability distribution attached to each variable. This process, known as a Monte Carlo simulation analysis, involves randomly generating a specific value for each individual variable (cost component or benefit component) according to the specific probability distribution attached to each variable. For any given draw of specific values, the net present value of the adaptation option is calculated. This process, by means of computer, is then repeated many thousands of times. The outcome of the analysis is a probability distribution of net present values. This probability distribution allows the computation of an “expected” net present value of the option, instead of solely a given net present value or a range of net present values.

Given the complexity and data requirements of probabilistic analysis it is recommended that more straightforward sensitivity analysis is undertaken. This should be done by varying the values of key inputs by plus and minus 20%.

4.1.11 Economic Appraisal Results

The main results of the economic appraisal will be the net present value and the internal rate of return. These are calculated by standard functions in EXCEL. To calculate these indicators, it is necessary to develop a discounted cash flow analysis for each option being tested. This looks like the table 24 below.

Table 26 Discounted cash flow analysis

Year	Capital Costs	Reduced Repair Costs	Reduced Economic Activity Costs	Reduced Labour Market Costs	Total Benefits	Present Value
1	A	B	C	D	E = B + C + D	F = - A + E
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						
15						
16						
Total						

Based upon the analysis of net present value and internal rate of return, the most appropriate investment, or policy action.

It should not be presumed that adaptation (climate proofing) should be pursued wherever technically feasible. From an economic point of view, not climate proofing a transport infrastructure may indeed be the best course of action in a number of specific circumstances. The outcome of the economic analysis of adaptation options, summarized as the net present value (NPV) of these options, will guide the nature of the recommendations. The decision rule guiding the selection of adaptations is similar to the decision rule for any investment project. If only one technically feasible adaptation option exists, then the decision rule is as follows:

- If expected NPV > 0 Recommend implementing the adaptation option based on the outcome of the economic analysis.
- If expected NPV < 0 Recommend rejecting the adaptation option (do nothing) based on the outcome of the economic analysis.
- If more than one technically feasible adaptation option exists, then the decision rule is to select the option with the largest expected NPV. If all adaptation options yield a negative expected NPV, then the best option is to do nothing.

4.2 Develop Investment Plan

The adaptation assessment results in a prioritised list of adaptation options for implementation, which are selected from among several possibilities. Their prioritization can be based on an assessment of their technical feasibility, their benefits and costs, their social acceptability, and the opportunities they may offer for synergies with national priorities. While the use and outcome of a cost-benefit analysis is often given more weight in the prioritization process, it is important to recognize that other factors and criteria may also influence decision making.

Following the assessment, recommendations should consider the full scope of ways that infrastructure assets can be enhanced.

To inform the further development of the intervention and to reduce the potential for redundant or repeat work, a straightforward project fiche should be developed and completed in each case.

Following the assessment, recommendations should consider the full scope of ways that infrastructure assets can be enhanced..

5 Application of the Guidelines - checklist

The methodology for flood and landslide hazard and risk assessment could be applicable on all planning and design stages, but the choice of algorithms is strongly depending on scale of analysis and thus is well connected with stages of road planning and design. Also, the methodology should be tailored for new road planning and design stages, in addition to the hazard and risk assessment for existing road or road section.

The best practice for implementing provisions for climate resilient road infrastructure, (landslide and flood hazard and risk assessment methodology) is to include it within early stages of planning (Pre-design stages), or early design stages (Conceptual and Preliminary design) of new roads. Scale of assessment is quite suitable for including climate and climate changing projection from National scenarios. The Main project design of new roads might already include slope stability calculations and results from previous design stages, as well as detailed hydrological and hydraulic modelling. Slope stability issue is supported by simulation of worst-case scenario – in case on maximal ground water table (or influence or pore water pressure), or with lowering shear strength parameters (cohesion and angle of friction) in the calculation. It is based on historical precipitation models (both cumulative and intensive) vs. occurrences of slope instabilities along new road corridor. Methodology for flood and landslide hazard and risk assessment for existing roads has to be supported by detailed field survey and more numerical simulation within landslide hazard and risk assessment procedure (according to the large scale assessment practice). That survey data should be upgraded with new environmental and climate/climate changes data and detail analysis of present site conditions vs. design conditions. Climate changes projection should be downscaled from National scenarios (if it is possible) and could be included in numerical calculations (probabilistic or deterministic). As a result of Assessment and field data from site it will be possible to propose Reconstruction, Rehabilitation or further maintenance measures for lowering the overall vulnerability of the existing roads/ roads sections.

This general method for using the guideline is based on the road planning and design stages as described below in Table 25:

Table 27 Application of the Guidelines in different stages of planning process

Stage	Deliverables	Incorporation of Climate Resilience
Strategy Development	Sector Strategy Business Model Development Pre-feasibility Study	Climate Resilience Strategy CVRA Hot spot identification and Prioritisation High Level Mitigation Options Identify Budgets
Project Planning	Conceptual Design Site Selection Technology Selection Cost estimating and financial/ economic modelling Feasibility Study ESIA Scoping	Geo-technical surveys Topographic surveys Hydrological surveys Site specific options Costing of Mitigation Options CBA of Mitigation Options Include climate change modelling in ESIA

Design	Front end Engineering Design Cost estimating and financial/ economic modelling Full ESIA and ESAP	Detailed site surveys Incorporate Mitigation Options Update CBA Include climate change modelling in ESAP

The specific steps to be included will be agreed with the client, based on the principle of the principal of the most useful approach to assist with the decision making based on increased information. As some of the models are based on projections, the increased level of detail that we can provide through this process will decrease the level of uncertainty.

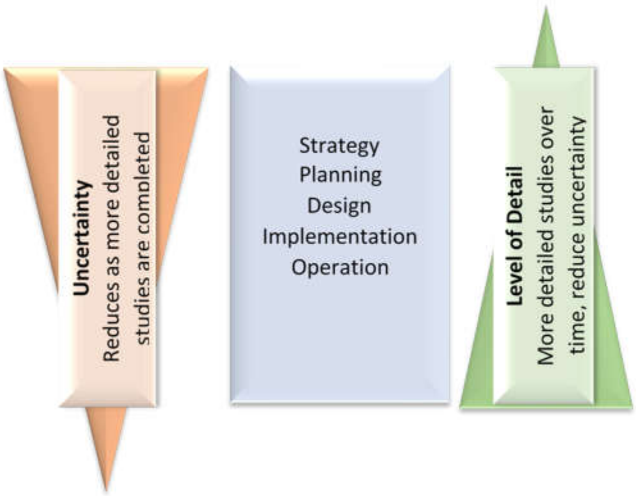


Figure 39 Level of uncertainty

With the increased level of details using this methodology the decision makers within PESR will be in a position to select informed solutions that will save costs in long term as the designs will be based on informed current and near future climate scenarios, looking into wider aspects of the network.

Integration into RAMS and Investment Planning: RAMS system needs to incorporate climate data that will assist the decision making process on the priority investment. But, introduction of RAMS by itself is not a guarantee that it will be used, or that it will be successful. PESR would also follow basic asset management principles. Strong involvement of executives and managers prior to and during the implementation of the system is absolutely necessary.

Within these Guidelines the risk assessment maps for Macedonia have been created, with current and near future scenarios (and further to 70 years). These have produced flooding and landslide prone hotspots which have been integrated in RAMS and should be used for future allignement planning and prioritisation of the regions for interventions. These maps need to be updated in 5 to 10 years.

The methodlogy for vulnereability and prioritisation on local level has been implemented on Polog region, with data and GIS files that have been incorporated in the RAMS system.

The recommendations on Engineering Measures and project specific Non Engineering Measures are in Part C of these Guidelines. The recommendations for the Non Engineering Measrues as well as the Institutional Non Engineering Measures are Part D of these Guidelines.

Annex 1 Checklists in form of Data Sheets

REGISTRATION FORM DUE TO HYDROLOGICAL HAZARDS
DRAINAGE GULLIES AND CANALS

ID No.*

1. GENERAL DATA			**2. Drainage area associated with the inspection gully (m^2): A***		**3. Type of gully:**	
Road mark*						
Locality*						
Coordinates*			A < 150 m^2		Kerbs and gully	
Chainage			150 m^2 > A > 250 m^2		Side Entry Gully	
Registration date*			250 m^2 > A > 500 m^2		Linear Drainage Channel	
Responsible researcher(s)*:			A > 500 m^2		Combined Kerb and Drainage Block	

4. Width of the road in m: W*		**5. Longitudinal gradient of the road near the gully: L***		**6. Cross-sectional gradient of the road near the gully: T***		**7. Type of road:**	
W < 3.5 m		L < 2.5 %		T < 3.0 %		Local	
3.5 m < W < 5.0 m		2.5 % < L < 5.0 %		3.0 % < T < 5.0 %		Motorway	
5.0 < W < 6.0 m		5.0 % < L < 8.0 %		5.0 % < T < 7.0 %		Regional	
W > 6 m		L > 8.0%		H > 7.0%		Highway	

8. Drainage canal/ditch		**9. Dimensions of drainage canal/ditch**	
Yes		Height (m)	
No		Width (m)	
10. Geometry of the drainage canal/ditch *		**11. Material of the drainage canal/ditch ***	
Trapezoidal		Earth	
Rectangular		Concrete	
Triangular		Stone mortar	
Longitudinal gradient (%)		Other	

12. Additional remarks (sketches, documents, number of photography, etc.):

Are the banks steep? Are the banks stable? Signs of erosion or deposition? Is the channel obstructed with vegetation?

*** REQUIRED FIELD FOR DATA INPUT**

REGISTRATION FORM DUE TO HYDROLOGICAL HAZARDS
CULVERTS CROSSING STREAM

ID No.*

1. GENERAL DATA			**2. Width of stream at the infrastructure crossing point: W***		**3. Gradient of stream bed at the infrastructure crossing: G***	
Road mark*						
Locality*						
Coordinates*			W > 10 m		G ≥10%	
Chainage			10 m > W > 5 m		10% > G ≥ 4%	
Registration date*			5 m > W > 3 m		4% > G ≥ 2%	
					2% > G ≥ 0.5%	
Responsible researcher(s)*:			W < 3 m		0.5% < G	

4. Area of drainage basin of the stream at the infrastructure crossing point: A		**5. Height from stream bottom to infrastructure at the crossing stream point: H***		**Sketch**
$A \geq 50$ km^2		H > 5 m		
50 km^2 > A ≥ 10 km^2		5 m > H > 2 m		
10 km^2 > A ≥ 1 km^2		2 m > H > 1 m		
1 km^2 > A		H < 1 m		

5. Dominant vegetation of valley side slope*		**6. Geology***
Urban area		Type of bedrock/lithology:
Agricultural area		
Eroded land		Geological age (OGK label):
Sparse perennial vegetation		
Perennial vegetation good set		Weathered crust/ thicness:

7. Stream water at crossing point of the road*		**Desintegration degree of the rock**	
Stream water is recognized all throughout the year		earth	
Stream water is recognized seasonally		fine debris	
Surface water is recognized abnormally		debris	
Not seen		blocks	

8. Plan shape of stream at the crossing point of infrastructure*			
straight		curved	

9. Additional remarks (sketches, documents, number of photography, etc.):

*** REQUIRED FIELD FOR DATA INPUT**

REGISTRATION FORM DUE TO HYDROLOGICAL HAZARDS
BRIDGE CROSSING RIVER/STREAM

ID No.*	

1. GENERAL DATA		
Road mark*		
Record bridge No. *		
Locality*		
Coordinates*		
Chainage		
Registration date*		
Responsible researcher(s)*:		

2. Morphology of the valley*	
alluvial plane	
river valley-hilly area	
river valley-mountainous area	

3. Change of river course*	
outside of the bridge length	
inside of the bridge length	
not applicable	

3. Predominant material in the riverbed*			
silt/clay		blocks	
sand		bedrock	
gravel			

Sketch

4. Position of the bridge pillars*	
Pillars in the riverbed and on the riverbanks	
Pillars on the banks of the river	
Pillars in the riverbed	

5. Position of bridge foundation (abutments and piers) in river/stream	
Under low water level in curved river course	
Under low water level in starlight river course	
Under high water level in curved river course	
Under low water level in starlight river course	
Outside high water level	
Unknown	

6. Type of pillar funding*	
Caissons foundation	
Pile foundation	
Shallow foundation	
Unknown	

7. Protection of bridge pillars*			
Yes		No	

8. Presence of the deposits in the bridge zone*					
Yes		Partially present		No	

9. Height from stream bottom to infrastructure at the crossing stream point: H*	
H < 1 m	
1 m < H ≤ 2m	
H > 2m	
H > 5m	

10. Hydraulic protection of the riverbed in the zone of intersection with the bridge *	
upstream and downstream	
upstream	
downstream	
doesn't exist	

LANDSLIDES DATA SHEET

ID NUMBER*

1. GENERAL DATA			2.1 GENERAL DATA ABOUT LANDSLIDING						
Road mark*			**Type of movement ***		**Type of material ***				
Location*			Fall**		Rock				
Coordinates*			Topple		Debris				
Chainage			Slide		Organic material				
Registration date*			Lateral spread		Man-made material				
(Re)activation date			Flow		Heterogenic material				
Responsible researcher(s)*			Complex		Soil	Clay		Sand	
			*Take attention on **!*			Silt		Gravel	

2.2 GENERAL DATA ABOUT LANDSLIDING								
Water content *		**Rate of movement***		**State of activity and slope condition ***				
Dry		Extremely slow		Marginally stable slope				
Moist		Very slow		Active	Active			
Wet		Slow			Suspended			
Very wet		Moderate			Reactivated			
It refers to the assesment of water content at the moment of process activation, not at the time of registration!		Rapid		Inactive	Dormant		Repaired/stabilized	
		Very rapid						
		Extremely rapid			Abandoned		Relict	

2.3 GENERAL DATA ABOUT LANDSLIDING				Sketch in cross section
Distribution of activity		**Style of activity**		
Retrogressing		Single		
Advancing		Successive		
Widening		Multiple		
Diminishing		Composite		

LANDSLIDES DATA SHEET

ID NUMBER*

Dos not refer to the direction of the mass movement!	Complex		

3 GENERAL DATA ABOUT TERAIN AND POSITION OF THE ROAD									
Relief along the road route					**Geological structure***				
Ridge					Type of bedrock – lithological structure:				
Valley									
Slope	Height	m	Route at the top		Age (OGK label):	Weathered rock	yes	no	
	Length	m	Route in the middle			Thickness of weathered rock		m	
	Slope	°	Route at the bottom						
Hydrology					Degree of desintegration/weathering				
Watercourses:								earth	
Permanent		Occasional						fine debris	
Other:								debris	
								blocks	

Hydrogeological characteristics							
H.G. function of material							
Type of an aquifer (level, inflow, discharge):							
HG Phenomena:							
Grundwater lake		Springs		Seepage spring		Diffuse	

4. DETAILED DESCRIPTION OF THE PHENOMENON								
Shape		**Geometry**		**Type of sliding***		**Causes of landslides***		
Round		Length*	m	Translational		Unfavorable caracteristic of rocks		
Eliptical		Width*	m	Rotational		Morfometry		
Frontal		Depth	m	Combined		Erosion of the slope toe		
Trapezoidal		Surface	m^2	Complex		Suffosion		
Elongated		Volume	m^3	**Scarp**	**Height**	Ma	Deflation	

LANDSLIDES DATA SHEET

ID NUMBER*

Fanlike		General slope angle from the top to the foot** °	Main m		Pumping
Irregular		Height from the top to the foot ** m	Minor m		Static load of the slope
					Dinamic loads
					Uncontrolled water intake
					Unproper Excavation & Cutting

Slope characteristics **			**Previous investigation***	
No. of dominant joint sets			Detailed	
Presence of single joint	Yes	No	Partially	
Orientation of joints relative to the route: Favorable Unfavorable			Registered	
Size of the block in dm³ max <8 8-125 >125 min <1 1-8 >8	Mechanizm	Plane	Technical documentation:	
		Wedge		
		Topple		
Height to the heighest source area: m				
Basic friction angle: °				

Direct trigger of the process*	
Precipitation	
Erosion of the slope toe	
Earthquake	
Sudden oscilations in groundwater level	
Direct man-made	
Other	

5. PHYSICAL VULNERABILITY OF THE ROAD

Position of the route relative to landslide occurrence*		**Vulnerability of the road from the landslide*** Yes No		**Elements of the road in zone of the landslide occurence***	
		Interruption of the traffic Yes No		Direction	Curvature
The road passes directly over the forehead part of landslide		Collapse of larger amount of the material on the road		At the terrain level	
The road passes over the upper part of the landslide		Occasional collapse of the material on the road		Embankment up to 3,0m height	
The road passes over the central part of the landslide		Continuous collapse of the material on the road		Embankment > 3,0m	
The road passes over the foot part of the landslide		Roadway structure hardly damaged, with the step-in cross section		Fill up to 3,0m	
Landslide in the wider road area		Roadway structure less damaged because the collapse of the material		Fill >3,0 m	

ID NUMBER*

Landslide on the road upslope		Roadway structure is not damaged, it is only covered with material		Cut up to 3,0m.	
Landslide on the road downslope		Roadway in the area of the occurrence is not damaged; it is possible to travel along the road with caution		Cut >3,0m.	
		Damage of the supporting structures on the cuts			

6. RECOMMENDATIONS

Regular maintenance   Urgent maintenance   Monitoring   Site specific investigation/Design   Urgent measures

7. ADDITIONAL REMARKS/SUGGESTIONS (sketches, documentation, number of photos, etc.):

REGISTRATION FORM
FOR FLOOD HAZARDS

ID No.*

1. GENERAL DATA		
Road mark*		
Locality/section*		
Registration date*		
Responsible researcher(s)*:		
Lat-Lon coordinates of the first observation point (increasing chainage)		
Chainage of the first observation point		
Lat-Lon coordinates of the last observation point (increasing chainage)		
Chainage of last observation point		
River/stream name		

2. RIVER/STREAM INFORMATION	
Permanent watercourse	
Temporary (seasonal) watercourse	
Watercourse curves in respect to the road route	
Watercourse is straight in respect to the road route	

3. STATE OF THE RIVER/STREAM CHANNEL	
Riverbed and channel unregulated but unvegetated	
Riverbed and channel unregulated and heavily vegetated	
Riverbed and channel regulated	
Only channel regulated	

4. HEIGHT FROM THE STREAM/WATER TABLE TO THE ROAD LEVEL (ONE ANSWER)	
H ≥ 5 m	
5 m > H ≥ 2 m	
2 m > H ≥ 1 m	
H < 1 m	

5. DISTANCE FROM THE RIVER/STREAM TO THE ROAD (ONE ANSWER)	
L ≥ 100 m	
50 m > L ≥ 100 m	
10 m > L ≥ 50 m	
L < 10 m	

6. ROAD CONSTRUCTION ELEMENTS (ONE ANSWER)	
Embankment up to 3 m high	
Embankment higher than 3 m	
Cut and fill up to 3 m high	
Cut and fill higher than 3 m	
Road at the terrain level	

7. PHYSICAL EXPOSURE OF THE ROAD	
Undermining erosion of the base of the road construction	
Highest flood level up to ½ of the road construction height	
Highest flood level up to the road level	
Highest flood level is over the road level	
Collapse of the entire road construction	

8. TRAFFIC BREAK (IF IT APPLIES, CHOOSE ONE OF THE ANSWERS)	
Less than 1 day	
From 1 to 7 days	
From 7 to 14 days	
More than 14 days	
Unknown	
Slow traffic, one lane used	

9. ADDITIONAL COMMENTS	10. SCATCH

*** REQUIRED FIELD**

Annex 2 Engineering and Non-Engineering Measures spreadsheet for field survey results

Road id	GPS coordinates		Hazard		Recommendations Measures			Cost in Euros	
Location	From	To	Hazard	Findings	Short Term measure	Long Term measure	Maintenance	Cost	Comments
A3 Locn No 2. West side 3.4km south of Makedonska Kamenitsa	42° 0'18.93"N 22°35'4.48"E	42° 0'22.28"N 22°35'7.73"E	Rock fall	Road passes through a cutting. The rock faces are a problem area on both sides of the road are shedding small rocks and debris down their faces onto the road edge. The high west side face (11m approx) is a particular problem. Much debris are being washed down from the top slope edge to slide down onto the road. The continual loss of material may result in larger rocks being loossened to fall onto the road.	Clean high slope face, and set back toe to install low catch wall (NJB) or alternatively a concrete lined catch ditch. Construct a ditch or earth dam above the slope to direct water away to the side valleys at either end of			Clean high face+low catch wall at toe and ditch above slope. Approximated around 27.000 Euros	This location is a typical problem of the many cut slopes that exist on the approach to MK form the north and the south. Rockfall interventions may be as frequent as 6 p.a.
						Set back rock face with catch ditch or catch wall to base and 2m berm at 5m height. Construct a ditch or earth dam above the slope to direct water away to the side valleys at either end of the cutting. Protect face with		Catch wall at toe, berm at 5.0m and ditch above slope + protect face with mesh. Approximated around 55.000 Euros, it may require expropriation and we don't have info	
							Increase frequency of inspection of the location and removal of fallen material. Record all rockfall events. Implement a mesaging system and dedicated phone line to enable road users to report rockfalls direct to PESR/Maintenance company. Advertise the		

Annex 3 Example Cost Benefit Analysis for Poroj Bridge

Purpose of CBA

This case study cost benefit analysis has been undertaken in order to demonstrate the application of the methodology set out in the design guidelines. The CBA below follows that methodology, identifying key data sources and areas where interpretation may be required.

Road Section Being Studied

The CBA was completed for a location with persistent flooding problems, which have led to damage to an important bridge on a number of occasions. The CBA is based upon the results of the engineering studies and site visits, undertaken by a joint consultant/PESR team in May 2019. The location lies on the regional road Tetovo-Jazince (border with the Republic of Kosovo), near the village of Poroj and is shown in the following figure

Source: Copernicus satellite image (07/08/2015)

Data from the floods that occurred in 2015, show that the bridge was mainly damaged by excessive amounts of sediment being rapidly washed down the Poroj River watershed. The estimated amount of sediment in the zone of the bridge, in this case was ~ 200,000 m^3.

Options Appraised

To enable the demonstration of the use of CBA as a method, two options have been tested, a combination of short term measures designed to be easily implemented and low cost, and a longer term package which deals with the whole of the problem and includes a mix of interventions. These two are compared against the Do Nothing scenario, and each other. These scenarios are made up from the menu of interventions set out below.

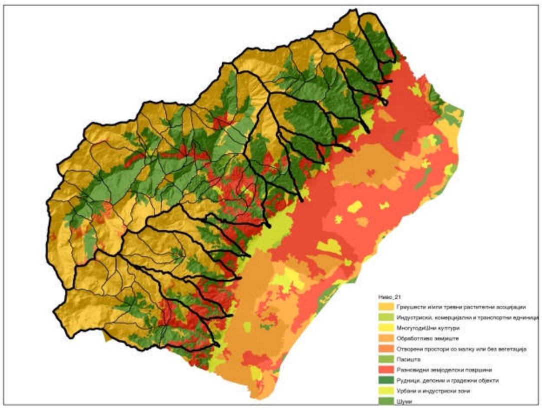
Non-structural measures, at watershed level

1. *Afforestation and management of bare lands in the catchment area (zones with high erosion)*
   Area: 300 hectares

   Estimated investment costs: 150,000 €

2. *Improving land use pattern and application of good agricultural practices (convert degraded arable land into meadows or forests, and obligation to convert annual into perennial crops and introduce crop rotations)*
   Area: 200 hectares

   Estimated investment costs: 50,000 €



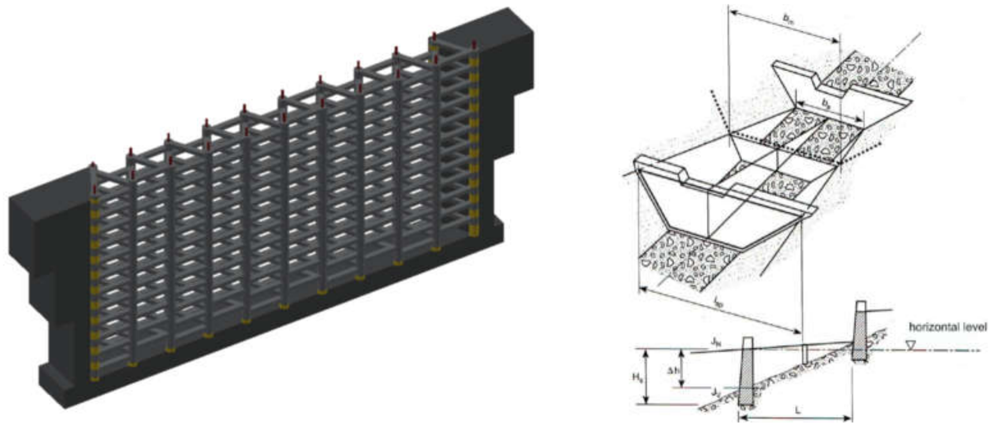
3. *Observation, early warning, alert and evacuation schemes*
   Estimated investment costs for installation of hydro-met station with direct access: 10,000 €

These measures cannot fully reduce the risk of flooding and sediment transport. It is estimated that these measures can reduce water and sediment quantities by 50%.

Structural measures, at watershed level

1. *Construction of technical facilities (Retention structures, small check dams) to reduce the slope of the river, to deal with erosion at the upper parts of the river*

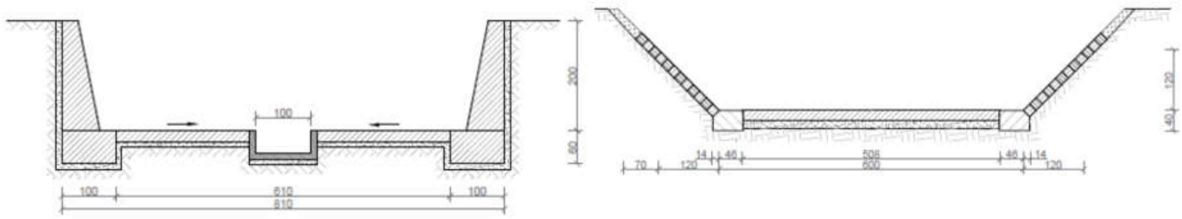
Estimated investment costs: 750,000 €



Structural measures, flood plain

1. *<u>Construction, reconstruction and maintenance of existing riverbeds (Increasing the capacity of the riverbed at the middle and lower parts of the rivers)</u>*

Estimated investment costs: 550,000 €



Capital Costs of Interventions

The capital costs of the proposed interventions were assessed based upon measurements taken during extensive site visits and outline designs produced subsequently. Two packages of interventions have been appraised, as shown in the table below.

Costs of Interventions and Packages

Package	Intervention	Cost MKD
Do Something - Short Term	Check dams	46,112,337
	early warning	614,831
	Total cost	46,727,168
Do Something – Long Term	afforestation	9,222,467
	land use	3,074,155
	early warning	614,831
	check dams	46,112,337
	river training	33,815,713
	Total cost	92,839,503

Source: Consultants estimates

Severity and Likelihood of Disruption

The starting point for the CBA is an analysis of the current situation. This is particularly the case for the impacts of climate events on the location. The location is a bridge which lies at the head of an extensive river catchment. The bridge has been regularly flooded and damaged by debris and water flow, with significant events occurring at least once every five years. Currently, during these events, the bridge will be closed for around 5 days, whilst flood water recedes and damage is repaired[29].

Data from Tetovo Municipality shows that the cost of repairs in 2015 was approximately €100,000 (MKD 6.148 million).

The effect of the proposed interventions will be to reduce the impact of a particular event. Given the nature of the impacts at the studied location, it is unlikely that flooding could be eliminated completely. However, it would be expected that the size of any event should be reduced and consequently, the impact of the event should be reduced. Estimates from the site visits and subsequent studies show that the amount of sediment is likely to be reduced by 50% if all the proposed measures are implemented.

Whilst it is difficult to draw linkages between the size of an event and the amount of damaged caused, for the purposes of this analysis it has been assumed that by reducing the amount of sediment by 50%, it is possible to reduce the extent of any damage by 50% as well. For the purposes of this appraisal, it has been assumed that the short term measures would reduce the extent of any damage by 10%. It has therefore been assumed that given another 2015 scale event, the bridge would be closed by 5 days in the Do Nothing scenario, 4 ½ days in the Do Something – Short Term scenario, and 2 ½ days in the Do Something – Long Term scenario.

Indirect Costs

The indirect costs related to the case study site have been assessed in two areas; costs related to a loss of economic activity in the area due to temporary loss of access, and lost personal income for people who are unable to get to work temporarily.

Economic Activity Costs

Economic activity costs are estimated, based upon the assumption that firms operating in the area affected by any disruption will lose output, as they will not be able to receive production inputs, or transport finished goods. To make this assessment, it was necessary to firstly estimate the number of firms in the area. Records on the locations of operational firms in Macedonia are difficult to access and often incomplete. For the purposes of this CBA, it has been assumed that there are 10 operational firms that would be affected by closure of the Poroj Bridge.

Next, it was necessary to estimate the typical output that each of those firms would create on any given day. This was estimated, based upon the figures shown in the following table. These figures show, based upon published statistics, estimates of daily output for different types of firm, operating in different sectors. Firms in the study area are likely to fall into one of a small number of these categories – manufacturing, trade and repair of motor vehicles, and transport and storage. Based upon these categories and taking into account the average outputs from other categories of firm, an average output of MKD40,000 per firm, per day, has been used for this CBA.

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[29] Information from local stakeholders and PESR databases

Daily Value Added per Enterprise

Sector	Number of Enterprises	Value Added by Sector (denar million)	Value Added by Enterprise (denar million)	Value Added Enterprise per Day (denar million)
Mining and Quarrying	185	9436	51.0	0.2
Manufacturing	7444	69933	9.4	0.04
Electricity, Gas, Steam and Air-conditioning	163	16973	104.1	0.4
Water Supply and Sewerage	229	5333	23.3	0.1
Construction	4483	27618	6.2	0.02
Trade and Repair of Motor Vehicles	22279	61562	2.8	0.01
Transport and Storage	5466	21523	3.9	0.02
Accommodation and Food Service	4204	5940	1.4	0.01
Information and Communication	1684	18441	11.0	0.04
Real Estate Activities	554	3375	6.1	0.02
Professional, Scientific and Technical	6953	14125	2.0	0.01
Administrative and Support services	1214	7297	5.9	0.02
Repair of computers and household appliances	501	330	0.7	0.003

Source: State Statistical Office of the Republic of North Macedonia, 2017 data.

Note: Data for value added per enterprise and daily value added per enterprise is extrapolated.

Based upon the estimates of how the level of delays will be reduced following the proposed interventions, it was then possible to estimate how the economic activity losses would be reduced. Using the same assumptions as for the level of damage, it was possible to show how these delays would reduce, as shown in the table below.

Estimated Reductions in Economic Activity Losses

	Do Nothing scenario	Short term scenario	Long term scenario	
Gross Output per day	40,000	40,000	40,000	per hour
Likely annual delays	1	0.9	0.5	Hours
Number of enterprises affected	10	10	10	
Total delays	400,000	360,000	200,000	MKD per year

Source: Consultants Estimates

Labour Market Costs

The estimates of labour market costs have been produced based upon estimates of the number of people who live in the area and work elsewhere. These people would be affected by a road closure.

The total population of the study area was estimated from published census data. The table below shows these statistics for the relevant area. From these figures, it was estimated that the working age population (those between 15 and 65 years) for the area, could be considered to be 40,859.

Study Area Population

Group	**0-14 years**	**15-24 years**	**25-39 years**	**40-49 years**	**50-64 years**	**65+ years**	**Unknown**	**Male**	**Female**	**Total**
Number	15,392	10,692	14,478	8,057	7,633	4,859	69	30,830	30,349	61,179

It is estimated that in Tetovo Province around 34% of the working age population is in formal employment[30] and could therefore be considered as at risk of losing income due to a dislocation. It is therefore expected that around 10,200 people who live in the area of the road, are likely to commute to another location.

To assess the likely costs of dislocation that may occur it was necessary to assess the average daily income that would be lost. For the purposes of this CBA, this was estimated based upon the average salary in North Macedonia. Whilst there are likely to be significant salary variations across North Macedonia, information on these is scarce. Therefore, the national average salary was taken as reflecting average salaries in Tetovo Province. A figure of MKD 2,394 per day was used[31].

The likely annual labour market costs in the three scenarios, are shown in the table below.

Likely Annual Labour Market Costs

Scenario	**Labour Market Costs**
Do nothing scenario	24,454,293
Short term scenario	22,008,864
Long term scenario	12,227,147

Cost Benefit Analysis Results

The results of the Cost Benefit Analysis are presented as a traditional discounted cash flow analysis. This shows the annual costs and benefits that would accrue, related to the intervention. The CBA results (see tables below) are generally presented as two main indices, the Economic Internal Rate of Return and the Net Present Value.

CBA Results – Do Something – Short Term Scenario

Year	**Capital costs**	**Benefits**				**Net Benefits**
		Reduced Repair costs	Economic Activity	Labour Market	Total	
2020	46,727,168				0	-46,727,168

[30] https://core.ac.uk/download/pdf/6253957.pdf
[31] http://www.salaryexplorer.com/salary-survey.php?loc=127&loctype=1

2021		614,831	40,000	2,445,429	3,100,260	3,100,260
2022		614,831	40,000	2,445,429	3,100,260	3,100,260
2023		614,831	40,000	2,445,429	3,100,260	3,100,260
2024		614,831	40,000	2,445,429	3,100,260	3,100,260
2025		614,831	40,000	2,445,429	3,100,260	3,100,260
2026		614,831	40,000	2,445,429	3,100,260	3,100,260
2027		614,831	40,000	2,445,429	3,100,260	3,100,260
2028		614,831	40,000	2,445,429	3,100,260	3,100,260
2029		614,831	40,000	2,445,429	3,100,260	3,100,260
2030		614,831	40,000	2,445,429	3,100,260	3,100,260
2031		614,831	40,000	2,445,429	3,100,260	3,100,260
2032		614,831	40,000	2,445,429	3,100,260	3,100,260
2033		614,831	40,000	2,445,429	3,100,260	3,100,260
2034		614,831	40,000	2,445,429	3,100,260	3,100,260
2035		614,831	40,000	2,445,429	3,100,260	3,100,260
2036		614,831	40,000	2,445,429	3,100,260	3,100,260
2037		614,831	40,000	2,445,429	3,100,260	3,100,260
2038		614,831	40,000	2,445,429	3,100,260	3,100,260
2039		614,831	40,000	2,445,429	3,100,260	3,100,260
2040		614,831	40,000	2,445,429	3,100,260	3,100,260
2041		614,831	40,000	2,445,429	3,100,260	3,100,260
					NPV	-MKD 20,788,383
					IRR	3.2%

As can be seen, the results of the CBA show that, in this case, the short-term package of interventions, whilst providing some benefit, is not economically viable, as the net present value is negative.

CBA Results – Do Something – Long Term Scenario

Year	Capital costs	Benefits				Net Benefits
		Reduced Repair costs	Economic Activity	Labour Market	Total	
2020	92,839,503				0	-92,839,503
2021		3,074,156	200,000	12,227,147	15,501,302	15,501,302
2022		3,074,156	200,000	12,227,147	15,501,302	15,501,302
2023		3,074,156	200,000	12,227,147	15,501,302	15,501,302
2024		3,074,156	200,000	12,227,147	15,501,302	15,501,302
2025		3,074,156	200,000	12,227,147	15,501,302	15,501,302
2026		3,074,156	200,000	12,227,147	15,501,302	15,501,302
2027		3,074,156	200,000	12,227,147	15,501,302	15,501,302
2028		3,074,156	200,000	12,227,147	15,501,302	15,501,302
2029		3,074,156	200,000	12,227,147	15,501,302	15,501,302
2030		3,074,156	200,000	12,227,147	15,501,302	15,501,302
2031		3,074,156	200,000	12,227,147	15,501,302	15,501,302
2032		3,074,156	200,000	12,227,147	15,501,302	15,501,302
2033		3,074,156	200,000	12,227,147	15,501,302	15,501,302
2034		3,074,156	200,000	12,227,147	15,501,302	15,501,302

2035		3,074,156	200,000	12,227,147	15,501,302	15,501,302
2036		3,074,156	200,000	12,227,147	15,501,302	15,501,302
2037		3,074,156	200,000	12,227,147	15,501,302	15,501,302
2038		3,074,156	200,000	12,227,147	15,501,302	15,501,302
2039		3,074,156	200,000	12,227,147	15,501,302	15,501,302
2040		3,074,156	200,000	12,227,147	15,501,302	15,501,302
2041		3,074,156	200,000	12,227,147	15,501,302	15,501,302
					NPV	MKD 21,769,102
					IRR	16.0%

As can be seen, in this case, the Long Term package of interventions is economically viable, as the net present value is positive. This confirms that the benefits that would accrue from this investment, outweigh the costs incurred.

Sensitivity Tests

To test the robustness of the findings of the CBA it is normal that a series of sensitivity tests be completed. These tests involve re-running the CBA but with slightly different assumptions regarding key variables. In this case, four sensitivity tests have been completed, varying the capital costs by ±20% and varying the level of benefits that would occur by ±20%.

The results of the sensitivity tests are shown in the table below. Overall, in this case, it is clear that the results of the CBA are robust. In all tests, the Long Term scenario remains viable, with a positive net present value. Similarly in all tests, the Short Term scenario remains unviable, with a negative net present value.

Sensitivity Test Results

	Short Term		**Long Term**	
	NPV	**IRR**	**NPV**	**IRR**
Base Case	20,788,383	3.2%	21,769,102	16.0%
Capital Costs +20%	29,132,520	1.4%	5,190,619	12.8%
Capital Costs - 20%	12,444,246	5.7%	38,347,584	20.5%
Benefits -20%	24,974,843	1.0%	836,799	12.2%
Benefits + 20%	16,601,922	5.2%	42,701,405	19.6%

Annex 4 Background climate background and current practices

1 The Republic of North Macedonia - background

The Republic of North Macedonia (hereafter referred to as Macedonia as well) is situated in the Western part of the Balkan Peninsula in South East Europe, with an area of 25.713 km^2. Macedonia has 2,075,301 inhabitants[32]. A significant proportion of the population live in the capital Skopje (around 15.8% live in Skopje's municipalities and around 30.2% in the Skopje region). Macedonia has averaged a population growth of 0.2% since 2003 and is urbanising.

Macedonia had an average GDP per capita of 4,827 Euros in 2017[33]. In 2018 the inflation rate was 1.5%[34] and the economy growing at 7.1% per year[35]. Employment is concentrated in the manufacturing and agriculture, forestry and fishing sectors. The at-risk-of-poverty rate in the Republic of North Macedonia in 2017 was 22.2% while the Gini coefficient (measure of income distribution inequality) was 32.5%[36].

The relief in the Republic of North Macedonia is predominantly comprised of mountains and valleys. Around 80% of the territory is represented by mountains and 20% by lowlands. Due to this, gravitational processes and floods are the most frequent hazards in general. The average height above mean sea level (amsl) is 829m. The lowest point near Gevgelija is 44m amsl and highest is the peak Golem Korab at height of 2.764m amsl.

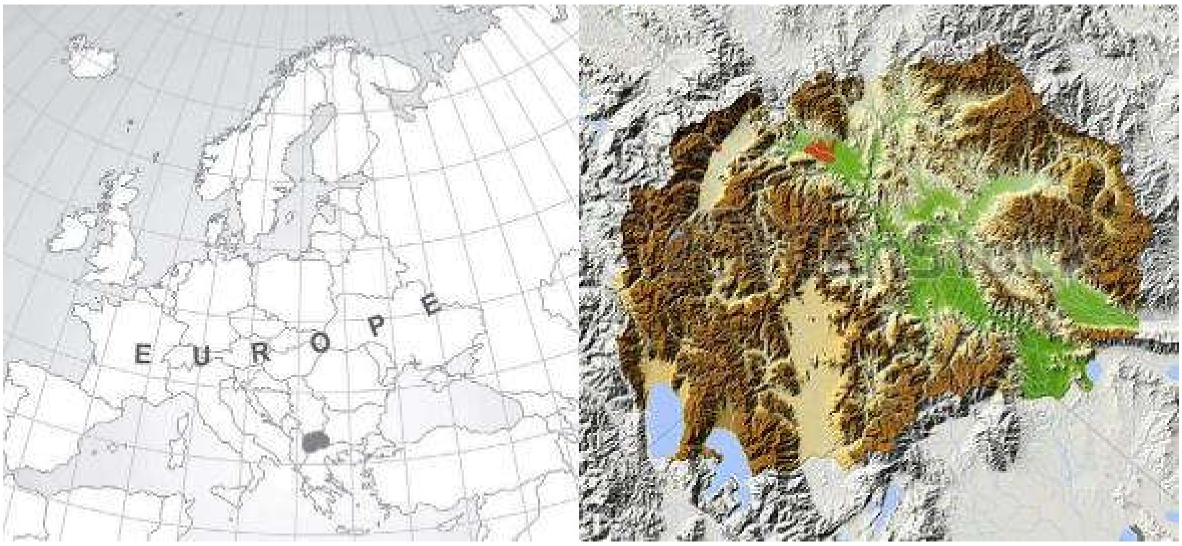


Figure 1 Geographical position and shaded relief Map of the Republic of North Macedonia.

The hydrological system of Macedonia consists of three main catchment zones: the Aegean, Adriatic and Black Sea. The largest by far is the Aegean catchment with 87% of the total territory. The main rivers in this catchment are the Vardar and Strumica. The Vardar river catchment is the largest, covering 20.535 km^2, comprising the majority of the country's water. The Adriatic catchment is smaller, covering around 15% of Macedonia territory with river Crn Drim as the main river. The Black Sea catchment has just one river named Binacka Morava. The main catchment areas are highlighted in Figure 2 below.

[32] MAKSTAT database - Population of the Republic of Macedonia on 31.12, by single age and sex, by years, 2017, Estimations of the Population by Sex and Age, by Municipalities and by Statistical Regions, State Statistical Office

[33] Press Releases - Gross domestic product in the Republic of Macedonia in 2017- preliminary data -, State Statistical Office

[34] State Statistical Office and NBRNM forecast

[35] Press Release - Gross Domestic Product, fourth quarter of 2018, State Statistical Office

[36] Press release - Laeken poverty indicators in 2017- final data, State Statistical Office

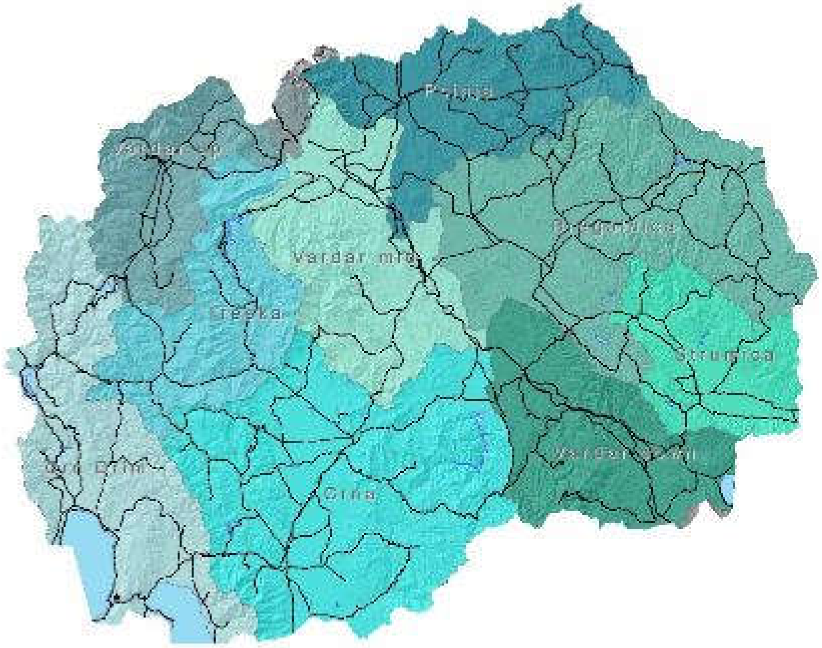


Figure 2 Main watershed catchments in Republic of North Macedonia Source: National Water Study Delineation with Consultant adaptations

The climate of the Republic of North Macedonia is influenced by the Eurasian landmass, the Atlantic Ocean and the Mediterranean Sea. There are several main climate regions, namely the sub-Mediterranean, a region with expressed translation of Mediterranean and continental climate, region with continental climate and region with mountain climate. Most of Macedonia is in the Hot-Continental and Continental Sub-Mediterranean climate zones (81.3%).

The average annual temperatures and precipitation distributions over the past 50 years are set out in **Error! Reference source not found.** below.

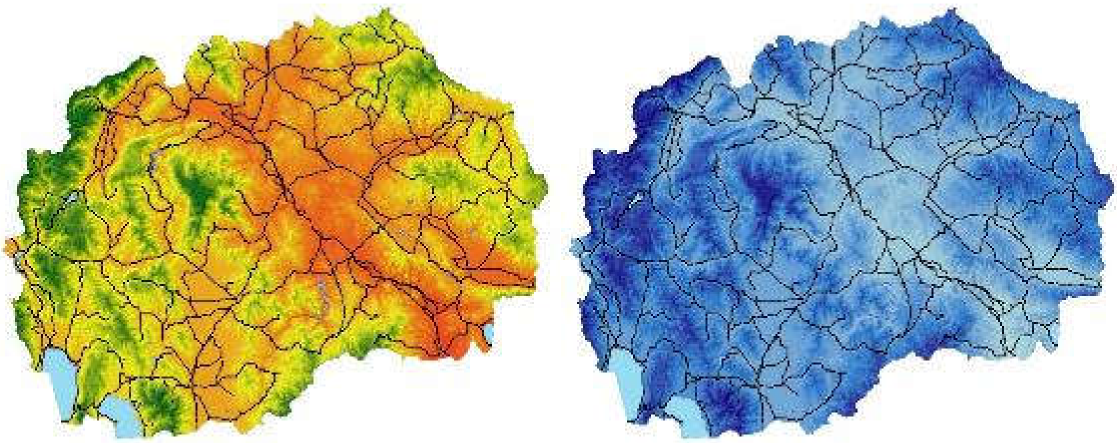


Figure 3 Annual Temperature Averages (left) and Annual Precipitation Distribution (right) for the Reference Period (1961-2010) Source: Source: National Water Study with Consultant adaptations

Macedonia is a parliamentary republic. The territory is divided in 8 planning regions that serve the purpose for statistical, economic and administrative purposes, as set out in Figure 4 below.

Figure 4 Statistical regions and in the Republic of North Macedonia Source: State statistical office with Consultant adaptations

1.1 Road network in Republic of North Macedonia

Macedonia has a road network of 14.410km, including highways, trunk, regional and local roads (Table 1). Around 62.2% (8,958 km) of these roads are paved (asphalt or cobbled) and 37.8% are un-pavement roads.

Table 1 Road categories in Republic of North Macedonia and total length

Category of State Road	Length (km)
A category state roads (motorways)	259
A category state roads (express ways and trunk roads)	640
R1, R2 and R29 category state roads (R1 R2 regional roads from first and second category). R29 roads that partially fulfil the criteria for state roads.	3,778
L category state roads (local roads)*	9,733
Total	14,410

(Source SSO, Transport and other services, 2017 MakStat, confirmed by PESR)

As of 2013, management of national and regional roads has been entrusted to the managerially and financially independent Public Enterprise for State Roads (PESR). The extent of road infrastructure managed by PESR in each of the eight administrative regions is set out in Table 2 below. The largest extent of the PESR's road network is in the Pelagonija region (18%), while the least in Polog with 9% of the total network length.

Table 2 Statistical regions of the Republic of North Macedonia and length of PESR road infrastructure in each of administrative regions

Statistical region	Length (km)	Ratio (%)
East	702	15%
South-East	551	12%
South-West	579	12%
Pelagonija	861	18%
Polog	433	9%
North-East	459	10%
Skopje	444	10%
Vardar	627	13%
Total	**4.655**	**100%**

Macedonia's principal transport connections with its surrounding neighbors are summarized as following:

- To the north, Macedonia is connected to the Republic of Serbia and Kosovo, through two main transport corridors (both include trunk roads and railway lines) passing in the valleys of rivers Marica and Lepenec. These corridors connect Macedonia with Central, West and North Europe.
- To the east the country borders with Republic of Bulgaria to which it is connected by three trunk roads. These roads pass through the valleys of the Kriva (Corridor VIII), Bregalnica and Strumica rivers. These are the main connections between Eastern European countries and Southwest Asia.
- To the south is Greece, to which Macedonia is connected by three road sections and two railway lines. The most important road section is the highway E75 – A1 (Corridor X) which passes through the Vardar valley, connecting the North border with Serbia and the South border with Greece. The second road passes through the Pelagonija valley and the third one is near the city of Dojran.
- To the west is Albania to which Macedonia is connected by four trunk roads. Two of the roads are passing through the Ohrid - Struga valley, the third one passes through the Prespa valley and the fourth one is the border crossing Blato – near city of Debar.

These transport links and the geographical position make Macedonia a strategically important part of the European Transport Network (TENt) – see Figure 5 below. As a result, the Macedonian road network not only serves local and national needs, but provides transit for a large quantity of goods, passengers and tourists each year.

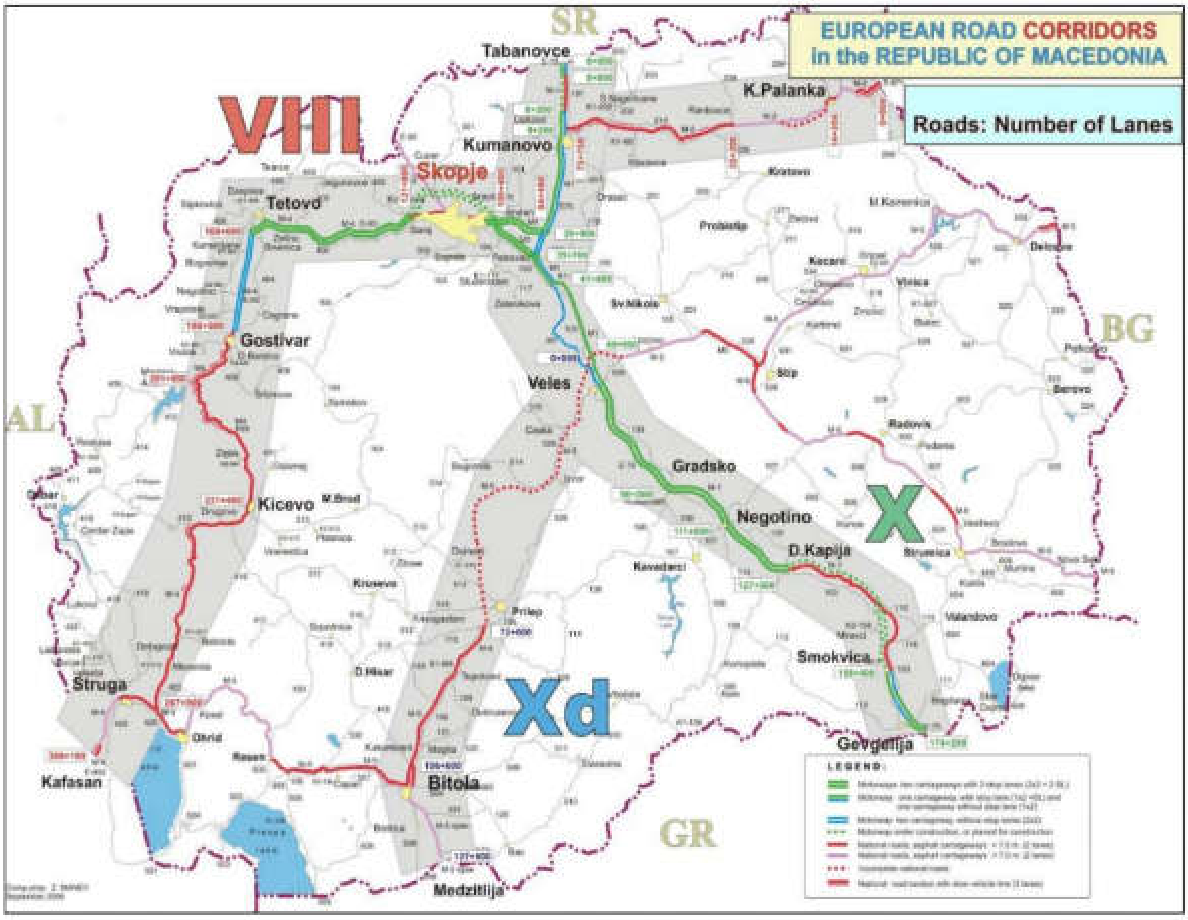
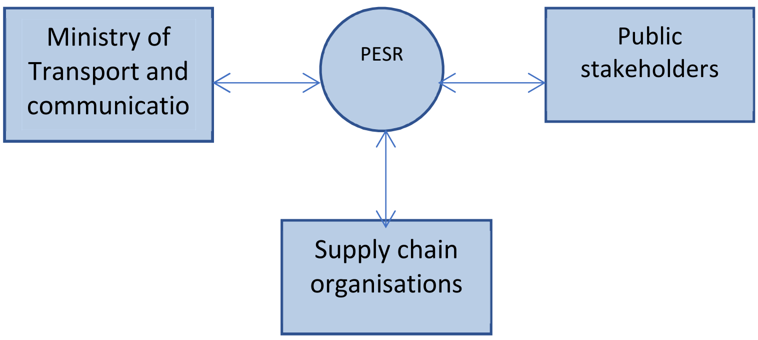


Figure 5 Road network on the TEN-T Corridor VIII and X, X-d

1.2 Public enterprise for state roads (PESR)

The PESR, for the purpose of these guidelines is looked through three dimensions:

- Ministry of Transport and communications (as parent body for PESR)
- Other public authorities (with which PESR cooperates delivering some services and/or data and from which expects services or data (i.e. in terms of hydrology or meteorology)
- Road maintenance supply chain organizations/companies



The Ministry of Transport and Communications oversees roads sector strategic guidance and policy. As of 2013, management of national and regional roads has been entrusted to the managerially and financially independent Public

Enterprise for State Roads (PESR), which is mandated as the owner of the national and regional road infrastructure, responsible for planning the construction, reconstruction, maintenance, operation and protection of the state roads, monitoring and analysis of the conditions in relation to the construction, reconstruction, maintenance and protection of the state roads. Local roads are entrusted to municipalities. National and regional roads receive funding from the state budget; these funds are planned and implemented by the Fund for National and Regional Roads (FNRR). Local roads management are financed by municipalities, which set aside funds within their budgets for this purpose. In addition, on a yearly basis all municipalities receive a transfer from the state budget specifically for the maintenance of local roads

North Macedonia's National Transport Strategy, which was adopted in 2007, confirmed the need for investments in roads to ensure better communication among the regional centres within the country, as one of the main tools to promote North Macedonia's competitiveness in international markets and to support harmonious development of the country as whole. The strategy stipulated that investments should focus on the maintenance and preservation of and repairs to existing roads and on enhancing the functionality of the existing road network, with a very limited expansion of that network.

1.3 Climate and climate changes impact on roads

Climate change does not necessarily create 'new' risks for the transport sector. Rather it typically represents a change to existing risk profiles – in other words, the risks from climate related hazards are already familiar issues facing transport operators on a daily basis (like rock falls, landslides, etc.). For instance, storm-related floods impact to transport infrastructure are already experienced in Macedonia, too. Climate change simply represents a potential change in the duration, predictability and/ or frequency of occurrence of these impacts, and their subsequent effects on transport infrastructure, operations and performance (see Table 3). Climate change will change future temperature and precipitation (storm intensity, frequency, seasonality, and overall rain and snow fall levels. This will impact upon flooding (both of rivers and flash floods) and subsequent landslide risk, and the potential scale/severity of winter measures.

Table 3 How the climate could impact on roads

Generic Option	Examples
Do minimum	Minimum actions necessary to maintain a safe and serviceable network. May include: developing contingency plans, monitoring changes and, for assets, doing patch-and-mend repairs/ like-for-like replacements, as required.
Future-proof designs	Updating design requirements, including technical standards and specifications, to provide additional capacity/ functionality. These updated requirements could apply to all 'designs' e.g. designs for new structures or new roads, as well as to designs for maintenance, renewal and improvement works when these are implemented within the normal cycle for such activities. Typically, it will be appropriate to adopt a precautionary approach in future-proofing designs, so that the asset/ activity will perform satisfactorily throughout its life in the event of climactic changes towards the extreme predictions.
Retro-fit solutions	Proactively applying modifications to existing assets/ activities outside of the 'normal' cycle for renewal/ replacement. For example, proactively replacing/ fitting additional equipment or components or providing additional provision/ capacity to exiting assets. This option could be applied everywhere on the network, or just at high risk sites. Work could

	start now, or only once climate change effects meet certain threshold criteria.
Develop contingency plans	Development of a pre-planned response for when/if climate change risks are realised so that their immediate effects can be managed. This option could apply where nothing can reasonably be done to mitigate an identified risk, during the period until other measures are put in place, or where there is a residual risk, despite adaptation actions being employed. It should be included as standard within the 'do minimum' option.
Update operating procedures	Updating operating procedures to take account of the impacts of climate change. For example, updating the procedure for working in high temperatures.
Research	The main purpose of research is to reduce uncertainty., where this presents a barrier to determining preferred adaptation options with a reasonable level of confidence. It could be done to provide better understanding of the likelihood and consequences of a risk for the road network. Alternatively, it could be done to help determine or refine appropriate adaptation options.
Monitor	Monitoring of the rate of climate change and/or subsequent effects on a particular asset/ activity to increase confidence in the appropriate adaptation option, or to determine the appropriate point at which to implement some pre-determined action. An important part of this option would be to identify indicators of change and threshold 'triggers' for action.

1.4 Climate-related natural hazards in the Republic of North Macedonia

The most important natural hazards affecting the territory of Macedonia are flooding, landslides, earthquakes, fires, erosion, droughts, and periods of extreme heat and cold. According to the study of the World Bank Macedonia is the fourth most vulnerable country in the region of Europe and Central Asia (ECA) to climate related natural disasters between 1990 and 2008 and ranked twelfth in terms of overall climate vulnerability based on an index of exposure, sensitivity, and adaptive capacity. The strength of Macedonia's future climate change relative to today's natural variability is also projected to be high. These Guidelines focus on the vulnerability and exposure of PESR assets to flooding and landslides, and how these roads are impacted by climate change. The two most important hazards are briefly introduced below.

1.4.1 Typical landslides in the Republic of North Macedonia

Landslide processes in Macedonia are one of the most frequently occurring natural hazards. In the past they have caused significant economic loss and unfortunately loss of life. In the absence of a database for landslides on the road network, systematic information for the landslide mechanism of landslides affecting the roads is missing. Therefore, we present only the general picture for landslide types in Macedonia and some statistical parameters for their properties. It is noted that most of the information is based on a research by Peshevski et al 2013[37].

This research lists information for over 250 landslides that have been mapped or registered in Macedonia in the period from 1960-2013. The key findings of the research are the following:

a. In relation to geological setting, 38% of the landslides have occurred in soil debris which covers schistose or granitic bedrock, 11% in limestone (mostly rockfalls), and 31% in lacustrine sediments. In the rest of the cases, landslides occurred in Pyroclastic materials, sandstones, flysch, fluvioglacial and proluvial sediments.
b. According to the landslide type, most of the landslides were defined as translational and rotational debris and earth slides and rock falls. One of the main issues of the available data is the imprecise definition of the landslide type (most are described either as transitional or rotational slides).
c. Considering the depth, landslides are defined as shallow <2 m, intermediate 2-10 m and deep >10 m. Over 60% of the occurrences have been defined as intermediate and deep, and those mostly occurred in debris material overlaying hard rock masses or in fluvioglacial and proluvial sediments. The depth of some of these landslides varies in the range from 5 to over 25-30 meters. The remaining 40% of the slides are shallow, and mostly occurred in sandstones, lacustrine and flysch sediments. Rock falls are usually classified as shallow slides.
d. Regarding to the location, rotational and translational debris and earth slides have mostly developed on the transition of steep mountain slopes and river valleys, while rock falls and rock slides are characteristic in the gorges on the north-west, south and eastern part of Macedonia. Due to the very developed river network and existence of mountain chains with different strike, there is no dominant orientation of sliding slopes in a geographical sense.
e. Earthquakes. From the historical documents it was found that the several slides are connected with seismic activity. These included the landslides Ramina and Crnik those were among the most damaging. Having in mind the tectonic setting of Macedonia, the potential for seismically induced landslides (co-seismic landslides) is very high.
f. Almost 70% of the landslides have been caused by heavy rainfalls, and the rest have been caused in combination of excavation and water saturation as the main prerequisite. Proluvial sediments are the most sensitive to excavation. For some landslides, a combination of several factors contributed to the triggering of instability.
g. Statistics showed that 10% of the landslides have endangered whole settlements, while 30% have damaged individual structures in rural or urbanized area. Water supply systems, electric power distribution networks and sewage systems have frequently suffered.

1.5 Affected infrastructure in general, roads, population

Every year, especially during the winter and spring periods, rock falls are very common on the state roads throughout the country. From the construction time of these roads, approximately 40-50 years ago, more than 1000 rock falls (ranging from smaller boulders to blocks of several cubic meters) have occurred. Most affected Road sections in the past have been: Highway - Corridor X (A1) – section Katlanovo-Veles (mostly rock falls), regional and magistral roads: Mavrovi Anovi – Debar-Struga, Bitola-Resen-Ohrid, Demir Kapija-Udovo (old road), Gevgelija – Kozuf mt., Kocani – M.

[37] Peshevski I., Jovanovski M., Markoski B., Petruseva S., Susinov B., Landslide inventory map of the Republic of Macedonia, statistics and description of main historical landslide events, Proceedings of the first regional Symposium on Landslides in the Adriatic-Balkan Region. 6-9 march, 2013, Zagreb, Croatia.

Kamenica - Delcevo, Vinica - Berovo, Berovo - Strumica, Stip -Negotino etc., as well as many local roads, especially in the north-west part of Macedonia.

Besides the unfortunate human losses, the landslides present major challenge in the maintenance of the roads. Namely, Peshevski et al. 2013, for a period of 2000-2013, found that remedial measures have been undertaken for 62 landslides (authors consider that this number is far greater). Rehabilitation works mostly consist of construction of support walls, road nets, water drainage systems under road, concrete piles, gabion walls, etc.

Each year from the budget of the PESR large amount of money is spent on preparation of design documentation and civil works for landslide remediation. For example: Preparation of design documentation for remediation of landslide on state road P2433 (P606), Radovis – Konce with value 2.230.200,00 MKD; Basic designs for landslide remediation design on the entire territory of Macedonia 28.350.000,00 MKD. For civil engineering works on a landslide along the trunk road A3, location Bukovo are spent 11.000.000,00 MKD; landslide on section Gradsko-Prilep, location Farish 10.000.000,00 MKD; landslide on trunk road Resen - Bitola 14.000.000,00 MKD. Numerous other landslides along route Ohrid-Kicevo (i.e. Botun), the road Strumica- Berovo, etc. However, precise information on the total losses on the road network due to landslides (direct and indirect) in not available. Table 4 gives brief overview of the available data.

One particular case study for landslide remediation on the PESR's road network is presented in Table 45.

Table 4 General overview of Impact of landslides in Macedonia

Affected	Damage
Road infrastructure damage	Not available – estimated in several millions of Euros annually
Traffic interruption	60% of the landslides have impended or stopped the traffic on regional or local roads
Population	Cases of whole settlements that needed to be moved (Jelovanje and Ramina for example)
Total economic loss	Not currently calculated, no national landslide database available
Human life loss	82 registered deaths ('70-'19), some from the rock falls on the road

1.6 Current landslide risk management practice in relation to PESR roads

1.6.1 Regular procedure

Detecting

The detection (first insight) of landslides is by the services of Public Enterprise (PE) "Makedonija Pat", primarily the maintenance service. The supervising engineer responsible for road maintenance in that region is immediately informed about the situation; they report to the PESR and PE "Makedonija pat", immediately reports the situation to the Ministry of Internal Affairs, the Automotive Union of Macedonia (AMSM), media etc., in order to ensure that road users are informed.

Inspection

The site of the landslide is immediately secured with the help of vertical signalisation and equipment, or other necessary measures by the PE "Makedonija pat" in order to ensure a normal and safe traffic flow.

The PESR organises a field inspection of the landslide within a maximum of 24 hours, to which representatives of the following organisations and institutions are invited:

- PESR
- Consultant - Faculty of Civil Engineering - Skopje (usually from the Department of Geotechnics)
- The Supervising Road Maintenance Engineer (in charge of that region)
- PE "Makedonija pat" - Skopje (from the associated subsidiary)
- Road Inspectorate (in certain cases)
- Ministry of Internal Affairs (in certain cases)

Based on the situation recorded at the field inspection, minutes are prepared which describe the location, the road chainage, the road number and the road section. In these minutes the current state of the terrain is identified and the remarks and recommendations of all institutions in the frame of their scope for the given case are included. The minutes are signed by all parties and serve as the basis for preparation of a Design for remediation of the landslide.

Design

The Design Program is prepared by the Consultant (Faculty of Civil Engineering) in coordination with the PESR. Once prepared and signed by all representatives who participated in its preparation, it is submitted to the PESR. An appropriate budget (financial resources) is included in the public procurement plan, depending on the scope of work foreseen in the Design Programme.

Response

There are three types of responses depending on the budget of available:

1. If the current year's public procurement plan has budget for the preparation of design documentation, the Design Programme is submitted to the public procurement sector, where the preparation of design documentation is published in a standard public procurement procedure.
2. If the current year's budget does not provide for the preparation of design documentation and the situation is not deemed emergency, a standard public procurement procedure is followed for the next financial year.
3. If the current year's budget does not provide for preparation of the design documentation, and the situation is deemed as critical (but not emergency), the budget is proposed and submitted to the PESR Management. The Board will decide whether there will be an addition to the public procurement plan. If the proposal for the necessity of preparation of the design documentation is accepted by the Management, changes and additions to the public procurement plan are made and a standard public procurement procedure is followed.

In addition to these three scenarios there is a special procedure for emergency situations, as detailed below.

Implementation of the design programme

The most favourable bid is selected through public procurement and a legal entity is selected as a Designer in accordance with the requirements of the Public Procurement. PESR concludes an agreement as contracting authority with the legal entity Designer as a service provider.

The Designer performs field investigations, measurements etc., as envisaged by the Design Programme. At the design stage, meetings are held between the Designer, PESR and the Faculty of Civil Engineering, in which they discuss solutions and proposals of best practice etc.

The design is then printed or sent in electronic form to PESR, which is then forwarded to the Reviewer (Faculty of Civil Engineering). In order to save time, Designers often send the design documentation directly to the reviewer. The Reviewer then submits the reviewed report to the PESR, which forwards the report to the Designer.

The Reviewer provides Final Review approval if the Designer has completed the envisaged goals of the Design Programme, and provided the Desing in accordance with the Law on Construction and other legal regulations. Once approved, the Design is submitted to PESR (6 hard copies and 2 electronic copies). A Bill of Quantities is included in the Design documentation. This is a predicted budget for the rehabilitation of the landslide and supervision of works.

Public Procurement Procedure

The most favourable bid for construction of the designed solution, и.e. legal entity 'Contractor' in accordance with the requirements of the Public Procurement is selected. Through a different public procurement, usually run in parallel, the most favourable bid submitted for the legal entity 'Supervisor' of the works in accordance with the requirements of the Public Procurement is selected.

As contracting authority, PESR concludes agreements with the legal entity 'Contractor' and with the legal entity 'Supervisor'.

In accordance with the signed contracts from inception until the implementation deadline, the Supervisor ensures that the Contractor is in accordance with the scope of work of the design documentation.

In accordance with the Agreement, the Law on Construction and other legal acts, the construction is performed.

Completion phase

Upon completion of the construction works, the Contractor shall notify the Supervisor that the works have been substantially completed. The Supervisor reports this to PESR, which forms a commission for internal technical acceptance of affairs. The Commission is usually composed of representatives of:

- The Contractor
- The supervisor authority
- PESR - Investor
- Designer (as needed)
- The reviewer of the Design documentation
- PE "Makedonija pat"
- Supervision of road maintenance

Minutes for an internal technical overview are compiled based on the field inspection and an overview of the overall documentation. If the Commission has no objections regarding the construction, i.e. if the planned works are in accordance with the needs of the Design, the contract documentation and the applicable laws and regulations, the road is put into operation and handed over to PE "Makedonija pat" for maintenance. The Supervisor issues a hand over certificate, after which the guarantee period starts.

During the two-year guarantee period, the Supervisor monitors the site and submits a report to the Investor every 6 months. At the end of the guarantee period the Supervisor submits a Final Report, thus formally legally completing the project (detection of landslide to completion).

1.6.2 Emergency – urgent works procedures

Following the detection and inspection procedures presented, if the situation put into risk the safety of the road users, private property, individual structures, or human life, recommendations are given immediately and undertaken to protect people and property.

The minutes are signed by all parties and serve as the basis for preparation of Design documentation for remediation of the landslide. On basis of the minutes, a Design Program is prepared by the consultant (Faculty of Civil Engineering) in the shortest possible timeframe in coordination with the PESR. Once the design program is prepared and signed by all the representatives who participated in its preparation, it is submitted to the PESR.

According to Article 99, Paragraph 1, Item 1, Line 3 from the Public Procurement Law, PESR has the right to contract design services with a short procurement procedure. This is to be arranged with an experienced design company that is on the list of approved and capable contractors that are specialised in the required area. The request is sent to 3 trusted consultants and the evaluation is prioritised to go into negotiations with the preferred bidder. This contract is not subject to open public procurement process. This method is used when there is major disruption to the road network, as well as in situations where the disruption may cause danger major threat to the road users.

Urgent work procedures then follow the same procedure as non-emergency cases.

There is no legal basis for expropriation procedure since the landslides are not treated in the Law on Construction or by laws, they are not foreseen to be a part of the Infrastructure Plan which is a precondition for an expropriation process. If the landslide is on a private owned land, the contractor is arranging access to site and financial compensation with the owner of the land and the contractor's obligation is to build access roads to the landslide location.

1.7 Floods in the Republic of North Macedonia

Macedonia is vulnerable to floods both in terms of flood severity, or impact, and flood intensity, or strength. Floods contributed to 44% of the hazards during the period 1989-2006 year with total of 7 flood events. (Source: EM-DAT: The OFDA/CRED International Disaster Database).

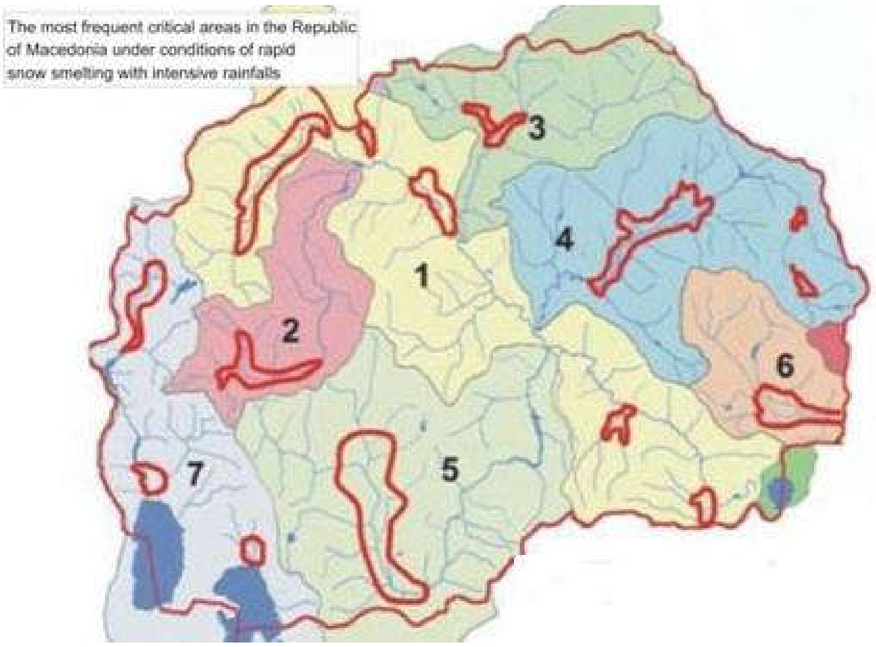


Figure 6 Critical flood areas in the Republic of North Macedonia

The most devastating flood in Macedonia since it gained its independence in 1991, occurred in 1995 and caused nearly $400 million in damage. More recently, flooding in 2004 affected over 100,000 people and caused almost $5 million in damage (Source: World Bank).

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 (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)

Floods in 2014: In 2014 the territory of Macedonia was exposed to constant rainy periods with moderate quantities of rainfalls. The rainfalls progressively increased the ground (soil) saturation, as well as the table/level of the surface watercourses. The oversaturation of the soil with water resulted in the inability of the soil to absorb the rainfall. This caused rapid flow into the watercourses, formation of ponds and lakes at locations featuring dense clay soils, as well as sporadic local overflows. These overflows occurred due to the reduced water permeability of the river channels, primarily due to the overgrowth of trees and bushes, the deposit of various waste, the deposit of large quantities of sediments, narrowed watercourse profiles under the bridges etc.

Severe flooding hit much of the country in January and February 2015, causing widespread damage and economic losses. Heavy rainfall caused rivers to overflow in many locations, and 44 out of 80 municipalities experienced flooding. The most affected regions were the basins of the Crna Reka, Bregalnica and Strumica rivers, which cover 45% of the watershed territory of the country. Roughly 170,000 people were affected in all. The floods caused major damages to roads and bridges, interrupting the road and railway transport. Much agricultural land was also flooded, causing extensive losses to farming families. Drainage and irrigation systems were also damaged, as well as private houses, private sector industrial facilities, schools and public facilities in some villages, etc. were also flooded.

In the flood aftermath, the Government commissioned a Rapid Damage and Needs Assessment (RDNA), with the aim to assess the full impact of the disaster on the country and, on the basis of the findings, to produce a feasible and sustainable Recovery Strategy for mobilizing financial and technical resources. The RDNA was coordinated by the Ministry of Agriculture, Forestry and Water Economy, in cooperation with experts from the World Bank and the European Union (EU).

The initial impact assessment estimated the total cost of the spring 2015 floods at EUR 35.691,672 million. Of this total, 62 % were classified as damages and 38% as losses (Table 5).

Table 5 Summary of damages and losses by sectors on national level

Sector	Total (EUR)	Share (%)
Agriculture	13,671,655	38.3
Industry	536,459	1.5
Transport	**15,276,736**	**42.8**

Electricity	976	--
Water and sanitation	235,439	0.7
Irrigation and drainage	4,900,680	13.7
Housing	975,504	2.7
Education	94,224	0.3
Total	**35,691,673**	**100**

The floods caused heavy damage to the country's transport infrastructure, including roads and bridges at national, regional and local level. According to the impact assessment, total costs in the transport sector were EUR 15.276 million, or 42.8 percent of all flood damages and losses.

Damage to roads was assessed at EUR 2.27 million overall, and damage to bridges, at EUR 2.117 million. In all, 197 roads with a total length of 124 kilometres were damaged, including 7 national roads, 21 regional roads and 169 local roads. The floods also completely destroyed 11 (3 regional and 8 local) and damaged 42 bridges (2 national, 6 regional and 34 local).

Damages to roads and bridges interrupted transport for short periods in many cases, and in some cases, there was total cut off of service. These floods had a negative impact on economic activities and travel between cities and villages in the affected areas. The resulting losses, traffic volume per day, the time required to rehabilitate or rebuild damaged infrastructure, the length of alternative routes and the unit price per kilometer were all calculated according to the PDNA methodology. In Table 6 are presented the estimated losses on the transport infrastructure in the Bregalnica river basin. Figure 7 represent distribution of losses per river basin.

Table 6 Transport infrastructure damages and losses per municipality due to flooding in Bregalnica river basin in 2015

N°	Municipality	Total damage roads	Total damage bridges	Losses	Total	Share of Total
		(EUR)	**(EUR)**	**(EUR)**	**(EUR)**	**%**
1	Zrnovci	0	975,610	5,940,000	6,915,610	80.8
2	Sveti Nikole	89,431	61,789	309,557	460,777	5.4
3	Delcevo	0	325,203	0	325,203	3.8
4	Probishtip	138,211	0	89,280	227,491	2.7
5	Cesinovo-Oblesevo	73,837	83,707	0	157,544	1.8
6	Pehcevo	52,033	81,301	0	133,334	1.6
7	Kocani	51,220	73,171	0	124,391	1.5
8	Vinica	56,098	48,780	0	104,878	1.2
9	Stip	92,683	0	0	92,683	1.1
10	Karbinci	8,130	0	0	8,130	0.1
11	Berovo	7,805	0	0	7,805	0.1
	TOTAL	**569,448**	**1,649,561**	**6,338,837**	**8,557,846**	**100**

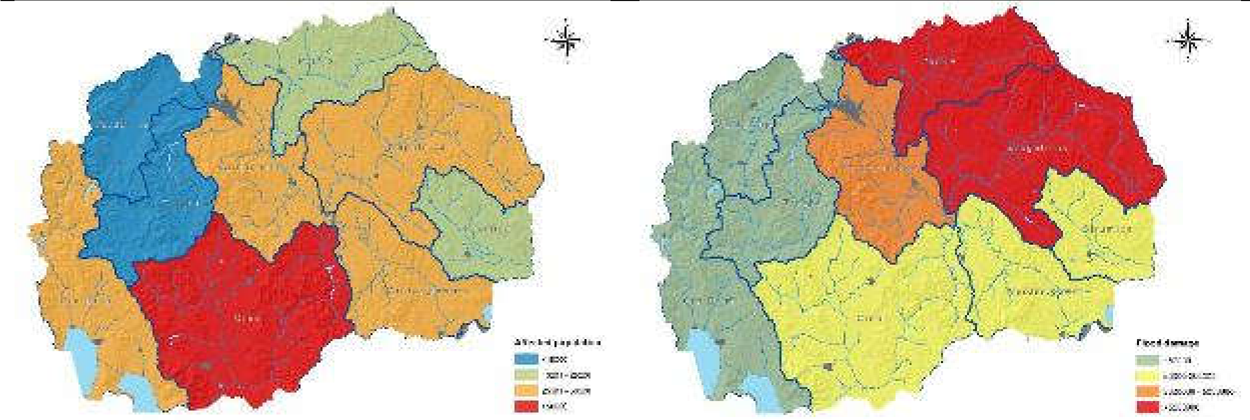


Figure 7 Affected population and transport infrastructure losses per river basins (floods in January and February 2015)

Floods in 2016: In the afternoon of August 6, 2016 at 6 pm local time, an exceptionally heavy rain began falling in the area around Skopje, the capital of Macedonia. The storm lasted for around four hours, having two peaks at 6:45 pm and 10 pm. 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 1000years) 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 (Figure 8).

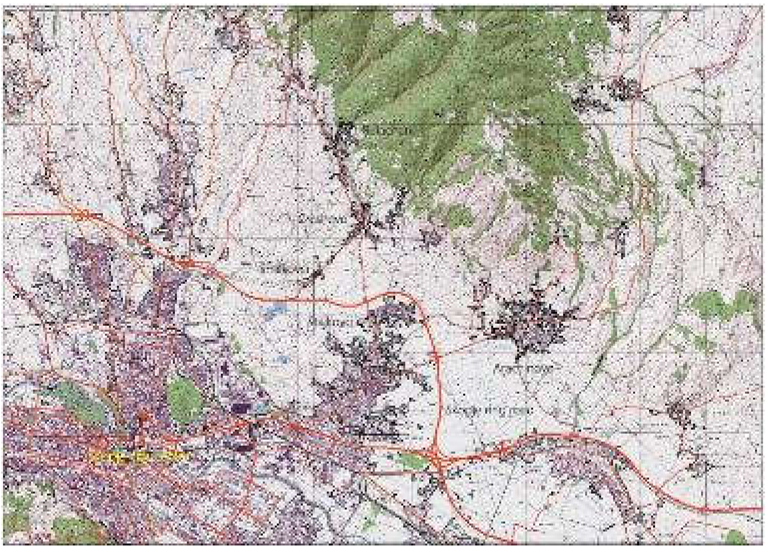


Figure 8 Most affected area of the capital Skopje during the August 6 2016 event

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 (figure based on media).

Damage to the road network was reported in the municipalities of Gazi Baba, Arachinovo, Butel and Kisela Voda. The PESR also reported damage within its area of coverage. The road sections affected are distributed within approximately 92.0 km, which corresponds to 0.65% of the national road network, but represents a key route in the affected area.

Most of the affected assets are local roads and streets (almost 88.00 km). The Skopje Bypass was affected as well, with a damaged section of 2.0 km. Approximately 2.0 km of secondary roads in municipality Kisela Voda were also affected. Besides the damage on road network, damages to vehicles were also reported.

Some of the affected road sections were closed for a few days following the floods. The bypass around the City of Skopje was closed for 3 days.

The damage and losses in the transport sector are estimated at a minimum of MKD 732.3 million. Out of the total, 99.5% corresponds to direct effects (damage to assets). Damage to local roads and streets account for the majority of the impacts, with reconstruction costs estimated at as MKD 396.1 million. The reconstruction costs of the Skopje Bypass amount to over MKD 306.9 million (Table 7). Applying apropriate methodology, after the event was performed hydraulic modelling (Figure 9).

Table 7 Summary of affected road infrastructure, according Angel Panov 2016? - *PointPro*

Location	Affected roads (km)	Damage and Losses (MKD)
Gazi Baba	55	300,699,750
Arachinovo	22	96,880,039
Butel	2	19,500,000
Kisela Voda	2	8,328,333
PESR	**2**	306,914,813
Total	**92**	**732,322,935**

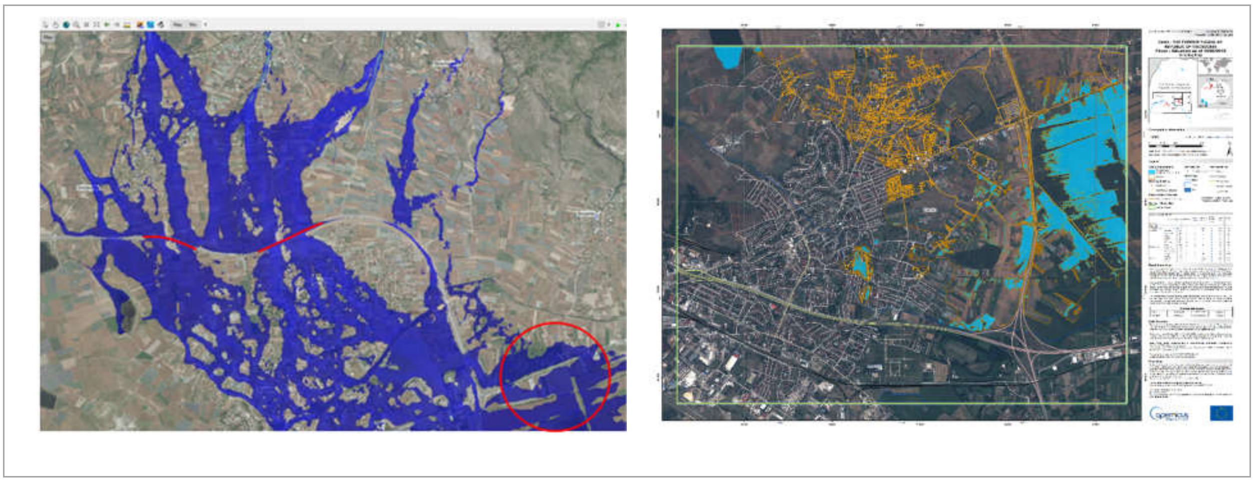


Figure 9 ***Hydraulic modelling of flood event from 6th of august 2016, Angel Panov - PointPro***

1.8 Current flood risk management in North Macedonia, regulatory framework

The most important sources of the present national regulatory and legal framework dealing with water management in the country or having reference to water related matters, including protection against harmful effects from water (e.g. floods), include:

1. Law on Waters (OG 87/2008, 06/2009, 161/2009, 83/2010, 51/2011, 44/2012, 23/2013, 163/2013, 180/2015, 146/2015, 52/2016)
2. Law on Protection and Rescue (OG 93/2012, 41/2014).

The Law on Waters provides legal basis for water management and protection in the country. It regulates the manner of water resources use and exploitation, protection against harmful effects of water, protection of water against exhaustive water extraction and pollution, water resources management, sources for and manner of financing water management activities, concessions, trans boundary water resources, and other issues of relevance with regard to the provision of a unique water use regime. As regards specifically flood risk assessment and flood protection the Law on waters stipulates the following:

- Section V.2 – Protection against harmful effects from water – Flood protection, defines: Basic and supplementary measures for flood protection; preparation of flood protection plans; flooding of protected areas (floodplains); responsibilities for maintenance of flood protection facilities; and reporting responsibilities.
- Section VIII.4 – Water resource management facilities and services – Dams and reservoirs, defines that the entity which is responsible for management of larger dams is obligated to prepare flood risk assessment analysis in case of a dam break.
- Section X – Material Base and Financing of Water Management and Development stipulates that funds collected by surface water use charges shall be used for, inter alia, construction and maintenance of riverbed regulation facilities and preparation of flood protection plans.

The **Law on Protection and Rescue** defines the system for protection of the population, environment, material assets, natural resources, biodiversity, and cultural heritage from disaster events including floods. The Law specifies the following: (1) basic provisions for protection and rescue; (2) rescue and protection planning; (3) responsibilities of central government, local government, public and private organizations regarding rescue and protection; (4) responsibilities of the population and the civil sector; (5) measures for rescue and protection; (6) rescue and protection forces; (7) self-defense rights and mechanisms; (8) monitoring of rescue and protection planning and implementation; (9) education and training for rescue and protection; (10) financing arrangements for rescue and protection; etc.

Following the Institutional framework for flood risk management and planning, the responsibilities is shared between MoEPP as a Competent Authority for integrated water management including flood risk management, Crisis Management System (CMS), Protection and Rescue Directorate (PRD) and municipalities.

Transposition of the Floods Directive is at an early stage, with only three provisions reported as transposed. With this situation, implementation of the flood risk protection legal system remains at an early stage, with only one obligation implemented so far, i.e. designation of the competent authorities.

As regards flood risk management in accordance with the Floods Directive, in recent years with financial support provided by development organizations active in the country, through different projects, planning documents have been developed for several major sub-basins: Preliminary Flood Risk Assessment (PFRA) for Crna Reka, Bregalnica and Crn Drim Rivers, and Flood Risk Management Plans (FRMP) for Strumica and Upper Vardar river sub-basins. However, all these plans are not fully in compliance with the Flood directive. Further activities are needed that prepared plans are additionally improved and put to the required level to meet the Flood Directive’s requirements and harmonization of envisage activities among different plans is needed and their prioritization.

In order to improve the situation significant efforts are needed for further harmonization with the relevant EU legislation in the country and straightening of the capacity of relevant administration in regards to flood management.

Below in Table 8 is an indicative timetable for implementation EU Flood directive, according to the Ministry of environment and physical planning.

Table 8 Indicative timetable for implementation EU Flood directive

Actual or estimated date for:	Day/month/year
Setting up of administrative arrangements– identification of the competent authority (Art. 3)	Completed
Description of Floods which have occurred in the past and which had significant adverse impacts on human health, the environment, cultural heritage and economic activity (Art. 4)	31.12.2017
Assessment of potential adverse consequences of future floods for human health, the environment, cultural heritage and economic activity (Art. 4)	31.12.2017
Preparation of flood hazard maps and flood risk maps (Art. 5)	31.12.2020
Establishing appropriate objectives for the management of flood risks (Art. 7)	31.12.2024
Establishing measures for achieving appropriate objectives for the management of flood risks (Art. 7)	31.12.2024
Establishing appropriate steps for coordinating application of Directive 2007/60/EC and Directive 2000/60/EG (Art. 9)	31.12.2018

Publishing preliminary risk assessment, flood hazard maps and flood risk maps, flood risk management plans making them available to the public (Art. 10)	01.01.2024
Full implementation	TBD