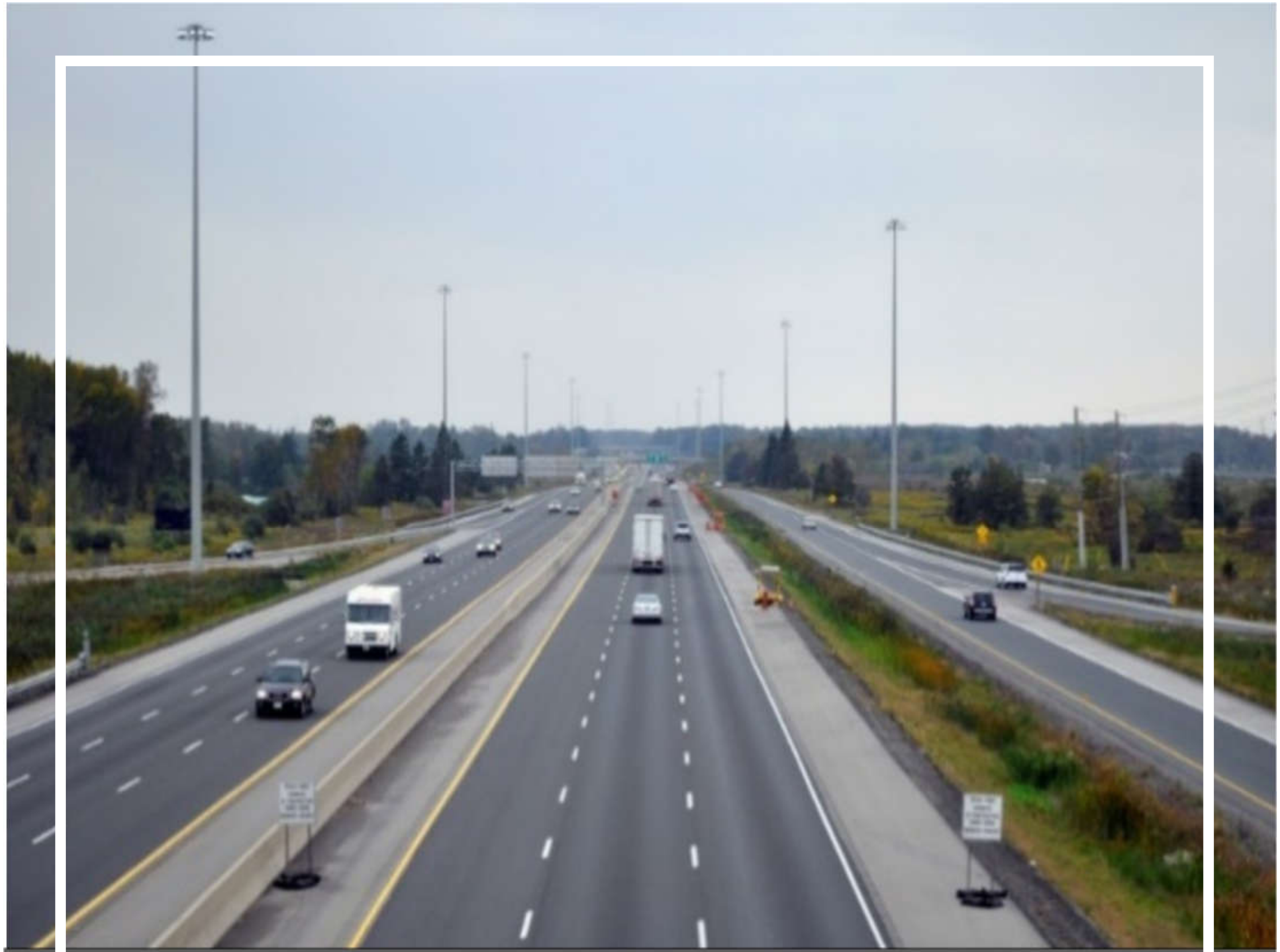

Using the PIEVC Protocol and Related Resources to Improve Risk-Informed Decision-Making Processes in the Republic of Georgia

Final Report

Climate Vulnerability Assessment

July 2023

CLIMATE RISK INSTITUTE

The project "Using the PIEVC Protocol and Related Resources to Improve Risk-Informed Decision-Making Processes in the Republic of Georgia" (Agreement Number: 81274990) is funded by the German Federal Ministry for Economic Cooperation and Development (BMZ) and supported by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH.

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The climate analysis and vulnerability assessment conducted for road infrastructure in the Racha-Lechkhumi and Kvemo Svaneti (R.L-K.S.) region was carried out by Stantec and supported the development of recommendations and conclusions presented in this report.

All findings presented in this report are based on information gathered and existing at the time of the work. The report relates solely to the specific project for which CRI was engaged and its specified set of objectives. Any use of this report or reliance of its content by third parties is the responsibility of the third party.

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Executive Summary

The Covid crisis exposed weaknesses in how societies plan for and respond to major hazards, exposing inadequate governance structures and decision-making processes. To "build back better," there is a need to significantly improve the risk-informed nature of governance structures and decision-making at all levels. The proposed project "Using the PIEVC Protocol and Related Resources to Improve Risk-Informed Decision-Making Processes in the Republic of Georgia" was initiated to help advance risk-informed governance in the transportation sector, by incorporating climate change and critical infrastructure risk assessment.

The main focus of the project was a desktop-based vulnerability assessment of road segments in a region of the Republic of Georgia particularly prone to the impacts of severe weather, especially in the form of landslide related events. The analysis includes historically-based analysis and development of climate change projections, evaluating the vulnerabilities of road infrastructure to specific climate hazards, the likelihood of related impacts, and the potential need for climate change and transportation resilience planning in the region and across the sector. The objectives of the project include raising awareness about the PIEVC Protocol and its resources, mapping opportunities to integrate PIEVC with broader climate and disaster risk management processes, and piloting new guidance and materials for applying the PIEVC Protocol in specific decision-making contexts.

The assessment focused on road infrastructure in the Racha-Lechkhumi and Kvemo Svaneti region, including three secondary roads of interest and local roads frequently used by residents [Kutaisi (Motsameta) – Tkibuli - Ambrolauri and in particular the Nakerala pass; Kutaisi - Tskaltubo - Tsageri - Lentekhi – Lasdili; and Alpana - Tsageri and Kutaisi – Alpana - Mamisoni Pass]. A Climate Analysis was conducted to understand relevant and potential hazards and impacts of climate change on the road infrastructure. The assessment identified 89 interactions between the described climate hazards and specific components of each element of road infrastructure, with 44 showing medium or high vulnerability for historical and future-projected conditions. Asphalt surfaces were deemed to be affected by more climate hazards than any other of the assessed component, with potential impacts linked to interactions with nine (9) different hazards. and seven (7) of these interactions – asphalt with temperature change, extreme heat, heat waves, extreme cold, short-duration high intensity rainfall, multi-day rainfall, and wildfire – resulting in medium to high vulnerability). High vulnerability ratings for component interactions were most frequently attributed to wildfire (asphalt surfaces, embankments, carriageway, seismic elastomeric/rubber bearings, tunnel ventilation, emergency/evacuation systems, mobile communications, and internet). The total number of vulnerability ratings among components was highest for short-duration high intensity rainfall, including asphalt surfaces, embankments, foundations, stormwater drainage, and emergency/evacuation systems.

Further exploration of climate-related risks is recommended, through application of the full PIEVC Protocol. Specific recommendations include:

- Further exploration of climate-related risks through application of the full PIEVC Protocol in the region complete with site visits, local engagement, and workshops to determine the consequence of climate hazard interactions with the infrastructure components identified as "most" vulnerable.
- Consider in greater detail the impacts of specific climate hazards on:
  - asphalt and road surfaces
  - drainage infrastructure and embankment.
- Assess the likelihood of wildfire events in the region, their potential impacts on road infrastructure, and related risks.
- Foster collaboration among stakeholders, including government agencies, road authorities, climate scientists, engineering professionals, communities, and users, to enable data and knowledge sharing. This collaboration will aid in assessing the severity of impacts caused by climate interactions on vulnerable infrastructure, analyse risks and propose adaptation measures.
- Utilize the high-level vulnerability assessment findings to facilitate additional engineering analysis, such as geospatial analysis, for a comprehensive segment-based study. Additionally, Hydrological Models can support the identification of potential freshet events and the subsequent impacts on roads. This approach will incorporate local physical conditions and enable the identification and prioritization of vulnerable regional road segments.

Applying a comprehensive risk assessment, along with implementing its recommendations and proposed adaptation measures can yield significant economic, social, and environmental benefits. These benefits include reduced maintenance costs, improved resource allocation, and optimized operations, providing long-term investment protection. Additionally, climate adaptation measures can support and enhance public safety, community resilience, and ecosystem preservation, thereby reducing the impacts of climate change and overall enhancing resilience.

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1. Introduction

1.2. Background

The Covid crisis exposed weaknesses in how our societies plan for and respond to major hazard-related events, at the global, national, regional, and sub-regional levels. In many instances, these weaknesses stem from inadequate governance structures and related decision-making processes. "*Building back better*" from the Covid crisis – to make our societies better prepared for and more resilient to all manner of hazards and associated risks - requires a focus on, among other things, *significantly improving the risk-informed nature of governance structures* and related decision-making. These improvements are required at all levels and scales. Particular emphasis should be placed on risk-informed governance and decision-making within and across societies' critical infrastructure sectors.

The Republic of Georgia stands as a highly vulnerable country, susceptible to the adverse impacts of climate change. These impacts encompass an increased frequency and severity of extreme temperatures, wildfires, droughts, flooding, and landslides. As the future brings further intensification of these climate-related hazards, the country faces a significant threat. The projected rise in extreme heat, heat waves, extreme precipitation, droughts, and wildfires underlines the pressing need for proactive planning and adaptation strategies. To address these challenges effectively, it is paramount to understand the specific influences of climate change on hazard events' frequency and characteristics. By conducting comprehensive climate risk assessments, we can bolster the risk-informed nature of governance structures and decision-making processes at all levels. This, in turn, empowers us to develop robust strategies and policies that adequately tackle the impacts of climate change, safeguarding a resilient future for the Republic of Georgia.

The proposed project titled "Using the PIEVC Protocol and Related Resources to Improve Risk-Informed Decision-Making Processes in the Republic of Georgia" was designed to support this objective initiated. This project focused on advancing risk-informed governance and decision-making in the transportation sector in the Republic of Georgia by building the information base required to start incorporating climate change and critical infrastructure risk assessment into sectoral governance structures and decision-making processes.

In particular, it focused on conducting preliminary screening of selected climate-related hazards and grey infrastructure components and assessing the climate-related vulnerability of the road infrastructure network in Racha-Lechkhumi and Kvemo Svaneti (R.L-K.S.) region, one of the most hazard-prone regions of the country. The results and datasets developed for this assessment, including tailored sets of climate projections, can support further climate change risk assessment and resilience planning for the transportation sector in the region and inform similar work elsewhere in the Country.

The project strongly aligns with disaster risk reduction initiatives supported by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) in the Republic of Georgia. Working with country partners, GIZ is helping to advance risk-informed governance and decision-making into sectoral structures and processes more broadly.

1.3. Project Objectives

This project aimed to advance the knowledge base for risk-informed decision-making in the transportation sector using the PIEVC Protocol, a well-established climate change and infrastructure vulnerability and risk assessment framework. Objectives of the project included working with country partners to:

- Raise awareness about the PIEVC Protocol and its broader family of resources, and how these resources can support risk-informed decision-making;
- Map opportunities for the PIEVC process and its outcomes to integrate with and inform broader climate and disaster risk management processes at the national and sub-national levels;
- Pilot new guidance "("High-Level Screening Guide" and/or Beta "Portfolio Manual") and related materials to apply the PIEVC Protocol in specific risk-informed decision-making contexts.

1.4. Project Scope

The assessment employed elements of the PIEVC Protocol methodology supported by its resources "High-Level Screening Guide" and Beta "Portfolio Manual" to preliminary screen selected climate-related hazards and grey infrastructure components and evaluate the vulnerability of a representative archetype of road infrastructure in the Racha-Lechkhumi and Kvemo Svaneti (R.L-K.S.) region. There are three secondary roads of interest in this region [Kutaisi (Motsameta) – Tkibuli - Ambrolauri and in particular the Nakerala pass; Kutaisi - Tskaltubo - Tsageri - Lentekhi – Lasdili; and Alpana - Tsageri and Kutaisi – Alpana - Mamisoni Pass] and local roads that are frequently used by residents. A Climate Analysis is an integral part of this assessment process, aimed at characterizing the potential hazards and impacts of climate change on road infrastructure.

1.5. Interpreting the Assessment and its Results

This vulnerability assessment has been scoped and conducted as a preliminary screening of selected climate-related hazards and grey road infrastructure components. It is important to note that the recommendations provided in this assessment are not based on a comprehensive risk assessment process. Thus far, the focus has been on identifying vulnerabilities. The subsequent steps involve assessing risks, proposing adaptation measures, developing plans, implementing actions, and continuously monitoring and evaluating the effectiveness of adaptation options. This process is intended to be iterative, as it accommodates emerging challenges, the availability of more comprehensive data, and the need for further evaluation and implementation.

1.6. Report Layout

This report showcases the methodology and findings of the Climate Vulnerability Assessment conducted in alignment with the PIEVC Protocol approach and its resources, "High-Level Screening Guide" and Beta Portfolio Manual". The assessment focuses on a representative archetype of the road infrastructure in the Racha-Lechkhumi and Kvemo Svaneti (R.L-K.S.) region. Section 2 provides an overview of the methodology used for the Climate Analysis and the Climate Vulnerability Assessment. Section 3 presents the results of the Climate Change Analysis, including the Climate profile for the Republic of Georgia and the identification of climate hazards. Section 4 delves into the detailed outcomes of the Climate Vulnerability Assessment. Conclusions and recommendations are provided and discussed in Section 5, while Section 6 highlights the limitations identified throughout the process.

2. Methodology

The methodology used for this assessment followed elements of the PIEVC protocol approach, supported by a range of resources, including the PIEVC Protocol High-Level Screening (HLSG) Guide, and the Beta Portfolio Manual. This assessment followed Step 1: to formulate the scope of the project. Step 2: Data Gathering and Sufficiency to analyse climate and infrastructure data, identify gaps, and determine the list of climate parameters and infrastructure components to be evaluated. Since the objective of this assessment was to conduct a preliminary screening of climate-related hazards and grey road infrastructure components, and evaluate the vulnerability, Step 3 of the protocol: Risk Assessment was partially applied. This step involved identifying the exposure and describing the potential impacts associated to the interaction between infrastructure components and infrastructure elements.

2.2. Data Sufficiency and Gaps Analysis

The objective of the data sufficiency and gaps analysis was to thoroughly review the data requested and collected for the assessment. Typically, assessments benefit from data on the meteorology and climate of the region or location under consideration. Understanding the climatic conditions, including historical weather patterns, extreme events, and projected climate change scenarios, provides valuable insights into the potential hazards and risks faced by the infrastructure system. In addition to meteorological and climate data, information about the infrastructure system itself is crucial. This includes details about the materials used in its construction, the design specifications, the current condition of the assets, and their specific locations. The characteristics and vulnerabilities of the infrastructure components play a significant role in determining their susceptibility to climate-related impacts.

The operation and maintenance practices of the infrastructure system are also essential factors to consider. Data related to the management and upkeep of the assets, such as maintenance schedules, repair records, and inspection reports, can help assess the system's resilience and its ability to withstand climate-related stressors. Past impacts and failures of the system provide valuable lessons and insights into its vulnerabilities. Assessing historical events, such as instances of infrastructure failure or disruptions in service levels, can help identify areas of weakness and inform future mitigation and adaptation strategies. Furthermore, the broader environment in which the system is located plays a significant role in assessing vulnerability. Understanding the ecological context, including the surrounding natural and built environment, can help identify additional stressors or interdependencies that may impact the performance and resilience of the infrastructure system. To conduct this analysis, the project team undertook a comprehensive desktop review of information provided by in-country partners, to identify and characterize gaps of potential consequence for our analysis. During this step of the project, an infrastructure component list was developed. This list, based on the findings of the desktop review and outlined in Table 1, identifies the main components and subcomponents of the road infrastructure, enabling a precise characterization of the typical road archetype.

Table 1: Infrastructure components and sub-components of typical road infrastructure in Georgia

System	Infrastructure Component	Infrastructure Sub-Components / Notable Examples	Descriptions of Sub-Components
Transportation	International/Secondary/Local Roads & Highways	Foundations	The lowest structural component of a roadway (also known as subgrade)
		Crushed-stone base course	Subbase of roadways composed of crushed stone beneath the asphalt
		Asphalt surfaces	The top surface of the roadway
		Retaining walls	Walls are designed to restrain soil, typically in a steep or vertical slope. Often located adjacent to a roadway to prevent earth material from moved onto roads
		Embankments	Structures used to prevent water from reaching the roadway to prevent flooding
	Bridges	Beams/Girders	Horizontal structures that support the deck and are supported by piers/abutments at either end
		Carriageway	The driving space on a bridge deck
		Seismic elastomeric/rubber bearings	Structural components to support concrete structure and transmit loads
		Railings/Parapets/Safety Fences	Barriers typically made of concrete or steel to protect users from the edge of the bridge
		Deck slab	The surface of a bridge
		Expansion joints	Joints that allow concrete to expand and contract without cracking
		Abutments	Structures that connect a bridge to roadways by supporting the ends of a bridge and acting as a foundation
		Piers	Supporting structure that extends to the ground or water to provide stability

System	Infrastructure Component	Infrastructure Sub-Components / Notable Examples	Descriptions of Sub-Components
	Tunnels	Interior Tunnel Walls	Structure designed and constructed to provide structural support, safety, and functionality within the tunnel environment
		Ventilation	System employed to control and manage air quality within the tunnel
		Emergency parking area/passage	A designated space or lane within the tunnel where vehicles can safely stop or pass in case of an emergency
		Supports/foundation	Structural elements that provide stability and load-bearing capacity to the tunnel, including rock bolts, steel supports and reinforced concrete linings
		Tunnel waterproofing	Protective materials to prevent the ingress of water into the tunnel structure
		Electricity/lighting	Electrical and lighting systems to ensure visibility, safety, and functionality within the tunnel
		Operation and maintenance	Ongoing activities and procedures involved in managing and ensuring the safe, efficient, and reliable operation of the tunnel
		Emergency/evacuation systems	Infrastructure, protocols, and procedures in place to ensure the safe evacuation of tunnel occupants and the effective response to emergencies or incidents within the tunnel
Water Management	Stormwater Drainage		Systems designed to manage the collection, conveyance, and disposal of rainwater runoff from road surfaces, adjacent areas, and surrounding landscapes

System	Infrastructure Component	Infrastructure Sub-Components / Notable Examples	Descriptions of Sub-Components
			(includes culverts, wells, trenches, and other drainage networks)
Public Services	Communications	Mobile Internet	Systems used for the exchange of information and data between various entities involved in road transportation that manages traffic, emergency responses, and operational coordination

2.3. Climate Profile

A crucial step in any Climate Vulnerability and Risk Assessment (CVRA) process involves utilizing climate change projections to evaluate the potential impacts of climate change hazards, such as extreme heat or drought, both presently and in the future. Table 2 presents the climate hazards and indicators utilized in the vulnerability assessment. To gain a comprehensive understanding of the current and anticipated future climate conditions in the Republic of Georgia, a climate profile and projections assessment have been conducted. This assessment involved gathering regional data on a national scale.

The establishment of the current climate profile involved analyzing data obtained from published literature, local climate data, and available gridded climate datasets such as the ECMWF ERA5 reanalysis. The ERA5 dataset was obtained via API request from the Copernicus Climate Data Store. ERA5 provides global hourly estimates of atmospheric, land and oceanic climate variables on a 0.25 x 0.25-degree grid (~25km) at an hourly temporal resolution. The preliminary ERA5 dataset spans from 1950 to 1978 and the official ERA5 dataset covers 1979 to present. Both datasets combine vast amounts of historical observations, including satellite and in-situ data into global estimates using advanced modelling and data assimilation systems. For the purposes of large-scale climate data collection and spatial coverage, the daily ERA5 dataset was used to compute historical baseline values for this study.

Future climate projections were based on the global database of statistically downscaled climate projections available from the US National Aeronautics and Space Administration (NASA) in the NASA Earth Exchange (NEX) Global Daily Downscaled Projections (GDDP) dataset and were selected for use in this project. The NEX data used for the future projections are based on a subset of the ensemble of global climate models used for the Fifth Assessment Report (AR-5) of the Intergovernmental Panel on Climate Change (IPCC), and the regional concentration pathway (RCP) 8.5 or high emissions scenario.

The NASA NEX-GDDP dataset represents a statistically downscaled set of climate models for 21 GCMs, generated using the Bias-Correction Spatial Disaggregation (BCSD) method. The dataset compiles 42 climate projections from 21 CMIP5 GCMs, projected for the period from 2006-2100. The historical experiment was generated for the period of 1950-2005. Each of the projections were available at a spatial resolution of approximately 0.25 degrees by 0.25 degrees (approx. 25 km by 25 km). Variables downloaded for this dataset include temperature (maximum, minimum, mean temperatures) and precipitation (daily precipitation) at an approximately 25 km by 25 km resolution.

The RCP 8.5 scenario is characterized by increasing greenhouse gas (GHG) emissions over time and is commonly referred to as the "business-as-usual" emissions scenario as current GHG emissions correspond with the RCP 8.5 trajectory. This also represents the most conservative scenario for assessing future vulnerabilities and risks. More on the climate change scenarios and hazards can be found in Section 3.1 if this report.

Table 2: Climate hazards and indicators used in the vulnerability assessment

	Hazard	Hazard Indicator
Temperature	Temperature Change	Percent change in mean temperature
	Extreme Heat	Days with Maximum Temperature exceeding 35°C
	Heat Waves	Frequency of 5 or more days consecutive that have an observed temperature greater than the 90th percentile of temperature values for the location
	Extreme Cold	Days with Minimum Temperature less than -15°C
Precipitation	Precipitation Change	Percent change in total precipitation
	SDHI (short duration high intensity rainfall)	Days with total precipitation exceeding 50mm
	Multi-Day Rainfall	Maximum 5-day precipitation percent change
Complex	Drought	Frequency of Standardized Precipitation and Evapotranspiration Index (SPEI) < -2, where negative SPEI values indicate drought conditions
	Wildfire	Keetch-Byram Drought Index > 150, where higher values are correlated with more wildfire fuel potential

2.4. Impact Statement Identification

Through the literature review and data collection process, climate parameters and projected changes for the country and region were categorized for the purpose of identifying possible impacts that may affect transportation infrastructure, assets, and services. An analysis of the climate hazards and impacts on transportation infrastructure in the region was conducted by assessing what changes may occur (e.g., no noticeable change, warmer and drier summer, more frequent and intense storm events, etc.).

The impact identification process identified key climate hazards and associated impacts by sector for consideration. The process screened out those climatic parameters that have no bearing on the transportation sector, leaving the remaining climate hazards and impacts by transportation sector (e.g., description of the hazard, historical occurrences, extent (or magnitude), and overarching associated potential impacts).

The screening for climate parameters and the development of the impact statement processes were informed by literature, country profiles and the team's professional judgment, informed by assessments conducted on similar road systems in various geographies around the world.

2.5. Vulnerability Assessment

For each impact statement identified, a vulnerability analysis was completed. Vulnerability is a multidimensional concept that encompasses sensitivity to the hazard, exposure to it and the adaptive capacity. It is the measure of the extent to which a segment or group of the population, asset, system, or sector is susceptible to or unable to cope with the impacts as a result of a changing climate. Risk is the evaluation of the possible consequence should the hazard event and impact occur (which is based on probability/likelihood). Risk analysis is not being conducted in this phase of the project, only vulnerability.

Vulnerability is defined as a function of an asset, infrastructure system or service areas' exposure, sensitivity, and adaptive capacity but also broader socioeconomic and environmental cross effects as well. These are defined as follows.

- Exposure – The level of contact or proximity which assets, infrastructure systems or service areas would interact with climate hazards. Exposure to climate-related hazards varies based on location and setting, design features, users, and other factors, which can change as climate impacts vary, interact and compound.
- Sensitivity – The degree to which assets, infrastructure systems or service areas are either positively or negatively influenced/impacted by climate hazards. The degree of sensitivity to climatic hazards depends not only on geographic conditions but also on socioeconomic factors, such as population and infrastructure. Sensitivity indicators can encompass geographical conditions, land use, demographic characteristics, etc.
- Adaptive capacity/deficit – The ability to prepare for and respond to impacts and consequences. Adaptive capacity depends on physical resources, access to technology and information, varieties of infrastructure, institutional capability, and the distribution of resources. Key determinants of adaptive capacity include economic and social resources, level of technology, available information and skills, social capital, and the effectiveness of existing institutions, etc. At an asset or asset component level, factors like age, design setting, load, maintenance, service levels, etc. can also be considered.

Figure 1 shows a schematic diagram of the process that used to assess the portfolio of road infrastructure in the Racha-Lechkhumi and Kvemo Svaneti region. The assets that comprise the portfolio were assessed using the archetype defined by the infrastructure component list shown in Table 1. Similarly, the climate hazards that interact with the portfolio were defined by the climate indicators shown in Table 2. Using this information, exposure, sensitivity, and adaptive capacity/deficit were determined and used to calculate vulnerability.

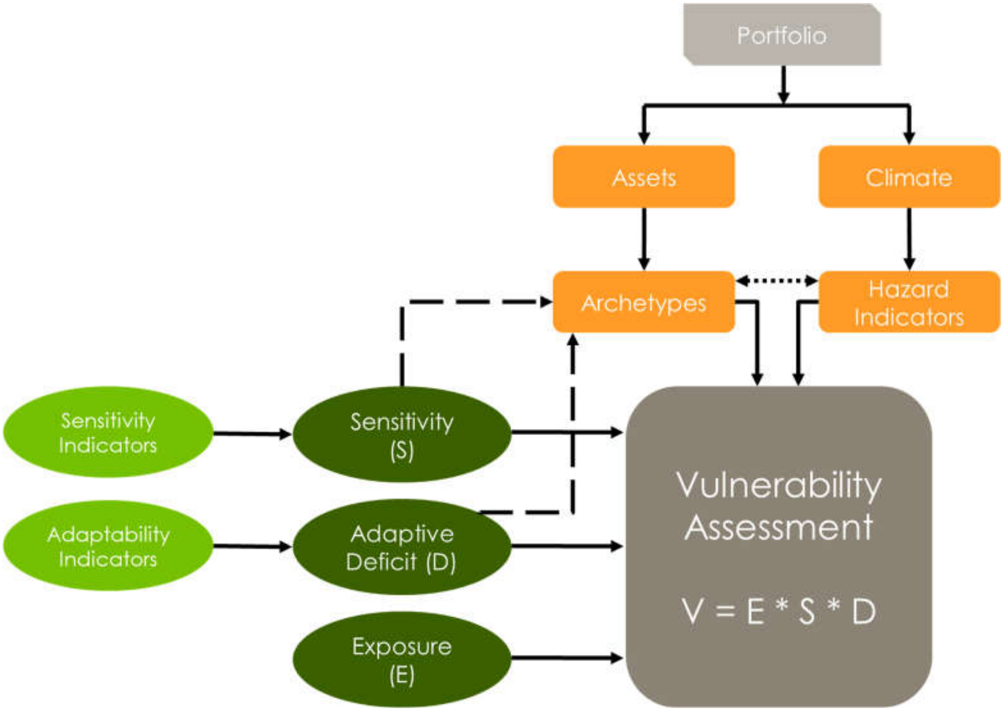

Figure 1: Schematic diagram of the PIEVC vulnerability assessment process

2.5.1. Assessing Exposure and Sensitivity

The first step in assessing sensitivity is to determine whether an asset is subject to any existing stress and whether the climate hazard could exacerbate that stress – this is the level of exposure.

Once an idea of exposure is developed, then a level of sensitivity can be determined. When assessing exposure and sensitivity, the following questions will be considered:

- Are there current climate hazards that result in impacts to the sector?
- Does the asset have limiting factors that may be affected or exacerbated by climate change?
- How would a climate impact affect the ability of the asset to function if it occurred today? (e.g., will climate change cause the demand for a resource or service to exceed its supply or current abilities?)

- Are there measures that are presently in place that are able to provide a buffer against predicted climate hazards?

2.5.2. Assessing Adaptive Deficit

In addition to understanding exposure and rating sensitivity, assessing vulnerability requires consideration of the main stressors, both climatic and non-climatic, as well as the socioeconomic influences on adaptive capacity. The impacts were assessed on the level of effort and intervention required to adjust to the impact to determine adaptive capacity. When assessing adaptive capacity, the following questions were considered:

- What is the ability of the current built, natural, or human systems in the community to accommodate changes, moderate potential damages, take advantage of opportunities, or cope with consequences?
- What current actions, plans, and policies are in place that could help mitigate the impacts?
- Are the current adaptive measures adequate?

2.5.3. Determining Vulnerability

In this context, vulnerability is the measure of the extent to which assets, infrastructure systems and services are susceptible to, or unable to cope with, the impacts or hazards of climate change. The vulnerability of an asset is determined using the formula **V = E x S x D**, where:

V = Vulnerability
E = Exposure (0 or 1)
S = Sensitivity (1, 2 or 3)
D = Adaptive Deficit (1, 2 or 3)

By examining the climate related hazards and possible interactions (exposure and sensitivity) with assets, infrastructure systems, and services as well as the ability to respond (adaptive capacity/deficit), the overall vulnerability to climate related hazards was determined using the matrix shown in the Table 3 below.

Table 3: Vulnerability Assessment Matrix

		Impact Rating (Severity + Exposure)		
		Low Vulnerability	**Medium**	**High**
Adaptive Deficit	**Low**	Low Vulnerability	Low Vulnerability	Medium Vulnerability
	Medium	Low Vulnerability	Medium Vulnerability	High Vulnerability
	High	Medium Vulnerability	High Vulnerability	High Vulnerability

2.6. Recommendations for Further Study

Based on the findings of the vulnerability assessment (Section 4.2.) recommendations are provided for areas that require further attention in future, more detailed PIEVC assessments. For instance, infrastructure components exhibiting medium or high vulnerability are recommended for in-depth analysis as part of a comprehensive PIEVC risk assessment process. The insights obtained from the high-level vulnerability assessment can also be utilized in geospatial analysis, enabling a more detailed examination of vulnerable road segments by incorporating local physical conditions. Additionally, the findings from the initial climate analysis conducted in this study can contribute to the development of more refined climate hazard indicators and interaction thresholds that are specific to the road archetypes

2.7. Stakeholders Consultation

Stakeholder engagement was conducted through two webinars and an email consultation.

PIEVC Webinar (April 2023) - This webinar aimed to familiarize participants with the PIEVC methodology, showcase its application in Georgia, present and validate initial climate analyses, raise awareness about data sharing opportunities, explore concerns regarding climate hazards, and update stakeholders on the project's upcoming steps.

Validation Process (June 2023)- Preliminary vulnerability analysis results were shared through email to gather feedback from stakeholders regarding their accuracy.

Final Presentation and PIEVC Applicability Session (July 2023) - This session involved the participation of stakeholders who had been part of the vulnerability assessment consultations as well as representatives from other sectors. It served to present the final project results and discuss the potential opportunities for applying the PIEVC Protocol on a broader scale to evaluate the country's infrastructure assets.

3. Climate Change Analysis

3.2. Climate Profile of the Republic of Georgia

Climate is usually defined as the "average weather," or more rigorously, as the statistical description in terms of the mean and variability of meteorological variables such as temperature, precipitation, and wind over a period of time. Climate profiles are important tools that describe what climate trends have been occurring in recent history (i.e., over the last 30 years or longer) and also describe future climate conditions to help inform planners, stakeholders, and decision-makers in managing climate change risks and planning for appropriate adaptation measures. Climate profiles rely on the historical climate record (usually in the form of meteorological data measured at weather stations) to describe climate from recent history and on climate projections data output from global climate models (GCMs). The historical climate profile puts future climate projections into context: the performance of the infrastructure from the past can be compared to both historical and future climates to understand better what adaptation measures should be implemented to ensure better performance in the future.

The historical or baseline climate profile is typically based on daily measurements of temperature, precipitation, and wind. Meteorological data from the last 30 years is preferred to help give a representative estimate of the climate of recent history at a given location – though longer periods are of even greater benefit in that they add even more to the story of an area's historical climate.

Climate projections are descriptions of the future climate and are most often collected from GCMs developed by many organizations worldwide. These GCMs are complex in that they all rely on many different assumptions about how they work (i.e., they focus more on different physical phenomena to estimate future climate, whether it be greenhouse gas (GHG) concentrations in the atmosphere or absorption of solar radiation by the ocean) and also on what will happen in the future. There are nearly 40 GCMs that have contributed to the Fifth Coupled Model Intercomparison Project (CMIP5), which forms the basis of many of the latest publications from the Intergovernmental Panel on Climate Change (IPCC). Since different GCMs focus more than others on different physical phenomena, there is a noticeable difference in the future climate that is predicted. Therefore, it is not recommended to rely only on one or two of these GCMs to estimate future climate. Instead, an average of several GCMs, known as an ensemble, tends to give a more reliable estimate of future climate.

In addition to the physics of the GCMs, global progress towards meeting GHG emissions targets is also a large source of uncertainty in future climate projections. There are four Representative Concentration Pathways (RCP)[1] scenarios adopted by the Intergovernmental Panel on Climate Change (IPCC) that are based on various future greenhouse gas concentration scenarios. Current global GHG concentrations are closer to following the RCP 8.5 pathway, despite global agreements/targets for GHG emissions reductions. RCP1.9 and RCP2.6 are considered as an aggressive action scenario in which the global mean temperature would not exceed 1.5°C and 2 °C, respectively. Carbon emission will have to peak around 2020s and then reduce drastically to near zero before the end of century. RCP4.5 is a medium emission scenario in which the global mean temperature is likely to exceed 2°C. It requires carbon emissions to be near zero by the end of the century. The RCP8.5 scenario is based on a "business as usual" future in which greenhouse gas emissions are not restricted. This scenario will result in a global mean temperature increase of 3.5°C at the end of the century. Local changes for temperature and precipitation are likely to be different than the overall change in global mean temperature under all scenarios.

The IPCC is the international body for assessing the science related to climate change. The IPCC was set up in 1988 by the World Meteorological Organization (WMO) and United Nations Environment Programme (UNEP) to provide policymakers with regular assessments of the scientific basis of climate change, its impacts and future risks, and options for adaptation and mitigation.

IPCC assessments provide a scientific basis for governments at all levels to develop climate related policies, and they underlie negotiations at the UN Climate Conference – the United Nations Framework Convention on Climate Change (UNFCCC). The assessments are policy-relevant but not policy-prescriptive: they may present projections of future climate change based on different scenarios and the risks that climate change poses and discuss the implications of response options, but they do not tell policymakers what actions to take.

Due to the low resolution of the GCMs, regional climate is often not well reflected in the GCM projections. The use of downscaled regional climate models (RCMs) tends to be more useful for generating a profile of local climate conditions that can be used in a climate risk assessment as RCMs better simulate local topography and regional climate phenomenon such as heat island effects, inversion etc. For this report, the NASA Earth Exchange (NEX) Global Daily Downscaled

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[1] RCP: Representative Concentration Pathways – a greenhouse gas concentration (not emissions) trajectories adopted by the Intergovernmental Panel on Climate Change (IPCC) for its fifth Assessment Report (AR5) in 2014.

Projections (GDDP) dataset was used to produce the bulk of the climate hazards for analysis. This dataset represents a series of daily data for three climate scenarios (historical, RCP4.5, and RCP8.5). This dataset represents a statistically downscaled set of climate models for 21 GCMs, generated using the Bias-Correction Spatial Disaggregation (BCSD) method. The dataset compiles 42 climate projections from 21 CMIP5 GCMs, projected from 2006-2100. The historical experiment was generated for the period of 1950-2005. Each of the projections is available at a spatial resolution of approximately 0.25 degrees by 0.25 degrees (approx. 25 km by 25 km). Variables downloaded for this dataset include temperature (maximum, minimum, and mean temperatures) and precipitation (daily precipitation).

Table 4: CMIP5 Models included in the NASA NEX-GDDP archive

Climate Scenario (Years)			
GCM	**Hist**	**RCP4.5**	**RCP8.5**
ACCESS1-0	1950-2005	2006-2100	2006-2100
BCC-CSM1-1	1950-2005	2006-2100	2006-2100
BNU-ESM	1950-2005	2006-2100	2006-2100
CanESM2	1950-2005	2006-2100	2006-2100
CCSM4	1950-2005	2006-2100	2006-2100
CESM1-BGC	1950-2005	2006-2100	2006-2100
CNRM-CM5	1950-2005	2006-2100	2006-2100
CSIRO-MK3-6-0	1950-2005	2006-2100	2006-2100
GFDL-CM3	1950-2005	2006-2100	2006-2100
GFDL-ESM2G	1950-2005	2006-2100	2006-2100
GFDL-ESM2M	1950-2005	2006-2100	2006-2100
INMCM4	1950-2005	2006-2100	2006-2100
IPSL-CM5A-LR	1950-2005	2006-2100	2006-2100
IPSL-CM5A-MR	1950-2005	2006-2100	2006-2100
MIROC-ESM	1950-2005	2006-2100	2006-2100
MIROC-ESM-CHEM	1950-2005	2006-2100	2006-2100
MIROC5	1950-2005	2006-2100	2006-2100
MPI-ESM-LR	1950-2005	2006-2100	2006-2100
MPI-ESM-MR	1950-2005	2006-2100	2006-2100
MRI-CGCM3	1950-2005	2006-2100	2006-2100
NorESM1-M	1950-2005	2006-2100	2006-2100

3.2.1. Climate Hazard Identification for Vulnerability Assessment

Climate hazards are the climate variables that can impact the project infrastructure components. Climate hazards used for this resilience assessment were chosen based on experience with previous climate resilience studies for similar types of infrastructure and on the information provided by GIZ and country partners through the information request and literature review conducted by the Stantec Team.

The climate hazards determined to have the most potential for impacting the Project infrastructure components include:

- Temperature change, extreme heat, and heat waves, which can lead to structural damages (e.g., cracking) of the infrastructure components (e.g., road surface), increased maintenance requirements and discomfort for the users.
- Freeze-thaw cycles, which can increase maintenance requirements for the proposed infrastructure components (e.g., expansion joints, asphalt/ concrete surface, and granular base).
- Precipitation change, short duration high intensity rainfall, and long duration rainfall, which can cause flooding, can lead to structural damage (i.e., erosion) of the infrastructure components, can increase maintenance requirements for roads, and can impact the functionality of the stormwater system.
- Complex parameters such as drought and wildfire, which can lead to loss of vegetation on slopes near roads and embankments, potentially increasing exposure to cascading hazards such as landslides and debris flows.

The climate variables selected for this resilience assessment are shown in Table 5. Once the climate variables are determined, a hazard indicator value is chosen for each climate variable. The hazard indicator value is normally associated with a likely impact or consequence on an infrastructure asset. Hazard indicators are used to help establish the likelihood that a particular climate event will occur over a defined period of time (e.g., by season, annually, or over the estimated lifetime of an asset). For this vulnerability assessment, likelihood scores were not established for the hazard indices since this would form part of the full PIEVC assessment process, not the vulnerability assessment process. For each hazard index, overall trends were established. Table 5 also presents both the trend and the confidence level associated with the projected trend for each climate hazard. Generally speaking, levels of confidence for projections based on GCMs and the downscaling of their outputs are:

- higher for general temperature and precipitation projections
- lower for extremes

- lower for combined events such as wildfire and drought (i.e., events create by compounding hazards or multiple climate variables)

Table 5: Climate Hazards and Hazard Indicators Selected for the Vulnerability Assessment

Hazard	Hazard Indicator	Trend	Confidence
Temperature			
Temperature Change	Percent change in mean temperature	Increasing	High
Extreme Heat	Days with Maximum Temperature exceeding 35°C	Increasing	High
Heat Waves	Frequency of 5 or more days consecutive that have T > TX90p	Increasing	High
Extreme Cold	Days with Minimum Temperature less than -15°C	Decreasing	High
Precipitation			
Precipitation Change	Percent change in total precipitation	Increasing	Moderate
SDHI	Days with total precipitation exceeding 50mm	Increasing	Moderate
Multi-Day Rainfall	Maximum 5-day precipitation percent change	Increasing	Moderate
Complex			
Drought	Frequency of SPEI index < -2	Increasing	Low
Wildfire	KBDI Index > 150	Slightly Increasing	Low

The following sections discuss the projected changes for each climate hazard across the Republic of Georgia. Section 3.1.2 focuses on temperature-related hazards while Section 3.1.3 focuses on precipitation-related hazards. Section 3.1.4 focuses on complex hazards.

3.2.2. Temperature

3.2.2.1. Mean Temperature

Summaries of mean historical temperature averaged for the baseline periods of 1981-2010 and 1991-2020 for the Republic of Georgia, and projected average change in mean temperature from the baseline to the 2020s, 2050s, and 2080s, for RCP4.5 and RCP8.5 scenarios, are shown in Table 6. Annual and seasonal mean temperatures are projected to increase across both scenarios, with the greatest increases (+3.0°C) and (+5.8°C) projected in the summer months for RCP4.5 and RCP8.5, respectively. Changes are not expected to be uniform across the country, as shown in the Figure 2 and Figure 3 of projected mean temperature change.

Table 6: Historical and Projected Mean Temperature (RCP4.5 and RCP8.5) for the Republic of Georgia

Season	Mean Temperature Climate Average 1981-2010 (°C)*	Climate Scenario	Projected Mean Temperature (Average Change in Mean Temperature from 1981-2010 Baseline) (°C)		
			2020s	2050s	2080s
Annual	7.9	**RCP4.5**	8.9 (+1.0)	9.9 (+2.0)	10.4 (+2.5)
		RCP8.5	9.1 (+1.4)	10.7 (+3.3)	12.5 (+5.6)
Winter	-3.4	**RCP4.5**	-2.6 (+0.8)	-2.0 (+1.4)	-1.3 (+2.1)
		RCP8.5	-2.5 (+0.9)	-1.2 (+2.2)	0.5 (+3.9)
Spring	6.9	**RCP4.5**	7.8 (+0.9)	8.6 (+1.7)	9.1 (+2.2)
		RCP8.5	7.9 (+1.0)	9.3 (+2.4)	10.9 (+4.0)
Summer	18.8	**RCP4.5**	20.1 (+1.3)	21.2 (+2.4)	21.8 (+3.0)

Season	Mean Temperature Climate Average 1981-2010 (°C)*	Climate Scenario	Projected Mean Temperature (Average Change in Mean Temperature from 1981-2010 Baseline) (°C)		
			2020s	**2050s**	**2080s**
		RCP8.5	20.3 (+1.5)	22.4 (+3.6)	24.6 (+5.8)
Fall	9.4	**RCP4.5**	10.4 (+1.0)	11.3 (+1.9)	11.8 (+2.4)
		RCP8.5	10.6 (+1.2)	12.2 (+2.8)	14.1 (+4.7)

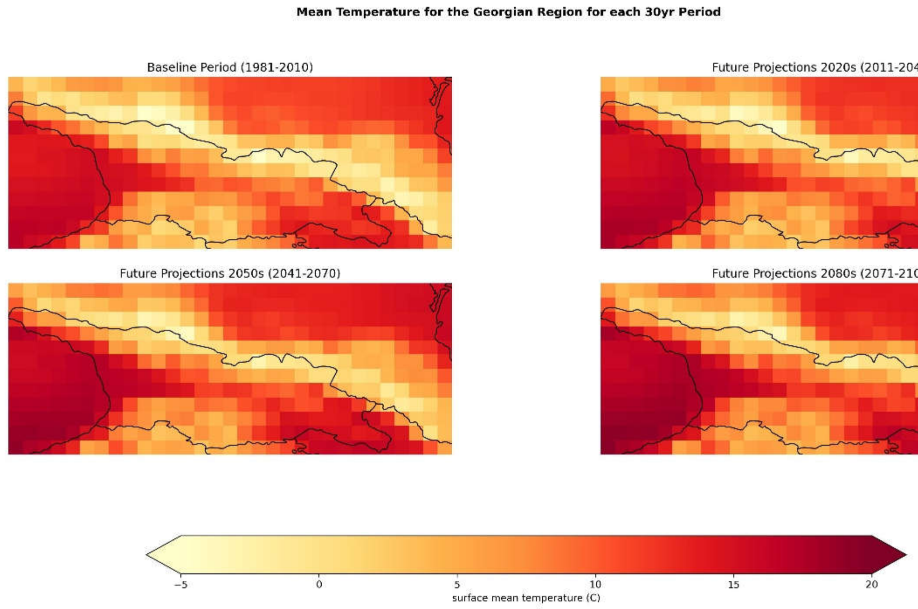

Figure 2: Projected Mean Temperature Change for Georgia, RCP4.5

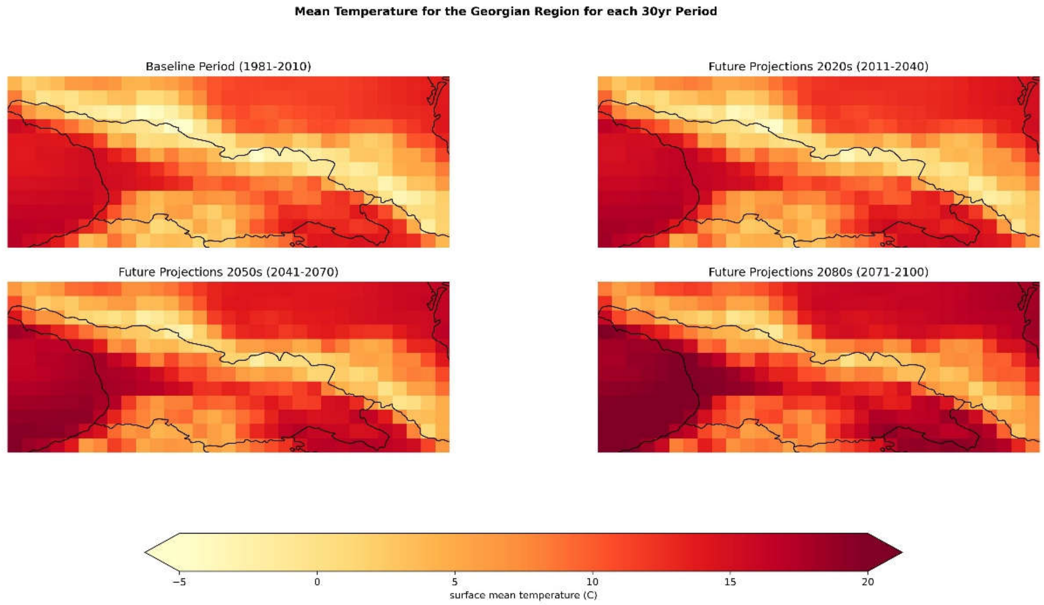

Figure 3: Projected Mean Temperature Change for Georgia, RCP8.5

3.1.2.2. Maximum Temperature

Summaries of maximum historical temperature averaged for the baseline periods of 1981-2010 and 1991-2020 for the Republic of Georgia and projected average change in maximum temperature from the baseline for RCP4.5 and RCP8.5 scenarios are shown in Table 7. Annual and seasonal maximum temperatures are projected to increase across both scenarios, with the greatest increases (+3.4°C) and (+6.3°C) projected in the summer months for RCP4.5 and RCP8.5, respectively. Like projected changes in mean temperature, maximum temperature changes are not expected to be uniform across the country as shown in Figure 4 and Figure 5.

Table 7: Historical and Projected Maximum Temperature (RCP4.5 and RCP8.5) for the Republic of Georgia

Season	Maximum Temperature Climate Average 1981-2010 (°C)*	Climate Scenario	Projected Max Temperature (Average Change in Max Temperature from 1981-2010 Baseline) (°C)		
			2020s	**2050s**	**2080s**
Annual	13.2	**RCP4.5**	14.3 (+1.1)	15.2 (+2.0)	15.8 (+2.6)
		RCP8.5	14.4 (+1.2)	16.2 (+3.0)	18.1 (+4.9)
Winter	0.8	**RCP4.5**	1.6 (+0.8)	2.3 (+1.5)	2.9 (+2.1)
		RCP8.5	1.7 (+0.9)	3.0 (+2.2)	4.8 (+4.0)
Spring	12.3	**RCP4.5**	13.2 (+0.9)	14.1 (+1.8)	14.6 (+2.3)
		RCP8.5	13.4 (+1.1)	14.9 (+2.6)	16.5 (+4.2)
Summer	25.0	**RCP4.5**	26.5 (+1.5)	27.7 (+2.7)	28.4 (+3.4)
		RCP8.5	26.7 (+1.7)	29.0 (+4.0)	31.3 (+6.3)
Fall	14.7	**RCP4.5**	15.8 (+1.1)	16.8 (+2.1)	17.4 (+2.7)
		RCP8.5	16.0 (+1.3)	17.8 (+3.1)	19.8 (+5.1)

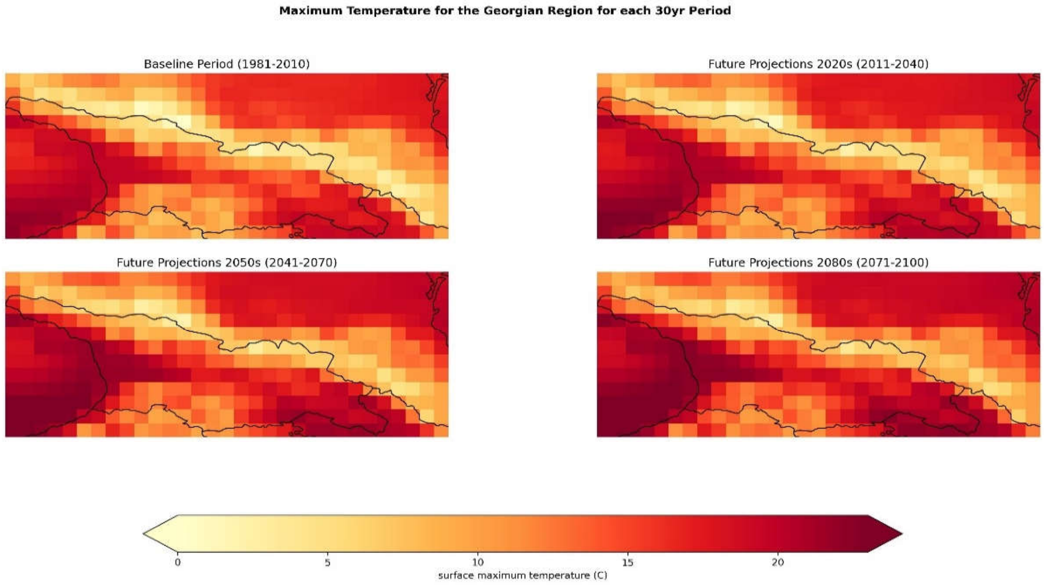

Figure 4 : Projected Maximum Temperature Change for Georgia, RCP4.5

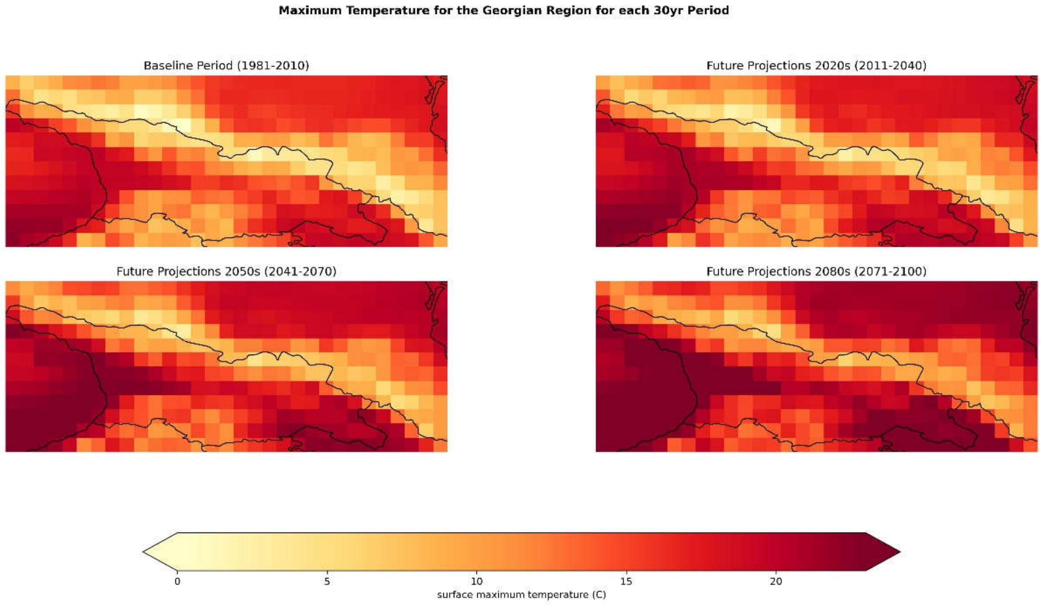

Figure 5: Projected Maximum Temperature Change for Georgia, RCP8.5

3.1.2.3. *Extreme Maximum Temperature Frequency*

Extreme heat can negatively affect some infrastructure. The average number of days with daily maximum temperatures greater than 30°C and 35°C in the Republic of Georgia. The frequency of extreme high temperatures is projected to increase for the region across all time periods as shown in Table 8 and Table 9, respectively.

Table 8: Occurrence of Maximum Daily Temperature > 30°C, Republic of Georgia (RCP4.5 and RCP8.5)

Average Annual Number of Days with Max. Temp > 30°C					
1981-2010 Baseline*	**1991-2020 Baseline***	**Climate Scenario**	**2020s**	**2050s**	**2080s**
21.5	25.2	**RCP4.5**	32.6	42.9	48.3
		RCP8.5	34.5	53.2	73.6

Table 9: Occurrence of Maximum Daily Temperature > 35°C, Republic of Georgia (RCP4.5 and RCP8.5)

Average Annual Number of Days with Max. Temp > 35°C					
1981-2010 Baseline*	**1991-2020 Baseline***	**Climate Scenario**	**2020s**	**2050s**	**2080s**
1.9	2.8	**RCP4.5**	5.1	9.8	12.9
		RCP8.5	5.9	16.4	31.4

3.1.2.4. *Minimum Temperature*

Summaries of maximum historical temperature averaged for the baseline periods of 1981-2010 and 1991-2020 for the Republic of Georgia and projected average change in maximum temperature from the baseline for RCP4.5 and RCP8.5 scenarios are shown in Table 10. Annual and seasonal maximum temperatures are projected to increase across both scenarios, with the greatest increases (+3.4°C) and (+6.3°C) projected in the summer months for RCP4.5 and RCP8.5, respectively. Similar to projected changes in mean temperature, maximum temperature changes are not expected to be uniform across the country as shown in Figure 6 and Figure 7.

Table 10. Historical and Projected Minimum Temperature (RCP4.5 and RCP8.5) for the Republic of Georgia

Season	**Minimum Temperature Climate Average 1981-2010 (°C)***	**Climate Scenario**	**Projected Minimum Temperature (Average Change in Min Temperature from 1981-2010 Baseline) (°C)**		
			2020s	**2050s**	**2080s**
Annual	2.6	**RCP4.5**	3.5 (+0.9)	4.4 (+1.8)	4.9 (+2.3)
		RCP8.5	3.7 (+1.1)	5.2 (+2.6)	6.9 (+4.3)
Winter	-7.6	**RCP4.5**	-6.8 (+0.8)	-6.2 (+1.4)	-5.6 (+2.0)
		RCP8.5	-6.7 (+0.9)	-5.5 (+2.1)	-3.9 (+3.7)
Spring	1.5	**RCP4.5**	2.4 (+0.9)	3.1 (+1.6)	3.5 (+2.0)
		RCP8.5	2.5 (+1.0)	3.8 (+2.3)	5.2 (+3.7)
Summer	12.5	**RCP4.5**	13.7 (+1.2)	14.7 (+2.2)	15.3 (+2.8)
		RCP8.5	13.9 (+1.4)	15.9 (+3.4)	18.0 (+5.5)
Fall	4.0	**RCP4.5**	4.9 (+0.9)	5.8 (+2.2)	6.3 (+2.8)
		RCP8.5	5.1 (+1.1)	6.7 (+2.7)	8.5 (+4.5)

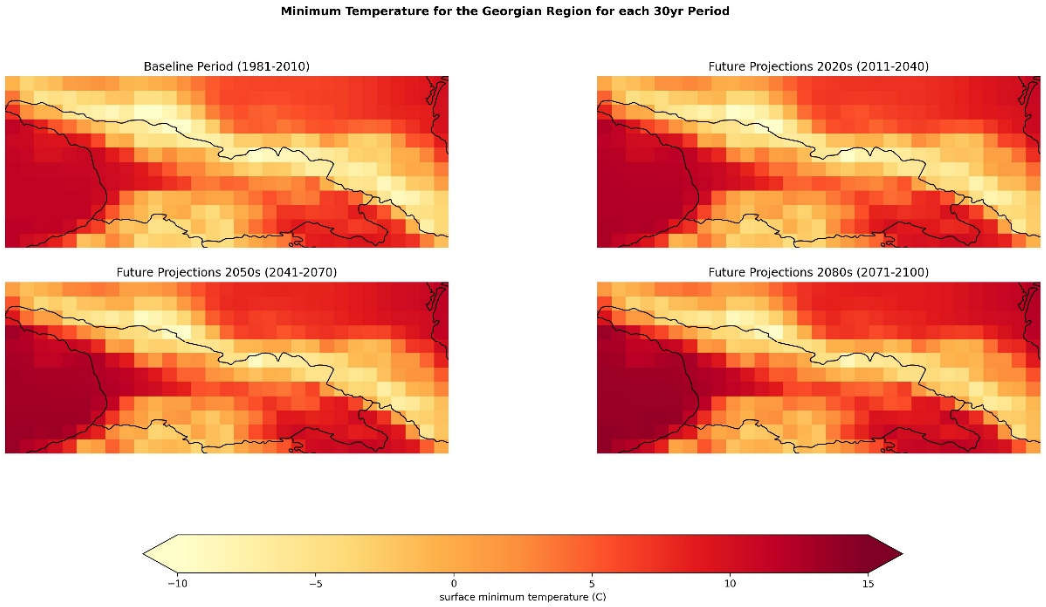

Figure 6. Projected Minimum Temperature Change for Georgia, RCP4.5.

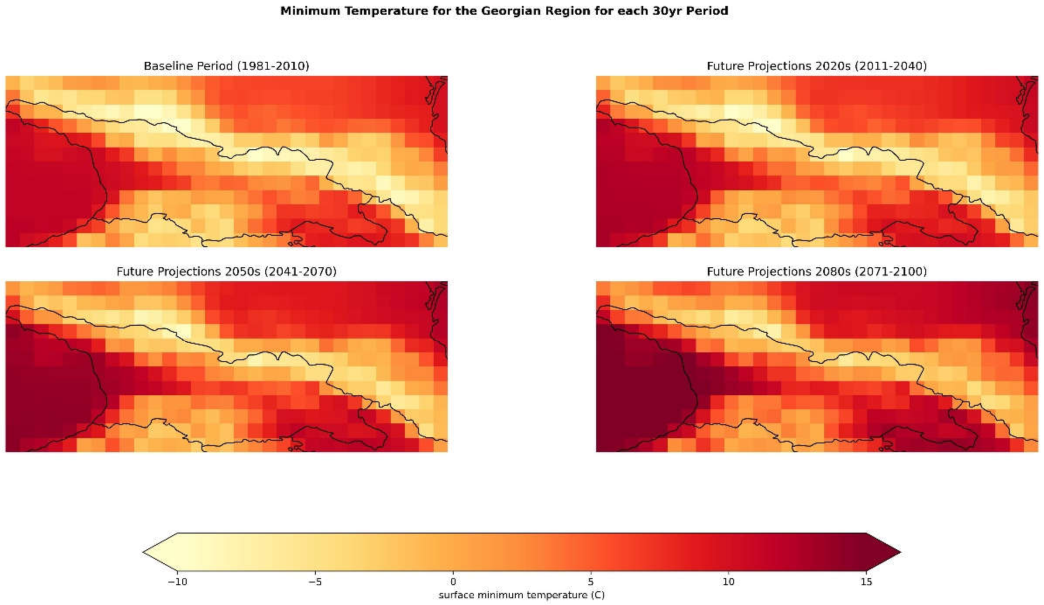

Figure 7. Projected Minimum Temperature Change for Georgia, RCP8.5

3.1.2.5. *Extreme Cold Day Frequency*

Extreme cold can negatively affect some road infrastructure. The average number of days with daily minimum temperatures less than -15°C is projected to decrease for the region across all time periods as shown in Table 11.

Table 11. Occurrence of Minimum Temperature < -15°C, Republic of Georgia (RCP4.5 and RCP8.5)

Average Annual Number of Days with Min. Temp < -15°C					
1981-2010 Baseline*	**1991-2020 Baseline***	**Climate Scenario**	**2020s**	**2050s**	**2080s**
20.8	19.6	**RCP4.5**	17.5	15.1	13.3
		RCP8.5	17.4	13.2	8.8

3.2.3. Precipitation

Total Annual and Seasonal Precipitation

Summaries of mean total annual and seasonal precipitation averaged for the baseline period of 1981-2010 for the Republic of Georgia and projected average change in mean temperature from the baseline for RCP4.5 and RCP8.5 scenarios are shown in Table 6. Annual and seasonal precipitation patterns are complex, with annual precipitation likely to increase in the short term and decrease in the long term, largely driven by projected decreases in summer precipitation (-13.3% and -22.0% for the RCP4.5 and RCP8.5, 2080s) and fall precipitation (-3.3% and -5.7% for the RCP4.5 and RCP8.5, 2080s). Changes are not expected to be uniform across the country, as shown in Figure 8 and Figure 9.

Table 12. Historical and Projected Total Precipitation (RCP4.5 and RCP8.5) for the Republic of Georgia

Season	**Total Precipitation Climate Average 1981-2010 (mm)**	**Climate Scenario**	**Projected Precipitation (Average Percent Change in Precipitation from 1981-2010 Baseline) (mm)**		
			2020s	**2050s**	**2080s**
Annual	846.3	**RCP4.5**	861.2 (+1.6%)	851.9 (+0.5%)	847.6 (0.0%)
		RCP8.5	861.3 (+1.8%)	840.9 (-0.6%)	833.6 (-1.5%)

Season	Total Precipitation Climate Average 1981-2010 (mm)	Climate Scenario	Projected Precipitation (Average Percent Change in Precipitation from 1981-2010 Baseline) (mm)		
			2020s	2050s	2080s
Winter	175.1	**RCP4.5**	187.9 (+7.6%)	197.8 (+13.3%)	193.6 (+10.9%)
		RCP8.5	189.9 (+8.5%)	198.4 (+13.3%)	205.7 (+17.5%)
Spring	228.9	**RCP4.5**	241.9 (+5.5%)	242.8 (+5.9%)	244.8 (+6.8%)
		RCP8.5	239.9 (+4.8%)	245.6 (+7.3%)	246.0 (+7.5%)
Summer	239.6	**RCP4.5**	226.9 (-5.7%)	213.5 (-11.3%)	208.6 (-13.3%)
		RCP8.5	229.7 (-4.1%)	202.6 (-15.4%)	187.0 (-22.0%)
Fall	202.8	**RCP4.5**	204.6 (+0.5%)	197.9 (-2.8%)	196.8 (-3.3%)
		RCP8.5	202.6 (-0.1%)	193.5 (-4.6%)	191.3 (-5.7%)

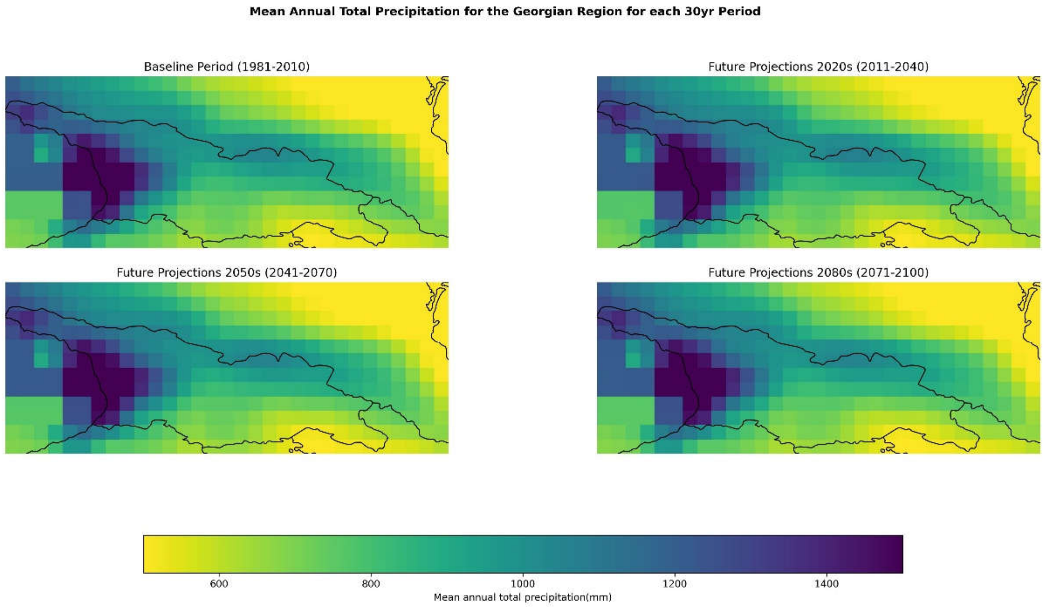

Figure 8. Projected Total Precipitation for Georgia, RCP4.5.

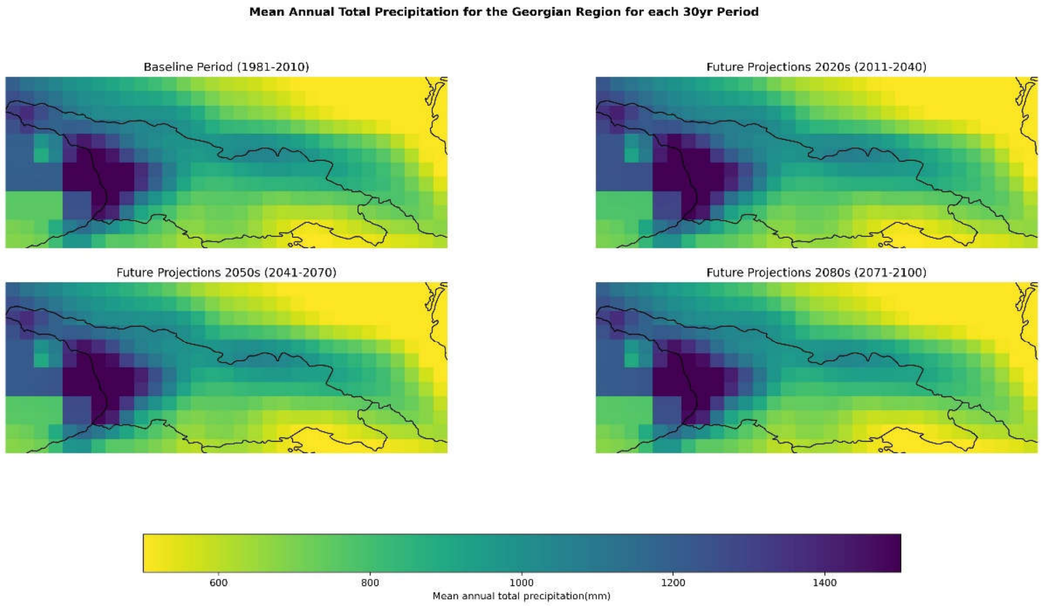

Figure 9. Projected Total Precipitation for Georgia, RCP8.5

Extreme Rainfall Days

Extreme rainfall is known to have direct impacts on roads and supporting infrastructure through the potential for exceeding design flow capacities of culverts, water ponding on roads, erosion of road embankments, and destabilization of steep cliffs that can lead to landslide activities. Rainfall events that accumulate more than 50 mm of rainfall in a single day can be used as an indicator for how intense rainfall events are expected to change in frequency across future time horizons. Typically, intensity and frequency of events can be adjusted using physical relationships between air temperature and the ability for air to contain more water per unit volume. For example, the Clausius-Clapeyron relation (C-C relation) indicates that there is, on average, a 7% increase in the air's holding capacity per 1°C of local warming. The C-C relation is founded on the atmospheric physics theoretical relationship between air temperature and the holding capacity of the atmosphere (*i.e.,* the amount of water the air could potentially contain). A similar or greater rate of increase in precipitation amounts is likely under a warming climate, dependent on the event duration. Rainfall vs. temperature relationships close to the C-C relation have been detected globally and regionally in observational studies (Westra et al., 2013; Panthou et al., 2014; Prein et al., 2016; Barbero et al., 2017). Therefore, it should be expected that where warming temperatures are expected to continue throughout the 21st century, the intensity and frequency of extreme rainfall events will also increase as shown in Table 13.

Table 13. Annual Frequency of Days with Precipitation Greater than 50mm

Days with Precipitation of > 50mm				
1981-2010 Baseline*	**Climate Scenario**	**2020s**	**2050s**	**2080s**
0.45	**RCP4.5**	0.51	0.52	0.55
	RCP8.5	0.62	0.68	0.79

Multi-Day Precipitation

Projections of precipitation extremes have higher uncertainty. Since climate model grid box precipitation projections are usually interpreted as spatially averaged values, the outputs tend to reduce extreme precipitation magnitudes (Chen and Knutson, 2008; Seneviratne et al., 2012), contributing to the systematic underestimation of precipitation. Considering the Clausius-Clapeyron relation, it is probable an increasing trend in precipitation accumulation would extend to longer rainfall duration events as well. Increases in the mean amount of precipitation for long duration events in Georgia are expected to increase, as shown in Table 14. Figure 10 and Figure 11 show the projected patterns of multi-day precipitation under RCP4.5 and RCP8.5, respectively.

Table 14. Multi-Day Precipitation Event Rainfall Amounts, 5-Day Precipitation, Republic of Georgia (RCP4.5 and RCP8.5)

5-Day Mean Precipitation Accumulation				
1981-2010 Baseline (Precipitation, mm)	**Climate Scenario**	**2020s**	**2050s**	**2080s**
80.3	**RCP4.5**	82.6 (+2.8%)	83.0 (+3.3%)	84.4 (+5.1%)
	RCP8.5	86.8 (+8.1%)	88.8 (+10.6%)	92.1 (+14.7%)

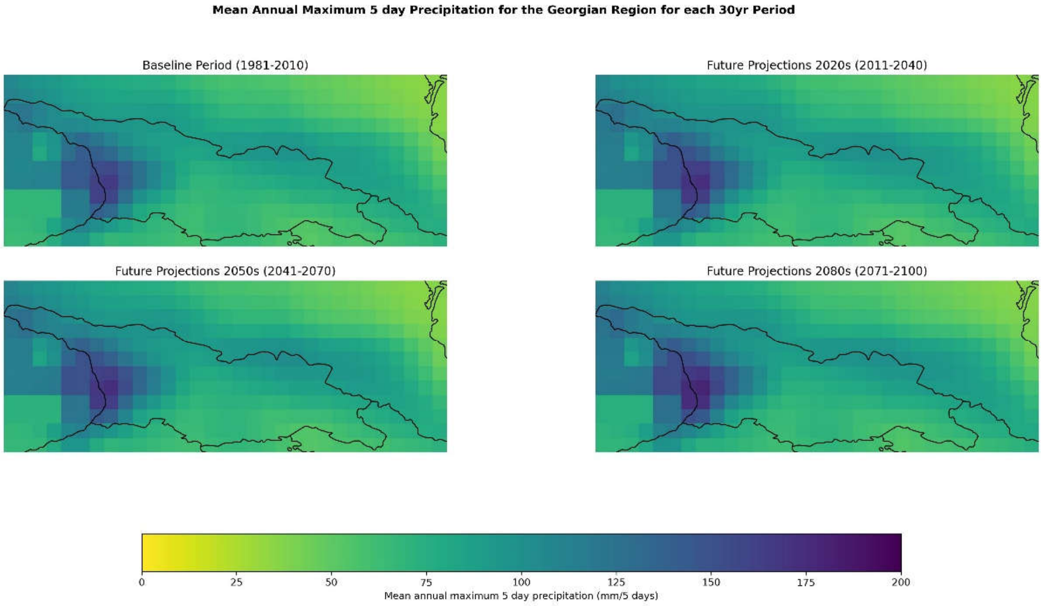

Figure 10. Projected 5-day Precipitation Totals for Georgia, RCP4.5.

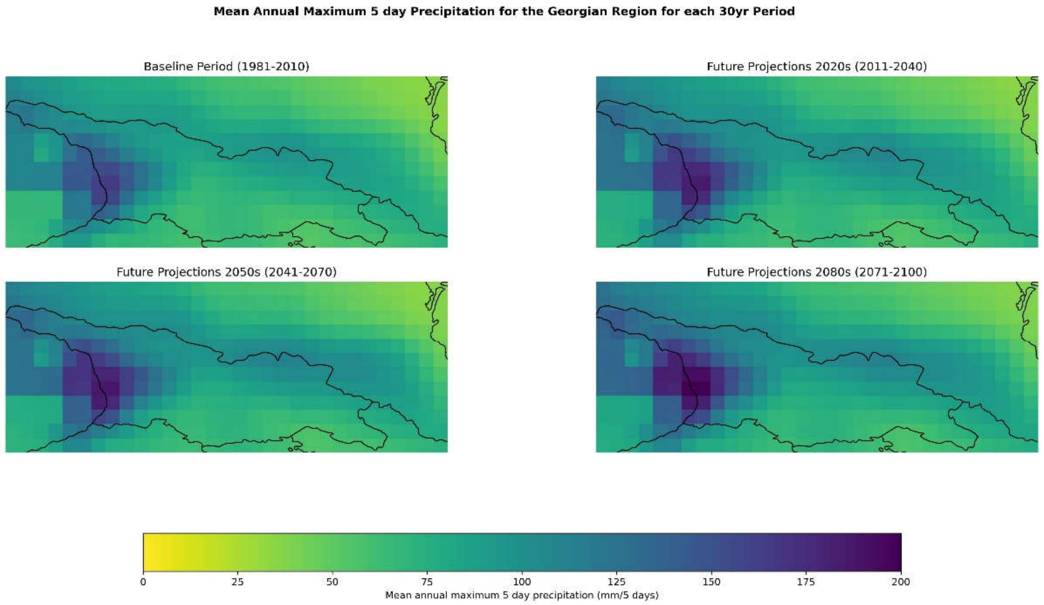

Figure 11. Projected 5-day Precipitation Totals for Georgia, RCP8.5

3.2.4. Complex Hazards

Drought

Drought can cause major agriculture, economic and environmental damage. As its effects are only apparent after a long period of dry conditions, it is generally very difficult to determine their onset, extent, and end of drought periods. To quantitatively measure and project the magnitude, duration and spatial extent of droughts, the Standardized Precipitation Evapotranspiration Index (SPEI) is considered. Using metrics such as precipitation, runoff rates, evapotranspiration, soil water content over an extended time period, the SPEI can monitor and analyze droughts and identify their characteristics in the context of climate change. A SPEI value greater than 1 is considered a wet state, while a value less than or equal to -1 is considered a dry state. GIZ (2021) researched severe drought conditions, defined as extended periods of SPEI < -2. Results of this work are shown in Figure 12. In general, drought is expected to increase across all of Georgia, particularly under the RCP8.5 scenario.

Drought conditions pose significant challenges to road infrastructure, particularly in areas with asphalt or concrete pavements. These dry spells can cause road surfaces to dry up, leading to cracks and deterioration. Additionally, prolonged drought can cause soil to dry and shrink, resulting in subsidence and settlement beneath roads. Consequently, road surfaces may become uneven or sunken, compromising stability and increasing the risk of accidents.

Furthermore, prolonged drought can have unexpected consequences during extreme rainfall events. As the ground becomes dry and hardened due to the lack of moisture, it reduces the soil's ability to absorb water. Consequently, increased overland flow can lead to higher stormwater runoff during intense downpours. This heightened runoff can overwhelm drainage systems and exacerbate the risk of flooding and related damage to road infrastructure.

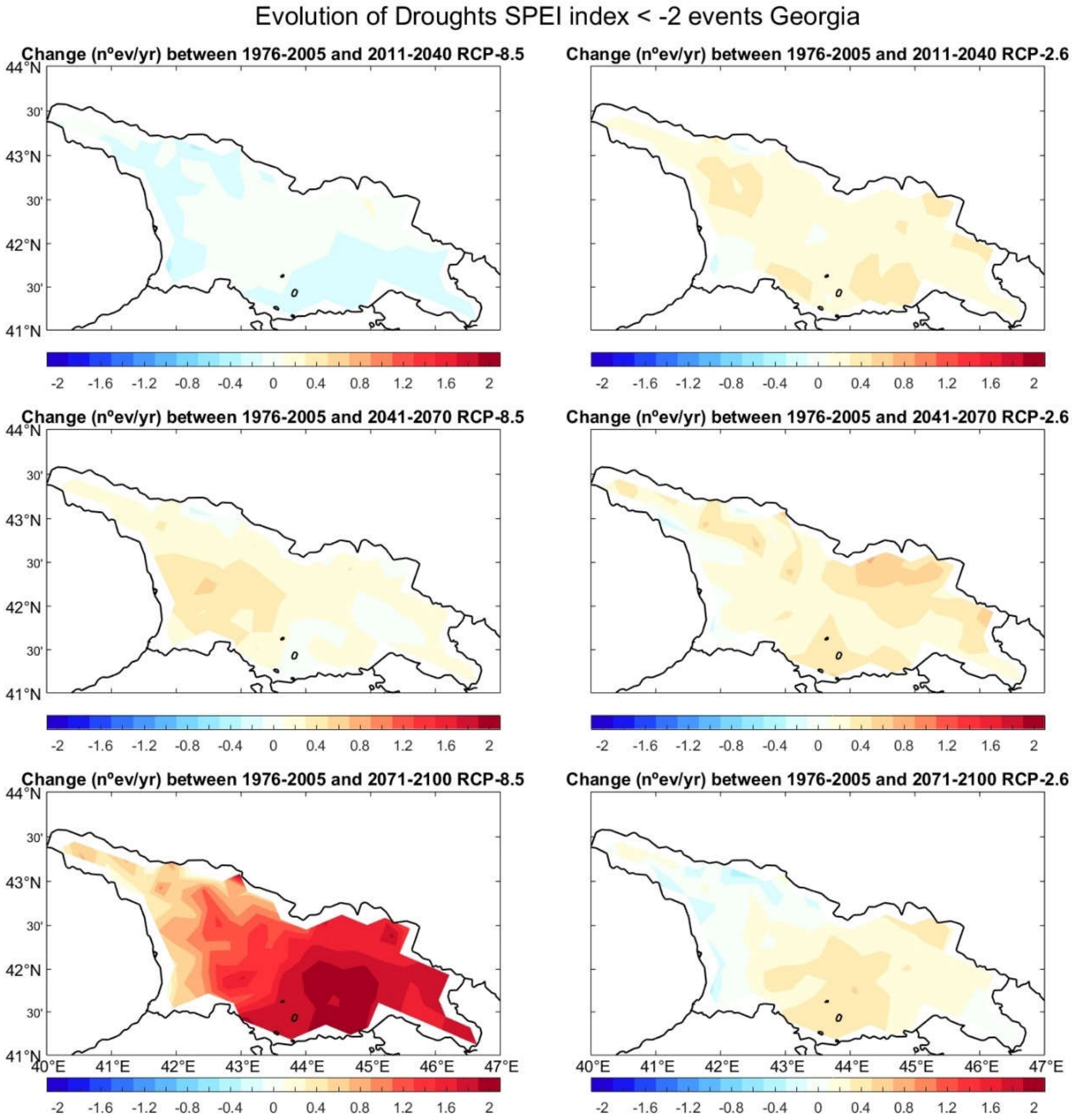

Figure 12. Extreme drought events under future climate conditions for the Republic of Georgia (GIZ, 2021).

Wildfire

Wildfire represents a critical ecosystem process. Recent decades have seen a noticeable increase in forest fire activity globally. The frequency of large wildfires is influenced by a combination of natural and human factors, such as temperature, soil moisture, relative humidity, wind speed and vegetation. Much research has been dedicated to understanding conditions that produce fire weather conditions through the development of particular indices such as the Keetch-Byram

Drought Index (KBDI) (Keetch and Byram, 1968). KBDI combines daily maximum temperature, daily precipitation, and annual precipitation, making assumptions that higher annual precipitation values correspond to more vegetation and, therefore, higher fuel content for any potential fires. GIZ (2021) produced projections of KBDI for the Republic of Georgia, finding that wildfire is most likely to increase in the southeast regions of the country, with less increase found in the rest of the country.

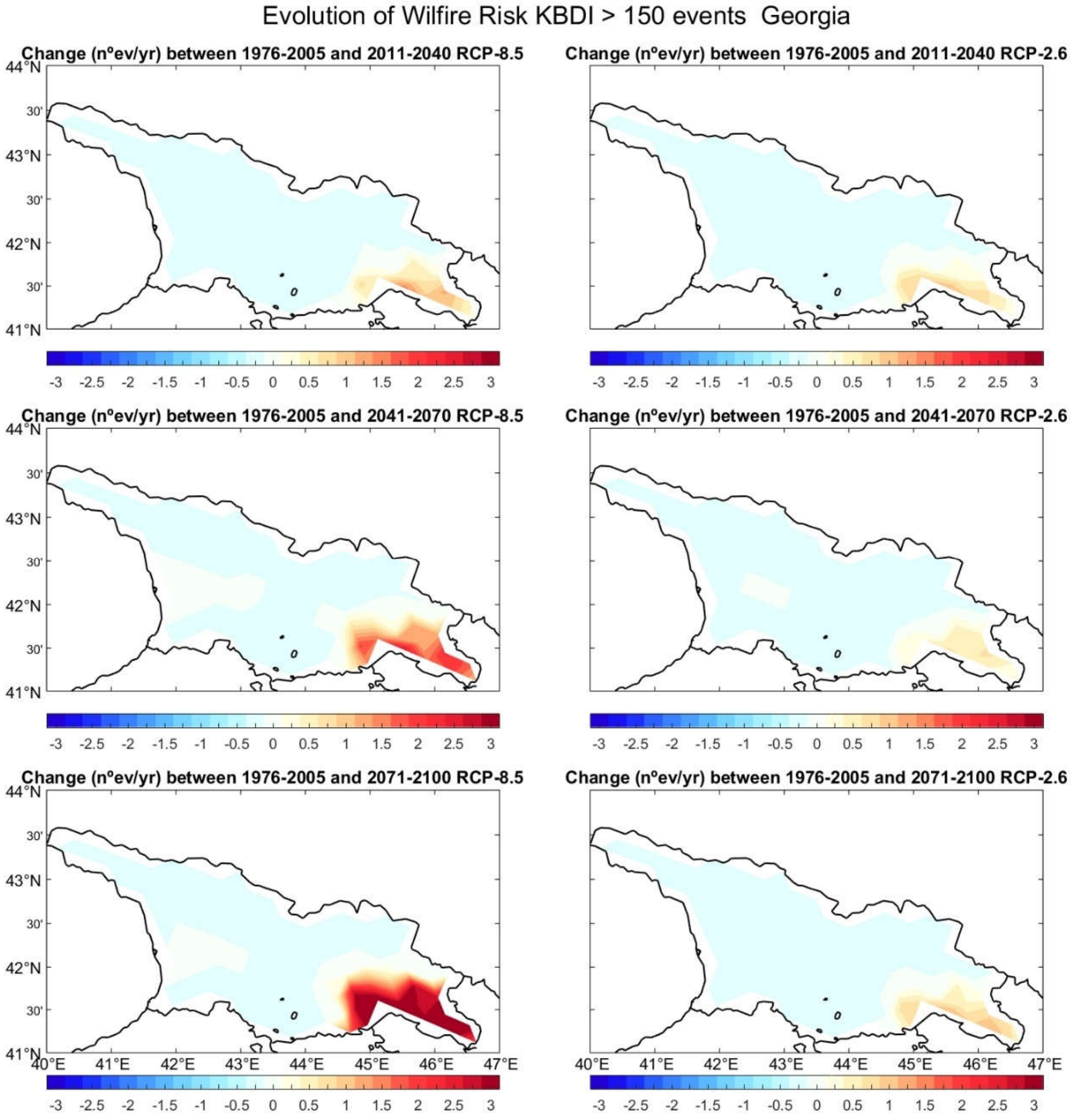

Figure 13. Wildfire Risk based on Keech Byram Drought Index Values for the Country of Georgia (GIZ, 2021)

4. Vulnerability Assessment Results

4.1. Exposure of Assets Under Assessment

Table 15 provides a summary of the assets assessed as being exposed through the vulnerability assessment.

Table 15: Exposure for Assets and Components Based on Climate Hazards

Hazard	Hazard Indicator	Exposed Assets
Temperature		
Temperature Change	Percent change in mean temperature	Asphalt surfaces; Foundations, Bridge bearings, Bridge deck slab
Extreme Heat	Days with Maximum Temperature exceeding 35°C	Asphalt surfaces, Retaining walls, Embankments, Foundations; Bridge beams, carriageway, bearings, railings, deck slab, expansion joints; Tunnel ventilation; Operation and Maintenance, Emergency systems; Stormwater drainage
Heat Waves	Frequency of 5 or more days consecutive that have T > TX90p	Asphalt surfaces, Retaining walls, Embankments, Foundations; Bridge beams, carriageway, bearings, railings, deck slab, expansion joints; Tunnel ventilation; Operation and Maintenance, Emergency systems; Stormwater drainage
Extreme Cold	Days with Minimum Temperature less than -15°C	Asphalt surfaces, Retaining walls, Embankments, Foundations; Bridge beams, carriageway, bearings, railings, deck slab, expansion joints; Tunnel ventilation; Operation and Maintenance, Emergency systems; Stormwater drainage
Hazard	**Hazard Indicator**	**Exposed Assets**
Precipitation		

Precipitation Change	Percent change in total precipitation	Crushed-stone base course, asphalt surfaces, embankments, foundations; Bridge carriageway, piers; Tunnel parking areas, electricity; Operations and maintenance; Stormwater drainage
SDHI	Days with total precipitation exceeding 50mm	Crushed-stone base course, asphalt surfaces, embankments, foundations; Bridge carriageway, piers, abutments; Tunnel parking areas, electricity; Operations and maintenance; Emergency systems; Communications; Stormwater drainage
Multi-Day Rainfall	Maximum 5-day precipitation percent change	Crushed-stone base course, asphalt surfaces, embankments, foundations; Bridge carriageway, piers, abutments; Tunnel parking areas, electricity; Operations and maintenance; Stormwater drainage
Hazard	**Hazard Indicator**	**Exposed Assets**
Complex		
Drought	Frequency of SPEI index < -2	Asphalt surfaces, embankments; Stormwater drainage
Wildfire	KBDI Index > 150	Asphalt surfaces, embankments; Bridge carriageway, bearings; Tunnel ventilation, emergency parking, electricity, and lighting; Emergency evacuation, stormwater drainage, and communications

4.2. Vulnerability Assessment Results

A desktop-level vulnerability assessment was conducted for each identified impact statement. Vulnerability refers to the extent to which a segment, population group, asset, system, or sector (as mentioned in the impact statement) is susceptible to or unable to cope with the impacts resulting from climate change. The assessment of vulnerability is based on evaluating three key factors as explained in Section 2.5: Exposure, Sensitivity and Adaptive Capacity/ Deficit.

Results of the vulnerability assessment showed that all nine climate hazards have impacted transportation infrastructure in the past or are likely to impact them in the future within the region.

Sub-components were most frequently exposed to SDHI, followed by extreme heat, heat waves, multi-day rainfall, wildfire, extreme cold, and precipitation change (Figure 14). Each of these climate hazards accounted for 11 – 16% of the total number of interactions. The lowest exposure rates were identified in drought and temperature change, accounting for 3 – 6% of total interactions.

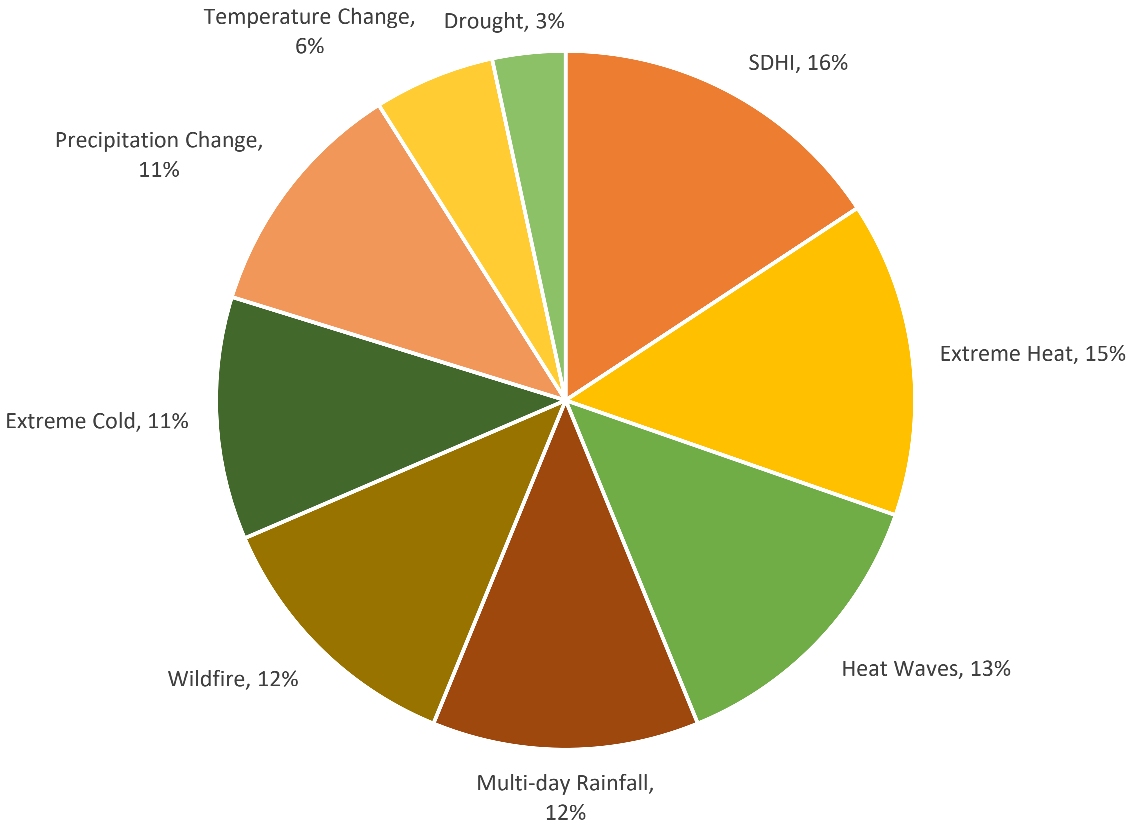

Figure 14. Proportion of Interactions Caused by Each Hazard.

Interactions with climate hazards were more frequently identified in roadways and highways than in tunnels or bridges. Asphalt surfaces were found to be the most exposed sub-components, as they were likely to interact with all nine climate hazards. Stormwater drainage was also highly exposed, particularly to impacts from precipitation change, SDHI, multi-day rainfall, and drought.

Eight sub-components were found to be exposed to more than half of the climate hazards. These were asphalt surfaces, embankments, foundations, carriageways, seismic elastomeric/rubber bearings, stormwater drainage, operation and maintenance, and emergency/evacuation systems.

For roads and highways, medium to high vulnerability was primarily due to precipitation and wildfires. For bridges, most medium to high vulnerability was due to extreme temperatures (heat and cold), and for tunnels from heat (extreme heat and heatwaves) and wildfire. Highest vulnerability of communication systems was due to wildfires.

Of the 89 vulnerabilities identified, 51% were found to be low, 29% were medium, and 20% were high (Figure 15). High vulnerability was most frequently identified in interactions with wildfires, SDHI, and multi-day rainfall.

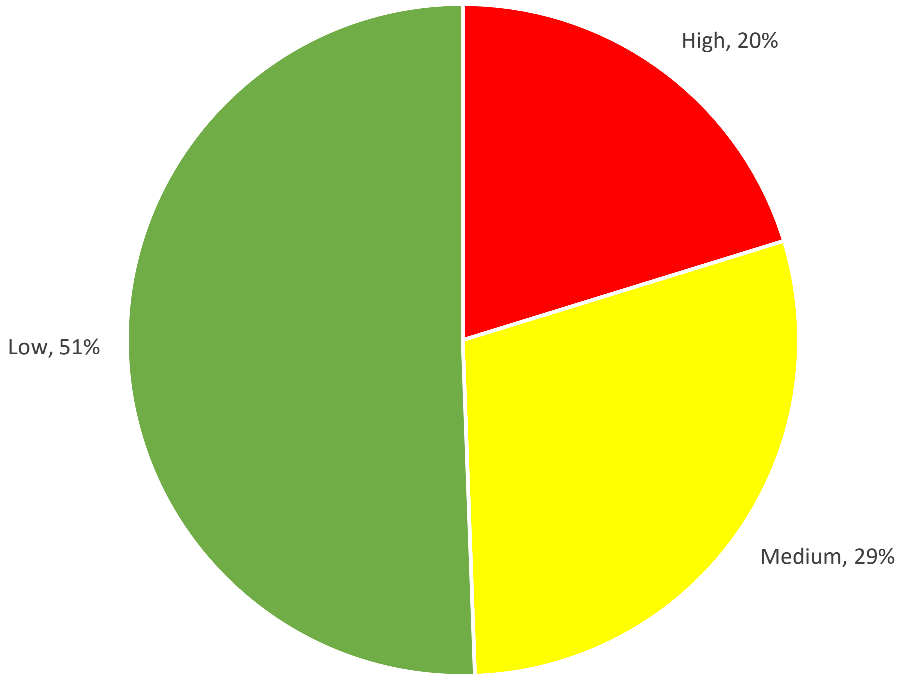

Figure 15. Percentage of Interactions at Each Level of Vulnerability.

The assessment determined that 44% of the 25 sub-components assessed had high vulnerability to at least one climate hazard, 52% had medium vulnerability, and 76% had low vulnerability (Figure 16). Embankments and tunnel ventilation had the highest number of high vulnerability interactions, asphalt surfaces had the highest number of medium vulnerability interactions, and stormwater drainage the highest number of low vulnerability interactions.

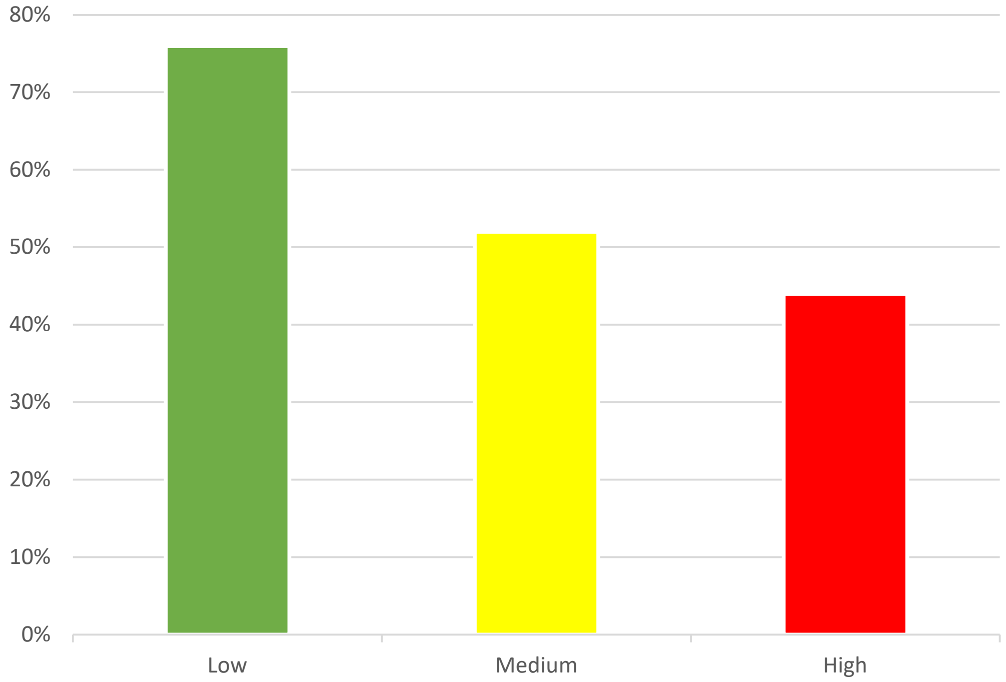

Figure 16. Percentage of Components at Each Level of Vulnerability.

Overall, the assessment identified 89 interactions, 44 of which resulted in medium or high vulnerability. Asphalt surfaces were the most affected components, with potential impacts from nine hazards and medium to high vulnerability to seven of these hazards ((temperature change, extreme heat, heat waves, extreme cold, short-duration high intensity rainfall, and multi-day rainfall, and wildfire). High vulnerability ratings for component interactions were most frequently attributed to wildfire (asphalt surfaces, embankments, carriageway, seismic elastomeric/rubber bearings, tunnel ventilation, emergency/evacuation systems, mobile communications, and internet). Total number of vulnerability ratings among components was highest for short-duration high intensity rainfall, including asphalt surfaces, embankments, foundations, stormwater drainage, and emergency/evacuation systems. Table 16 shows a summary of medium and high vulnerability infrastructure and associated sensitivity, adaptive deficit, and impact statements.

Table 16: Vulnerability Assessment Summary for Medium and High Vulnerability Components

Hazard	Component Affected	Sensitivity Score	Adaptive Deficit Score	Vulnerability	Impact statement
Temperature Change	Asphalt surfaces	2 - Medium	2 - Medium	Medium Vulnerability	Extreme heat can reduce the durability of the asphalt layer of the pavement resulting in more maintenance requirements.
Extreme Heat	Asphalt surfaces	2 – Medium	2 – Medium	Medium Vulnerability	Extreme heat can reduce the durability of the asphalt layer of the pavement resulting in more maintenance requirements.
	Carriageway	2 - Medium	2 - Medium	Medium Vulnerability	Extreme heat may cause expansion of materials and decrease the service life of the components. Extreme heat deteriorates the material properties (cracking, fissuring, etc.) and decrease the service life of the components.
	Seismic elastomeric/rubber bearings	2 - Medium	2 - Medium	Medium Vulnerability	
	Expansion joints	2 - Medium	2 - Medium	Medium Vulnerability	
	Ventilation	3 - High	2 - Medium	High Vulnerability	Extreme heat may cause decreases in local air quality and low-level ozone development, causing issues for ventilation in tunnels and enclosed areas
	Operation and maintenance	3 - High	3 - High	High Vulnerability	Extreme heat can cause challenging conditions for operations and maintenance staff and introduce health related impacts. Extreme heat wave can cause some road pavement to buckle and may result in road closures.
Heat Waves	Asphalt surfaces	2 - Medium	2 - Medium	Medium Vulnerability	Extreme heat can reduce the durability of the asphalt layer of the pavement resulting in more maintenance requirements.
	Carriageway	2 - Medium	2 - Medium	Medium Vulnerability	Extreme heat may cause expansion of materials and decrease the service life of the components. Extreme heat deteriorates the material properties (cracking, fissuring, etc.) and decrease the service life of the components.
	Seismic elastomeric/rubber bearings	2 - Medium	2 - Medium	Medium Vulnerability	
	Expansion joints	2 - Medium	2 - Medium	Medium Vulnerability	
	Ventilation	3 - High	2 - Medium	High Vulnerability	Extreme heat may cause decreases in local air quality and low-level ozone development, causing issues for ventilation in tunnels and enclosed areas
	Operation and maintenance	3 - High	3 - High	High Vulnerability	Extreme heat can cause challenging conditions for operations and maintenance staff and introduce health related impacts. Extreme heat wave can cause some road pavement to buckle and may result in road closures.

Hazard	Component Affected	Sensitivity Score	Adaptive Deficit Score	Vulnerability	Impact statement
Extreme Cold	Asphalt surfaces	2 - Medium	2 - Medium	Medium Vulnerability	Freeze-thaw cycles create erosion and damage on infrastructure surface by intermittent expansion to surface cracks wherever water in the cracks freezes as the temperature drops, and then ice expands; it pushes the crack apart, making it larger. Road surface or culverts can be structurally affected by extreme cold due to deformations associated with the volumetric changes when water freezes to ice and vice-versa. The decrease in the number of extreme cold days is likely to reduce this impact. Freeze-thaw creates ice and ripens the snowpack making it much heavier, but typically there are not long-term freeze thaws that create significant melting and erosion until spring.
	Retaining walls	2 - Medium	2 - Medium	Medium Vulnerability	Freeze-thaw cycles create erosion and damage on infrastructure surface by intermittent expansion to surface cracks wherever water in the cracks freezes as the temperature drops, and then ice expands; it pushes the crack apart, making it larger.
	Carriageway	2 - Medium	2 - Medium	Medium Vulnerability	Freeze-thaw cycles create erosion and damage on infrastructure surface by intermittent expansion to surface cracks wherever water in the cracks freezes as the temperature drops, and then ice expands; it pushes the crack apart, making it larger. Road surface or culverts can be structurally affected by extreme cold due to deformations associated with the volumetric changes when water freezes to ice and vice-versa. The decrease in the number of extreme cold days is likely to reduce this impact. Freeze-thaw creates ice and ripens the snowpack making it much heavier, but typically there are not long-term freeze thaws that create significant melting and erosion until spring.
	Deck slab	2 - Medium	2 - Medium	Medium Vulnerability	Freeze-thaw cycles create erosion and damage on infrastructure surface by intermittent expansion to surface cracks wherever water in the cracks freezes as the temperature drops, and then ice expands; it pushes the crack apart, making it larger.
	Expansion joints	2 - Medium	3 - High	High Vulnerability	Extreme cold causes buildup of ice in expansion joints and reduces the flexibility of surrounding pavement, increasing pressure and cracking.
	Operation and maintenance	2 - Medium	2 - Medium	Medium Vulnerability	In extreme low temperatures, maintenance may become more difficult and less effective; for example, the frozen road surface limits the effectiveness of sand.
Precipitation Change	Crushed-stone base course	2 - Medium	2 - Medium	Medium Vulnerability	With increased precipitation, water infiltration into the stone base course of the road is more likely to cause issues with erosion and force earlier maintenance cycles.

Hazard	Component Affected	Sensitivity Score	Adaptive Deficit Score	Vulnerability	Impact statement
	Embankments	2 - Medium	2 - Medium	Medium Vulnerability	Intense rain events may exceed the design flow capacities for culverts, resulting in water ponding against, overtopping, or flowing uncontrollably through the road embankment. Saturated road embankments may lose structural strength, causing potholes when heavily loaded. Embankments can be susceptible to changes in spring melt, rainfall frequency, intensity, and duration, as well as groundwater levels resulting in internal erosion. Internal and external erosion can impact the structural integrity raising the possibility of washouts, more repair work and loss of sediment to watercourses, affecting the surrounding environment (e.g., sensitive or fish bearing watercourses).
	Stormwater Drainage	2 - Medium	2 - Medium	Medium Vulnerability	Extreme weather events and large volumes of rainfall may overwhelm the capacity of some existing drainage structures, which can result in localized flooding and washouts, and negative effects to the surrounding environment. Drainage structures that cross the embankment, such as culverts and rock drains, are considered at higher risk to climate change than diversion structures that do not (e.g., flow channels and ditches) because of the potential severity. The high-volume water, sediment and debris blockages can increase pressure and erosion damage to culverts.
SDHI	Crushed-stone base course	2 - Medium	2 - Medium	Medium Vulnerability	Intense precipitation may cause water infiltration into the stone base course of the road, leading to local erosion and failure of road structure
	Asphalt surfaces	2 - Medium	2 - Medium	Medium Vulnerability	Intense rain events may exceed the design flow capacities for culverts, resulting in water ponding against, overtopping, or flowing uncontrollably through the road embankment. Saturated road embankments may lose structural strength, causing potholes when heavily loaded.
	Embankments	3 - High	3 - High	High Vulnerability	Intense rain events may exceed the design flow capacities for culverts, resulting in water ponding against, overtopping, or flowing uncontrollably through the road embankment. Saturated road embankments may lose structural strength, causing potholes when heavily loaded. Embankments can be susceptible to changes in spring melt, rainfall frequency, intensity, and duration, as well as groundwater levels resulting in internal erosion. Internal and external erosion can impact the structural integrity raising the possibility of washouts, more repair work and loss of sediment to watercourses, affecting the surrounding environment (e.g., sensitive or fish bearing watercourses).

Hazard	Component Affected	Sensitivity Score	Adaptive Deficit Score	Vulnerability	Impact statement
	Foundations	2 - Medium	2 - Medium	Medium Vulnerability	Intense rain events may exceed the design flow capacities for culverts, resulting in water ponding against, overtopping, or flowing uncontrollably through the road embankment. Saturated road embankments may lose structural strength, causing potholes when heavily loaded.
	Emergency/evacuation systems	2 - Medium	3 - High	High Vulnerability	Localized flooding due to short duration high intensity rainfall can block evacuation routes and cause water damage to emergency system power sources.
	Stormwater Drainage	3 - High	3 - High	High Vulnerability	Extreme weather events and large volumes of rainfall may overwhelm the capacity of some existing drainage structures, which can result in localized flooding and washouts, and negative effects to the surrounding environment. Drainage structures that cross the embankment, such as culverts and rock drains, are considered at higher risk to climate change than diversion structures that do not (e.g., flow channels and ditches) because of the potential severity. The high-volume water, sediment and debris blockages can increase pressure and erosion damage to culverts.
Multi-day Rainfall	Crushed-stone base course	2 - Medium	2 - Medium	Medium Vulnerability	Intense precipitation may cause water infiltration into the stone base course of the road, leading to local erosion and failure of road structure
	Asphalt surfaces	2 - Medium	2 - Medium	Medium Vulnerability	Intense rain events may exceed the design flow capacities for culverts, resulting in water ponding against, overtopping, or flowing uncontrollably through the road embankment. Saturated road embankments may lose structural strength, causing potholes when heavily loaded.
	Embankments	3 - High	3 - High	High Vulnerability	Intense rain events may exceed the design flow capacities for culverts, resulting in water ponding against, overtopping, or flowing uncontrollably through the road embankment. Saturated road embankments may lose structural strength, causing potholes when heavily loaded. Embankments can be susceptible to changes in spring melt, rainfall frequency, intensity, and duration, as well as groundwater levels resulting in internal erosion. Internal and external erosion can impact the structural integrity raising the possibility of washouts, more repair work and loss of sediment to watercourses, affecting the surrounding environment (e.g., sensitive or fish bearing watercourses).
	Foundations	2 - Medium	2 - Medium	Medium Vulnerability	Intense rain events may exceed the design flow capacities for culverts, resulting in water ponding against, overtopping, or flowing uncontrollably through the road embankment. Saturated road embankments may lose structural strength, causing potholes when heavily loaded.

Hazard	Component Affected	Sensitivity Score	Adaptive Deficit Score	Vulnerability	Impact statement
	Stormwater Drainage	3 - High	2 - Medium	High Vulnerability	Extreme weather events and large volumes of rainfall may overwhelm the capacity of some existing drainage structures, which can result in localized flooding and washouts, and negative effects to the surrounding environment. Drainage structures that cross the embankment, such as culverts and rock drains, are considered at higher risk to climate change than diversion structures that do not (e.g., flow channels and ditches) because of the potential severity. The high-volume water, sediment and debris blockages can increase pressure and erosion damage to culverts.
Drought	Stormwater Drainage	2 - Medium	2 - Medium	Medium Vulnerability	Drought can cause the accumulation of pollutants, debris, and sediments in stormwater drainage that requires additional maintenance to clear. Prolonged drought can lead to increased overland flow in extreme rainfall conditions, increasing overall stormwater runoff during intense downpours.
Wildfire	Asphalt surfaces	3 - High	3 - High	High Vulnerability	While asphalt does not typically burn during wildfires, fires can cause cracking, deformation, and potholes in the asphalt surface that will lead to cascading impacts. Damage can occur from heavy firefighting machinery where trucks and heavy equipment travel on road infrastructure that is more pliable due to heat.
	Embankments	3 - High	3 - High	High Vulnerability	Wildfires destroy vegetation and weaken road embankments, which can lead to large scale erosion and failure of embankments. Internal and external erosion can impact the structural integrity raising the possibility of washouts, more repair work and loss of sediment to watercourses, affecting the surrounding environment (e.g., sensitive or fish bearing watercourses).
	Carriageway	3 - High	3 - High	High Vulnerability	While asphalt does not typically burn during wildfires, fires can cause cracking, deformation, and potholes in the asphalt surface that will lead to cascading impacts
	Seismic elastomeric/rubber bearings	3 - High	3 - High	High Vulnerability	Wildfire may cause expansion of materials and decrease the service life of the components. Wildfire heat deteriorates the material properties (cracking, fissuring, etc.) and decrease the service life of the components
	Ventilation	3 - High	3 - High	High Vulnerability	Smoke from wildfire can reduce local and regional air quality, overwhelming ventilation in tunnels
	Emergency parking area/passage	2 - Medium	2 - Medium	Medium Vulnerability	Wildfire reduces the ability to use emergency access to parking and passage areas due to smoke and possible interface fires
	Electricity/lighting	2 - Medium	2 - Medium	Medium Vulnerability	Wildfire can damage electrical towers and lines, causing local and regional power outages in areas with ongoing fire

Hazard	Component Affected	Sensitivity Score	Adaptive Deficit Score	Vulnerability	Impact statement
	Emergency/evacuation systems	3 - High	3 - High	High Vulnerability	Wildfire reduces the ability to use emergency and evacuation systems due to smoke and possible interface fires. Emergency evacuation routes may become overwhelmed in the event of a fire.
	Mobile	3 - High	3 - High	High Vulnerability	Wildfire can damage communications towers and lines, limiting capacity to relay emergency calls or provide cell service
	Internet	3 - High	3 - High	High Vulnerability	Wildfire can damage communications towers and lines, limiting capacity to relay emergency calls or provide internet service

5. Conclusions and Recommendations

The climate vulnerability assessment methodology is consistent with the screening stage of the PIEVC Large Portfolio Assessment Manual and aligns with ISO 31000: Risk Management and ISO 14090/14091/14092: Adaptation to Climate Change Standards. This assessment serves to inform country partners in the Republic of Georgia on the vulnerable components of road infrastructure and supporting assets that should be carried forward for further analysis of climate change related risks through full application of the PIEVC Protocol.

This assessment has identified the climate hazards that road and supporting infrastructure are exposed to, their sensitivity and adaptive deficit, and suggests potential climate thresholds (climate hazard indices) for future likelihood analysis. Infrastructure interactions with each climate hazard were examined, and associated sensitivity and adaptive deficit ratings were assigned to each interaction. The climate hazards that appear to pose the most vulnerability to road infrastructure in the Republic of Georgia are short duration high intensity rainfall, long duration rainfall, extreme heat and heat waves, and wildfire.

Some specific findings related to higher vulnerability interactions include:

- Asphalt surfaces are exposed to the maximum number of evaluated climate hazards in this assessment, with 6 hazards (temperature change, extreme heat, heat waves, extreme cold, short-duration high intensity rainfall, and multi-day rainfall) rated medium vulnerability and 1 hazard (wildfire) rated high vulnerability. In any future analysis, climate hazard impacts on asphalt and road surfaces need to be considered due to the potential impacts of extreme heat and cold events on the overall longevity of road surfaces, considering the deterioration of material properties that may occur if pavement mixes are not properly chosen. Further exploration of the risks posed by affected asphalt and road surfaces should be conducted in a full PIEVC assessment.

- Several other road infrastructure components also exhibit potentially high vulnerability, including embankments and stormwater drainage, base on exposures to short-duration high intensity rainfall events and multi-day rainfall events. High sensitivity and high adaptive deficit exist for these types of events due to the complex topography of the Region, as well as the potential for future climate events to trigger cascading impacts such as landslides and mudslides, overwhelm the designed capacity of culverts, and initiate debris flows along the roadway. Sensitivity was rated high for these interactions due to the lack of alternative routing for residents in the Region as well as history of previous events (Ministry of Environment, 2014). It is recommended that further exploration of the potential risks stemming from impacts to drainage infrastructure and embankments be conducted in a full PIEVC assessment. This assessment can be supported by the new PIEVC Green Protocol which helps consider the condition and potential hazards and impacts posed by the landcover of surrounding areas, that may potentially contribute to other cascading impacts on the drainage and embankments.

- Wildfire-related interactions were rated as high vulnerability for a number of components within the analysis, including asphalt surfaces, embankments, bridge carriageway and bearings, tunnel ventilation, stormwater drainage, and communications. For each of these components, the adaptive deficit was rated as high due to the potential for severe physical damage, gaps in emergency response, and probable interruptions to supply chains. Sensitivity ratings were also high, due to fire-proofing design deficiencies, lack of redundancies, potentially confounding system complexities, and the potential for cascading impacts. It is recommended that a full PIEVC assessment explore in detail the likelihood of wildfire events in the region and their consequences and mediated through the transportation system. Data from the climate profile suggests that wildfire may not become a major threat in the Region. However, due to the number of high vulnerabilities related to this the type of event, wildfire should be carried forward for further analysis.

Although "high" and "medium" vulnerabilities have been identified during this phase of the project, further exploration of the character of the resultant risks is recommended, based on a full PIEVC assessment.

Other specific recommendations include:

- Development of full complete climate likelihood analysis based on thresholds developed for future use in a full application of the PIEVC Protocol in the region.
- In order to facilitate a comprehensive PIEVC assessment in the future, it is recommended to foster collaboration among relevant stakeholders, including government agencies, road authorities, climate scientists, engineering professionals, and communities and users. This collaboration would enable sharing of data, knowledge, and best practices, which are crucial for gathering data, and enhancing the level of detail in vulnerability and impact evaluations. In addition to up-to-date climate data and infrastructure design reports, various other types of data are relevant for understanding the context and analyzing the severity of impacts. These include maintenance and operational data, such as maintenance practices, incident reports, road condition reports, operational capacity, emergency response plans, and maintenance history reports. Land use information, such as patterns surrounding the road infrastructure, is also important. Hydrological data, including information on drainage systems and water table levels and socioeconomic data, which encompasses economic activities and critical infrastructure dependencies, further contribute to a comprehensive assessment. By incorporating these various datasets, a more comprehensive understanding of vulnerability and impacts can be achieved.
- Utilize the high-level vulnerability assessment findings to facilitate additional engineering analysis, such as geospatial analysis, for a comprehensive segment-based study. Additionally, Hydrological Models can support the identification of potential freshet events and the subsequent impacts on roads. This approach will incorporate local physical conditions and enable the identification and prioritization of vulnerable regional road segments.
- In order to determine the consequence of climate hazard interactions on identified vulnerable infrastructure components, the assessment process should involve site visits, local engagement, and workshops to determine the consequence of climate hazard interactions on the identified vulnerable

infrastructure components. These activities will contribute to a more thorough understanding of the risks associated with climate hazards.

6. Benefits and Opportunities

Conducting climate vulnerability and risk assessments and implementing their recommendations can yield numerous financial, social, and environmental benefits. The UN highlights that investing in climate-resilient infrastructure can generate a benefit-cost ratio of approximately 6 to 1, resulting in significant cost savings and economic gains[2]. By incorporating adaptation measures based on the recommendations of risk assessments, infrastructure systems can enjoy various advantages. Firstly, there are **financial benefits**, including reduced maintenance costs, improved resource allocation, and optimized operations. Additionally, integrating climate resilience into infrastructure planning offers long-term investment protection by mitigating risks and ensuring infrastructure functionality over time. Secondly, there are **social benefits**, as climate adaptation measures can enhance public safety and bolster community resilience, strengthening the ability to withstand and recover from climate-related hazards. Lastly, there are **environmental benefits**, as the identification and implementation of adaptation measures can help preserve ecosystems, reduce the impacts of climate change on natural resources, and uphold their crucial functions, often enhancing their resilience.

7. Limitations

This vulnerability assessment and the accompanying climate profiles were completed using the best information available to the assessment team at the time of the study. The assessment represents the potential vulnerabilities associated with the current climate (1981-2010) and potential future climate-road infrastructure interactions in the Republic of Georgia, with a focus on the road infrastructure of the Racha-Lechkhumi and Kvemo Svaneti (R.L-K.S.) region. The climate data and trends (current and future projections) used in this study were obtained through various sources, as described in earlier sections of the report. Cross-verification between climate information sources was conducted where possible to identify potential discrepancies between the data sources used.

The assessment and recommendations of this vulnerability assessment are based on the information available within the time frame and scope of this assessment and on the authors' experience in similar assessments. The climate vulnerability assessment methodology is consistent with the screening stage of the PIEVC Large Portfolio Assessment Manual and confirms with ISO 31000: Risk Management and ISO 14090/14091/14092: Adaptation to Climate Change Standards.

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[2] (UN,2019) https://press.un.org/en/2019/sgsm19807.doc.htm

The availability of weather data to define the intensity thresholds of the selected climate hazards, as well as their occurrence in the current climate, are based on data from the received from GIZ and country partners, as well as the ERA5 reanalysis dataset. It is recognized that extreme weather events are often very localized, so it is possible that the selected weather stations may not have captured or provide representative measurement of the intensity of some of these events. This uncertainty is considered by the climate resilience assessment methodology during the analysis, as well as the knowledge of the team members in the analysis of asset vulnerabilities or infrastructure elements.

Future climate projections used in this study are based on the Fifth Coupled Model Intercomparison Project (CMIP5) climate projections data. There are nearly 40 GCMs that have contributed to CMIP5, which forms the basis of the Fifth Assessment Report publications from the Intergovernmental Panel on Climate Change (IPCC). The US National Aeronautics and Space Administration (NASA) in the NASA Earth Exchange (NEX) Global Daily Downscaled Projections (GDDP) dataset uses a subset of 42 climate projections from 21 of these models to produce reliable, high-resolution downscaled climate projections globally (Thrasher et al., 2012). Climate projections for the RCP4.5 and RCP8.5 emission scenarios were used in developing the climate profile for this assessment.

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Appendices

Appendix A Vulnerability Matrix

			Climate Hazard Indicator																																			
Infrastructure System			**Temperature**																**Precipitation**												**Complex**							
System	**Infrastructure Component**	**Infrastructure Sub-Components**	**Temperature Change**				**Extreme Heat**				**Heat Waves**				**Extreme Cold**				**Precipitation Change**				**SDHI**				**Multi-day Rainfall**				**Drought**				**Wildfire**			
			E	**S**	**A**	**V**	**E**	**S**	**A**	**V**	**E**	**S**	**A**	**V**	**E**	**S**	**A**	**V**	**E**	**S**	**A**	**V**	**E**	**S**	**A**	**V**	**E**	**S**	**A**	**V**	**E**	**S**	**A**	**V**	**E**	**S**	**A**	**V**
Transportation	International/ Secondary/ Local Roads & Highways	Crushed-stone base course																	x	M	M	**M**	x	M	M	**M**	x	M	M	**M**								
		Asphalt surfaces	x	M	M	**M**	x	M	M	**M**	x	M	M	**M**	x	M	M	**M**	x	L	L	**L**	x	M	M	**M**	x	M	M	**M**	x	L	L	**L**	x	H	H	**H**
		Retaining walls					x	L	L	**L**	x	L	L	**L**	x	M	M	**M**																				
		Embankments					x	L	L	**L**	x	L	L	**L**					x	M	M	**M**	x	H	H	**H**	x	H	H	**H**	x	M	L	**L**	x	H	H	**H**
		Foundations	x	L	L	**L**									x	M	L	**L**	x	L	L	**L**	x	M	M	**M**	x	M	M	**M**								
	Bridges	Beams					x	L	L	**L**	x	L	L	**L**																								
		Carriageway					x	M	M	**M**	x	M	M	**M**	x	M	M	**M**	x	L	L	**L**	x	M	L	**L**	x	M	L	**L**					x	H	H	**H**
		Seismic elastomeric/rubber bearings	x	L	L	**L**	x	M	M	**M**	x	M	M	**M**	x	L	L	**L**																	x	H	H	**H**

			Climate Hazard Indicator																																							
Infrastructure System			**Temperature**																**Precipitation**												**Complex**							
System	**Infrastructure Component**	**Infrastructure Sub-Components**	**Temperature Change**				**Extreme Heat**				**Heat Waves**				**Extreme Cold**				**Precipitation Change**				**SDHI**				**Multi-day Rainfall**				**Drought**				**Wildfire**			
			E	**S**	**A**	**V**	**E**	**S**	**A**	**V**	**E**	**S**	**A**	**V**	**E**	**S**	**A**	**V**	**E**	**S**	**A**	**V**	**E**	**S**	**A**	**V**	**E**	**S**	**A**	**V**	**E**	**S**	**A**	**V**	**E**	**S**	**A**	**V**
		Railings/parapets/safety fences					x	L	L	**L**																												
		Deck slab	x	L	L	**L**	x	M	L	**L**	x	M	L	**L**	x	M	M	**M**																				
		Box girder																																				
		Expansion joints	x	L	L	**L**	x	M	M	**M**	x	M	M	**M**	x	M	H	**H**																				
		Abutments																					x	L	M	**L**	x	L	M	**L**								
		Piers																	x	L	L	**L**	x	L	L	**L**	x	L	L	**L**								
	Tunnels	Walls																																				
		Ventilation					x	H	M	**H**	x	H	M	**H**		L	L																		x	H	H	**H**
		Emergency parking area/passage																	x	L	L	**L**	x	L	L	**L**	x	L	L	**L**					x	M	M	**M**
		Supports/foundation																																				
		Tunnel waterproofing																																				
		Electricity/lighting																	x	L	L	**L**	x	L	L	**L**	x	L	L	**L**					x	M	M	**M**

			Climate Hazard Indicator																																			
Infrastructure System			**Temperature**																**Precipitation**												**Complex**							
System	**Infrastructure Component**	**Infrastructure Sub-Components**	**Temperature Change**				**Extreme Heat**				**Heat Waves**				**Extreme Cold**				**Precipitation Change**				**SDHI**				**Multi-day Rainfall**				**Drought**				**Wildfire**			
			E	**S**	**A**	**V**	**E**	**S**	**A**	**V**	**E**	**S**	**A**	**V**	**E**	**S**	**A**	**V**	**E**	**S**	**A**	**V**	**E**	**S**	**A**	**V**	**E**	**S**	**A**	**V**	**E**	**S**	**A**	**V**	**E**	**S**	**A**	**V**
		Operation and maintenance					x	H	H	**H**	x	H	H	**H**	x	M	M	**M**	x	L	L	**L**	x	M	L	**L**	x	M	L	**L**								
		Emergency/ evacuation systems					x	L	L	**L**	x	L	L	**L**	x	L	L	**L**		L	L		x	M	H	**H**									x	H	H	**H**
Water Management	Stormwater Drainage						x	L	L	**L**	x	L	L	**L**	x	L	L	**L**	x	M	M	**M**	x	H	H	**H**	x	H	M	**H**	x	M	M	**M**	x	L	L	**L**
Public Services	Communications	Mobile																					x	L	L	**L**									x	H	H	**H**
		Internet																					x	L	L	**L**									x	H	H	**H**

Appendix B List of Resources Consulted for Vulnerability Assessment

	Author	Year	Document Title	Type
Context	Ministry of Environmental Protection and Agriculture of Georgia	2019	Georgia's Second Biennial Update Report 2019 Under the United Nations Framework Convention on Climate Change	Report
	Climate Forum East (CFE) and Georgia National Network on Climate Change Anna Rukhadze, Ina Vachiberidze& Marina Fandoeva	2014	National Climate Vulnerability Assessment: Georgia	Report
	Georgian National Committee of Disaster Risk Reduction & Environment Sustainable Development	2010	Who Does What Where in Disaster Risk Reduction in Georgia Second edition	Report
	Ministry of Environmental Protection and Agriculture of Georgia	2021	Fourth National Communication to the UNFCCC	Report
	Mariam Shotadze & Eliso Barnovi	2011	Technical Report 2. Rapid Assessment of the Rioni and Alazani-Iori River Basins of Georgia	Report
Geospatial	Ministry of Environment and Natural Resources Protection of Georgia	2014	Geological Report envisaged by the Project on Development of climate resilient flood and flash flood and geological disaster management practices for Rioni river basin"	Report
	-	2021	Information geological bulletin 2021: Racha-Lechkhum-Kvemo Svaneti area	Bulletin
	LSI National Environment Agency	2022	Weather data	Data
	GIZ		Geological maps of Georgia	Maps
Infrastructure	Ministry of Economy and Sustainable	2022	National Road Safety Strategy	Report

	Development of Georgia			
	Roads Department of the Ministry of Regional Development and Infrastructure of Georgia (RDMRDI)	2016	Volume II Road Project-3	Design Drawings
	Roads Department of the Ministry of Regional Development and Infrastructure of Georgia (RDMRDI)	2016	Update of Feasibility Studies for E-60 Highway Section from Zemo Osiauri to Argveta and Undertaking Detailed Design for E-60 Highway Section from Zemo Osiauri to Chumateleti: FINAL REPORT of Activity -2	Report
	Roads Department of the Ministry of Regional Development and Infrastructure of Georgia (RDMRDI)		Vision - Roads and Highways - Georgia	Presentation
	Roads Department of the Ministry of Regional Development and Infrastructure of Georgia (RDMRDI)	2016	Update of Feasibility Studies for E-60 Highway Section from Zemo Osiauri to Argveta and Undertaking Detailed Design for E-60 Highway Section from Zemo Osiauri to Chumateleti: Technical Description of the Preferred Recommended Alignment VOLUME IV-1	Design Drawings
	Roads Department of the Ministry of Regional Development and Infrastructure of Georgia (RDMRDI)	2016	Update of Feasibility Studies for E-60 Highway Section from Zemo Osiauri to Argveta and Undertaking Detailed Design for E-60 Highway Section from Zemo Osiauri to Chumateleti: Technical Description of the Preferred Recommended Alignment VOLUME IV-2	Design Drawings
	GIZ	2022	GIS shapefiles for Georgia	Shapefiles