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Climate Resilient Road Assets in Albania

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The World Bank

February 2019

GFDRR Global Facility for Disaster Reduction and Recovery

WORLD BANK GROUP Transport

Table of content

List of Figures

List of Tables

Acknowledgments

This report was prepared by Jing Xiong, Senior Transport Specialist, and Xavier Espinet, Transport Specialist with the support of Artan Guxho, Senior Infrastructure Specialist, and Yuka Makino, Senior Disaster Risk Management Specialist. The report consolidates the findings and recommendations from the Technical Assistance (TA) for Climate Resilient Road Assets in Albania, carried out by Consulting Firms Deltares and SEED, and financed through a grant provided by the Global Facility for Disaster Reduction and Recovery (GFDRR).

The team would like to acknowledge the timely and valuable support, guidance and advice received from Maryam Salim, Country Manager of Albania, Karla Gonzalez Carvajal, Practice Manage of Europe Transport, Juan Gaviria, Practice Manager for LAC and former Practice Manager of Europe Transport, Shomik Raj Mehndiratta, Practice Manager for Asia, and former Lead for Green Transport Global Solution Group (GSG).

Special thanks go to peer reviewers Fiona Collin, Lead Transport Specialist and Co-lead for Green Transport GSG, Kulwinder Rao, Lead Transport Specialist, Alanna Simpson, Senior Disaster Risk Management Specialist, Akiko Toya, Disaster Risk Management Specialist, Nicolas Pondard, Disaster Risk Management Specialist, and Elif Ayhan, Senior Disaster Risk Management Specialist. The team also received logistics support from Elda Hefizi, Program Assistant, and Andoria Indah Purwaningtyas, Program Assistant.

Most importantly, the team would also like to acknowledge the support and contributions from our counterparts in Albania: Ministry of Infrastructure and Energy (MoE), Civil Emergency, Albania Roads Authority, Albania Development Fund, Geosciences, Energy, Water and Environment Institute, and State Authority for Geospatial Information.

Executive summary

This report consolidates the findings and recommendations from studies on Climate Resilient Road Assets in Albania, financed through a grant provided by the Global Facility for Disaster Reduction and Recovery (GFDRR). The objective of the work is to assist the Albanian authorities in the prioritization of current and future climate, and seismic resilient investments in the road sector. The work has used climate and seismic vulnerability assessments, and proposed mitigation measures to improve climate and seismic resilience of the Albanian road network. The report finds that the investment in resilience and mitigation measures on the Albanian national road network is cost effective and is much less than the estimated annualised cost of the damage and loss that would accrue if mitigation measures are not put in place and maintained.

Albania is the most threatened country in Europe from multiple hazards[1] It is ranked number 39 on the list of countries with the highest World Risk Index, where that Index is based on exposure and vulnerability to natural hazards, and the adaptation capacity of the country and its institutions[2]. The risks of river flooding, coastal flooding, landslides, and earthquakes are all rated as high[3]. For example, the impacts of a major flood event in Albania in December 2017 were catastrophic, with 1,575 persons evacuated, 3,500 houses flooded, 65 bridges collapsed, 56 public schools damaged, and 15,000 hectares of land under-water[4].

Roads are of critical importance to a well-functioning society. Transportation plays a crucial role in building climate resilient communities, and conversely, unreliable road connectivity will negatively impact the economic growth of a country. In Albania, natural hazards pose a great risk to roads and the road users.

Within this context, the recommendations made in this report will support decision-makers in the Ministry of Infrastructure and Energy and the Albanian Road Authority, to identify and prioritize investments that would provide a more resilient road transport network in Albania. To achieve this objective, the report assesses vulnerability to landslides, coastal and fluvial flooding, and earthquakes, of 1,494 km of primary road network on fifteen major corridors and recommends economically viable interventions based on a Cost Benefit Analysis (CBA). The vulnerability of a given corridor under a given hazard is reflected by the annual expected damage (AED), which is calculated as the annualized damage based on the probability of the hazard occurring, where annualised damage is the sum of the physical damage and the economic losses that result from a road transport service disruption.

Key conclusions and policy recommendations

Fluvial flooding is the major natural hazard risk to the primary road network in Albania. It accounts for 84 percent of the total AED, compared to 11 percent from landslides, and 5 percent from earthquakes. For example, Corridor 4 Tirana to Durres and Corridor 5 Durres to Vlore, are the most critical routes in Albania. These corridors are vulnerable to flood events, and the annualised damage could be as high as Euro 13 million, due to the large traffic volumes and the economic importance of these corridors.

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[1] *Balkaneu.com (2017)- https://www.balkaneu.com/natural-disasters-world-report-on-risk-albania-is-the-most-threatened-one-in-europe/*
[2] *World Risk Report, Institute for the Environment and Human security of the United Nations University (UNU-EHS), 2017*
[3] *Natural Disasters Hotspot – A Global Risk Analysis, World Bank, 2005*
[4] *Emergency plan for action, Albania floods, www.Ifrc.org*

Bridges and culverts are the most vulnerable and exposed elements of the road network with estimated AED of Euro 18.7 million. The study identified 19 bridges and 16 culverts (Appendix B.1 for details) that have design capacity deficiency. Based on the CBA results, all 16 culverts warrant a replacement to increase the capacity. Due to lack of available data on bridge attributes, this study doesn't include the CBA analysis of replacement bridges but recommends further investigation to take place. ARA has also undertaken a recent survey of bridges and their results should be consolidated with the findings from this study.

The "build back better" approach, based on improved and updated design criteria, hydrologic data and performance standards, should be applied to the new bridges and culverts. Given the exposure characteristics of Albania and the vulnerability of road infrastructure to flooding, bridge and culvert designs should be based on updated design norms and peak flow predictions, to ensure that the new bridges and culverts have the capacity to withstand the increasingly higher intensity and higher frequency storms that Albania is exposed to.

Good asset management and maintenance practices will enhance climate resilience and reduce damage. While the assessment assumes a good state of maintenance of the structures, the study looked at the influence that reduced levels of maintenance would have on the performance of the system and the damage impacts. For example, the study models a reduction of discharge capacity of 50 percent which could reasonably result from a lack of maintenance. The results suggest that inadequate maintenance on bridges and culverts could lead to additional damages of up to Euro 6 million annually.

Compared with flooding, landslides have a smaller overall economic impact reflected by AED. Retro-fitting mitigation measures comes at a relatively high cost with low effectiveness, and landslides are more likely to affect mountainous roads with little redundancy. The sensitivity analysis shows that mitigation measures to reduce landslides risks are only economically viable in high-volume road sections along Corridor 5 Durres to Vlore, and Corridor 6 Tirana to Pogradec. However, for the low-volume mountainous roads with little redundancy, such as Corridor 1 Milot to Morine, even when the CBA result does not warrant interventions, social impact concerns, e.g. a village becomes isolated from the outside world, may suggest mitigation measures are necessary.

Earthquake risk is low, but high intensity events would impact some bridges in the southern part of the country. The impact would be significant only for very low-probability events (1 in 2,475 years) and could lead to more than Euro 70 million in losses. But given the low probability, annualised damage is low and does not warrant replacement or retrofitting of existing assets. However, when assets are replaced in the normal replacement cycle, they should be designed with resilience to seismic events, especially for bridges.

Coastal flooding does not pose a high risk to the national road network as there is a very limited length of national road network in floodable coastal areas. However, coastal flooding may affect secondary and local roads, particularly in the northern part of the country near Shködra. Providing resilience or redundancy measures to allow evacuation and connectivity during flooding events needs to be considered, however this study did not focus on the secondary and local road network. Further investigation on secondary and local roads in Shkodra area is needed.

In summary, the report estimates that the cost of prioritized interventions that would provide positive investment returns and improve resilience to natural hazards, would be about Euro 14.5 million. The analysis shows that the identified investments to address flooding resilience are always economically viable, but investments to provide mitigation measure for landslides only have positive investment returns on the most critical highly trafficked corridors such as Corridor 5 Durres to Vlore and Corridor 6 Tirana to

Pogradec. An investment of about Euro 0.7 million is required to improve resilience to floods by increasing the capacity of culverts (without considering the bridges), while investments to improve resilience to landslides on Corridor 5 and 6 would amount to Euro 13.8 million Euro, and would include stabilizing measures such as retaining walls, gabions and soil-nailing.

Finally, integrating vulnerability and exposure data collected from this study and prioritization of mitigation measure into the Road Asset Management Systems (RAMS) that is under development, is critical to ensure sustainability and resilience of the transport network. The RAMS will use condition, inventory and traffic data to identify multi-year road maintenance and rehabilitation programs. Formulating a way to integrate vulnerability and exposure data into the RAMS, would be an important measure to ensure sustainability and resilience of the transport network in view of climate change and natural hazards. Traditionally, a RAMS does not include natural hazard risk assessment. This report suggests that natural hazard risk assessment should be incorporated into the RAMS to enhance climate resilience. Additional parameters that should be addressed and analysed in the RAMS being developed, include information on damage caused by natural hazards, such as cause of damage, extent of damage, repair costs, and the duration of full or partial interruption. In addition, algorithms would need to be developed to ensure that assessment of the vulnerability and exposure data is included in the RAMS maintenance planning and prioritisation functions.

1 Introduction

Albania ranks as the most threatened country in Europe from multiple hazards[5] and is ranked number 39 on the list of countries with the highest World Risk Index, which is based on exposure to natural hazards, vulnerability, coping, and the adaptation capacities of the country[6]. The country is prone to hydro-meteorological hazards such as floods, drought, heavy snowfalls, extreme temperatures, and geological hazards such as earthquakes and landslides. The risks of river flooding (fluvial flooding), coastal flooding, landslides and earthquakes are all rated as high[7]. At the same time, climate change will lead to more intense and more frequent natural hazards in the future. Over the past years this topic has become increasingly important and several studies have been made to investigate the possibilities for disaster risk management in Albania[8;9], and in the Western Balkan[10].

Climate change is expected to put at risk many of the transport infrastructure investments to date. Sea level rise may put coastal transport infrastructure at risk, while shorter but more intense rainfalls are expected to lead to a higher likelihood of fluvial flooding and landslides.

Roads are of critical importance to the functioning of society. Their unavailability and unreliability will lead to significant negative effects on the economic growth of the country. At the same time, transportation plays a crucial role in building climate resilient communities. The mentioned natural hazards already pose a great risk to the roads and the road users.

Keeping this in mind, it seems prudent to study the effects of hydro-meteorological and geological hazards that can affect the national road network of Albania.

As such the **main objective** of this study is:

To assist the Albanian stakeholders in the prioritization of current and future climate, and seismic resilient investments in road assets.

The objective is achieved through applying a climate and seismic vulnerability assessment of the Albanian national road network, as well as proposing mitigation measures to improve climate and seismic resilience of national roads. As such the project can be divided into two parts:

Part 1: Risk Analysis

Part 1 of the project provides with information regarding the locations of the road network with the highest risk to the different hazards, and includes an overview of:

- The hazards that present the greatest risk
- The locations which are the most vulnerable to a specific hazard
- The probability of a hazard affecting a specific road section.

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[5] *Balkaneu.com (2017)- https://www.balkaneu.com/natural-disasters-world-report-on-risk-albania-is-the-most-threatened-one-in-europe/*

[6] *World Risk Report, Institute for the Environment and Human security of the United Nations University (UNU-EHS), 2017*

[7] *Natural Disasters Hotspot – A Global Risk Analysis, World Bank, 2005*

[8] *Albania: Disaster Risk Management and Adaptation to Climate Change, World Bank, 2013*

[9] *Third national Communication of the Republic of Albania on Climate Change, Ministry of Environment Albania, UNDP, and GEF, 2016*

[10] *Development of master curricula for natural disasters risk management in Western Balkan countries, NatRisk - EU funded project, 2016*

- The impact of the different hazards expressed in repair costs and losses due to disruption of the road (in Euro)

A risk analysis (i.e. the determination of network vulnerability, criticality and risk assessment) is performed for the primary road network. The results of part 1 were presented and discussed with local stakeholder in a workshop in September 2018.

Part 2: Mitigation Measures and CBA analysis

Part 2 of the project focusses on the locations which have the highest risk profile and provides suggestions on how to decrease the risk. It provides

- An overview of potential solutions
- Selects solutions based on a Cost/ Benefit ratio
- Helps determine adaptive strategies

The risk mitigation measures for the primary road network are investigated. Through a CBA analysis, economic viable measures were recommended for investment. The results were presented and discussed with local stakeholders in a workshop in February 2019.

1.1 Scope of the project

The road network under consideration in this study encompasses 1,494 km of roads, consisting of 1,370 km of primary roads and some extensions with secondary roads on request of ARA, and can be seen in Figure 1.1.

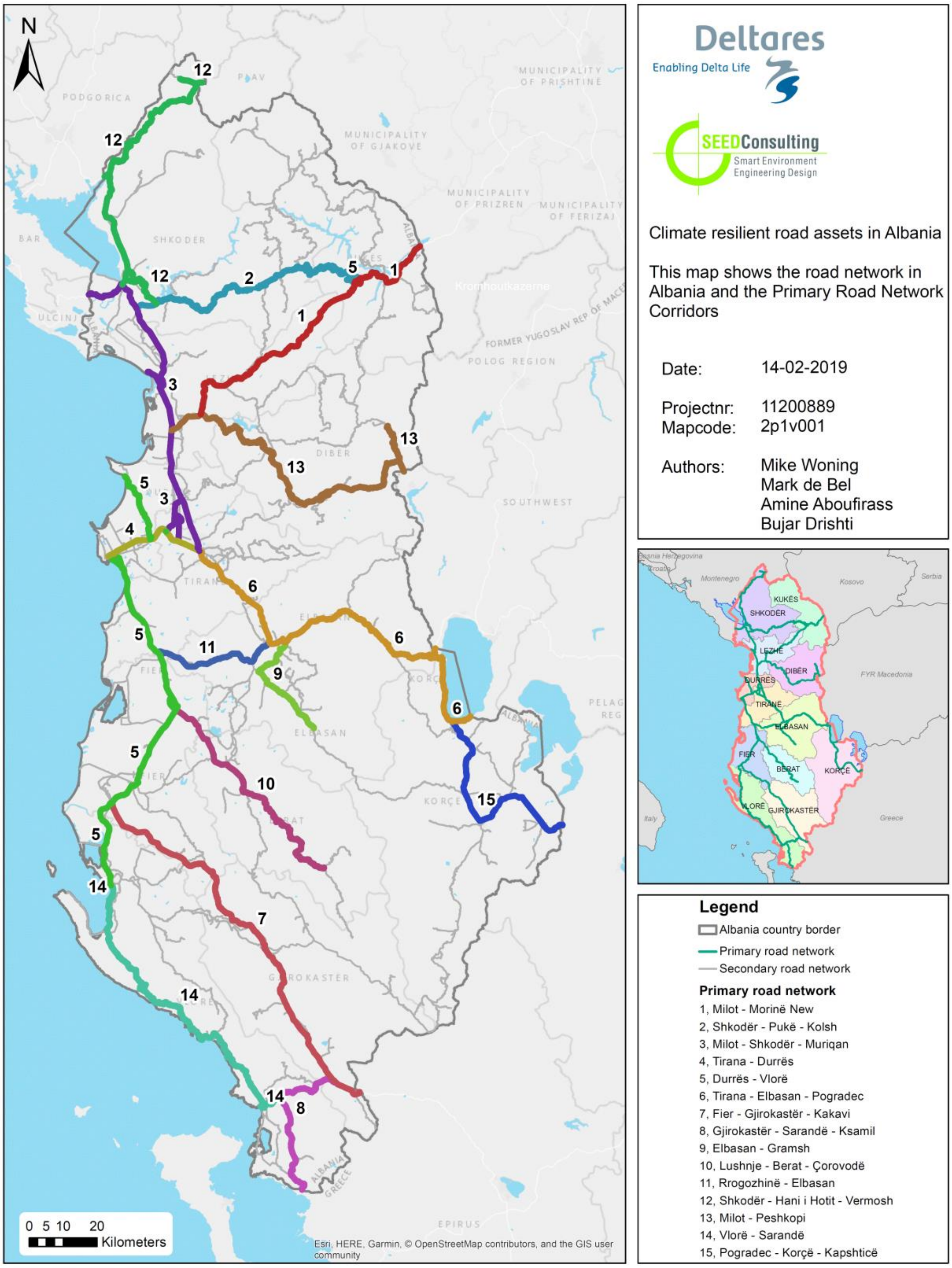

Figure 1.1 Map showing the primary network under consideration of this project. The colours indicate the various corridors within the primary road network

This includes the main transport corridors of the country, which are of economic value and provide access to neighbouring countries. This project focus on the following assets of the road network:

- Roads
- Bridges
- Culverts
- Tunnels

For the roads in the primary national road network, we analyse the following hazards may affect the roads:

- Flooding (pluvial and coastal)
- Landslide (precipitation and seismic induced)
- Seismic events

1.2 Project approach

The objectives of Part 1 and Part 2 are achieved through a combination of 13 actions. The flow chart Figure 1.2 shows the main actions taken, and how they are linked to each other. Note that although the description of the flow chart mentions various products that are sometimes the result of a sub-step, not all these products are separately reported.

Step 0. Collection of data (hazard & other) and development of datasets

This is a general data collection step aiming to provide the necessary analyses with information. We developed an overview of the data necessary per risk analyses and category, including: Geographical data; Meteo-hydrological data; Reservoirs (dams); Hazards database; Hazard maps; Socio-economic data; Vulnerability database; and Criticality.

Step 1. Make hazard maps

This is a step that uses the GIS input data gathered during the previous action to produce hazard maps that indicate susceptible road sections per hazard. This first step is to determine the locations where the various hazards pose a threat to the road network. This allows zoning of where damages may occur. Where possible, hazard maps were produced for different climate change scenarios and different return periods, since these will influence the hazard levels.

Step 2. Determine vulnerability curves

This step determines the relationship between the hazard level and the relative level of damage that could take place in the infrastructure. The output of this step are vulnerability curves for flood depths on road embankments (coastal flooding), under capacity of culverts and bridges (fluvial flooding), for peak ground acceleration on road assets (seismic events) and for susceptibility levels in relation to road assets (landslides).

Step 3. Determine value of the assets

This step determines the value of the asset in euros and as such it is the maximum amount of money that the Road Authority needs to invest to repair a damaged asset. These are called the direct costs of failure. This determination of the direct costs of failure, in combination with Step 1 (Make hazard maps) and Step 2 (Determine vulnerability curves) allows us to determine the actual expected damage to the road assets in euros for each return period and climate change scenario in Step 4.

Step 4. Make vulnerability maps

These vulnerability maps describe the damage to the road assets per hazard. This step provides insight into the expected damage to the road, which is needed to determine the total damage, including loss of production costs, in Step 6. Furthermore, it helps to prioritize where to increase the resilience first by using the annual expected direct cost maps. These maps also provide the Road Authority with an indication of how much money should be set aside yearly to cover repair/ reconstruction costs.

Step 5. Determine maximum possible indirect effects

This step determines the economic effect on road users of a road section being unavailable due to a hazard. The impact of a hazard affecting the road network does not only result in costs for the road owner but also affects production of the road users e.g. industry. These damages are determined by means of a traffic analysis together with an analysis of network redundancy.

Step 6. Determine the total damage, including loss of production costs

This step determines the estimated total damage for a given Climate Change scenario and Return Period. This step is needed for the following Step 7 where the Expected Annual Damage (EAD) per road stretch is determined. In the Step 6 we determine the total damage, i.e. direct damage to the infrastructure as well as the loss of production due to unavailability of the road.

Step 7. Make risk maps based on Annual Expected Damage (AED)

This step provides an overall risk in the form of Annual Expected Damages for the threatened road sections, taking both, direct and indirect consequences into account. This is done by determining the overall risk for every road section. Sections that score higher in this assessment require a higher prioritization for investments to secure availability due to extreme weather.

Step 8. Determine criticality of road sections

The criticality of a road section is a measure of its 'importance' for economic performance and wellbeing for a specific area. It makes use of the results of the traffic analysis and combines these with other socio-economic factors where there is a special emphasis on the commodities flow from major cities/seaports. This is done using a Multi Criteria Analysis (MCA) to form 5 criticality categories ranging from low (1) to high (5) criticality. To do this, we first determine which factors (e.g. agricultural areas, industry, tourism, (inter)national corridors) need to be considered for the determination of the criticality. This was done together with the local stakeholders during the discussion that took place in September 2018.

Step 9. Make Priority map

This step combines the output of Step 8 with the output of Step 7 in a priority map. In this sense it sets the costs that the Road Authority needs to make (or in other word ‘feels’) against the socio-economic costs that the society bears. The purpose of this step is to advise the Road Authority where the steps (investments for building resilience) should be made first.

Step 10. Determine level of acceptable risk

Although there are no explicitly set standards available for the level of acceptable risk for the different hazards which the road network in Albania should be able to deal with, there is an implicit standard. Within this project we assume that any measure that is to be implemented to reduce vulnerability of the road network for a specific hazard should have a sufficiently high benefit/cost ratio. Within the cost-benefit analysis, investments in measures increasing the resilience of the road network should have a benefit/cost (B/C) ratio of at least 0.8 to be implemented. A ratio of 0.8 is chosen as, at this stage, several uncertainties and unaccounted-for benefits can exist, that are not taken into consideration in the economic analysis. Therefore, total discounted benefits should reach at least 80% of investment costs to be considered as having attained adequate economic return on investment.

Step 11. Identify measures & cost of measures

Measures were determined based on local experience and expert judgment. These were then categorised accordingly and checked for completeness. The costs of the measures were determined by local experts, also based on their extensive experience. The costs of the measures were determined for a generic measure typology i.e. local, while site-specific considerations were not taken into account.

Step 12 and 13. Define/Describe intervention strategy; measures and CBA

The investments towards the reduction of the vulnerability of the road network to the different hazards are subjected to an economic analysis. This analysis consists of a comparison of the investment costs of the measures with the discounted benefits over a period of 25 years.

Step 14. Determine resilience building strategy using decision making under deep uncertainty (DMDU) techniques

To ascertain the impact of any system uncertainties on the Albanian road network, we proposed the decision making under deep uncertainty (DMDU) methodology to this study. However, during the risk assessment phase of this project, it became evident that the uncertainties represented in the system were either insufficient or beyond the scope of this project to analyse further. As such the DMDU approach was not applied but other techniques were used to evaluate the sensitivity and relevance of uncertainty in the economic evaluation (steps 12 and 13).

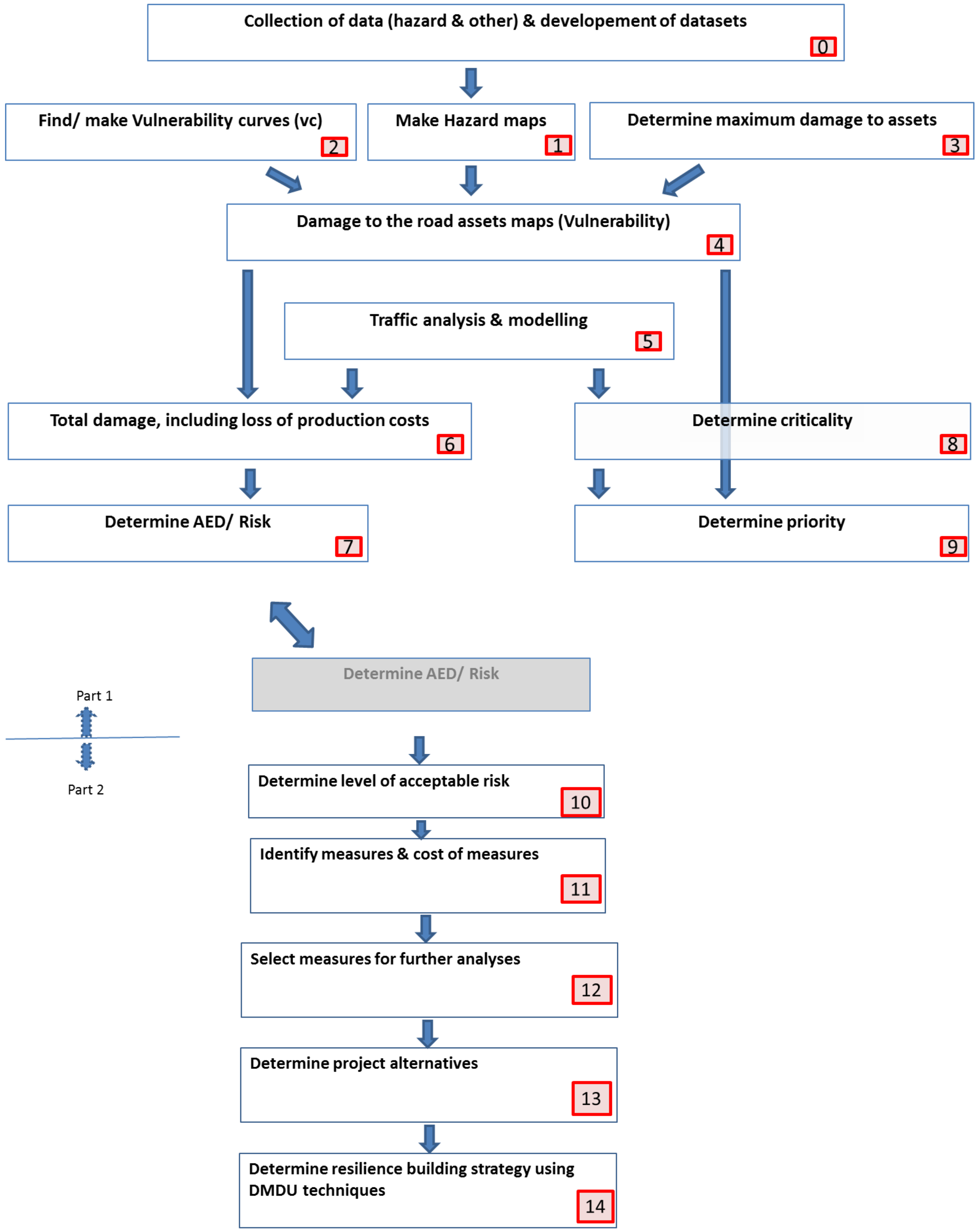

Figure 1.2 Flow chart showing project approach for parts 1 and 2.

1.3 Relevant stakeholders in Albania

Many stakeholders are involved in the project. Both in terms of providing data and knowledge to the project and in terms of discussions and usage of the results of the project. A list of stakeholders is provided in the table below:

Table 1.1 Project stakeholders

Stakeholder	How will they use the project results	Relation between Institutions	The reaction in case of disasters
Ministry of Infrastructure and Energy (MIE)	MIE allocates resources based on requests from ARA	Government	MIE activate the Contractors of Maintenance for the stabilization of the situation and the measures plan for traffic deviation
Albanian Road Authority	Executing institution that constructs and maintains national roads and infrastructure	Agency that falls under MIE	
Institute of Geoscience, Energy, Water and Environment	May use the results in their studies and can distribute the information	National research unit that operates under the Polytechnic University of Tirana	
Albanian Geological Service	May use the results in their studies and can distribute the information	Institution under MIE	Asses the source of disaster and make relative studies
National Agency for Water Management	May use the results in their studies and can distribute the information	Agency that falls directly under the prime minister Office	
Civil Emergencies - Ministry of Defence	The preparation of organization plan for people rescue and intervention in field with tools made available by the Ministry of Défense and support of military forces to minimize the damages	Department within the Ministry of Defence	
State Authority for Geospatial Information (ASIG)	Uses the results in their studies and can distribute the information	Agency that falls directly under the prime minister	
Ministry of Agriculture and Rural Development	The Ministry does not have the tools to act directly in field, but they can prepare studies or implement programmes, aiming to deliver the assistance to help rebuild the live and to increase the resilience of	Government	

	floods affected communities.		
Ministry of Tourism and Environment	The Ministry does not have the tools to act directly in field, but they prepare studies or implement programmes to help rebuild the life and minimize the impact of the disasters.	Government	

1.4 Structure of the report

The report starts off with an introduction (this chapter) which states the report objective and project approach. Subsequently, Chapter 2 provides background of the Disaster and Transport Network profile in Albania. Chapter 3 describes the methodology and presents the results for the multi-hazard risk assessment by corridor. Chapter 4 identifies the mitigation measures for each specific hazard, describes the methodology, and presents the results at corridor level. Finally, chapter 5 provides the conclusions, recommendations and areas for improvement.

2 Albania Disaster Profile and Road Network

In this chapter the historic profile of Albania's natural disasters is presented together with an overview of the road transport sector. Albania is exposed to several natural hazards, such as: earthquakes, flooding (due to extreme rainfall, relative sea level rise, storm surge, and tsunami), and landslides. Possible future changes in the natural hazards intensity will be discussed by reviewing the current situation and providing a brief explanation of expected climate deviations.

2.1 Disaster Profile

Albania lies in South-Eastern Europe. The country has an estimated population of around 3 million people of which around half million live in the two largest cities Tirana and Durrës[11]. Albania ranks as one of the top 10 countries in the world at the highest risk from multiple hazards [12]. 88.5 percent of generated GDP, 86.4 percent of the total area, and 88.6 percent of the population are exposed to two or more types of hazards.

Centro Internazionale in Monitoraggio Ambientale (CIMA) and United Nations Office for Disaster Risk Reduction (UNISDR) have performed research based on past recordings of disaster losses in Albania over the period of 1851-2013.. Recently much more reporting has been done compared to a century ago, but no significant findings relate to trends. However, the report provides interesting insights into the likelihood and consequences of different types of hazardous events [13].

Eight types of disasters are taken into account in the report including (1) Geophysical: earthquake, avalanche and sedimentation; (2) Meteorological: snowstorm, rain, storm, windstorm, hailstorm, thunderstorm, fog, cold wave, heat wave and frost; (3) Hydrological: flood, flash flood and surge; (4) Landslides: dry and wet mass movement; (5) Climatological: forest fire and drought; (6) Biological: epidemic and plague; (7) Technological: leak, structure, contamination, explosions, accident and fire; and (8) Other: events that cannot be included in the previous categories.

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[11] *World Health Organization (WHO) - http://apps.who.int/gho/data/view.main.POP2040ALL?lang=en*
[12] *Natural Disasters Hotspot – A Global Risk Analysis, World Bank, 2005*
[13] *Historical Collection of Disaster Loss Data in Albania, CIMA Research Foundation, 2014, ISBN: 9788890606847*

Table 2.1 Occurrence and relative consequences of different types of hazards[14]

Type of hazard	Relative number of recorded events (out of 4305 events in period 1851-2013)	Relative number of people affected (out of 800,000 people affected / 1652 casualties in period 1851-2013)	Relative economic loss (out of 92,305,500 USD in period 1995-2013)
Geophysical	4 %	14 % / 51 %	2 %
Meteorological	33 %	45 % / 15 %	10 %
Hydrological	21 %	25 % / 18 %	72 %
Landslides	14 %	12 % / 3 %	13 %
Climatological	22 %	0 % / 0 %	0 %
Biological	3 %	0 % / 4 %	0 %
Technological	2 %	4 % / 3 %	3 %
Other	1 %	0 % / 6 %	0 %

It should be noted that one major earthquake (1851) and three major floods (1905, 2002 and 2010, all in Shkodra) have a big effect on the presented numbers. Using the relative numbers provided in the report, the average absolute numbers per event are calculated as well, to get an idea of the consequences of one single event.

Table 2.2 Consequences of different types of hazards[15]

Type of hazard	Average number of affected people per event	Average number of casualties per event	Average economic loss per event
Geophysical	650	5	10,721
Meteorological	253	0	6,497
Hydrological	221	0	73,514
Landslides	159	0	19,910
Climatological	0	0	0
Biological	0	1	0
Technological	372	1	32,162
Other	0	2	0

Based on these numbers, it may be concluded that:

- The most common hazards are meteorological, hydrological, climatological and to some extent also landslides;

[14] *Historical Collection of Disaster Loss Data in Albania, CIMA Research Foundation, 2014, ISBN: 9788890606847*
[15] *Historical Collection of Disaster Loss Data in Albania, CIMA Research Foundation, 2014, ISBN: 9788890606847*

- Hazards with the highest consequences are:

  – Related to number of affected people: geophysical hazards are the most important, but also meteorological, hydrological, landslides and technological hazards need to be considered in this regard

  – Related to casualties: geophysical hazards are the most important, but all hazards apart from climatological may lead to casualties

  – Related to economic losses: looking at both the absolute and relative numbers, hydrological hazards lead to the highest economic losses. Also, geophysical, meteorological, technological hazards and landslides lead to economic losses.

Information from the Emergency Events Database (EM-DAT) regarding the consequences of disasters with data from 1967 to 2018[16] has also been gathered. The database is found to be limited in a number of events. Apparently only the 'bigger' events are considered in the database. Data on damage costs only seems to be available for floods.

Table 2.3 Occurrence and consequences of different types of disasters according to EM-DAT [17]

Disaster	Occurrence	Affected	Casualties
drought and wildfire	2	3,200,000	0
earthquake	6	8,429	47
epidemic	2	292	7
extreme temp	5	237,235	82
flood	15	205,584	23
landslide	1	26	57
storm	2	525,000	8

The following can be concluded from the EM-DAT database:

- Flood events are most common, followed by extreme temperatures and earthquakes.
- Drought can affect all inhabitants of Albania. Extreme temperatures and floods affect most of them.
- Extreme temperatures, earthquakes, landslides and floods lead to the most casualties.

Combining the different data sources and looking at the effects of the disasters on roads, the following is concluded:

- Flooding events are the most common disasters in Albania with effects on the road network. Also, earthquakes and landslides need to be considered in this regard.
- Regarding the consequences of disasters, it is difficult to differentiate between the different types of hazards. Floods have the biggest consequences, but earthquakes and landslides also have high impact on the road network.

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[16] *EM-DAT: The Emergency Events Database – Université catholique de Louvain (UCL) – CRED, – www.emdat.be, Brussels, Belgium*

[17] *EM-DAT: The Emergency Events Database – Université catholique de Louvain (UCL) – CRED, – www.emdat.be, Brussels, Belgium*

2.2 Climate and projections for the future

Albania has several climate zones, which vary from the lowlands, close to the Adriatic and Ionic seas, to the highlands, and more land inwards. The lowlands have a Mediterranean climate with hot, dry summers and cool, wet winters. The highlands in the northern, central and southern parts of the country have a more continental climate with dry summers and snow precipitation from November until March (Figure 2.1). The annual average precipitation in Albania ranges from 600 mm in the southeast to 3,000 mm in the Albanian Alps. Flooding is frequent and typical for the period November – March[18]. The country combines a coastal plain in the West with mountains in the northern, central and southern part of the country, with many ridges exceeding an altitude of 2,000 m.

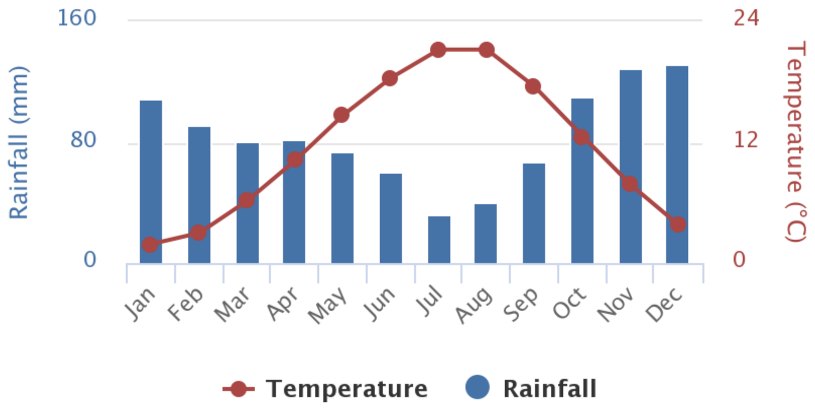

Figure 2.1 Mean historical monthly temperature and rainfall for Albania during the time 1901-2015[19]

The most relevant meteorological hazard is rainfall since this may cause landslides as well as flooding. In the European CORDEX projections[20], the change in precipitation under various climate change projections was analysed. On average, the annual precipitation amounts in Albania are projected to go down, both under the RCP45 and RCP85 scenarios. This is demonstrated in Figure 2.2. However, when going into more detail, the precipitation is mainly going down in the months with lower rainfall amounts, i.e. February to August. In the winter months, an increase in monthly average precipitation could be expected. This is shown in Figure 2.3 for Tirana. In general, this pattern is applicable for most of the country of Albania.

Temperature changes in Albania follow the global patterns, increasing in temperature for all future climate projections. This is shown in Figure 2.4. The change in temperature influences snow accumulation and snow melt processes in Albania, as well as (potential) evaporation.

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[18] Assessment of the capacity for flood monitoring and early warning in enlargement and Eastern/Southern Neighbourhood countries of the European Union, JRC, 2018
[19] Climatic Research Unit (CRU) of University of East Anglia (UEA)
[20] CORDEX-EURO: World Climate Research Programme's Working Group on Regional Climate, and the Working Group on Coupled Modelling, former coordinating body of CORDEX and responsible panel for CMIP5

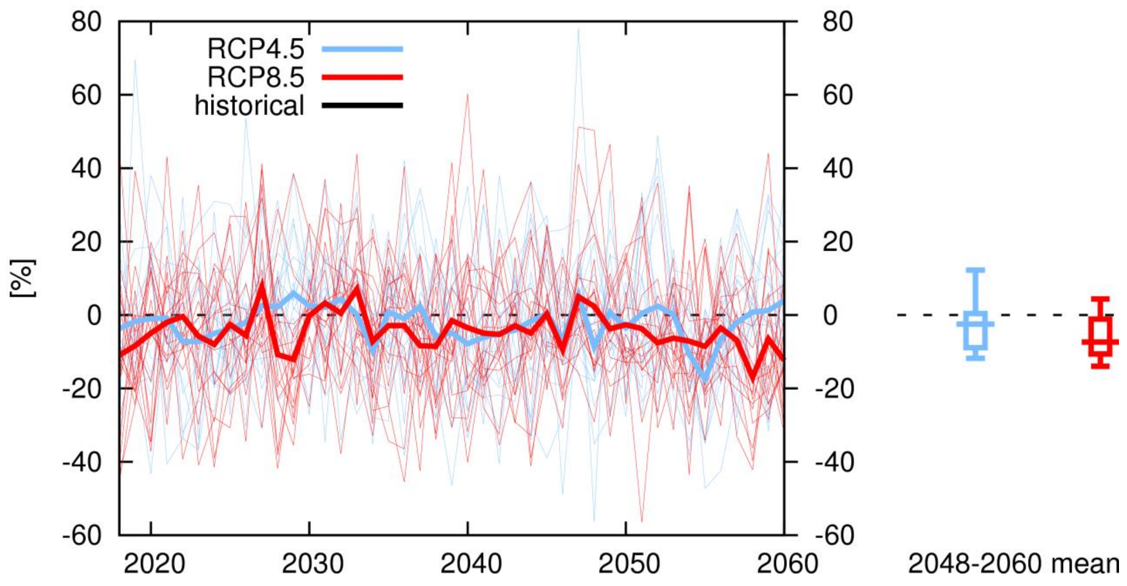

Figure 2.2 Predicted mean change in precipitation for Albania during the time 2018 to 2060.

Note: The change shown is relative to the average mean precipitation between 2005 and 2017 for the two climate change scenarios RCP4.5 and RCP8.5[21] (based on CORDEX-44 climate data).

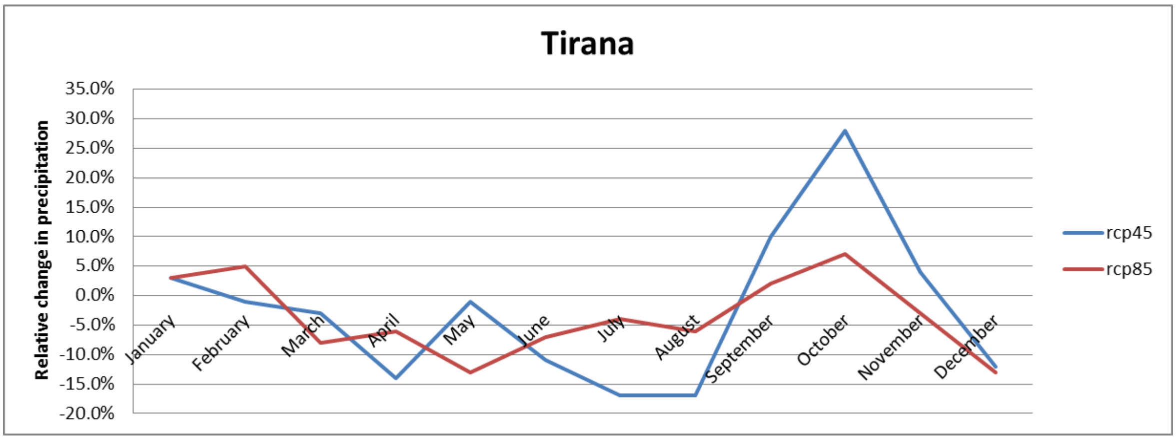

Figure 2.3 Relative change in precipitation based on the CORDEX climate change projections, for a specific location (Tirana) in Albania.

[21] CORDEX-EURO: World Climate Research Programme's Working Group on Regional Climate, and the Working Group on Coupled Modelling, former coordinating body of CORDEX and responsible panel for CMIP5

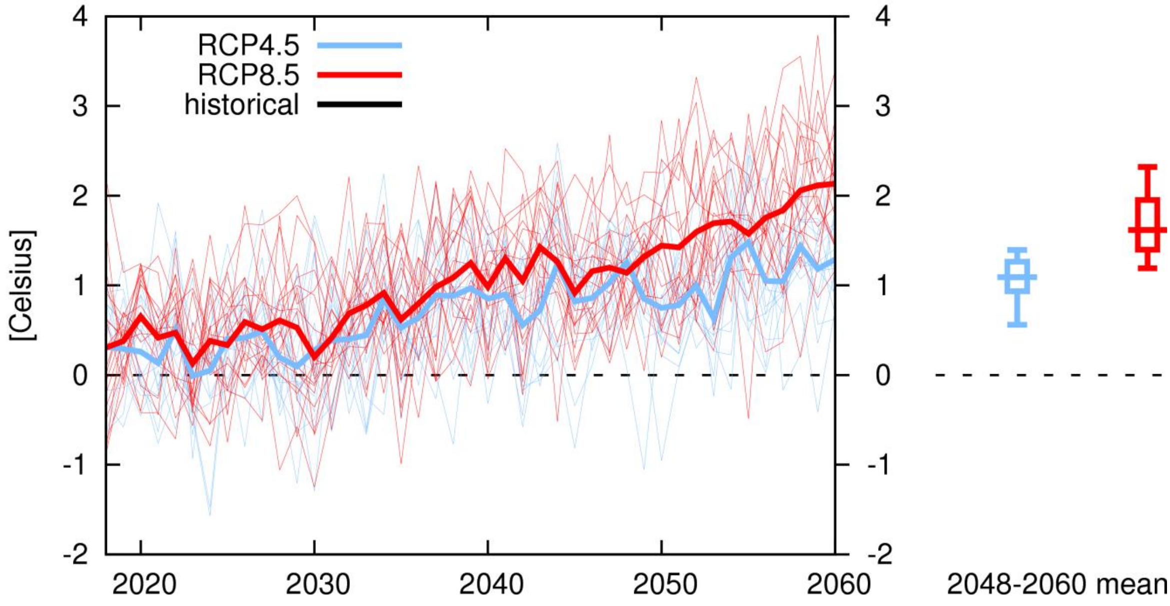

Figure 2.4 Predicted Mean temperature change for Albania during the time 2018 to 2060.

Note: The change shown is relative to the average mean temperature between 2005 and 2017 for the two climate change scenarios RCP4.5 and RCP8.522 (based on CORDEX-44 climate data).

The conclusion is also that 1-day precipitation amounts, which could trigger landslides and flash floods, could increase in the North of Albania at higher altitudes, but at the same time a decrease is expected in the central and southern parts of the country at lower altitudes[23] like the expected changes found in another report[24]. The changes in 1-day precipitation are not determined during this project, but it is recommended that in future works, the results of this recent study are considered to assess the increase in risk from flash floods and rainfall induced landslides. For the climate change impacts assessment performed in this study, the relative changes in monthly temperature and monthly precipitation are considered.

Natural sea level fluctuations occur at the Albanian coast, where the highest sea levels are observed during November and December, when the southern winds push the water mass to the North. During July and August, the levels are lowest. Expected impacts of sea-level rise are a decrease in the wetland area and an increase in the coastal floodplain area[25]. Coastal forest area and lower un-vegetated wetlands area are also likely to decrease.

Conclusion on climate change and future projections

Based on the above, the following conclusions can be made for analyses with regards to climate change and future projections:

- Climate change predictions show that higher temperatures should be expected.
- Due to climate change, the average annual precipitation is expected to decrease in the future. However, there are small differences across the country: a decrease in the North and an increase in the central part and in the South.

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[22] CORDEX-EURO: World Climate Research Programme's Working Group on Regional Climate, and the Working Group on Coupled Modelling, former coordinating body of CORDEX and responsible panel for CMIP5
[23] Reder, A., Iturbide, M., Herrera, S. et al. Climatic Change (2018) 148: 123. https://doi.org/10.1007/s10584-018-2184-4
[24] Albania's Second National Communication to the Conference of Parties under the United Nations Framework Convention on Climate Change, Ministry of Environment, Forestry and Water Administration, 2009
[25] Albania's Second National Communication to the Conference of Parties under the United Nations Framework Convention on Climate Change, Ministry of Environment, Forestry and Water Administration, 2009

- The changes in monthly average precipitation show a strong pattern: reduced precipitation amounts in the dryer months of the year and increasing precipitation in the wetter period of the year. It can be concluded that climate variability over the year will increase under both climate change projections.

2.3 The road network

The overall length of the road network in Albania totals about 18,000 km. The main network is constituted by the national roads network of 3,700 km, administered by the Ministry of Infrastructure and Energy (MIE) through the Albanian Road Authority (ARA). The national road network can be split into the primary network about 1,370km, the secondary network about 2,100km, while the remaining about 230km are newly planned roads. The national road network under the jurisdiction of ARA also includes a total of 590 bridges (with each bridge having an overall length of over 10 m) and over 3,000 culverts. This network carries most of the country's traffic, averaging 6,700 vehicles per day for the Primary and Primary-secondary roads, and 1,705 vehicles per day in the rest of the network.

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The Albanian network is a relatively small network compared to many other countries both in the region and worldwide. However, its density (0.62 km/km²) compares well with Albania's main neighbours. The present condition of the road network ranges from fair to poor with only 60% of national roads in fair to good condition as shown by Table 2.4 below.

Table 2.4 Condition of Albanian road network [26]

Road Network	Good (%)	Fair (%)	Poor (%)
National	20	40	40
Rural	30	25	45
Urban	15	40	45
Other	0	0	100

All roads in the primary network and 70% of the total length of the secondary network are paved. About 48% of the primary network road is located on flat terrain; 56% of the roads in the secondary network are in a mountainous terrain.

The principal corridors of the national road network in Albania which are subject to the study are (Figure 1.1):

- Corridor 1 Milot - Morinë New
- Corridor 2 Shkodër - Pukë - Kolsh
- Corridor 3 Milot - Shkodër - Muriqan (Montenegro Border)
- Corridor 4 Tirana - Durres
- Corridor 5 Durrës - Vlore
- Corridor 6 Tirana - Elbasan- Pogradec (Tushemisht- North Macedonian Border)
- Corridor 7 Fier (Levan) - Gjirokaster-Kakavi (Greek Border)
- Corridor 8 Gjirokaster (Jorgucat) - Sarande - Ksamil (Greek Border)
- Corridor 9 Elbasan - Gramsh

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[26] *Planning and preparation of the results-based road maintenance and safety project (RRMSP) – Inception report,2014*

- Corridor 10 Lushnje - Berat - Çorovode
- Corridor 11 Rogozhine - Elbasan
- Corridor 12 Shkodër - Hani i Hotit - Vermosh
- Corridor 13 Milot - Peshkopi
- Corridor 14 Vlore - Sarande
- Corridor 15 Pogradec — Korce - Kapshtice (Greek Border)

3 Risk Assessment

3.1 Introduction

This risk assessment focussed on the effects of natural hazards, i.e. flooding, landslides and seismic events, on the primary national road network in Albania. For this analysis the primary road network was divided into 15 corridors (see Table 3.1). The number of vehicles for the studied corridors is based on the data collected during the Road Side Surveys carried out in April 2018. The road sections that are used for the modelling in this study closely follow the system used by the “Review of Albanian National Transport Master Plan Study” (ANTP-2) (see also appendix A for more details).

Table 3.1 Primary corridors in Albania with length and average daily traffic density [27]

Corridor	Length (km)	# Vehicles
01 Milot - Morine New	104	2,271
02 Shkoder - Puke - Kolsh	126	170
03 Milot - Shkoder - Muriqan (Montenegro Border)	127	14,566
04 Tirana - Durres	32	40,602
05 Durres - Vlore	152	15,338
06 Tirana - Elbasan - Pogradec (Tushemisht- North Macedonian Border)	139	7,891
07 Fier (Levan) - Gjirokaster-Kakavi (Greek Border)	128	4,910
08 Gjirokaster (Jorgucat) - Sarande - Ksamil (Greek Border)	58	71
09 Elbasan - Gramsh	41	189
10 Lushnje - Berat - Çorovode	86	5,151
11 Rrogozhine - Elbasan	40	5,513
12 Shkoder - Hani i Hotit - Vermosh	125	4,695
13 Milot - Peshkopi	136	5,329
14 Vlore - Sarande	131	1,987
15 Pogradec - Korce - Kapshtice (Greek Border)	69	4,172

The hazard and risk assessments are comprised of several actions:

- Determine if/how much weather-related events may alter due to climate change
- Determine, per hazard, which corridors could potentially be affected (spatial extent) and what the vulnerability of the assets to the specific hazard is (e.g. Peak Ground Acceleration);
- Determine, per hazard, the amount of damage [€] to the road assets and the duration of the unavailability (days) of the road as a function of the intensity of the hazard
- Determine, per hazard, the losses resulting from service interruption by using a traffic analysis;
- Prioritize locations where actions (i.e. building resilience) could be taken by using a combination of total economic damages and criticality.

[27] *The number of vehicles for the studied corridors is based on the data collected during the Road Side Surveys carried out in April 2018. The road sections that are used for the modelling in this study follow closely the system used by the “Review of Albanian National Transport Master Plan Study” (ANTP-2) (see also appendix A for more details).*

Note that the hazard and risk assessments were undertaken under the assumption that all assets are well maintained and are fully operational. Sensitivity analysis on maintenance was introduced later in the chapter. Details on methodology and analysis for the risk assessment can be found in the Appendix A.

3.2 Weather and climate change

In case of flooding and landslides, weather and climate change may impact the probability of occurrence and extent of those hazards. The following can be concluded concerning weather, climate change and the relevant hazards:

- Climate change predictions show that higher temperatures should be expected. Increased temperature will most likely affect the snow accumulation and melt and hence might have an impact on flood hazard resulting from (rapid) snow melt.
- Due to the climate change, the predicted changes in monthly average precipitation show a strong pattern of reduced precipitation amounts in the dryer months of the year and of increasing precipitation (up to 30%) in the wetter period of the year. It can be concluded that climate variability over the year will increase under both climate change projections (RCP 4.5 and RCP 8.5) that were considered within this study.
- The average annual precipitation is expected to decrease in the future. However, across the country there are small differences: a decrease in the North and an increase in the centre and the South.
- As such, higher discharges at the locations of culverts and bridges are to be expected in the future.

3.3 Flooding hazard

For the flooding hazard, two types of flooding were analysed:

- Coastal flooding
- Fluvial flooding

Coastal flooding

The coastal flooding analysis imposes Storm Surge Levels (SSL) of up to 2m (Return Period (RP) 1: 1000 years) onto the model. A worst-case situation (SSL +3m; RP >> 1:1000) was analysed and shows that only very limited areas are vulnerable to coastal flooding. This does not pose a major risk to the primary road network. However, note that areas in the North of Albania (city of Shkoder area) could be vulnerable to flooding from the rivers in times of high SSL. Moreover, the Durres harbour also seems prone to coastal flooding.

Fluvial flooding

In the fluvial flooding analysis, peak flows are determined to be expected during a rainfall event with a different extent and return period (RP) at the location of a bridge or culvert. The peak flow depends on the rainfall intensity and duration, the size of the catchment area and its characteristics, and the conditions (already wet or dry) of the catchment at the start of the event. The peak flow was modelled using the Delft-*Wflow* hydrological modelling framework[28]. The capacity of the bridges and culverts was determined based on the cross-section (or diameter) and a standard formula for calculating the flow capacity based on area, length, roughness and slope.

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[28] *https://oss.deltares.nl/web/wflow/home*

In this analysis, damages are expected at locations where the peak flow is larger than the capacity of the bridge or culvert (see Figure 3.1 for example). With increasing RP's and increasing rainfall amounts resulting in increased discharges, the number of bridges/ culverts that fail (and how the damages themselves change) will also increase. However, there is no specific information available to determine how strong the increase of said damages would be. Therefore, we have used a vulnerability function based on expert engineering judgement. However, based on the vulnerability function and the model used in the risk analysis, the increase in failing culverts and bridges due to climate change is limited.

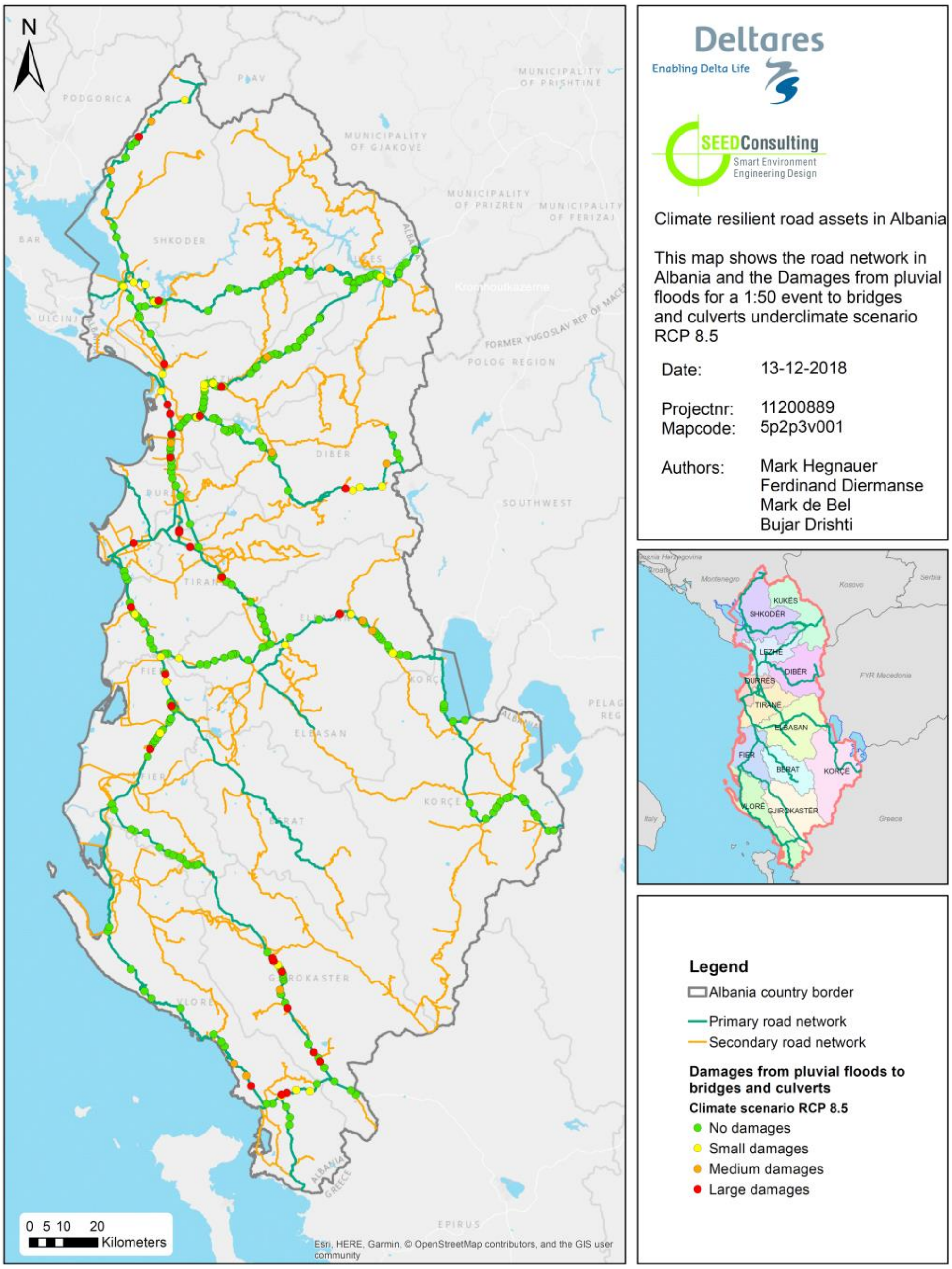

Figure 3.1 Amount of damage due to insufficient capacity of all bridges and the largest 100 culverts with a 1: 50-year probability for the RCP 8.5 climate scenario.

Through a statistical analysis, the probability of a disruption of services was determined per size of damage (small, medium, large) and per corridor. This resulted in the damages for the different types of events as shown in Table 3.2. As can be seen from this table there is quite a significant difference in damages from floods per corridor. Especially corridors 3, 4, 5, 6 and 7 have substantial damages from high combined exposure and relatively high costs of service interruption.

Table 3.2 AED from floods per corridor (in 1,000 €)

Floods Annual Expected Damages	Repairs (1,000 €)	Interuption (1,000 €)	Total (1,000 €)
01 Milot - Morine New	4	12	**17**
02 Shkoder - Puke - Kolsh	9	5	**13**
03 Milot - Shkoder - Muriqan	288	1,253	**1,540**
04 Tirana - Durres	80	1,713	**1,793**
05 Durres - Vlore	115	9,866	**9,981**
06 Tirana - Elbasan - Pogradec	98	2,907	**3,005**
07 Fier - Gjirokaster - Kakavi	225	1,027	**1,252**
08 Gjirokaster - Sarande - Ksamil	39	2	**41**
09 Elbasan - Gramsh	1	0	**1**
10 Lushnje - Berat - Çorovode	40	214	**254**
11 Rrogozhine - Elbasan	1	6	**6**
12 Shkoder - Hani i Hotit - Vermosh	50	140	**190**
13 Milot - Peshkopi	53	465	**517**
14 Vlore - Sarande	28	108	**136**
15 Pogradec - Korce - Kapshtice	-	-	**-**

Note: corridor 15 does not "fit" in the traffic model as there are no alternative routes in the underlying road network

3.4 Seismic hazard

A Probabilistic Seismic Hazard Analysis (PSHA) was undertaken to determine the extent and intensity of the seismic hazard to the road. This was carried out as a desktop study, considering ten seismic source zones and making use of an up-to-date earthquake catalogue. Peak Ground Acceleration (PGA) of up to 0.55 – 0.61g can be expected for a 2,475-year event in de Shkoder area.

The resulting Peak Ground Accelerations (PGA's) were then linked to an amount of damage, using vulnerability functions. The assessment showed that there is very little impact to be expected for culverts, tunnels, and roads from seismic hazards in Albania. The analysis showed that bridges have some vulnerability to seismic events. In the assessment for bridges, vulnerability functions for Greek bridges were used and slightly adapted for the Albanian situation. Bridges may experience significant damage due to seismic hazards, albeit only at relatively high return periods. The seismic hazard is independent of weather and climate change caused hazards.

In general, it can be concluded that although the damages from seismic events for some corridors can be quite significant, because of the low probability, the AED from seismic events is very low in comparison with floods.

Table 3.3 Total AED for seismic events

Earthquakes Annual Expected Damages	Repair Costs (1,000 €)	Inter. (1,000 €)	Total (1,000 €)
01 Milot - Morine New	2	4	**6**
02 Shkoder - Puke - Kolsh	13	1	**14**
03 Milot - Shkoder - Muriqan	127	50	**178**
04 Tirana - Durres	56	135	**191**
05 Durres - Vlore	153	197	**351**
06 Tirana - Elbasan - Pogradec	50	78	**127**
07 Fier - Gjirokaster - Kakavi	33	28	**62**
08 Gjirokaster - Sarande - Ksamil	5	0	**6**
09 Elbasan - Gramsh	26	1	**27**
10 Lushnje - Berat - Çorovode	23	19	**42**
11 Rrogozhine - Elbasan	30	20	**50**
12 Shkoder - Hani i Hotit - Vermosh	20	11	**31**
13 Milot - Peshkopi	7	20	**27**
14 Vlore - Sarande	12	11	**24**
15 Pogradec - Korce - Kapshtice	47	39	**86**

3.5 Landslide hazard

For the landslide hazard analysis, a European landslide susceptibility map was used (ELSUS). Likelihood and magnitude of landslide events for the various susceptibility levels were deduced using a landslide catalogue of past events. Based on this analysis, an amount of damage per kilometre of road was determined (see Figure 3.2).

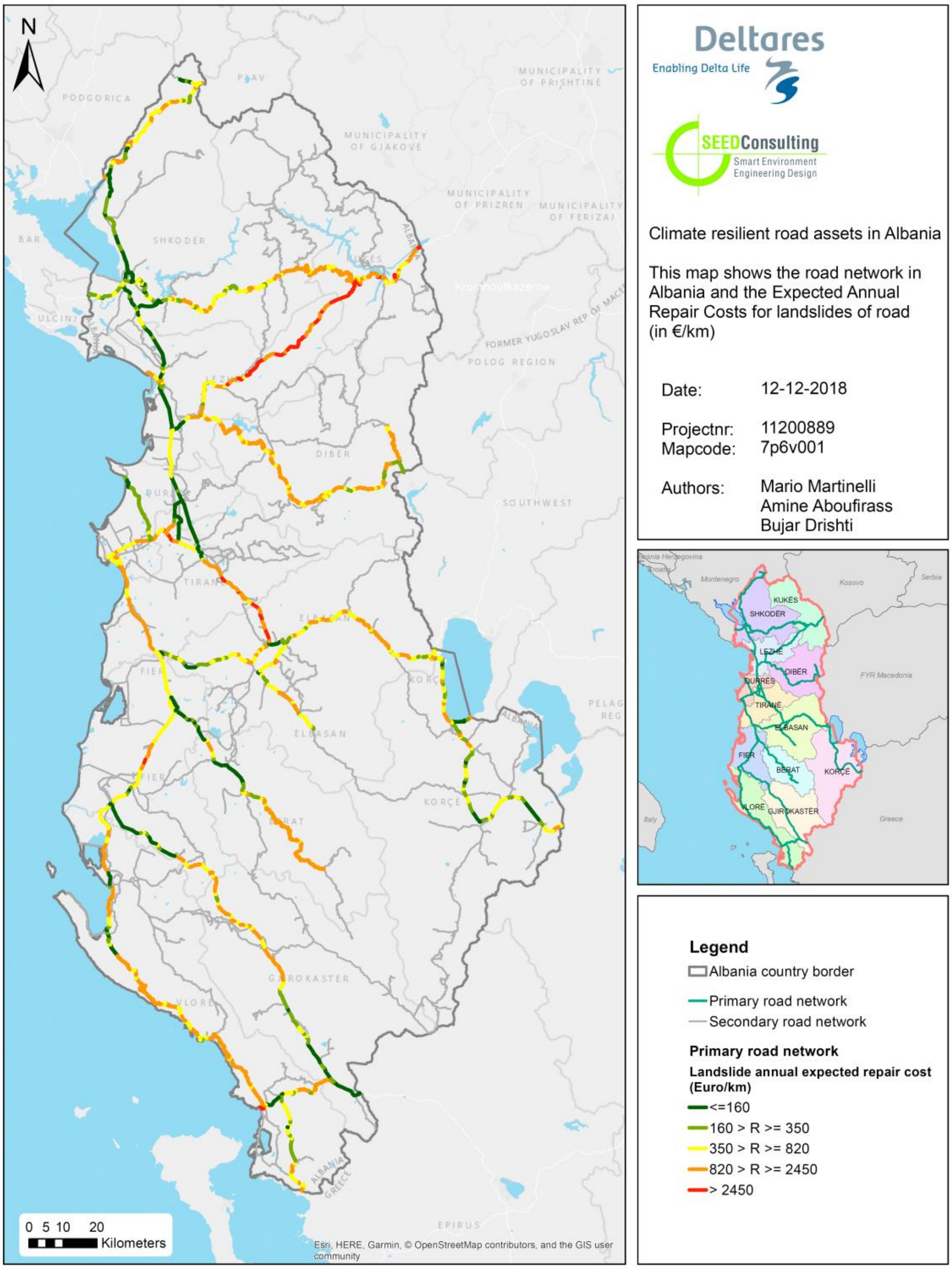

Figure 3.2 Landslide Annual Expected Damages risk map (i.e. annual repair costs per corridor). The risk is expressed as annual expected damage (in euro) per km of road.

The disruption of services for the different corridors is dependent on the number of events and magnitude of the events of each corridor. A statistical analysis was made in which the total number of events was used to determine the probability and duration of disruption per corridor. In the analysis the probability of the different scales of events (small, 1-hour delay; medium, 1-day interruption; large, 1-week interruption + 23 days with 1-hour delay) were categorized and their combined probability determined through the square root of their combined individual probabilities.

Table 3.4 AED from expected repair costs and damages from interruption of services due to landslide

Landslides Annual Expected Damages	Repairs (1,000 €)	Interuption (1,000 €)	Total (1,000 €)
01 Milot - Morine New	287	38	**324**
02 Shkoder - Puke - Kolsh	110	3	**113**
03 Milot - Shkoder - Muriqan	38	52	**90**
04 Tirana - Durres	45	72	**116**
05 Durres - Vlore	150	363	**513**
06 Tirana - Elbasan - Pogradec	200	256	**457**
07 Fier - Gjirokaster - Kakavi	61	45	**106**
08 Gjirokaster - Sarande - Ksamil	39	0	**40**
09 Elbasan - Gramsh	25	2	**26**
10 Lushnje - Berat - Çorovode	64	30	**93**
11 Rrogozhine - Elbasan	17	12	**29**
12 Shkoder - Hani i Hotit - Vermosh	76	21	**97**
13 Milot - Peshkopi	124	74	**198**
14 Vlore - Sarande	146	32	**178**
15 Pogradec - Korce - Kapshtice	22	45	**67**

3.6 Summary of multi-hazard risk assessment

The analysis of the different hazards has shown that there is a large variation in the extent of impact of different hazards on the Albanian road network. Total Annual Expected Damage (AED) from the hazards for the different corridors depends on the repair costs, and / or from economic losses from an interruption of services. The losses from an interruption of services are the result of consequential delays or additional travel time from needed alternative diversions. As could be expected the biggest total AED occur on corridors that have high traffic density and / or have lengthy diversion routes i.e. for these corridors the repair costs play a less significant role. Examples of this are corridor 4 which shows limited repair costs but high losses from service disruption, and corridor 5 that has high repair costs and has very high losses due to disruption of service. Consequently, both corridors have high annual expected damage (AED). On the other hand, corridor 1, which has high repair costs, has very little losses from disruption of services, resulting in low total AED. The repair costs and losses from interruption of services per corridor for all analysed hazards are summarized as AED in Table 3.5 and Figure 3.3

Table 3.5 Repair costs and damages from interruption of services per corridor for all three hazards together

Annual Expected Damages	Length (km)	Repairs (1,000 €)	Interuption (1,000 €)	Total (1,000 €)	€/km (1,000 €)
01 Milot - Morine New	104	293	54	**347**	**3.3**
02 Shkoder - Puke - Kolsh	126	131	9	**140**	**1.1**
03 Milot - Shkoder - Muriqan	127	453	1,355	**1,808**	**14.2**
04 Tirana - Durres	32	181	1,920	**2,101**	**65.1**
05 Durres - Vlore	152	418	10,427	**10,845**	**71.3**
06 Tirana - Elbasan - Pogradec	139	347	3,241	**3,589**	**25.8**
07 Fier - Gjirokaster - Kakavi	128	319	1,100	**1,419**	**11.1**
08 Gjirokaster - Sarande - Ksamil	58	84	2	**86**	**1.5**
09 Elbasan - Gramsh	41	52	3	**54**	**1.3**
10 Lushnje - Berat - Çorovode	86	127	263	**390**	**4.6**
11 Rrogozhine - Elbasan	40	48	38	**85**	**2.1**
12 Shkoder - Hani i Hotit - Vermosh	125	147	173	**319**	**2.6**
13 Milot - Peshkopi	136	184	559	**743**	**5.5**
14 Vlore - Sarande	131	187	151	**338**	**2.6**
15 Pogradec - Korce - Kapshtice	69	70	84	**153**	**2.2**

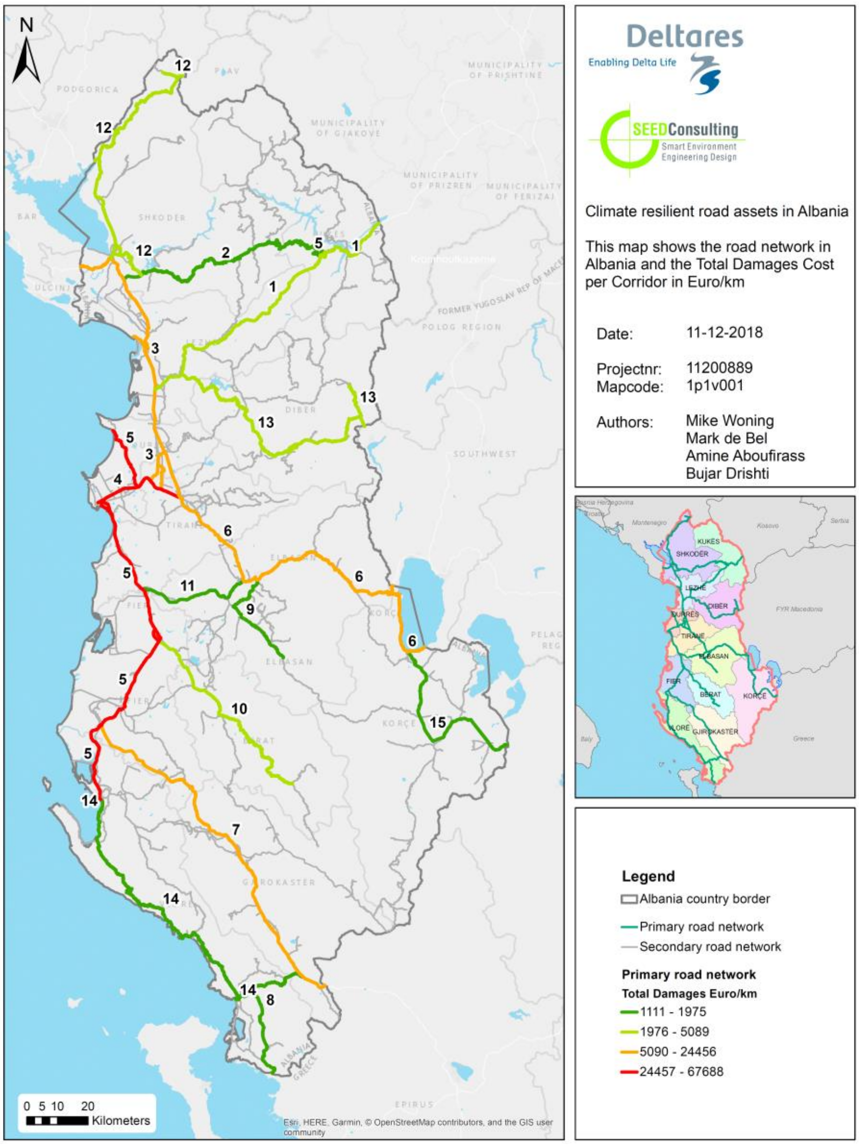

Figure 3.3 Total annual damages expressed as Annual Expected Damages (AED) in €/km per corridor

Further detailing of prioritisation of interventions for building resilience for the road network can be made based on the AED/km and the extent of the hazard within the corridor i.e. priority should be given to high AED/km in combination with (preferably) small stretches of road where measures need to be implemented. Based on the risk and criticality analyses:

- Floods priority should go to the corridors 3, 4, 5, 6 and 7 because of the high total AED, and especially corridors 4 and 6 because of the low number of assets that need upgrading.
- The total AED for landslides is expected to be too low to warrant an active approach towards mitigation measures. Only for corridor 5 and 6 hotspots could benefit from increasing resilience for landslides due to their short length. Although landslides are a serious problem for corridors 1, 2, 7, 10 and 13, total AED is expected to be insufficient to make mitigation measures an economically feasible activity.

- For seismic events there are insufficient damages to warrant replacement or retrofitting of existing assets. When assets are replaced in the normal replacement cycle it is good to consider building the road assets with adequate resilience to seismic events, especially for bridges.

For coastal floods there is no indication that the corridors will be impacted by the hazard. The analysis of the coastal flood hazard would improve when the more accurate height of the road embankment, if become available, would be used in the flood hazard maps to further detail the actual impact of the hazard on the road.

3.7 Criticality

Parallel to the assessment of risks from the different hazards, a criticality analysis was made for the primary road network, to assess the perceived importance of the different corridors. The analysis was conducted through the input of Albanian stakeholders, who provided input through a multi criteria assessment (MCA) in which the importance of the different corridors in respect of several criteria was scored. This resulted in a relative measure of importance for the different corridors. The criteria that stakeholders used to determine the criticality of the corridors are:

- Internationality of a corridor
- An industrial zone connection
- A hub connection
- Tourism area proximity
- Agricultural area proximity or connection
- (An evacuation corridor)[29]

Both the results from the risk assessment and the criticality analysis can be used in the prioritisation of interventions for the different corridors. For a more comprehensive description of the criticality analysis, please see Appendix A. The results of the risk assessment and the criticality are presented in Table 3.6. The colour coding presents the suggested prioritisation, where red has the highest priority and green the lowest. This table illustrates that corridors 4 and 5 have the highest risk and have the highest criticality. Priority in interventions for risks reduction activities should thus be given to these corridors. Corridors 2 and 9 show both low total damages per km of road as well as low criticality.

Table 3.6 Overview of total damages and criticality

[29] *During the analysis of the criticality assessment results, it turned out that too few people had scored this criterion. Therefore, this was not considered during the determination of the final criticality results.*

Corridor	Length (km)	Total (1,000 €)	€/km (1,000 €)	Criticality
01 Milot - Morine New	104	347	3.3	41.6
02 Shkoder - Puke - Kolsh	126	140	1.1	24.2
03 Milot - Shkoder - Muriqan	127	1,808	14.2	36.7
04 Tirana - Durres	32	2,101	65.1	53.4
05 Durres - Vlore	152	10,845	71.3	51.7
06 Tirana - Elbasan - Pogradec	139	3,589	25.8	42.2
07 Fier - Gjirokaster - Kakavi	128	1,419	11.1	36.5
08 Gjirokaster - Sarande - Ksamil	58	86	1.5	38.5
09 Elbasan - Gramsh	41	54	1.3	26.1
10 Lushnje - Berat - Çorovode	86	390	4.6	23.6
11 Rrogozhine - Elbasan	40	85	2.1	36.7
12 Shkoder - Hani i Hotit - Vermosh	125	319	2.6	40.0
13 Milot - Peshkopi	136	743	5.5	30.1
14 Vlore - Sarande	131	338	2.6	39.2
15 Pogradec - Korce - Kapshtice	69	153	2.2	44.8

4 Mitigation Measures and Cost Benefit Analysis

Part 1 shows that the analysed hazards in some cases lead to a significant impact and risks, i.e. repair costs as well as losses from service interruption. Planning for and reducing the impact of a disaster is called disaster risk management. It often consists of a 'before the event' part, 'during the event' part and an 'after the event' part. This is summarized in the Disaster cycle.

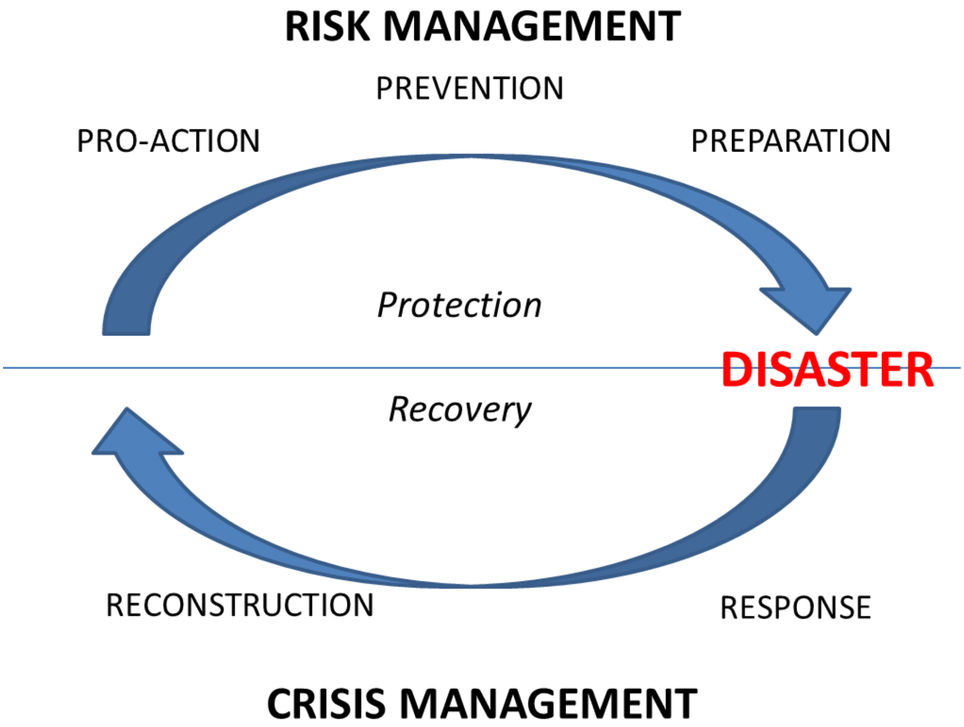

Figure 4.1 Steps in the disaster risk management cycle

Measures may fall into the following steps of the disaster cycle:

- PRO-ACTION: activities in this stage aim to assess the possibility of an extreme event, e.g. flood risk assessment. The objective of this stage is to gain insight into the extent and probability of hazards and their potential impact on the road network in term of damages and interruption of services.
- PREVENTION: activities in this stage aim to reduce vulnerability, e.g. raising a road above the high-water level. The objective of this stage is to enable smooth and safe traffic.
- PREPARATION – In preparation of an extreme event: activities in this stage aim to minimise consequences, e.g. early warning system for floods. The objective of this stage is to support disaster preparedness.
- RESPONSE – During an extreme event: activities in this stage aim to minimize the loss of functions. This is often done by shutting down systems preventatively e.g. closing off roads at key junctions.
- RECONSTRUCTION – after an extreme event: activities in this stage aim to restore transport functionality, e.g. repairs through improved standards (build back better).

The objective of this stage is to provide improved and reliable access for recovery of an affected area.

Which measures make the most sense to take depends on how effective and expensive they are. For example: to prevent a road from flooding one could replace the existing road with a road on a high embankment. Although this measure is very effective assuming the embankment is high enough, it is also very costly. The relationship between cost and effectiveness will be determined in a Cost-Benefit Analysis (CBA).

Investments towards the reduction of the vulnerability of the road network to the different hazards are subjected to an economic analysis. This analysis consists of a comparison of the investment costs of the measures with the discounted benefits over a period of 25 years. During this period, an increase in vehicle number is assumed to depend on the predicted economic growth. For the economic analysis it is assumed that growth in vehicle numbers remains stable in the period between 15 – 25 years to the growth numbers in year 15, as official information for the period is not available.

For the determination of the costs in the cost-benefit calculations, several starting points and basic assumptions were made:

- All costs are assumed to take place in the first year
- Benefits are considered over a period of 25 years only, which is assumed as the technical lifespan of the implemented measures
- As only 15 years of traffic predictions are available, growth in vehicle numbers is assumed to be constant for the next 10 years
- A net discount rate (discount rate – economic growth) of 4 % is used
- Considering the large uncertainties in both the costs estimates as well as the benefit calculations, the investments for measures are only evaluated using Benefit Cost Ratio (B/C ratio); A Net Present Value or Internal Rate of Return calculation would be less suitable for such a threshold analysis.

4.1 Measures for flood hazard

An inventory was made together with the local experts to determine which commonly used measures could be taken within the Albanian road network for each hazard. This inventory is not complete. The measures were selected on their applicability within the Albanian context and to show the principles of selecting measures based on an economic evaluation and local acceptance.

The identified flooding measures are presented in the table below:

Table 4.1 Identified measures considered under this project for flooding hazard

	Coastal flooding	Fluvial flooding
Prevention	Coastal flooding does not lead to significant repairs and losses, related to the main road network. Therefore, no measures have been suggested	- increase capacity culverts/ bridges - reduce peak flow (retention ponds/reforestation) - (improved) regular/preventative maintenance
Preparation		- erosion protection

Reconstruction	- Better repair plan (i.e. shorter to reaction times) - build back better based on improved/ updated design criteria and performance standards

Coastal flooding

The risk analysis shows that coastal flooding does not lead to significant impact for any of the analysed corridors. A more in-depth analysis was not conducted for this hazard, e.g. actual embankment heights of the road, and therefore no measures will be suggested for reducing the impact on the corridors from coastal flooding.

However, a simultaneous occurrence of an increase in the coastal storm surge and high discharges in coastal rivers may lead to significantly elevated river levels and subsequently to flooding due to the overtopping of river levees. These secondary consequences of high Storm Surge Levels (SSL's) were not considered within this study.

Although information on coastal/ fluvial inundations is available, e.g. for the Shkoder area[30], this information was mostly used to estimate the impacts of flooding on critical infrastructure and does not provide specific data on road infrastructure. Furthermore, this type of information is not available for the whole country. The flooding extent we used in our study is based on a discharge model, where we could change the expected precipitation and temperature for future scenarios. The reason for such an approach was that this way we could run a hydrological model and could include the different climate change scenarios. For this reason, we did not include fluvial inundations in our analysis, but instead used the modelled discharges in the risk assessment

Although high SSL's do not affect the analysed corridors, the coastal areas, e.g. low-lying areas in and around Durres, may depend on these roads during coastal flooding events to evacuate the area and/ or help the area after a flooding event. As such, it makes sense to check the height (and design) of the embankments of the roads within the lower coastal areas.

Fluvial flooding

For the fluvial flooding events, we look at a single type of failure, i.e. culverts/ bridges that do not have enough design capacity to handle potential peak flows[31]. All measures are therefore geared towards decreasing the risk of failure of the culverts from having too little design capacity to handle peak discharges from intense rainfall.

The design capacity of the culverts/ bridges was determined based on maximum head and effective diameter/ flow area. The peak discharges in the streams and rivers were determined based on an analysis of the digital terrain model (DTM) to estimate characteristics of the catchment area. The peak discharge from extreme rainfall was modelled using the Delft-*Wflow* model. Normally, model results should be calibrated to historical events. Unfortunately, insufficient data was available to allow for these validations. Prior to the implementation of measures, a more detailed and local analysis should be conducted to determine the actual required design capacity for the bridges and

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[30] *'Flood Risk Management Plan Shkoder Region, June 2015 In the frame of the project: Climate Change Adaptation in Western Balkans (CCAWB). Implemented by: Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, on behalf of German Federal Ministry for Economic Cooperation and Development (BMZ); Increasing Resilience through Earth Observation – IncREO (2012) Collaborative project on emergency response management and risk-preparedness, co-funded by the European Union's 7th Framework Programme, European Commission`s Work Programme (2012)*

[31] *Other types of bridge failure such as erosion/ scour of bridge foundations or effects of debris flows, were not included in the analysis due to lack of available data.*

culverts and assess requirements for erosion control at locations that are assessed to be susceptible to damages from peak discharges.

4.1.1 Increase capacity culverts/ bridges

For culverts and bridges that have a design capacity that is too low for the calculated peak discharges, the most obvious solution is to increase the capacity of the culvert. For bridges this would require replacing the bridge itself due to lack of available data on bridge attributes, this section doesn't include the replacement of bridges in the analysis. Despite this limitation, the location and ID of these bridges due for replacement are identified by this study and presented in the Appendix B, for the further investment planning. For culverts this analysis is much simpler, and the measures would require either replacing the existing culvert and/ or adding an additional culvert next to the existing one. The actual work to be implemented under this measure would entail ripping out the overlaying road surface, excavating a trench, installing the culvert with any required erosion protection, backfilling the road embankment and then resurfacing the road, preferably without significant traffic interruption.

Typical application: those (culvert) locations that have been calculated to be critical (note: verify the calculation with historical field data).

Approximate cost: The costs of replacing or adding a culvert depends on the design(Table 4.2 provides the costs per culvert). More details of construction and costs are provided in Appendix B.

Table 4.2 Unit costs for replacement of culverts[32]

Discharge (m3/s)	Unit Cost (€)
Q50	75,000
Q16	42,000
Q2.5	8,000
Q0.75	5,000

Miscellaneous measures (not used in CBA)

This section presents a number of measures that are frequently applied to reduce fluvial flood hazards for roads but that were not included in this analysis due to lack of available data on road profiles and geo-morphological conditions. This pertains especially to data from field observations on the basis of which designs can be made. Moreover, the determination of their effectiveness in reducing the level of damages also requires more information. For this reason, these measures are described briefly, but are not actually suggested to be implemented.

Reduce peak flow (retention ponds/ reforestation)

Reducing the peak flow at the location of a culvert or bridge can also be an effective measure. This can be done by creating 'man made' retention facilities e.g. retention ponds upstream of the asset or by increasing the concentration time (the time needed for water to flow from the most remote point in a catchment to the culvert/ bridge) by increasing the 'roughness coefficient'. This can sometimes be achieved by replanting vegetation (e.g. trees) in the catchment area.

[32] The culvert unit costs were based on local knowledge

Retention facilities require a substantial area which is often not present, especially in hilly/ mountainous areas. This also requires enough local knowledge to determine if such space is available. Similarly, determining the amount, location and effectiveness of reforestation requires detailed local knowledge.

(Improved) regular/ preventative maintenance

There are two types of maintenance strategies[33]:

Breakdown maintenance strategy

The simplest maintenance strategy is that of ‘breakdown maintenance’. This is where assets are deliberately run until they fail. When failure occurs, reactive maintenance is performed to fix the asset and return it to full operation.

Advantages:

- Minimal planning is required
- The process is very simple, so it is easy to understand
- Less staff is required as less work is done on a day-to-day basis

Disadvantages:

- Final effect is highly unpredictable
- It can be extremely costly
- The process poses a safety risk

Preventive maintenance

The purpose of preventative maintenance is to avert assets from breaking down by performing maintenance regularly – instead of conducting maintenance only in case of a failure occuring. Preventative maintenance predominantly features two different types of maintenance: periodic maintenance and predictive maintenance.

Advantages:

- Keeps assets up and running for longer than other types of maintenance
- Long-term repair costs are usually significantly lower
- Safety is improved due to reduced likelihood of catastrophic failure

Disadvantages:

- More complex than other types of maintenance
- Requires more investment early on

Preventative maintenance is the first to be subjected to budget cuts which also seems to be the case in Albania. However, preventative maintenance is a cost-effective way to reduce long term repair costs. For flooding, such activity may include:

- Inspection of culverts and removal of any (partial) blockages
- Removal of loose debris/ vegetation in the (immediate) upstream area of a culvert

Erosion protection

[33] *Woning, M, Casares, A., Rivas, E., Van Marle, M., Elkadi, A., Abraham, G., 2017, Building Resiliency to Climate Events in the Road network of Paraguay*

As mentioned above, we have not analysed the susceptibility of the bridges/ culverts for erosion/ scour as this requires detailed, local input; both for the erosion protection and its effectiveness.

However, note that erosion protection may decrease the likelihood of the asset being damaged (despite erosion protection the road might still become unavailable due to flooding, however the subsequent damage might be (significantly) reduced).

Build back better

Especially for bridges, this seems like an obvious measure. To reduce downtime of the road, a bridge design based on updated building regulations/ norms and peak flow predictions could already be made beforehand to decrease the time in between damage and a new bridge. However, how effective such a measure might be, as well as what it might cost is unclear and falls outside the scope of this project.

Better response/ repair plan (shorter response times)

Being able to get back to business as usual quicker after a disaster also reduces the risk. However, during the risk analysis, we found out that current response times are already quite short for small and medium events, which are covered by regular maintenance contracts. However, for larger events, i.e. events that fall outside of the regular maintenance contracts, shorter repair times might be possible. This would require organizing such repairs more effectively i.e. streamlining the design, build and contracting process. It is not clear how this should be done, or how effective it could prove to be. An analysis of the organisational processes that are relevant to this step falls outside of the scope of this project.

4.1.2 Overview of the application of flooding hazard measures

Since the only failure mode with damages to the road infrastructure for floods is the culvert size, only measures for the increase in culvert size are considered. Based on the failure mode, an adequate replacement in culvert diameter and discharge capacity is proposed for culverts with significant failure for low return periods as indicated in Table 4.3. Replacement of bridges is not included in the assessment, as no standard costs for bridge replacement were available due to the site-specific requirements for bridges.

Table 4.3 Criteria and costs for the application of flooding hazard measures

Flood measure category	Type of flood measure	Typical application	Approx. cost per road crossing [€]
Increase capacity of culverts bridges	replace culvert	design capacity too low for expected peak flow	5,000 – 75,000
	replace bridge	not advised as preventative measure	-

4.2 Measures for Seismic hazard

For seismic events the analysis in Part 1 showed that although significant damages can occur due to seismic hazard, the AED are too small to justify preventive replacement of road assets. However, several measures that can be taken have been identified as ones that can be applied when building new assets, either when constructing additional assets to the current road network, when replacing existing assets, or in the case of major maintenance for existing assets. Furthermore, as the current of the seismic hazard uses vulnerability curves from Greece, a more detailed analysis of the road assets in Albania is required to make the vulnerability functions more location specific.

The following seismic measures were identified:

Table 4.4 Identified measures considered in this study for seismic hazard

	Seismic events
Prevention	replace asset e.g. bridge
	retrofit asset
	(improved) regular/ preventative maintenance
Reconstruction	Better response/ repair plan (i.e. shorter response times)
	Build back better based on improved/ updated building codes and performance standards

4.2.1 Miscellaneous measures

Replace asset

Based on the risk analysis, we see that damage and unavailability of the corridors due to seismic hazards only happens due to the collapse of bridges. This only happens because of strong seismic events with a low probability (i.e. a high Return Period (RP)). Typical measures would include rebuilding the bridge in a more robust manner. However, because of the high RP, the Annual Expected Damages are quite low, whereas installing a new bridge is (very) costly. This means that replacing a bridge never makes sense based on the Benefit/ Cost ratio. So, we recommend installing new bridges once the old ones need replacing, either due to old age/ unacceptable condition or due to seismic events damage.

In such a case, to reduce the replacement cost to a minimum, a preliminary design, which takes into account modern/ updated building standards and norms as well as future traffic growth predictions makes sense.

Retrofitting of bridges might make sense in some cases. However, the determination of where and what kind of retrofitting measures might be necessary, requires detailed, bridge-specific analysis, which falls outside the scope of this project.

(Improved) regular/ preventive maintenance

Considerations for maintenance are analogous to the case for flood measures.

Build back better

Especially for bridges this seems like an obvious measure. To reduce the downtime of a road, a bridge design based on updated building regulations/ norms could be made beforehand to decrease the time in-between damage and a new bridge. However, how effective such a measure might be, as well as what it might cost is unclear and falls outside the scope of this project.

Better response/ repair plan (shorter response times)

Being able to be back to business as usual quicker after a disaster also reduces the risk. However, during the risk analysis, we found out that current response times are already quite short for small and medium events, which are covered by regular maintenance contracts. However, for larger events, i.e. events that fall outside of the regular maintenance contracts, shorter repair times might be possible. This would require organizing such repairs more effectively i.e. streamlining the design, build and contracting process. It is not clear how this should be done, or how effective this could prove to be. An analysis of the organisational processes that are relevant to this step falls outside of the scope of this project.

4.3 Measures for Landslide hazard

For landslides, the difference between pro-action and prevention measures is somewhat ambiguous. In every slope there are forces which tend to promote downslope movement and opposing forces which tend to resist movement. Pro-active landslide measures aim to increase the opposing forces and/ or reduce the downslope forces, thus increasing the safety factor. On the other hand, prevention measures prevent a moving landslide from affecting the road. For landslides, some measures may do both at the same time i.e. prevent a landslide from occurring as well as prevent a landslide from reaching the road. This is the case for retaining structures, and accordingly, retaining structures are mentioned in both measure typologies in the following discussion.

Note that, for a landslide measure to be effective, one must identify the most important controlling processes that affect the stability of the slope; and determine the appropriate measure to be sufficiently applied to reduce the influence of that process. The measure must be designed to fit the condition of the specific slope under study.[34]

As such, this report provides the first suggestion for which landslide measures might be adequate. This was based on a Google street view inventory, but cannot replace proper in-situ field investigation completed by specialists, and resulted in design recommendations tailored to the local situation.

Landslide measures fall into several categories[35]:

- Retaining structures e.g. gabion walls, reinforced concrete wall, retention nets
- Modification of slope geometry e.g. stepped slope embankment
- Internal slope reinforcement e.g. rock bolts, micro piles, soil nailing, grouting
- Drainage

For landslides, the following measures were identified:

[34] *Lynn M. Highland, United States Geological Survey, and Peter Bobrowsky, Geological Survey of Canada, 2008, The Landslide Handbook—A Guide to Understanding Landslides*
[35] *LANDSLIDE CAUSAL FACTORS AND LANDSLIDE REMEDIATIAL OPTIONS, Mihail E. Popescu,*

Table 4.5 Identified measures considered under this project for landslide hazard

	Landslides
Pro-action	– retaining structures e.g. retaining walls, gabion walls – modification of slope geometry e.g. stepped slope embankments – internal slope reinforcement e.g. rock bolts – drainage – reforestation
Prevention	– retaining structures e.g. retaining walls, gabion walls – (improved) regular/ preventative maintenance
Reconstruction	– Better response/ repair plan (i.e. shorter response times)

Note that in the following paragraphs, the costs of the measure are given per 10m of road.

4.3.1 Retaining structures

Retaining structures are engineered to retain soil and/or rock. They are commonly used to accommodate changes in grade, provide increases in right-of-way and buttress the toe of slopes. In a broad sense, retaining structures can be classified according to their face inclination: if it is greater than 70 degrees, they are typically characterized as retaining walls, while slopes have a face inclination flatter than 70 degrees. There are several types of retaining structures, including gabion walls, gravity, sheet pile, cantilever, and anchored earth/ mechanically stabilized earth (reinforced earth) walls and slopes.[36]

Retaining structures are widely used throughout Albania. In this report we have divided them into: (1) Retaining walls and (2) Shotcrete and drainage.

Retaining walls

Description: There are various types and sizes of retaining walls. To be able to execute the CBA, we have chosen reinforced concrete walls with a maximum height of 6m (including base of the wall, based on local landslide measure typologies. Unless the wall is designed to retain water, it is important to have proper drainage behind the wall to limit the pressure to the wall's design value. Drainage materials will reduce or eliminate the hydrostatic pressure and improve the stability of the material behind the wall. Furthermore, they should be installed according to proper, contemporary engineering norms., The surrounding slope may also have to be reshaped, if needed.

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[36] *https://www.exponent.com/services/practices/engineering/civil-engineering/capabilities/geotechnical/retaining-structures/?serviceId=d2d152c5-7452-4144-b686-9613dd4317c7&loadAllByPageSize=true&knowledgePageSize=3&knowledgePageNum=0&newseventPageSize=3&newseventPageNum=0*

Figure 4.2 picture of typical retaining wall in Albania with landslide activity at location where the wall ends

Typical application: The typical environment for application of such walls are locations with soft rock and/ or much loose soil/ debris. Moreover, a location where erosion due to concentrated water flows off the road is to be expected. Especially low lying stretches of road (‘bottom of the hill’) in areas traversing gullied slopes (the gullies act as funnels, which concentrate water to one point). In some cases, culverts may be found at these low laying locations. Moreover, such retaining walls are typical for locations with a limited height difference between the two sides of the road. Approximate cost: € 11,000 per 10 meters.

Shotcrete and drainage

Description: Shotcrete and gunite are types of concrete that are applied by air jet directly onto the surface of an unstable rock face. This is a rapid and relatively uncomplicated method commonly used to provide surface reinforcement between blocks of rock and to reduce weathering and surface scaling. Because an (impermeable) layer is sprayed onto the rock face, it is important to make sure water pressure cannot build to unacceptable levels.

Typical application: Shotcrete is typically used in areas where the rock may weather quickly, and/ or the rock is highly fractured. Approximate cost: € 14,000 per 10 meters

4.3.2 Stepped slope embankment

Description: A stepped slope embankment is a modification of the slope geometry and consists of a series of “steps” cut into a deep soil or rock face for reducing the driving forces (see Figure 4.3). They are mainly effective in reducing the incidence of shallow failures and intercepting rock fall. Also benches reduce tensional forces in the surface rock and reduce surface erosion rates. However, they have little or no effect on potential deep-seated rock failure. Stepped slope embankments can be combined with gabions/ gabion walls. Gabions are wire mesh, box-like containers filled with cobble-sized rock that are 10 to 20 centimetres. Gabion walls are usually inexpensive, simple, and quick to construct. Three-tiered walls up to 2.5 meters (8 feet) high can usually be constructed without the need for any detailed engineering analysis.

Figure 4.3 Picture of typical stepped slope embankment in Albania

Typical application: Stepped slopes (in combination with gabions/ gabion walls) are often applied if the bedrock is prone to weathering or is much fractured. Approximate cost: € 42,000 per 10 meters.

4.3.3 Rock anchors and wire mesh

Description: This is a type of internal slope reinforcement. For this measure, the emphasis lays with the used rock anchors (Figure 4.4). Rock anchors can transmit an applied tensile load to the rock mass and may be used, for example, to reinforce rock slopes.[37] The tensile load increases the friction force and thus increases the safety factor of the slope. This requires that the rock is not excessively fractured/ discontinuous. Wire mesh is added to prevent loose cobbles and boulders from falling onto the road. A gabion wall may form the toe of the slope, thus retaining the loose debris. In some cases, shotcrete may be used to prevent loose debris from detaching from the wall.

Figure 4.4 Picture of rock anchors and wire mesh in Albania

Typical application: such landslide measures are expected to be applied in areas with much hard, intact rock. These are often characterized by high, steep walls/ slopes with bare rock (approximate cost: € 121,000 per 10 meters).

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[37] *Brown, E.T., 2015, Rock engineering design of post-tensioned anchors for dams – a review.*

4.3.4 Miscellaneous measures

In this paragraph several measures are discussed that are frequently applied to reduce landslide hazards for roads. However, the design and planning of these measures would require more information than is currently available within this project. For this reason, these measures are described briefly, but are not actually suggested to be implemented.

Drainage

Although drainage can be a very effective measure, in this analysis we see drainage as an integral part of other measures. In other words, we have not taken this into account as a standalone measure by itself and included the cost of drainage in the costs of relevant measures where drainage is included.

Reforestation

Description: It has long been known that a well-developed forest cover minimizes the occurrence of shallow landslides on steep hillslopes. A natural spatial scale at which to consider landslides, their impacts, and their control is the river basin. In some cases it is possible to control erosion by reforesting an entire basin. However, it is unrealistic to expect this at a large scale in areas where people rely on the land for their livelihoods. On the other hand, landslides do not normally occur uniformly across a basin; typically, they are concentrated in critical areas of topography, soil and land use. It has therefore been proposed that reforestation of only small parts of a basin, carefully targeted, could produce a disproportionately large reduction in landslide occurrence and sediment yield[38]. Amongst others, we were not able to determine the effectiveness of this measure or link it to normal practice in Albania.

Improved regular/ preventative maintenance

Considerations for maintenance are analogous to the case for flood measures (see 0).

Better response/ repair plan (shorter response times)

Being able to be back to business as usual quicker after a disaster also reduces the risk. However, during the risk analysis, we found out that current response times (for general repairs and landslide events) are already quite short for small and medium events, which are covered by regular maintenance contracts. However, for larger events i.e. events that fall outside of the regular maintenance contracts, shorter repair times might be possible. This would require organizing such repairs more effectively i.e. streamlining the design-build and contracting process. It is not clear how this should be done, nor how effective this could prove to be. An analysis of the organisational processes that are relevant to this step falls outside of the scope of this project.

4.3.5 Overview of application of landslide measures

The following table provides an overview of how measures were appointed to the corridors that were assessed.

Table 4.6 Criteria and costs for the application of landslide measures

[38] Bathurst, J.C., Bovolo, C.I., Cisneros, F. 2009 Modelling the effect of forest cover on shallow landslides at the river basin scale

Landslide measure categories	Type of landslide measure	Typical geology/ geomorphology	Misc. criteria
Retaining structures	New retaining wall	Large amounts of alluvial/ colluvial soil/ debris present. Steep slope in combination with gulley, possibly some erosion already visible on downslope side of road	wall up to 4 - 5m high (max)
	Shotcrete and drainage	Bare, weathered, often soft rock	
Modification of slope geometry	Stepped slope embankment with gabions	Large amounts of alluvial/ colluvial soil/ debris visible on a shallow (not steep) slope. Often soft/ fractured bedrock	higher than 4m
Internal slope reinforcement	Rock anchors, wire mesh/ netting	Steep, high slopes (higher than 4m) of bare, hard rock	

4.4 Measures per corridor

4.4.1 Measures for Floods Hazard

4.4.1.1 Assessment of damages for flooding

Based on discharge calculations with the D-*Wflow* model, an assessment was made of damages to the road infrastructure from floods that are caused by intense rainfall with different return periods (1:5, 1:20. 1: 50 and 1:100 years). The calculated discharges were compared to the design capacity of the culverts in the road to assess flooding damages in 3 categories (small, medium, large), see the Part 1 for more detail. Consequently, the vulnerability of the assets was used to determine the annual expected damages (AED) resulting from the damages to the assets and the interruption of service of the different corridors. The results of this analysis are presented in Table 4.7, which presents AED per corridor. As the vulnerability of the road infrastructure is determined by the discharge capacity of the culverts, measures to reduce the impact should either reduce the discharges in the catchment areas or increase the design capacity of the culverts. For this analysis we have assumed that the increase of the capacity of a culvert is achieved through increasing the diameter of the culvert by replacing the existing culvert with a larger one with a capacity that will allow for the calculated discharge without causing significant damages in more frequent return periods (1:5 and 1:20 years). ,

Based on the assessment in the map (Figure 4.5), the locations were identified for which the discharge capacity of the culverts should be increased. This procedure is not possible for bridges, because no construction details were available for bridges. Therefore, the increase in capacity was limited to culverts only. Furthermore, the selection of culverts was limited to those culverts that had large or medium damage categories for frequent return periods (1:5 and 1:20 years), to have the most significant results in the economic evaluation.

Table 4.7 AED from floods per corridor for cost of repairs and interruption of services (in 1,000 €)

Floods Annual Expected Damages	Repairs (1,000 €)	Interuption (1,000 €)	Total (1,000 €)
01 Milot - Morine New	4	12	**17**
02 Shkoder - Puke - Kolsh	9	5	**13**
03 Milot - Shkoder - Muriqan	288	1,253	**1,540**
04 Tirana - Durres	80	1,713	**1,793**
05 Durres - Vlore	115	9,866	**9,981**
06 Tirana - Elbasan - Pogradec	98	2,907	**3,005**
07 Fier - Gjirokaster - Kakavi	225	1,027	**1,252**
08 Gjirokaster - Sarande - Ksamil	39	2	**41**
09 Elbasan - Gramsh	1	0	**1**
10 Lushnje - Berat - Çorovode	40	214	**254**
11 Rrogozhine - Elbasan	1	6	**6**
12 Shkoder - Hani i Hotit - Vermosh	50	140	**190**
13 Milot - Peshkopi	53	465	**517**
14 Vlore - Sarande	28	108	**136**
15 Pogradec - Korce - Kapshtice	-	-	**-**

Note: corridor 15 does not "fit" in the traffic model as there are no alternative routes in the underlying road network.

4.4.1.2 Assessment of measures for flooding

To assess which measures should be taken for which structures, a list was made for all structures that caused “Large” damages for frequent return periods. As bridges do not have standard dimensions, bridges were excluded from this analysis at this point since it is not possible to determine unit construction costs for bridges at this point in the analysis. For this reason, only culverts were selected, as for those structures standard characteristics were available. In the map (Figure 4.5), all culverts depicted with red dots were selected for replacement. This resulted in the list below (Table 4.8) of structures to be replaced with their original design discharges and failure category.

Table 4.8 Failure level of selected culverts for corridors 2, 5, 6, 7, 12, 13 and 14

ID	Corridor	Capacity (m3/s)	R_5	R_20	R_50	R_100
B_0210	02 Shkoder - Puke - Kolsh	30.1	66.83	95.1	113.02	126.44
C_0375	05 Durres - Vlore	0.56	0.77	1.1	1.3	1.46
C_0505	05 Durres - Vlore	1.58	4.85	6.89	8.17	9.14
C_3099	05 Durres - Vlore	0	1.38	1.87	2.18	2.41
C_1014	06 Tirana - Elbasan - Pogradec	3.54	43.91	61.14	72.07	80.25
C_3603	07 Fier - Gjirokaster - Kakavi	0.56	0.39	1.59	2.38	2.59
C_2988	07 Fier - Gjirokaster - Kakavi	1.58	39.58	69.25	88.37	97.74
C_2995	07 Fier - Gjirokaster - Kakavi	6	13.27	25.05	32.67	36.08
C_3502	07 Fier - Gjirokaster - Kakavi	0.26	9.77	14.26	17.12	19.04
C_3527	07 Fier - Gjirokaster - Kakavi	8	16.75	26.19	32.23	35.91
C_3601	07 Fier - Gjirokaster - Kakavi	0.56	1.81	3.54	4.65	5.19
C_3613	07 Fier - Gjirokaster - Kakavi	6	21.98	36.07	45.14	49.78
C_0083	12 Shkoder - Hani i Hotit - Vermosh	1.58	1.81	2.76	3.36	3.81
C_2855	13 Milot - Peshkopi	1.58	7.82	13.14	16.54	18.59
C_2871	13 Milot - Peshkopi	1.58	1.18	2.84	3.91	4.43
C_2724	14 Vlore - Sarande	1.58	2.6	6.67	9.32	10.18
C_2703	14 Vlore - Sarande	1.58	10.43	14.94	17.8	19.94

Damage categories	
(red)	Large
(orange)	Medium
(yellow)	Small
(white)	None

In Table 4.9 the capacity of the suggested replacement of culverts is presented that will result in a reduction in damage category and associated damages.

Table 4.9 Design discharges of replacement culverts

ID	Corridor	Old Capacity (m3/s)	New Capacity (m3/s)
B_0210	02 Shkoder - Puke - Kolsh	30.1	50
C_0375	05 Durres - Vlore	0.56	2.5
C_0505	05 Durres - Vlore	1.58	16
C_3099	05 Durres - Vlore	0	2.5
C_1014	06 Tirana - Elbasan - Pogradec	3.54	50
C_3603	07 Fier - Gjirokaster - Kakavi	0.56	2.5
C_2988	07 Fier - Gjirokaster - Kakavi	1.58	50
C_2995	07 Fier - Gjirokaster - Kakavi	6	50
C_3502	07 Fier - Gjirokaster - Kakavi	0.26	16
C_3527	07 Fier - Gjirokaster - Kakavi	8	50
C_3601	07 Fier - Gjirokaster - Kakavi	0.56	2.5
C_3613	07 Fier - Gjirokaster - Kakavi	6	50
C_0083	12 Shkoder - Hani i Hotit - Vermosh	1.58	16
C_2855	13 Milot - Peshkopi	1.58	2.5
C_2871	13 Milot - Peshkopi	1.58	16
C_2724	14 Vlore - Sarande	1.58	2.5
C_2703	14 Vlore - Sarande	1.58	16

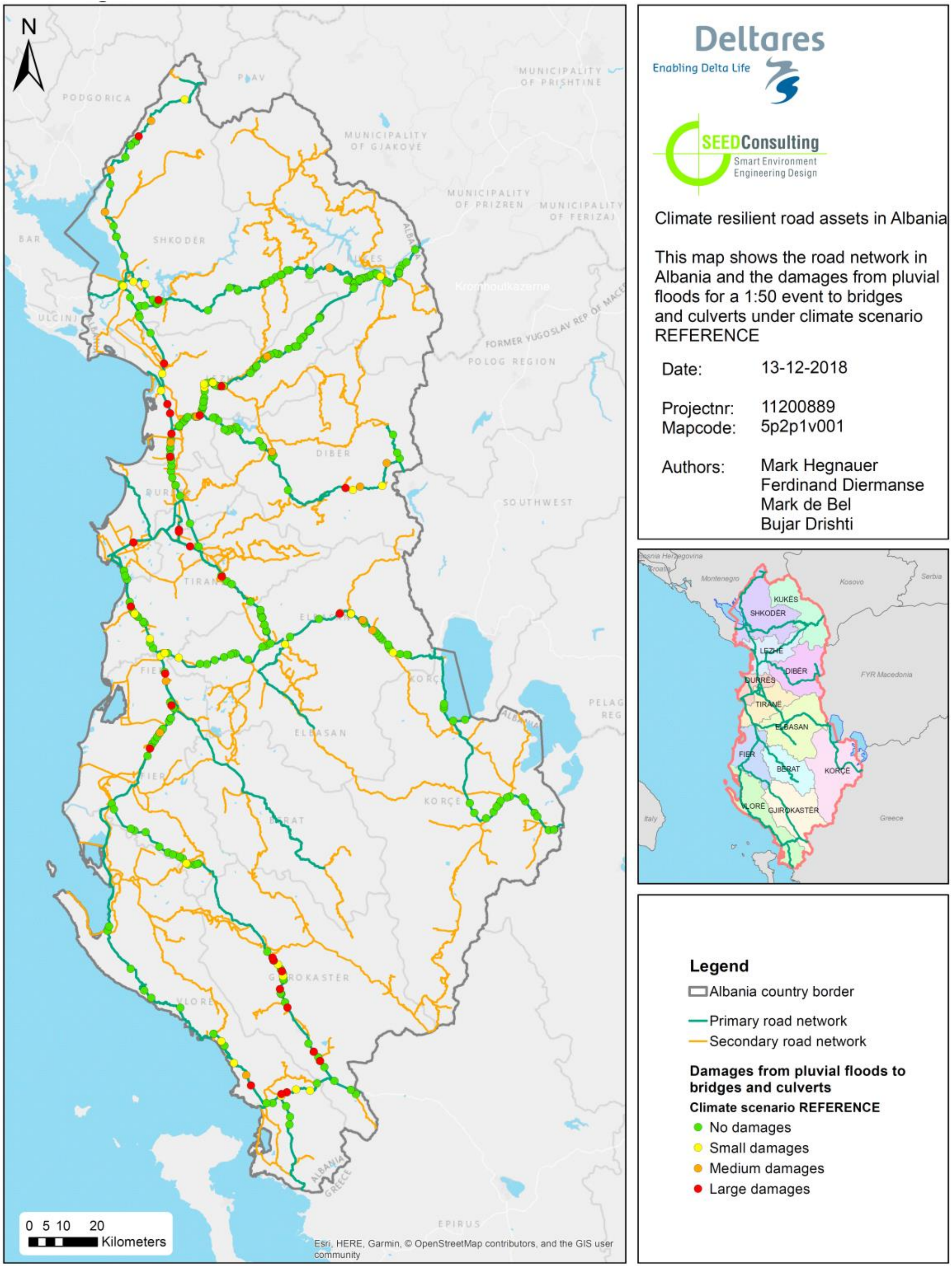

Figure 4.5 Damage category from pluvial floods for culverts and bridges under current climate conditions

4.4.1.3 Costs of measures for flooding

The costs for the replacement are based on the bill of quantity (BoQ) as presented in appendix B.2 and summarized in Table 4.2. Based on these costs and the dimensions of the culverts to be replaced per corridor, a cost estimate can be made per corridor (see Table 4.10). These costs are used in the cost-benefit analysis which is presented in paragraph 4.4.1.4.

Table 4.10 Bill of quantity for culvert replacement (2.5; 16 or 50 m^3/s) (€)

Corridor	Q50	Q16	Q2.5	Q50	Q16	Q2.5	Investment (€)
01 Milot - Morine New	0	0	0	-	-	-	
02 Shkoder - Puke - Kolsh	1			75,000	-	-	75,000
03 Milot - Shkoder - Muriqan				-	-	-	-
04 Tirana - Durres				-	-	-	-
05 Durres - Vlore		1	2	-	42,000	16,000	58,000
06 Tirana - Elbasan - Pogradec	1			75,000	-	-	75,000
07 Fier - Gjirokaster - Kakavi	4	1	2	300,000	42,000	16,000	358,000
08 Gjirokaster - Sarande - Ksamil				-	-	-	-
09 Elbasan - Gramsh				-	-	-	-
10 Lushnje - Berat - Çorovode		1		-	42,000	-	42,000
11 Rrogozhine - Elbasan				-	-	-	-
12 Shkoder - Hani i Hotit - Vermosh		1		-	42,000	-	42,000
13 Milot - Peshkopi		1	1	-	42,000	8,000	50,000
14 Vlore - Sarande		1	1	-	42,000	8,000	50,000
15 Pogradec - Korce - Kapshtice				-	-	-	-

4.4.1.4 Cost Benefit Analysis for flooding

For the cost-benefit calculations, several basic assumptions were made:

- All costs are assumed to take place in the first year
- Benefits are considered over a period of 25 years only[39], which is assumed as the technical lifespan of the implemented measures.
- As only 15 years of traffic predictions are available, growth in vehicle numbers is assumed to be constant for the next 10 years
- A net discount rate (discount rate – economic growth) of 4 % is used

Table 4.11 Design discharges for new culverts and new damage assessment for current climate

ID	Corridor	Old Capacity (m3/s)	New Capacity (m3/s)	R_5 (return values of discharge (m3/s), current climate)	R_20	R_50	R_100
B_0210	02 Shkoder - Puke - Kolsh	30.1	50	66.83	95.1	113.02	126.44
C_0375	05 Durres - Vlore	0.56	2.5	0.77	1.1	1.3	1.46
C_0505	05 Durres - Vlore	1.58	16	4.85	6.89	8.17	9.14
C_3099	05 Durres - Vlore	0	2.5	1.38	1.87	2.18	2.41
C_1014	06 Tirana - Elbasan - Pogradec	3.54	50	43.91	61.14	72.07	80.25
C_3603	07 Fier - Gjirokaster - Kakavi	0.56	2.5	0.39	1.59	2.38	2.59
C_2988	07 Fier - Gjirokaster - Kakavi	1.58	50	39.58	69.25	88.37	97.74
C_2995	07 Fier - Gjirokaster - Kakavi	6	50	13.27	25.05	32.67	36.08
C_3502	07 Fier - Gjirokaster - Kakavi	0.26	16	9.77	14.26	17.12	19.04
C_3527	07 Fier - Gjirokaster - Kakavi	8	50	16.75	26.19	32.23	35.91
C_3601	07 Fier - Gjirokaster - Kakavi	0.56	2.5	1.81	3.54	4.65	5.19
C_3613	07 Fier - Gjirokaster - Kakavi	6	50	21.98	36.07	45.14	49.78
C_0083	12 Shkoder - Hani i Hotit - Vermosh	1.58	16	10.43	14.94	17.8	19.94
C_2855	13 Milot - Peshkopi	1.58	2.5	1.81	2.76	3.36	3.81
C_2871	13 Milot - Peshkopi	1.58	16	7.82	13.14	16.54	18.59
C_2724	14 Vlore - Sarande	1.58	2.5	1.18	2.84	3.91	4.43
C_2703	14 Vlore - Sarande	1.58	16	2.6	6.67	9.32	10.18

Damage categories	
(red)	Large
(orange)	Medium
(yellow)	Small
(white)	None

[39] *Normally road assets like culverts and bridges have a technical lifespan of 50 – 100 years. For the CBA we took 25 years only to account for (lack of) additional O&M and thus shortened the technical life of the assets.*

Because of increasing the design capacity of the culverts, the original damage categories of the culverts changed to a new damage category and corresponding reduced damages. The new damage categories of the replaced culverts are presented in Table 4.11. Based on these newly determined damage categories new damages from repair costs and damages from service interruption can be calculated. The reductions in damages for the corridors are the benefits of the replacement of the culverts. The results of this calculation are presented in Table 4.12, which provides the annual benefits in comparison with the old situation, see also appendix B.3 for more details of the benefit calculations.

Table 4.12 Annual benefits for replacement of culverts for different damage categories per corridors (1,000 €)

Benefits culvert replacement	**Repairs**	**Interuption**	**Total**
Annual Benefits	**(1,000 €)**	**(1,000 €)**	**(1,000 €)**
01 Milot - Morine New	-	-	**-**
02 Shkoder - Puke - Kolsh	3	1	**4**
03 Milot - Shkoder - Muriqan	-	-	**-**
04 Tirana - Durres	-	-	**-**
05 Durres - Vlore	69	5,651	**5,721**
06 Tirana - Elbasan - Pogradec	40	1,071	**1,111**
07 Fier - Gjirokaster - Kakavi	182	678	**860**
08 Gjirokaster - Sarande - Ksamil	-	-	**-**
09 Elbasan - Gramsh	-	-	**-**
10 Lushnje - Berat - Çorovode	40	214	**254**
11 Rrogozhine - Elbasan	-	-	**-**
12 Shkoder - Hani i Hotit - Vermosh	40	131	**171**
13 Milot - Peshkopi	41	385	**426**
14 Vlore - Sarande	26	103	**129**
15 Pogradec - Korce - Kapshtice	-	-	**-**

Based on the annual benefits presented in Table 4.12, a CBA is made based on reduced costs for repairs and for all economic damages, including additional costs incurred by road users. In Table 4.13 the CBA is presented taking only benefits from reduced repair costs into consideration. From the analysis for all corridors the replacement of the culverts is economically feasible, as B/C ratio are generally above 1. The only exception is corridor 2 where the B/C ratio for only repairs is 0.6. However, when the economic damages are added (Table 4.14), the B/C ratio becomes 1.4, making this replacement also economically feasible.

Table 4.13 CBA for repair costs only for replacement of culverts per corridor

Corridor	Investment (1,000 €)	Benefits (1,000 €)	B/C ratio
01 Milot - Morine New		-	
02 Shkoder - Puke - Kolsh	75	47	0.6
03 Milot - Shkoder - Muriqan	-	-	
04 Tirana - Durres	-	-	
05 Durres - Vlore	58	1,080	19
06 Tirana - Elbasan - Pogradec	75	617	8
07 Fier - Gjirokaster - Kakavi	358	2,830	8
08 Gjirokaster - Sarande - Ksamil	-	-	
09 Elbasan - Gramsh	-	-	
10 Lushnje - Berat - Çorovode	42	624	15
11 Rrogozhine - Elbasan	-	-	
12 Shkoder - Hani i Hotit - Vermosh	42	621	15
13 Milot - Peshkopi	50	641	13
14 Vlore - Sarande	50	410	8
15 Pogradec - Korce - Kapshtice	-	-	

Table 4.14 CBA for all economic damages for replacement of culverts per corridor

Corridor	Investment (1,000 €)	Benefits (1,000 €)	B/C ratio
01 Milot - Morine New			
02 Shkoder - Puke - Kolsh	75	107	1.4
03 Milot - Shkoder - Muriqan	-	-	
04 Tirana - Durres	-	-	
05 Durres - Vlore	58	141,300	2,436
06 Tirana - Elbasan - Pogradec	75	27,430	366
07 Fier - Gjirokaster - Kakavi	358	21,240	59
08 Gjirokaster - Sarande - Ksamil	-	-	
09 Elbasan - Gramsh	-	-	
10 Lushnje - Berat - Çorovode	42	6,275	149
11 Rrogozhine - Elbasan	-	-	
12 Shkoder - Hani i Hotit - Vermosh	42	4,225	101
13 Milot - Peshkopi	50	10,530	211
14 Vlore - Sarande	50	3,200	64
15 Pogradec - Korce - Kapshtice	-	-	

4.4.1.5 Sensitivity of flooding analyses due to lack of maintenance

The current assessment assumes a good state of maintenance of the structures. We looked at the influence of maintenance on the performance of the system and impact on damages. We compared a reduction of culvert capacity to the reference situation, in which all culverts and bridges are fully operational (100 % of design capacity). For this comparison, the discharge capacity was reduced by 50 %. This resulted in the additional damages compared to the reference situation as provided in the Table 4.15.

Table 4.15 Additional damages (illustrative) that are incurred due to reduction of culvert capacity by 50% due to lack of maintenance

Corridor	Add. Repairs/ year (1,000 €)	Add. Econ. Dam./ year (1,000 €)	Tot. Add. Dam/ year (1,000 €)
01 Milot - Morine New	29	107	**136**
02 Shkoder - Puke - Kolsh	32	13	**45**
03 Milot - Shkoder - Muriqan	44	690	**734**
04 Tirana - Durres	-	-	**-**
05 Durres - Vlore	57	3,524	**3,581**
06 Tirana - Elbasan - Pogradec	86	602	**688**
07 Fier - Gjirokaster - Kakavi	97	382	**479**
08 Gjirokaster - Sarande - Ksamil	41	1	**42**
09 Elbasan - Gramsh	4	3	**7**
10 Lushnje - Berat - Çorovode	1	4	**5**
11 Rrogozhine - Elbasan	5	12	**17**
12 Shkoder - Hani i Hotit - Vermosh	58	77	**135**
13 Milot - Peshkopi	71	232	**303**
14 Vlore - Sarande	19	48	**67**
15 Pogradec - Korce - Kapshtice	2	5	**6**

The table shows that especially corridors 3, 5, 6, 7, 12 and 13 are sensitive to reduced efforts in maintenance. The influence of the degree of reduced performance of the bridges and culverts is illustrated by Figure 4.6. This figure shows that damages gradually increase with decreasing performance of discharge of the culverts. However, currently there is no insight into the status of maintenance of the culverts and bridges. As a result, no direct recommendations can be provided towards the influence of improved performance on the current performance of the network.

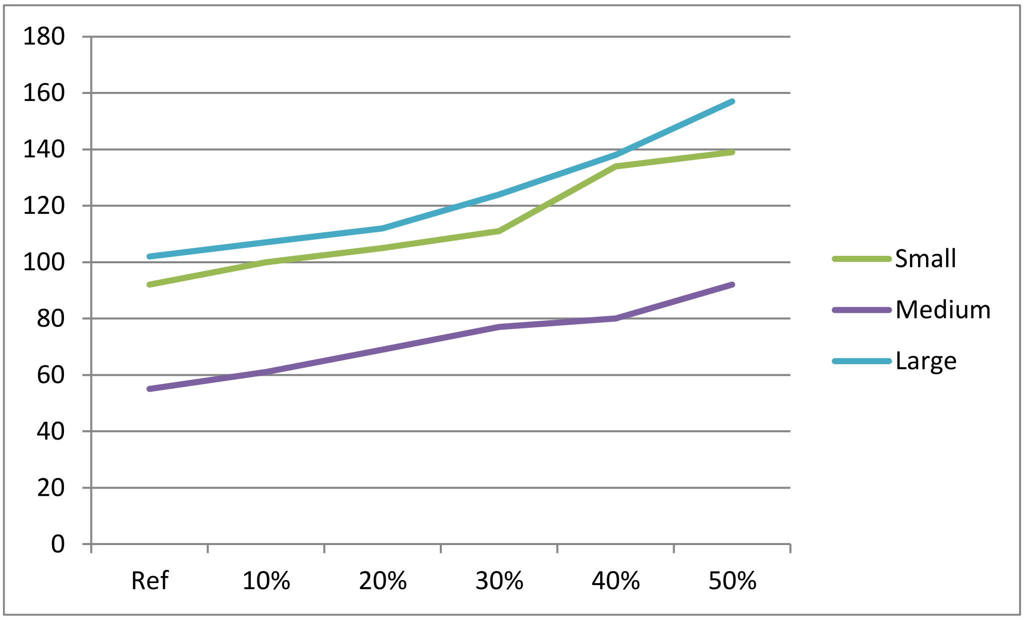

Figure 4.6 Increase of number of failures (illustrative) to show the importance of proper maintenance (under small, medium and damage categories)

4.4.2 Measures for landslides

4.4.2.1 Assessment of damages for landslides

For the assessment of landslides three damage categories are defined, based on historical data and thresholds of 100 m^3 and 1,000 m^3 per event, as shown in Table 4.16. Combined with the established probability of the different event classes (Table 4.17) and the landslide susceptibility classes, as presented in Figure 4.7, the annual expected damages from landslides in Albania are calculated and presented in Table 4.18.

Table 4.16 Magnitude of damage categories for landslide events

Event class	Volume range m^3
Small	< 100
Medium	100-1,000
Large	>1,000

Table 4.17 Landslide probability overview

Landslide susceptibility class	Probability of one event per year per km [x100]		
	Small	Medium	Large
1	0.05	0.03	0.02
2	0.11	0.07	0.05
3	0.22	0.14	0.09
4	0.58	0.37	0.25
5	1.05	0.68	0.45

From the assessment of the susceptibility of the corridor, combined with the probability of the occurrence of events, an evaluation is made to identify corridors that will benefit from measures that will reduce the frequency of occurrence of landslides. Considering the damages per corridor, this analysis is focused on corridors 1, 5, 6, 13 and 14, as these corridors have both substantial AED from landslides as well as a limited stretch of road network that has a high susceptibility to landslides (susceptibility classes 4 and 5). Corridor 1, differently than the other four corridors, has a high susceptibility class, which requires measures over the full length of the corridor (104 km).

Note that during the final workshop with local stakeholders, a comment was made that the total damages for some corridors with low landslide susceptibility seem high. This may be due to several factors:

1. For corridors with a high traffic density, a small damage class sometimes still leads to significant economic damages for the corridor
2. For long corridors, when determining the damages per corridor, adding small economic damages/ km of road over enough length can lead to significant total damages per corridor.

When both factors occur in a single corridor, and due to the general character of the analysis, for long corridors with relatively high traffic density, total damages per corridor could be overestimated.

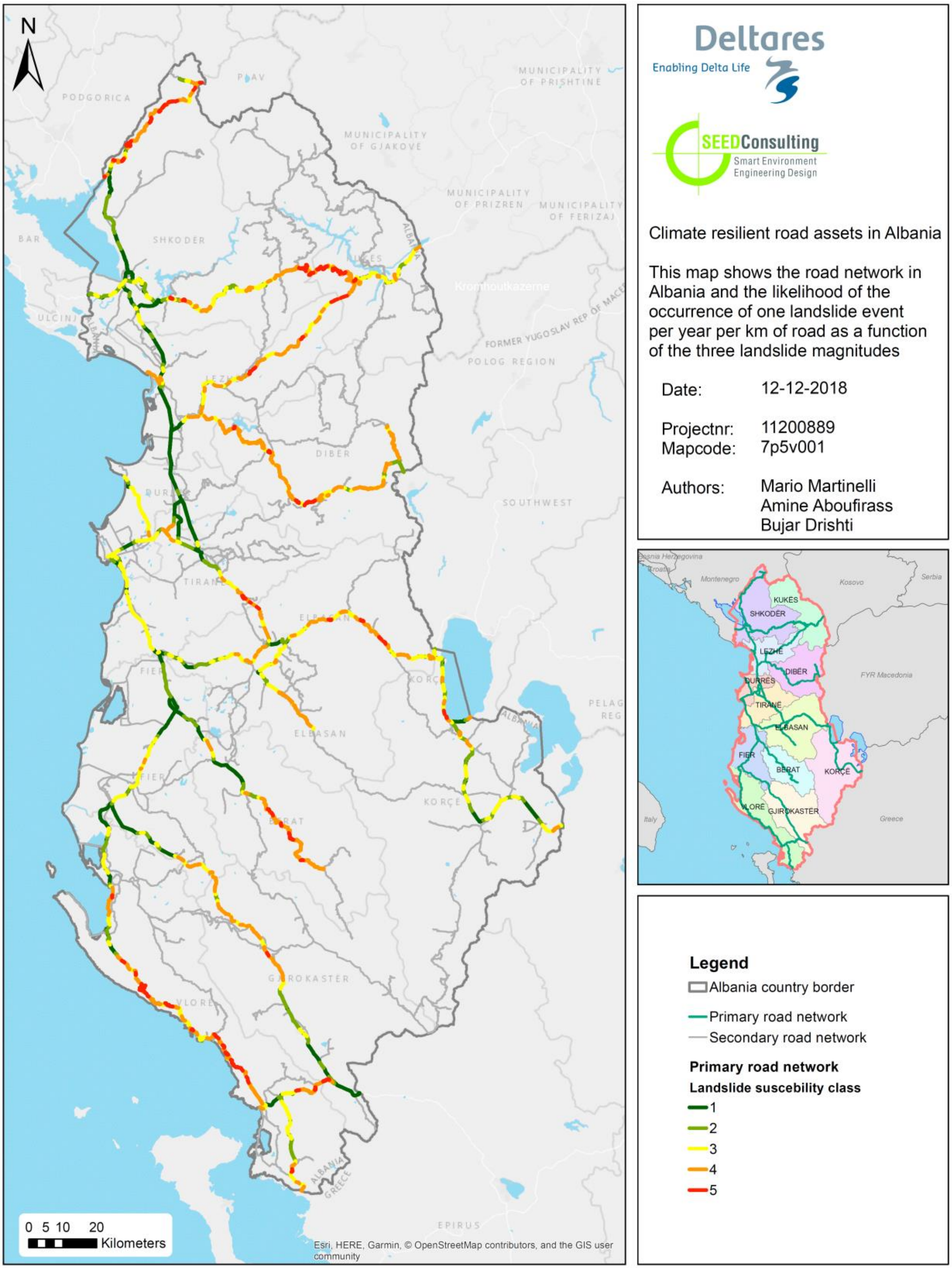

Figure 4.7 Landslide susceptibility for corridors in Albania

Table 4.18 Damages from landslides per corridor in Albania (1,000 €)

Landslides Annual Expected Damages	Repairs (1,000 €)	Interuption (1,000 €)	Total (1,000 €)
01 Milot - Morine New	287	38	**324**
02 Shkoder - Puke - Kolsh	110	3	**113**
03 Milot - Shkoder - Muriqan	38	52	**90**
04 Tirana - Durres	45	72	**116**
05 Durres - Vlore	150	363	**513**
06 Tirana - Elbasan - Pogradec	200	256	**457**
07 Fier - Gjirokaster - Kakavi	61	45	**106**
08 Gjirokaster - Sarande - Ksamil	39	0	**40**
09 Elbasan - Gramsh	25	2	**26**
10 Lushnje - Berat - Çorovode	64	30	**93**
11 Rrogozhine - Elbasan	17	12	**29**
12 Shkoder - Hani i Hotit - Vermosh	76	21	**97**
13 Milot - Peshkopi	124	74	**198**
14 Vlore - Sarande	146	32	**178**
15 Pogradec - Korce - Kapshtice	22	45	**67**

4.4.2.2 Assessment of measures for landslides

Based on the landslide susceptibility, AED per corridor and geomorphological characteristics for some corridors, several measures are suggested to improve the resilience of that specific corridor. The proposed measures are presented below per corridor.

Corridor 1

There is a high susceptibility to landslides along the entire corridor, especially between Kurkës and Lezhë, with a landscape varying from soft sediments to hard rock formations.

Based on these characteristics and on a google street view analysis, we have suggested the following measures: 500m of Retaining Wall due to potential road edge failure; 1600m of Retaining Wall in combination with 1700m of stepped embankment; 500m of slope protection using shotcrete for stretches with soft and/or weathered rock or soil upslope; 400m of gabion walls and wire mesh/anchors is suggested for hard rock slopes. During the inventory for the measures for the corridor recent measures against landslides could be observed. The proposed investments are supplementary to the already existing measures.

Corridor 5

We have focused on the vulnerable locations from Vlore to Radhimë, a total length of 14km. The areas of focus have varying landscape characteristics. Bare intact rock weathered soft rock to shallow soil slopes can all be found in this corridor.

Based on these landslide characteristics and on a google street view analysis, we have suggested 100m of Retaining Wall due to potential road edge failure. Furthermore, 600m of Retaining Wall were suggested due to soft and/or weathered rock or soil upslope. Lastly, 450m of gabion walls and wire mesh/anchors were suggested for the steep slopes of bare/intact rock.

Corridor 6

We have focused on the vulnerable locations from Librazhd to Qukës, of total length of 19km. The areas of focus can be characterized by shallow soil slopes.

Based on these landslide characteristics and on a google street view analysis, we have suggested 3,000m of Retaining Wall.

Corridor 13

For corridor 13, we have focused on the vulnerable locations from Ulëz to Bulquizë, a total length of 61.3 km. The areas of focus have varying landscape characteristics. Bare intact rock weathered soft rock to shallow soil slopes can all be found in this corridor.

Based on these landslide characteristics and on a google street view analysis, we have suggested 7,000m of Retaining Wall due to potential road edge failure. Furthermore, a total of 20,000m of Retaining Wall was suggested due to soft and/or weathered rock or soil upslope. Lastly, 200m of gabion walls and wire mesh/anchors were suggested for the steep slopes of bare/intact rock.

Corridor 14

We have focused on the vulnerable locations from Himare to Borsh, a total length of 17km. The areas of focus can be characterized mainly by steep slopes of bare intact rock or shallow slopes of weathered rock together with soil.

Based on these landslide characteristics and on a google street view analysis, we have suggested 10,000m of Retaining Wall due to potential road edge failure.

4.4.2.3 Costs for measures for landslides

Based on the suggested measures from the previous paragraph, Table 4.19 presents the investment costs for the 5 corridors.

Table 4.19 Investment costs per corridor for landslides measures (per km and million €)

Engineering measures	Cost/ km (M€)	01 Milot - Morine N.		05 Durres - Vlore		06 Tirana - Pogradec		13 Milot - Peshkopi		14 Vlore - Sarande	
		km	Cost	km	Cost	km	Cost	km	Cost	km	Cost
Road Edge failure											
Retaining Wall	1.1	0.50	0.6	0.10	0.1		-	7.0	7.7	10.0	11.0
Soft rock											
Retaining Wall	1.1	1.60	1.8	0.20	0.2	3.10	3.4	20.0	22.0		-
Stepped slope embankement with gabion walls	4.2	1.70	7.1		-	0.50	2.1		-		-
Slope protection with Shotcrete, anchors, drainage	1.4	0.50	0.7	0.40	0.6	0.50	0.7		-		-
Hard rock											
Slope protection with gabion walls, Wire mesh, anchors	12.1	0.40	4.8	0.45	5.4	0.10	1.2	0.2	2.4		-
	TOTAL		**15.0**		**6.3**		**7.4**		**32.1**		**11.0**

4.4.2.4 Cost Benefit Analysis for landslide measures

For the purpose of the cost benefit analysis, it is assumed that the effectiveness of the proposed measures will reduce the probability of the different classes of susceptibility for landslides by 50 %, thus also reducing the damages from landslides by 50 %. This results in benefits for the corridors of 50 % of the damages presented in Table 4.18 per corridor.

The result of the cost benefit analysis is presented in Table 4.20. Based on the CBA taking measures for corridor 5 is economically viable under the current assumptions. For corridor 6 this is less clear. For corridors 1, 13 and 14 the investments are much higher than the anticipated benefits. As the B/C ratio for corridor 5 is the highest, priority should be given to the intervention measures against landslides in this corridor.

Table 4.20 Costs and benefits (in M€) from investments for landslides

Corridor	Investment (M €)	Benefits (M €)	B/C ratio
01 Milot - Morine New	15.0	4.2	0.3
05 Durres - Vlore	6.3	6.7	1.1
06 Tirana - Elbasan - Pogradec	7.4	6.0	0.8
13 Milot - Peshkopi	32.1	2.6	0.1
14 Vlore - Sarande	11.0	2.3	0.2

For the measures against landslides, a sensitivity analysis is made on the effectivity of the measures. In the analysis the effectivity is varied between 25 % and 100 % effectivity of the measures. The sensitivity analysis is presented in Table 4.21. The sensitivity analysis shows that investments for landslide measures for corridor 5 are economically viable from an effectivity of 33 % and higher. Measures for corridor 6 need to be at least 50 % to be economically viable. Measures for the corridors 1, 13 and 14 are not economically viable even if the effectivity is 100%.

Table 4.21 Sensitivity analysis for effectiveness of investments for landslides

Corridor	25%	33%	50%	66%	75%	100%
01 Milot - Morine New	0.1	0.2	0.3	0.4	0.4	0.6
05 Durres - Vlore	0.5	0.7	1.1	1.4	1.6	2.1
06 Tirana - Elbasan - Pogradec	0.4	0.5	0.8	1.1	1.2	1.6
13 Milot - Peshkopi	0.0	0.1	0.1	0.1	0.1	0.2
14 Vlore - Sarande	0.1	0.1	0.2	0.3	0.3	0.4

4.5 Decision making under deep uncertainty

Nowadays, decision makers face deep uncertainties about a myriad of external factors, such as climate change, population growth, new technologies, economic developments, as well as their impacts. For investments in transport infrastructure, where capital expenditures can be high and asset lifespans long, decision makers need to be confident that the decisions they take today will continue to apply in the future. They also need to be confident that the planned infrastructure is designed to cope with the changing conditions. To meet this challenge, new methods and approaches have been developed to help decision makers identify and evaluate robust and adaptive strategies, and thereby make sound decisions in the face of these challenges.

The decision making under deep uncertainty (DMDU) methodologies comprise several approaches to deal with high levels of uncertainty during decision making. Deltares adopts DMDU into a Dynamic Adaptive Policy Pathways (DAPP). DAPP is an approach to interventions are sequenced into 'pathways', with each pathway ensuring that the specified policy objectives continue to be achieved as conditions change. Its essence is proactive and dynamic planning in response to how the future unfolds. It explores alternative sequences of decisions or interventions (i.e. adaptation pathways) under multiple futures, which help to illuminate any path-dependencies. The approach recognizes that policy interventions have uncertain design lives, and sooner or later may fail to achieve their objectives as conditions change or may not be feasibly implemented until certain conditions exist. DAPP supports planners to design dynamic adaptive plans that cover short-term actions, long-term options, and adaptation signals which identify when to implement actions or revisit decisions.

DAPP is most useful when there exists a high potential for 'regret' in terms of not acting, acting in the wrong direction, taking insufficient action, or over-investing. It is also most usefully applied in situations where the system is sensitive to the changing conditions, and where there exists a path- or temporal-dependencies. That is, where one action precludes another from being taken, when switching from one action to another involves significant transfer costs, or when taking actions today has different consequences from taking actions in the future.

The DAPP analysis framework has been applied in this study. During the earliest phases of our analysis, it became evident that the uncertainties represented in the system were either insufficient or beyond the scope of this project to analyse further. The remainder of this chapter presents our rationale for having reached this conclusion. After a discussion of the applicability of the various uncertainties present in the system to the DAPP analysis, we then present a sensitivity analysis of those uncertainties that were deemed most relevant.

4.5.1 Drivers of uncertainty

As Part 1 indicates, the Albanian road network is vulnerable to flooding, seismic and landslide hazards. Disruption from these hazards to roads, bridges, and culverts not only generates direct repair costs, but also leads to (the often greater) indirect impacts due to service interruptions. Communities can be isolated; and trade and business operations can be disrupted as transport is deferred, delayed, or forced to seek alternative routes.

The driving forces behind these impacts encompass both inherently uncertain physical and socioeconomic factors. Table 4.22 presents key drivers identified for the Albanian road network with potentially the greatest impact on expected annual damages for national road assets. Physical drivers determine the magnitude of the hazard to be experienced, while the socioeconomic drivers influence the eventual impacts of the hazard in terms of the (indirect) damages incurred.

Table 4.22 Key physical and socioeconomic drivers of uncertainty relevant to the Albanian road network

Driver	**Anticipated state change**	**Impact**
Key Physical Drivers		
Climate change	Sea level rise	Coastal flooding (from combined SLR and storm surge)
	Increased rainfall (duration & frequency)	Fluvial flooding Landslides

	Increased rainfall intensity	Fluvial flooding Landslides
Seismic activity	Ground acceleration	Earthquakes Landslides
Key Socioeconomic Drivers		
Economic Growth	Increased traffic flows	Increased damages (all hazards)

4.5.1.1 Climate change

Sea Level Rise

Climate change is expected to result in higher sea and storm surge levels (SSL), with the magnitude of these changes uncertain. However, as indicated in Part 1, even extreme climate change is not anticipated to yield coastal flooding in Albania that renders key national road assets vulnerable.

Consequently, sea level rise and storm surges and the consideration of coastal flooding risks have been removed from the DMDU analysis and broader risk assessment, as it is *extremely* unlikely that the former will disrupt traffic or cause direct damages to key road assets.

Increased rainfall: duration, frequency and intensity

Climate change is also expected to lead to uncertain changes in rainfall in terms of duration, frequency or intensity that could lead to increased incidences of fluvial flooding or landslides that impact road assets. As outlined in Part 1, the average precipitation change for the country is negative under both mean RCP 4.5 and RCP 8.5 conditions. When more localised effects are considered, our assessment indicates that future 1-day maximum precipitation volumes may increase at higher altitudes in northern Albania and decrease at lower altitudes in central and southern regions. Consideration of the uncertainty in future precipitation patterns therefore remains relevant to the DMDU analysis and is discussed further below.

4.5.1.2 Seismic activity

As a DMDU approach, DAPP is particularly useful to apply in situations where the driving conditions change in clearly identifiable trends over time. Seismic activity does not fit this category, as its effects are largely random and independent of time. In such situations, developing adaptation pathways for increasing levels of ground motion makes little sense. Conventional planning approaches that set earthquake construction standards for infrastructure according to the incidence probabilities for specified levels of ground acceleration will typically suffice. As such, any considerations of seismic effects have been removed from the DMDU analysis.

4.5.1.3 Economic growth

Socioeconomic drivers of uncertainty for road networks relate to those factors influencing the amount of traffic using the road network. This project applies the GDP methodology to determine traffic demand forecasts, where GDP growth rates are multiplied with the elasticity of demand for vehicle travel. Under this methodology, other socioeconomic effects (e.g. population growth) are not considered as separate drivers of traffic volume but are rather incorporated into the economic growth rate figure. Consideration of the impacts of uncertainty in the economic growth rate remains pertinent to the DMDU analysis and is discussed further below.

Note we do not consider the other economic assumptions applied in the demand analysis, Value of Time (VoT), Vehicle Operating Costs (VOC), or the damage classes as key drivers of uncertainty in terms of AED.

4.5.2 Sensitivity analysis of relevant uncertainty drivers

4.5.2.1 Changing precipitation patterns

Fluvial flooding

Increases in daily rainfall intensity across mountainous parts of Albania have been assessed to determine whether it leads to localised fluvial flood damage to bridges and large culverts in key road corridors. In Table 4.23 the classification of damage to infrastructure is presented as was determined in the Part 1.

Table 4.23 Damage classification for floods for the Albanian road network

Ratio Peak flow: Culvert capacity	Damage classification
< 1	None
1 – 2	Small
2 – 4	Medium
>4	Large

Figure 4.8 represents the flood hazard modelling outputs for the assessed bridges and culverts for expected peak discharges for a 1:100-year flood event. This figure demonstrates that most bridges and culverts have been designed to withstand peak discharges much larger than those experienced across the road network.

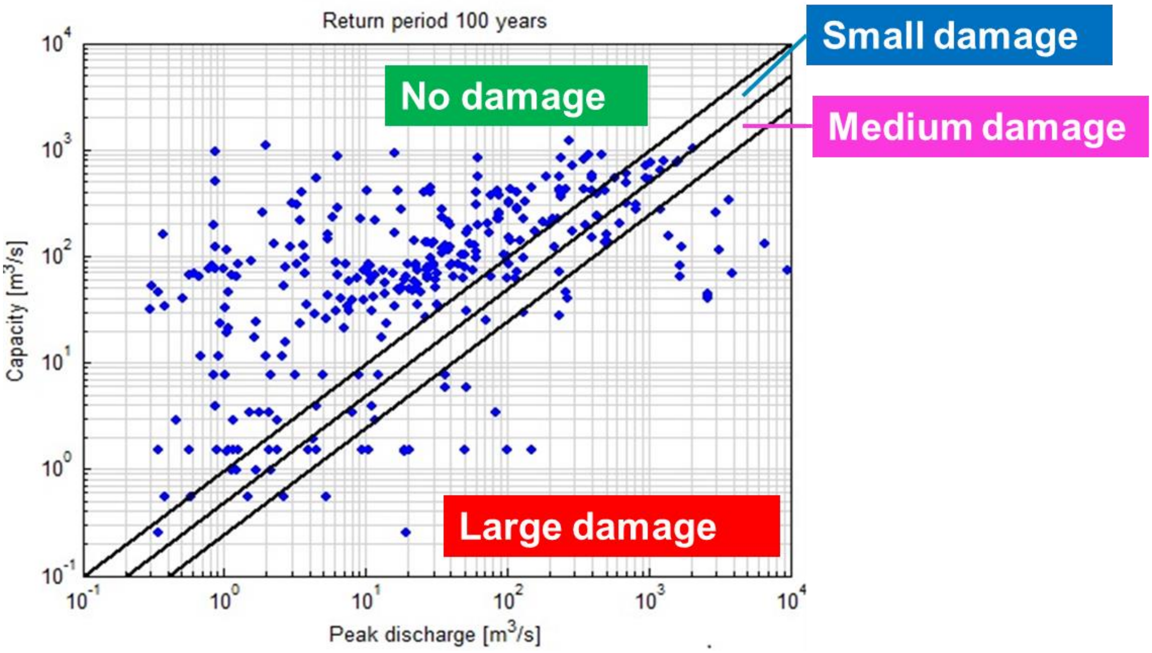

Figure 4.8 Plot of 1:100-year peak of peak fluvial discharge against the design flow capacity of analysed bridges and large culverts, indicating expected damage classes

Nevertheless, the sensitivity of the system to changing precipitation patterns could result in some assets ‘tipping’ over into the next damage class under future conditions. To ascertain any impacts of climate change on the damage class for the affected culverts, the analysis above was repeated for both RCP 4.5 and RCP 8.5 conditions. Figure 4.9 presents these outcomes in terms of the incidence of damage in each of the classes across the entire road network for four return periods of peak discharge. The analysis demonstrates that there are relatively few changes in the number of bridges and culverts switching damage classes due to climate change. Moreover, under RCP 8.5, the incidence of large damages mainly decreases relative to the reference situation for most return periods. This is not unsurprising, as any precipitation increase would need to yield peak fluvial discharges approximately 50-100% greater than those present in the reference case to force a relative increase in the damage classification for each bridge or culvert.

This suggests that the anticipated changing precipitation patters will not exert significant influence on the calculation of AED as it has been performed in this project. Although uncertainty exists, its degree is minor, such that it will have little bearing on the timing of any discharge-related ‘tipping points’ in the system. The risk of implementing measures that result in undersized or stranded assets is extremely small in terms of climate uncertainty. As such, we see little benefit in proceeding further with the DMDU analysis as it relates to fluvial impacts on expected damages.

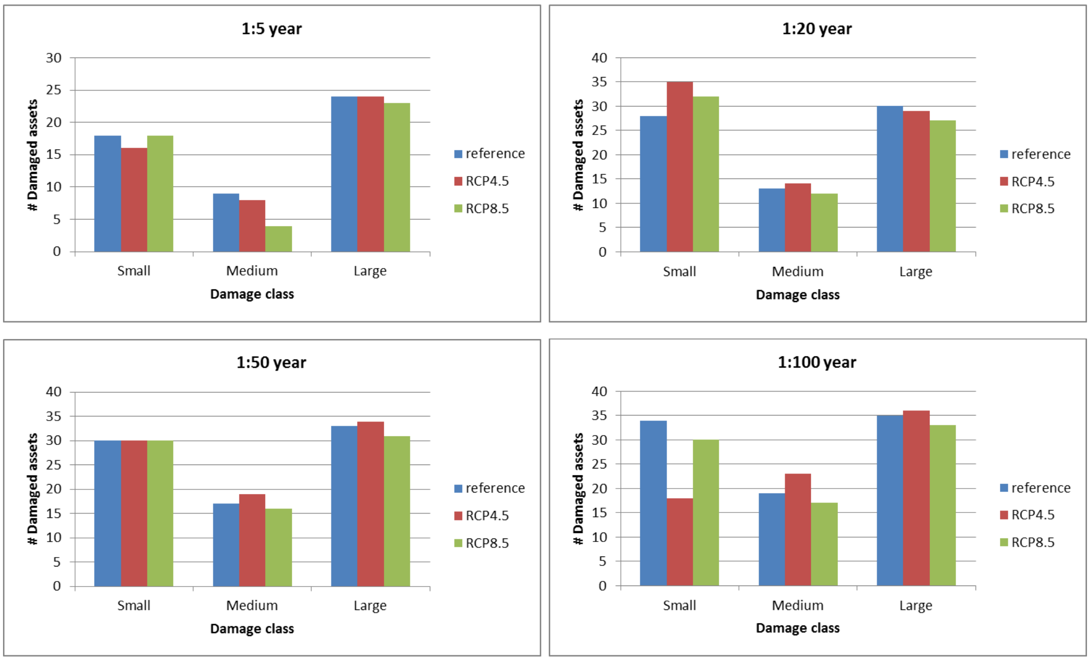

Figure 4.9 Numbers of damaged assets for the three damage classes per peak discharge return period under climate conditions subject to no forcing (reference), and RCP 4.5 and RCP 8.5

Moreover, as Table 4.23 illustrates, most bridges and culverts in the Albanian road network are well-designed. It is only a relative minority of assets that are undersized and could benefit from being upgraded to convey greater peak discharges. Priority for these upgrades should go to the corridors 3, 4, 5, 6 and 7 as per the results of the risk assessment presented in the Part 1, and could occur as part of a regular process of network asset management and upgrade as per the analysis presented in chapter 4.4.

Landslides

The landslide hazard assessment carried out in this project was based on an analysis of susceptibility. As such, an explicit consideration of the impacts of changing precipitation patterns on future landslide hazards was not possible within the scope of the DMDU analysis.

4.5.2.2 Economic growth

Uncertainty in the future of the economic growth rate influences the number of vehicles using the Albanian road network and, hence, potential damages incurred across all three hazard types. Under the GDP methodology applied for traffic forecasting, an increase/decrease in economic growth will result in a commensurate increase/decrease in traffic volumes (subject to the demand elasticity applied), as well as the relative costs and benefits of any mitigation measures taken/not taken.

To ascertain the sensitivity of the economic analysis to changes in traffic volume, we undertook an initial assessment of the impacts of varying the economic growth rate on the benefit-cost ratios (B/C ratio) for hazard mitigation in selected corridors (Table 4.24). Assuming it becomes feasible to act with a B/C ratio greater than 0.8, acting in corridor 5 makes sense for growth rates of approximately 2% and above, while for corridor 6 this only occurs for growth rates greater than approximately 4%. It remains infeasible to act in corridor 13 even for unlikely growth rates of 12%, while in corridors 1 and 14; implementation feasibility is only reached at growth rates of approximately 11%. Given the IMF forecast of an anticipated 4.7% growth rate for the coming five years, the below results also suggest a relatively small B/C ratio sensitivity to small (1% – 2%) changes in *plausible* growth rates for each transport corridor. The feasibility or otherwise of acting will by-and-large remain unchanged for anticipated ranges of plausible growth. As such, we see little benefit in including the impacts of economic growth uncertainty within the framework of the analysis.

Table 4.24 Impact of different economic growth rates on B/C ratio for selected corridors for a 25-year time horizon

Corridor	2%	4%	8%	12%
01 Milot - Morine New	0.2	0.3	0.6	1.2
05 Durres - Vlore	0.8	1.1	2.1	4.4
06 Tirana - Elbasan - Pogradec	0.6	0.8	1.6	3.3
13 Milot - Peshkopi	0.1	0.1	0.2	0.3
14 Vlore - Sarande	0.2	0.2	0.4	0.9

Moreover, if we consider the implications of economic growth in terms of actual traffic volumes, the usefulness of assessing the present road network's robustness against varying future traffic volumes becomes questionable. Assuming equal growth in travelled distances, Table 4.25 demonstrates that 2% economic growth nominally leads to a traffic increase after 25 years 1.5 times the present-day. Growth of 4% leads to an approximate 2.5 times traffic increase, while 8% delivers ~5.5 times the number of vehicles using the roads. Naturally, the present road network has not been sized to handle traffic demands of this magnitude. With growth rates higher than 3% (doubling), increased traffic flows after 25 years will likely mean the road network will already have needed to be augmented in many locations via road widening, duplication and so forth. A complete, comprehensive future traffic analysis is required to determine the necessary road design capacity requirements for each of the main transport corridors under these conditions. The climate resilience of any such asset augmentations would need to be assessed during their design, and adequate provisions made. Such an analysis of road network capacity falls well beyond the scope of this project, assessing the climate resilience of present network assets.

Table 4.25 Influence of economic growth rate on traffic volume after 25 years

GDP	Change in Traffic compared to present day (multiplier)
4.7% - 3.8% (applied in the economic analysis)	2.63
2%	1.56
4%	2.41
6%	3.70
8%	5.62
12%	12.75

5 Conclusions, Recommendations and Areas for Improvement

Coastal flooding conclusions and recommendations

- The coastal flooding analysis shows only a limited extension of vulnerability to coastal flooding, not posing a major risk to the primary road network. However, although the primary road network is not at risk, note that lower class roads (secondary or local) in the areas in the North of Albania (Shkoder area) could be vulnerable to flooding from the rivers in times of high Storm Surge Levels. Similarly, the area around Durres harbour also seems prone to coastal flooding that could result in impact to the lower-class roads in that area. Having the roads in these two areas that are prone to coastal flooding at sufficient elevation may allow for effective evacuation before and during the event and response/ rebuilding after the event.

Fluvial floods conclusions and recommendations

- The fluvial flooding risk analysis looked at bridges and major culverts. Based on the CBA results, all suggested locations warrant a replacement of the culvert. For practical purposes, the road operator could start with implementing the measures in order of decreasing B/C ratio. Note that the analysis shows that reduced repair cost in itself provides sufficient benefits to justify the investments in the replacement of culvert with inadequate design capacity.
- The sensitivity analysis for replacement of culverts shows that the replacement for the identified culvert is a no-regret decision under all circumstances

Seismic conclusions and recommendations

- The analysis showed that bridges have some vulnerability to seismic events. There is very little impact to be expected for culverts, tunnels and roads from seismic hazards in Albania.
- Retrofitting/ strengthening of existing bridges requires detailed analysis of the bridge design and is therefore situation/ bridge specific. Within the context of this analysis we have therefore not suggested any measures against the effects of seismic hazards. However, should an earthquake result in bridge collapse, it is common sense to build the bridge back better i.e. according to updated/ current seismic standards and design codes.
- Adequate inspection of bridges to check for signals that the bridge is no longer up to design specifications, e.g. cracks and metal fatigue, may allow for timely repairs and prevent unexpected collapse.

Landslides conclusions and recommendations

- The landslide risk analysis focussed on the damage to the roads themselves. Based on the current CBA only corridors 5 and 6 warrant investment of measures against landslides. A sensitivity analysis also shows that only measures for corridor 5 and 6 are potentially economically feasible.
- Measures that serve multiple hazards like reforestation (which may also reduce the risk for floods) could be efficient. However, this could not be assessed at this point as sufficient information (how much is needed, how effective) is not available.

Decision Making Under Deep Uncertainty

- The principal drivers of uncertainty for the Albanian road network include climate change (coastal inundation, fluvial flooding), seismic activity (earthquakes, landslides) and economic growth (traffic demand). Sensitivity analysis of their respective impacts reveals these are anticipated to be either insufficient or not to vary significantly in time to warrant further analysis using the analytical methods adopted for the assessment.
- Prioritised measures should be implemented where they will yield most benefit and are economically feasible, in targeted hotspot locations (e.g. for landslides), or alternatively when a regular process of asset management offers the opportunity to upgrade/remedy vulnerable assets at minimum cost. In the case of the latter, any residual system vulnerabilities may then be gradually removed from the system as a part of regular road maintenance.

Action planning

- Based on the results of the analyses, the following Table 5.1 provides a presentation how resilience building activities could be prioritized using AED (€/km) and criticality to prioritize actions. The tick marks in the 'damage' columns for flooding and landslides indicate if significant damages are to be expected. The tick marks and crosses in the 'interventions' column indicate if a CBA was executed and whether the CBA was positive or not. A green tick mark indicates a B/C ratio > 1 (i.e. a positive CBA), an orange tick mark indicates a B/C ratio that indicates a positive CBA under specific circumstances and a red cross indicates that the B/C ratio was too low to warrant taking measures from a CBA point of view.
- Actions for corridors 4 and 5 have the highest priority based on high scores for AED (€/km) and criticality.
- For flooding, all actions are economically feasible based on the B/C ratio. However, flooding measures in corridor 2 are not economically feasible based only on repair costs. However, if the economic damages due to service interruption are also taken into account then the B/C ratio becomes sufficiently favourable to take measures.
- For landslides, taking measures for corridor 5 are economically favourable. However, corridor 6 has a B/C ratio just below 1. As corridor 6 has a relatively high criticality, this can also motivate a decision to implement measures for this corridor. For corridors 1, 13 and 14, the B/C ratio is never high enough to warrant investing in measures from an economic point of view. Furthermore, the corridors 13 and 14 also have a relatively low score for criticality, further reducing the feasibility of risk reduction measures.

Table 5.1 Summary of risk analysis (AED), prioritization (criticality) and B/C ratio of proposed measures

Corridor	Length (km)	AED (€/km) ('000)	Criticality	Floods		Land slides	
				Damage	Intervention	Damage	Intervention
01 Milot - Morine New	104	3.3	42			✓	✗
02 Shkoder - Puke - Kolsh	126	1.0	24	✓	✓ (orange)	✓	
03 Milot - Shkoder - Muriqan	127	12.8	37	✓			
04 Tirana - Durres	32	59.1	53	✓	✓		
05 Durres - Vlore	152	69.0	52	✓	✓	✓	✓
06 Tirana - Elbasan - Pogradec	139	24.9	42	✓	✓	✓	✓ (orange)
07 Fier - Gjirokaster - Kakavi	128	10.6	37	✓	✓		
08 Gjirokaster - Sarande - Ksamil	58	1.4	39	✓			
09 Elbasan - Gramsh	41	0.7	26				
10 Lushnje - Berat - Çorovode	86	4.1	24	✓	✓		
11 Rrogozhine - Elbasan	40	0.9	37				
12 Shkoder - Hani i Hotit - Vermosh	125	2.3	40	✓	✓		
13 Milot - Peshkopi	136	5.3	30	✓	✓	✓	✗
14 Vlore - Sarande	131	2.4	39	✓	✓	✓	✗
15 Pogradec - Korce - Kapshtice	69	1.0	45				

Experiences and lessons learned from this study

- One corridor specific measure that was not taken into account is the possibility of increasing the redundancy in the primary road network in order to reduce additional travel time in case of an event. This is especially relevant for corridor 5 and corridor 14.
- Next to the risk assessment, the criticality that was established through the input of the stakeholders with the Albanian roads sector proved an adequate tool to assist in prioritising investments between the different corridors
- Based on our experience during the risk analysis, where we were confronted with a lack of data concerning hazards and their consequences, we recommend a number of subjects that could be recorded in the RAMS that would improve the quality and efficiency of a similar future analysis. We therefore suggest to record the following information:
  - Date & location of damage
  - Cause of damage
  - Extent of damage
  - Repair costs
  - Duration of interruption
  - Duration of repair
  - Possible duration of reduced capacity (or interruptions) during repair
- Before further steps for investment, a more detailed assessment of proposed measures is recommended.

- As the length and effectiveness of measures play an important role on the economic viability of resilience measures for landslides, it is important that a more detailed investigation of landslide probability for the corridors is conducted in the field. Parallel a detailed assessment of measures to increase resilience against landslides is required. Furthermore, a more detailed traffic model could assist in identifying in higher detail, than the currently used level at corridors, the economic viability for measures for the separate road segments.
- For floods the current assessment should be completed with an inventory in the field to verify the modelled discharges and design capacity. Moreover, potential damages from larger scale inundation for areas that are prone to large scale inundation should be assessed. This would require more detail in the longitudinal profiles of the different road segments.

Area for Improvements

- A number of measures were not taken into account for the CBA due to lack of information and/ or lack of the required information to determine the amount of the measure needed. Such measures include preventative measures, reforestation of slopes, erosion protection, build back better, etc. Although these measures were not taken into account for the CBA, they should be further investigated, especially when looking at the road profiles and geomorphological conditions of the areas adjacent to the road and specific characteristics of the catchment areas draining to the road assets like culverts and bridges.
- Technics to reduce the uncertainty in the CBA assessment for fluvial flooding:
  - Improving the peak flow calculations by comparing to actual peak flows. This requires data collection in the field (flow gauges) under peak rain conditions.
  - Improving peak flow calculations by taking the effects of dams and their impact on peak discharges into account. This will require coordination with the dam operators.
  - Improving the characterisation of the catchment area. Especially those locations that now show significantly too low design capacities, as compared to the calculated peak flows, are possibly incorrect.
  - Improving damage functions by basing these on actual historical data. Again, this requires collection of field data and assessment of damages after critical events.
  - Improving the costs of the measures based on a detailed, location specific design. Note that the CBA is based on key numbers for generic measures. Actual measures might be different from initial assessment as they need to be tailored to the local situation. As a result an updated CBA should be made which should be based on the updated cost of the tailored, location specific measure.
- Technics to reduce the uncertainty in the CBA assessment for landslides:
  - Improving the landslides risk analysis by basing it on a more extensive historical database. This will also allow for validation of the landslide hazard probability in connection with the landslide susceptibility map
  - Improving the damage functions by basing these on actual and extensive historical data. This will require collection of field data and assessment of damages after landslide events.

- Improving the costs of the measures based on detailed, location specific design. Note that the CBA is based on key numbers for generic measures. Actual measures might be different from initial assessment as they need to be tailored to the local situation, even more so than for fluvial flooding. As a result an updated CBA should be made which should be based on the updated cost of the tailored, location specific measure.

Appendix A: Risk Assessment Methodology and Analysis

A.1 Introduction

To assess the vulnerability of the primary road network in Albania, the annual expected damage (AED) is calculated for each of the corridors from the three identified types of natural hazards; floods, landslides and earthquakes. The levels of AED for the different corridors reflect the vulnerability of the road network in Albania. The AED is calculated according to the physical damages caused to the road asset by different hazards and the economic damages that result from a disruption of service of the corridor and the resulting vehicle loss hours. The duration and the intensity of the disruption depend on the intensity/ scale of the hazard and the vulnerability of the road/ corridor to the specific hazard.

The following sections describe in detail each of the methodological approaches including: (1) economic impact of disruption, and the risk assessment (calculation of AED) from (2) flooding, (3) earthquakes and (4) landslides. This section finishes with a brief description of the methodology used to determine the socio-economic criticality of each corridor.

A.2 Economic Impact of Disruption - Approach

The economic impact of the disruption of the corridor depends on both the traffic intensity and the duration of the disruption and the additional distance to be travelled on the diversion. Thus, the economic impact of the disruption of a certain duration of a corridor with high traffic intensity, such as a road leading to the national port, will be larger than the disruption of the same duration of a corridor where there is low traffic density. The extent of the damages is calculated based on a traffic model which analyses the additional travel time and distance needed from the use of alternative routes to bypass the disrupted part of the corridor. The methodology is illustrated in Figure A.1, outlining the damage from the impact of the hazard on the road asset and the disruption of services.

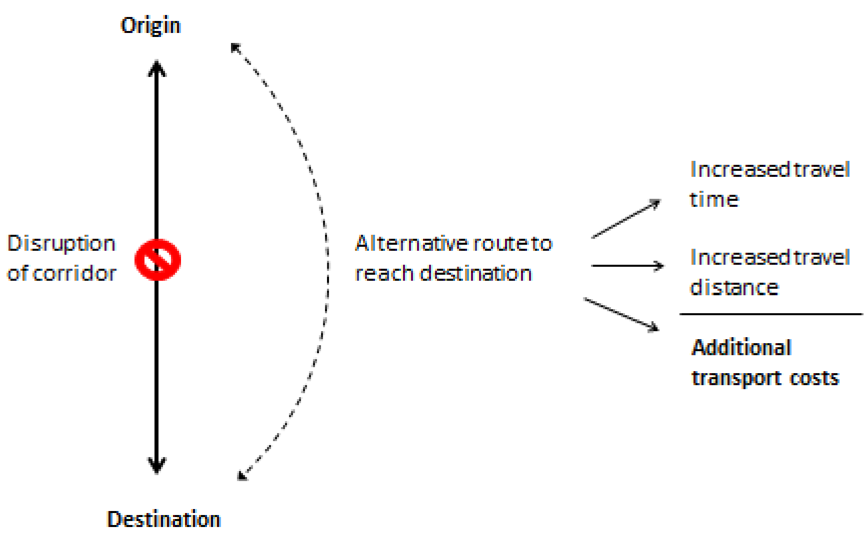

Figure A.1 Traffic analysis methodology

To calculate the expected transport damages that result from the interruption of services from the natural hazards we need to have regard for the following components:

1. A network and zoning system – to determine the primary road network of Albania in corridors, to establish origin/ destination matrices, including border crossings;
2. Traffic demand analysis – to determine the current use (demand) and forecast future demand, the traffic volume of the corridors, transport characteristics such as travel motive, vehicle types;
3. Economic factors for valuation – to be able to assess the increased travel time and distance to a monetary value;
4. Natural hazards – the effects of the different hazards on the corridor in terms of impact, duration of disruption of services and probability of the event.

In the calculation of the additional time and distance in case of a diversion, the assumption is made in the model that only one corridor at a time will be blocked. In the model, secondary roads are used as alternative routes but impacts of the hazards on the secondary roads are not taken into consideration.

A.2.1 Traffic demand analysis

The vehicle fleet in Albania has increased very rapidly over the past decades. The number of vehicles doubled in 2016 compared to 2007. Table A.1 and Figure A.2 present the growth of types of vehicles over the period 2007 - 2016. The car growth in the last five years has been 8-9% per year. The sudden decrease in the number of minibuses followed after a change in law, in which it was no longer allowed to use minibuses for public transport between major urban centres of Albania.

Table A.1 Number of vehicles in Albania over the period 2007 - 2016

Year	Cars	Buses/Minibuses	Trucks and Vans	Motorcycles	Total
2007	237,932	29,506	68,329	13,859	349,626
2008	264,828	6,645	88,258	18,329	378,060
2009	281,236	6,598	89,867	20,874	398,575
2010	294,729	7,035	94,699	24,022	420,485
2011	300,974	6,723	79,124	24,009	410,830
2012	297,341	5,279	66,538	25,492	394,650
2013	341,691	5,713	72,074	26,664	446,142
2014	378,053	6,093	76,003	30,975	491,124
2015	403,680	6,477	78,839	33,070	522,066
2016	436,013	7,050	83,889	36,096	563,048

Source: INSTAT

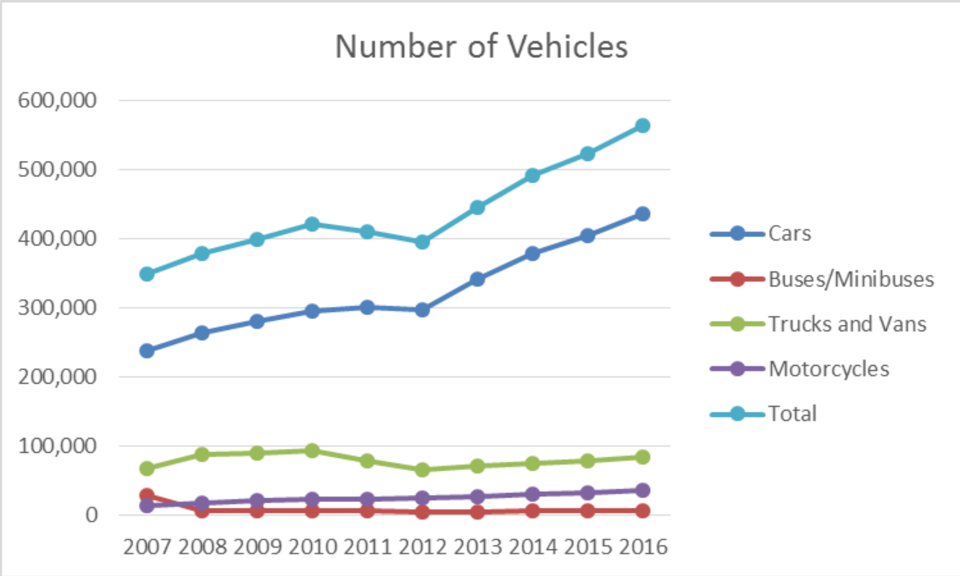

Figure A.2 Number of vehicles in Albania over the period 2007 - 2016

There are some issues with the actual number of vehicles in circulation in Albania, since many of the demolished vehicles are still registered in the National Vehicle Database. Currently the number of cars is about 160 passenger cars per 1,000 inhabitants. Albania still has a relatively low number of cars per 1,000 inhabitants in comparison with neighbouring countries that have about 300-350 cars per 1,000 inhabitants.

The number of vehicles for the studied corridors is based on the data collected during the Road Side Surveys carried out in April 2018. Traffic volume data have been recorded by Automatic Traffic Counting equipment for a seven-day period, to acquire the weekly variation pattern of traffic. The traffic during this period is multiplied by a factor to correct for seasonal influences to obtain the Average Annual Daily Traffic (AADT). This is done in accordance with the procedures as determined in the yearly assessment during the Albanian National Transport Plan Report.

The road sections that are used for the modelling in this study closely follow the system used by the "Review of Albanian National Transport Master Plan Study" (ANTP-2). It includes 39 internal centroids representing the administrative Districts of the Country, and 14 external stations denoting the main border stations, ports and the Tirana International Airport.

A.2.2 Methodology for Demand Forecast

The methodology applied for traffic forecasting is based on the gross domestic product (GDP) and the elasticity of demand to GDP. Commonly known as the GDP methodology, it recognizes the direct effect of economic conditions or regional travelling and is suitable for both passengers and freight.

In the present case, GDP growth rates of any one year are multiplied with the elasticity of demand for travel (by light vehicles, buses and trucks) pertaining to that year. The results derived thus express the annual growth of the respective traffic for the following year.

It is worth noting that the same growth rates were applied to internal, external, and transit traffic. This approach conveys the assumption that external and transit traffic are anticipated to be significant, in recognition of the strategic role of international and trans-European corridors through the Country in the future.

According to international experience, passenger demand elasticity may vary from 1.30 - 1.20 in the initial year to 0.80 in the last year of a 35- to 40-year study period. In the case of Albania, the following elasticity[40] was adopted:

- Light vehicles: 1.2 in period from 2018 to 0.80 in 2033
- Buses: 1.2 in period from 2018 to 0.80 in 2033
- Trucks: 1.0 in period from 2018 to 2033

GDP Growth of Albania was very steady from 2009 to 2015. IMF forecast foresees a GDP growth which goes up to 4.7 % for the next 5 years. The rest of GDP forecast is estimated by the Consultant. The following table shows the GDP forecast for Albania in the next 15 years.

Table A.2 GDP growth in Albania 2018 - 2033

	2018-2028	2028-2033
GDP	4.7%	3.8%

Source: International Monetary Fund

The combination of these factors sees almost a doubling of all vehicles in Albania in the period from 2018 to 2033. Assuming equal growth in travelled distances, this means that damages in 2033 will double in nominal terms over this period.

A.2.3 Economic valuation factors

To translate the increase in travel time and distance to a monetary value we need to determine the value of travel time (VoT) and the value of vehicle operating costs (VOC) for the three types of vehicles (cars, trucks and buses) and travel motive (work related or private). These values are expressed in monetary terms (€/hour).

Value of time (VoT): The VoT refers to the cost of time spent (by the driver) on transport. Travel time is one of the largest categories of transport costs, and time savings are often the greatest expected benefit of transport improvement projects. In our calculations we come up with two values: one for travel time during work hours (paid hours) and one for travel time outside of work hours. The latter category includes leisure, holiday, and commuting trips. The VoT of trips made during “work” hours is higher than the VoT of trips made during “non-work” hours. They are based on the average salaries of state employees and on the following assumptions:

- Cars are assumed to have two persons riding together, while buses have on average 20 passengers
- In general transport motive is 25% business related, while 75 % is for commuting or leisure
- VoT for trucks is determined based on costs of cargo transport as found in different European countries and adjusted for the purchasing power parity (PPP) for Albania

[40] *Elasticity is assumed to change linear over time*

VoT for trucks

The value of time for transport of cargo with trucks differs from cars, as the primary reason is not the transport of persons but of goods. Costs are quantified through delays in delivering cargo at its destination on time. Although VoT data for Albania is available for cars and buses, no data is available for transport of cargo. Therefore, use is made of European data to estimate VoT for trucks in Albania. To calculate the VoT for trucks, data from the EU and the Netherlands was used, which was converted using purchasing power parity (PPP) to make them applicable for Albania.

Value of vehicle operating costs (VOC): The VOC refers to the costs that vary with the vehicle usage. The main factors included in these calculations are fuel costs, oil costs, tyres, spare parts, and overhead costs. Many of these costs are mileage-dependent costs. The values for the VOC are shown in Table A.3 and are based on the following assumptions:

- An average travel speed of 60 km per hour
- An average fuel usage per vehicle category

Table A.3: VoT and VoC in Albania for cars, trucks and buses

	Car	Truck	Bus
VoT (€/h)	2.58	19.40	25.79
VoC (€/h)	8.28	25.32	27.87

A.2.4 Modelling process

To obtain vehicle loss hours and additional distance travelled a traffic model was used. The modelling process was done using TransCAD[41] version 8 transport modelling software.

The traffic Assignment was carried out following an "all-or-nothing" procedure which assumes that traffic follows the shortest path from origin to destination in the use of the diversion and that the original corridor is completely blocked. The modelling procedure was performed for cars, buses and trucks for each scenario. For each scenario a specific link (corridor) is closed and traffic follows the remaining corridors and the secondary network. There are 15 scenarios in which it is assumed the specific corridor is closed for one day and calculate the time lost and additional distance travelled for closure of the specific corridor. The outcome of this modelling exercise is used in the calculation of the impact of the hazards on the corridors.

The period of interruption and the modelled damages are used to calculate the economic losses from service interruption per corridor. Whereas repairs are a function of the damages that are specific for the type of road (surface type, two or more lanes, etc.) the economic damages are a function of the traffic flow of the specific corridor. In the assessment of the economic damages from interruption of services we assume that one (or more) damage(s) to the road results in a temporary limitation of the capacity or complete shutdown of the entire corridor for a specific period, depending on the seriousness of the damage. For floods and landslides damages are categorised into three classes, small, medium and large. A "small" damage will result in a temporary limitation of the capacity resulting in a delay in passage for the corridor for 1 hour during a time span of 1 day. A

[41] *https://www.caliper.com/press/pr20180308-transcad.htm*

“medium” damage will result in the complete shutdown of the corridor for 1 day, which will necessitate the use of an alternative route. The additional time and distance travelled are the results as modelled with the traffic model. A “large” damage is the shutdown of the corridor for 1 week and delay in passage for the corridor for 1 hour for the remainder of a month (i.e. 23 days). For earthquakes the actual interruption of services for each type of road asset is determined by the earthquake model, which provides the actual repair time and period of interruption of services. See Table A.4 for the damages from the different types of impact for the different corridors

Table A.4: Characteristics and modelled losses in € for interruption of service per corridor

#	Corridor	Length (km)	# Vehicles	1 hour (€)	1 day (€)	1 week & 23 days (€)
1	Milot - Morine New	104	2,271	13,205	121,699	1,155,605
2	Qele - Puke	126	170	930	9,526	88,068
3	Milot - Shkoder	127	14,566	86,987	198,110	3,387,461
4	Tirana - Durres	32	40,602	238,851	234,949	7,138,207
5	Durres - Fier	152	15,338	99,696	2,258,276	18,100,939
6	Tirana- Elbasan	139	7,891	48,160	844,688	7,020,504
7	Fier - Tepelene	128	4,910	39,147	104,058	1,628,783
8	Sarande - Greqi	58	71	427	263	11,656
9	Elbasan - Gramsh	41	189	738	13,134	108,921
10	Lushnje - Gramsh	86	5,151	32,958	44,568	1,070,016
11	Rrogozhine - Elbasan	40	5,513	36,160	34,904	1,075,999
12	Shkoder - Hani - Hotit	125	4,695	28,645	-	658,844
13	Milot - Peshkopi	136	5,329	28,402	179,205	1,907,683
14	Vlore - Sarande	131	1,987	12,356	71,767	786,562
15	Pogradec - Korce	69	4,172	25,027	397,124	3,355,487

A.3 Flooding

A.3.1 Coastal flooding

A.3.1.1 Description of methodology

To assess the current and future coastal flooding hazard several flood maps were produced for different flood levels and return period under current and two climate change scenarios (RCP 4.5 and RCP 8.5). From (Vousdoukas et al, 2016) and LISCOAST[42] data storm surge levels (SSL) and sea level rise (SLR) projections were derived for the Albanian situation. These storm surge levels were combined with a digital elevation model as provided by the State Authority for Geospatial Information (ASIG) to produce coastal flood maps.

Based on these data several flood maps have been produced for storm surge levels as shown in Table A.5. An extreme scenario with a SLR of 3 meters has been added to assess a future "worst case" scenario. This extreme scenario does not have a probability, as it falls outside any current prediction.

Table A.5 Storm Surge Levels for different return period under RCP 8.5

Return period (~)	RCP	SSL
5 years	00 (current climate)	1.0 meter
100-1000 years	8.5 (2050-2100)	2.0 meter
Extreme	-	3.0 meter

A.3.1.2 Where may the coastal hazard affect the road

In Figure A.3 the flood depth map is presented for the extreme scenario with 3-meter increase in SSL. As can been seen from the figure the effect on the different corridors is very limited, even in the extreme scenario. Furthermore, the assessment does not take into consideration that roads are normally constructed at an embankment, especially in lower areas. Furthermore, this is a static analysis, roughness and duration of the event are not taken into consideration, thus overestimating the actual flood extend.

[42] http://data.jrc.ec.europa.eu/collection/LISCOAST

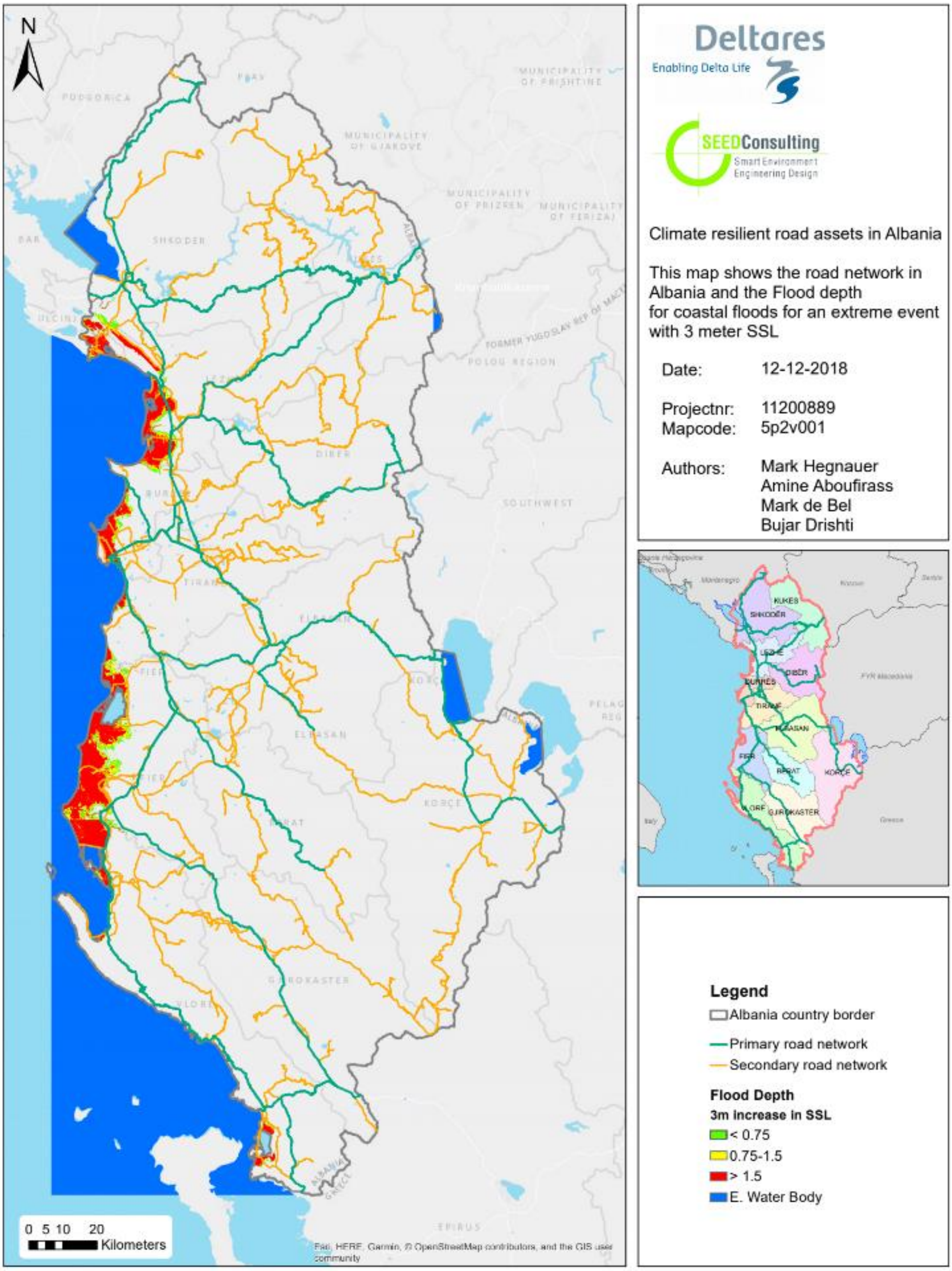

Figure A.3: Flood depth map for coastal floods for an extreme event with 3-meter SSL

For the area around Fier a more detailed assessment is made in which water depth at the road is indicated in the map, see Figure A.4. As the water level at the road is mostly less than 2 meters, also the detailed assessment shows little to no impact at the actual road body. When a more detailed embankment level of the different corridors will be available, this detailed assessment could be repeated to obtain a more detailed insight in actual exposure to coastal floods of the road assets.

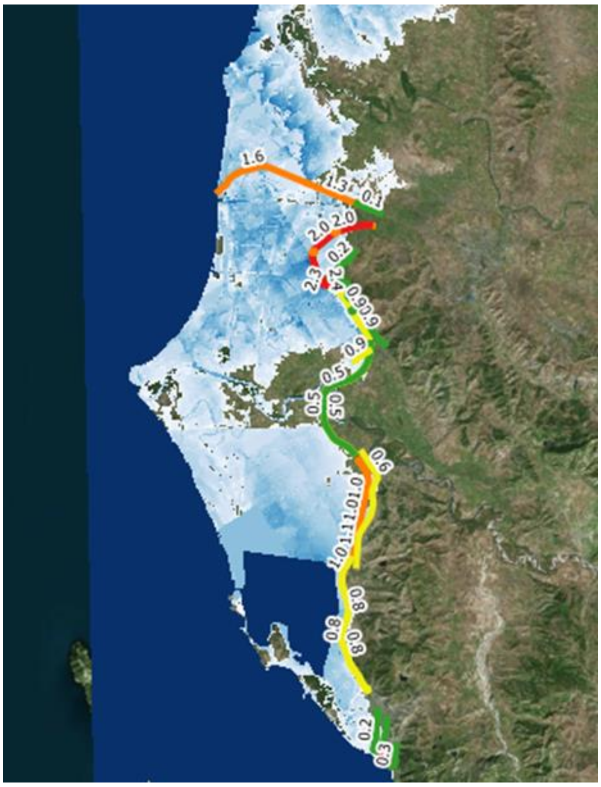

Figure A.4 Water depth at the road for an extreme scenario.

Based on this assessment it is concluded that there is no actual danger of damages from coastal floods for the road assets, neither under current climate condition, nor under an RCP 8.5 climate change scenario for return periods up to 1 in 1000 years. Therefore, no further assessment of coastal flood hazards will be made in this report.

A.3.2 Fluvial flooding

A.3.2.1 Description of methodology

To assess the fluvial flood hazard, we followed basically a four-step approach:

1) Geographical data collection and setup of a rainfall runoff model (*Wflow*[43]).
2) Rainfall and temperature data collection and analysis.
3) Peak flow estimation using the *wflow* model and collected meteorological input.
4) Impact assessment for the selected culverts and bridges (points of interest).

The steps are summarized in Figure A.5.

[43] *https://oss.deltares.nl/web/wflow/home/-/blogs/welcome-to-the-wflow-webpage*

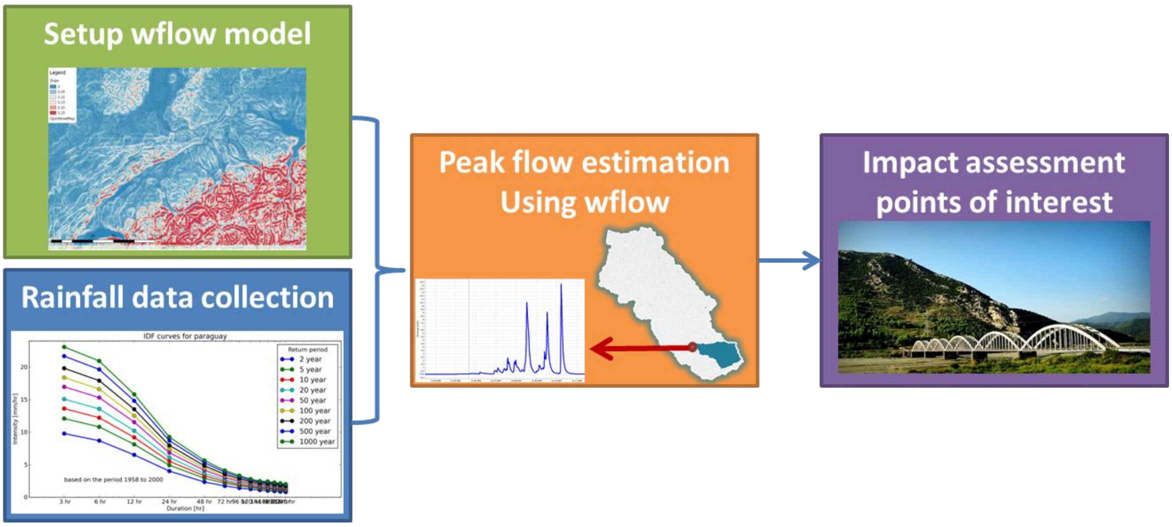

Figure A.5 Overview of the steps for estimating the fluvial flood hazards for the Albanian road network.

This approach is described in more detail in the following steps:

Step 1: Setting up the hydrological *wflow* model

To calculated discharge from the rainfall input, a hydrological model is used that covers the whole country of Albania and its upstream catchments. For this task, Deltares' open source hydrological modelling framework *wflow* (Schellekens et al., 2017) is used. *Wflow*[44] can be classified as a fully distributed, physically based hydrological model. In the model, the important runoff generating processes are included:

- Infiltration and exfiltration of water to or from the groundwater
- Snow melt
- Interception
- Routing of the water (both surface and subsurface water)

An overview of the processes in the *Wflow* SBM model is shown schematically in Figure A.6.

The schematization of the *Wflow* SBM model is based on SRTM (version 4, 30 meter) elevation data (Jarvis et al., 2009), land use data from USGS based on MODIS earth observations () and soil database from the FAO (). The river layer in the model is based on a combination of HydroSheds rivers () and Open Street Map data (). The model also uses a dynamic Leaf Area Index (representing leaf coverage per month), based on (Liu et al., 2012). The model resolution is 250x250 m^2.

No discharge data was available for any calibration or validation for the model. Therefore, the values for the model parameters were selected based on derived relationships between land use and soil types and runoff generation processes for different locations around the world. It is known that this method induces large uncertainty in the resulting discharge time series, especially in areas with very heterogenic soil types (e.g. Karts). The results should be evaluated very carefully and can only be used for this project. If data would be available, the model could be improved by calibrating the model results to the observed discharge time series.

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[44] *https://oss.deltares.nl/web/wflow/home/-/blogs/welcome-to-the-wflow-webpage*

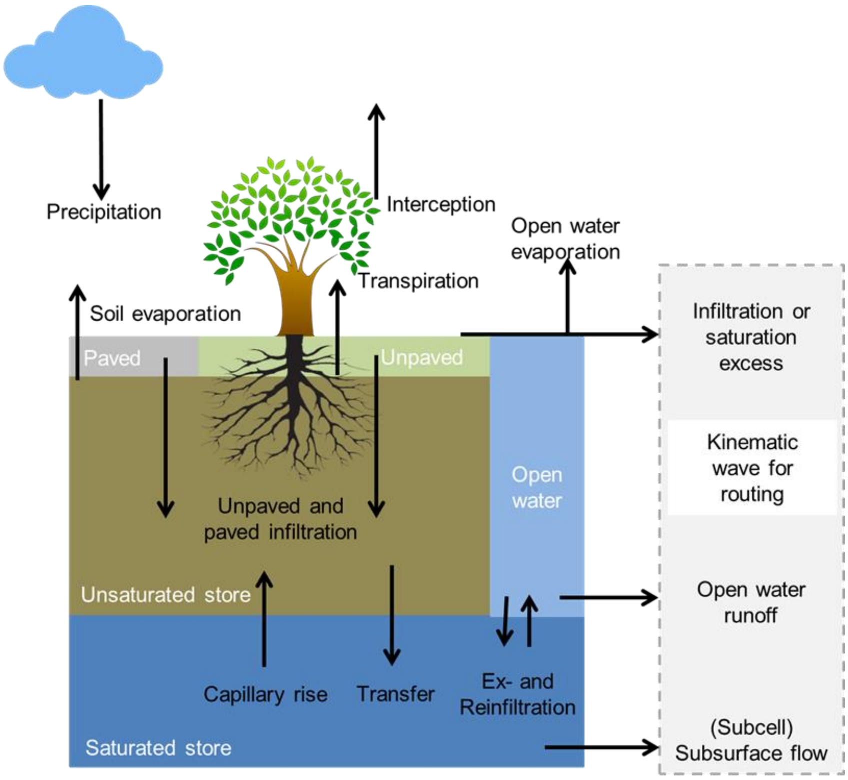

Figure A.6 Schematic overview of the processes in the wflow SBM model, used to simulate the runoff from rainfall. Snow melt processes are not included in the figure but are calculated in the model using a so-called degree-day factor method.

The model is forced with rainfall and temperature data from step 2. The model is run continuously daily[45] for the period 1980-2014. The result is discharge time series for the period 1980-2014 for all locations in the model (grid cells). Calculated discharge time series from the model can be seen for two locations in Figure A.7. The model generates time series like these for all points of interest.

The model also calculates the amount of snowfall and snow melt spatially and in time. This is an important process in the runoff generating process in Albania, especially when high rainfall coincides with higher temperature at the end of winter, inducing snow melt to increase the discharge in the rivers.

[45] *The wflow model can be run on hourly time step as well, but given the large uncertainty in the input data it was chosen to run the model on daily basis and correct output to translate from daily average to hourly runoff data.*

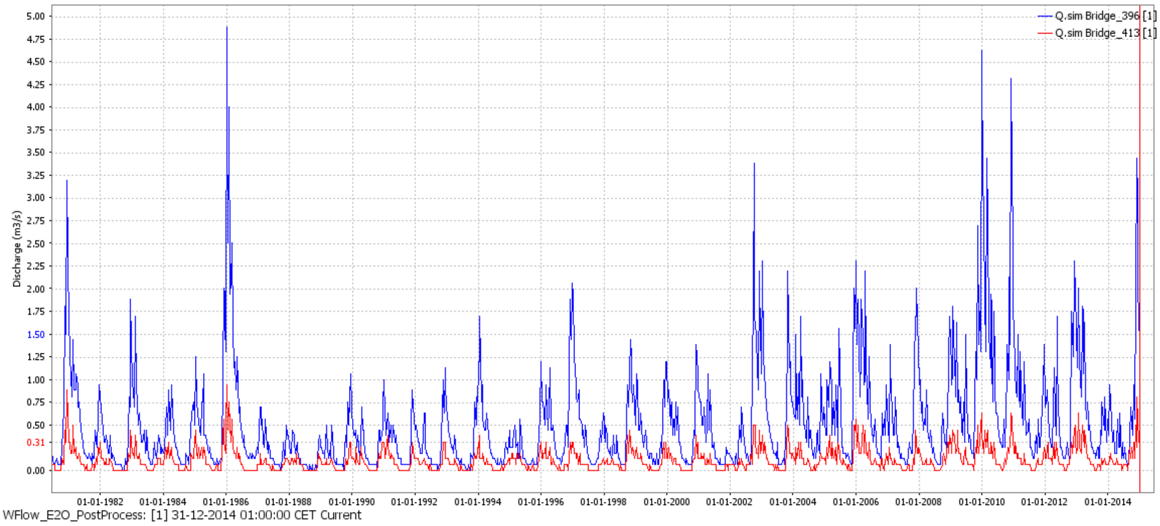

Figure A.7 Discharge time series (period 1980-2014) for two bridge locations in Albania.

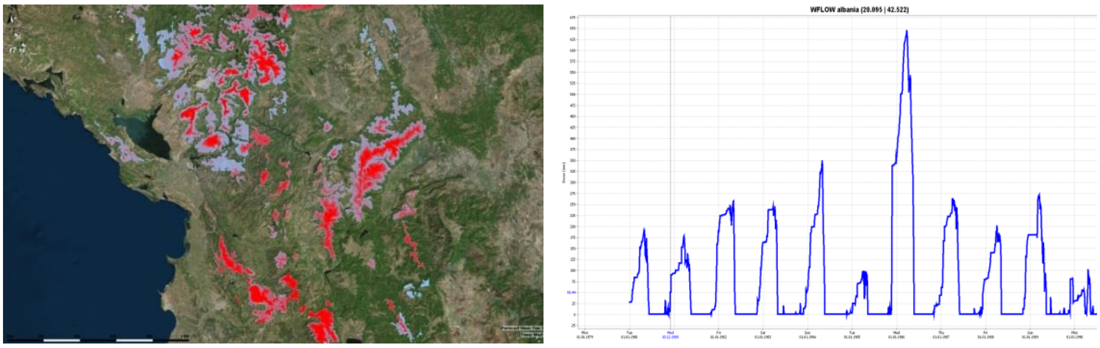

Figure A.8 Snow cover as simulated by the wflow model (left) and for specific location the temporal thickness of the snow pack over time.

Step 2: The meteorological data

The fluvial flood hazard is originating from rainfall or snowmelt events. Therefore, the rainfall and temperature data are crucial for the analysis. Unfortunately, no local data could be collected over the course of this project.

Global precipitation data was gathered on a 0.25 by 0.25 degrees lat-lon grid resolution (Beck et al., 2017). The data is available from 1980 up to and including 2014, so 35 years in total. Several precipitation statistics were derived for all 51 grid cells of which the centre was located within the Albanian border. Figure A.9, for example, shows the annual mean precipitation for each of the grid cells. It shows precipitation totals are highest north of the 41.5 degrees latitude line and south of the 40.5 degrees latitude line. Low annual precipitation totals are observed in the central coastal area and in the eastern most part of the country. Mean annual precipitation varies between 650 mm and 2100 mm.

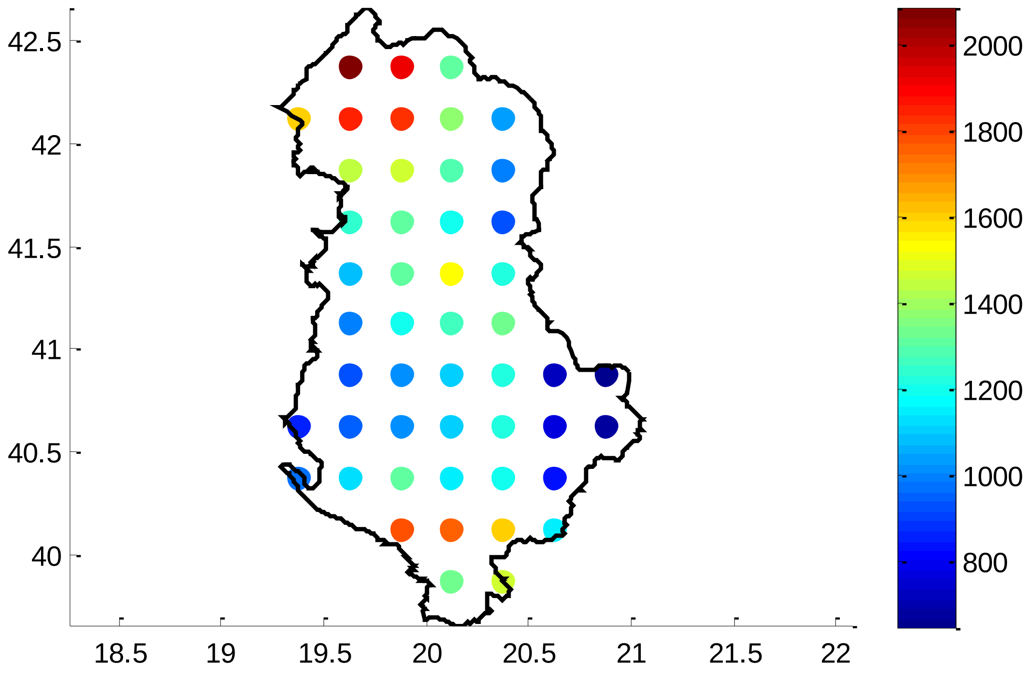

Figure A.9: Annual mean precipitation for 51 grid cells of 0.125 by 0.125 degrees lat-lon.

For flood risk analysis, maximum daily totals are more relevant than annual mean precipitation. For each grid cell, annual maximum daily precipitations were derived, and a Gumbel distribution was subsequently fitted to derive return values of precipitation for a range of return periods. The resulting 100-year return values are shown in Figure A.10. These vary between 60 mm and 180 mm. The spatial variation in Figure A.10 is very similar to those in Figure A.9, with highest values in the northernmost and southernmost parts of the country.

We suspect that actual 100-year return values are higher than the ones shown, because the data used here is “averaged out” over the grid cell, which typically results in lower peak values compared to point rainfall.

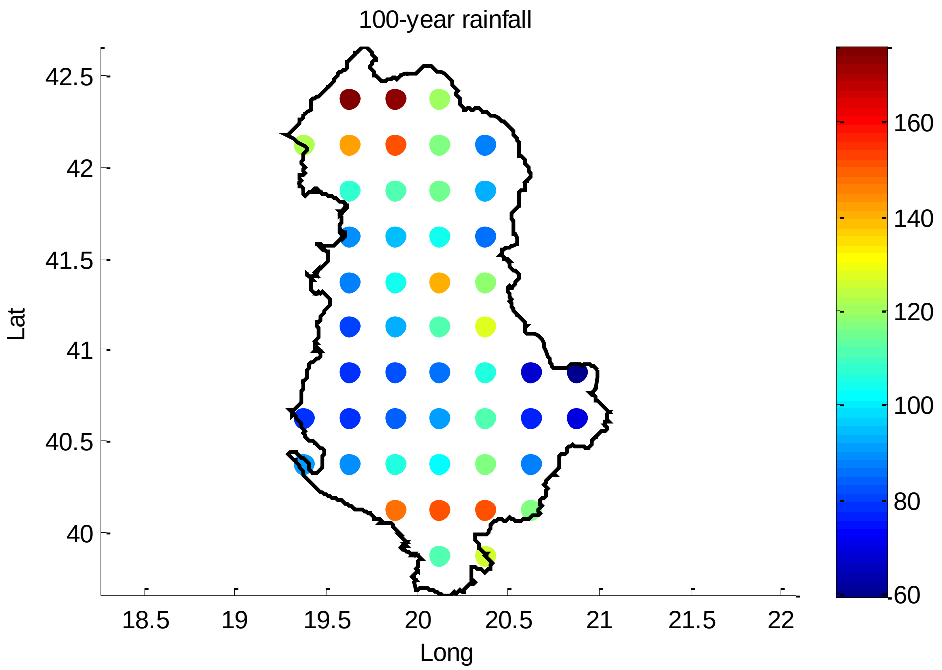

Figure A.10: 100-year return values of the annual maximum daily rainfall for 51 grid cells of 0.125 by 0.125 degrees lat-lon.

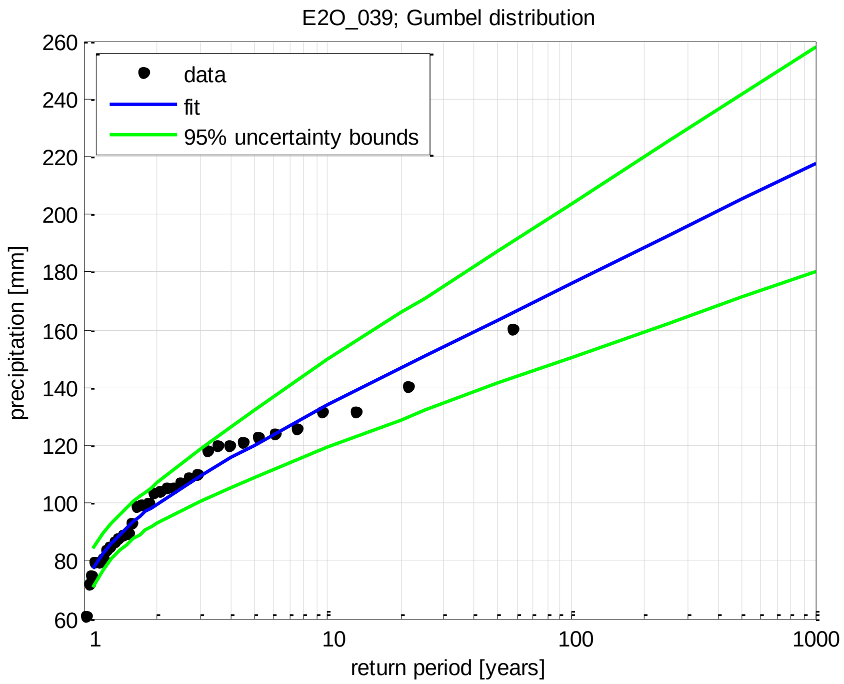

Figure A.11: Example Gumbel fit for annual maximum precipitation for one of the 51 grid cells

To assess the impact of future climate change on the fluvial flood hazard, the *wflow* model is also forced with rainfall data from two climate change scenarios, corresponding to RCP45 and RCP85 respectively. The climate data is derived from the EURO-CORDEX project (Jacob et al., 2013).

To overcome the bias correction issue, only the relative monthly change in precipitation was used. These changes were applied to the MSWEP dataset and used as input to the *wflow* model. In Figure A.12 and Figure A.13 examples of the climate change signal are shown for one month (September).

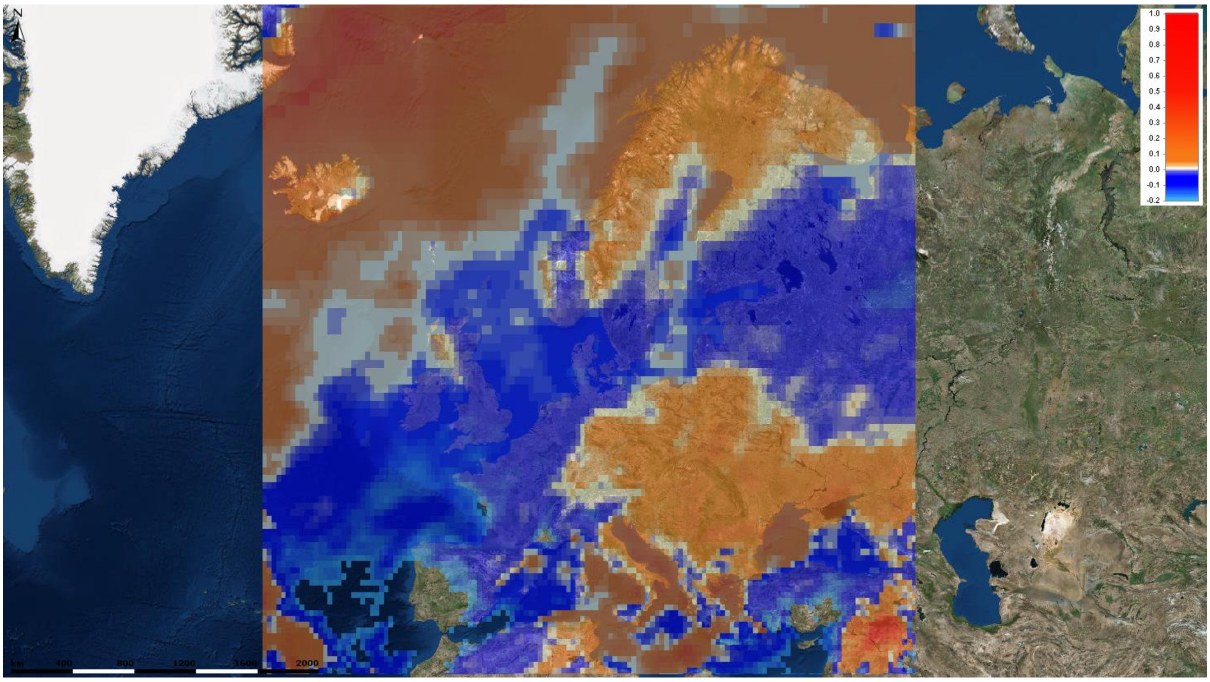

Figure A.12 Change in September precipitation for Europe, based on EURO-CORDEX dataset.

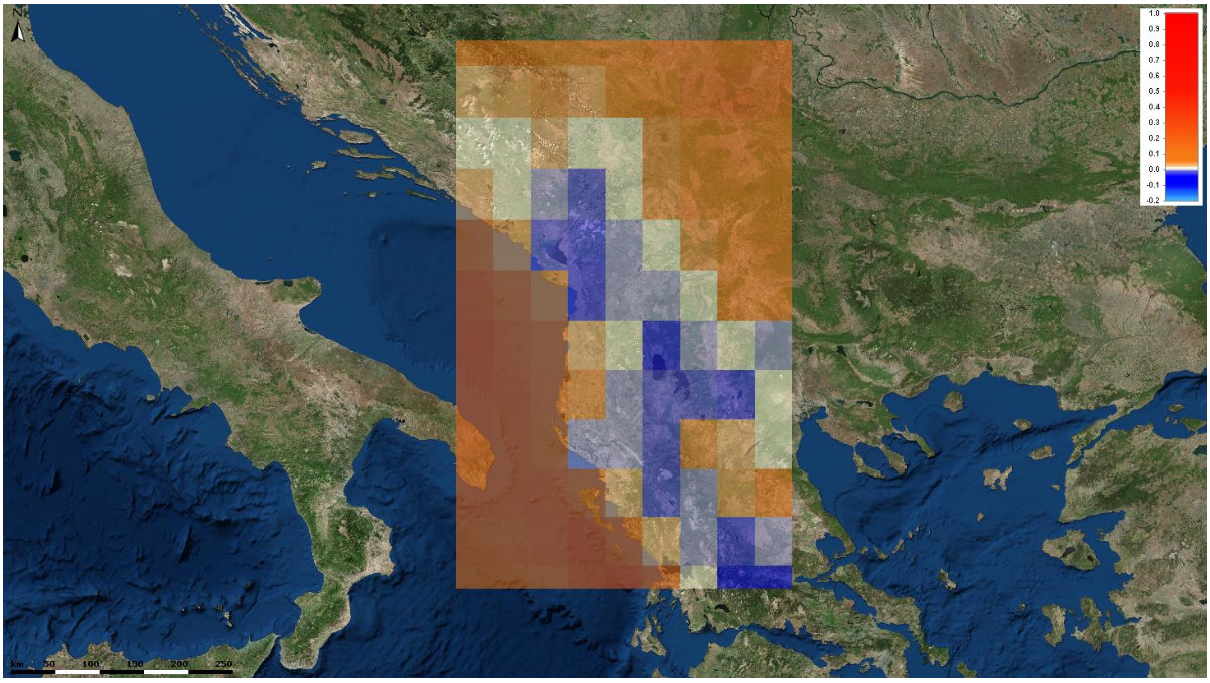

Figure A.13 Change in September precipitation for Albania, based on EURO-CORDEX dataset.

Step 3: Peak flow estimation for the points of interest

The 35-year rainfall data was used as an input for the hydrological *wflow* model, resulting in 35-year series of discharge at virtually any location in Albania. Discharge series for relevant bridges (284 in total) and culverts (103 in total) were selected. Subsequently, annual maximum discharges were derived, and Gumbel distributions were applied to derive return values of discharge at each location of interest. Figure A.14 shows the process of selected annual maximum discharges from the time series. Figure A.15 shows an example of a fit of the Gumbel distribution on the data.

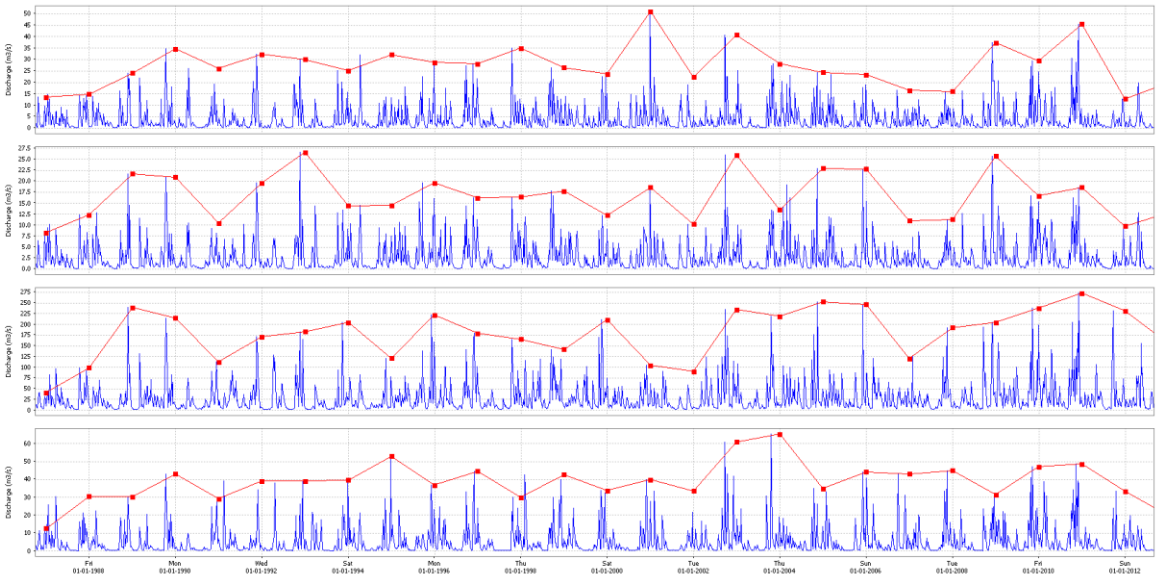

Figure A.14 Discharge time series (blue lines) and their annual maximum peak discharge (red markers) for 4 locations in the model (e.g. at the location of a bridge or culvert).

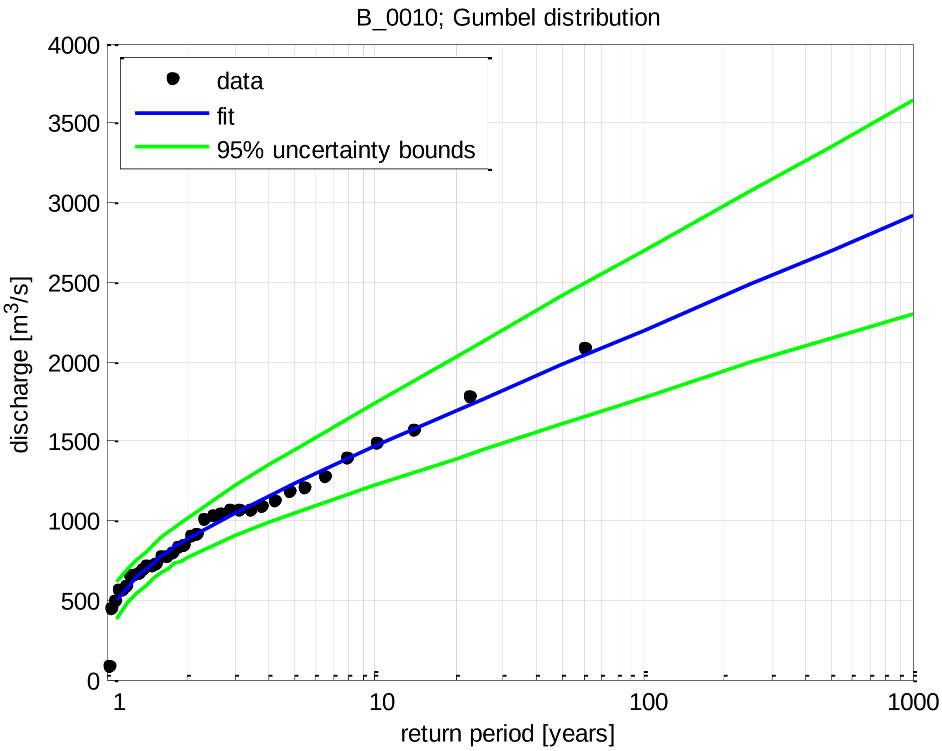

Figure A.15: Example Gumbel fit for annual maximum discharge for one location

The *wflow* simulations were carried on at the daily time scale. This can lead to significant underestimation of actual peak discharges, especially in small catchments where water levels can rise and fall in a matter of minutes/hours. Peak discharges are therefore most likely underestimated. To account for this, we applied the Fuller method (1914) that relates daily discharges and actual peak discharges through the following equation:

$$Q_{peak} = cQ_{day} \quad ;c = \left(1 + 2A^{-0.3}\right) \qquad (1)$$

Where Q_{peak} is the peak discharge, Q_{day} is the corresponding daily discharge and A is the catchment area in *square miles*. If the catchment area is expressed in km^2, this relation changes into:

$$Q_{peak} = cQ_{day} \quad ; c = \left(1 + 2.66A^{-0.3}\right) \qquad (2)$$

Figure A.16 shows the correction factor, *c,* as a function of the catchment size. It shows that *c* is large for relatively small catchments and it decreases towards 1 for increasingly large catchment size.

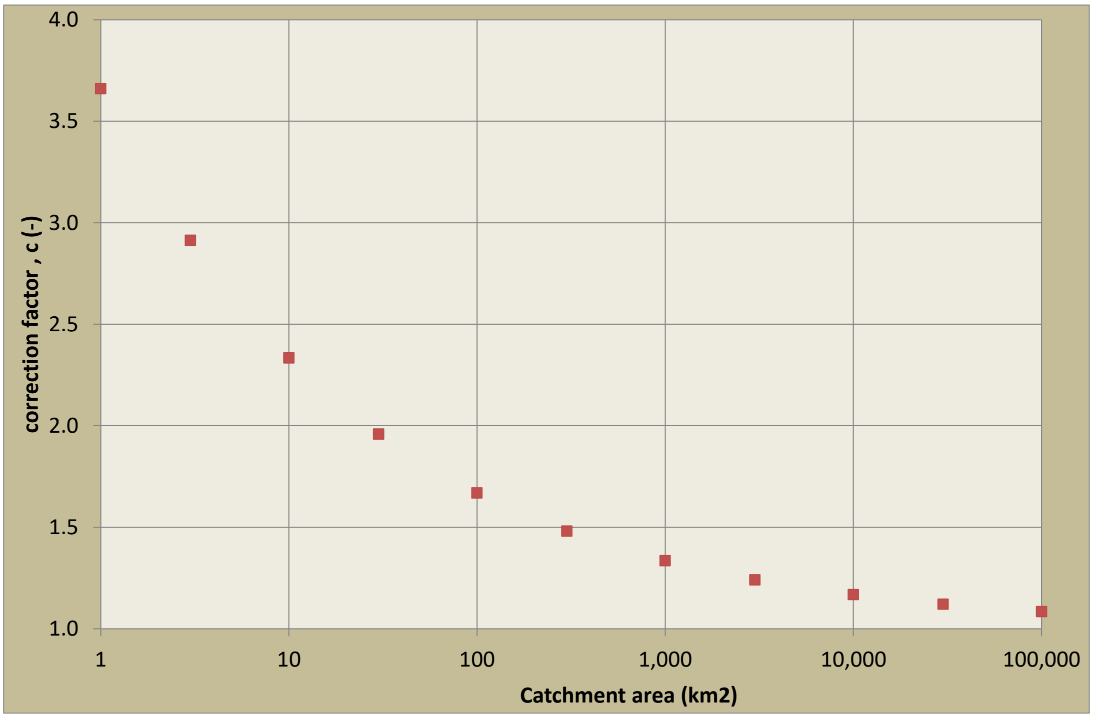

Figure A.16: Applied correction factor as a function of catchment size for translating daily discharges to peak discharge (from Fuller, 1914).

The flow capacity of the bridges and culverts was assessed by using equation 3, where Q is the capacity of the structure, μ is a coefficient for the friction losses, A is the cross section and $|h_1 - h_2|$ is the head loss over the length of the structure.

$$Q = \mu A\sqrt{2g\,|h_1 - h_2|} \qquad (3)$$

For this analysis, not all data was present to accurately calculate all parameters. Only data to calculate the cross section was available and used. For the μ parameter, a value of 0.5 was assumed. For the head difference between upstream and downstream a value of 1 meter was assumed.

By using these parameter values, the calculated average flow velocity trough these structures were calculated to be around 2 m/s. This value is assumed to be realistic. Higher flow velocities might even result in damage to the structure.

Note that this approach does not look at flooding depth. The choice not to take flooding depth into account was made based on:

1. For roads flooding damage is expected to occur rather due to insufficient capacity of culverts than submersion of the road. This in turn can lead to (local) flooding. However, flooding does not always lead to damage of the road and / or the culvert. Or, in other words, flooding depth does not directly relate to damage to the road, whereas damage to roads does often occur around culverts without flooding of major areas
2. Determination of flooding depth requires extensive analysis and input data, which were not part of the scope of this project.

This analysis focuses on all bridges (187) and the 104 biggest culverts (with a diameter of 1 meter or more) in the primary road system of Albania. The reasoning for not taking all culverts into consideration mainly has to do with the availability of a detailed digital elevation model (DEM). The smaller the catchment areas become, the more detailed the DEM needs to be to perform an automated catchment area determination. Therefore, taking smaller diameter culverts into account would require much more manual determination and tweaking and as such fall outside the scope of this project.

A.3.2.2 How may the fluvial flooding hazard effect the road?

As is stated above, the flooding analysis relates the peak flow from a catchment area to the associated culvert that crosses the road and its capacity. The capacity of the culverts is calculated from the given dimensions in the dataset, which uses the cross section of the culvert and assumes a length and slope of the culvert under the bridge. The ratio 'peak flow / culvert capacity' is used to determine the amount of damage to the road. The relationship is based on expert judgement and should be validated based on historical data.

No vulnerability functions were found that link the 'catchment peak flow/ culvert capacity ratio' to the amount of damage. However, a study carried out in the Netherlands[46] relates the water level difference between entrance and exit of the culvert to the flow velocity and subsequent erosion pit. This study shows that for sandy soils (covered by vegetation) in the Netherlands, erosion may be expected at water level differences between entry and exit, of 1m and more.

For higher flow velocities the water level difference between entry and exit must increase. However, this is bounded by the level of the culvert below the road as water will then start to flow over the road itself. We were not able to find any information on how much damage may subsequently occur. Therefore, we have assumed the following:

Table A.6 Vulnerability function linking the 'catchment peak flow/ culvert capacity ratio' to the amount of damage

[46] *Bles, T. Hendriks, A. Pereboom, D., Post, W., 2014, Verdiept inzicht in de beschikbaarheid van hoofdwegennet tijdens evacuaties, pg 38*

'Catchment peak flow/ culvert capacity	Description of situation	Effect on road	Amount of damage
<1	all water flowing through culvert	road is passable	None
1 - 2	culvert at maximum capacity; some water flowing over road surface	road is passable but slow driving through water	Small
2 – 4	culvert at maximum capacity; signficant water flowing over road	road is not passable; light repairs	Medium
>4	culvert at maximum capacity; very large amounts of water flowing over road and/ or high flow velocity over road	road is not passable; embankment/ culvert failure	Large

The following graph depicts all the 'peak flow / capacity ratio' of all and the 100-largest culverts.

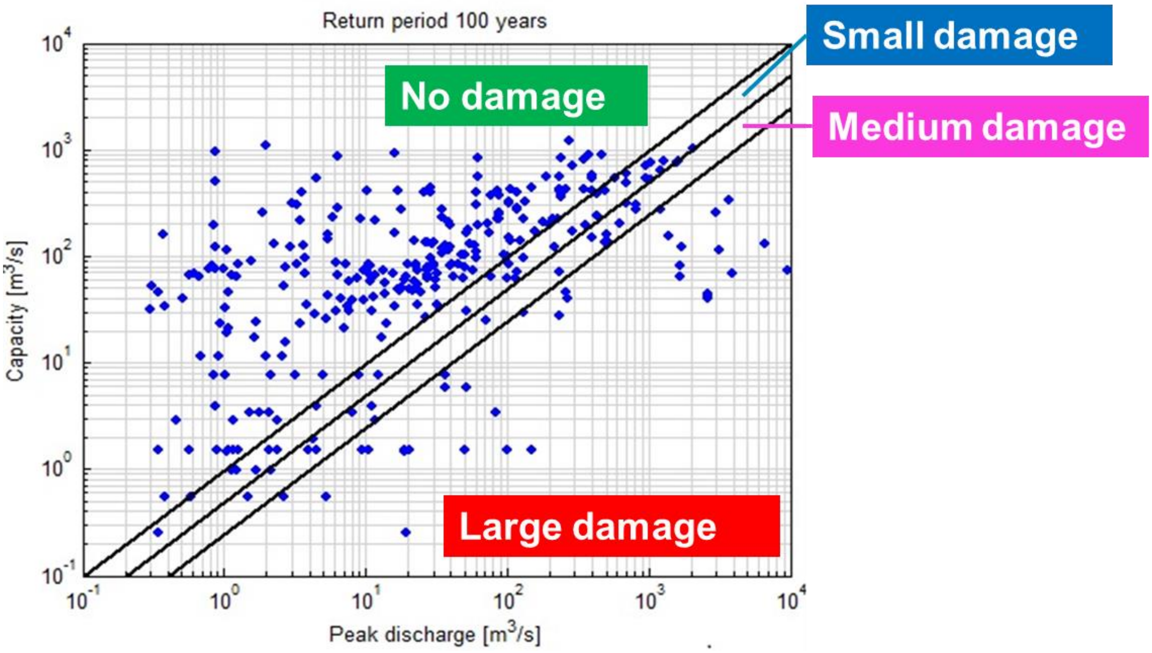

Figure A.17 Plot of the 100 year –ratio of peak discharge and capacity of bridges / culverts also indicating the damage classes

A.3.2.3 What is the effect of a fluvial flooding hazard?

The disruption of services for the different corridors is dependent on the number of events and magnitude of the events for each corridor. A statistical analysis was made in which the total number of events was used to determine the probability and duration of disruption per corridor. In the analysis the probability of the different types of events (small, medium and large) were categorized and their combined probability determined through the square root of their combined individual probabilities.

Through a statistical analysis the probability of disruption of services was determined per type of damage (small, medium, large) and per corridor. This resulted in the damages for the different types of events as shown in Table A.7. As can be seen from this table there is a quite significant difference in damages from floods per corridor. Especially the corridors 3, 4, 5, 6 and 7 have substantial damages from high combined exposure and relatively high costs for service interruption.

Table A.7 AED from floods per corridor per type of event

Floods	Repairs				Losses from service interuption				Total
Annual Expected Damages	Small	Medium	Large	Sub-total	Small	Medium	Large	Sub-total	
01 Milot - Morine New	3,200	1,050	-	**4,250**	3,968	8,519	-	**12,487**	**16,737**
02 Qele - Puke	-	5,550	3,000	**8,550**	-	3,525	1,321	**4,846**	**13,396**
03 Milot - Shkoder	1,100	6,450	280,000	**287,550**	18,093	82,810	1,151,737	**1,252,640**	**1,540,190**
04 Tirana - Durres	-	-	80,000	**80,000**	-	-	1,713,170	**1,713,170**	**1,793,170**
05 Durres - Fier	2,700	7,050	105,000	**114,750**	44,016	998,158	8,824,208	**9,866,382**	**9,981,132**
06 Tirana- Elbasan	1,600	13,050	83,000	**97,650**	10,427	337,875	2,558,974	**2,907,276**	**3,004,926**
07 Fier - Tepelene	1,600	14,850	209,000	**225,450**	8,867	68,990	948,766	**1,026,623**	**1,252,073**
08 Sarande - Greqi	2,250	4,950	32,000	**39,200**	101	87	1,539	**1,727**	**40,927**
09 Elbasan - Gramsh	625	-	-	**625**	92	-	-	**92**	**717**
10 Lushnje - Gramsh	-	-	40,000	**40,000**	-	-	214,003	**214,003**	**254,003**
11 Rrogozhine - Elbasan	800	-	-	**800**	5,532	-	-	**5,532**	**6,332**
12 Shkoder - Hani - Hotit	1,750	8,550	40,000	**50,300**	8,307	-	131,769	**140,076**	**190,376**
13 Milot - Peshkopi	3,025	9,600	40,000	**52,625**	10,282	72,757	381,537	**464,575**	**517,200**
14 Vlore - Sarande	1,625	1,500	25,000	**28,125**	3,262	6,316	98,320	**107,898**	**136,023**
15 Pogradec - Korce	-	-	-	**-**	-	-	-	**-**	**-**

A.4 Seismic

A.4.1 Description of methodology

The goal of the seismic hazard analyses is to determine how much physical damage may occur per road corridor and how much this may affect the availability of the various corridors.

The applied approach consists of two main steps:

1. A Probabilistic Seismic Hazard Analysis (PSHA)
2. A Seismic Loss Estimation of the primary road network

These steps are depicted in the Figure A.18 below and are further explained in the following paragraphs.

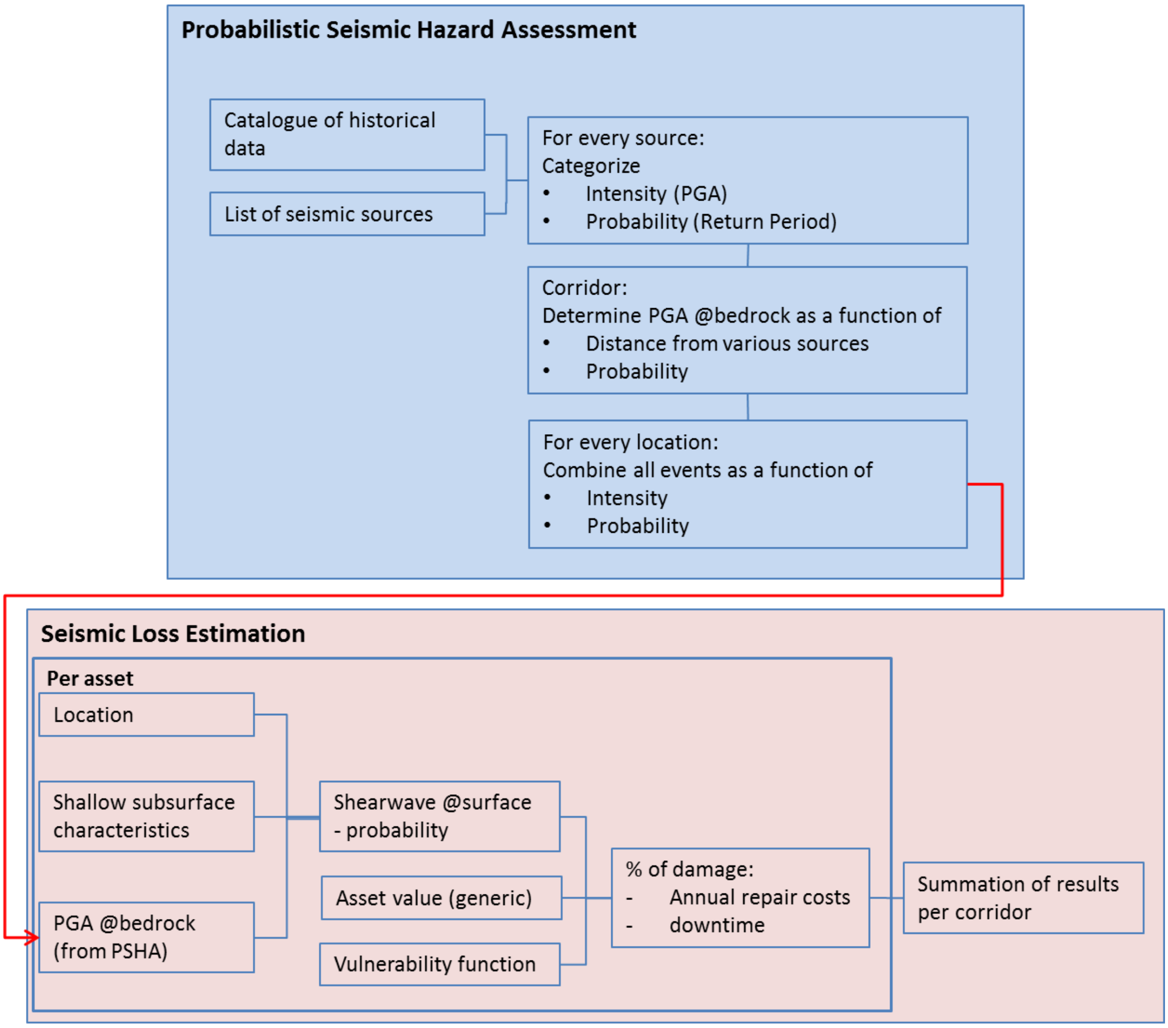

Figure A.18 schematic overview of seismic hazard analysis approach

A.4.1.1 Probabilistic Seismic Hazard Analysis (PSHA)

This step aims to determine the intensity and related likelihood of an earthquake occurring at a given location. The Peak Ground Acceleration (PGA) at bedrock is determined for 10%, 2%, 41% and 63% probability of exceedance in 50 years, corresponding to return periods of 475, 2475, 95 and 50 years respectively. Note that the reason 10% PoE in 50 years is always mentioned first is since is considered as the design basis return period as per the Eurocode, when looked at from the perspective of structures such as buildings, bridges, etc. In this study open source software Open Quake-engine, developed by Global Earthquake Model (GEM) Foundation[47] is utilized.

Cornell (1968)[48], where the statistics related to the seismic phenomena are deduced from the seismic information available. The latest and updated earthquake catalogue from the IGEWE, Tirana was used for this study. The catalogue consists of both historical and instrumental data, with a total of 470 main events, from the years 58 AD – August 2018. The approach considers all possible earthquake events and resulting ground motions, along with their associated probabilities of occurrence, to find the level of ground motion intensity.

This is done in five sub steps:

1. Identify all earthquake sources capable of producing damaging ground motions. For Albania, there are ten sources in total based on previous studies[49] [50] [51] [52].
2. Characterize the distribution of earthquake magnitudes (the rates at which earthquakes of various magnitudes are expected to occur).
3. Characterize the distribution of source-to-site distances associated with potential earthquakes.
4. Predict the resulting distribution of ground motion intensity as a function of earthquake magnitude, distance, etc.
5. Combine uncertainties in earthquake size, location and ground motion intensity

These steps lead to maps that allow for showing the Peak Ground Acceleration (PGA) at bedrock for all locations on the primary road network.

A.4.1.2 A Seismic Loss Estimation of the primary road network

The objective of this step is to relate the PGA@bedrock to annual losses (economic losses and repair times) for the various road assets and sum these per corridor.

The average annual losses [€] and average annual loss ratios [%] for each portfolio type are computed based on Event-based PSHA Calculator incorporated in OpenQuake-engine[53]. This requires fragility curves per type of asset, for various damage (limit) states and consequence models. These are derived from existing studies e.g. Moschonas et al, [2008][54] and Hazus®MH MR4, 2003[55] since there is a lack of the similar studies for Albanian asset topologies.

The Seismic Loss Estimation comprises the following steps:

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[47] GEM (2018). The OpenQuake-engine User Manual. Global Earthquake Model (GEM) OpenQuake Manual for Engine version 3.1.0. doi: 10.13117/GEM.OPENQUAKE.MAN.ENGINE.3.1.0, 198 pages

[48] Cornell, C. A. (1968). "Engineering seismic risk analysis." Bulletin of the Seismological Society of America, 58(5), 1583-1606. (The original document describing PSHA).

[49] Aliaj S, Adams J, Halchuk S, Sulstarova E, Peci V, Muco B (2004) Probabilistic seismic hazard maps for Albania. In: 13th World conference earthquake engineering, Vancouver, BC, Canada, paper no. 2469, 14 pp.

[50] Aliaj, Shyqyri & Kociu, Siasi & Muco, Betim & Sulstarova, Eduard. (2010). Seismicity, seismotectonics and seismic hazard assessment in Albania.

[51] Fundo, A & Duni, Llambro & Kuka, Sh & Begu, Enkela & Kuka, Neki. (2012). Probabilistic seismic hazard assessment of Albania. Acta Geodaetica et Geophysica Hungarica. 47 10.1556/AGeod.47.2012.4.7.

[52] Muco, Betim & Kiratzi, Anastasia & Sulstarova, E & Kociu, Siasi & Peci, V & Scordilis, Emmanuel. (2002). Probabilistic Seismic Hazard assessment in Albania. AGU Fall Meeting Abstracts.

[53] GEM (2018). The OpenQuake-engine User Manual. Global Earthquake Model (GEM) Open-Quake Manual for Engine version 3.1.0. doi: 10.13117/GEM.OPENQUAKE.MAN.ENGINE.3.1.0, 198 pages

[54] Moschonas, I.F., Kappos, A.J., Panetsos, P., Papadopoulos, V., Makarios, T., Thanopoulos, P. [2009] "Seismic fragility curves for greek bridges: methodology and case studies," Bull Earthquake Eng, Vol. 7, pp. 439-468.

[55] Hazus® (2003). Hazus®MH MR4 Technical Manual. Multi-hazard Loss Estimation Methodology.

1. Determine the probabilistic hazard intensity at each asset location, through sets of ground motion fields. The ground shaking amplification at each site is estimated from the site model directly into the ground motion prediction equations. To do this, information concerning the soil type & thickness is used.
2. Create the exposure model for each portfolio, which consists of the location, taxonomy, price etc., for each asset in a given portfolio.
3. Vulnerability Model, which contains the vulnerability function for each taxonomy of a given portfolio.
4. By combining the hazard, exposure and vulnerability model information and by utilizing the OpenQuake-engine, the risk metric such as average annual losses are estimated
5. The adjusted ground shaking intensities at each site and the vulnerability function assigned to each asset are used to compute the loss ratios. The final loss is obtained by multiplying this ratio by the associated replacement cost.

A.4.2 How may the seismic hazard effect the road assets?

The seismic hazard analysis takes the following asset portfolios into account:

- Bridges
- Culverts
- Tunnels
- Roads

For each portfolio, the assets are described according to one or more generic typologies. Furthermore, for each typology fragility curves are described. The following paragraphs are a summary of the vulnerability functions analysis that has been done for the above-mentioned asset portfolios.

A.4.2.1 Bridges portfolio

The bridge portfolio comprises 283 bridges of reinforced concrete and composite types.

Based on the type of superstructures the bridges are classified according to Table A.8.

Table A.8 Pictures of different bridge type in the primary road network in Albania

Bridge type			
Slab	**Arch**	**Pre-stressed Beam**	**Composite (Concrete-Steel)**
			
			

There are no studies of Albanian bridge typology and fragility functions available. Therefore, we have used and adapted studies of bridge fragility curves for Greece, Turkey, USA etc. In the study of Moschonas et al, [2008][56] for Greek bridge fragilities, some similar topologies with our bridge of interest are found. In addition, the seismicity of Greece is

[56] *Moschonas, I.F., Kappos, A.J., Panetsos, P., Papadopoulos, V., Makarios, T., Thanopoulos, P. [2009] "Seismic fragility curves for greek bridges: methodology and case studies," Bull Earthquake Eng, Vol. 7, pp. 439-468.*

slightly higher than the one of Albania. For these reasons, these bridge fragility curves are adapted to be used to characterize the fragility of Albania bridges.

An example of vulnerability curves of slab bridge type for single and multi-span is presented in Figure A.19 (below).

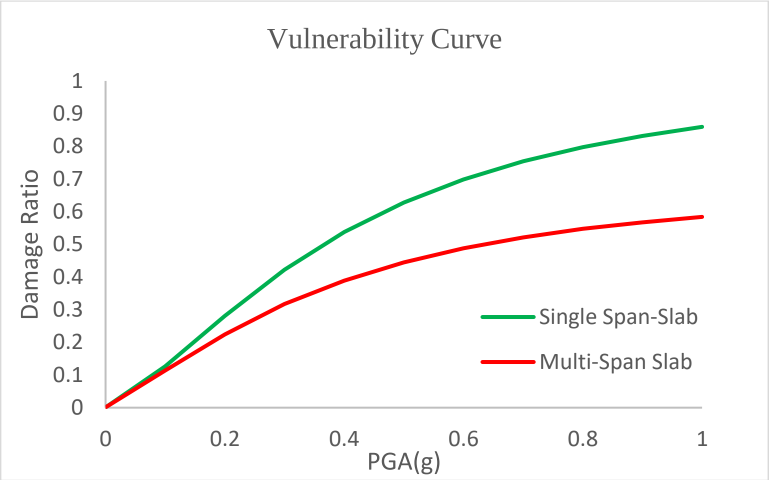

Figure A.19 Example of vulnerability curves of single and multi-span slab bridge

A.4.2.2 Culverts portfolio

Culverts portfolio of the primary road network in Albania consists of 2,108 culverts which are made of concrete, reinforced concrete or steel. As in the case of bridges, the fragility curves are taken from previous studies. For estimating the loss of culverts in monetary and % terms, the damage functions given in Hazus®MR manual[57] are utilized. The considered fragility curves consider only damages coming from structural behaviours without considering soil failure.

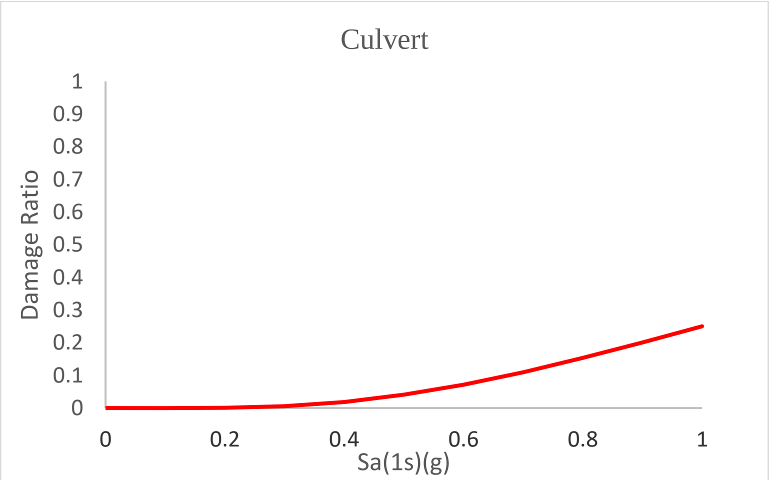

Figure A.20 Vulnerability Curve of Culverts

[57] *Hazus® (2003). Hazus®MH MR4 Technical Manual. Multi-hazard Loss Estimation Methodology*

A.4.2.3 Tunnels portfolio

Tunnels portfolio of the primary road network in Albania consists of three reinforced concrete tunnels. As in the case of culverts, the fragility curves are taken from previous studies. For estimating the loss of tunnels in monetary and % terms, the damage functions given in Hazus®MR manual are utilized. From the manual, the fragility of cut & cover tunnels is selected. In Figure A.21 (below) the used vulnerability curve for tunnels is given.

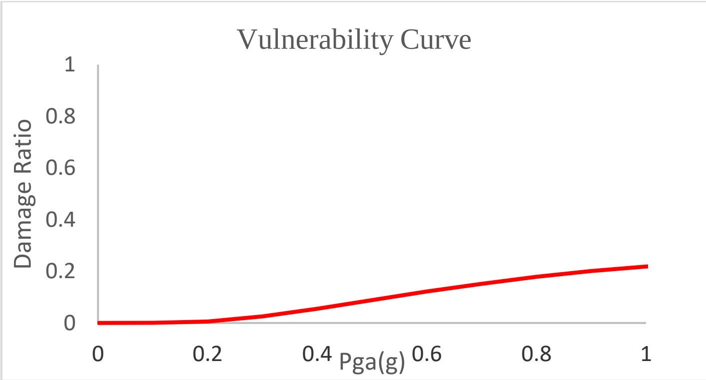

Figure A.21 Vulnerability Curve of Tunnels

A.4.2.4 Roadways portfolio

The length of the roadway of the primary road network is 1,370 km. For creating an exposure model, the roadways are represented by an equally spaced point. The distance between points is 5 km in average.

Fragility curves for roads in case of earthquake-triggered slides as a function of peak ground acceleration (PGA) are developed by (Argyroudis et al., 2011)[58] and use in the SAFELAND project (https://esdac.jrc.ec.europa.eu/projects/safeland). In this respect, the existing HAZUS curves are modified using Bray and Travasarou displacement (2007)[59] model.

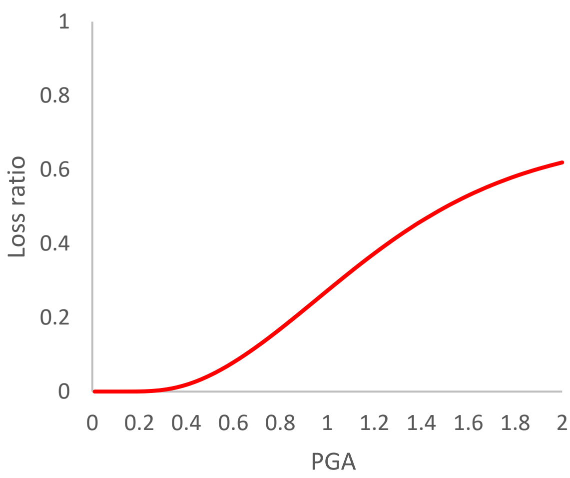

Figure A.22 Fragility functions for Major Roads

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[58] Argyroudis, S., Fotopoulou, S., Pitilakis, K. [2011] "Semi-empirical assessment of road vulnerability to seismically induced slides", Proceedings of the Second World Landslide Forum

[59] Bray JD and Travasarou F, [2007] "Simplified Procedure for Estimating Earthquake-Induced Deviatoric Slope Displacements", Journal of Geotechnical and Geoenvironmental Engineering. 133 (4):381-392.

A.4.3 Where may the seismic hazard effect the road

The following maps form the results of step 1 of the Seismic hazard analysis i.e. of the PSHA:

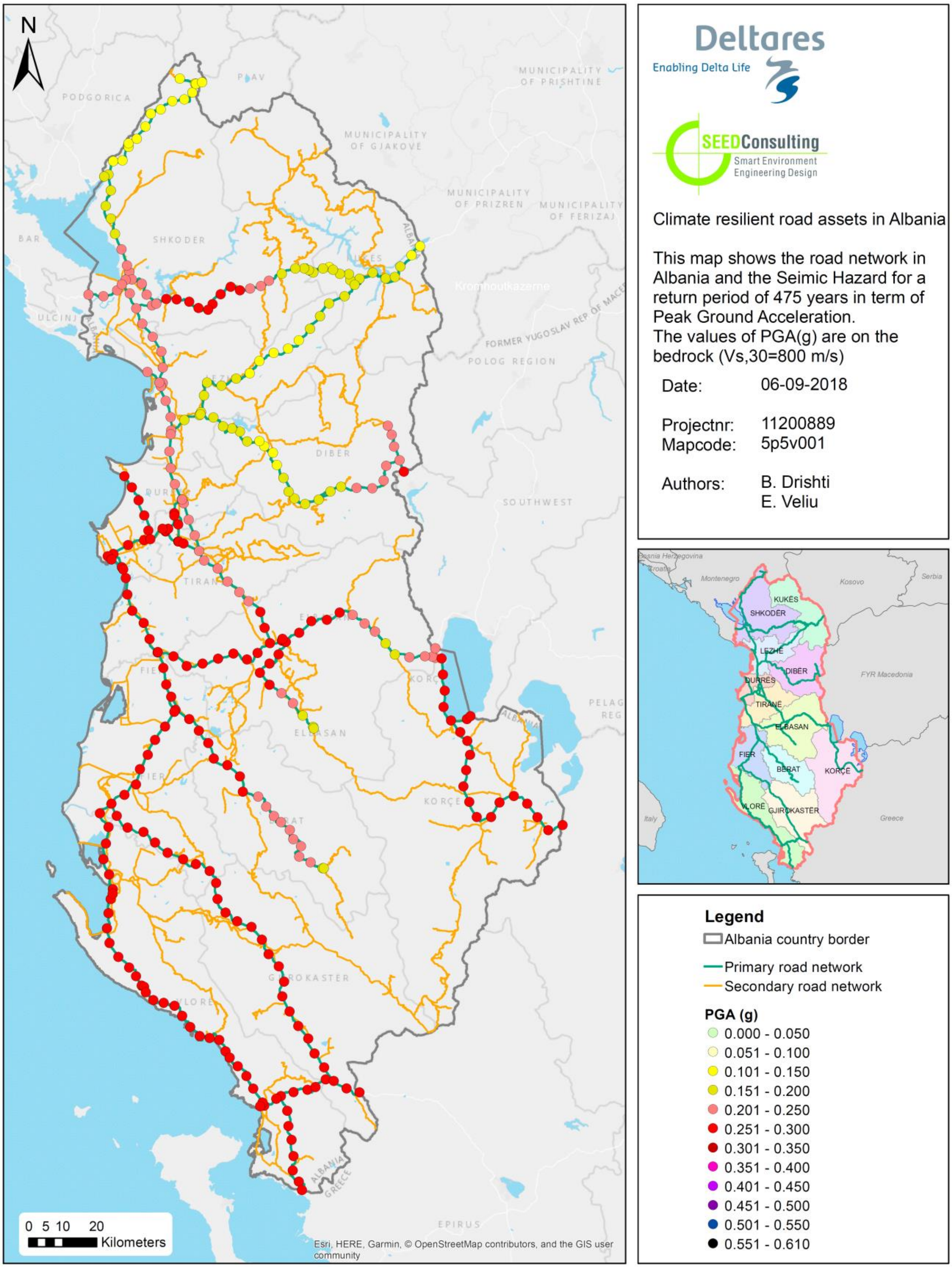

Figure A.23: Seismic Hazard Map, Mean PGA (g), 10% PoE in 50 years, corresponding return period 475 years.

A.4.4 What is effect of the seismic hazard?

The earthquake model provides the repair costs and the interruption of service for each of the road assets in a specific corridor. It is assumed that repairs of the assets are done in parallel, thus the time of interruption is the time needed to repair the damage with the longest repair duration. In Table A.9 the duration for interruption of service is provided per corridor. Based on this interruption the economic damages are calculated for the different return period for each corridor (see Table A.10). Based on the repair costs and the damages from interruption of services the total economic damages are calculated as a risk (AED) per corridor. The calculated AED is presented in Table A.11.

Table A.9 : Duration of interruption of service per corridor and return period

Earthquakes	Damages (service interuption) per return period			
Corridor	50	95	475	2475
01 MIlot - Morine New	0.4	0.6	1.2	67.5
02 Qele - Puke	0.7	1.0	65.5	140.9
03 Milot - Shkoder	0.8	1.3	65.2	125.6
04 Tirana - Durres	0.9	1.4	72.0	148.3
05 Durres - Fier	0.9	1.8	74.6	145.5
06 Tirana- Elbasan	0.9	1.5	77.1	147.6
07 Fier - Tepelene	1.0	2.2	80.5	143.0
08 Sarande - Greqi	0.6	0.9	44.0	109.8
09 Sarande - Greqi	0.8	1.4	68.5	138.6
10 Lushnje - Gramsh	0.9	1.5	70.8	141.1
11 Rrogozhine - Elbasan	0.9	1.8	72.7	141.1
12 Shkoder - Hani - Hotit	0.7	0.9	58.6	117.0
13 Milot - Peshkopi	0.7	1.0	52.6	107.0
14 Vlore - Sarande	0.9	1.7	78.5	157.8
15 Pogradec - Korce	0.9	1.5	82.3	160.5

Table A.10: Economic damages per return period for each corridor

Earthquakes	Damages (service interuption)				Total (€)
Expected Damages	50	95	475	2475	
01 MIlot - Morine New	48,680	73,020	146,039	1,650,785	**267,738**
02 Qele - Puke	6,669	9,526	121,072	191,171	**137,267**
03 Milot - Shkoder	158,488	257,543	6,449,390	11,703,383	**6,865,421**
04 Tirana - Durres	211,454	328,929	17,169,930	35,394,227	**17,710,313**
05 Durres - Fier	2,032,449	4,064,897	22,547,374	29,615,810	**28,644,720**
06 Tirana- Elbasan	760,220	1,267,033	9,288,851	12,684,148	**11,316,104**
07 Fier - Tepelene	104,058	228,928	3,605,697	6,052,372	**3,938,682**
08 Sarande - Greqi	158	236	17,632	45,720	**18,026**
09 Sarande - Greqi	10,508	18,388	137,344	189,096	**166,240**
10 Lushnje - Gramsh	40,111	66,852	2,414,712	4,731,675	**2,521,675**
11 Rrogozhine - Elbasan	31,414	62,827	2,620,015	5,093,334	**2,714,256**
12 Shkoder - Hani - Hotit	-	-	1,478,103	3,150,994	**1,478,103**
13 Milot - Peshkopi	125,443	179,205	2,549,572	4,094,649	**2,854,220**
14 Vlore - Sarande	64,590	122,004	1,385,837	2,365,682	**1,572,431**
15 Pogradec - Korce	357,412	595,686	4,664,395	6,621,501	**5,617,493**

Table A.11: Total AED for seismic events

Earthquakes Annual Expected Damages	Repair Costs (€)	Interruption of service	Total (€)
01 MIlot - Morine New	2,384	3,694	**6,079**
02 Qele - Puke	13,225	969	**14,194**
03 Milot - Shkoder	127,407	50,380	**177,787**
04 Tirana - Durres	56,192	135,251	**191,444**
05 Durres - Fier	153,460	197,270	**350,730**
06 Tirana- Elbasan	49,549	77,864	**127,413**
07 Fier - Tepelene	33,175	28,384	**61,559**
08 Sarande - Greqi	5,403	149	**5,553**
09 Sarande - Greqi	26,337	1,147	**27,484**
10 Lushnje - Gramsh	23,388	18,946	**42,334**
11 Rrogozhine - Elbasan	29,574	20,362	**49,935**
12 Shkoder - Hani - Hotit	19,920	11,434	**31,355**
13 Milot - Peshkopi	7,178	20,239	**27,417**
14 Vlore - Sarande	12,133	11,380	**23,513**
15 Pogradec - Korce	47,116	38,938	**86,054**

A.5 Landslides

A.5.1 Description of methodology

Landslide risk assessment typically requires a multi-hazard approach, as different types of landslides may occur, each with different characteristics and causes and probabilities. (Figure A.24) gives the framework of rainfall-induced landslide risk assessment, with an indication of the various steps.

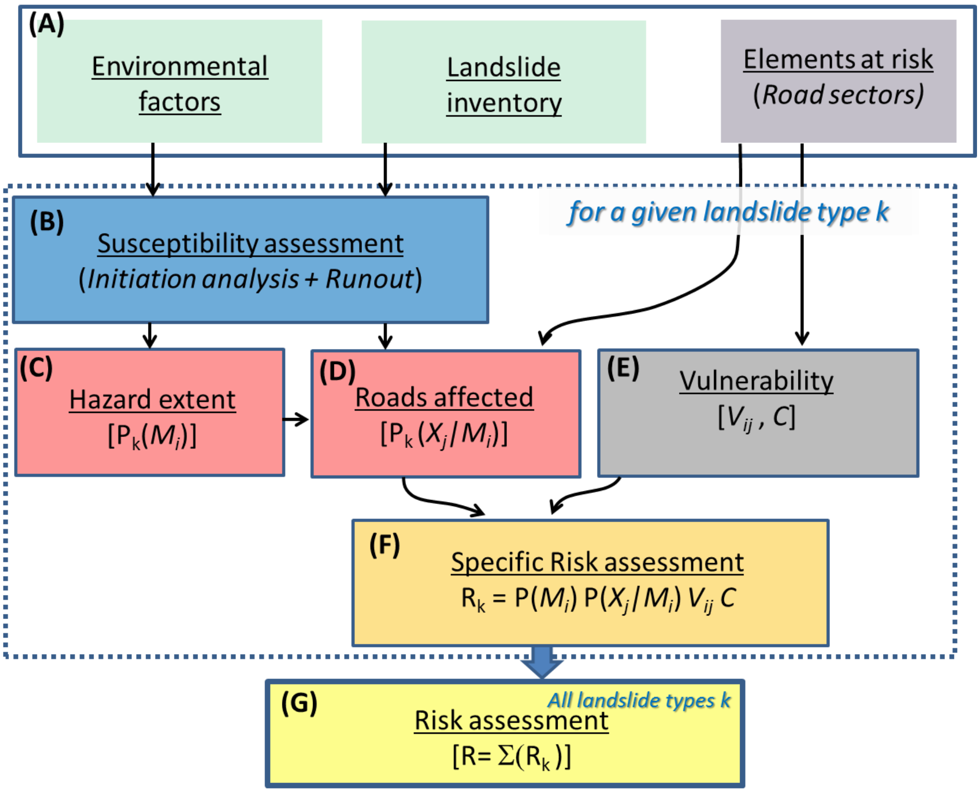

Figure A.24: Framework of multi-hazard landslide risk assessment

The second step (B) focuses on hazard analysis, i.e. understanding the factors that influence the likelihood of occurrence of the hazard. The resulting maps will display the source areas for the modelling of potential runout areas.

The third step (C) deals with landslide hazard extent & probability assessment. This heavily depends on the availability of so-called event-based landslide inventories, which are inventories of landslides caused by the same triggering event (e.g. rainfall, seismic events). The result of the hazard assessment gives the hazard map, which gives the probability Pk (Mi) of occurrence of a landslide type ‘k’ of a given magnitude ‘M’ in the time interval ‘I’ defined in the risk (e.g. one year) for each reference area. Commonly, the landslide magnitude is the measure of the landslide size and it can be described by its volume or its area.

The fourth step (D) determines which roads may potentially be affected.

Step (E) focuses on vulnerability i.e. the amount of damage to the road that may be expected.

Lastly, the cumulative risk assessment is computed in step (G), in which the risk for a given return period due to several landslides types is combined.

A.5.2 How may the landslide hazard affect the road?

A good and reliable landslides risk assessment requires a complete landslide inventory database. The inventory is only implicitly considered in the European landslide susceptibility map (ELSUS Version 2, scale 1: 200,000), developed by Wilde et al. (2018)[60], which subdivides the country in five different susceptibility classes.

The updated map was prepared using the same semi-quantitative method as for ELSUS1000, combining landslide frequency ratios information with a spatial multi-criteria evaluation model of three thematic predictors: slope angle, shallow subsurface lithology and land cover. However, the new map was prepared also using : (i) an extended landslide inventory, containing 30% of additional locations for model calibration, map validation and classification and (ii) a new lithological data set derived from the International Hydrogeological Map of Europe (IHME).

The data available at this moment provides some information of approximately 170 landslides along Albanian highways over the last three years. For each landslide event, the location, lithology, vegetation, and soil type are provided, together with some general information about the damages to the road. For only 31 events out of 170, the approximate damaged length of the road and the costs of reparation are also provided. Note that no differentiation was made between pluvial induced landslides and seismic induced landslides. Thus, there is not enough information to make this differentiation within the scope of this project.The values of hazard are summarized in Table A.12.

Table A.12 Hazard value for each susceptibility class

Susceptibility Value	km of road segments	# events	Hazard (events/km/year)
1	297	5	0.0056
2	237	9	0.0126
3	395	30	0.0253
4	416	82	0.0656
5	112	40	0.1189

Due to the limited landslide database, it was not possible to determine the relationship between magnitude and susceptibility class. Therefore, the distribution of the entire set was determined, irrespective of the susceptibility class. All events are subdivided depending on their volume. Three magnitude classes are defined, based on the two thresholds 100 m^3 and 1,000 m^3. Table 4.16 shows the number of events for each magnitude class and the frequency of occurrence of a landslide for a given magnitude

Table A.13: Frequency of occurrence of landslides of a given magnitude class

Magnitude class	**Volume range [m^3]**	**# events [-]**	**Frequency of occurrence f [-]**
M-I	< 100	136	0.8
M-II	100-1,000	26	0.15
M-III	>1,000	8	0.05

80% of all the events have a volume lower than 100 m^3, 15% between 100 and 1,000 m^3, and only 5% is larger than 1,000 m^3. Both logical thinking as well as the landslide database, lead to the conclusion that a larger landslide is expected to result in more damage to the

[60] *Wilde, M., Günther, A., Reichenbach, P., Malet, J.-P., Hervás, J., 2018. Pan-European landslide susceptibility mapping: ELSUS Version 2. Journal of Maps, 14(2): 97-104 and supplemental map.*

road. Table *A.14* summarizes the number of events for each magnitude class. A "severity" factor can be defined for each magnitude class and represents the probability of having a landslide which produces significant damages to the road. This factor is computed for each magnitude class as the ratio between the number of severe events and the total number of events (e.g. 15/136 for magnitude class M-I). This ratio shows that the 75% of large events (class M-III) produce significant damages, whereas only 11% of the small landslides (M-I) have the same relevant effect.

Table A.14: Severity factor per magnitude class of landslides

Magnitude class	**Volume range [m^3]**	**# events [-]**	**Severity factor SF [-]**
M-I	< 100	15	0.11
M-II	100-1000	10	0.38
M-III	>1,000	6	0.75

Results are shown in Table 4.17 below for each susceptibility class. The values represent the probability of a landslide occurring in one year per km of road. The probability concerns five susceptibility classes and three landslide sizes.

For example, the probability of one event of magnitude M-I that produced damage in 1 year per km of road in susceptibility class 1, is computed as follows:

$$P_{event/year/km}(M-I \mid SC=1) = P_{any\,event/year/km}(SC=1)\cdot f(M-I)\cdot SF(M-I) = 0.0056\cdot 0.8\cdot 0.11 \approx 0.05\%$$

where $P_{any\,event/year/km}(SC=1)$ is the probability of one event of any magnitude in susceptibility class 1; $f(M-I)$ and $SF(M-I)$ are respectively the frequency of occurrence and the severity factor of landslides of magnitude M-1.

Table A.15 Landslide probability overview

Landslide susceptibility class	**Probability** of one event in 1 year per km with effects to the road [x100]		
	Landslide Class M-I	**Landslide Class M-II**	**Landslide Class M-III**
1.00	0.05	0.03	0.02
2.00	0.11	0.07	0.05
3.00	0.22	0.14	0.09
4.00	0.58	0.37	0.25
5.00	1.05	0.68	0.45

A.5.3 What is effect of the landslide hazard?

According to the JTC-1 guidelines (Fell et al. 2008)[61], vulnerability is the degree of loss to a given element at risk within the area affected by a landslide, and it is expressed on a scale from 0 (no loss) to 1 (total loss). Vulnerability can be directly assessed by comparing the monetary loss per damaged section of the infrastructure by a landslide (e.g. Euro/km) with the actual construction costs. This approach was also applied by Jaiswal et al. (2010)[62] for the Indian railways and road system.

Data available on existing rehabilitation projects (approx. 31) are used to determine a correlation between the vulnerability of the road section directly affected by the landslide and the landslide volume. The vulnerability is computed as the ratio of the total restoration costs of a damaged length of road to the costs of a new construction, and the values are distinguished per landslide magnitude. The vulnerability can theoretically be greater than unity, since repair can cost more than constructing new infrastructure as it includes the additional cost of removing debris and replacing damaged components. By limiting the maximum value of the ratio to one, the vulnerability value is determined for each landslide magnitude, as shown in Table A.16. As expected, the vulnerability increases per landslide class. For small magnitudes (class M-I), 40% of the value is compromised; for class M-II, 80% of the value is damaged, and for large events, a total loss is assumed.

Existing data on rehabilitation projects are also used to determine the averaged damaged length for each magnitude class of the landslide. The values are summarized in Table A.17 and show that for small landslides (class M-I), damage only occurs along 50 m of the road, whereas larger events affect 100 m and 250 m, respectively for class M-II and M-III.

The vulnerability factors per km of road are listed in Table A.18. These are computed as the product between V_{sect} (Table A.16) and L_d (Table A.18).

Table A.16: Vulnerability factor for the roads affected by the landslides for each magnitude class

Magnitude class	Vulnerability of the road section affected by the landslide V_{sect} [1/event]
M-I	0.4
M-II	0.8
M-III	1.0

Table A.17: Damaged length ratio for each magnitude class

Magnitude class	Damaged length of road L_d [km]
M-I	0.05
M-II	0.10
M-III	0.25

[61] Fell R., Corominas J. Bonnard C., Cascini L., Leroi E., Savage W. Z.- Guidelines for landslide susceptibility, hazard and risk zoning for land use planning. Engineering Geology Volume 102, Issues 3–4, 1 December 2008, Pages 85-98

[62] Jaiswal P., C. J. van. Westen, and V. Jetten, (2010) - Quantitative assessment of direct and indirect landslide risk along transportation lines in southern India - Nat. Hazards Earth Syst. Sci., 10, 1253–1267, 2010

Table A.18: Vulnerability factor per km of road

Magnitude class	Vulnerability per km of road V_{km} [1/event]
M-I	0.02
M-II	0.08
M-III	0.25

The risk for each km of road is computed considering the probability of occurrence of a landslide of a given magnitude class (Table A.12). Furthermore, the vulnerability factors and the average cost of construction for each road type (Table A.19) lead to the final risk costs.

Table A.19: Average construction costs for each road type in Albania.

Road Type	Details	Euro / km
A	Highway	€ 6,000,000
B	Main Interurban Road	€ 4,000,000
C	Secondary Interurban Road	€ 1,000,000
D	Main Urban Road	€ 1,200,000
E	Secondary Urban Road	€ 1,000,000
F	Local Road	€ 800,000

The risk for each km of road is computed as follows:

$$R = \left[P(M_{M-I}) V_{M-I} + P(M_{M-II}) V_{M-II} + P(M_{M-III}) V_{M-III} \right] C$$

Where the probability of occurrence of a landslide of a given magnitude class (P_M) is provided in Table 4.17. The vulnerability factors (V_M) are in Table A.18. The average cost of the construction (C) for each road type is summarized in Table A.19.

The disruption of services for the different corridors is dependent on the number and magnitude of events of each corridor. A statistical analysis was made in which the total number of events was used to determine the probability and duration of disruption per corridor. In the analysis the probability of the different types of events (small, 1-hour delay; medium, 1-day interruption; large, 1-week interruption + 23 days with 1-hour delay) were categorized and their combined probability determined through the square root of their combined individual probabilities.

Table A.20 AED from expected repair costs and damages from interruption of services due to landslide per corridor

Landslides	Repair Costs	Damages (service interuption)			Sub-total	Total (€)
Annual Expected Damages	(€)	Small	Medium	Large	(€)	
01 Milot - Morine New	**286,714**	806	4,985	31,868	**37,659**	**324,373**
02 Qele - Puke	**109,519**	64	444	2,782	**3,289**	**112,808**
03 Milot - Shkoder	**38,473**	2,645	3,960	44,962	**51,567**	**90,040**
04 Tirana - Durres	**44,776**	4,935	3,164	63,503	**71,602**	**116,378**
05 Durres - Fier	**150,035**	3,765	56,579	302,927	**363,272**	**513,307**
06 Tirana- Elbasan	**200,240**	3,214	38,185	214,917	**256,316**	**456,556**
07 Fier - Tepelene	**60,806**	2,115	3,741	39,197	**45,052**	**105,858**
08 Sarande - Greqi	**39,453**	19	8	230	**257**	**39,710**
09 Elbasan - Gramsh	**24,677**	20	238	1,307	**1,566**	**26,243**
10 Lushnje - Gramsh	**63,581**	1,822	1,642	26,413	**29,877**	**93,458**
11 Rrogozhine - Elbasan	**17,366**	810	510	10,403	**11,724**	**29,090**
12 Shkoder - Hani - Hotit	**76,293**	1,834	-	19,209	**21,043**	**97,336**
13 Milot - Peshkopi	**123,935**	2,028	8,740	63,355	**74,123**	**198,058**
14 Vlore - Sarande	**146,329**	921	3,676	27,551	**32,148**	**178,477**
15 Pogradec - Korce	**22,438**	644	6,685	37,405	**44,734**	**67,172**

A.6 Criticality

To prioritize where to focus resilience building activities, the importance or criticality of the roads may be considered. The criticality may take various criteria into account and can then be combined with the EAD to prioritize actions.

To assess the criticality of the different corridors, a workshop with all stakeholders wre organized, where a scoring table was prepared in which stakeholders could indicate their respective importance of several criteria for the different corridors. Also, the criteria could be given a weight to indicate the importance the stakeholder attached to the specific criteria. Prior to filling in the scoring table, the criteria that should be considered were discussed and confirmed. One criterion was added: “Evacuation”. The criteria that stakeholders were asked about, value the importance of the function of the corridor as access to:

- An international corridor
- An industrial zone
- A harbour
- Tourism area
- Agricultural area
- An evacuation corridor

A total of 29 stakeholders attended the workshop and completed the questionnaire table. The score of the stakeholders for the importance of the weight of the function, as well as the importance of the corridor of each specific function is presented in Table A.21. It is worthy to mention that the score is relative term to show criticality among 15 corridors.

Table A.21: Criticality score by Albanian stakeholders in the road sector

	Weight	Corridor														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
International	3.61	12.7	5.0	12.2	13.6	12.4	11.5	11.5	11.4	6.6	6.2	10.6	13.3	7.6	10.7	13.4
Industry	2.19	5.3	3.7	5.5	8.0	7.0	6.9	4.7	4.1	4.1	3.6	6.2	5.5	5.2	5.0	5.4
Harbour	3.10	8.2	4.0	6.7	11.8	10.4	7.4	5.7	7.4	4.2	3.8	7.3	6.6	5.1	10.0	5.2
Tourism	3.04	10.1	6.9	6.6	11.9	12.8	8.9	7.6	9.8	6.0	3.6	4.8	7.4	6.7	8.3	13.0
Agriculture	2.52	5.3	4.7	5.7	8.2	9.1	7.5	7.0	5.9	5.2	6.5	7.9	7.1	5.5	5.3	7.7
Evacuation*	3.33	12.5	10.0	8.0	10.5	14.0	16.0	14.0	13.1	12.5	11.1	11.1	12.2	11.0	11.3	14.1
Summation		41.6	24.2	36.7	53.4	51.7	42.2	36.5	38.5	26.1	23.6	36.7	40.0	30.1	39.2	44.8

* Evacuation was reported by only 4 participants and is therefore not considered in the summation of the scores

From the Table A.21 the most important corridors are numbers 1, 4, 5, 6 and 15 (in red colour). The least important corridors are corridors 2, 9 and 10 (green), although corridor 9 is deemed important as an evacuation route. Furthermore, there are a few corridors that are considered for specific functions, like corridor 12 as an international corridor.

Appendix B: Detailed Results from Flooding CBA

B.1 Attributes of failing and/or replaced culverts and bridges

ID	Corridor	Capacity (m3/s)	Lat	Long	R_5	R_20	R_50	R_100
B_0210	02 Shkoder - Puke - Kolsh	30.10	42.0982528745	20.2258569533	66.83	95.1	113.02	126.44
B_0010	03 Milot - Shkoder - Muriqan	42.35	41.6525426129	19.6720529291	1414.94	1971.88	2326.81	2561.55
B_0264	03 Milot - Shkoder - Muriqan	46.55	41.5915719222	19.6700175609	1427.99	1986.34	2342.1	2578.45
B_0424	03 Milot - Shkoder - Muriqan	157.85	41.8378253542	19.6426288755	726.27	1025.92	1217.13	1339.84
B_0425	03 Milot - Shkoder - Muriqan	84.00	41.7308329489	19.6566480430	875.23	1235.23	1465.06	1610.54
B_0426	03 Milot - Shkoder - Muriqan	66.15	41.7066540057	19.6666165745	878.78	1239.19	1469.29	1615
B_0434	03 Milot - Shkoder - Muriqan	46.55	41.5915934250	19.6701393098	1427.99	1986.34	2342.1	2578.45
B_0009	03 Milot - Shkoder - Muriqan	42.00	41.6525318920	19.6722136628	1414.94	1971.88	2326.81	2561.55
B_0053	04 Tirana - Durres	352.80	41.3623515713	19.5444723757	2068.78	2780.27	3231.16	3569.04
B_0055	04 Tirana - Durres	118.65	41.3540138685	19.7440828348	1765.51	2378.07	2766.75	3050.4
B_0091	05 Durres - Vlore	76.65	40.8164964273	19.6137118240	4985.59	7056.57	8369.01	9352.5
C_3099	05 Durres - Vlore	-	41.1926609361	19.5399583086	1.38	1.87	2.18	2.41
C_0505	05 Durres - Vlore	1.58	41.0164768108	19.6627383884	4.85	6.89	8.17	9.14
B_0191	06 Tirana - Elbasan - Pogradec	136.85	41.1800181360	20.2713465514	3241.59	4788.55	5768.91	6503.55
B_0192	06 Tirana - Elbasan - Pogradec	280.35	41.1825082278	20.2737704916	594.98	878.93	1058.88	1193.73
C_1014	06 Tirana - Elbasan - Pogradec	3.54	41.2750631982	19.8573443277	43.91	61.14	72.07	80.25
B_0443	07 Fier - Gjirokaster - Kakavi	127.05	40.2306350309	20.0830227830	867.16	1238.47	1473.78	1650.12
C_2988	07 Fier - Gjirokaster - Kakavi	1.58	40.0180628911	20.1952178057	39.58	69.25	88.37	97.74
C_2995	07 Fier - Gjirokaster - Kakavi	6.00	39.9936048579	20.2172975296	13.27	25.05	32.67	36.08
C_3502	07 Fier - Gjirokaster - Kakavi	0.26	40.1350194508	20.1033948586	9.77	14.26	17.12	19.04
C_3527	07 Fier - Gjirokaster - Kakavi	8.00	40.1835542648	20.0764170429	16.75	26.19	32.23	35.91
C_3601	07 Fier - Gjirokaster - Kakavi	0.56	40.2589498816	20.0539258571	1.81	3.54	4.65	5.19
C_3603	07 Fier - Gjirokaster - Kakavi	0.56	40.2605928009	20.0526180604	0.39	1.59	2.38	2.59
C_3613	07 Fier - Gjirokaster - Kakavi	6.00	40.2666915036	20.0495955153	21.98	36.07	45.14	49.78
B_0154	08 Gjirokaster - Sarande - Ksamil	46.90	39.9101254529	20.1041416318	93.56	175.57	228.59	251.76
B_0298	08 Gjirokaster - Sarande - Ksamil	41.30	39.9048123128	20.0850211722	98.57	183.82	238.94	263.11
C_0458	10 Lushnje - Berat - Çorovode	1.50	40.9316000541	19.6874904013	9.88	13.93	16.49	18.42
C_0083	12 Shkoder - Hani i Hotit - Vermos	1.58	42.4394901544	19.5385655960	10.43	14.94	17.8	19.94
C_2871	13 Milot - Peshkopi	1.58	41.5140464421	20.2896726274	7.82	13.14	16.54	18.59
C_2703	14 Vlore - Sarande	1.58	39.9274515781	19.9795955317	2.6	6.67	9.32	10.18
B_0112	#N/A	262.15	41.3981902793	19.7042838119	1704.29	2296.48	2672.36	2944.62
B_0026	#N/A	70.35	41.7802135003	19.8471114122	2068.57	2887.89	3407.11	3796.19
B_0030	#N/A	28.70	42.0064465826	19.6188248719	136.54	181.39	209.81	231.11
C_2927	#N/A	1.58	41.7023168098	19.7713825006	76.64	110.11	131.44	145.46
C_0776	#N/A	1.58	41.3929470771	19.7041244421	27.5	37.73	44.21	49.06

ID	Corridor	Old Capacity (m3/s)	New Capacity (m3/s)
B_0210	02 Shkoder - Puke - Kolsh	30.1	50
C_0375	05 Durres - Vlore	0.56	2.5
C_0505	05 Durres - Vlore	1.58	16
C_3099	05 Durres - Vlore	0	2.5
C_1014	06 Tirana - Elbasan - Pogradec	3.54	50
C_3603	07 Fier - Gjirokaster - Kakavi	0.56	2.5
C_2988	07 Fier - Gjirokaster - Kakavi	1.58	50
C_2995	07 Fier - Gjirokaster - Kakavi	6	50
C_3502	07 Fier - Gjirokaster - Kakavi	0.26	16
C_3527	07 Fier - Gjirokaster - Kakavi	8	50
C_3601	07 Fier - Gjirokaster - Kakavi	0.56	2.5
C_3613	07 Fier - Gjirokaster - Kakavi	6	50
C_0083	12 Shkoder - Hani i Hotit - Vermosh	1.58	16
C_2855	13 Milot - Peshkopi	1.58	2.5
C_2871	13 Milot - Peshkopi	1.58	16
C_2724	14 Vlore - Sarande	1.58	2.5
C_2703	14 Vlore - Sarande	1.58	16

B.2 Bill of Quantity for replacement of culverts

BoQ For Replacement of a Culvert 800 mm

No	Description	Unit	Quantity	Unit Rate ALL	Exchange Rate EURO to ALL	Unit Rate EURO	Total Cost EURO
	Provide for traffic control during works	km-day	4.00			250.00	1,000.00
	Site preparation (traffic measures, rip out asphalt & base layer, diverge the stream through the culvert, take away vegetation)	day	2.00			200.00	400.00
	Excavation + Transport	m^3	45.00			5.20	234.00
	S.P. New Concrete Pipe culvert Ø 800mm	ml	10.00			78.00	780.00
	Construct new inlet and outlet structures to Ø 800mm pipe culverts	Unit	2.00			400.00	800.00
	Wearing Course layer of granulated stone, (4cm) , diffused and compressed by machinery	m^2	35.00			7.10	248.50
	Binder Layer (6cm)	m^2	35.00			9.75	341.25
	Place and Compact crushed stone base material	m^3	6.00			8.00	48.00
	Place and Compact subbase material	m^3	6.00			7.50	45.00
	Fill with material	m^3	28.00			5.00	140.00
	TOTAL						4,036.75
	Value Added Tax 20%						807.35
	TOTAL						4,844.10

BoQ For Replacement of a Culvert 1500 mm

No	Description	Unit	Quantity	Unit Rate ALL	Exchange Rate EURO to ALL	Unit Rate EURO	Total Cost EURO
	Provide for traffic control during works	km-day	4.00			250.00	1,000.00
	Site preparation (traffic measures, rip out asphalt & base layer, diverge the stream through the culvert, take away vegetation)	day	2.00			200.00	400.00
	Excavation + Transport	m^3	170.00			5.20	884.00
	S.P. New Concrete Pipe culvert Ø 1500 mm	ml	10.00			188.99	1,889.90
	Construct new inlet and outlet structures to Ø 1500mm pipe culverts	Unit	2.00			600.00	1,200.00
	Wearing Course layer of granulated stone, (4cm) , diffused and compressed by machinery	m^2	50.00			7.10	355.00
	Binder Layer (6cm)	m^2	50.00			9.75	487.50
	Place and Compact crushed stone base material	m^3	10.00			8.00	80.00
	Place and Compact subbase material	m^3	10.00			7.50	75.00
	Fill with material	m^3	45.00			5.00	225.00
	TOTAL						6,596.40
	Value Added Tax 20%						1,319.28
	TOTAL						7,915.68

BoQ For Replacement of a Culvert "Tubosider" 4654X3032 mm							
No	Description	Unit	Quantity	Unit Rate ALL	Exchange Rate EURO to ALL	Unit Rate EURO	Total Cost EURO
	Provide for traffic control during works	km-day	6.00			250.00	1,500.00
	Construct new diversion road with gravel surfacing	km	0.03			68,000.00	2,040.00
	Site preparation (traffic measures, rip out asphalt & base layer, diverge the stream through the culvert, take away vegetation)	day	2.00			200.00	400.00
	Excavation + Transport	m³	400.00			5.20	2,080.00
	Pile drilling with machinery Ø600, (0-10m) -Sheet piles for separated works on each lane	ml	20.00			60.00	1,200.00
	S.P. New Concrete Pipe culvert 4654x3032 mm L=10 m(an autocrane 100 tonnes included)	kg	5,510.00			3.90	21,489.00
	Sand under the pipe	m³	40.00			11.14	445.67
	Construct new inlet and outlet structures to 4654x3032 mm pipe culverts	Unit	2.00			1,000.00	2,000.00
	Wearing Course layer of granulated stone, (4cm) , diffused and compressed by machinery	m²	150.00			7.10	1,065.00
	Binder Layer (6cm)	m²	150.00			9.75	1,462.50
	Place and Compact crushed stone base material	m^3	30.00			8.00	240.00
	Place and Compact subbase material	m^3	50.00			7.50	375.00
	Fill with material	m^3	100.00			5.00	500.00
	TOTAL						**34,797.17**
	Value Added Tax 20%						**6,959.43**
	TOTAL						**41,756.60**

BoQ For Replacement of a Culvert "Tubosider" 7620X6200 mm							
No	Description	Unit	Quantity	Unit Rate ALL	Exchange Rate EURO to ALL	Unit Rate EURO	Total Cost EURO
	Provide for traffic control during works	km-day	6.00			250.00	1,500.00
	Construct new diversion road with gravel surfacing	km	0.03			68,000.00	2,040.00
	Site preparation (traffic measures, rip out asphalt & base layer, diverge the stream through the culvert, take away vegetation)	day	2.00			200.00	400.00
	Excavation + Transport	m³	1,100.00			5.20	5,720.00
	Pile drilling with machinery Ø600, (0-10m) -Sheet piles for separated works on each lane	ml	25.00			60.00	1,500.00
	S.P. New Concrete Pipe culvert 7620X6200 mm L=10 m(an autocrane 100 tonnes is included)	kg	9,940.00			3.90	38,766.00
	Sand under the pipe	m³	80.00			11.14	891.33
	Construct new inlet and outlet structures to 7620X6200 mm pipe culverts	Unit	2.00			2,000.00	4,000.00
	Wearing Course layer of granulated stone, (4cm) , diffused and compressed by machinery	m²	230.00			7.10	1,633.00
	Binder Layer (6cm)	m²	230.00			9.75	2,242.50
	Place and Compact crushed stone base material	m^3	40.00			8.00	320.00
	Place and Compact subbase material	m^3	80.00			7.50	600.00
	Fill with material	m^3	450.00			5.00	2,250.00
	TOTAL						**61,862.83**
	Value Added Tax 20%						**12,372.57**
	TOTAL						**74,235.40**

B.3 Detailed damages and benefits from replacement of culverts and bridges

Original damages from failure of culverts and bridges

Floods	Repairs				Losses from service interuption				Total
Annual Expected Damages	Small	Medium	Large	Sub-total	Small	Medium	Large	Sub-total	
01 Milot - Morine New	3,200	1,050	-	**4,250**	3,968	8,519	-	**12,487**	**16,737**
02 Shkoder - Puke - Kolsh	-	5,550	3,000	**8,550**	-	3,525	1,321	**4,846**	**13,396**
03 Milot - Shkoder - Muriqan	1,100	6,450	280,000	**287,550**	18,093	82,810	1,151,737	**1,252,640**	**1,540,190**
04 Tirana - Durres	-	-	80,000	**80,000**	-	-	1,713,170	**1,713,170**	**1,793,170**
05 Durres - Vlore	2,700	7,050	105,000	**114,750**	44,016	998,158	8,824,208	**9,866,382**	**9,981,132**
06 Tirana - Elbasan - Pogradec	1,600	13,050	83,000	**97,650**	10,427	337,875	2,558,974	**2,907,276**	**3,004,926**
07 Fier - Gjirokaster - Kakavi	1,600	14,850	209,000	**225,450**	8,867	68,990	948,766	**1,026,623**	**1,252,073**
08 Gjirokaster - Sarande - Ksamil	2,250	4,950	32,000	**39,200**	101	87	1,539	**1,727**	**40,927**
09 Elbasan - Gramsh	625	-	-	**625**	92	-	-	**92**	**717**
10 Lushnje - Berat - Çorovode	-	-	40,000	**40,000**	-	-	214,003	**214,003**	**254,003**
11 Rrogozhine - Elbasan	800	-	-	**800**	5,532	-	-	**5,532**	**6,332**
12 Shkoder - Hani i Hotit - Vermosh	1,750	8,550	40,000	**50,300**	8,307	-	131,769	**140,076**	**190,376**
13 Milot - Peshkopi	3,025	9,600	40,000	**52,625**	10,282	72,757	381,537	**464,575**	**517,200**
14 Vlore - Sarande	1,625	1,500	25,000	**28,125**	3,262	6,316	98,320	**107,898**	**136,023**
15 Pogradec - Korce - Kapshtice	-	-	-	**-**	-	-	-	**-**	**-**

Damages from failure after replacement of culverts and bridges

Floods	Repairs				Losses from service interuption				Total
Annual Expected Damages	Small	Medium	Large	Sub-total	Small	Medium	Large	Sub-total	
01 Milot - Morine New	3,200	1,050	-	**4,250**	3,968	8,519	-	**12,487**	**16,737**
02 Shkoder - Puke - Kolsh	-	5,550	-	**5,550**	-	3,525	-	**3,525**	**9,075**
03 Milot - Shkoder - Muriqan	1,100	6,450	280,000	**287,550**	18,093	82,810	1,151,737	**1,252,640**	**1,540,190**
04 Tirana - Durres	-	-	80,000	**80,000**	-	-	1,713,170	**1,713,170**	**1,793,170**
05 Durres - Vlore	1,800	3,750	40,000	**45,550**	30,308	564,569	3,620,188	**4,215,064**	**4,260,614**
06 Tirana - Elbasan - Pogradec	2,075	13,050	43,000	**58,125**	10,065	337,875	1,488,347	**1,836,288**	**1,894,413**
07 Fier - Gjirokaster - Kakavi	3,025	900	40,000	**43,925**	17,381	4,995	325,757	**348,133**	**392,058**
08 Gjirokaster - Sarande - Ksamil	2,250	4,950	32,000	**39,200**	101	87	1,539	**1,727**	**40,927**
09 Elbasan - Gramsh	625	-	-	**625**	92	-	-	**92**	**717**
10 Lushnje - Berat - Çorovode	-	-	-	**-**	-	-	-	**-**	**-**
11 Rrogozhine - Elbasan	800	-	-	**800**	5,532	-	-	**5,532**	**6,332**
12 Shkoder - Hani i Hotit - Vermosh	1,925	8,550	-	**10,475**	8,909	-	-	**8,909**	**19,384**
13 Milot - Peshkopi	3,000	8,550	-	**11,550**	10,225	68,994	-	**79,219**	**90,769**
14 Vlore - Sarande	1,425	450	-	**1,875**	2,576	2,153	-	**4,729**	**6,604**
15 Pogradec - Korce - Kapshtice	-	-	-	**-**	-	-	-	**-**	**-**

Benefits from replacement of culverts and bridges

Benefits Floods	Repairs				Losses from service interuption				Total
Annual Benefit	Small	Medium	Large	Sub-total	Small	Medium	Large	Sub-total	
01 Milot - Morine New	-	-	-	**-**	-	-	-	**-**	**-**
02 Shkoder - Puke - Kolsh	-	-	3,000	**3,000**	-	-	1,321	**1,321**	**4,321**
03 Milot - Shkoder - Muriqan	-	-	-	**-**	-	-	-	**-**	**-**
04 Tirana - Durres	-	-	-	**-**	-	-	-	**-**	**-**
05 Durres - Vlore	900	3,300	65,000	**69,200**	13,708	433,589	5,204,020	**5,651,317**	**5,720,517**
06 Tirana - Elbasan - Pogradec	(475)	-	40,000	**39,525**	361	-	1,070,627	**1,070,988**	**1,110,513**
07 Fier - Gjirokaster - Kakavi	(1,425)	13,950	169,000	**181,525**	(8,514)	63,996	623,009	**678,491**	**860,016**
08 Gjirokaster - Sarande - Ksamil	-	-	-	**-**	-	-	-	**-**	**-**
09 Elbasan - Gramsh	-	-	-	**-**	-	-	-	**-**	**-**
10 Lushnje - Berat - Çorovode	-	-	40,000	**40,000**	-	-	214,003	**214,003**	**254,003**
11 Rrogozhine - Elbasan	-	-	-	**-**	-	-	-	**-**	**-**
12 Shkoder - Hani i Hotit - Vermosh	(175)	-	40,000	**39,825**	(602)	-	131,769	**131,167**	**170,992**
13 Milot - Peshkopi	25	1,050	40,000	**41,075**	57	3,763	381,537	**385,357**	**426,432**
14 Vlore - Sarande	200	1,050	25,000	**26,250**	686	4,162	98,320	**103,168**	**129,418**
15 Pogradec - Korce - Kapshtice	-	-	-	**-**	-	-	-	**-**	**-**