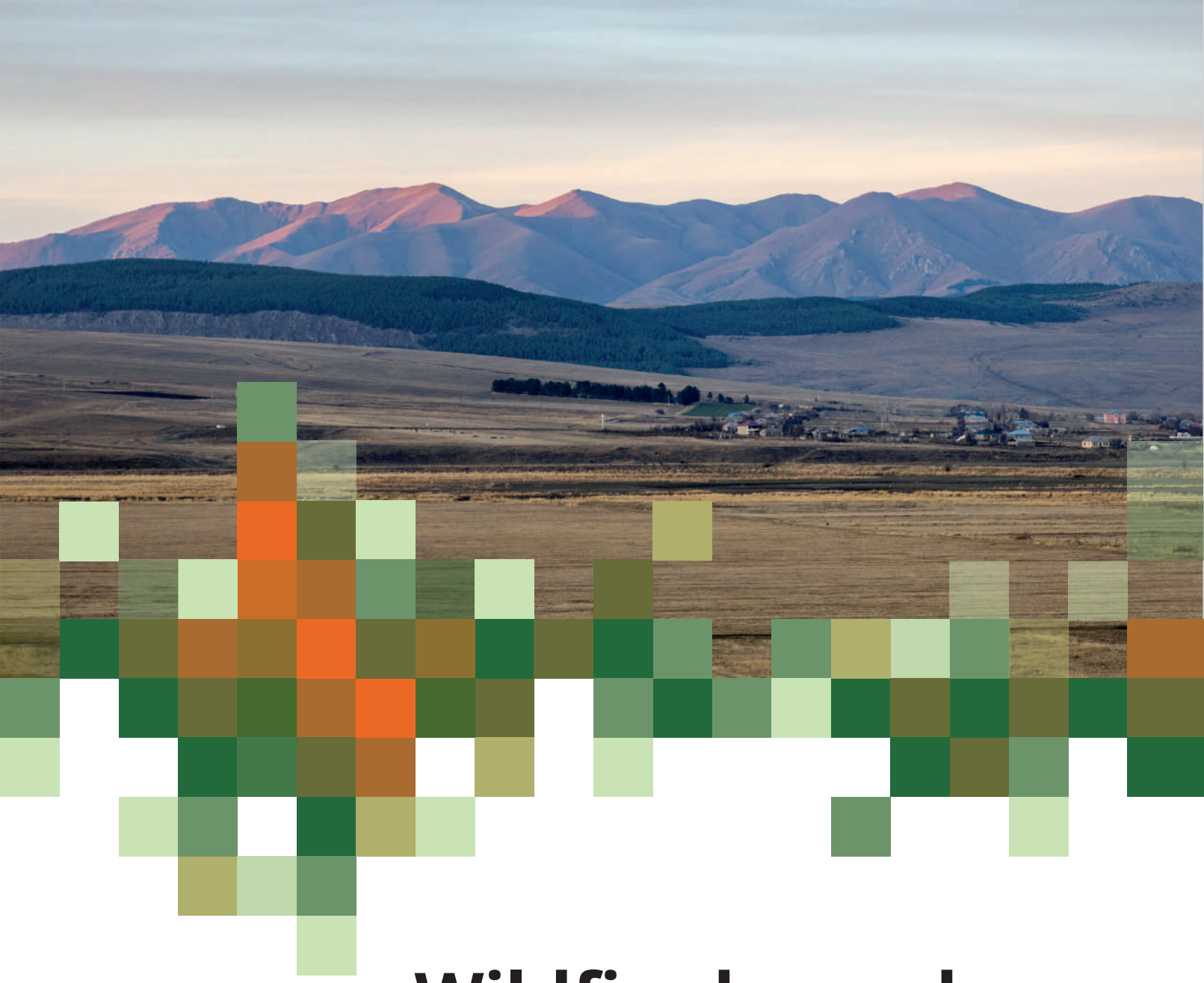


# Wildfire hazard mapping and risk assessment in Armenia and Georgia

## LORI AND KVEMO KARTLI PILOT REGIONS

OSCE Organization for Security and Co-operation in Europe

# Contents


**Executive Summary** 6

**1 Introduction** 8

**2 Study Area – Lori Province (Armenia) and Kvemo Kartli Region (Georgia)** 15

2.1 Topography and Physical Setting 15
2.2 Climate Dynamics 16
2.3 Vegetation Land Cover and Land Use 18
2.4 Social Conditions and Economic Activities 19

**3 Hazard Mapping and Risk Assessment for Lori and Kvemo Kartli Regions** 20

3.1 Wildfire hazard maps 20
3.2 Wildfire exposure maps 24
3.3 Vulnerability maps 26
3.4 Wildfire risk maps 28

**4 Key findings and way forward** 31

**Annex 1. Assessment Methodology** 34

Technical approach and methodological rationale 34
Assumptions and limitations 37

**References** 38

**Glossary** 39

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**Cover:** Kvemo Kartli, Georgia.

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**Photo:** Armen Asryan, Northern Armenia



# Executive Summary

**This report presents the results of a transboundary wildfire risk assessment conducted under the Organization for Security and Co-operation in Europe (OSCE) Joint Risk Mapping Initiative in the South Caucasus.**

The assessment forms part of broader efforts to address climate-related security risks and strengthen co-operation between Armenia and Georgia. It provides a shared, evidence-based understanding of wildfire hazard, exposure, vulnerability, and overall risk across selected pilot areas: the Tashir community in Lori Province (Armenia) and Bolnisi Municipality in Kvemo Kartli region (Georgia).

Over the past two decades, both countries have experienced an increase in wildfire frequency, intensity, and spatial extent. These trends are driven by the combined effects of climate change manifested through rising temperatures, prolonged droughts, and unsustainable land-use practices such as overgrazing, agricultural burning, and forest-edge encroachment. Given the continuous ecological landscapes and shared river basins across the Armenia-Georgia border, wildfire dynamics are inherently transboundary. Fires can spread across borders through connected forests, grasslands, and valleys, making isolated national approaches insufficient. This underscores the need for co-ordinated risk assessment and joint management strategies.

The present assessment applies a harmonized, Geographic Information System (GIS[1]) based methodology integrating remote sensing, climate data, national datasets, and field validation. It follows an internationally recognized framework structured around four components: **Hazard** (likelihood and intensity of wildfire occurrence), **Exposure** (presence of people, infrastructure, and assets), **Vulnerability** (susceptibility and coping capacity) and **Risk** (combined effect of the above factors). Spatial datasets of the two countries were standardized and analyzed at a resolution of approximately 30 meters, ensuring comparability across both countries. The assessment is designed to be scalable and replicable.

The analysis reveals a clear pattern of shared wildfire risk across the transboundary landscape, particularly along the Debed–Khrami river basin corridor connecting northern Armenia and southern Georgia. Wildfire hazard is primarily driven by similar environmental conditions on both sides of the border, including mountainous terrain, forest-grassland mosaics, and increasing climatic dryness. High hazard areas are concentrated: in the Lori Province along the forested slopes of the Debed River valley and mountainous zones near Stepanavan and Tumanyan—in the Kvemo Kartli region—within the Khrami River basin and southern parts of Bolnisi municipality. The highest overall wildfire risk occurs where hazard overlaps with dense settlements, infrastructure, and economic activity, particularly in valley corridors. Key hotspots include: Stepanavan and Tashir in Armenia and Bolnisi and Marneuli in Georgia. These areas are characterized by forest-agriculture interfaces, active land use, and transport networks, which increase both ignition likelihood and potential socio-economic impacts.

1 Descriptions of key terms can be found in the Glossary at the end of this publication.



**Photo:** © Shutterstock, Inc.

The findings confirm that wildfire risk is shaped by continuous ecological and socio-economic systems rather than administrative boundaries, highlighting the need for co-ordinated, cross-border approaches. To address the identified risks, the report identifies several opportunities for co-operation:

- Conduct in-depth local assessments in high-risk areas to support targeted, municipality-level interventions that take into account the diverse needs and vulnerabilities of the population
- Further improve data quality and availability, including high-resolution spatial and socio-economic datasets
- Strengthen transboundary data sharing through joint platforms and harmonized methodologies
- Strengthen integrated monitoring and early warning systems to enhance preparedness and response
- Develop joint cross-border fire governance mechanisms to co-ordinate prevention, planning, and emergency response
- Enhance community awareness and preparedness, particularly in high-risk settlements
- Strengthen the engagement of women and youth in fire prevention and response mechanisms

As wildfire risk continues to increase under climate change, sustained joint action will be essential to reduce impacts, strengthen resilience, and safeguard communities and ecosystems across the region.

# Introduction

**The present wildfire risk assessment is conducted as part of the Joint Risk Mapping Initiative, supported by the OSCE and implemented in close collaboration with Armenian and Georgian experts. This work builds on the OSCE's long-standing engagement in addressing potential linkages between climate change and security, in particular by implementing the extra-budgetary project *"Strengthening responses to security risks from climate change in South-Eastern Europe, Eastern Europe, the South Caucasus and Central Asia* which is directly supporting the implementation of the Ministerial Council Decision 3/2021 "Strengthening Co-operation to address the Challenges caused by Climate Change."**

1



**Photo:** Shulaveri Fortress Ruins, Kvemo Kartli, Georgia

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Within the framework of this project, the OSCE in partnership with *adelphi global*, the *Global Fire Monitoring Center (GFMC)* and *GEO Outlook* jointly developed a series of strategic documents[2] aimed at strengthening cross-border co-operation between Armenia and Georgia to enhance climate resilience. These efforts were underpinned by an inclusive, participatory process involving extensive co-ordination and consultations with stakeholders from governmental institutions, civil society organizations, and academia in both countries.

As a result of this process, Armenia and Georgia agreed to develop a pilot initiative focused on cross-border co-operation to reduce wildfire risks, of which this risk assessment constitutes a foundational analytical component.

Over the past two decades, Armenia and Georgia have experienced a marked increase in wildfire frequency, severity, and spatial extent. The growing impact of these events is evident in the charts below, which show the annual area burned by wildfires between 2002 and 2022.[3]




**Figure 1.** Area burned by wildfires by land cover type in Armenia and Georgia[4]

2 (2021): Regional Consultation for the South Caucasus - Armenia and Georgia: Co-operation opportunities for addressing the security implications of climate change | OSCE Projects; (2023): Scoping study: Co-operation in Northern Armenia and Southern Georgia | OSCE Projects; (2024): Joint Co-operation Strategy on Climate Change and Security in Northern Armenia and Southern Georgia | OSCE Projects

3 https://ourworldindata.org/wildfires#all-charts

4 Our World in Data https://ourworldindata.org/wildfires#all-charts

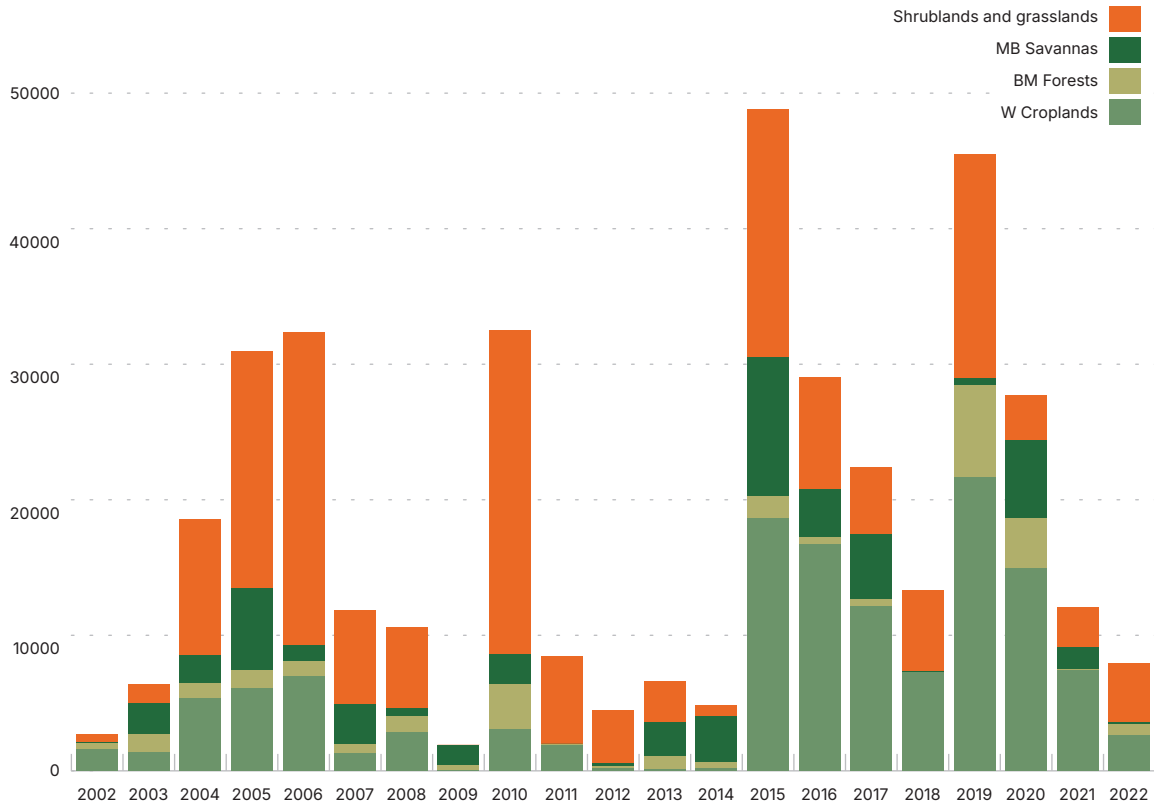



**Figure 2**. Monthly temperature anomalies in Armenia and Georgia 1940-2026[5]

While fire can be a natural process in many ecosystems or a traditional practice in land management, recent trends indicate a diversion from historical fire regimes, driven by the combined effects of climate change and unsustainable land management practices, e.g. overgrazing, uncontrolled pasture and agricultural burning, forest-edge encroachment, and inadequate fuel (dry wood) management. Regional climate trends characterized by rising average temperatures, prolonged dry periods, increased frequency of heatwaves, and greater variability in precipitation have created conditions increasingly conducive to fire ignition and rapid spread. One of the clearest manifestations of these trends is the increase in temperature anomalies observed across the region as illustrated in the charts below for Armenia and Georgia.[6]

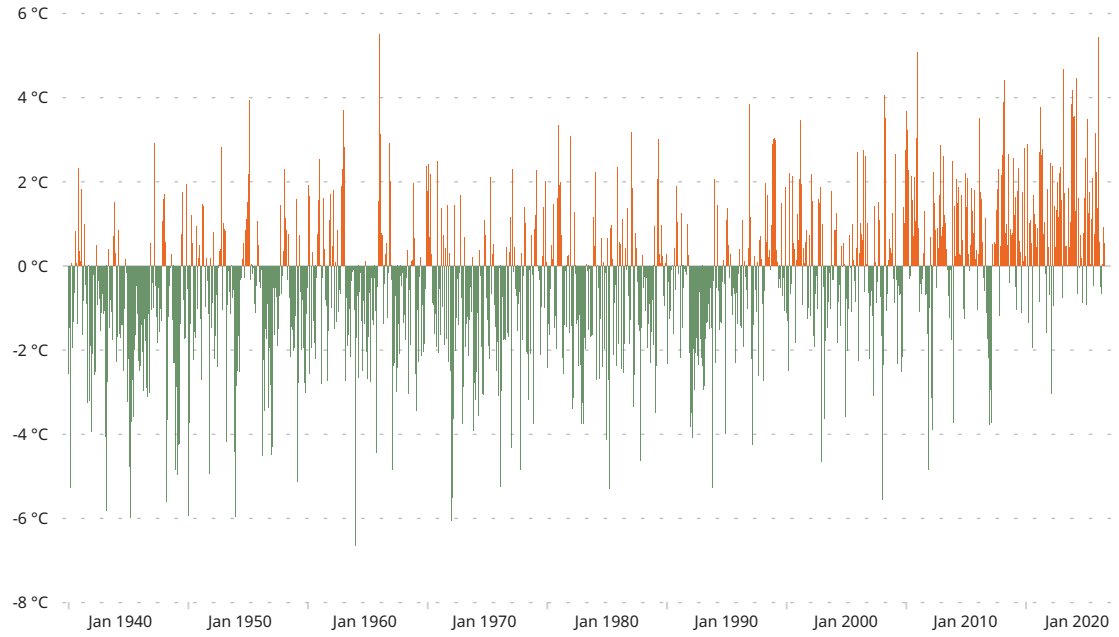
At the same time, anthropogenic pressures such as land-use change, landscape fragmentation, overgrazing, uncontrolled burning of agricultural residues, and pastures, and inadequate fuel management at the forest-agriculture interface have increased fuel continuity and fire intensity. These trends have expanded wildfire hazard into ecological zones that historically were less fire-prone, have increased the vulnerability of settlements and critical infrastructure and thus, altogether, amplified the socio-economic impacts of wildfires on communities, ecosystems, and local economies. Together, these climatic and human drivers interact to elevate wildfire risk and strain existing prevention and response capacities.

5 Our World In Data https://ourworldindata.org/wildfires#all-charts

6 Our World In Data https://ourworldindata.org/wildfires#all-charts

## Monthly temperature anomalies, Armenia, Jan 1940 to Aug 2026

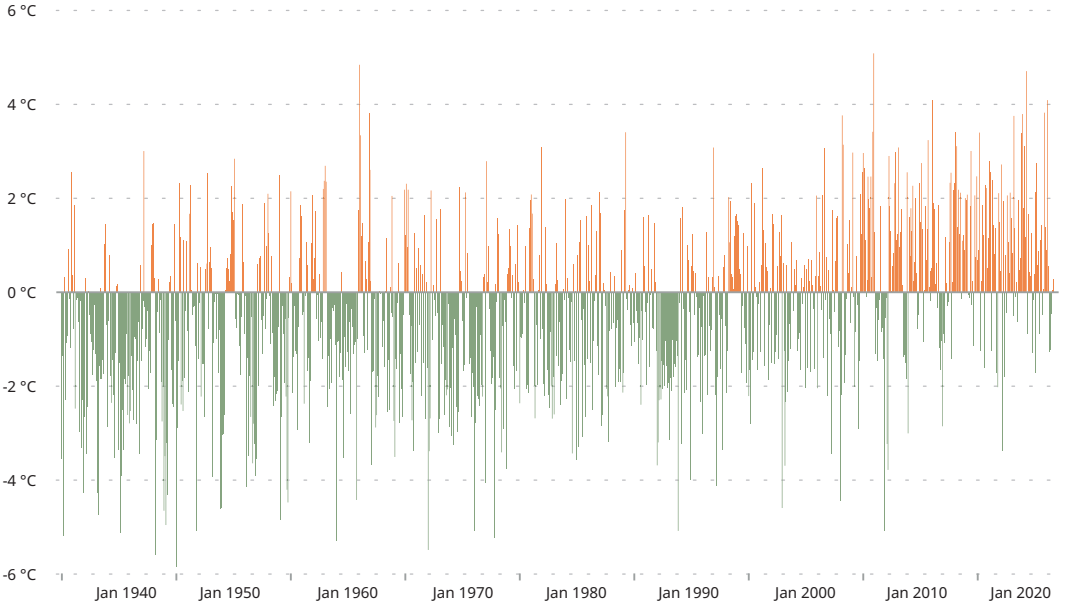
Difference of a specific month's average surface temperature from the 1991-2020 mean, in degrees Celsius.




Data source: Contains modified Copernicus Climate Change Service information (2026) OurWorldinData.org/climate-change | CC BY

## Monthly temperature anomalies, Georgia, Jan 1940 to Aug 2026

Difference of a specific month's average surface temperature from the 1991-2020 mean, in degrees Celsius.




Data source: Contains modified Copernicus Climate Change Service information (2026) OurWorldinData.org/climate-change | CC BY

Evidence from national fire records and satellite-based observations (including MODIS and VIIRS active fire and burned area datasets) covering the period since 2000 confirms an upward trend in burned area in both Armenia and Georgia, as well as shifts toward earlier fire seasons and longer-duration fire events. In Armenia, recurrent wildfires have affected diverse landscapes from dry woodlands to highland meadows, with notable fire activities in Lori, Syunik, and Shirak provinces. In Georgia, regions such as Kvemo Kartli and Samtskhe-Javakheti have experienced large fire events affecting forest, grassland, and agricultural areas. These evolving patterns highlight the need for an integrated risk assessment approach that systematically combines climatic, ecological, and socio-economic factors.

Wildfires in the South Caucasus increasingly represent not only an environmental hazard but also a human security concern, a core focus of the OSCE's work on climate change and security. Large and uncontrolled fires undermine socio-economic stability, threaten public health, damage critical ecosystems and infrastructure, and place additional pressure on communities, as well as national and local authorities. The November 2025 wildfires in the vicinity of neighboring regions of Armenia and Georgia highlighted these risks, requiring large-scale emergency response efforts and threatening communities, forests, and tourism areas across the border region of Armenia. As climate change acts as a risk multiplier, wildfire hazards intersect with and can compound broader security dynamics, including resource stress, livelihood insecurity, gender inequality and altered mobility patterns. In transboundary contexts, effective solutions to these challenges require institutional co-operation and co-ordinated actions of the affected countries.

**Photo:** Armen Asryan, Northern Armenia



Against this background, the present assessment was designed to operationalize the objective of producing a shared, evidence-based understanding of climate-related security risks that affect both Armenia and Georgia. The assessment focuses on two representative and environmentally significant border regions: the Tashir consolidated community in the Lori Province, Armenia, and Bolnisi Municipality in the Kvemo Kartli region, Georgia. These communities have been identified as pilot communities for supporting transboundary co-operation and adaptation measures in earlier consultations processes within the above-mentioned OSCE project. Administratively, the assessment covers all municipal units within these areas and applies a harmonized geospatial risk assessment methodology, jointly developed and implemented by expert teams from the two countries to ensure comparability of results and transparency of assumptions across both countries. This approach enables a unified analysis of wildfire hazard, exposure, vulnerability, and aggregated risk, forming a common analytical baseline for dialogue and co-operation in fire management and climate adaptation.

In line with the Joint Risk Mapping Initiative and the OSCE's mandate to support efforts addressing climate-related security risks in the OSCE area, the purpose of this assessment is not only analytical but also to build mutual confidence between stakeholders and facilitate action. It seeks to generate actionable spatial intelligence for a broad range of actors, including national and regional forest and environmental agencies, emergency management services, municipal authorities, civil society organizations, and international partners, including the OSCE. Intended applications include supporting joint fire prevention and preparedness planning, informing targeted fuel reduction and land management interventions, strengthening early warning and response systems, and facilitating co-ordinated risk communication at the community level.

## Kvemo Kartli (Georgia)

### Population

- **~438,000 people**
- ~ 45% urban / 55% rural
- **Key urban centres:** Rustavi, Marneuli Bolnisi, Tsalka, Dmanisi

### Area & Density

- **Area:** ~6,528 km²
- **Population density:** ~67 people/km²

### Key Infrastructure

- **Industrial hub:** Rustavi (manufacturing, metallurgy)
- **Energy infrastructure**
  - → Agricultural production zones (crop farming, livestock); important pastures
  - → Major transport corridors connecting to Armenia,
  - → Urban utilities and logistics facilities

## Lori (Armenia)

### Population

**~235,000 people**
• Predominantly rural with small urban centres
• **Key towns:** Vanadzor, Tashir, Alaverdi, Stepanavan

### Area & Density

- **Area:** ~3,789 km²
- **Population density:** ~62 people/km²

### Key Infrastructure

- **Mining and metallurgy** (Alaverdi, Teghut)
- **Forest management areas**
  - → Agriculture and livestock farming,
  - → mountain road networks,
  - → tourism and cultural heritage sites

This assessment applies a harmonized transboundary methodology to analyze wildfire risk in selected areas of Armenia and Georgia. Combining remote sensing, climate, environmental, and socio-economic data within a GIS framework, it evaluates wildfire hazard, exposure, vulnerability, and risk using a consistent approach across both countries. The methodology is designed to support joint planning, risk reduction, and emergency preparedness while providing a scalable model for broader application across the South Caucasus. Methodological assumptions, weighting approaches, and preliminary results were validated during a technical workshop in Yerevan on 3–4 December 2025, involving Armenian and Georgian experts, local authorities, and international partners.

The resulting risk maps and analytical outputs also serve as baseline tools for monitoring future changes in wildfire risk, assessing the effectiveness of mitigation and adaptation measures, and integrating wildfire considerations into broader climate adaptation, disaster risk reduction, and environmental security planning processes. By grounding discussions in shared data and jointly agreed methodologies, the assessment directly contributes to fostering trust, enhancing technical co-operation, and identifying entry points for subsequent phases of joint risk reduction and resilience-building interventions.

**Recognizing the dynamic nature of wildfire risk under a changing climate, this assessment is framed as an initial, scalable model. While focused on two sub-regions, the methodology and data workflows are designed for replication and upscaling at national and regional levels, supporting climate adaptation reporting and longer-term co-operation on shared environmental security challenges. In this way, the assessment lays a foundation for sustained cross-border engagement and evidence-based decision-making.**

**Photo:** Armen Asryan, Northern Armenia



# Study Area – Lori Province (Armenia) and Kvemo Kartli Region (Georgia)

**The pilot areas selected for the joint wildfire risk assessment are located in Lori Province in northern Armenia and Kvemo Kartli Region in southern Georgia. Together, these regions form a continuous transboundary ecological and socio-economic corridor characterized by diverse landscapes, shared river basins, and closely linked climatic and land-use dynamics.**

2

The pilot areas selected for the joint wildfire risk assessment are located in Lori Province in northern Armenia and Kvemo Kartli Region in southern Georgia. Together, these regions form a contiguous transboundary ecological and socio-economic landscape. Lori and Kvemo Kartli share similar climatic conditions, including comparable precipitation regimes, temperature patterns, and seasonal drought trends, which influence ecosystem dynamics across the border. Both regions are characterized by extensive forest ecosystems that exhibit similar responses to climatic variability and extreme weather events. These shared environmental conditions, combined with interconnected livelihoods, agricultural activities, and land-use practices, create a common landscape in which wildfire risks transcend administrative boundaries. As a result, effective wildfire risk assessment and management require a co-ordinated transboundary approach that reflects the ecological and socio-economic interdependencies of the two regions.

## 2.1 Topography and Physical Setting

Lori Province occupies roughly 3,789 km² in northern **Armenia** and forms part of the Southern Caucasus Mountain system shared with Georgia. Its landscape is shaped by multiple interconnected mountain ranges, including Bazum, Pambak, and Gugark, with elevations ranging from about 380 m in the Debed River valley to over 3,190 m at Mount Achkasar. The Debed River and its tributaries, including the Dzoraget and Pambak,

dominate the region's drainage and connect Lori hydrologically to southern Georgia through the Khrami–Debed basin. The topography and hydrology of the region underscore the shared ecological and fire-fighting interests as well as co-operation opportunities across borders.

Lori hosts three key sanctuaries: *Gyulagarak* (2,576 ha near Gyulagarak village in Qarhanqjur Valley, protecting forests), *Margahovit* (3,368 ha in Aghstev Valley for mesic forests and fauna), and *Rhododendron caucasicum* near Aghstev River for subalpine rhododendron habitats. Additional sites include *Stepanavan Dendropark* and *Vanadzor Botanical Garden*.

Kvemo Kartli is situated in southeastern **Georgia**, south of Tbilisi, and borders Armenia to the south, as well as Kakheti, Shida Kartli, Mtskheta-Mtianeti, and Samtskhe-Javakheti within Georgia. Covering approximately 6,528 km² (about 9.4% of Georgia's territory), the region exhibits highly fragmented relief shaped by the Trialeti and Samsari mountain ranges and adjacent lowlands. The study area can be broadly divided into three main physiographic zones:

**I.** the Kvemo Kartli Lowland (300-600 m above sea level), encompassing fertile plains and rolling hills dominated by agricultural land and industrial development around Rustavi. This area includes the municipalities of Gardabani, Marneuli, and partly Bolnisi;

**II.** a hilly and mountainous zone, including Bolnisi, Dmanisi, and Tetritskaro municipalities, where elevations rise sharply toward the Trialeti Range, reaching up to 2,850 m at Shaviklde Peak; and

**III.** the high-mountain volcanic plateau of Tsalka, averaging around 1,500 m above sea level and characterized by expansive sub-alpine and alpine meadows, rich in endemic and medicinal plants. The area is particularly notable for its abundance of natural lakes.

The region is part of the broader Mtkvari (Kura) River basin, with its main tributaries including the Khrami-Ktsia, Debeda, and Algeti rivers.

Kvemo Kartli contains several important protected areas, including: *Algeti National Park*, which covers an area of 24,260 hectares and safeguards Nordmann fir and Caucasian spruce forests; the *Algeti River gorge*, and the *Gardabani Managed Reserve*, a wetland area near Tbilisi that supports rich biodiversity and is particularly important for birdlife, as well as species such as jackals and wild pigs.

## 2.2 Climate Dynamics

**Armenia** has experienced significant climate warming over recent decades, with average annual temperatures rising by over 1 °C since the early 20th century, alongside declining and increasingly variable precipitations.[7] These trends have intensified drought conditions, altered hydrological regimes, and increased climate-related risks nationwide. Climate projections indicate continued warming throughout the 21st century, with temperature increases of up to around 2.8 °C by mid-century under high-emission scenarios and an overall reduction in precipitation of approximately 8% by 2100, exacerbating water stress and extreme weather events.[8] According to assessments submitted to the UNFCCC[9] and the World Bank,[10] these changes are expected to adversely affect water availability, agricultural productivity, ecosystems, and economic resilience. In the Lori region, characterized by mountainous terrain and extensive forest cover, rising temperatures and longer dry periods are increasing forest fire risk and stressing already vulnerable forest ecosystems. Climate-driven aridity, combined with land degradation pressures, is likely to contribute to more frequent and severe wildfires, underscoring the need for strengthened forest management, early warning systems, and region-specific adaptation measures.[11]

Lori Province exhibits a highland continental climate with pronounced seasonal contrasts. In Vanadzor (about 1,350 m above sea level), average winter temperatures are around -8 °C and summer averages near 15 °C, with annual precipitation of approximately 570 mm reflecting relatively abundant moisture in the highlands. In northern localities such as Tashir, the climate is more

7 Ministry of Environment of the Republic of Armenia. (2020). Fourth National Communication to the UNFCCC.

8 ibid.

9 ibid.

10 World Bank Group. (2024). Climate Action in Armenia Can Deliver Cleaner Air, Healthier Communities, and Stronger Economic Growth. Washington, DC.

11 Food and Agriculture Organization of the United Nations. (2023). Armenia Makes Progress in Building Forest Resilience. FAO Regional Office for Europe and Central Asia



**Photo:** Armen Asryan, Northern Armenia

continental, with stronger seasonal contrasts, and higher precipitation (around 770 mm annually). Similar to country-wide projections, the Lori region is expecting rising temperatures, increasing climate variability, and heightened exposure to droughts and heat stress are projected to affect water availability, soil moisture, vegetation health, and fire-weather conditions, particularly in mountainous regions. The Tashir Community, located in northern Lori (and bordering Bolnisi Municipality in Georgia) at about 1,500 m elevation, illustrates these regional dynamics at a local scale. It experiences a classic continental mountain climate with cold winters (average January temperature -4.3 °C), moderate summers (average July temperature 17 °C), and relatively high annual precipitation (~770 mm), conditions that help sustain grasslands and agricultural production.

The Fourth National Communication of **Georgia** to UNFCCC indicates that signs of climate change have been visible in Georgia since the 1950s, with impacts becoming increasingly rapid and noticeable. A comparison of two 30-year periods, 1956-1985 and 1986-2015, shows that mean daily daytime temperatures increased by 0.25 to 0.58 °C depending on the region, with a national average rise of 0.47 °C. The most significant warming occurred in Dedoplistskaro (Kakheti region), where the annual increase reached 0.73 °C[12].

Temperature trends show a clear seasonal pattern. Eastern Georgia experienced stronger warming from June to October and from January to March, while the average temperature in Guria-Adjara remained largely unchanged. Changes in precipitation have also been recorded. Annual precipitation generally increased in western Georgia, with the largest rise, up to 15 %,

12 Ministry of Environmental Protection and Agriculture of Georgia (2021). Fourth National Communication to UNFCCC

observed in Poti and Khulo, equivalent to 60 to 75 mm per decade. However, precipitation decreased in Guria and in the high mountainous zone of Adjara, particularly around Goderdzi Pass. In eastern Georgia, a significant decline was recorded in some parts of the central Kartli region (Tianeti), where precipitation fell by about 18%, or 39 mm per decade. In addition, the months with the highest precipitation shifted from summer to spring, particularly May and June[13], which can contribute to increased wildfire risk by promoting early-season vegetation growth that subsequently dries out during hotter, drier summer conditions.

In Kvemo Kartli region, average annual temperatures range from 10-12 °C in the lowlands to 5-8 °C in mountainous areas. The climate is temperate continental, with relatively dry summers and mild winters, while precipitation averages 400-600 mm in the lowlands and increases to 800 mm or more in mountainous zones due to orographic effects. Rainfall is unevenly distributed, with most precipitation occurring in spring and early summer. Climate projections suggest[14] that eastern lowland areas of Kvemo Kartli could experience substantial declines in annual precipitation by the end of the 21st century, significantly increasing water stress and wildfire risk.

## 2.3 Vegetation Land Cover and Land Use

Vegetation patterns in both regions closely reflect their topographic and climatic diversity.

Vegetation patterns in the Lori Province of **Armenia** encompass dry mountain steppes in northern lowlands, extensive native broadleaf and mixed mountain forests on north-facing slopes between 500-2,500 meters, subalpine meadows above 2,300 meters, and riparian vegetation along river valleys. Forests cover about 29% naturally and 0.32% non-naturally as of 2020 positioning the province as one of the most forested provinces of Armenia.

Land cover features fragmented forests, dominant grasslands, and steppes, with relict wetlands in valleys adding unique habitats. Agricultural land use prevails on 66.3% arable lands, hayfields, and pastures, constrained by steep terrain, shallow soils, and climate variability, while mining and overgrazing fragment habitats and elevate fire risks. Vegetation land cover and land-use patterns strongly influence wildfire risk in the pilot areas. Grasslands and overgrazed pastures accumulate fine, dry fuels that ignite easily, while fragmented forests and forest–agriculture edges increase fuel continuity and human ignition pressure. Combined with agricultural burning and increasing climatic dryness, these factors accelerate fire spread and intensify wildfire hazard. These patterns underpin ecological services like water regulation and soil conservation but face pressures from human activities.

The Kvemo Kartli region of **Georgia** comprises a mosaic of steppe and semi-desert landscapes in parts of Marneuli and Gardabani, broadleaf forests in Tetritskaro, Bolnisi, and parts of Dmanisi, and extensive sub-alpine and alpine meadows on the Tsalka Plateau. In particular, Tsalka and Dmanisi are located at relatively high elevations, averaging between 1,200 and 1,400 meters above sea level with domination of grasslands and agricultural landscapes. In contrast the municipalities of Bolnisi and Tetritskaro contain more mountainous terrain, with substantial forest cover. The municipalities of Gardabani and Marneuli are situated within the “Kvemo Kartli” plain, which forms part of the Mtkvari (Kura) River basin.

Forests occupy about 145,000 hectares (approximately 4% of the 43% forest area of the country). The grasslands support traditional pastoral livelihoods and host a rich diversity of mountain flora, including endemic and medicinal plant species.

In both regions, human land-use practices, including grazing, agricultural burning, forestry activities, and settlement expansion, interact with climatic stressors to influence fuel availability and landscape fragmentation, shaping wildfire risk patterns.

13 ibid.

14 Ministry of Environmental Protection and Agriculture of Georgia (2021). Fourth National Communication to UNFCCC

## 2.4 Social Conditions and Economic Activities

The Lori Province of **Armenia** features a mix of urban centers and rural communities, with many villages dependent on agriculture, small enterprises, and seasonal labor. According to the latest data from the Statistical Committee of Armenia, the population of the province is 222,805 (7.6% of Armenia). The population structure remains relatively stable, with about 58-59% urban and 41-42% rural residents. The province includes eight urban settlements; while following administrative reforms it is currently organized into fewer consolidated municipal communities (eight urban and 105 rural communities). Administrative center, Vanadzor, is the largest city with a population of 84,500.[15] Industrial activities, including metallurgy and mining around towns such as Alaverdi and Teghut, complement food processing and construction materials production. Tourism, centered on forested landscapes, river gorges, and cultural heritage sites, has grown in importance as an economic complement to traditional sectors. Forest resources contribute both to ecological health and to local economies through timber, non-timber products, and potential eco-tourism opportunities.

Social conditions vary across the province, with some rural areas experiencing limited infrastructure, accessibility challenges, and reduced access to services, contributing to differential vulnerability to environmental hazards. For instance, due to socio-economic situation people may revert to burning wood (mostly via illegal logging) instead of natural gas. If improperly applied (e.g., by using unsuitable ovens or herds, or burning moist timber), the burning of wood can be unhealthy and impacts mostly women, children, and elderly who are at home for most of the day.

The local economy in Tashir is shaped by agriculture, livestock, and food processing, including dairying and canning, while its location near regional transport routes supports connectivity and access to markets. These socio-economic and environmental characteristics make Tashir representative of highland communities that both contribute to and are shaped by broader climatic, ecological, and development trends in Lori Province.

**The Kvemo Kartli Region of Georgia has a population of approximately 438,000, representing nearly 12% of Georgia's total population. The region is ethnically diverse, with about 45% of residents living in urban areas and 55% in rural settlements.[16] Rustavi serves as the administrative and industrial center, while municipalities such as Marneuli, Gardabani, and Bolnisi support large rural populations. Economically, Kvemo Kartli contributes around 7.1% of Georgia's GDP, driven by manufacturing, agriculture, and energy production.[17] Rustavi alone accounts for roughly 20% of national industrial output. The region is a major agricultural producer, supplying vegetables, beef, and dairy products to national markets, while highland areas such as Dmanisi and Tsalka rely heavily on livestock grazing.**

15 Statistical Committee of the Republic of Armenia (Armstat). (2023). Population of the Republic of Armenia by Marzes (2022 Census Results). https://armstat.am

16 National Statistic Office of Georgia. (2024). Population Census of Georgia (Preliminary Results). https://www.geostat.ge/en/modules/categories/12/2024-population-census-of-georgia-preliminary-results

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# Hazard Mapping and Risk Assessment for Lori and Kvemo Kartli Regions

3

## 3.1 Wildfire hazard maps

**The wildfire hazard map identifies areas within the administrative units of the Lori Province and the Kvemo Kartli Region, where wildfire ignition and spread are most likely, based exclusively on environmental and climatic conditions. Hazard was calculated using four groups of variables: fuel and vegetation (weighted 30%), fire weather and climate (25%), topography (20%), and historical fire occurrence (25%).**

**Photo:** Armen Asryan, Northern Armenia



The *fuel and vegetation* component was derived from land cover datasets (Copernicus Global Land Cover) and satellite-derived vegetation indices (MODIS NDVI/EVI), which indicate vegetation density and biomass that determine available fuel load. Higher vegetation density and forest cover were classified into higher hazard classes due to their potential to support more intense fires. The *fire weather and climate* component incorporated seasonal indicators including air temperature, precipitation, solar radiation, and wind speed, derived from open-access hydrometeorological datasets (e.g., ERA5 and WorldClim). These variables represent environmental conditions that influence vegetation dryness and fire spread potential. The *topographic* component was derived from Digital Elevation Models obtained from Copernicus terrain data. From the DEM, slope, aspect, and elevation were calculated, as steep slopes and south-facing exposures tend to accelerate fire spread and increase fuel drying. Finally, the *historical fire occurrence* component was developed using MODIS and VIIRS satellite fire detection datasets,[18] which provide long-term records of fire activity. Kernel density analysis was applied to map areas with higher historical fire frequency.

Each sub-layer was reclassified to a standardized five-class scale (1-5) ranging from very low to very high hazard. The layers were then combined using weighted raster overlay, producing a composite Wildfire Hazard Index. The resulting hazard map highlights areas where environmental conditions are most conducive to wildfire ignition and propagation.

Hazard mapping for **Kvemo Kartli** region indicates a very high risk of wildfire in the Khrami River basin, particularly in the southern part of Bolnisi municipality. This area is predominantly hilly and covered with natural forests. Elevated risk levels were also identified in the central part of Tetritskaro municipality and in areas surrounding the Algeti Reservoir. In contrast, most of the remaining territories of Kvemo Kartli demonstrate relatively low levels of forest fire risk.

**Map1:** Wildfire hazard map: Bolnisi, Dmanisi, Gardabani, Marneuli, Tetritskaro, Tsalka, and Rustavi municipalities of the Kvemo Kartli Region, Georgia

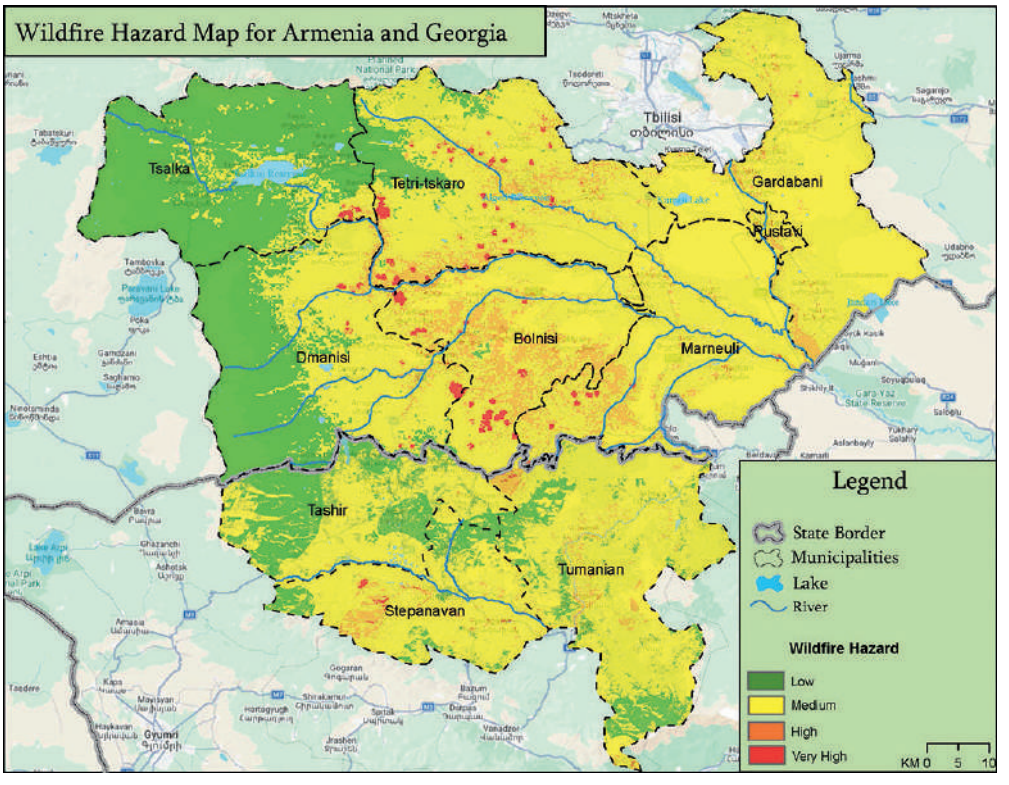



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**Map 2:** Wildfire hazard map: Tashir, Stepanavan, and Tumanyan communities of the Lori Marz, Armenia




**Map 3:** Wildfire hazard map of two bordering regions: Kvemo Kartli (Georgia) and Lori Marz (Armenia)



In the **Lori Province** of Armenia, elevated wildfire hazard is particularly evident in the forested mountain slopes surrounding the Debed River valley, and in the mountainous areas between Armenia and Georgia. These locations combine steep slopes and dense forest cover, factors that contribute to the fast spread of fire, and climatic conditions that favor vegetation drying during the summer season. In contrast, the relatively flat agricultural landscapes around Tashir town and the central valley corridors show generally lower hazard levels due to reduced fuel continuity and gentler terrain.

**Photo:** © Shutterstock, Inc



## 3.2 Wildfire exposure maps

The exposure map highlights areas where people, infrastructure, and economic activities could be affected by wildfire events. The analysis considers the spatial distribution of key elements at risk, such as settlements, agricultural lands, transport corridors, protected areas, and critical infrastructure including schools, hospitals, and other essential facilities.

The analysis incorporated the following exposure layers:

- Settlements and population distribution, derived from national administrative datasets and population raster datasets such as WorldPop.
- Agricultural land and grazing areas, extracted from land cover datasets and national agricultural land use information.
- Transport infrastructure, derived from OpenStreetMap datasets, including major roads, secondary roads, and local access routes.
- Critical infrastructure, including schools, health facilities, and key public services mapped using OSM and national spatial data.
- Protected areas and ecologically sensitive sites, obtained from national environmental databases and the World Database on Protected Areas (WDPA).

Each exposure layer was standardized and reclassified to a five-class scale reflecting increasing levels of exposure. Areas with dense settlement patterns, key infrastructure, or extensive agricultural activity received higher exposure values.

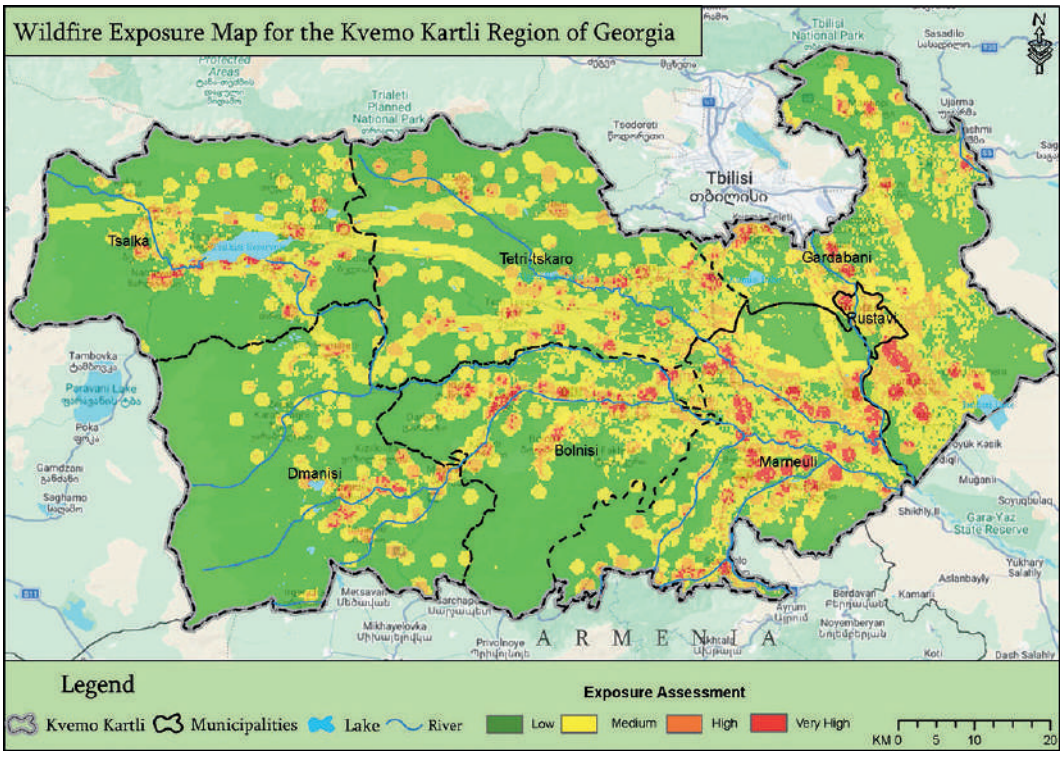
The layers were then integrated using weighted overlay analysis, producing a Composite Exposure Index. The resulting exposure map highlights areas where wildfire events could have the greatest potential impact on human populations, economic activities, and natural ecosystems.

The analysis indicates that Marneuli municipality exhibits the highest level of exposure within the region. This is largely attributable to its comparatively large population and high population density, which are associated with a greater concentration of educational facilities, administrative units, and other critical infrastructure.

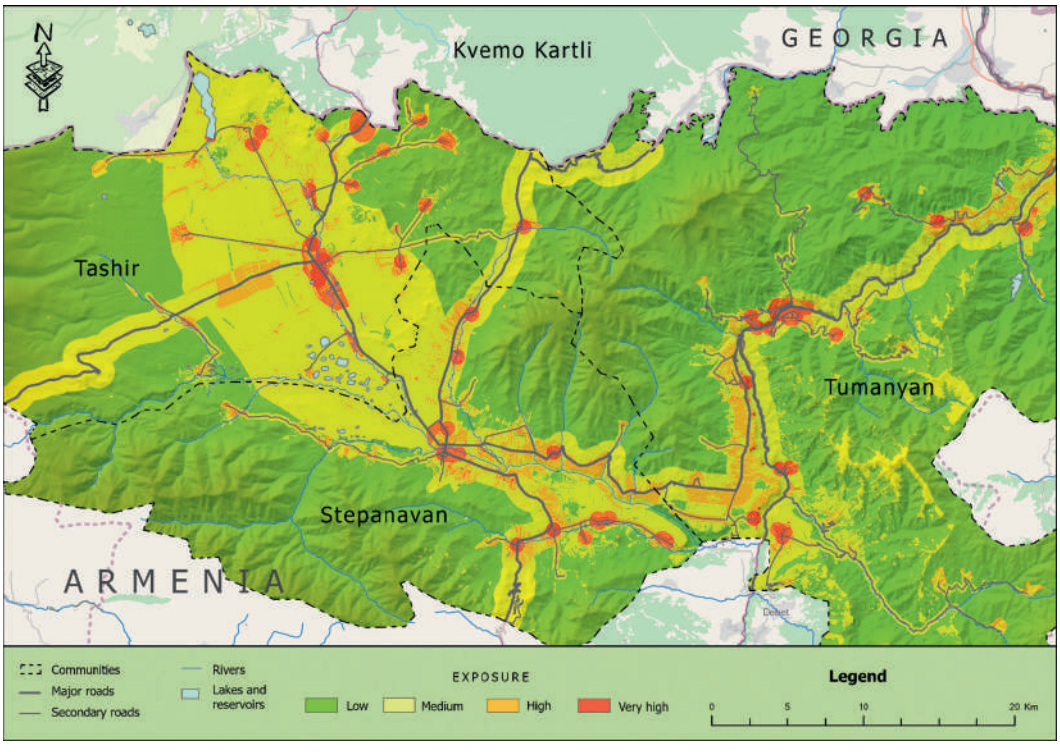
Bolnisi, Tetritskaro, and Gardabani municipalities follow in terms of exposure levels, while Tsalka and Dmanisi municipalities show comparatively lower exposure levels due to their smaller populations and lower density of infrastructure.

**Higher exposure levels are concentrated along the main Debed River corridor, where settlements, agricultural lands, and infrastructure are clustered. The towns of Stepanavan, Tashir, and Tumanyan, together with surrounding villages, represent the most exposed areas due to their higher population density and proximity to major transportation routes connecting Armenia with Georgia's Kvemo Kartli region. Agricultural lands and pasture areas in the valley floor further increase exposure levels, while remote mountainous areas with limited human presence exhibit comparatively lower exposure.**

**Map 4:** Wildfire exposure map: Bolnisi, Dmanisi, Gardabani, Marneuli, Tetritskaro, Tsalka, and Rustavi municipalities of Shida Kartli, Georgia




**Map 5:** Wildfire exposure map: Tashir, Stepanavan, and Tumanyan communities of Lori Marz, Armenia



## 3.3 Vulnerability maps

The vulnerability assessment evaluated how susceptible exposed communities and ecosystems were to wildfire impacts. Unlike hazard and exposure, vulnerability focused on social, environmental, and accessibility-related factors that influence coping capacity and response capability. The assessment incorporated population density, mobility constraints in mountainous settlements, populated areas, land use patterns, and forest health conditions derived from vegetation indices.

- Population distribution and settlement patterns, derived from population density datasets such as WorldPop.
- Accessibility and response capacity, estimated through spatial analysis of road networks and travel constraints in mountainous terrain.
- Physical constraints, built-up areas derived from land cover datasets.
- Environmental sensitivity and forest condition, assessed using vegetation health indicators derived from satellite vegetation indices (NDVI/EVI).

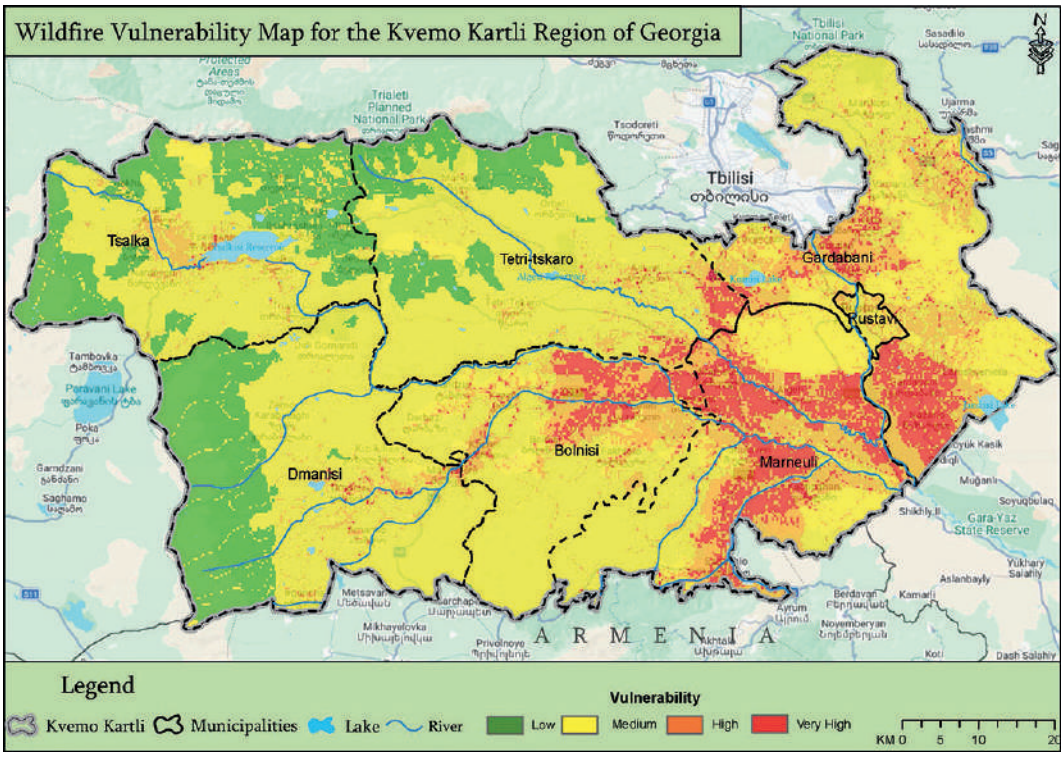
Each variable was reclassified into a standardized five-level vulnerability scale representing increasing susceptibility to wildfire impacts. These layers were then combined using a weighted overlay approach to produce a Vulnerability Index.

Due to limitations in the availability of detailed and harmonized socio-economic datasets across the pilot regions, vulnerability indicators rely primarily on proxy spatial indicators, and therefore represent a relative rather than absolute measure of vulnerability.

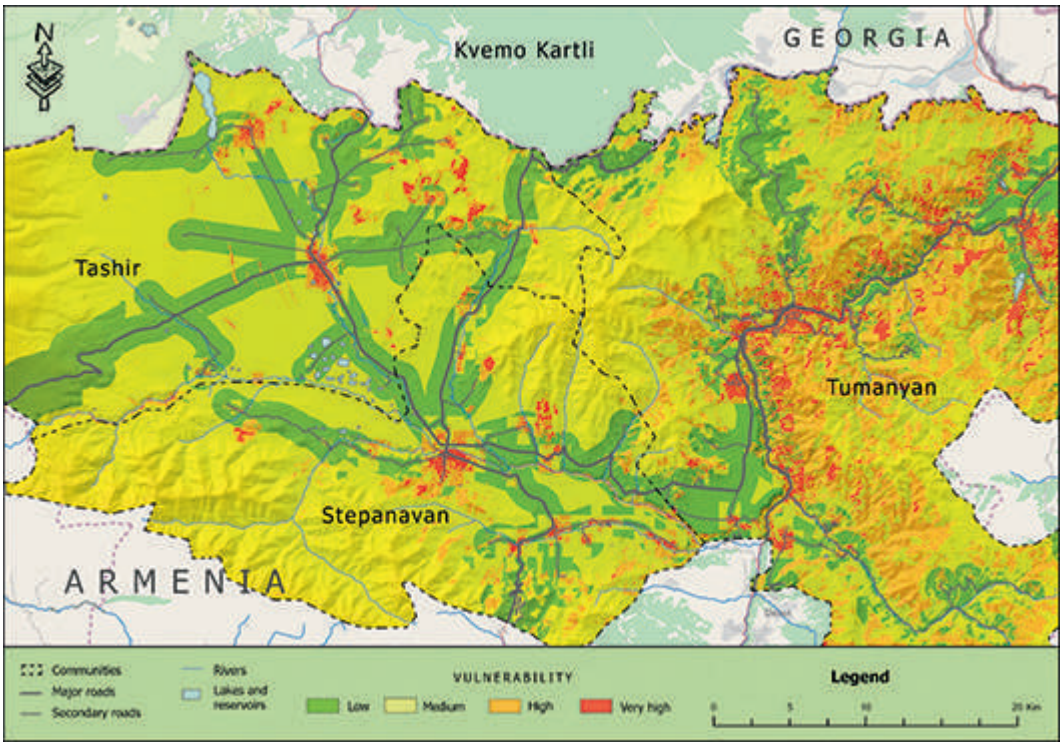
The results of Kvemo Karti assessment indicate that Marneuli, Bolnisi, and Gardabani municipalities demonstrate the highest levels of vulnerability within the region. Tetritskaro municipality exhibits moderate vulnerability, while Tsalka and Dmanisi municipalities show comparatively lower vulnerability levels.

**In Lori, higher vulnerability levels are visible in the Debed valley settlements, particularly localities around Stepanavan, Tashir, and Tumanyan community centers, where dense settlement patterns, limited evacuation routes, and close proximity to forested landscapes increase the potential consequences of wildfire events. Areas surrounding Tashir show moderate vulnerability due to agricultural land use and dispersed settlements, while more remote mountainous regions with lower population density generally exhibit lower vulnerability despite ecological sensitivity, which stems from the presence of valuable forest ecosystems, biodiversity-rich habitats, and ecosystem services that may be significantly affected by wildfire.**

**Map 6:** Wildfire vulnerability map: Bolnisi, Dmanisi, Gardabani, Marneuli, Tetritskaro, Tsalka, and Rustavi municipalities of Shida Kartli, Georgia




**Map 7:** Wildfire vulnerability map: Tashir, Stepanavan, and Tumanyan communities of Lori Marz, Armenia



## 3.4 Wildfire risk maps

The wildfire risk map combines the results of the hazard, exposure, and vulnerability analyses to identify areas where wildfire events could have the greatest overall impact, using the conceptual relationship:

**Risk = Hazard × Exposure × Vulnerability**

**For the integration stage, the model applied the following weights: Hazard: 50%, Exposure: 30%, Vulnerability: 20%.**

Hazard received the highest weight because environmental conditions such as vegetation, terrain, and climate primarily determine where wildfires can occur and how they spread. Exposure reflects the spatial concentration of people, infrastructure, and economic activities that may be affected by fire events. Vulnerability represents the relative susceptibility of these exposed elements to wildfire impacts.

The three raster indices were combined using weighted raster algebra, producing a Composite Wildfire Risk Map classified into four categories: low, medium, high, and very high wildfire risk.

The resulting map identifies priority areas where favorable fire conditions coincide with significant human presence and limited response capacity, highlighting zones where prevention, preparedness, and cross-border co-operation measures should be prioritized.

The integrated risk assessment demonstrates significant spatial variation in forest fire risk across Kvemo Kartli region. The municipalities of Bolnisi and Marneuli emerge as priority areas, where elevated hazard, exposure, and vulnerability factors converge. These are followed by Tetritskaro and Gardabani, which present moderate levels of risk. In contrast, Dmanisi and Tsalka municipalities are classified as relatively low-risk areas within the region.

**Map 8:** Wildfire risk map: Bolnisi, Dmanisi, Gardabani, Marneuli, Tetritskaro, Tsalka, and Rustavi municipalities of Shida Kartli, Georgia



**Map 9:** Wildfire risk map: Tashir, Stepanavan, and Tumanyan communities of Lori Marz, Armenia




**Map 10:** Wildfire risk map of two bordering regions: Kvemo Kartli (Georgia) and Lori Marz (Armenia)

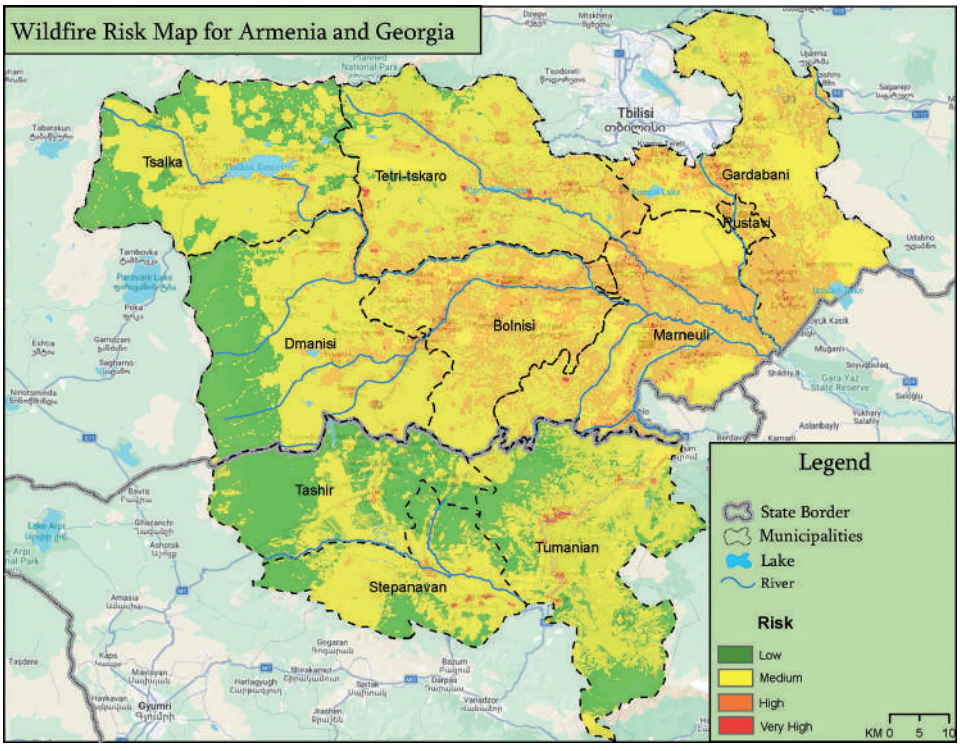




**Photo:** Forest in Southern Georgia

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From a geographical perspective, the Khrami River basin represents the most critical zone, extending from the Dashbashi Canyon to the Samshvilde Canyon. In addition, the Mashavera River basin, which traverses Bolnisi municipality, represents another area of particular concern due to its spatial characteristics and associated risk factors.

The highest risk zones in the Lori region are concentrated along the Debed River valley, particularly around Stepanavan and Tumanyan community centers, where elevated fire hazard intersects with dense settlements, transportation corridors, and critical infrastructure. Additional pockets of increased risk appear near Tashir and along major roads linking local communities and cross-border transport routes toward Georgia. In contrast, more remote mountainous areas north and south of the valley tend to display lower overall risk despite moderate hazard levels, primarily due to lower exposure of people and infrastructure.

# Key findings and way forward

**The spatial analysis reveals a clear pattern of shared wildfire risk across the transboundary landscape, particularly along ecological corridors that extend across the Armenia-Georgia border. The assessment shows that wildfire hazard is strongly influenced by similar environmental drivers on both sides of the border, including mountainous terrain, forest-grassland mosaics, seasonal vegetation drying, and increasing fire-weather pressures.**

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Elevated hazard zones are concentrated in forested and hilly areas associated with the Debed-Khrami river basin system, which connects northern Armenia with southern Georgia. In Lori, higher hazard levels appear along the forested slopes surrounding the Debed River valley and the mountainous zones between Stepanavan and Tumanyan communities, and the Georgian border, while in Kvemo Kartli, the Khrami River basin, and southern parts of Bolnisi municipality demonstrate similar hazard patterns. The findings indicate that wildfire risk is shaped by continuous ecological and climatic conditions rather than administrative boundaries that underscores the importance of co-ordinated monitoring and prevention efforts between the two countries.

The integrated risk analysis further demonstrates that the most critical cross-border risk areas emerge where wildfire hazard coincides with concentrations of people, infrastructure, and economic activities, particularly along major settlement corridors and transportation routes. In both regions, valley settlements such as Stepanavan and Tashir in Armenia, and Bolnisi and Marneuli in Georgia, represent locations where elevated exposure and vulnerability intersect with moderate to high wildfire hazard. These areas combine agricultural land use, transport infrastructure, and forest–agriculture interface zones, creating conditions where fires can both ignite more easily and produce greater socio-economic impacts.

The analysis also highlights the transboundary nature of wildfire dynamics, as shared landscapes, grazing areas, and river valleys create pathways for fire spread across national borders.

As a result, effective wildfire risk reduction in this corridor requires joint risk monitoring, coordinated fire management strategies, and harmonized early warning systems between Armenia and Georgia, supported by shared spatial data and collaborative planning frameworks.

# Potential Opportunities for Further Co-operation

### Organize In-depth Assessment of Identified High-Risk Areas:

- As a next step building on the spatial analysis, it is important to implement more detailed, site-specific assessment in the identified most critical transboundary areas of Stepanavan and Tashir in Armenia and Bolnisi and Marneuli in Georgia. This localized assessment could aim to generate actionable, municipality-level insights that can directly inform targeted wildfire prevention, preparedness, and land management strategies. Namely, the results could be translated into priority zones for fuel reduction and firebreak establishment, areas requiring enhanced protection of infrastructure and settlements and also safe evacuation routes and emergency access points.

## Further Improve Data for Wildfire Risk Assessment:

- Strengthening wildfire risk assessment in the region requires improved availability, quality, and harmonization of spatial and socio-economic data. Future analyses would benefit from access to more high-resolution and regularly updated datasets, particularly on land use, forest condition, infrastructure, and socio-economic indicators at the local level. Expanding the use of national forest inventories, detailed cadastral data, and higher-resolution satellite imagery would improve the accuracy of fuel characterization and exposure mapping. In addition, improving access to historical fire records from national agencies, including ignition causes and suppression data, would enhance the calibration and validation of hazard models.

  The accuracy and reliability of the assessment results depend, to a large extent, on the availability of up-to-date datasets, which can sometimes be sourced only from state institutions and other official providers. Consequently, both the costs of data acquisition and the time required to obtain and process such data should be duly considered in the planning and implementation of cross-border wildfire risk assessments.

## Strengthen Transboundary Data Sharing:

- Equally important is strengthening institutional co-operation and data sharing mechanisms between Armenia and Georgia. Consider reinforcing co-operation towards establishing a joint geospatial data platform or shared repository for wildfire-related datasets that would enable consistent, cross-border analysis and reduce discrepancies between national data sources.

## Strengthen Joint Monitoring and Early Warning Mechanisms:

- Regular technical exchanges, joint trainings, and harmonization of monitoring methodologies would further improve the comparability and reliability of results. Enhanced collaboration between environmental agencies, emergency services, meteorological institutions, and local authorities would also support the integration of real-time monitoring data, improve early warning systems, and facilitate co-ordinated response planning.

## Establish Joint Cross-border Fire Governance:

- A joint working group between Armenia and Georgia could oversee the joint wildfire risk management. Such a working group would enable formalized co-operation for coordinating prevention, preparedness, and response strategies, facilitating regular information exchange (seasonal risk outlooks, fire incidents), supporting joint planning and decision-making for high-risk zones and organizing annual cross-border meetings and simulation exercises.

## Strengthen Community Safety and Awareness:

- Raising community awareness is a critical component of effective wildfire risk reduction, particularly in high-risk, transboundary landscapes such as those shared by Armenia and Georgia. Increased awareness may contribute to reducing wildfire ignitions, as a significant proportion of fires are caused by activities in rural and forest–agriculture interface zones. Aware communities can report fires at an early stage, significantly improving the chances of quick containment and reducing the scale of damage. Well-informed residents of high-risk settlements of Stepanavan, Tashir, Bolnisi, and Marneuli about wildfire risks will be better equipped to undertake preparedness and response activities. On the other hand, emergency response mechanisms and planning exercises would benefit from being tailored to different needs and vulnerabilities of communities as well as from ensuring the meaningful engagement of women and youth in decision-making processes.

Together, the implementation of these proposals for further co-operation would significantly strengthen the evidence base for wildfire risk assessment, establish co-ordinated approaches for wildfire management and support more effective, joint risk reduction strategies in the transboundary region.

# Annex 1. Assessment Methodology

## Technical approach and methodological rationale

In recent years, Armenia and Georgia have both experienced destructive fire events that underscore the urgent need for a harmonized, transboundary wildfire risk assessment approach. The forested and semi-forested landscapes of northern Armenia and southern Georgia form a continuous ecological and socio-economic corridor in which wildfire dynamics are not constrained by administrative borders. As climate change accelerates, these interconnected ecosystems are expected to face longer fire seasons, more extreme fire-weather conditions, and increasing pressure on local communities and response institutions.

In this context, the joint Armenia–Georgia wildfire risk assessment was developed to provide a fast, reliable, accessible, and cost-effective technical methodology that can be applied consistently across both countries. The assessment applies a harmonized, GIS-based approach that integrates remote sensing, climate data, national datasets, and local knowledge. The selected pilot areas – Bolnisi Municipality in Kvemo Kartli (Georgia) and the Tashir consolidated community in Lori Province (Armenia) – represent a complex highland–lowland transition zone where agricultural burning practices, expanding settlement areas, forest and grassland ecosystems, and rugged terrain interact to create elevated wildfire risk conditions. The close spatial proximity between human activities, combustible vegetation, and difficult topography increases both wildfire ignition probability and the potential for rapid fire spread.

Developing a unified wildfire risk assessment for Armenia and Georgia required reconciling differences in national datasets, institutional capacities, and data standards. The rationale behind the jointly developed methodology is therefore threefold:

### 1. Build on the existing work and ensure continuity

Both countries have previously developed hazard maps, forest inventories, climate atlases, and fire-related datasets. The methodology consolidates these official national datasets with open-access global sources to maximize reliability while maintaining comparability across borders. Stakeholder validation ensures that scientific modelling aligns with local conditions, traditional knowledge, and the operational realities of firefighting units.

### 2. Create a scalable, replicable approach

The method is intentionally designed to be lightweight and adaptable by leveraging widely available and accessible data, such as from EU Copernicus programme (DEM, land cover, forest change), NASA Digital Elevation Models), MODIS and VIIRS fire products, Sentinel-2 for high-resolution burn scars, WorldClim and GEFF/ERA5 climate indicators, and OSM and national infrastructure layers.

This approach remains applicable even in areas with limited national GIS capacity. This is critical for replication across the South Caucasus and beyond.

### 3. Produce a unified, transboundary risk picture

Wildfire does not stop at borders. Shared pasturelands, valleys, and forest patches create conditions for cross-border fire spread, yet risk assessments are often produced at the national scale. This methodology intentionally focuses on a specific, shared geographic corridor, enabling technical co-operation, joint analysis, and harmonized risk layers. It also promotes data sharing between agencies and fosters joint emergency planning—an important strategic goal for both countries as climate hazards increasingly intersect with socio-economic vulnerabilities.

The wildfire risk assessment applies a harmonized, GIS-based and transboundary methodology **to analyze and map wildfire hazard, exposure, vulnerability, and integrated risk** across selected areas of Lori Province (Armenia) and Kvemo Kartli region (Georgia). The approach balances scientific robustness and operational usability, ensuring that outputs are suitable for planning, prevention, preparedness, and cross-border co-ordination.

The methodology follows internationally recognized wildfire risk assessment frameworks and is structured around four interrelated components: Hazard, Exposure, Vulnerability, and Risk. This structure allows a clear distinction between the physical drivers of wildfire behavior, the assets potentially affected by fire, and the vulnerability of communities and systems, while enabling their integration into a coherent spatial risk model. The framework is modular and designed for replication and scaling to the national level.

It must be highlighted that the present assessment relies solely on datasets and information that were openly accessible and available to both countries. Given the differences in data types, levels of detail, and, in some cases, limited accessibility, particular attention was paid to ensuring a harmonized cross-border representation. These challenges were addressed through the application of expert judgment, the use of alternative or proxy datasets where direct data were unavailable, and the alignment of methodological approaches to ensure consistency and comparability in the development of fire hazard maps.

## Data Integration and Spatial Framework

The assessment integrates open-access global datasets with national and regionally validated spatial information from Armenia and Georgia. Global datasets ensure consistency and comparability across borders, while national datasets reflect local environmental, institutional, and socio-economic conditions. Core inputs include:

- Digital elevation models (DEM)
- Land cover and forest-change datasets
- Satellite-derived burned area and active fire records
- Hydrometeorological and fire-weather indicators
- Spatial data on settlements, transport networks, and land use

All datasets are processed in a unified GIS environment using UTM Zone 38N and a harmonized working resolution of approximately 30 m, enabling seamless overlay and spatial analysis.

## Wildfire Hazard Assessment

The wildfire hazard component identifies where fires are most likely to ignite and spread, independent of human assets. Hazard mapping focuses on the physical and environmental drivers of fire behavior, grouped into four categories: fuel and vegetation, fire weather & climate, topography, and historical fire occurrence.

### Hazard Variables and Sub-Layers

Hazard is represented through the following sub-layers:

1. **Fuel and Vegetation (30%)** - Land cover and vegetation type, Forest cover and forest-loss indicators, Vegetation density proxies (e.g. NDVI). Fuel and vegetation receive the highest weight, reflecting their dominant role in determining ignition likelihood, fire intensity, and spread potential.

2. **Fire Weather & Climate (25%)** - Air temperature, drought indicators, Fire Weather Index components (where available). These variables capture seasonal and inter-annual variability in fire danger and strongly influence fuel dryness.

3. **Topography (20%)** - Slope (8%), Aspect (6%), Elevation (6%). Topographic variables influence fire spread rate, direction, and fuel moisture conditions.

4. **Historical Fire Occurrence (25%)** - Burned area frequency, active fire density and recurrence. Historical fire data identify chronic ignition zones and reinforce model realism.

Each hazard sub-layer is reclassified to a standardized five-class scale (1 to 5) from very low to very high hazard. Weighted raster overlay integrates all sub-layers into a Wildfire Hazard Index, **classified into low, medium, high, and very high hazard zones**.

## Exposure Assessment

Exposure assessment identifies elements potentially affected by wildfire, focusing on human, economic, and environmental assets. Exposure layers include: settlements and population clusters, agricultural land and grazing areas, transport infrastructure, critical infrastructure and services, protected areas and ecologically sensitive sites.

Exposure layers are standardized and weighted equally due to their potential impact on human lives and well-being, with livelihood systems coming next:

- Settlements and population: 20%
- Critical infrastructure and services: 20%
- Agricultural land and livelihoods: 20%
- Transport networks: 20%
- Protected and sensitive natural areas: 20%

Distance-based buffers are applied where appropriate to reflect decreasing sensitivity with distance from fire-prone areas. The resulting exposure layers are combined into a Composite Exposure Index.

## Vulnerability Assessment

Vulnerability assessment evaluates how susceptible exposed elements are to wildfire impacts, considering social, physical, institutional, and environmental factors. Vulnerability indicators include: population distribution and settlement patterns, accessibility and distance to emergency response services, physical constraints such as terrain steepness and remoteness, environmental sensitivity and forest condition. Vulnerability sub-layers are weighted as follows:

- Social: Population density and mobility constraints 40%
- Physical: Building/residential density 30%
- Environmental sensitivity and degradation via forest health NDVI proxy: 30%

Each sub-layer is classified on a standardized five-class scale and integrated into a Vulnerability Index, highlighting areas with limited coping capacity.

### Risk integration

Overall wildfire risk is calculated through the spatial integration of hazard, exposure, and vulnerability, following the conceptual relationship:

**Risk = Hazard × Exposure × Vulnerability**

For integration, the three components are weighted as:

- Hazard: 50%
- Exposure: 30%
- Vulnerability: 20%

The weighting scheme assigns 50% to Hazard, 30% to Exposure, and 20% to Vulnerability to reflect the relative influence of environmental drivers, the presence of assets, and the susceptibility of communities to wildfire impacts in the study area. Wildfire occurrence and spread are primarily controlled by biophysical conditions such as vegetation fuel load, terrain characteristics, and fire-weather dynamics, which are particularly important in the mountainous landscapes of the Lori Province and the Kvemo Kartli Region, and therefore the hazard component receives the highest weight. Exposure is given a significant weight because settlements, agricultural lands, and transport corridors present in the area increase the potential socio-economic impacts of wildfire events. Vulnerability is assigned a comparatively lower weight because the availability of consistent and comparable socio-economic and infrastructure datasets across the two pilot regions was more limited.

Raster-based weighted algebra produces a Composite Wildfire Risk Map, classified into priority categories ranging from low to very high risk. These categories identify areas where wildfire is both likely to occur and likely to cause significant impacts.

## Validation, Ground-Truthing, and Stakeholder Engagement

The methodology combines remote sensing analysis with field-based data gathering and stakeholder consultations. In November 2025, on-site field visits were conducted at the villages of Tashir, Sarchapet, Privolnoye, Stepanavan and Jiliza (Armenia) and Bediani, Chrdiebis Ubani, Khareba, Darbazi and Chatakhi Ukanagori (Georgia) to verify land-cover classifications, fuel conditions, accessibility constraints, and fire-affected areas.

Methodological assumptions, weighting schemes, and preliminary results were validated through consultations with national experts during a dedicated technical workshop on 3-4 December 2025 in Yerevan, bringing together Armenian and Georgian specialists, local authorities, and international partners. This process ensured transparency, participation and enhanced transboundary compatibility.

## Assumptions and limitations

The assessment relies on the availability and quality of open-access and national datasets, which may vary spatially and temporally. Satellite-based fire detections may under-represent small or short-duration fires, particularly under dense canopy or cloudy conditions as well as year-to-year climate fluctuations (an in-depth analysis would incorporate additional multi-year and multi-seasonal bio-climatic data), socio-economic data availability and currency, varied spatial and temporal resolutions used in the analysis. Weighting schemes reflect expert judgment and stakeholder input but remain subject to fine-tuning with additional geographic/bioclimatic localization and expert engagements with respective national institutions. Finally, the assessment provides a static representation of risk based on recent historical and climatic conditions and does not fully capture rapid land-use changes or future socio-economic developments.

Despite these considerations, the applied methodology provides a robust, transparent, and replicable foundation for joint wildfire risk assessment and cross-border co-operation between Armenia and Georgia.

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# Glossary

**Active Fire Detection**
Satellite systems can detect heat signals from fires occurring on the Earth's surface. These observations help identify the location and timing of wildfire activity.

**Aspect**
Aspect describes the direction that a slope faces (north, south, east, or west). Slopes facing the sun for longer periods tend to become drier and may present higher wildfire risk.

**Buffer Zone**
A buffer zone is a mapped area created at a defined distance around a geographic feature such as a road, settlement, or river. It is used to represent zones of influence or potential impact.

**Burned Area**
Burned area refers to land that has been affected by wildfire. Satellite imagery is often used to map and monitor the spatial extent of burned areas.

**Composite Index**
A composite index combines multiple indicators into a single value or map. In wildfire risk assessment, hazard, exposure, and vulnerability indicators are often integrated into a composite risk index.

**Digital Elevation Model (DEM)**
A digital representation of the Earth's terrain showing elevation values across a landscape. DEMs are used to derive slope, aspect, and elevation for spatial analysis.

**Distance Analysis**
A GIS technique used to calculate the distance between geographic features. In wildfire studies, it helps estimate how proximity to roads, settlements, or forests influences risk.

**Enhanced Vegetation Index (EVI)**
A satellite-based indicator used to measure vegetation density and productivity. It improves vegetation monitoring by correcting for atmospheric effects and dense canopy conditions.

**Exposure**
Exposure refers to the presence of people, infrastructure, ecosystems, and economic activities in areas that could be affected by wildfire. Higher exposure means more assets may be impacted during a fire event.

**Fire Weather Index (FWI)**
A system used to estimate wildfire danger based on weather conditions such as temperature, humidity, wind speed, and precipitation. It helps assess how favorable the environment is for fire ignition and spread.

**Fuel Load**
Fuel load describes the amount of combustible vegetation present in an area. Higher fuel loads can lead to more intense and rapidly spreading wildfires.

**Geographic Information System (GIS)**
A computer-based system used to store, analyze, and visualize spatial data. GIS allows multiple environmental and socio-economic datasets to be combined for mapping and modelling.

**Ground Truthing**
Ground truthing involves verifying satellite or model-based observations through field visits and local observations. This process improves the accuracy and reliability of spatial analysis.

**Hazard**
(1) A fuel complex, defined by volume, type, condition, arrangement, and location, that determines the degree both of ease of ignition and of fire suppression difficulty; (2) a measure of that part of the fire danger contributed by the fuels available for burning. Note: Hazards are worked out from their relative amount, type, and condition, particularly their moisture contents.

**Land Cover**
Land cover refers to the physical material present on the Earth's surface, such as forests, grasslands, agricultural land, or built-up areas. Different land cover types influence fuel availability and fire behavior.

**Landscape fire**
A fire burning in the vegetation of natural and cultural landscapes, e.g., natural
and planted forest, organic terrain (such as peatlands), shrub, grass, pastures, agricultural lands,
and peri-urban areas, regardless of ignition sources, damages, or benefits. (Global Fire Monitoring Center)

**MODIS (Moderate Resolution Imaging Spectroradiometer)**
A satellite sensor used to monitor environmental conditions globally. MODIS provides widely used datasets for detecting active fires and burned areas.

**NDVI (Normalized Difference Vegetation Index)**
A satellite-derived indicator that measures vegetation greenness and density. Higher NDVI values typically indicate healthier vegetation with greater biomass.

**Raster Data**
A spatial data format consisting of a grid of pixels where each cell represents a value such as elevation, vegetation density, or temperature. Raster data are commonly used in environmental modelling.

**Reclassification**
A GIS process that converts continuous data values into defined categories. In wildfire analysis, variables are often classified into risk levels such as low, medium, high, and very high.

**Remote Sensing**
The collection of information about the Earth's surface using satellites or airborne sensors. Remote sensing allows large areas to be monitored efficiently for environmental changes.

**Risk**
Risk represents the potential impact of wildfire events. It is typically calculated by combining hazard, exposure, and vulnerability.

**Slope**
Slope refers to the steepness of terrain. Fires generally spread faster uphill because rising heat dries and preheats vegetation above the flames.

**Spatial Resolution**
Spatial resolution refers to the size of the smallest unit represented in a dataset. Higher resolution means smaller pixels and more detailed spatial information.

**Topography**
Topography describes the shape and physical features of the land surface, including mountains, valleys, and plains. It plays a significant role in wildfire behaviour and spread.

**VIIRS (Visible Infrared Imaging Radiometer Suite)**
A satellite sensor capable of detecting active fires and environmental changes with improved spatial resolution compared to earlier systems.

**Vulnerability**
Vulnerability refers to the susceptibility of people, ecosystems, and infrastructure to damage from wildfire events. It reflects factors such as accessibility, preparedness, and environmental sensitivity.

**Weighted Overlay Analysis**
A GIS technique used to combine multiple spatial datasets into a single map. Each dataset is assigned a weight based on its relative importance in influencing wildfire risk.

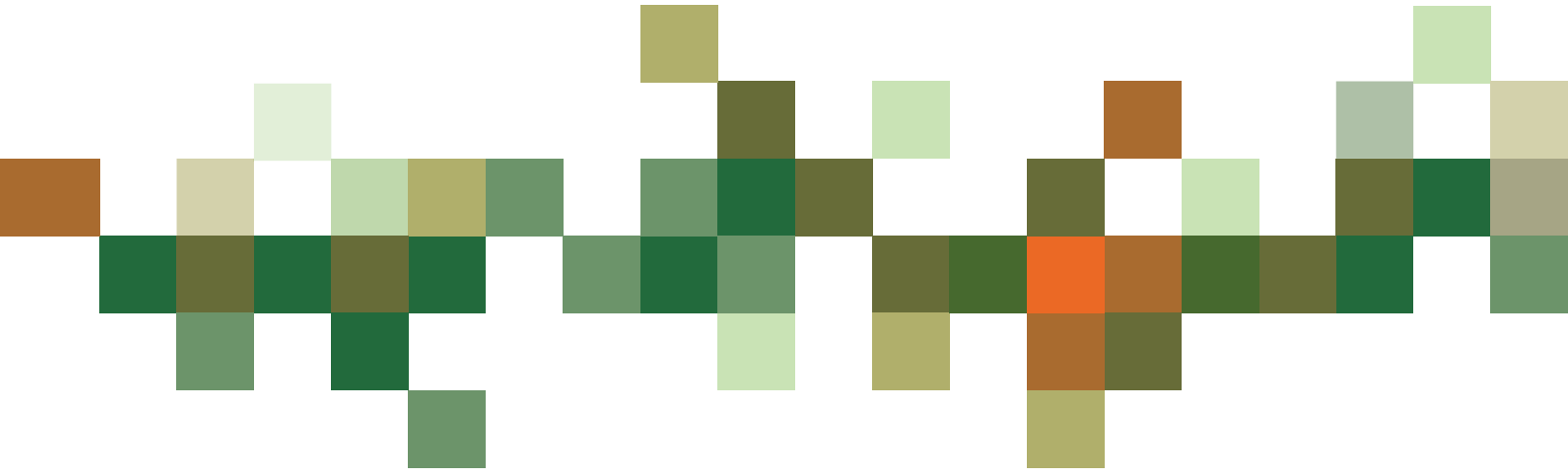
**Wildfire**
Any unplanned or uncontrolled fire in vegetation of natural, cultural, industrial and residential landscapes, which regardless of ignition source may require (i) suppression response, or (ii) other action according to agency policy, e.g., allowing the fire to burn freely as long as it meets land management objectives (Global Fire Monitoring Center)

**Wildfire Hazard Index**
A composite measure representing the likelihood of wildfire occurrence and spread based on environmental factors such as vegetation, climate, and terrain.

**Wildfire Risk Map**
A spatial representation of areas where wildfire impacts are most likely and potentially severe. It integrates hazard, exposure, and vulnerability components.

## Notes

## Notes



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