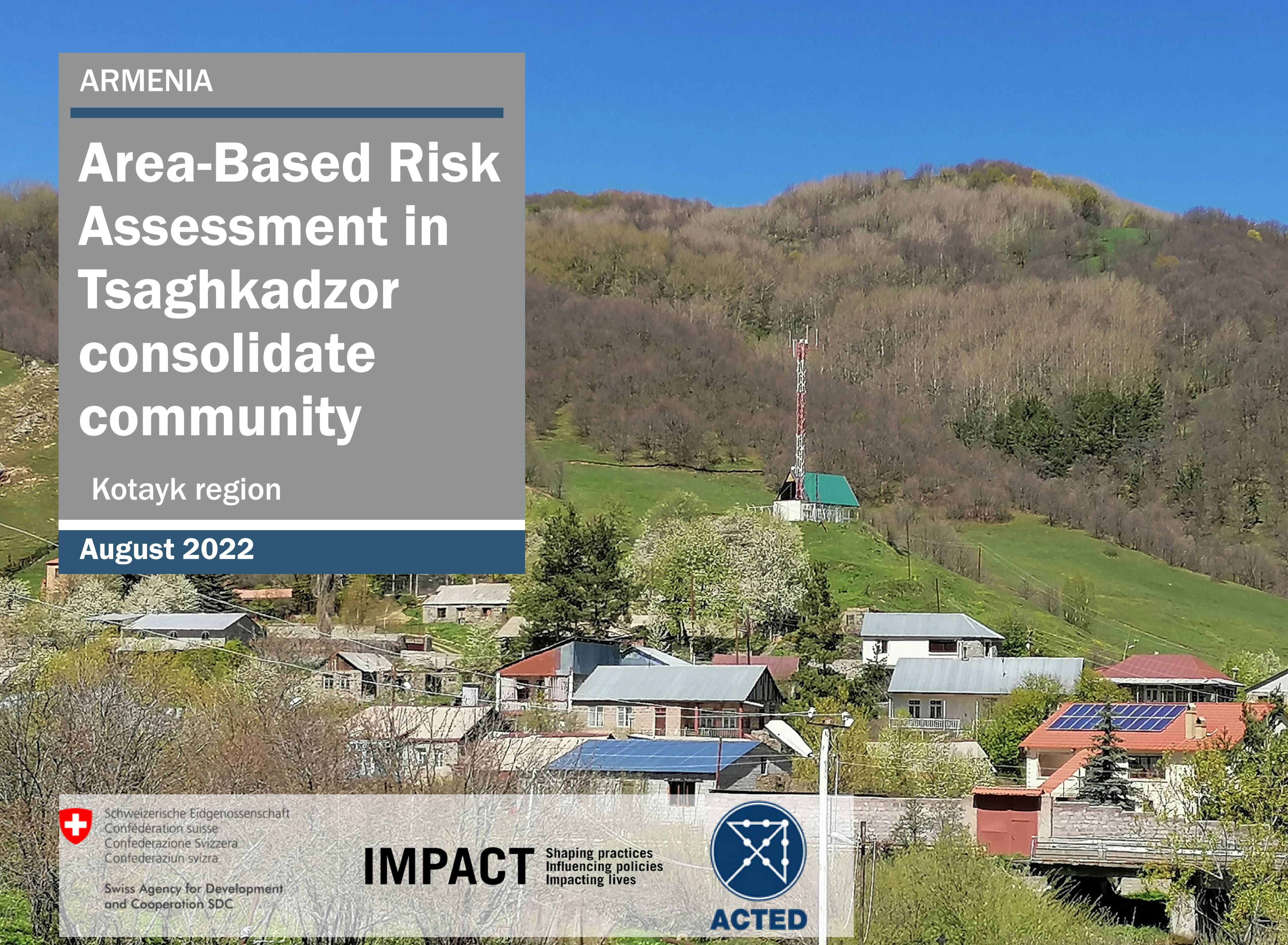

ARMENIA

Area-Based Risk Assessment in Tsaghkadzor consolidate community

Kotayk region

August 2022

Schweizerische Eidgenossenschaft
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ACTED

Cover images: Source: IMPACT, Esri, Maxar, Earthstar Geographics, and the GIS User Community

Who are we?

About IMPACT

IMPACT Initiatives is a leading Geneva-based think-and-do tank which aims to improve the impact of humanitarian, stabilisation and development action through data, partnerships and capacity building programmes. The work of IMPACT is done through its three initiatives: REACH, AGORA and PANDA.

About GLOMOS

Global Mountain Safeguard Research (GLOMOS) is a joint initiative between EURAC Research and the UN University Institute for Environment and Human Security (UNU-EHS), which aims to enhance disaster risk reduction (DRR), climate change adaptation and emergency response preparedness in mountain regions worldwide

About ACTED

ACTED (Agency for Technical Cooperation and Development) is a non-governmental organization with headquarters in Paris, founded in 1993. ACTED's vocation is to support vulnerable populations affected by wars, disasters and/or economic and social crises, and to accompany them in building a better future.

SUMMARY

Natural and man-made disasters have been threats for Armenia for years. According to the national statistics as well as historical data, natural hazards (e.g. earthquakes) and man-made disasters (e.g. fires) have persistently occurred in Armenia over the last decades. Adding to this, the previous studies such as Multi-Sectoral Needs Assessment (MSNA) and Capacity and Vulnerability Assessment (CVA) carried out by IMPACT Initiatives (2021) reveals the need for preparedness to disasters in the rural communities, especially for the refugee-like population moved from the Nagorno-Karabakh as a result of hostilities in 2020.

With this in mind, IMPACT Initiatives, along with his sister organization ACTED, carried out Area-based Risk Assessment (ABRA) in the mountainous region of Kotayk under the funding of Swiss Development and Cooperation Agency. The project was conducted in the Tsaghkadzor consolidated community and thus also included the settlements within the community – Tsaghakdzor, Meghradzor, Aghavnadzor, Artavaz, Marmarik, Hankavan. The project localized the hazard risk according to the local climate and measured its impact on the community. Out of 302 hazards, included in the UNDRR/ISC Sendai Hazard Definition and Classification Review[1], ABRA covered 8 major ones of more perceived concern in mountainous communities, namely earthquake, landslides, flood, wildfire, drought, cold wave, biodeversity loss, and technological hazards.

The project reveals that even though there are several natural and anthropogenic hazards the Tsaghkadzor consolidated community is exposed to, each settlement is being affected differently depending on the hazard exposure, coping capacity, adaptive capacity, and susceptability.

On top of this, Meghradzor and Aghavnadzor settlements has the highest level of multi-hazard risk, in terms of drought, hazardous facilities, landlides and floods.

Meghradzor is the most exposed to hazards due to the highest population density. Poor infrustructure condition increase Meghradzor vulnerability to some hazard. This releaves the need to rehabilitate the water drainage pipeline channels and mitigation of flash flooding and mudslide/rockslide into the community from old degraded soviet infrastructure.

Hankavan is the most vulnerable to hazards due to the longest distance to service (i.e health care) and high percent of population involved in agriculture.

Tsaghkadzor urban settlement and Artavaz rural settlement are the least at risk settlements due to lower hazard exposure and higher coping capacity.

The project also provides recommendation on disaster risk reduction, which were developed and discusssed at the stakeholder workshop Safeguarding Mountain Communitie: case study on the Tsaghkadzor consolidated community. While considering the international best practices, the recommendations were also localized according to the local climate, mountainous relief and feasibility.

Within the scope of the project, ACTED has also invested in disaster risk-related activity in the Tsaghkadzor community. After the site examination and discussion with local and regional authorities, ACTED made the decision to provide three sound announcement system to three different settlements aiming to support in improving emergency management communication with residents.

Marmaric River

Hrazdan Termal Power Plant

Meghradzor gold mine

Meghradzor forested area

Water drainage system in Meghradzor

Water pipeline and rock-falls

Agriculture land in Meghradzor

Landslide near Tsaghkadzor

CONTENTS

RATIONALE

The findings from IMPACT initiatives' published Early Recovery Needs Assessment (2021) funded by the United Nations Development Programme (UNDP), highlight climate-change driven hazards as the top disaster risk to families and livelihoods reported by host and refugee-like populations interviewed in Kotayk region.[2]

Households interviewed viewed natural hazards as a risk even bigger than COVID-19 and conflict escalation.

Households commonly reported that, although they were aware of some actions to mitigate risks, they lacked the resources and know-how in terms of what actions to undertake

Ranked 45 out of 191 countries by the 2021 Inform Risk Index, Armenia falls in the high disaster risk category, due to uprooted vulnerable groups, significant exposure to hazards such as earthquakes, floods, and drought.[3]

From 1994 to 2014, the country lost over $1.5 billion to natural hazards like floods, drought, and earthquakes, being one of the most seismically active regions of the world.[4] While large areas of the country face drought risk (Ararat valley), others (including the Ararat and Shirak valleys) face increased flood risk. Around 40,000 people are affected by flooding each year, with estimates of the annual cost to national GDP ranging between $20 to $100 million.[3] Additionally, around 15% of the total population is exposed to landslide hazard, primarily in foothill and mountain areas, causing average annual damage to $10 million.[5]

The new law[6] on the consolidation of settlements into extended municipalities with new geographic and administrative responsibilities was the main reason for defining the area of the pilot case study as consolidated community level. In support to local self-government in Armenia, the municipalities reform through merging the vast majority of Armenian cities and villages into bigger multi-settlement consolidated community. As a result of the reform, Pyunik settlement was merged with Artavaz and Gorgoch settlement with Meghradzor.

Tsakhkadzor is one of the most popular tourist destinations in Armenia, particularly as a ski resort in winter with 250,000 overnight visitors a year. This influx of tourist population should be considered in the local disaster management plans.

The risk of disasters in Armenia is expected to rise in the near future, especially due to: i) an increase in numbers, duration, and intensity of extreme natural hazards, primarily due to climatic change, and ii) an increased vulnerability of population to these natural events.[7]

This Area-based Risk assessment (ABRA) aims to investigate the level of exposure of populations and infrastructure to anthropogenic and natural hazards affecting the raion, by collecting, processing, and utilising existing openly-availabe satellite remote sensing data and enviromental monitoring data from Statistical Committee of the Republic of Armenia.[8] The ABRA utilises secondary data from a range of sources, including from global geospatial data portals, data requested from local authorities.

Subsequently, a deeper dive into the key hazards and vulnerabilities specifically affecting Tsaghkadzor community aims to assist communities, local government and industries to better predict, prepare for and respond to current and future risks in the city. The assessment is also intended to support implementation of risk reduction programmes, resilience-building activities and help to inform local-level disaster risk reduction planning.

Why an ABRA?

- Focuses on lower level administration for area of analysis in a line with administration reform compared to National or Provincial research
- Provide multi-hazard insight of relevance to local area
- Utilizes remote sensing and GIS technologies for localized analysis

AREA OVERVIEW

Tsaghkadzor is one of the most important tourist destinations in Armenia, especially during the winter due to the skiing resorts. It is 60 km far from Yerevan to the north in the Kotayk region. Tsaghkadzor is 15km away from Hrazdan, the regional main town. Tsaghkadzor was a single settlement and after the consolidation process at the end of 2021 it was reconsolidated with the Meghradzor rural community. At the moment, within the Tsaghkadzor consolidated community there are the following settlements: Tsaghkadzor as an urban settlement and Meghradzor, Aghavnadzor, Artavaz, Marmarik and Hankavan as rural settlements (see Map 1).

According to its climatic conditions, the Tsaghkadzor consolidated community falls within the Middle Mountain Steppe zone (1,400-2,300 m.a.s.l.). The mountainous relief is the pivotal factor for the diverse biodiversity of Armenia. At the same time, mountain regions are highly susceptible to many natural hazards like earthquakes, floods, droughts, and landslides. Climate change intensifies many kinds of mountain hazards and resulting disasters. Disaster risk reduction requires a combination of climate change mitigation, wise decisions regarding construction and urban planning, engineering mitigation of hazard impacts, engineering mitigation of hazard impacts, ecosystem-based disaster risk reduction, and hazard early warning systems (EWSs). [9]

After the hostilities in and around Nagorno Karabakh, tens of thousands people were displaced into the regions of Armenia. Kotayk was the second place in terms of high number of refugee-like population.[10] The ABRA shows that there are still 333 people living in different settlements of Tsaghkadzor consolidated community. 64% of the refugee-like population living in the settlements are women of different ages. With this in mind, it is vital that the newcomers know about the hazardous risks of the local areas as well as the Action Plan in the case of each hazard, so that they are aware of the protocol activities.

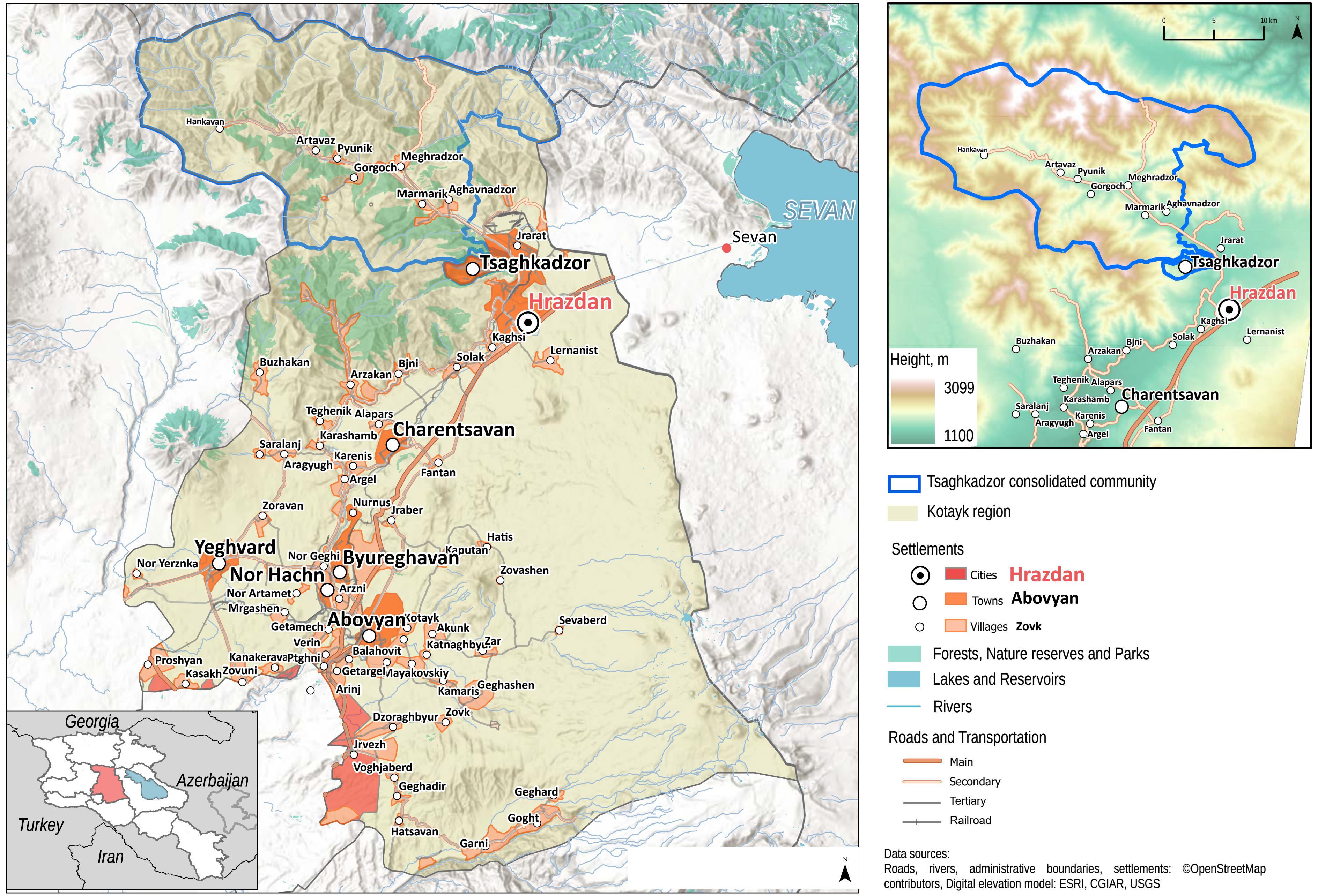
The main factor which has played a huge role in tourism developed is availability of ropeway in the city. The ropeway was founded in 1967 and it was fully renovated and equipped with the most recent techniques in 2004. Besides, modern winter ski resorts have also been founded in the 2000s which created new opportunities in terms of tourism development. Since then, hundreds of thousands of tourists visit Tsaghkadzor each year.

Meghradzor settlement is located 15 km far from the regional center and 60 km from the capital. Before being consolidated with Tsaghkadzor settlement, Meghradzor settlement has already been consolidated with Aghavnadzor, Artavaz, Hanqavan and Marmarik settlements in 2017.

The rural community inhabitants are ennaged in crop production, animal keeping and beekeeping. Among the main cultivated crops are wheat, potato, legumes. As for the animal keeping, the mountainous climate is favorable for sheep and cattle keeping with highlight on milk and cheese production. Beekeeping is also widespread among the inhabitants.

The settlements are also surrounded with forests due to which the settlement surroundings are rich of fruit and decorative trees, berries, nectar producing plants for honey bees as well as herbs used in medicine. The forest side products in the surroundings of the settlements are one of the key income generation sources for the inhabitants which is the reason why ABRA focused also on biodiversity loss while studying the hazards.

Map 1. Overview map of Kotayk Region and Tsaghkadzor community



Data sources:
Roads, rivers, administrative boundaries, settlements: ©OpenStreetMap contributors, Digital elevation model: ESRI, CGIAR, USGS

METHODOLOGY

Methodological approaches used within this work fall within the framework of The Global Facility for Disaster Reduction and Recovery (GFDRR), a global partnership that helps countries better understand and reduce their vulnerability to natural hazards and climate change. This methodology was adapted by IMPACT based on the World Risk Index[11], using multi-hazard Risk equation (Graph 1). The concept of the WorldRiskIndex, including its modular structure, was developed by the Bündnis Entwicklung Hilft with the United Nations University's Institute for Environment and Human Security (UNU-EHS).

In this assessment, IMPACT analyzed key hazards, exposure, vulnerability, risk across the region, based on the following definitions:

- **Hazard**: a process, phenomenon or human activity that may cause loss of life, injury or other health impacts, property damage, social and economic disruption or environmental degradation. Hazards may be natural, socionatural or anthropogenic in origin (UNDRR, 2017)
- **Exposure**: the situation of people, infrastructure, housing, production capacities and other tangible human assets located in hazard-prone areas (UNDRR, 2017)
- **Vulnerability**: the conditions determined by physical, social, economic and environmental factors or processes which increase the susceptibility of an individual, a community, assets or systems to the impacts of hazards. Components of vulnerability include susceptibility, which is the likelihood of suffering harm; coping capacity, the capacities to reduce negative consequences; and adaptive capacity (e.g. ecosystem based adaptation to climate change[12]), the capacities for long-term strategies for societal change (UNDRR, 2017).

Data for the vulnerability indicators were found through secondary data review of open sources at the local level, and finalized in consultation with GLOMOS.

The Area-Based Risk Assessment aims to collect, process, and utilize existing openly-available geospatial data on vulnerability and hazard exposure as well as to assess risks in the target areas from January 2021 to December 2021 as a basic timeframe. The long-term datasets covering up to 20 years will be also utilized if need to derive climatic indicators.

Secondary data review included the analysis of a number of existing and recently published disaster risk and climate risk assessments and projects key findings, conducted on national and regional level (such as National Communication on Climate Change, Armenia National Risk Profile, Armenia's Third Biennial Update Report, Armenia Climate Risk Profile, etc.).

Global hazard, exposure and vulnerability data is used in the first steps of every risk assessment. This data includes global datasets, such as the satellite imagery (for example MODIS, Sentinel, or Landsat 8 imagery available through Google Earth Engine services), global exposure datasets and crowdsourcing map geodata services like OpenStreetMap.

Data from MODIS and Landsat are produced and processed by The National Aeronautics and Space Administration (NASA), and Sentinel data is produced and processed by the European Space Agency (ESA), both of which are globally-trusted sources for remotely-sensed data. OpenStreetMap is a crowd-sourced platform for geographic data, and is also widely used in various contexts, including in humanitarian organizations such as Humanitarian OpenStreetMap Team.

Data for vulnerability indicators were collected from the ArmStat as well as requested from the local authority. Also, previous assessments conducted by REACH and AGORA were also used. Considering the specific mountain community hazards and disaster risk in the local target area, the study aims to find the susceptibility to hazard impacts and coping and adaptive capacity, specific to mountain community, defined based on local knowledge from the engagements with local authorities.

Among the main hazards in the target area the local authorities informed about the riverine floods, landslides, droughts, biodiversity loss. The list of other potential hazards in the target area is defined by secondary data review. A number of data sources is available that is compiled and analysed to provide the appropriate information at the sub-regional level.

Satellite imagery used in this report is end-user data, pre-processed by NASA or ESA, and is collected through global space agency databases such as Google Earth Engine, and USGS Global Visualization Viewer (GloVis)/ Earth Explorer. Analysing imagery is done through desk review of published research and established scientific convention. Calculations do not alter the original data, and are derived from scripts in Google Earth Engine, establishing minimum, maximum, mean, and other values from the data itself. These are validated as needed, and are stored in a repository for access.

Suggested risk mitigation approaches were developed for reach of the hazard during the stakeholder workshop where preliminary finding were presented and disscussed in the working groups of local and regional experts, local authorities perpesentatives as well as global DRR experts from GLOMOS.

The full methodology and data sources are available in the Term of References and may be provided upon request.

CLIMATE CHANGE

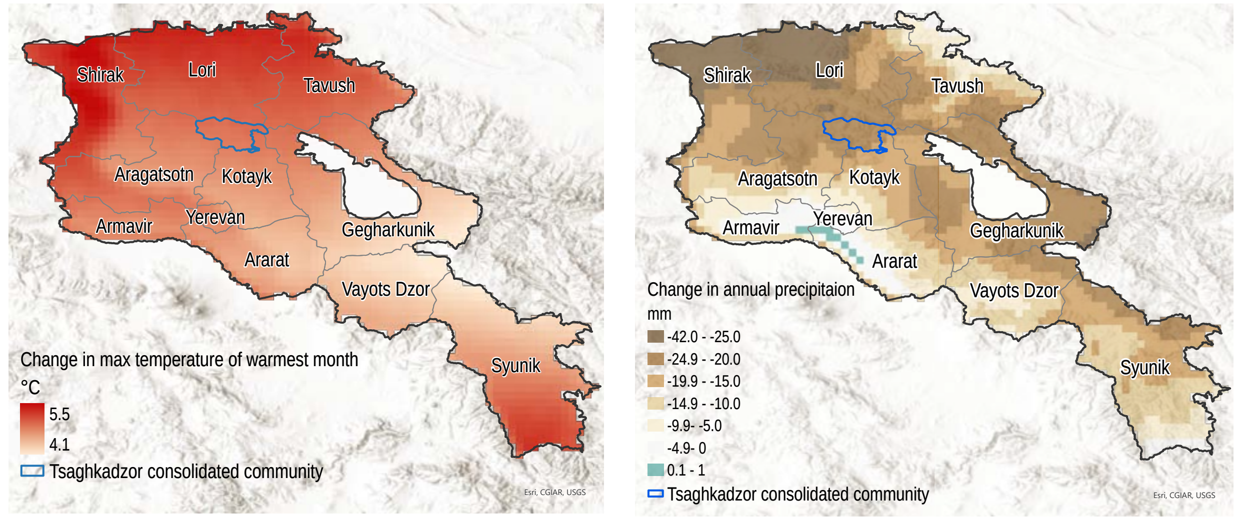
Six out of eight hazards included in this ABRA are driven by climate chage. The forecasted impact of climatic change must be taken into account, as they may have different manifestations in the local mountain environment.

An increase of frequency and intensity of meteorological hazards are forecasted for Armenia due to the climate change. Based on the available projections, by 2100 temperatures are expected to climb by 1.7°C, and precipitation is predicted to decrease by 10%. As a result, boundaries of thermal belts in mountain areas will possibly shift upwards by 150-900 meters. The lengths of dry season are expected to increase, precipitation to become more intense during wet seasons, and the number of extremely moist and extremely dry years to rise. A shift in the beginning, peak and duration of hydrological drought and flood periods is expected, owing to greater share of rainfall and glacial melt and smaller proportion of snowmelt in river flow. Alternating drought and flood periods, together with shifting rainfall patterns, could expand mudflow zones in foothill areas.[13]

According to the modeling of different scenarios of climate change in Armenia, a significant and continuous increase in temperature is planned for the years 2030, 2070, 2100, especially in the spring and summer months. The increase in temperature will be more significant in the western and central regions of Armenia (Ararat Valley): 1.1°C until 2030, 2.7°C until 2070, 4.4°C until 2100.[14]

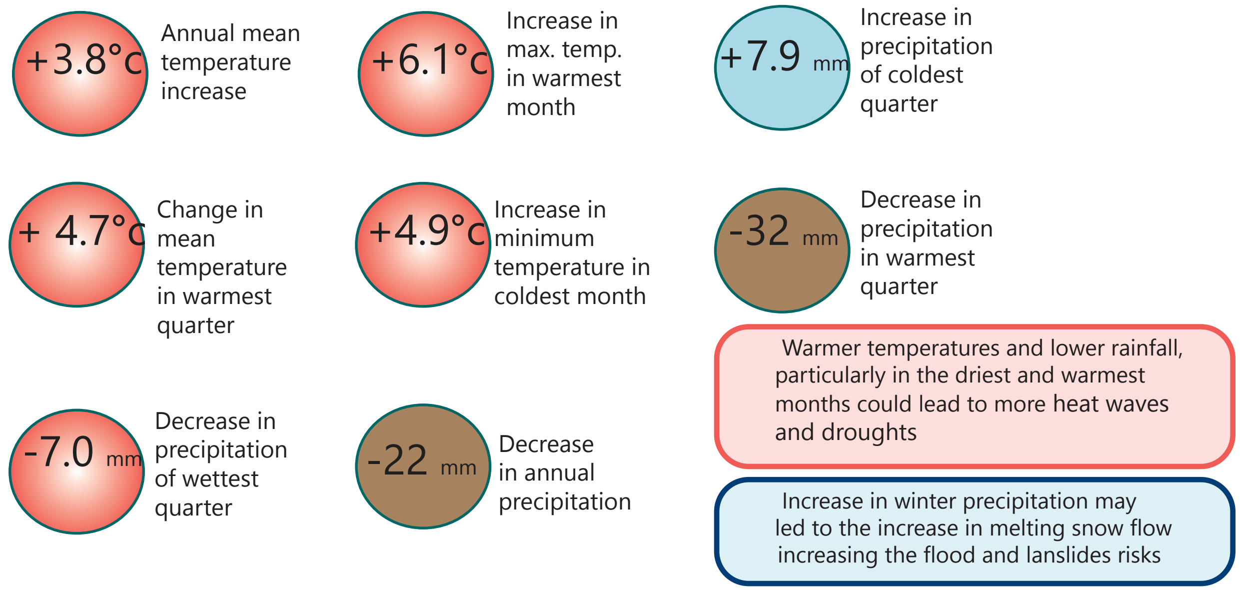
Bioclimatic variables from WorldClim were analysed to estimate projected temperature and precipitation changes from the baseline (1970-2000) to the near future (2041-2060) within the Tsaghkadzor consolidated community (graph 2).[15] Temperature rise is expected at slightly higher rate compared to country average.

Map 2. Bioclimatic variables from WorldClim were analyzed to estimate projected temperature (A) and precipitation (B) changes from the baseline (1970-2000) to the near future (2041-2060)



A B

Graph 2. Projected changes in bioclimatic variables of Meghradzor community, between 1970-2000 and 2041-2060



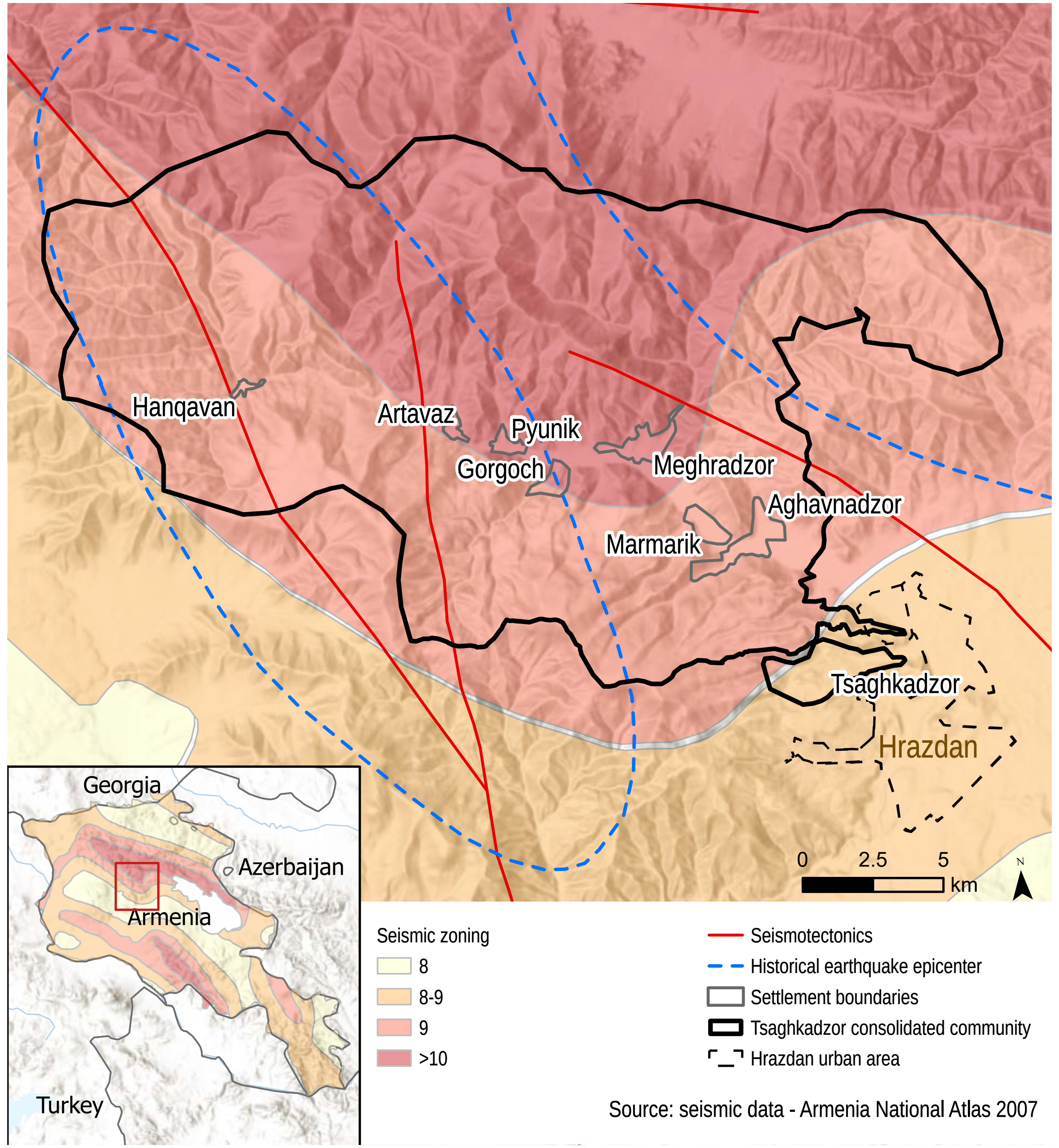
EARTHQUAKE

Armenia is the 3rd place in the world in terms of earthquake risk and the whole territory of the country is prone to earthquakes.[16] Over the last decades, the most devastating earthquake which took place in Armenia was in Spitak city in 1988 that killed 25,000 people, injured 15,000, left 517,000 people homeless, and resulted in direct economic losses of $ 14.2 billion.[17] As a result of this seismic event, during the 1980s, Armenia ranked first in the world in terms of vulnerability to earthquakes[18]. In this context, relative vulnerability is calculated based on the number of persons killed per million exposed—which was 7,653. Moreover, the average annual death toll due to earthquake is extremely high at 1,190 in Armenia in comparison with other countries such as Turkey where it was 950[19].

Tsaghkadzor consolidated community is located in the area with one of the highest seismology activity over the country (see map 3.1). To assess the earthquake hazard within the community, seismic zoning map from Armenia National Atlas (2007) was used. It indicated that Meghradzor, Gorgoch, Artavaz, and Pyunik ranked with the highest seismology risk, and Tsaghkadzor with the lowest.

In the map 3.1, the red lines represent discontinuous tectonic forms characterized by the amplitude of land movement in the direction along which cracks and shifts are formed, which may led to land displacements. Blue area on the map represent the epicenters of the strongest earthquakes in Armenia over the past 10,000 years. According to historical data, the destructive earthquake happened in the community in 1827

Map 3.1. Seismic zoning map



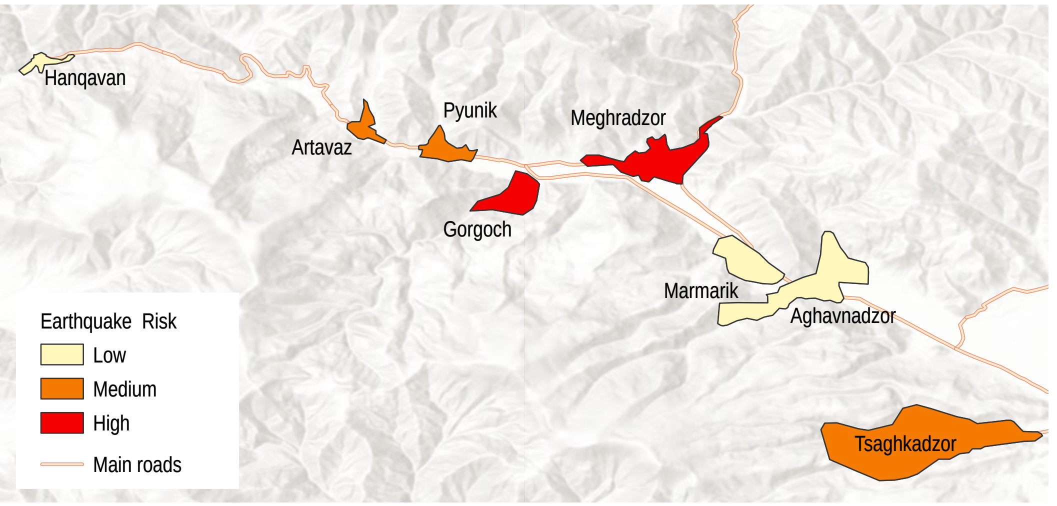
Source: seismic data - Armenia National Atlas 2007

Table 1. Earthquake risk indicators

Settlement		Hazard	Exposure		Vulnerability		
	Earth-quake risk*	Seismology	Popu-lation density	Num-ber of tourists staying over the night	Ratio of HH with IDPs	Per-cent of popula-tion with disability	Dis-tance to hospital
Aghavnadzor	0.2	0.3	0.4	0.1	0.1	0.3	0.1
Artavaz (with Pyunik)	0.5	1.0	0.3	0.3	0.1	0	0.6
Hanqavan	0.2	0.3	0.0	0.2	0	0	1.0
Marmarik	0.2	0.3	0.3	0	0	0.4	0.2
Meghradzor (with Gorgoch)	0.6	1.0	1.0	0.1	0.2	0.5	0.4
Tsaghkadzor	0.4	0	0.6	1.0	1.0	1.0	0

* Hazard, exposure and vulnerability values were calculated as a relative indicator (for more details please see the Annex 2)

Map 3.2. Earthquake risk



with magnitude of 6.5 and episenter including Hanqavan, Gorgoch, Artavaz, and Pyunik[20].

Measure of earthquake hazard exposure included estimation of the potentially affected population, where Meghradzor was ranked as the most exposed, with the highest dwelling population as well as the highest number of tourists visiting the areas, which ranked Tsaghkadzor with the highest value in this category (see Table 1).

Tsaghkadzor is considered as the most vulnerable to the earthquakes according to the highest percentage of population with disability (5.4%) and the highest ratio of refugee-like households (16%) . People with reduced mobility will need more help in rescue operations, and internaly displaced persons (IDPs) are less aware about the local area specifics and natural condition. Also IDPs have been cut off from their usual support networks and may less rely on the assisstance from the host population.

When it comes to the service accessibility, Hangavan population has the highest vulnerability due to the longest distance to hospital.

Thus, Meghradzor with Gorgoch were identified as highest earthquake risk areas, followed by Tsaghkadzor and Artavaz. Despite the fact that Tsaghkadzor is located in the area with lower seismology activity, but higher exposure (number of tourists) and vulnerability will give the relatively high risk values.

Suggested risk reduction approaches

- Regional level: Investment in retrofitting infrastructure for tourists, hotels, etc. without proper safety codes for earthquakes (perhaps more policy/permit/site visit checks)
- Local level: Earthquake preparedness communication awareness in businesses & early education (how to identify the alarm warning, what to do)

LANDSLIDES

Landslides are the sliding of mountain rocks on steep slopes under the influence of gravity, which is facilitated by a number of factors. Landslides occur in mountainous and foothill regions. They can cover significant areas, including settlements, roads, various infrastructures, and agricultural fields.[21]

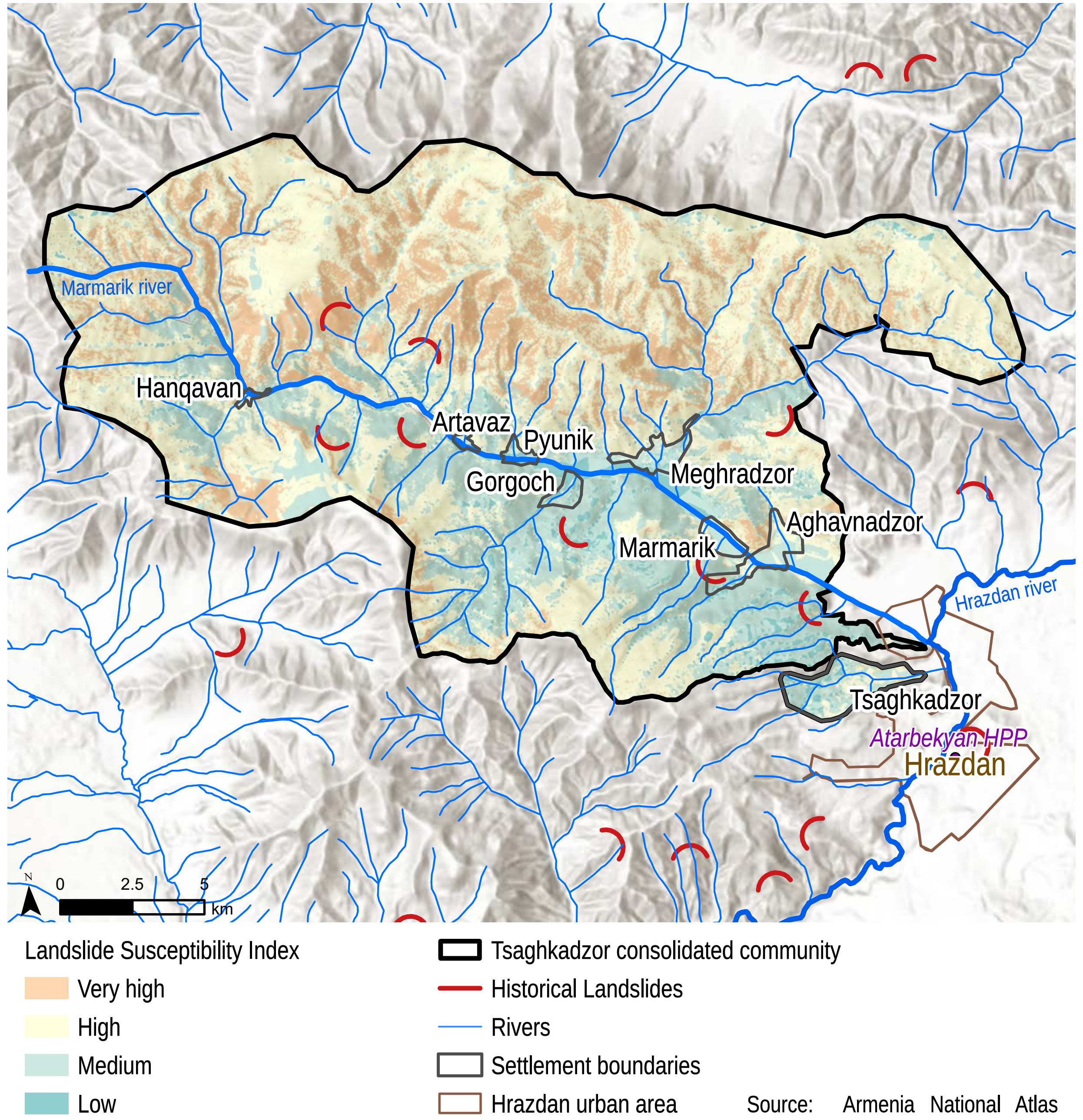
Within Armenia, active landslides are widespread in the Lori-Pambak-Aghstev-Tavush regions, especially in the valleys of Debed and Pambak, in the southern regions - in the valleys of Akhuryan, Hrazdan, and Vedi, and as active landslide areas, we can mention the valleys of the Vorotan and Voghji rivers.[22] Landslide-exposed areas in the Republic of Armenia cover around 122,000 hectares or 4.1% of the country's total territory; and around 35% of settlements (before administrative consolidation processes) are located on landslide-related vulnerable areas.[23]

According to 2004 landslide inventory data, landslide destruction has had direct social and economic impact by amounting to some US$43 million costs. Armenia lost about 20% of its forest cover (around 63,000 hectares) within the 1990-2005 period of time, which in turn greatly increased the likelihood of mudflows and landslides.[24]

More than half of Armenia is susceptible to mudflow, particularly in medium-altitude mountainous areas. Mudslides are a threat especially to the cities and surrounds of Yerevan as well as Kapan.[25] During 2004-07, mudflows damaged around 200 settlements and 600 sites on main transportation routes. Average annual damage from mudflows is $2.9 million for the 2006-2010 period.[26]

Today, there are more than 3,000 landslide centers of different sizes in Armenia.[27] The Ararat valley is not notable for landslides, but individual sites are known for intense landslide activity. Among them are Hrazdan, the valleys of the Vedi rivers, as well as separate areas of the foothills of the Near Araksian Mountains. In the Hrazdan valley, landslides have developed especially on the left slope near the Atarbekyan HydroPower Plant (HPP), located sourth of Hrazdan city. As a rule, landslides in the Hrazdan valley were either caused or activated under the influence of man-made factors.[28]

Map 4.1. Landslides susceptibility index



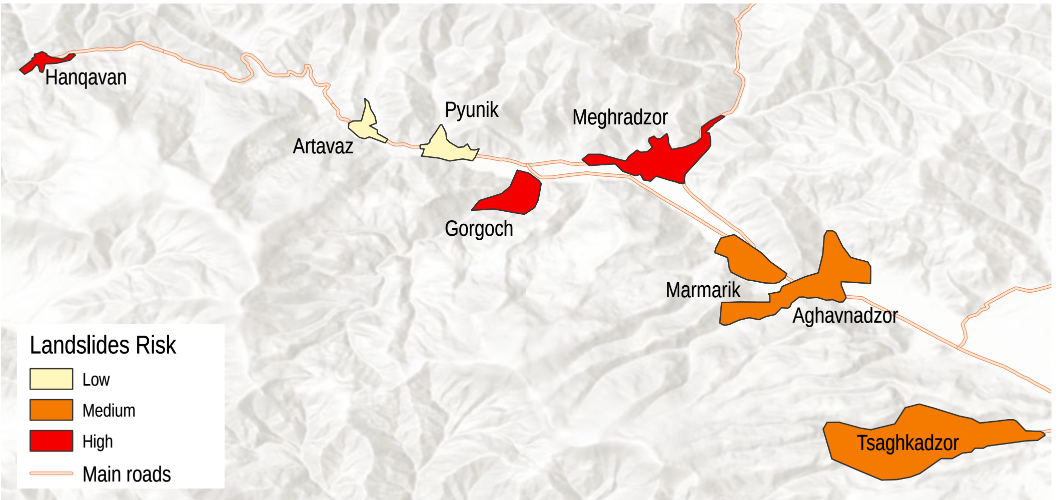
Source: Armenia National Atlas 2007, ©OpenStreetMap contributors

Table 2. Landslides risk

Settlement		Hazard			Exposure			Vulnerability	
	Land-slides Risk*	Percent of the area with highest landslide susceptibil-ity index in 2 km of the settlements	Soil moisture (mean over the spring months)	Natural vegetation distur-bances (forest and grasslands) in 5-km within the settlement in 2011-2021	Popu-lation density	Nunber of tourists staying over the night	Road length to com-munity center	HHs depend-ing on agricul-ture	Percent of popula-tion with disability
Aghavnadzor	0.4	0.5	0.8	0.1	0.4	0.2	0.1	1.0	0.3
Artavaz (with Pyunik)	0.2	0.1	1.0	0.1	0.3	0	0.6	0	0
Hanqavan	0.6	1.0	0.8	1.0	0	0.2	1.0	1.0	0
Marmarik	0.4	0.4	0.8	0.1	0.3	0	0.2	1.0	0.4
Meghradzor (with Gorgoch)	0.5	0.4	1.0	0.0	1.0	0	0.4	0.7	0.5
Tsaghkadzor	0.4	0.4	0	0.3	0.6	1.0	0	0	1.0

* Hazard, exposure and vulnerability values were calculated as a relative indicator (for more details please see the Annex 2)

Map 4.2. Landslides risk



Eight active landslides areas had been detected within the Tsaghkadzor consolidate community (see Map 4.1) according to the water management altas of Armenia (2018), four of those landslides are along to the Artavaz-Hankavan road close to Hankavan settlement and two areas are close to Marmarik and Marmarik-Hrazdan road.

Landslide susceptibility index was used as landslide hazard indicator. Seismology risk, soil type (clay component), slope and vegetation cover were taken into account for its calculation. In addition soil moisture data of the spring months in 2022 and distrubances to forest and grassland cover over the last decade, detected with satellite remore sensing, were included in landslide hazard calculation. Vegetation can reduce susceptibility by acting as a natural buffer, with roots absorbing water that may trigger erosion and dispersing energy from storm surge. Distrubance to natural vegetation cover, such as wildfires, according to those data, Hanqavan was defined as the most susceptible to landslides. Due to the road length to community center (Tsaghkadzor) and closest regional hub (Hrazdan) as well as the absence of alternative route, Hankavan has also high landslide exposure value.

According to the landslide vulnerability indicators, Meghradzor, Marmarik and Aghavnadzor were defined as the most vulnerable to lansslides according to the percentage of population with disability and ratio of households depending on agriculture. Artavaz settlement is the least vulnerable in this regard.

Hanqavan and Meghradzor were ranked respectivle as first and second due to final higher landslides risk (see Map 4.2).

Suggested risk reduction approaches

- National level: Green disaster risk reduction interventions, terracing, and planting of key vegetation to reduce landslides & flash flooding in mountainous areas near to communities
- Regional/local level: Underground channels (water & gas pipelines are typically above ground and susceptible to be damaged & impact community if rockfall) if larger mass landslide of entire shift in land this would still cause similar damages/risks
- National level: Landslide mapping and development of a sound landslide susceptible map in coordination with geological services

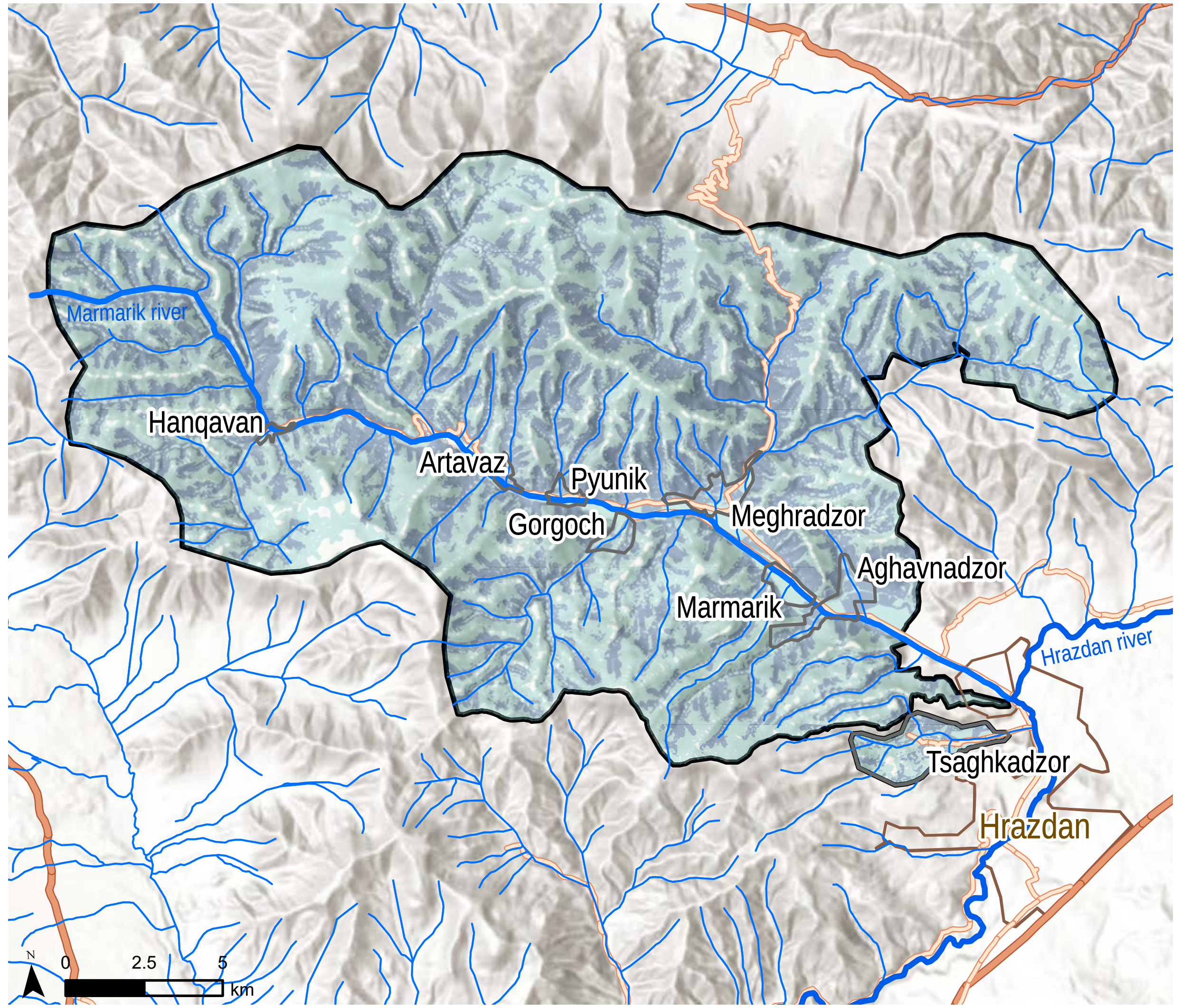
FLOOD

Flood is a temporary inundation of significant areas of land as a result of rising water levels in rivers, lakes, reservoirs, and seas. Being a dangerous hydrological phenomenon, floods are among the most widespread, frequently recurring natural hazards and are the most dangerous from the point of view of the human and material losses they cause.[29]

Armenia does not have overflowing surface water, however around 55-70% of annual leak occurs iduring spring due to melting snow. As a result, water volume may increase in some river basins by ten times and even trigger seasonal flooding severely by damaging property and infrastructure, particularly in the Araks, Hrazdan, and Aghstev river basins.[30] 58% of the 6,859 million m^3 water volume that is formed on the territory of the republic on average annually flows in the spring months.[31] The population density in watershed areas susceptible to flooding is about 80 inhabitants per sq. km, which creates relative vulnerability, that is, five or six deaths per million people exposed.[32] According to the Natural Hazards Assessment Network (NATHAN), 31% of Armenia is at risk of flooding.

On top of this, floods have occurred several times with devastating consequences in Armenia. Every year Armenia suffers significant losses due to floods which is mainly a consequence of inadequate preparation for floods.[33] In 1997 alone, material losses caused by catastrophic floods in 8 regions of the republic were estimated at about 2 billion AMD which is equivalent to around 4 million USD. There were also human casualties.[34] The studies carried out during 2011-2015 show that the annual damage from floods, early spring floods, floods in Armenia is equivalent to about 2.9 million USD. Therefore, the protection of the

Map 5.1. Flood susceptibility index



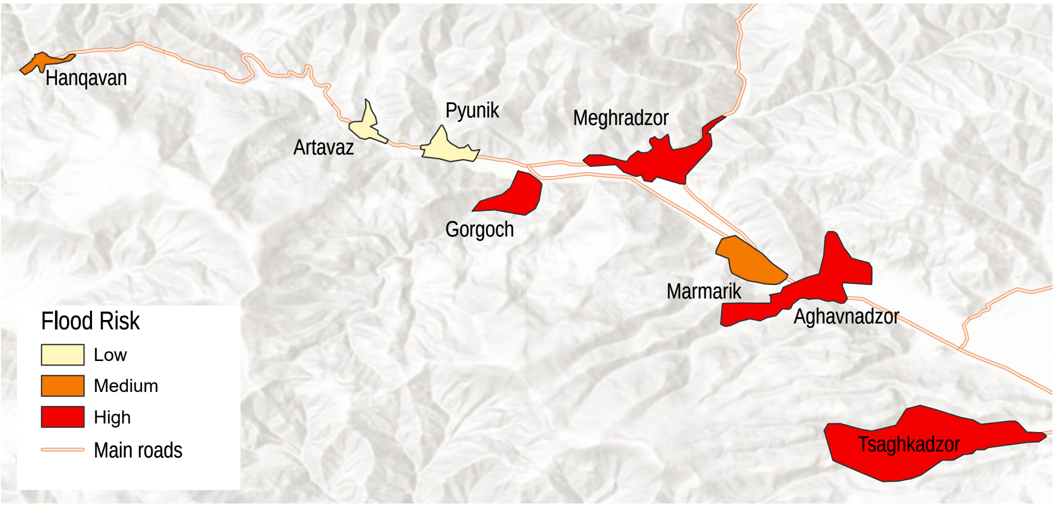
Source: Armenia National Atlas 2007, ©OpenStreetMap contributors

Table 3. Flooding risk calculation

Settlement		Hazard	Exposure		Vulnerability		
	Flood Risk*	Flood suscep-tibility index	Population density	Nunber of tourists staying over the night	Percent of popula-tion with disability	Road length to communi-ty center	HHs depending on agriculture
Aghavnadzor	0.6	0.9	0.4	0.2	0.3	0.1	1.0
Artavaz (with Pyunik)	0.2	0.1	0.3	0	0	0.6	0
Hanqavan	0.3	0	0	0.2	0	1.0	1.0
Marmarik	0.3	0.2	0.3	0	0.4	0.2	1.0
Meghradzor (with Gorgoch)	0.7	1.0	1.0	0	0.5	0.4	0.7
Tsaghkadzor	0.6	0.8	0.6	1.0	1.0	0	0

* Hazard, exposure and vulnerability values were calculated as a relative indicator (for more details please see the Annex 2)

Map 5.2. Flooding risk



population and territories from floods is not effective only with the measures implemented in operational situations.[35]

In the Tsaghkadzor consolidated community, the most flood danger areas is Marmarik reservoir as well as Hrazdan and Marmarik rivers during snow melting in spring.

Flood susceptibility of each settlement was calculated out of soil type (clay component), slope, forest cover, mean yearly precipitation and rain erodibility index (see Map 5.1). The highest precipitation rate is observed near Hanqavan (800-1,000 mm/year) which is about 200 mm higher than observed at other settlements within Tsaghkadzor community. But according to the total areas with high flood susceptibility index Meghradzor is ranked first followed by Aghavnadzor and Tsaghkadzor.

Population density and number of tourists staying over night were considered as flood exposure component. Road length to community hub (Hrazdan) was considered as vulnirability indicator (as the effort needed to deliver the assistance in case of the emergency) in addition to the percentage of population with disability and ratio of HHs depending on agriculture.

Tsaghkadzor community has a flood contingency plan which was renewed this year and includes evacuation plans and other relevant measures.

Suggested risk reduction approaches

- National level: Major reservoir flood, whether triggered by earthquake or poor maintenance that would be catastrophic for all settlements and wider Kotayk region, acute warning system such as sirens for all settlements that is different from earthquake alarm but specific to dam break/flooding, and annual training/testing of these alarms, including in early education on what to do
- Regional/local level: rainfall / snow melting triggered floods a flood model should identify core areas of flood likelihood and EWS based on meteorological forecast could be helpful.
- Regional and local level: Reconstruction of the Megradzor drainage system

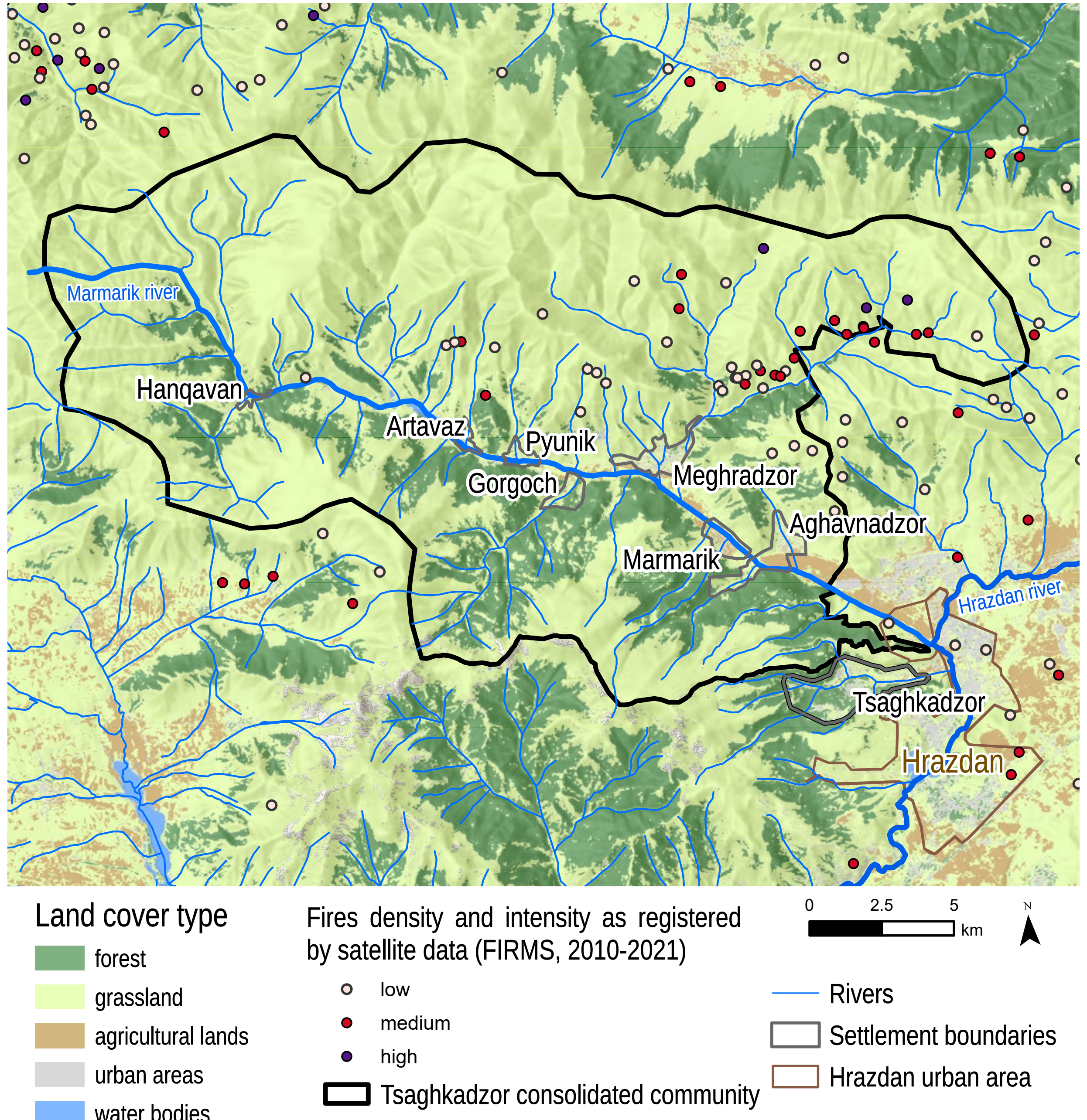
WILDFIRE

Wildfires and urban fires are a major hazard to the environment, populations and infrastructure. Triggered by a variety of natural and anthropogenic activities, they can lead to both direct (severe burn, smoke inhalation) and indirect mortality (longer term health hazards) and destroy large swathes of natural habitat and manmade structures (houses, factories or utility infrastructure). With rising global temperatures and an increase in the frequency and severity of heat waves, the frequency of fires globally is growing every year (IPCC, 2018).

Forest fires in Armenia must be extinguished by the organizations that manage these forests. The forester is obliged to reveal the fire and take measures for its elimination. A small fire is extinguished by the forester himself. Voluntary groups and the population come to the rescue when necessary. Specialized units equipped with a fire truck, sidecar motorcycles and mobile pumpers operate adjacent to forestry.[36]

75% of the forests of Armenia is managed by "Hayantar" State Non-Commercial Organization (SNCO) under the Ministry of Agriculture. The rest 25% (forests in specially protected nature areas) is managed by the RA Ministry of Nature Protection. There are 13 forest sanctuaries in the structure of forest lands managed by "Hayantar" SNCO, where there is a need for further development of management plans as well as clarification of boundaries. The activities on mapping and clarification of boundaries have been implemented for Arzakan-Meghradzor Sanctuary located in the structure of Hrazdan Forest Enterprise of "Hayantar" SNCO and the forest management

Map 6.1. Wildfire frequency according to satellite data



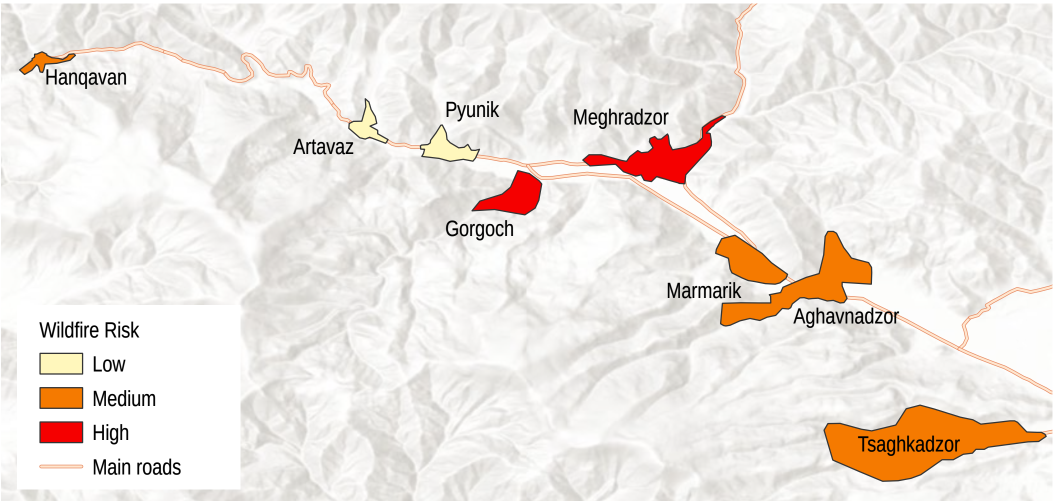
Source: Fire Information for Resource Management System (FIRMS), ©OpenStreetMap contributors, ESA land cover (2021)

Table 4. Wild fire risk indicators

Settlement		Hazard		Exposure	Vulnerability			
	Wild-fire*	Fire fre-quency	Prox-imity to the fuel (km) (forest)	Population density	HHs depend-ing on agricul-ture	Per-cent of popula-tion with disability	Ratio of vehicle per person	Distance to firefighter unit (km)
Aghavnadzor	0.5	0.3	0.5	0.4	1.0	0.3	0.7	0.1
Artavaz (with Pyunik)	0.3	0.1	0.5	0.3	0	0	1.0	0.6
Hanqavan	0.5	0.1	1.0	0.0	1.0	0	0.5	1.0
Marmarik	0.4	0	0.2	0.3	1.0	0.4	0.5	0.2
Meghradzor (with Gorgoch)	0.8	1.0	0.8	1.0	0.7	0.5	0.8	0.4
Tsaghkadzor	0.4	0.4	0.4	0.6	0	1.0	0	0

* Hazard, exposure and vulnerability values were calculated as a relative indicator (for more details please see the Annex 2)

Map 6.2. Wild fire risk



planning activities have been implemented in 2014.[37]

To assess the wildfire susceptibility, the historical records of setellite-detected fires were used from the Fire Information for Resource Management System (FIRMS) of National Aeronautics and Space Administration (NASA) over the years of 2010-2021 (see Map 6.1). It indicates that the highest fire frequency over the last 10 years is observed north of Meghradzor (see Table 4).

The analysis also indicates that the most of the fires were recorded in pastures and grassland areas, less fires were detected in forested areas. Predominant broad-leaved forests in the area are less susceptible to forest fires, and fire prevention measures are carried out by forest management. At the same time more concerns are about the pastures areas which are highly important for livestock grazing and firebreaks measures are not implemented for this type of ecosystem.

Considering hazard, exposure and vulnerability indicators, Meghradzor has the highest wildfire risk due to the highest wildfire frequency, high population density and high rate of people with disability, as they need the assistance in case of evacuation.

Suggested risk reduction approaches

- National/regional level: Implement more natural firebreaks around key forest zones more susceptible to wildfires, or around tourist/key infrastructure and pastures
- Regional/local level: Increase fire prevention information materials / bords for visits/tourists both domestic from Yerevan and international (English, Russian, German, French, Japanese, etc.)
- National/regional level: Invest in Forest Management department/ resources for EWS and mitigation including more regular monitoring systems (including the Copernicus Fire Weather Index tools), video surveillance, and forest understory cleaning to reduce fuels and fire starters (broken glass, etc.)

DROUGHT

Drought is a long-term lack of precipitation, often in conditions of high air temperature and low relative humidity, due to which the moisture reserves in the soil are depleted, the crop is sharply reduced or destroyed.

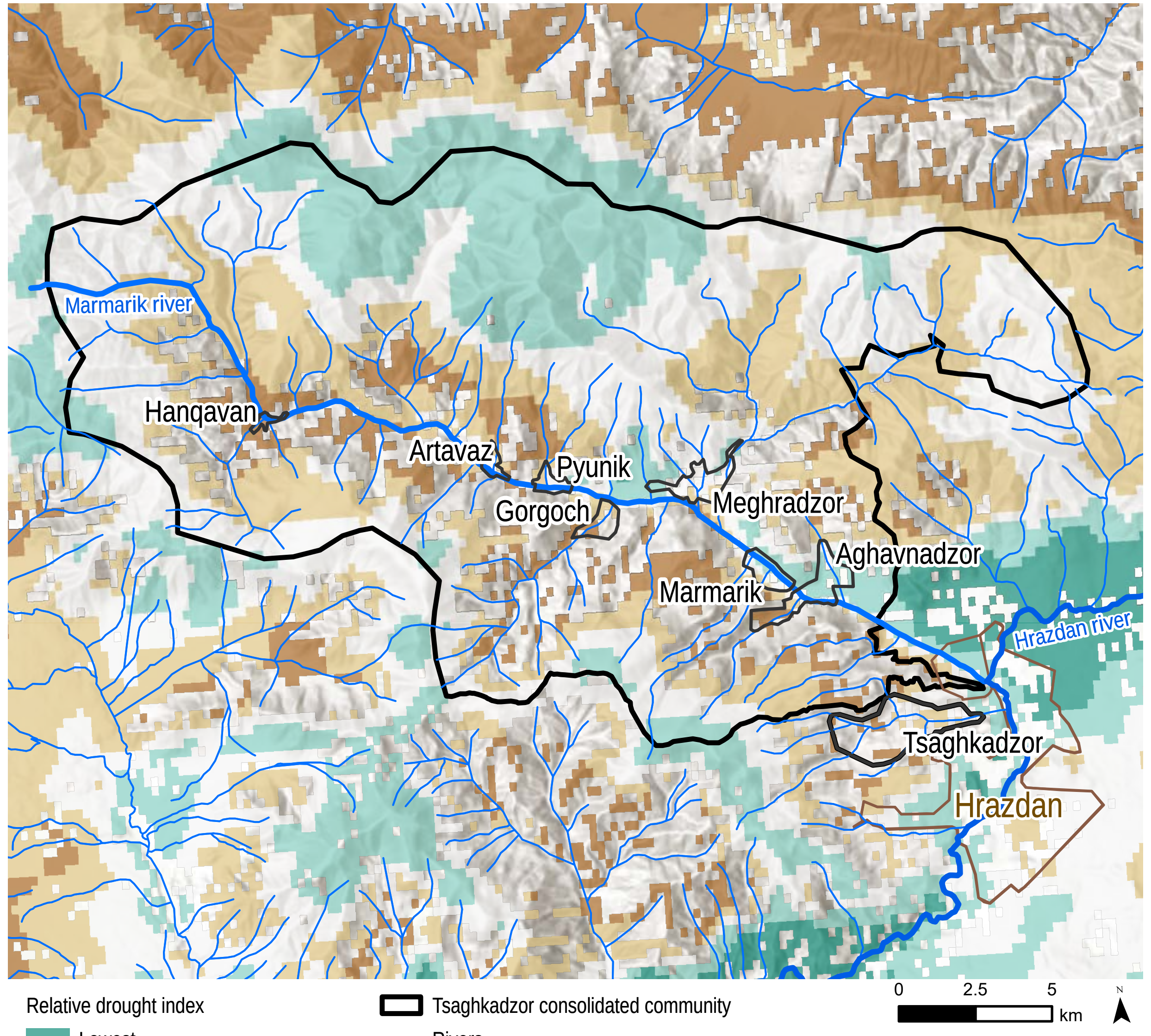
According to the Natural Hazards Assessment Network (NATHAN), 98% of Armenia is at risk of drought. Severe droughts are more observed in the Ararat plain and in its foothills with 52-57% frequency. It is also significant in some regions of Vayots Dzor and Syunik marzes: 40-50%: The percentage of the frequency of precipitation causing drought phenomena is quite small in Shirak, Lori and Tavush marzes as well as in Aparan and Hrazdan areas (7-10%), and in the rest of the areas it ranges from 15-25%.[38]

According to the intensity, droughts are: very severe - the regions up to 1000m altitude, in particular, the Ararat Plain and the lowlands of Syunik; severe - the areas at an altitude of 1000-1400m altitude, in particular, the areas of Talin, Ashtarak, Nairi, Vayots Dzor and Syunik; and moderate - 1400-1800m altitude, mostly in Northern lowland and interior areas. The consolidated community of Tsaghkadzor ranks last.[39]

Drought occurs almost every year in one or more areas of Armenia.[40] In the last 50 years, severe droughts occured 10 times in all 4 seasons and the highest temperatures were observed twice [41] (in 2000, 37 days air temperature exceeded 36 °C and 22 days exceeded 38 °C in the Ararat Plain).[42] In 2000-01, a severe drought resulted in losses of around $143 million in Armenia (with 297,000 people affected).[43]

The number of days with strong and very strong droughts during the period of 2000-2017 increased by 33 days as compared to the 1961-1990 averages with the expansion to mountainous areas[44].

Map 7.1. Drought index



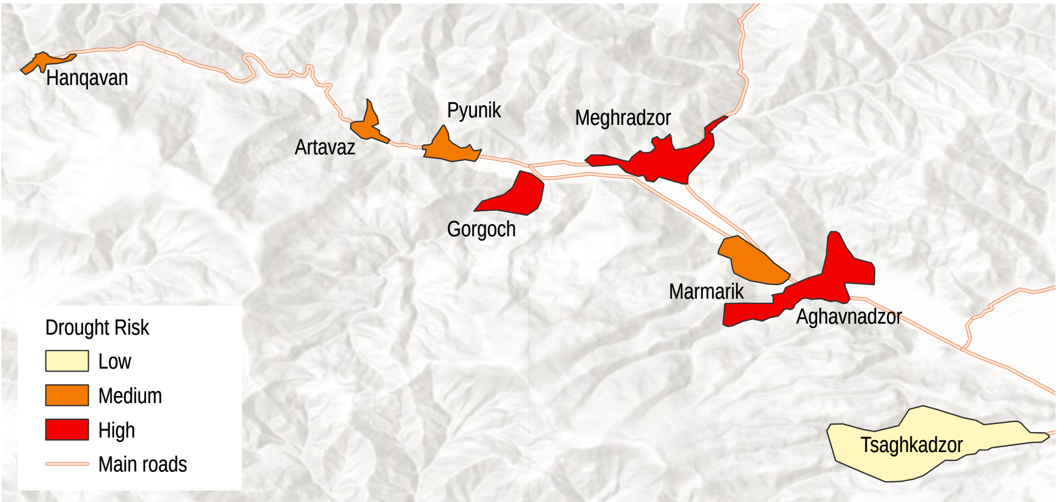
Drought hazard index calculated for each 500m x 500m pixel from summed vegetation condition index (VCI) from spring and summer months between 2001 and 2020. VCI calculated from MOD13A1. Shown for agricultural areas and grassland, masked using ESA land cover (2021)

Table 5. Drought risk calculation

Settlement	Drought Risk	Hazard: Percent of crop and grassland with high drought index in 5 km of settlement	Hazard: Percent of crop and grassland with very high drought index in 5 km of settlement	Hazard: Heatwave	Exposure: Population density	Vulnerability: HHs depending on agriculture	Vulnerability: Economic capacity	Vulnerability: Distance to water source (river)
Aghavnadzor	0.7	0.6	0.7	1.0	0.4	1.0	-0.1	0
Artavaz (with Pyunik)	0.5	0.5	1.0	0	0.3	0	-0.2	0
Hanqavan	0.6	1.0	0.7	0.1	0	1.0	0	0
Marmarik	0.5	0.5	0.7	0.4	0.3	1.0	-0.1	0
Meghradzor (with Gorgoch)	0.8	0.6	0.8	0.9	1.0	0.7	-0.7	0.1
Tsaghkadzor	0.3	0	0	1.0	0.6	0	-1.0	1.0

* Hazard, exposure and vulnerability values were calculated as a relative indicator (for more details please see the Annex 2)

Map 7.2. Drought risk



Map 7.1 shows overall drought hazard, based on accumulated vegetation condition index (VCI) between 2001 and 2021. VCI is a drought severity index, calculated here using satellite-derived vegetation health data (MODIS EVI)[45], based on UN-Spider methodology[46] (see Map 7.1). According to the total area with high and very high drought severity index Hanqavan is ranked first followed by Artavaz (Table 5).

Heat wave index was also considered as drouht hazard indicator component calculated as the average proportion of days during the summer when the land surface temperature exceeds +37°C, based on data from MODIS (2001-2021). Tsaghkadzor was ranked first according to this indicator, followed by Aghavnadzor and Meghradzor with 5-6 days of heat-wave during summer season (Table 5).

Economic capacity (mean HH's income per settlement) and distance to water sources (river) were considered as a component of vulnerability to drought hazard, as the capacity of HHs to invest in drought mitigation measures, like irrigation system. HHs depending on agriculture were also considered to be more vulnerable to drought.

According to final drought risk values Meghradzor and Aghavnadzor were ranked the highers drought risk values and Tsaghakdzor with the lowest. This is a serious risk to take into consideration as all the settlements are rural except Tsaghkadozor and agriculture plays a huge role in terms of income generation.

Suggested risk reduction approaches

- National/Regional/local level: Utilise existing early warning systems to prepare for droughts, including satellite-based services for agriculture, e.g. European Drought Observatory[47],
- Regional level: Landscape contouring and adjustment, e.g. developing ridges and furrows, basins, and water spreading.
- Local level: Sustainable agricultural water management and rainfall retention
- National/Local level: Invest in drought-resistant crops
- National level: Support development of consultancy services on Climate Smart Agriculture practice

COLD WAVE

According to a study of global climate-related mortality (2000 to 2019), published in the Lancet, extreme cold resulted in ~4.5 million annual deaths worldwide[48].

Cold waves are defined by either a rapid drop in air temperature or sustained period of excessive cold. Severe cold is a threat to human health as prolonged exposure can lead to conditions such as hypothermia, frostbite and cardiac arrests. Many people exposed to cold waves suffered health problems, as well as hot water and electrical system breakdowns, heating interruptions and carbon monoxide poisoning in attempts to heat shelters. Icy and snowy conditions can also lead to increased risks of road accidents (e.g. lowered visibility from snowfall, decreased traction from ice patches). Utility networks, such as water, heating and electricity may also be disrupted. In addition, crops may be damaged, affecting food production and livelihoods. There are three types of frostbite. radiative frost, advective frost and mixed types of frost. In the case of radiative frost, it is relatively easy to avoid the hazard and its damage does not cost much.[49]

Advective frosts are caused by the intrusion of cold air currents, in which the temperature can drop from 0°C to -6°C or more. Frosts of this type are long-lasting (1-5 days) and can be over large areas, occupying certain communities, marzes and can even spread over the entire territory of the republic. Fighting this type of frostbite is quite difficult. A similar frost occurred in 2004, when the temperature dropped to -13°C on April 13-14 in the Ararat plain, which resulted in 100% of crop losses. Mixed-type frosts occur when initial cold air currents are followed by clear weather conditions with low overnight temperatures with strong convection. In the Republic of Armenia, especially in the Ararat Plain, 80-85% of frosts have a mixed

Map 8.1. Cold wave mapping: Percent of days with temperature below 15°C (for December-February, years 2001-2021)

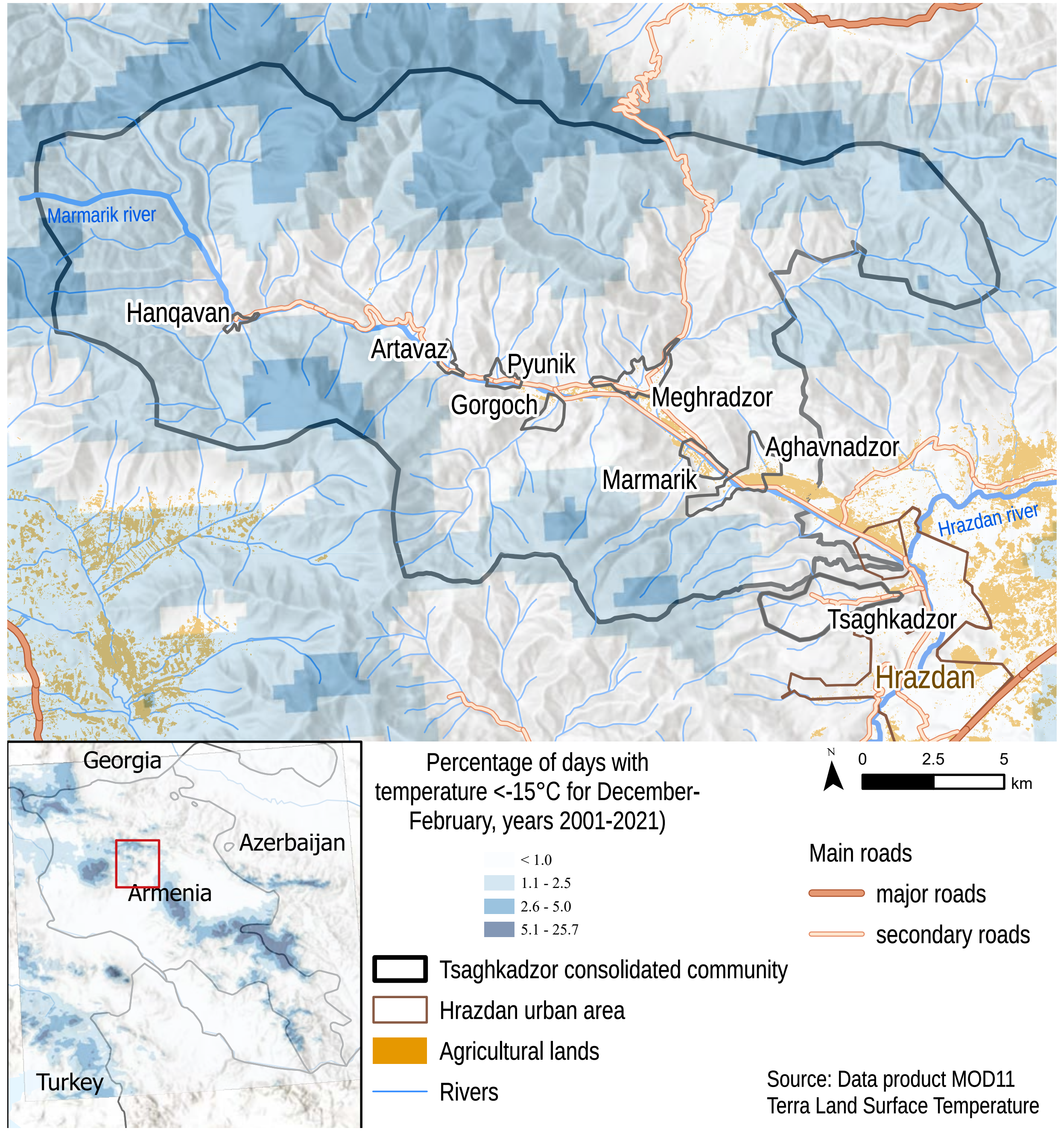
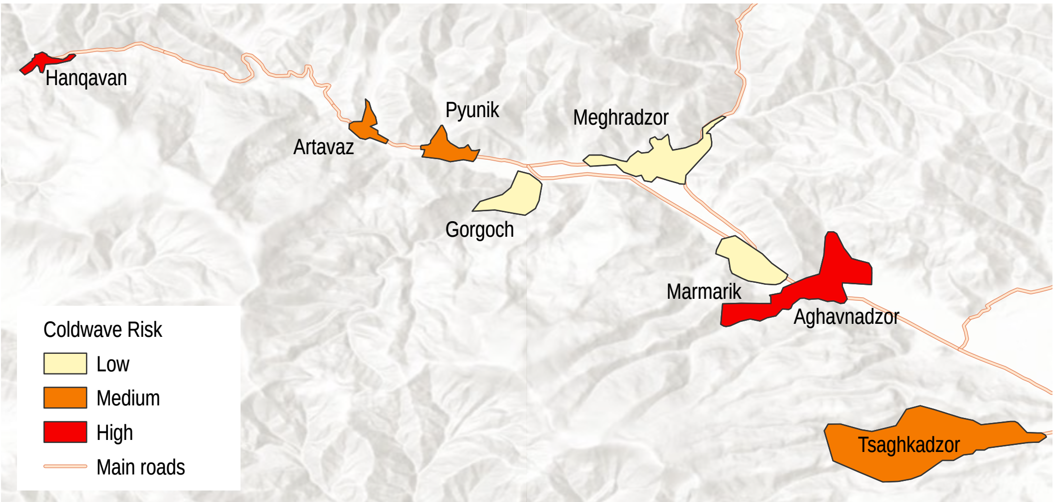


Table 6. Cold wave risk indicators

Settlement		Hazard	Exposure		Vulnerability
	Cold-wave Risk*	Percent of days with temperature below 15°C (for December-February, years 2001-2021)	Road length to community center	Population density	Frequency of electricity shortage
Aghavnadzor	0.7	0.9	0.1	0.4	1.0
Artavaz (with Pyunik)	0.4	0.5	0.6	0.3	0.3
Hanqavan	0.7	1.0	1.0	0	0.5
Marmarik	0.1	0.2	0.2	0.3	0
Meghradzor (with Gorgoch)	0.3	0	0.4	1.0	0.3
Tsaghkadzor	0.6	0.7	0	0.6	0.8

* Hazard, exposure and vulnerability values were calculated as a relative indicator (for more details please see the Annex 2)

Map 8.2. Cold wave risk



origin.[50]

The frost that occurred in the period from March 30 to April 1, 2014 is notable for the damages it caused, as a result of which 31,716 rural inhabitants from 287 communities of Aragatsotn, Ararat, Armavir, Kotayk, Lori, Vayots Dzor, Syunik and Tavush marzes of RA were damaged. Overall, 9,185 ha of perennial plantation areas were damaged. winter frosts are also possible, which mainly affects orchards and autumn grain crops. In December 2001, there were unprecedented winter colds in the Ararat plain, the temperature in some places dropped to -30°C to -32°C, and orchards, unburied vineyards were almost completely frozen.[51]

Information about abnormally-cold temperatures in the Region was calculated using MODIS Land Surface Temperature and Emissivity data (MOD11) based on temperature observations in December, January and February (winter), between 2001 and 2021. This is shown in Map 8.1 as the % of days with temperatures below -15°C during this period.[52] Higher frequency of days with extremely low temperatures can be observed near Hankavan and Aghavnadzor with 3 days of coldwave during the winter, which is relatively row value (see Table 6).

Aghavnadzor has high coldwave risk due to high vulnerability and higher recorded frequency of electricity shortage, caused by old and outdated wires and weather conditions (wind and snow).

Suggested risk reduction approaches

- National level: Climate insurance to protect livelihoods as well as Climate insurance trust/acceptance campaign (needs advocacy from Armenian Government and private insurance)
- Regional/local level: Increase awareness of initiatives for communal hot spot locations in the case of complete failure of heating supply.
- National/regional level: Increase awareness on best practices to keep shelter warm and safely heat shelter during disruptions to conventional heating supply.
- Local level: Local responders to identify the most susceptible populations groups in the community, especially those that may require assistance.

BIODIVERSITY LOSS

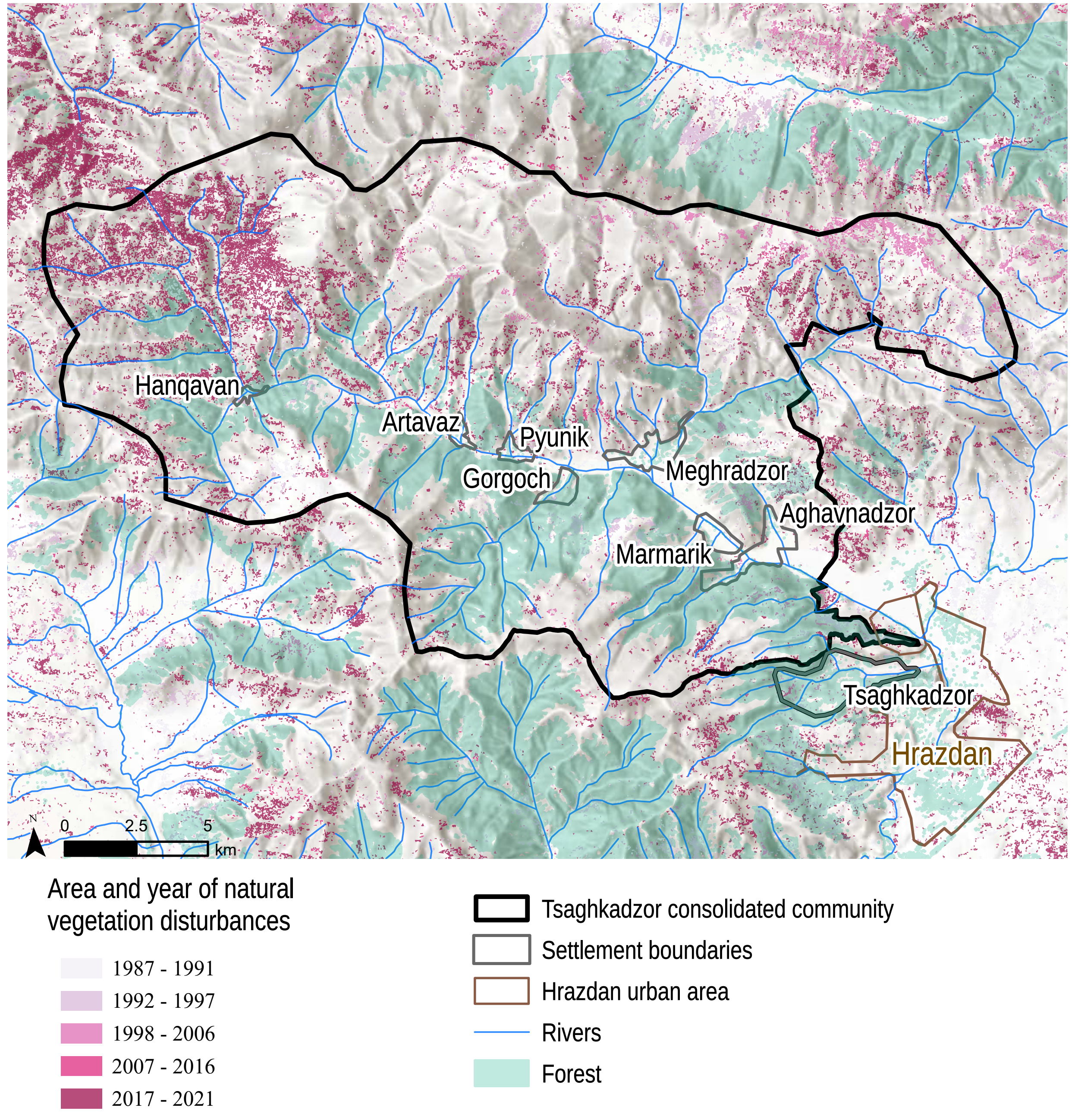
Based on the modeling of the changes in natural ecosystems the climate change risk assessment has been done for 452 species registered in the Red Book of Armenia. For 74 species of high vascular plants the ecosystem and habitat changes conditioned by the climate change will become decisive factors for their existence. First of all these are the species adapted to mesophilous conditions of sub-alpine and alpine belts and for which the climate change will result in a sharp reduction of their habitat area. These species include, for example, Botrychium lunaria, Allium egorovae, Antennaria caucasica, Eriophorum latifolium, Rhododendron caucasicum, Lomatogonium carinthiacum, Scilla rosenii and others.[53]

Climate change, in particular the increase of water temperature can bring to the thermal stress of hydrobionts and disruption of physiological processes and change of the behavior of organisms. The climate change results also in the warming of the bottom cold water layers, due to which during summer months an optimal area for existence of the fish species adapted to cold waters is severely reduced. In Lake Sevan the most valuable Salmonidae fish species prefer cold water. Therefore, the increased water temperature will create unfavorable conditions for them. In this regard, Large Sevan is a more vulnerable area, as in comparison with Small Sevan its depth is significantly less and it is more subject to temperature changes.[54]

Diverse ecosystems and rich biodiversity with high levels of endemism have been formed due to the location of Armenia in the intersection of three biogeographical provinces, diversity of climatic conditions and active geological processes. There are about 3800 species of vascular plants, 428 species of soil and water algae, 399 species of mosses, 4207 species of fungi, 464 species of lichens, 549 species of vertebrates and about 17200 species of invertebrate within the small territory of Armenia, many of which are considered endemics. Armenia is ranked among first-place countries in the world in terms of the density of high vascular plants with about 107 species per 1000 km^2. In addition, more than 50 new species were subject to protection during 2003-2013.[55]

Armenia is also a globally significant center of origin of agrobiodiversity. A number of wild relatives of many cultivated plants and of a number of domestic animals have been preserved in the country. Armenia is thought to be a global conservation center of

Map 9.1. Natural vegetation distrubanses



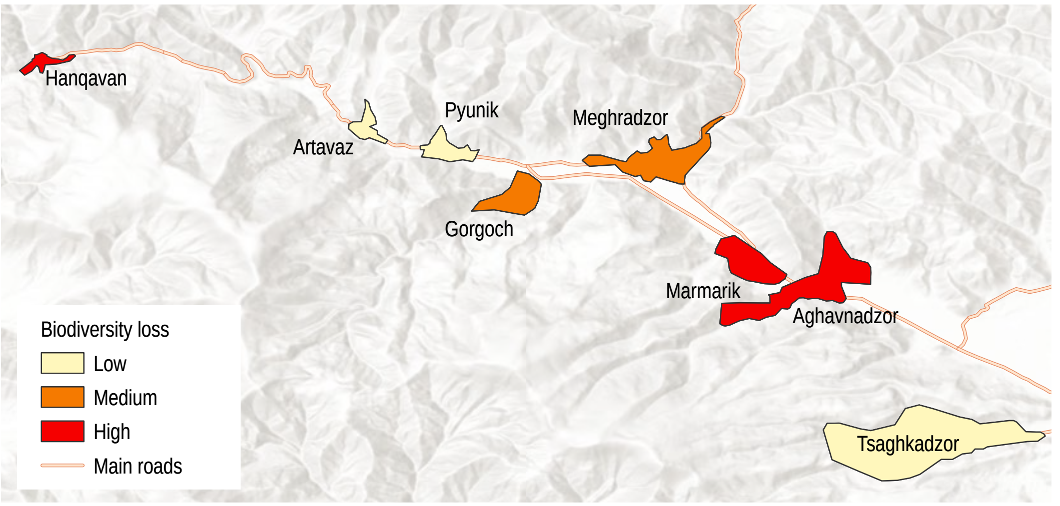
Source: Land Trend analysis using Landsat imagery of 1986-2021 (https://emapr.github.io/LT-GEE)

Table 7. Biodiversity loss indicators

Settlement	Biodi-versity loss*	Hazard: Mean temperature rise in 5-km within the settlement (2001-2010 to 2010-2021)	Hazard: Natural vegetation dis-trubances (forest and grasslands) in 5-km within the settlemen in 2011-2021	Vulnerability: HHs depending on agriculture
Aghavnadzor	0.7	0.6	0.1	1.0
Artavaz (with Pyunik)	0.1	0.3	0.1	0
Hanqavan	0.8	0	1.0	1.0
Marmarik	0.7	0.7	0.1	1.0
Meghradzor (with Gorgoch)	0.5	0.6	0	0.7
Tsaghkadzor	0.3	1.0	0.3	0

* Hazard, exposure and vulnerability values were calculated as a relative indicator (for more details please see the Annex 2)

Map 9.2. Biodiversity loss risk



wild wheat (Triticum), rye (Secale), aegilops (Aegilops) and barley (Hordeum); many of these species have been spread from Armenia throughout the world. More than 60% of the Armenian lands is under active agriculture. As for the active agriculture in semi desert and mountainous steppe zones, the figure reaches up to 80-90%. As a result, overexploitation triggered reduction and pollution of the areas covered by wild biodiversity, changes in the services provided by ecosystems and even loss of habitats of certain species.

The flora of Armenia is very rich in useful species among which the following groups of used plants. In particular, there are about 200 species of edible plants (e.g. sickleweed (Falcaria), asparagus (Asparagus)); about 120 species of wild fruits and berries (e.g. walnut (Juglans), hazel (Corylus)); about 350 species of honey plants (e.g. apricot, plum, sour cherry) widely distributed in all landscape zones; 290 species of edible mushrooms (e.g. oyster mushroom (Pleurotus ostreatus), meadow mushroom (Agaricus campestris)) and macrofungi are of top importance.

Local population actively collects and uses different kinds of medicinal and edible steppe plants for personal and family consumption and sale in local markets. The steppes located on sharp slopes are used as hay-making areas (limited cases) and pastures.

Due to climate change and rising temperatures some areas previously considered non-vulnarable like grasslands and pastures are now exposured to land degradation, which is particularly observed in mountainous regions. To assess the temperature rise rate in Tsaghkadzor community the the mean satellite-derived land surface temperature difference between the decade of 2010-2021 and the decade of 2001-2010 was calculated. This value was used as the indicator of the susceptibility to biodiversity loss. The higherst temperature rise was recorded for Tsaghkadzor, followed by Marmarik and Aghavnadzor (Table 7).

Natural vegetation distrubances was also considered as biodiversity loss indicator. It was calculated based on Land Trend analysis of vegetation condition of forests and grassland areas using Landsat imagery of 1986-2021[56]. It indicates that the area north of Hanqavan was exposed to vast grassland disturbances over the last ten years (see Map 9.1), which might be related to droughts (see Map 7.1). Grassland degradation due to drought were also menshioned by LAs in the area.

This is of great importance because Hanqavan and Tsaghkadzor community grassland areas are widely used for cattle grazing also by otherdistant communities. Hanqavan is also considered as one of the top resort and tourist destinations in Armenia and further studies need to be carried out in order to find the reasons behind this phenomenon.

Suggested risk reduction approaches

- National level: Regularly monitor biodiversity and strengthen control in protected areas
- National level: Control of the spread of invasive species
- National/local level: Support rewilding initiatives

ANTHROPOGENIC HAZARD

One of the major industrial site, located in Tsaghkadzor community is Meghradzor Gold Mine. Besides, The Hrazdan Hydro Power Plant opened in 1959, the Hrazdan Thermal Power Plant opened in 1966, and the Hrazdan Cement factory opened in 1970, which are among the largest plants in Armenia, are locate close to the study area in Hrazdan. In 1999 the Qualitech Machinery machine tool-plant also started to operate in Hrazdan. The town has also minor industrial firms including Hidro Storm metal-plastic manufacturing plant founded in 2009, as well as Arjermek and Hakobyan plants for building materials.

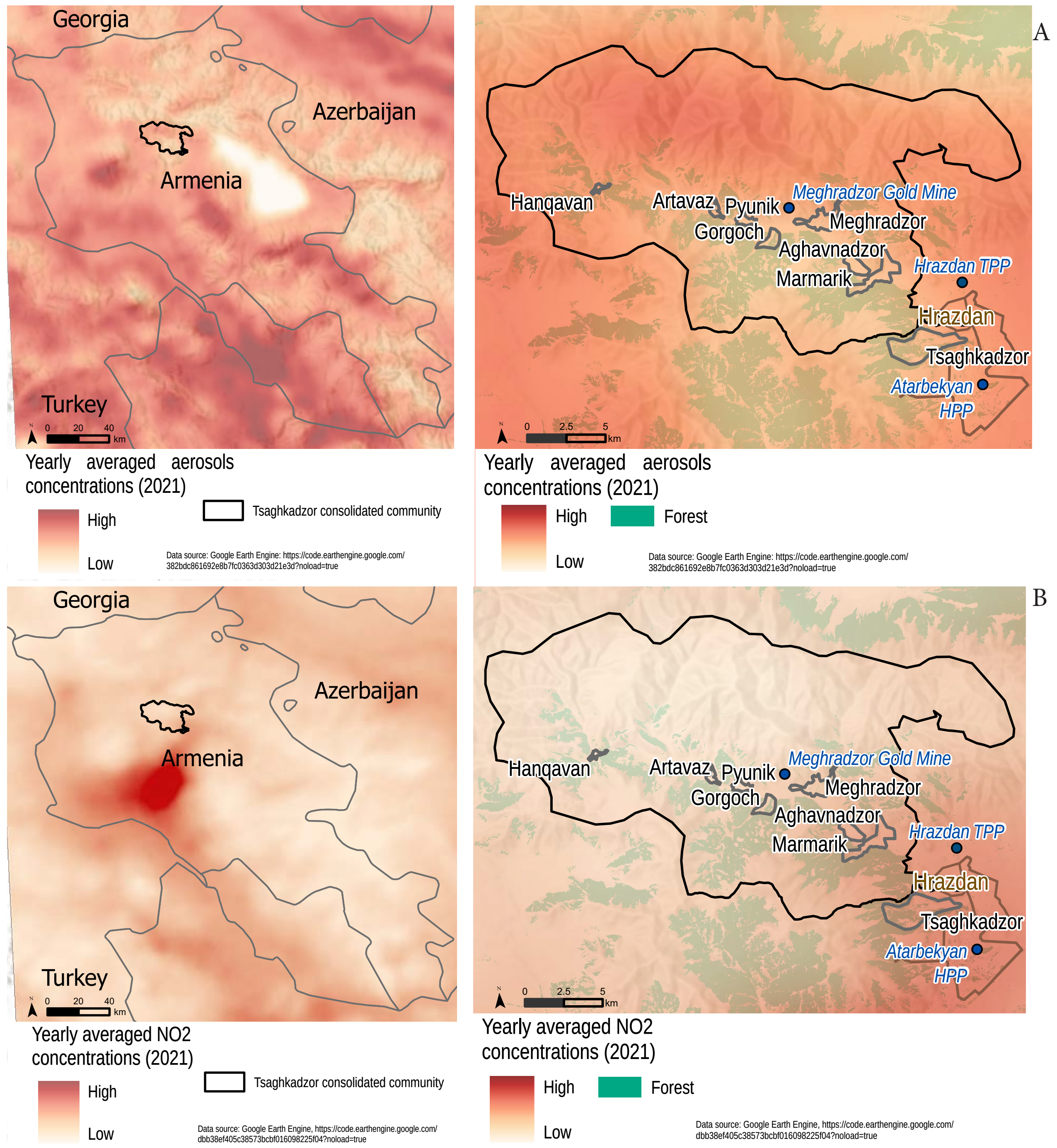
As the component of industrial hazard susceptibility, the distance to potentially hazardous objects were considered. Aghavnadzor is located the closest to the Hrazdan Thermal Power Plant and Meghradzor is located near the Meghradzor Gold Mines. Human health and enviromental exposure areas to industrial hazard potentially may be caursed by Meghradzor Gold Mine is shown on Maps 11.1-11.2.

Air pollution was considered as a second component of industrial hazard susceptibility within the stydy area (Table 8). According to WHO, air pollution poses a major threat to the climate and human health, causing around seven million premature deaths annually, primarily due to stroke, heart disease, chronic obstructive pulmonary disease, lung cancer and acute respiratory infections[57].

Air pollution sources include gases (e.g. ammonia, carbon monoxide, sulfur dioxide, nitrous oxides, methane and CFCs), particulates and biological molecules. Both human activity and natural processes generate air pollution.

Since July 2018, the European Space Agency Sentinel-5P satellite mission has been collecting

Map 10.1. Nitrogen dioxide (A) and aerosols (B) concentration according to satellite data



global atmospheric data on NO_2, SO_2, Carbon monoxide (CO) and aerosol concentrations. In combination with ground-based air monitoring posts, it is an effective tool to detect primary pollution sources and assess settlement-level pollution risk. As atmospheric emissions can spread over large areas, yearly averaged satellite data from 2021 were used as industrial hazard indicator.

According to the satellite-driven air quality data (see Map 10.1-A), a higher nitrogen dioxide (NO_2) concentration is observed near Hrazdan. NO_2 primarily gets in the air from the burning of fuel and from emissions from cars, trucks and buses, power plants, refining of petrol and metals, commercial manufacturing, and food manufacturing.

Map 10.1-B shows that yearly average aerosol concentration is higher in the areas located in the northern areas from Hanqavan and Artavaz settlements in the high altitute areas. That might be related to the higher frequency of strong winds (including hails), that in the aric conditions causes the activation of wind erosion (deflation).

With relatively low air pollution index on national level, Tsaghkadzor was ranked first among the Tsaghkadzor community settlements, according to air pollution indicator, followed by Aghavnadzor.

Economic capacity was considered as vulnerability indicator to inducstrial hazard as the capacity HH to invest in health care services.

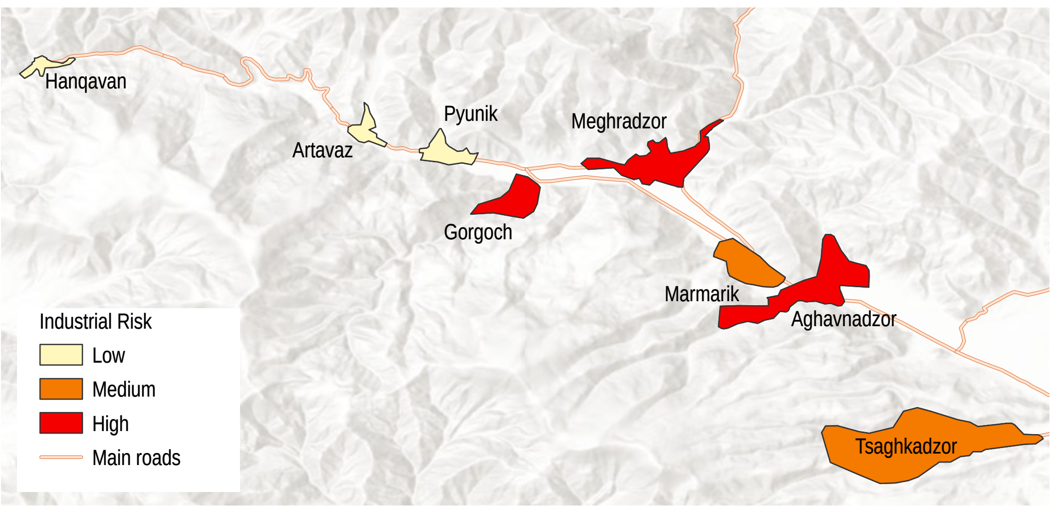
Considering analised industrial hazard risk components (Table 8), the higest risk was recorded for Aghavnadzor mainly due to close location to hazardous facilities and high air pollution rates. Second highest risk rate is recorded for Meghradzor also due to close location to the industrial site but also due to highest population density.

Table 8 Industrial hazard indicators

Settlement		Hazard			Exposure	Vulnerability
	Industrial hazard risk*	Distance to hazardous facilities	Air pollution: NO2 concentration based on Sentinel-5P data	Number of registered vehicles	Population density	Economic capacity
Aghavnadzor	0.8	0.9	0.7	0.1	0.4	-0.1
Artavaz (with Pyunik)	0.3	0.6	0.1	0	0.3	-0.2
Hanqavan	0.2	0.5	0	0	0	0
Marmarik	0.5	0.4	0.6	0.1	0.3	-0.1
Meghradzor (with Gorgoch)	0.7	0.8	0.4	0.2	1.0	-0.7
Tsaghkadzor	0.5	0.8	1.0	1.0	0.6	-1.0

* Hazard, exposure and vulnerability values were calculated as a relative indicator (for more details please see the Annex 2)

Map 10.2. Industrial risk



Suggested risk reduction approaches

- National/local level: Installation or repair of filtration systems & air emission monitoring near hazardous objects should be carried out.
- Local level: Restoration of vegetation cover on closed mine and spoil tip areas should decrease wind erosion risk.

Case study on Meghradzor Gold Mine

"Meghradzor Gold" LLC was registered on September 8, 2010. The company was granted for extension of the mining license by 17.2 years, which expires in September 2023.

The annual productivity of the underground mine is 60,000 tons of ore. According to the extraction plan of the company, it would extract all the industrial ore reserves by underground mining within 17.2 years. Meghradzor mine directly affected Marmarik River and its Gomur tributary as the mine waters flow there. Marmarik River is regularly polluted by water leaking from the tails of the Meghradzor Gold Mine Processing Plant. One more alarm of such pollution was beaten in May 2021.

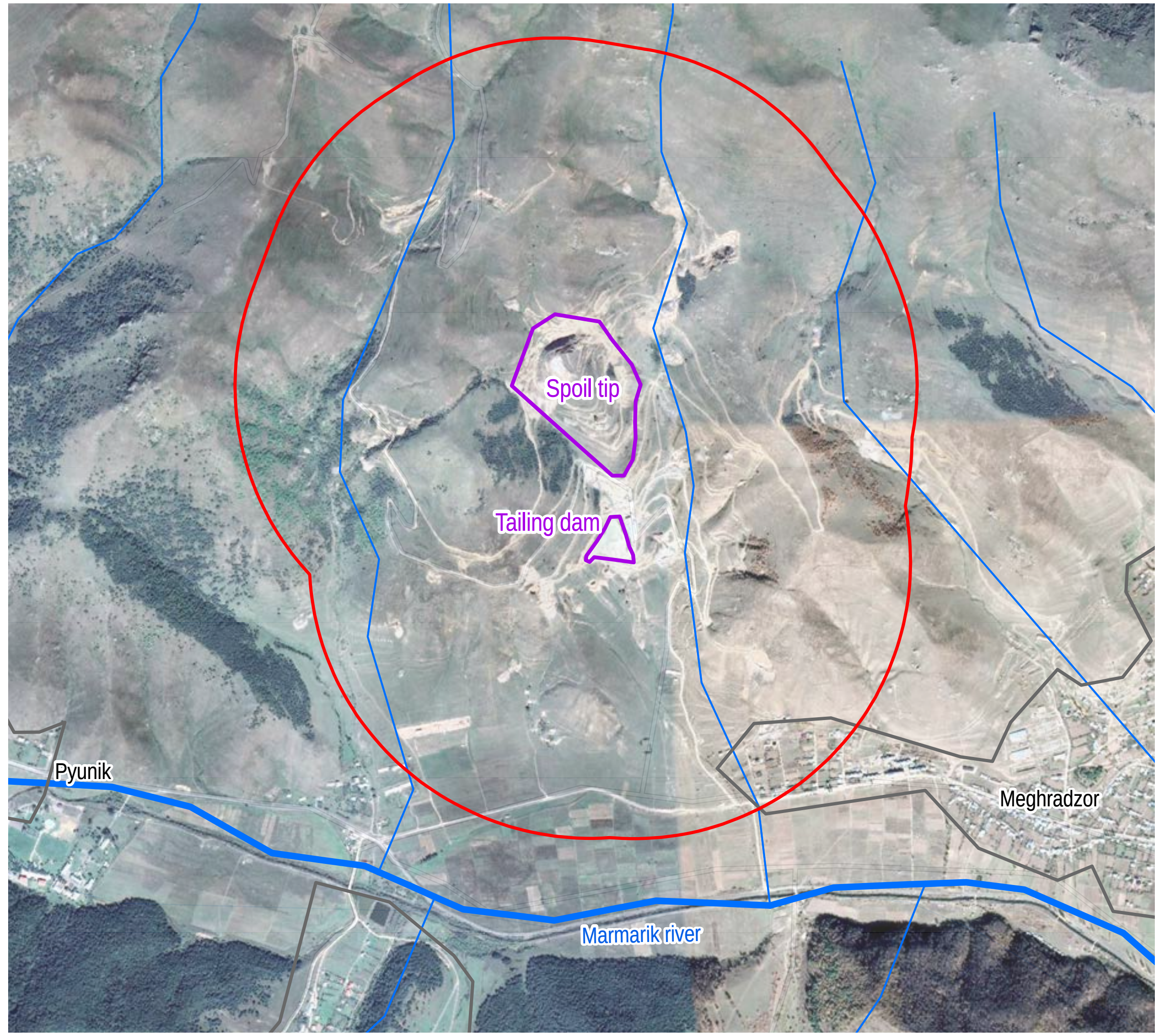
According to the year-end data for 2020 presented by "Hydrometeorological Monitoring Center" the river in the Marmarik estuary was polluted with vanadium, iron, barium and potassium.[58] The project says that the results of the monitoring carried out by the Institute of Mining and Metallurgy CJSC in the river sections 500 m below the mine in 2020 showed that the concentration of arsenic and that of determined metals in the waters of the Marmarik River corresponds to the quality of water grades 1-2, whereas the concentration of sulfates, chlorides and mineralization corresponds to the grade 3 of water quality.[59]

After mechanical cleaning, the water of the mine transport ways flows into the Gomur River. Depending on the concentration of the material, the river is again of class 5 quality. Water quality according to zinc is in Classes 1-2.

Hazardous emissions also occur as a result of mine operation. In particular, about 5 tons of harmful substances are emitted into the atmosphere annually, out of which 1.33 tons during explosion and 3,246 tons during operation. In general, the volume of waste generated is about 35 tons per year.

The FEAT methodology to map the potential industrial hazard exposure areas. FEAT was developed by the National Institute for Public Health and Environment (RIVM) for UNEP and UNOCHA, based on EU Directives on hazardous substances (see map 11.1 - 11.2)

Map 11.1. Human health exposure area to industrial hazard (Meghradzor Gold Mine)

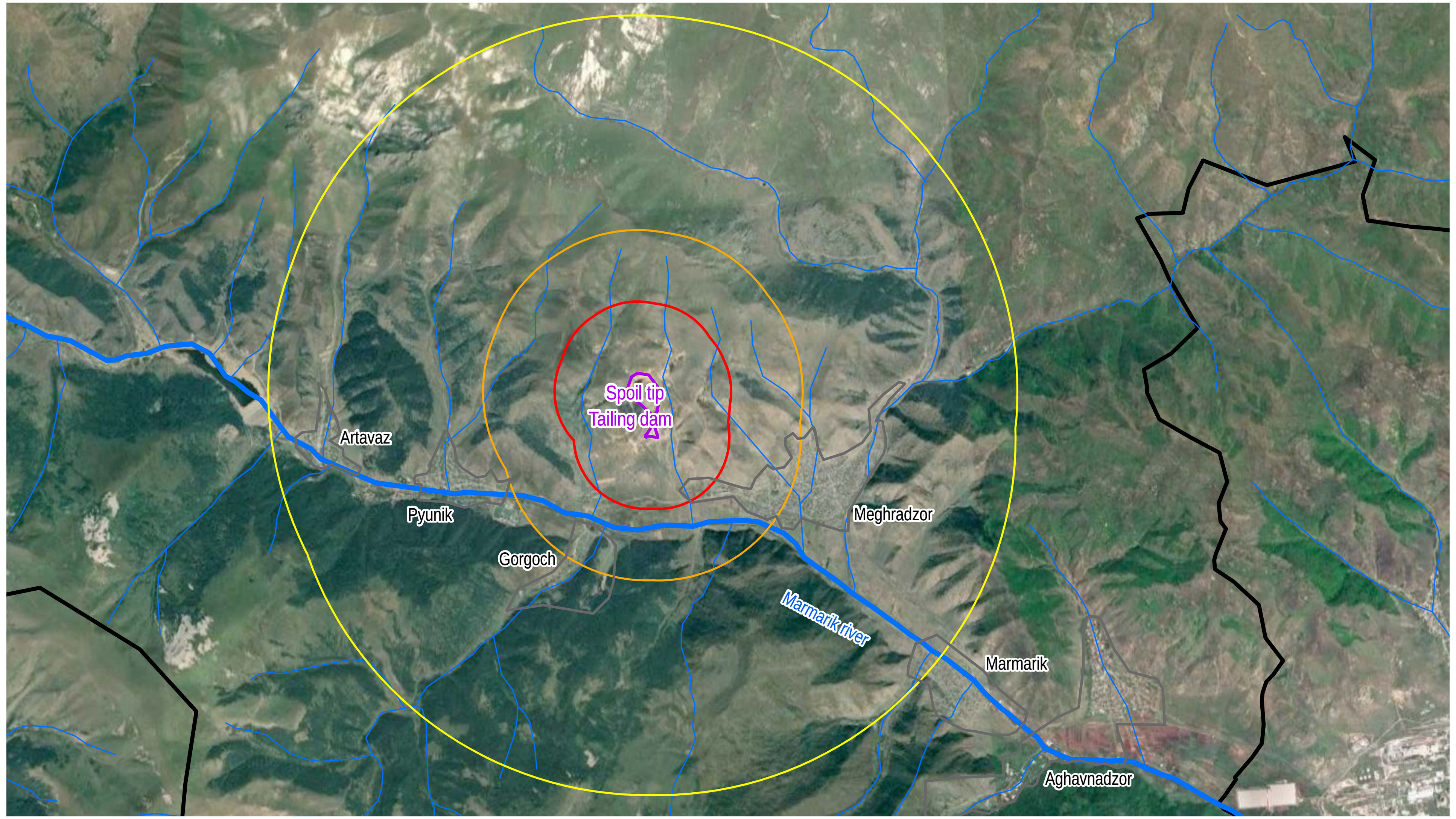


Meghradzor Gold Mine area
1 km zone of human health exposure to potentially toxicity
Settlement boundaries
Rivers

0 0.25 0.5 km

Source:OpenStreetMap contributors, ESRI satellite imagery base layer

Map 11.2 Environmental exposure area to industrial hazard (Meghradzor Gold Mine)

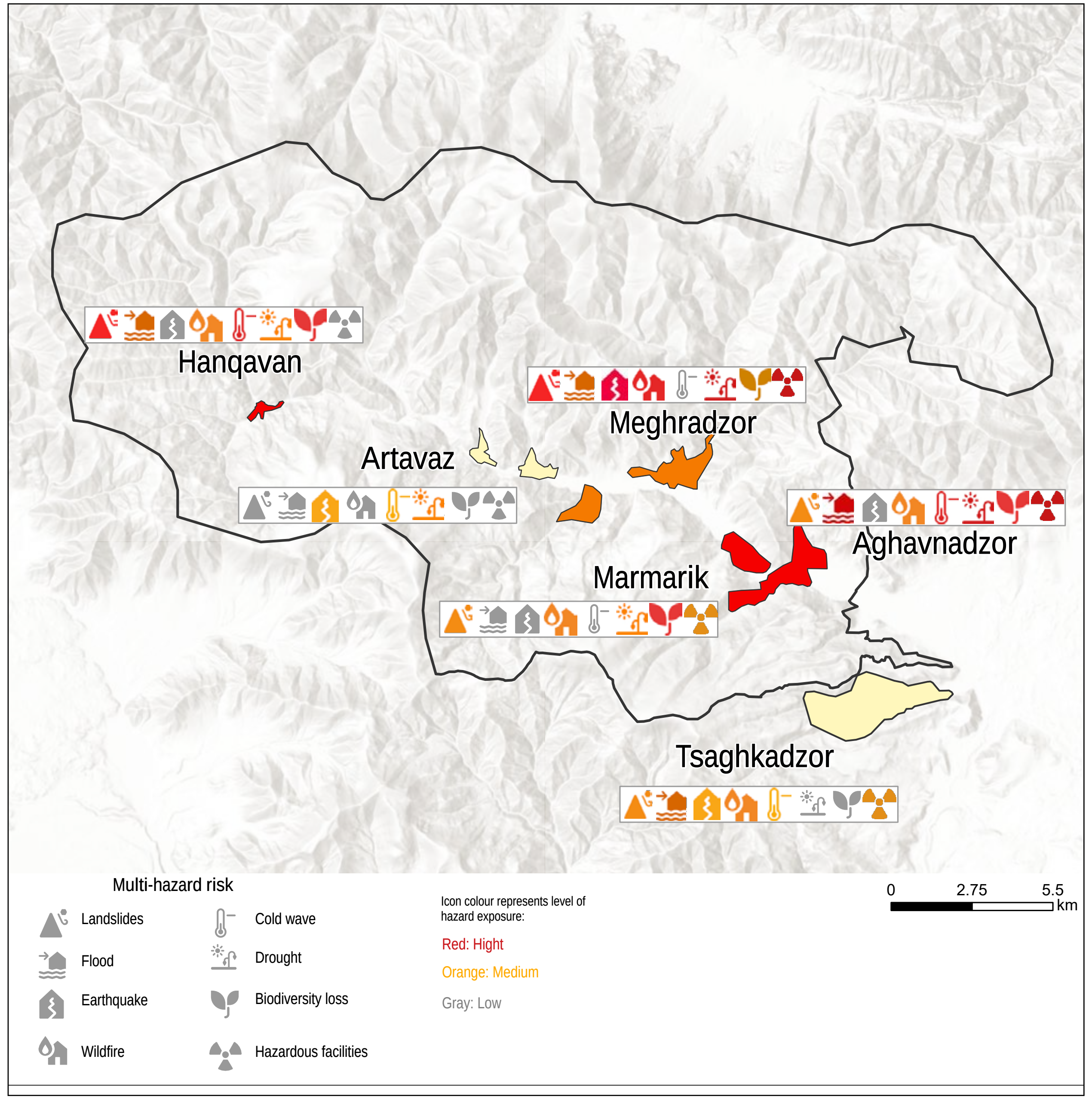


Meghradzor Gold Mine area
1 km zone of human health exposure to potentially toxicity
2 km zone of environmental (soil) exposure to potentially toxicity
3 km zone of environmental (rivers) exposure to potentially toxicity
Tsaghkadzor consolidated community
Settlement boundaries
Rivers

0 0.5 1 km

Source:OpenStreetMap contributors, ESRI satellite imagery base layer

Map 12 Final Hazard Map



MULTI-HAZARD RISK

Multi-hazard risk index shows the ranking of each settlement containing several hazards at the same time. According to the index, each settlement ranks differently according to the level of hazard risk. The index has distributed the level of danger of hazards into three categories: red – the most dangerous, orange – medium, and grey – the lowest level.

In this regard, Tsaghkadzor and Artavaz settlements have the least risks as they do not hit the red dangerous line ranked by the index. This is very important especially for Tsaghkadzor city as it hosts tens of thousands tourists each year and thus it is relatively safer place in comparison with the neighbouring settlements. Notwithstanding this, some hazards such as earthquake and cold waves have medium level of danger for these two settlements.

According to the index, Meghradzor settlement is the riskiest settlement followed by Aghavnadzor. Such hazards as earthquake, drought and hazardous facility are the ones which are most dangerous for both of these settlements.

Full information for the multi-hazard risk index is provided in the Map 12.

CONCLUSIONS

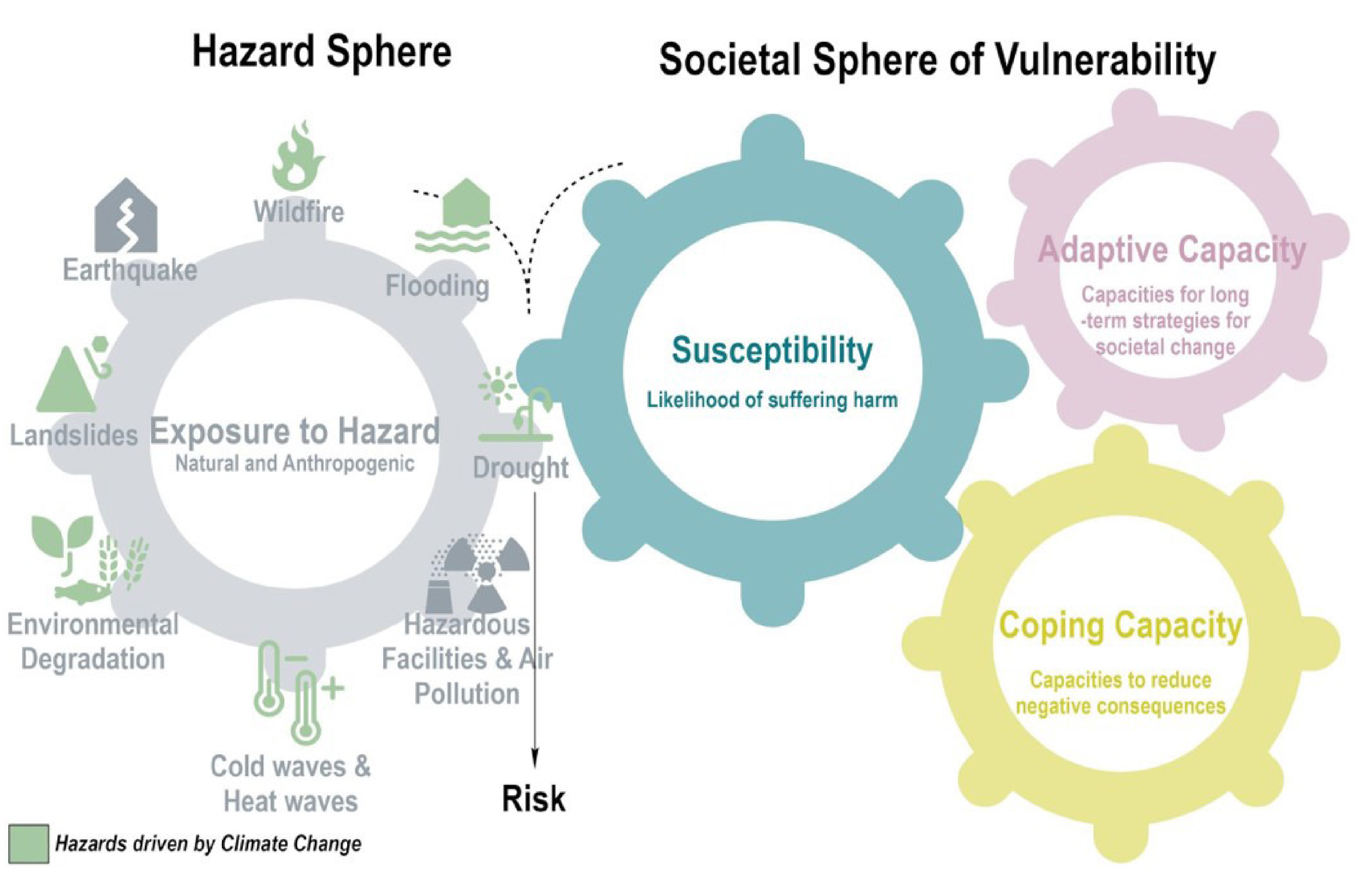
Despite the potential severe impact of such hazards, a gap remains in the analysis of a) the level of exposure of populations to such hazards or b) the extent to which certain populations would be more vulnerable or resilient in case of emergency. This fact prevents elaboration of both strategic and operational response planning to environmental and technological risks posed by active hostilities. Armenian national emergency system and the international humanitarian response structures have been focusing on providing relief/responding to humanitarian and emergency needs. In contrast, joint preparedness/contingency planning in terms of conflict negative consequences for people due to contaminated/impacted environment currently missed or limited. Understanding and evidence-based decision making for mitigation and preparation for industrial and natural hazards are inadequate due to the lack of data, capacity, and low prioritization.

This assessment aims to compile and analyze information on multi-hazard risks in the local mountainous community. It aimed to inform preparedness and risk mitigation planning by authorities and support response from international/national development and humanitarian organizations. Through investigation of the range of multi-hazard risks, this assessment aims to assist governmental bodies in increased preparedness to potential future events and facilitate the response process. In addition, the assessment will serve a guide for prioritizing humanitarian interventions and assist in planning processes, providing a clear picture of the scale, geographical coverage, and people's exposure to various environmental and technological disasters that might exacerbate by the accidents for international and national humanitarian and development organizations.

Relevant stakeholders: Swiss Agency for Development and Cooperation, ACTED, IMPACT Initiatives, UNU-EHS GLOMOS, UNDP, UNICEF, GIZ, Embassy of Japan in Armenia, ARNAP, Ministry of the Emergency Situations of RA, Ministry of the Environment of RA, Kotayk marzpetaran, Tsaghkadzor consolidated community administration.

ANNEX 1

Graph 1. Multi-hazard risk concept



ANNEX 2

Hazard, exposure and vulnerability index calculations

Hazard, exposure and vulnerability indicators were calculated as a relative indexes for each of the settlement using the formular:

$$I = (Ix - Imin) / (Imax - Imin),$$

where I is an indicator, Ix - hazard, exposure or vulnerability value for the particular settlement, Imin - minimal hazard/exposure or vulnerabilty value through all the settlements, I max - maximum hazard/exposure or vulnerabilty value through all the settlements.

Hazard	Data source	Methodology
Earthquake	Armenia National Atlas (2007).	Hazard indicator: Seismic zoning. Seismic zoning map was developed under the Armenian National Survey for Seismic.
Landslides	Soil data from Armenia National Atlas; 10-meter digital elevation model; vegetation cover from Copernicus Proba-V Land cover (2019).	Hazard indicator: Landslide susceptibility index. Landslide susceptibility index was calculated based on equal weighting of slopebangle (calculated from 10-meter digital elevation model) and vegetation cover (higher slope angle = higher susceptibility + higher vegetation cover = lower susceptibility). Vegetation cover approximated from normalised difference vegetation index (NDVI), calculated from Sentinel 2 multispectral image. In addition soil moisture data of the spring months in 2022 and distrubances to forest and grassland cover over the last decade, detected with satellite remore sensing, were included in landslide hazard calculation.
Flood	Soil data: Armenia National Atlas, 10-meter elevation model. Vegetation cover: Copernicus Proba-V Land cover (2019).	Flood susceptibility of each settlement was calculated out of soil type (clay component), slope, forest cover, mean yearly precipitation and rain erodibility index.
Wildfire	NASA FIRMS (2010-2021). Copernicus Proba-V Land cover (2019).	Number of satellite-detected fires (2010-2021) from FIRMS within a settlement or within 2km of a settlement as well as proximity of settlement to fuel (forest landcover).
Drought	VCI data derived from MODIS EVI (2001-2020).	Overall drought hazard was calculated in Google Earth Engine based on accumulated vegetation condition index (VCI). Satellite derived vegetation health data from spring and summer months between 2001 and 2020 (MODIS EVI) was used. Methodology adapted from UN Spider.

ANNEX 2

Hazard, exposure and vulnerability index calculations

Hazard	Data source	Methodology
Cold wave	MODIS MOD11 (2000-2021).	Percentage of days with land service temperature below -15°C in December, January and February (2000-2021), calculated from MODIS Land Surface Temperature and Emissivity (MOD11).
Biodivercity loss	Trends Earth (1980-2021).	LandTrendr spectral-temporal segmentation algorithms run in GoogleEarthEngine for change detection in a time series (1980-2021) of moderate resolution satellite imagery (primarily Landsat)
Anthropogenic hazard	Infrastructure data from OSM. Sentinel-5P satellite data on concentrations of NO_2, SO_2, CO and aerosols	Distance from the settlement to hazardous facilities. Yearly-averaged raster datasets over the settlement for main pollutants (NO_2, SO_2, CO and aerosols) were calculated using GoogleEarthEngine.

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