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# Atlas of Multihazard Risk Assesment of Abkhazia







# Atlas of Multihazard Risk Assessment of Abkhazia

Author of the publication  
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Multi-Hazard Risk Atlas of Abkhazia includes 11 maps on: Wildfires, Snow Avalanches, Hailstorms, Windstorms, Debris Flows, Landslides, Rockfalls, Drought and Earthquakes and Floods.

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# ABKHAZIA

Abkhazia covers 8,660 squarekilometers and has a population of around 340,00 (UNDP, 2015). The territory is prone to different hazards like Earthquake Hazard, Flood Hazard, Landslide Hazard, Mudflow hazard, Rockfall Hazard, Snow Avalanche Hazard, Wildfire Hazard, Drought Hazard, and Windstorm hazard (Varazanashvili et al., 2012). Though there are high-risk areas in Abkhazia, availability of local information that can be used to access risk and hazard is limited. Political instability and lack of resources are the main causes of the limited local information. Poverty level, lack of coping capacity, lack of effective communication among governmental bodies also affect the vulnerability of the people of Abkhazia (ACF, 2013). Due to different limitations institutions responsible for DRR in Abkhazia, most of the data used for this study was generated using available data from various sources on the internet to generate a database for Abkhazia related to multi-hazards with the main focus to mass movement hazards.

## OBJECTIVES

The main objective of this study is to create a national scale multi-hazard risk assessment for the independent territory of Abkhazia using the available data, which is secondary data obtained from counterparts in Georgia and Abkhazia or that can be obtained from the internet. The development of this multi-hazard risk assessment is based on the following specific objectives:

- To create factor maps e.g. DEM, slope steepness, land cover, geology, soils, population, roads, and building density.
- To collect historical event data from the internet such as up to date landslide inventories, precipitation data, and other pre-existing hazards.
- Carry out susceptibility assessment for mass movement hazards (landslides, debris flows, floods, earthquakes, coastal hazards).
- Use existing susceptibility maps from other hazards, generated from the MATRA project.
- Generate multi-hazard exposure and risk assessment.

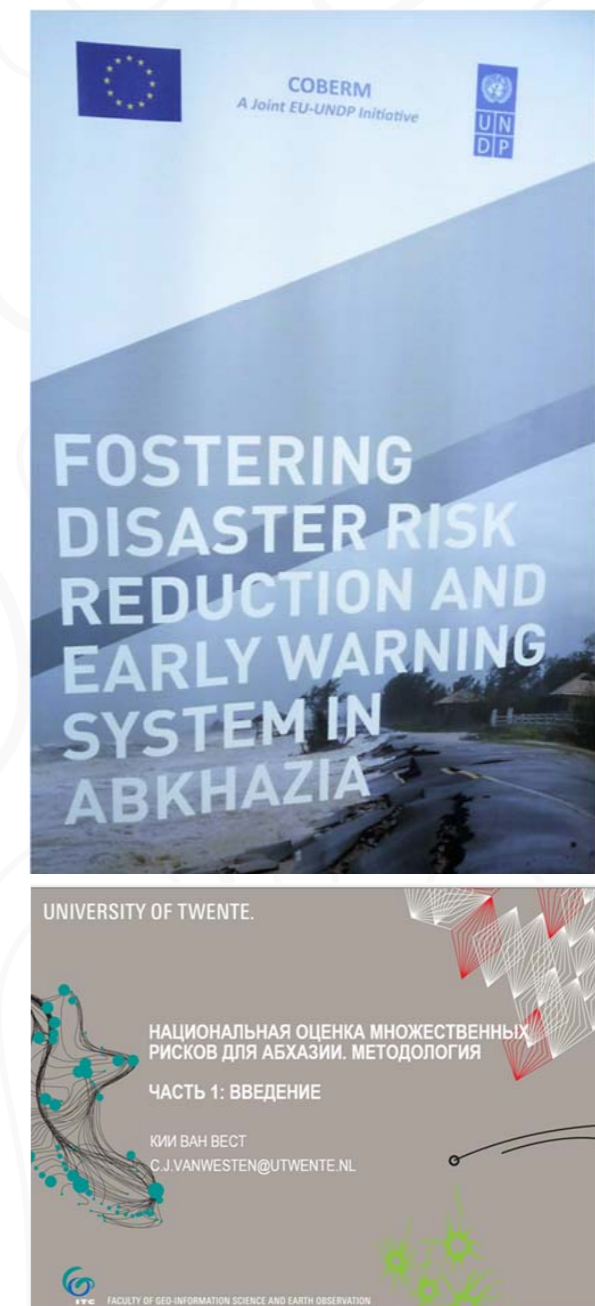


FIGURE 1: WORKSHOP IN ARMENIA



# DATA PREPARATION AND PROCESSING

From several internet sources, different spatial data layers were downloaded and prepared in ARCGIS & ILWIS GIS software. All data obtained were georeferenced according to the coordinate system : WGS\_1984\_UTM\_Zone\_38N, WKID: 32638 Authority: EPSG. Raster data was resampled to 12.5 meters pixel size before they were used for other processes.

## HISTORICAL DATA

Historical data was obtained from a number of sources, including the National Environmental Agency (NEA) of Georgia, and the results from the MATRA project. For the individual hazard types, the available historical data will be discussed in the subsequent chapters. Overall, there was a major scarcity of historical data for Abkhazia. As can be seen from Figure 2, the total number of available data is very limited. It is difficult to obtain historical disaster data from international databases such as EM-DAT ([www.emdat.be](http://www.emdat.be)) or through the Global Assessment Data Platform (GAR2015) as data for Abkhazia is included in the data from Georgia, and cannot be separately extracted. Besides, the available data in these locations is very limited. Therefore we used data that was collected as part of the MATRA project (MATRA, 2012).

Even though there are more data available for Abkhazia, the amount is still not sufficient to generate proper hazard maps for certain types of hazards (e.g. landslides, wildfires) and therefore only susceptibility maps can be made. Hazard maps show intensities of certain hazards (e.g. Peak Ground Acceleration, Water depth) for a given probability of occurrence, or Return Period. Susceptibility maps only give the relative likelihood of occurrence of hazardous processes (in relative terms like high, moderate, low).

## CAUSAL FACTOR DATA

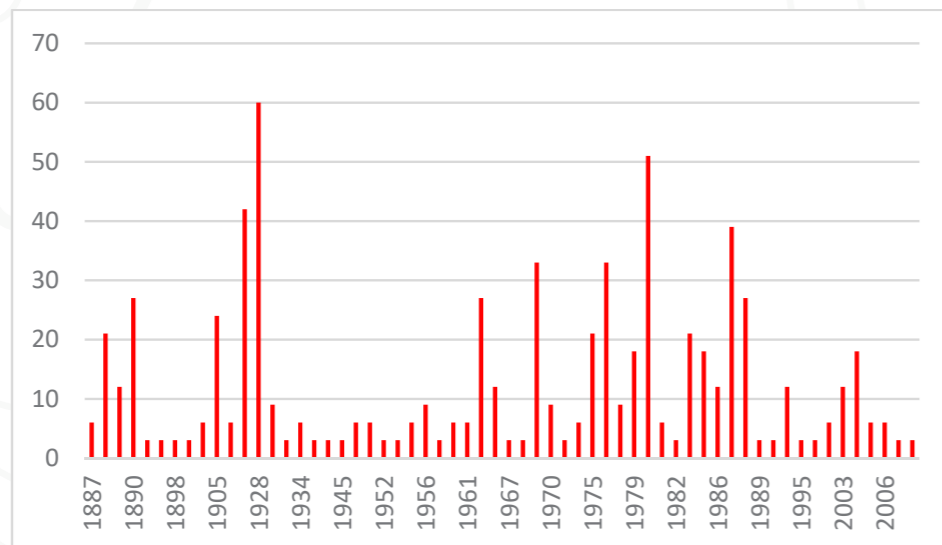


FIGURE 3: NUMBER OF REPORTED DISASTER EVENTS IN ABKHAZIA PER YEAR. SOURCE: MATRA (2012)

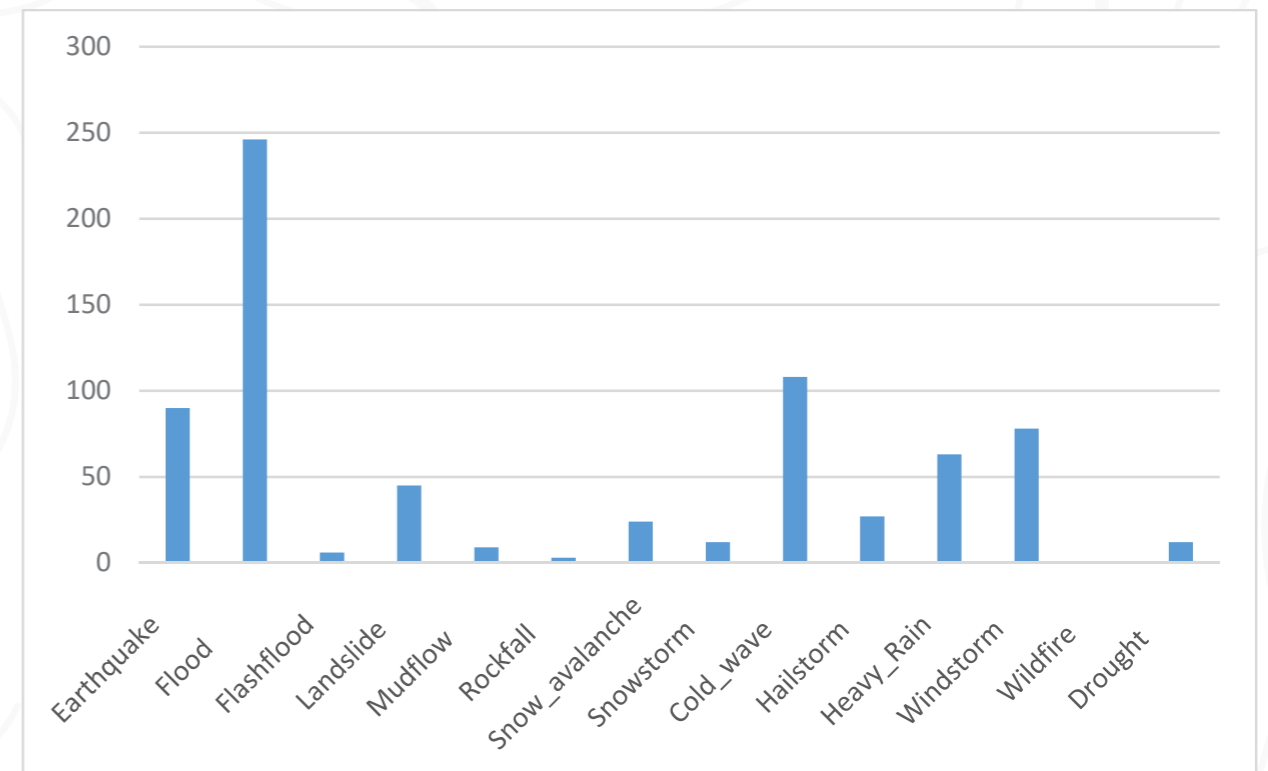


FIGURE 2: OVERVIEW OF NUMBER OF EVENTS IN ABKHAZIA AVAILABLE IN THE HISTORICAL DISASTER DATABASE, COVERING THE PERIOD BETWEEN 1887 AND 2008. SOURCE: MATRA (2012)

Different factors maps that contribute to hazards were generated, based on available information, which was mostly derived from the internet, or processed on the basis of internet data.

- A Digital Elevation Model data was generated using SRTM data with 30 and Alos Palsar data with 12.5-metre spatial resolution. The latter data was collected from the vertex (“Vertex: ASF’s Data Portal,” n.d.) which is Alaska’s satellite facility’s data for a remotely sensed image of the earth and merged in GIS, after which several derivative maps were made. e.g. slope steepness, slope direction, elevation and ridges maps.
- Geological data (fault data): Fault data of Abkhazia was obtained from (British geological survey, 2017) and converted to fault map in

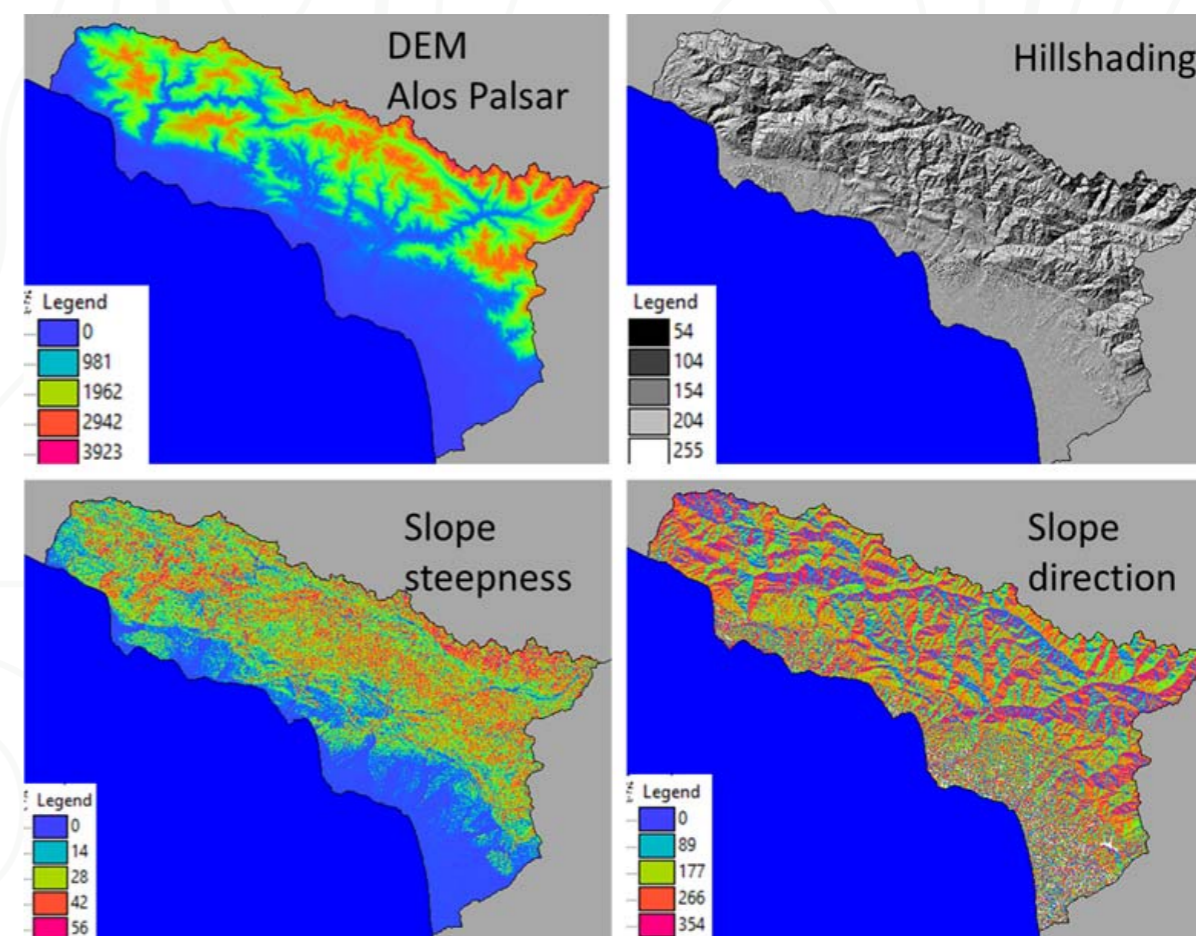


FIGURE 4: DEM DATA, GENERATED FROM ALOS PALSAR DEM WITH 12.5 M SPATIAL RESOLUTION.

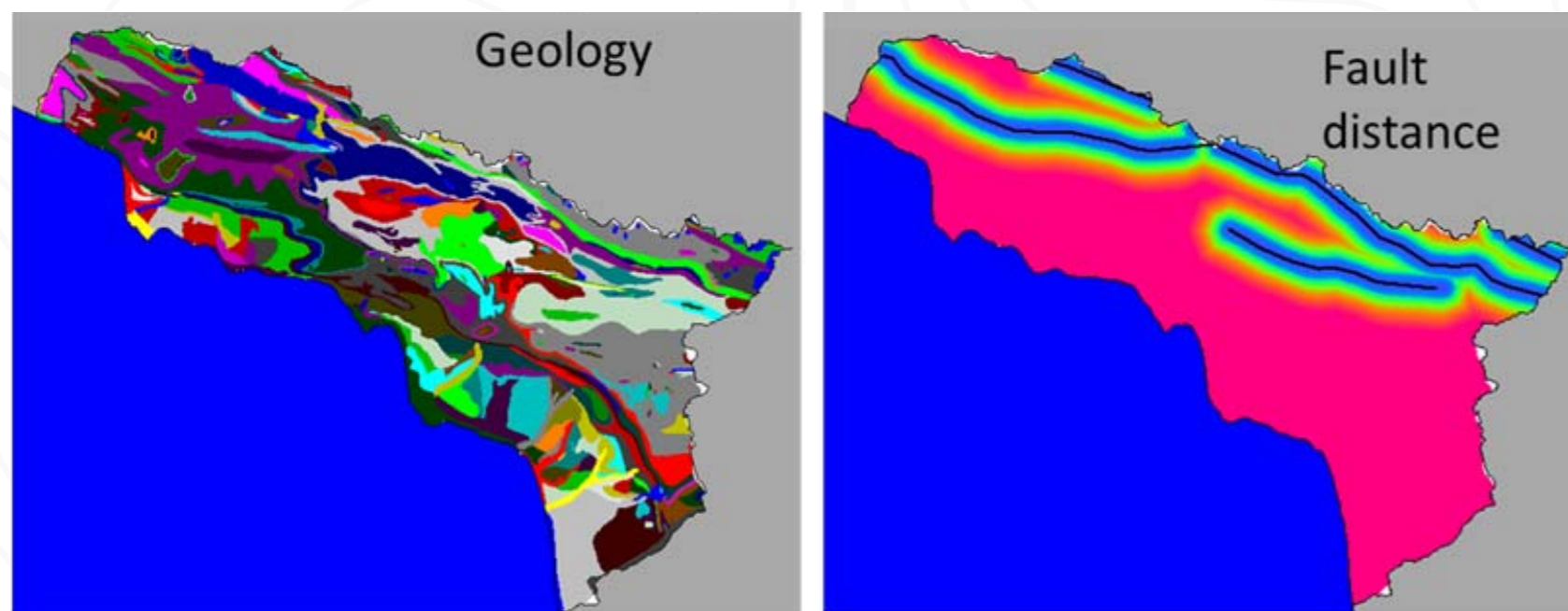


FIGURE 5: GEOLOGICAL FACTOR MAPS. DERIVED FROM ONEGEOLOGY AND LOCAL DATA.

Arc GIS to be used in SMCE for landslide susceptibility assessment.

- Soil data was obtained at course resolution of 250 meters from Soil Grids website (Hengl et al., 2017) and classified into 13 classes, from



which soil types, soil depth, and soil texture maps were created. These data are general and have been derived through geo-statistical analysis. But they do give a general indication.

- Vegetation and land cover were obtained from European Space Agency (ESA). Then the classification was performed in ARC GIS were by classified map was obtained with a total of 13 classes. However, this map had a very poor spatial resolution and also contained a considerable number of errors, and missing data. We also had a polygon map of land use which was obtained from the MATRA project (MATRA, 2012), most probably through image classification. This map contained different legend units, and contained a strange class “land” which contained both cropland as well as grassland. Both maps did not match in a number of places. We therefore combined both maps using a more simple legend, see Figure 7.

#### ELEMENT AT RISK DATA

Element at-risk data such as buildings, roads, for-

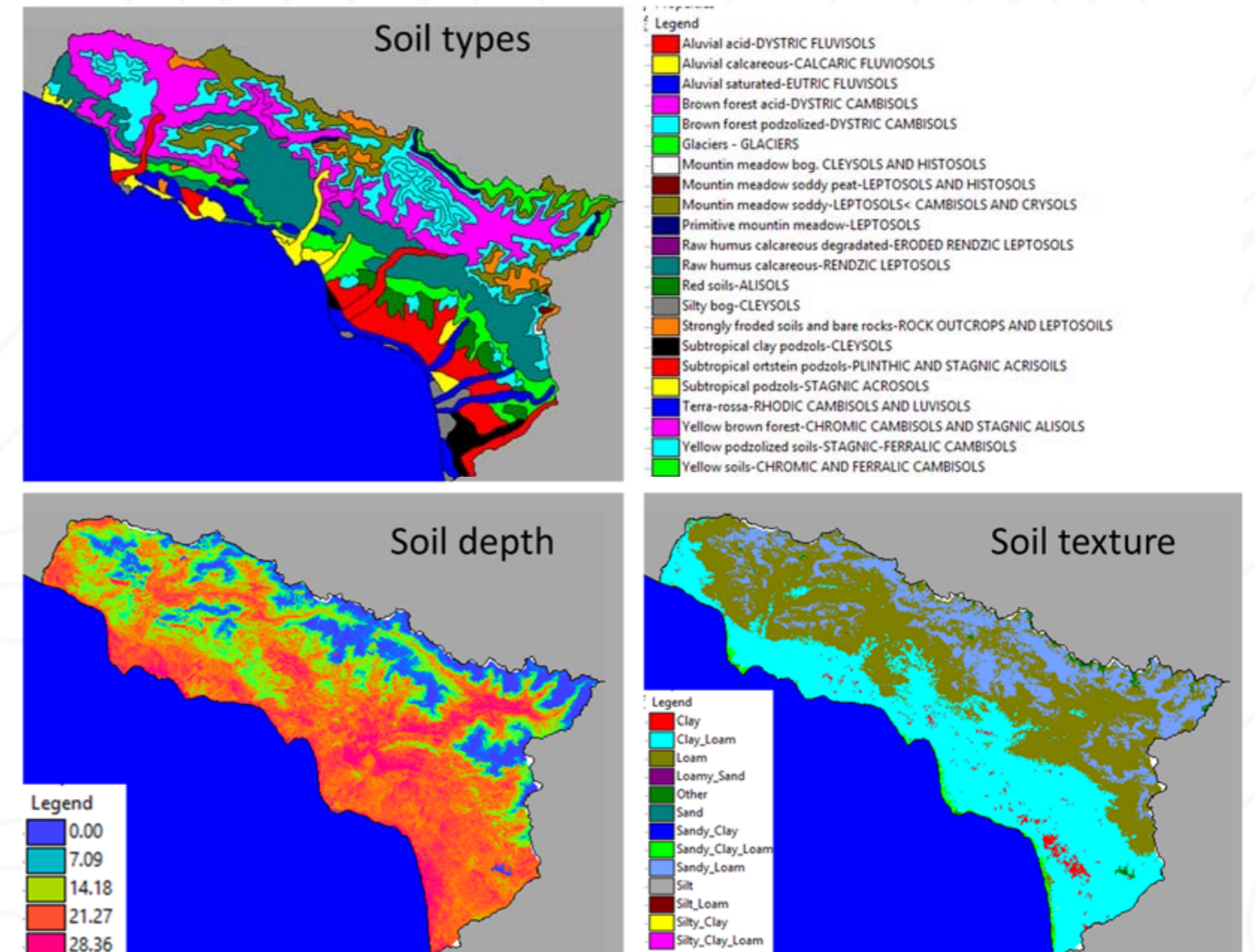


FIGURE 6: SOIL DATA, MOSTLY DERIVED FROM SOILGRIDS.ORG AND LOCAL DATA.

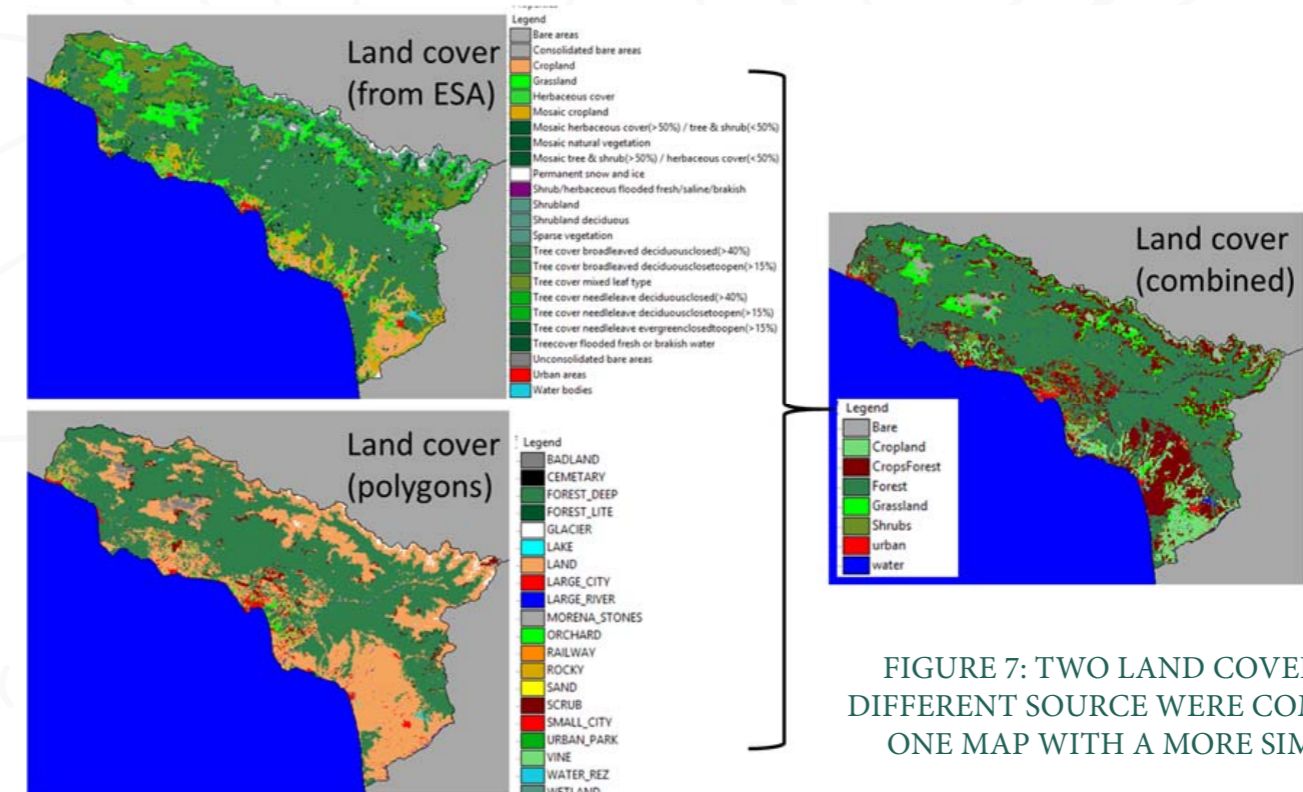


FIGURE 7: TWO LAND COVER MAPS FROM DIFFERENT SOURCE WERE COMBINED INTO ONE MAP WITH A MORE SIMPLE LEGEND.



est, and crops were obtained by downloading these layers from the OpenStreetMap (OSM). Then a generation of point file with a point for each building was performed in ARC GIS. Also, the creation of polygon and raster maps for crops and forest was performed in ARC GIS and then all these data were used in ILWIS software. Population data was created based on the information obtained in building footprint together with the information on the land use. An estimation of the number of people was calculated considering the spatial distribution of people in the daytime and night-time scenario to obtain population density.

- **Building footprints and building types (incomplete) were downloaded from OpenStreetMap (OpenStreetMap, 2018). As for the buildings without type information, assumption of residence was made.**
- **Population data is based on building information. Since floor information is missing, population estimation is also based on assumptions (e.g. apartment with 3 floors, hotel with 8 floors, hospital with 6 floors).**
- **Road map was updated by the use of OpenStreetMap (OpenStreetMap Foundation, 2018).**
- **Crops map and Forest map were clipped from the maps for Georgia.**

| Factor maps                    | Description                                                                                                                                            | Original resolution | Source                                                                                                       |
|--------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------|--------------------------------------------------------------------------------------------------------------|
| DEM                            | 5 tiles were obtained and mosaicked in ArcGIS for the whole Abkhazia region                                                                            | 12.5 m              | Phased Array type L- band Synthetic Aperture Radar (ALOS PALSAR) (ASF DAAC, 2015)                            |
| DEM                            | 5 tiles were obtained and mosaicked in ArcGIS for the whole Abkhazia region                                                                            | 30m                 | Shuttle Radar Topographic Mission (SRTM) (LP DAAC, 2017)                                                     |
| Elevation class                | Generated from DEM, 5 classes                                                                                                                          | 30m                 | DEM (Alos)                                                                                                   |
| Slope angle                    | Generated from DEM, 4 classes                                                                                                                          | 30m                 | DEM (Alos)                                                                                                   |
| Aspect                         | Generated from DEM, 8 classes                                                                                                                          | 30m                 | EM (Alos)                                                                                                    |
| Distance to ridges             | Generated from DEM, 5 classes                                                                                                                          | 30m                 | DEM (Alos))                                                                                                  |
| Distance to faults             | 2 classes                                                                                                                                              | 100m                | Fault map of Georgia                                                                                         |
| Distance to roads              | 5 classes                                                                                                                                              | 100m                | Road map of Georgia                                                                                          |
| Distance to drain-ages         | Generated from DEM, 4 classes                                                                                                                          | 30m                 | DEM (SRTM)                                                                                                   |
| Soil texture                   | 12 classes, generated by combining clay content (%), sand content (%) and silt content (%) according to United States Department of Agriculture (USDA) | 250m                | SoilGrids (ISRIC, 2018)                                                                                      |
| Soil depth                     | Absolute depth to bedrock (m), 6 classes                                                                                                               | 250m                | SoilGrids (ISRIC, 2018)                                                                                      |
| Soil type                      | 22 classes                                                                                                                                             | -                   | Soil map of Georgia                                                                                          |
| Land cover                     | 29 classes                                                                                                                                             | 300m                | European Space Agency (2018)                                                                                 |
| Precipitation                  | Multi-year monthly mean (mm) with 7 classes, generated from monthly average rainfall intensity (2015-2017).                                            | 0.1 degree          | Tropical Rainfall Measuring Mission (TRMM) and Global Precipitation Measurement (GPM) (Huffman et al., 2014) |
| Peak ground acceleration (PGA) | 4 classes                                                                                                                                              | 500m                | PGA map of Georgia                                                                                           |
| Geological data                |                                                                                                                                                        |                     | Geology map                                                                                                  |

TABLE 1: OVERVIEW OF FACTOR MAP



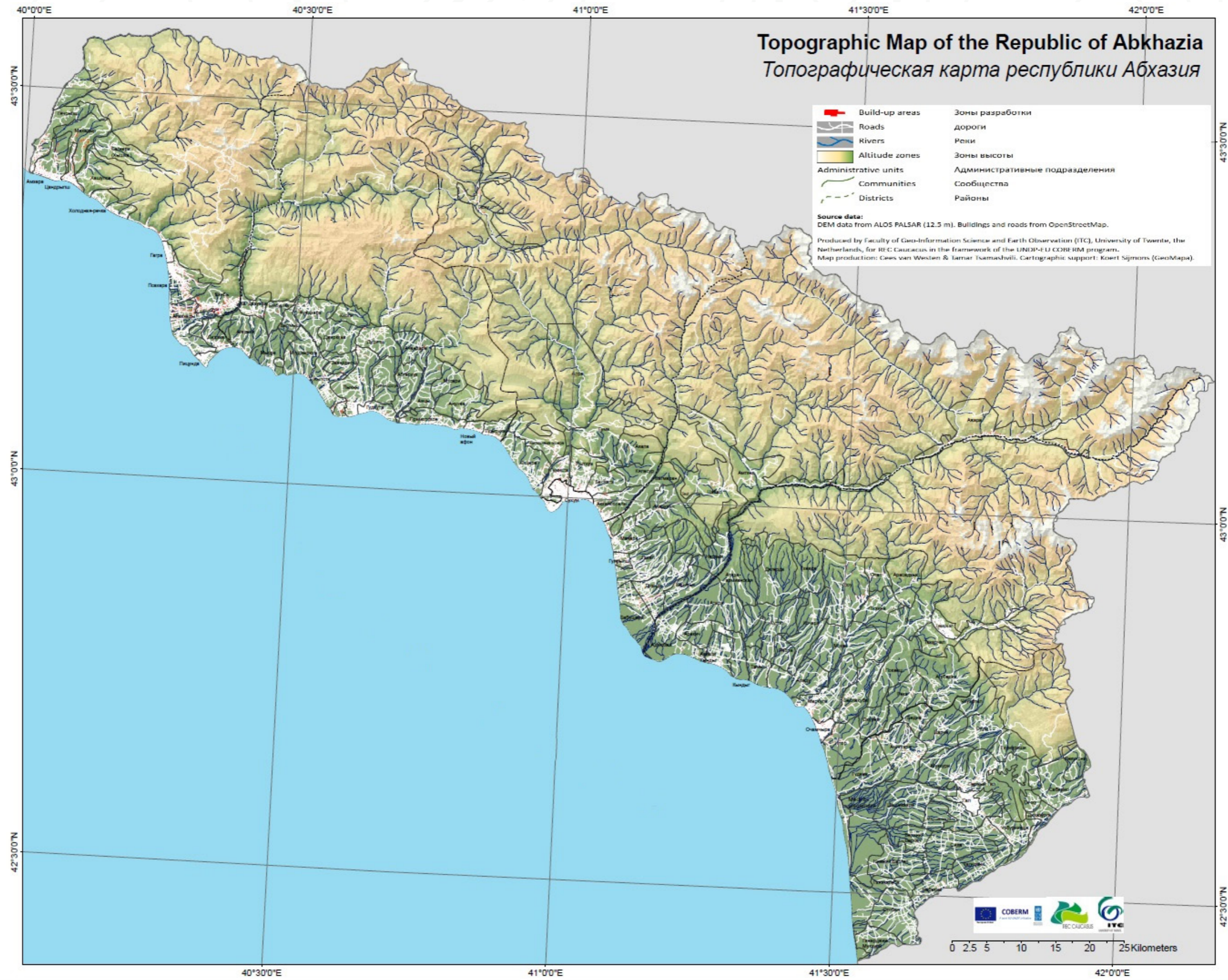


FIGURE 8: TOPOGRAPHIC MAP FOR ABKHAZIA, COMBINING ELEVATION, HILLSHADING, DRAINAGE, ROADS, BUILDINGS, AND ADMINISTRATIVE UNITS.



# MASS MOVEMENTS

Before being able to make the susceptibility or hazard maps we first collected historical information.

## HISTORICAL DATA COLLECTION

We collected historical landslide data from different sources. One of these were from NEA in Georgia, which was also used for the MATRA project (MATRA, 2012). However, these were very limited (only 286 landslide points), and were somehow only related to local landslides in the low areas of Abkhazia. See Figure 9. The historical data did not contain information on the type of landslide, or the date of initiation. Therefore it was not possible to use this data in a hazard assessment, as we could not make a relation between landslides and triggering events.

To increase the number of landslide points in the hilly and mountainous areas of Abkhazia, we made an interpretation of historical Google Earth images. We digitized landslides as single points, and did not have the time to make a classification of the type, nor of the temporal occurrence. This way we digitized another 1216 landslide initiation points in Abkhazia, shown as green dots in Figure 9.

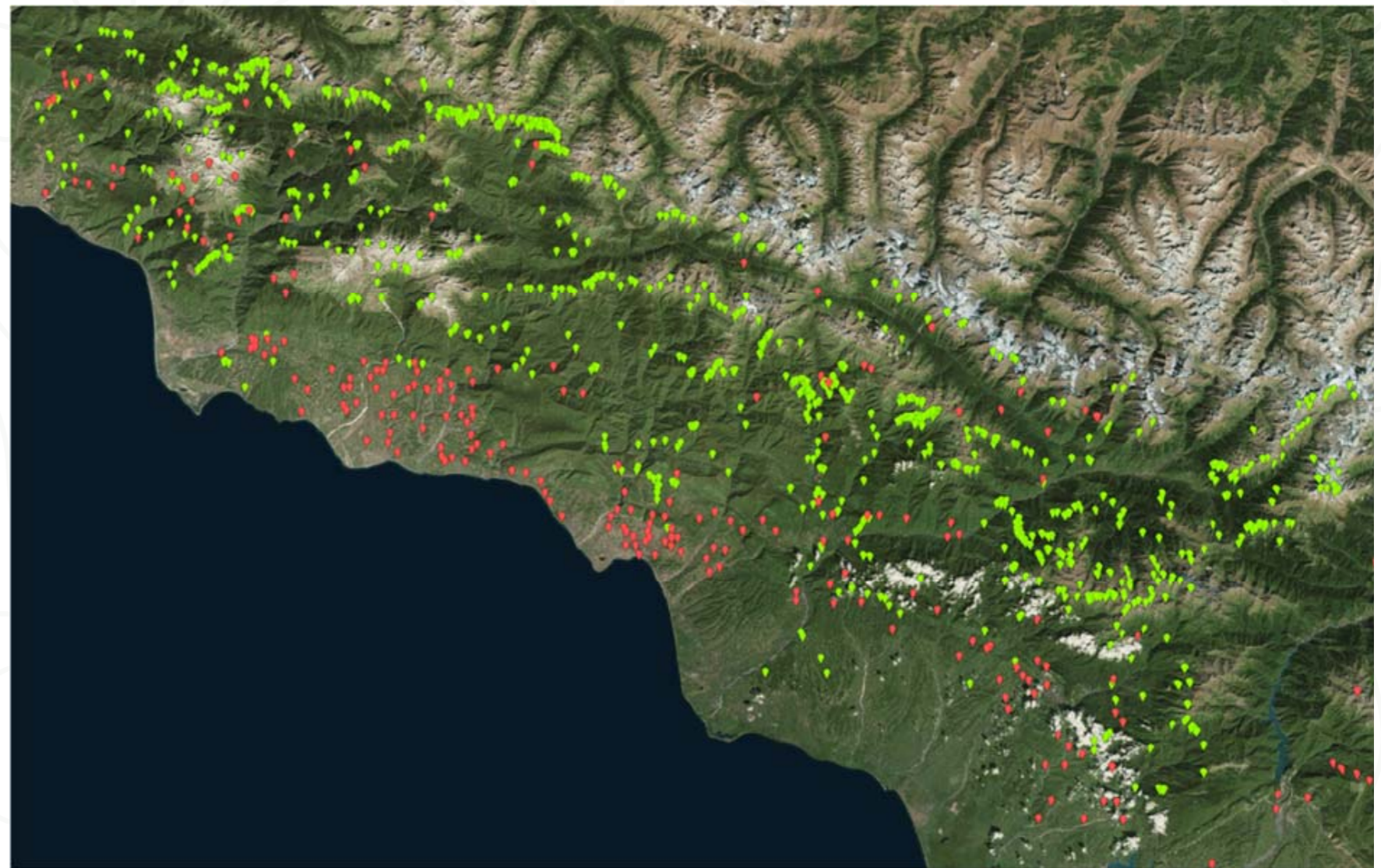


FIGURE 9: HISTORICAL MASS MOVEMENTS IN ABKHAZIA. RED: POINTS COLLECTED FROM HISTORICAL ARCHIVES. GREEN: LANDSLIDE LOCATIONS THROUGH IMAGE INTERPRETATION OF GOOGLE EARTH HISTORICAL IMAGES.



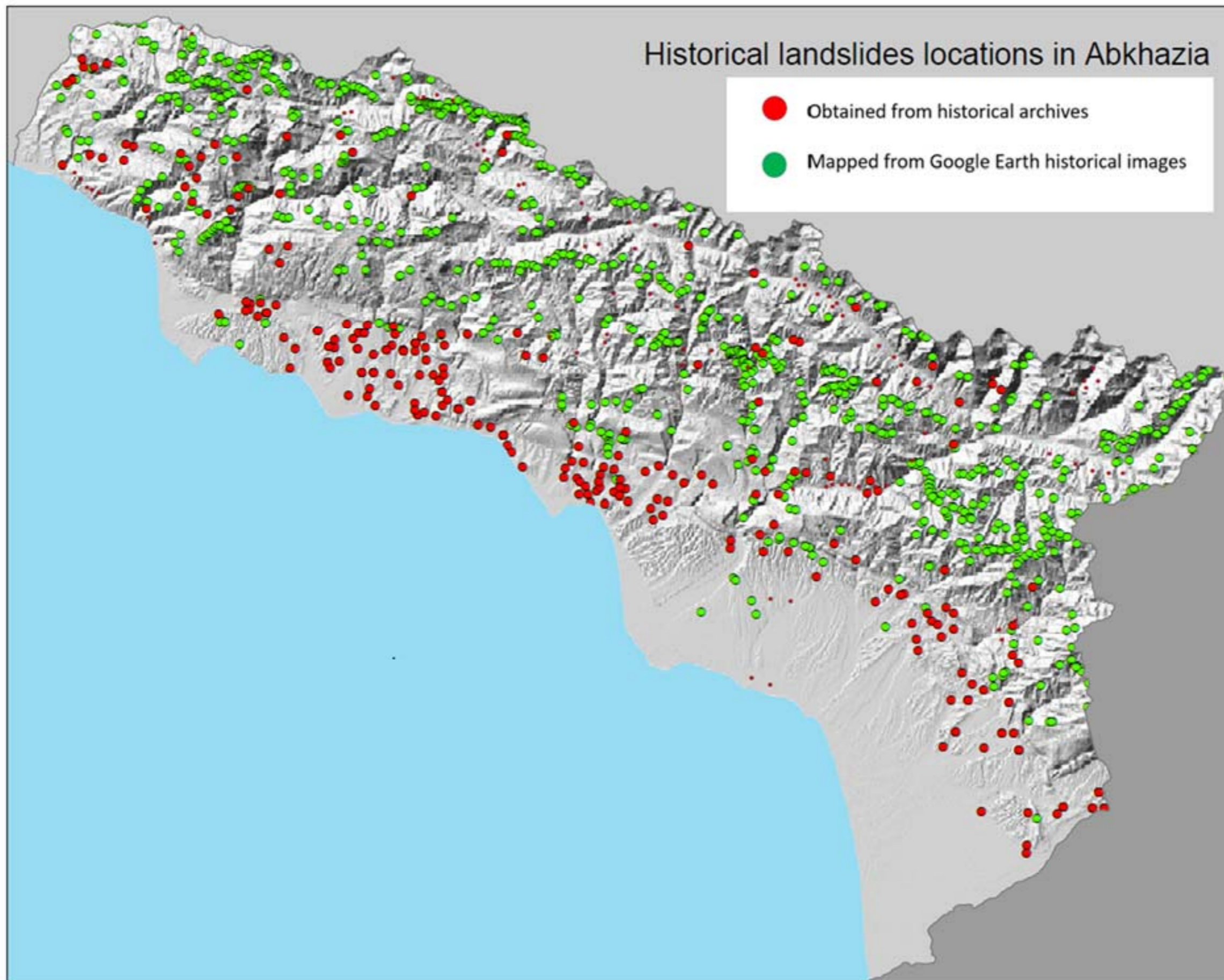


FIGURE 10: LANDSLIDE INVENTORY MAP FOR ABKHAZIA.



STATISTICAL ANALYSIS

A GIS-based script was used to carry out the Weight Of Evidence modelling for each factor map in combination with the landslide and rockfall inventory map. Based on the calculated weights of evidence a selection was made of the most relevant causal factors. The results of the statistical analysis obtained provided useful results which helped to evaluate the importance of the factor maps in the contribution of the landslide hazards.

SPATIAL MULTI-CRITERIA EVALUATION

A criteria tree for landslides was generated in which various causal factors was grouped into 5 groups for landslide as shown in criteria tree diagram in Figure 11. Then a standardization of the individual causal factors was performed, based on calculated weights of evidence. The standardization resulted in values for each factor map ranging from 0-1.

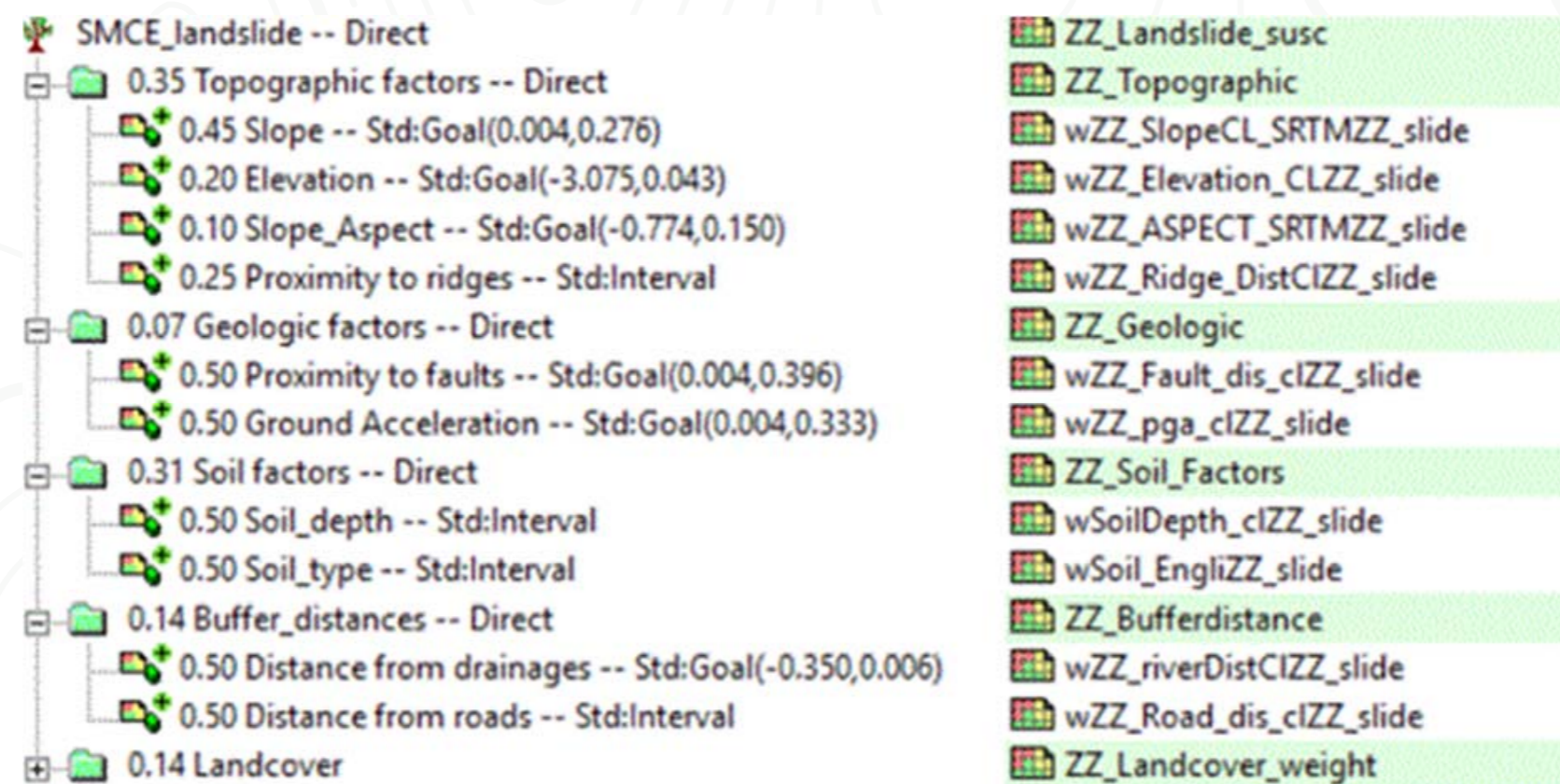


FIGURE 11: CRITERIA TREE USED FOR THE LANDSLIDE INITIATION SUSCEPTIBILITY ASSESSMENT AFTER STANDARDIZATION, A COMBINATION OF THE DIRECT AND PAIRWISE METHOD WAS USED TO WEIGHT THE FACTOR MAPS AND THE VARIOUS GROUPS BY COMPARING THEM WITH EACH OTHER AND BY ASSIGNING VALUES RANGING FROM 0 TO 1. THEN A GENERATION OF THE COMPOSITE MAP WAS DONE, WHICH COMBINED THE STANDARDIZATION AND WEIGHTING FOR ALL INDICATORS IN THE CRITERIA TREE. THE SUCCESS RATE CURVES OBTAINED WAS USED TO CLASSIFY THE SUSCEPTIBILITY MAP VALUES INTO 3 CLASSES NAMELY HIGH, MODERATE AND LOW. THE SUCCESS RATE CURVES ARE SHOWN IN FIGURE 12.

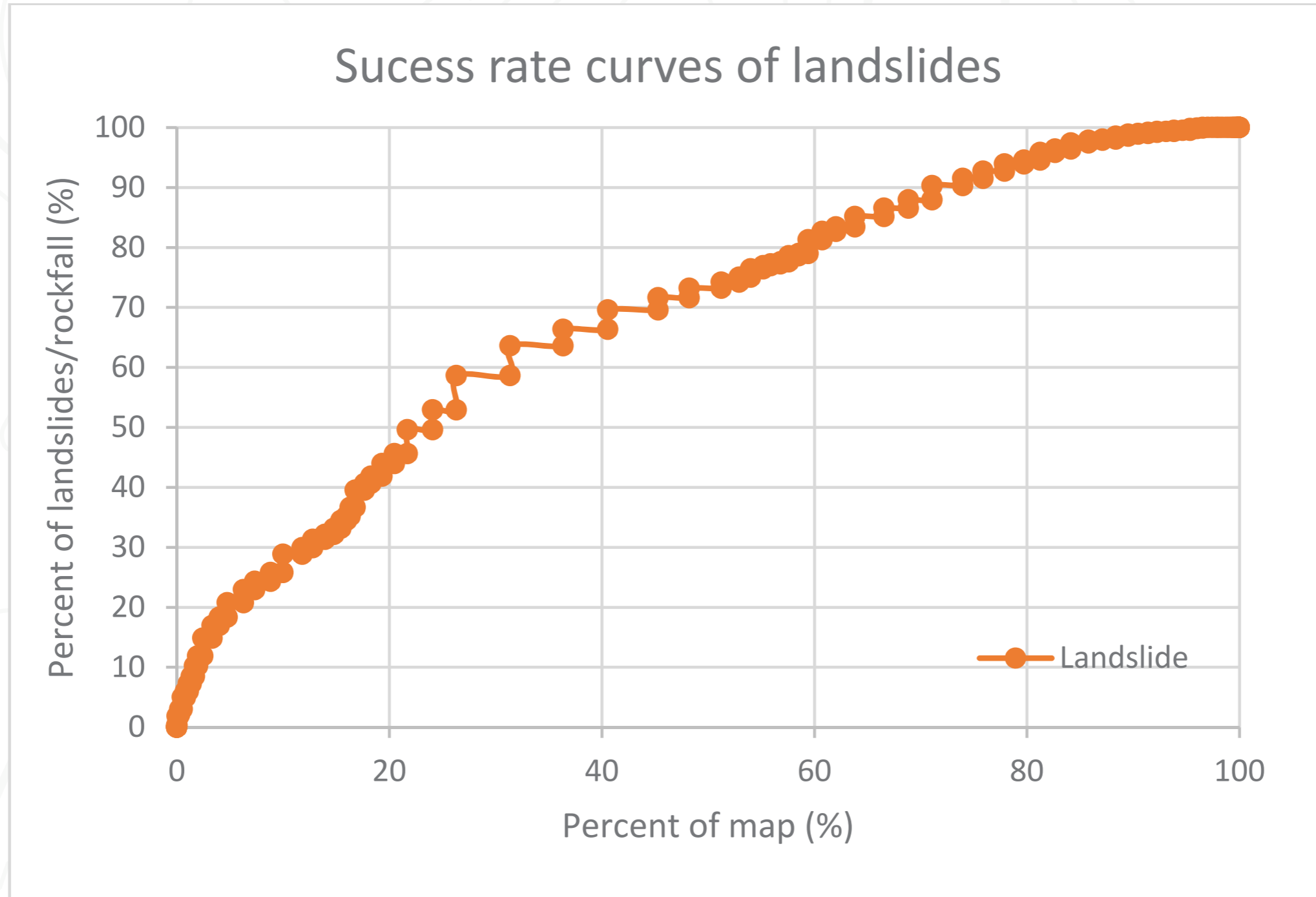


FIGURE 12: SUCCESS RATE CURVE OF THE LANDSLIDE SUSCEPTIBILITY MAP.



## EMPIRICAL RUNOUT MODELLING

Runout modelling was performed using FLOW R software. Digital Elevation Model (DEM) of 12.5 and 30-meter resolution together with landslide initiation (source) was used as an input data for runout assessment and this data was converted in ArcInfo ASCII format. The travel angle of 0.1 degrees was used to assure that the maximum travel distance is obtained. The validation of the runout model was done by overlaying the landslides inventory points to the runout extent map and the results were not the same for different DEM resolution. A comparison of the two runout extent results was made to compare the effect of DEM differences in resolution and the effect of this difference in runout analysis.

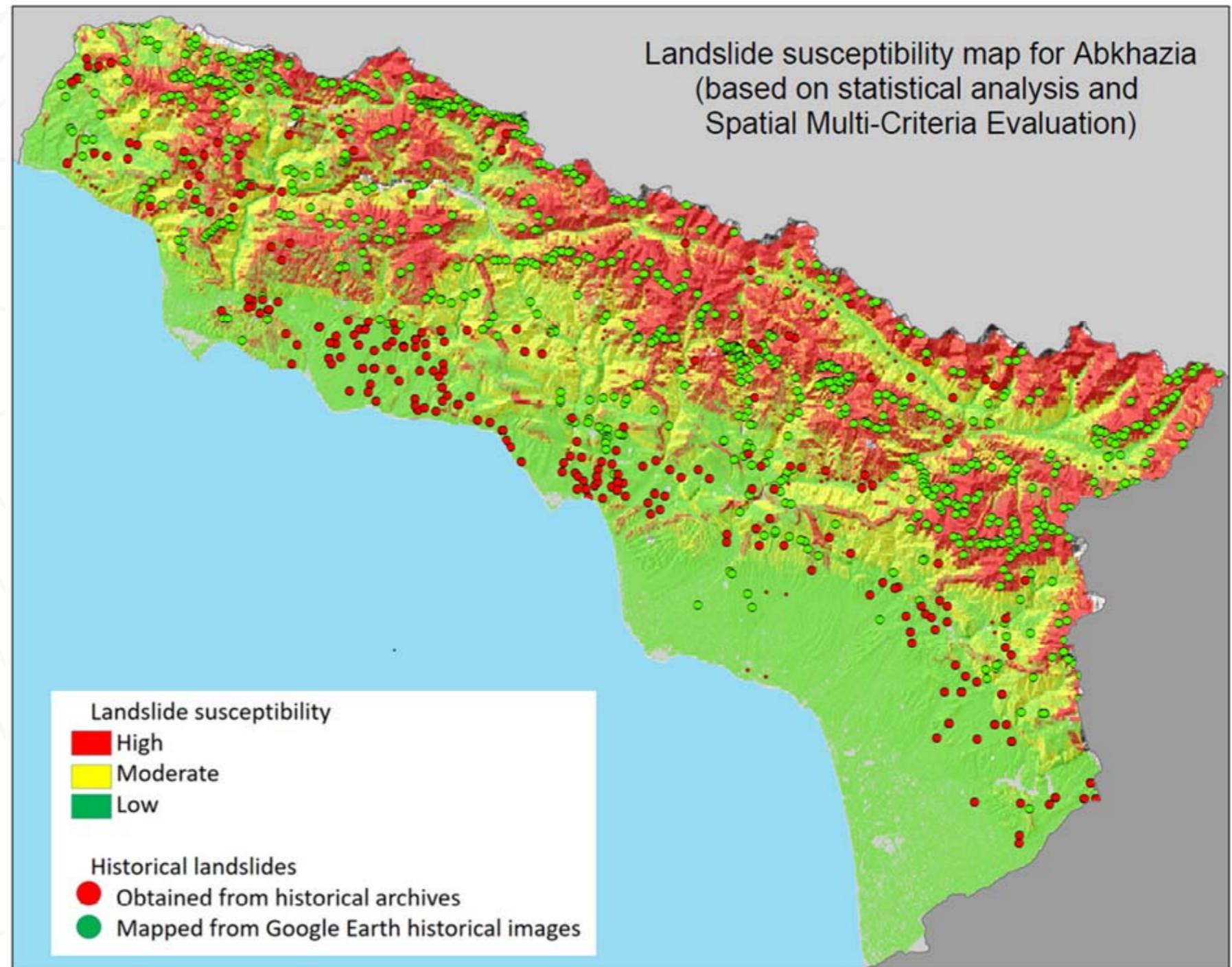


FIGURE 13 : STATISTICAL LANDSLIDE SUSCEPTIBILITY MAP FOR ABKHAZIA.



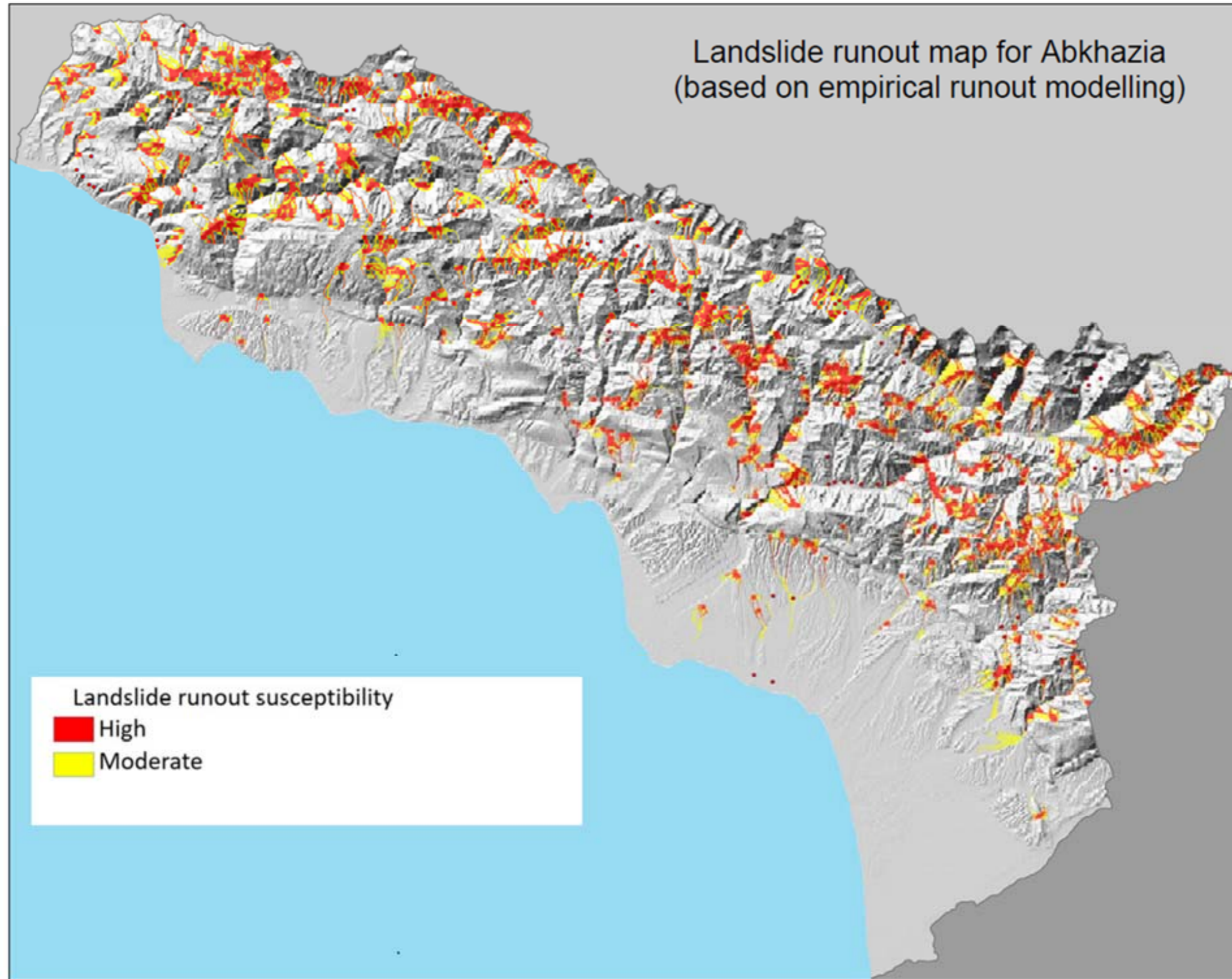


FIGURE 14: EMPIRICAL RUNOUT MAP FOR DEBRISFLOWS FOR ABKHAZIA



## INFINITE SLOPE MODEL

The calculation of the Safety factors was performed by using infinite slope model approach. This was deployed in a GIS in pixel basis calculation (van Westen, van Asch, & Soeters, 2006). The safety factor was calculated based on the following formula (Thiel & Resources, 2009).

$$F_s = \frac{c' + (\gamma - m\gamma_w)z \cos^2 \beta \tan \phi'}{\gamma z \sin \beta \cos \beta}$$

Where  $c'$  is the effective cohesion (N/m<sup>2</sup>),  $\gamma$  is the unit weight of soil (N/m<sup>3</sup>),  $m$  is the ratio of  $z_w/z$  (dimensionless),  $\gamma_w$  is the unit weight of water (N/m<sup>3</sup>),  $z$  is the depth of failure surface below the surface (m),  $z_w$  is the height of water table above failure surface (m),  $\beta$  is the slope surface inclination (degree),  $\phi'$  is the effective angle of shearing resistance.

In this study, the consideration was made for the dry, semi-saturated and completely saturated condition. The parameters used for safety factors calculation for these three situations are shown in table 2. Also, the soil values used to calculate the factor of safety was obtained from the literature.

The domain was created in ILWIS software having 3 classes; unstable, critical and stable and then by using a slicing tool operation a safety factor maps were created.

| Parameters | Dry                                                                        | Completely saturated                                                       |
|------------|----------------------------------------------------------------------------|----------------------------------------------------------------------------|
| $c'$       | According to different soil texture, values from Geotechdata.info. (2013a) | According to different soil texture, values from Geotechdata.info. (2013a) |
| $\gamma$   | 11000                                                                      | 16000                                                                      |
| $m$        | 0                                                                          | 1                                                                          |
| $\gamma_w$ | 10000                                                                      | 10000                                                                      |
| $\beta$    | Slope angle from factor map                                                | Slope angle from factor map                                                |
| $z$        | Soil depth from factor map                                                 | Soil depth from factor map                                                 |
| $\phi'$    | According to different soil texture, values from Geotechdata.info. (2013b) | According to different soil texture, values from Geotechdata.info. (2013b) |

TABLE 2 : PARAMETERS FOR SAFETY FACTORS CALCULATION



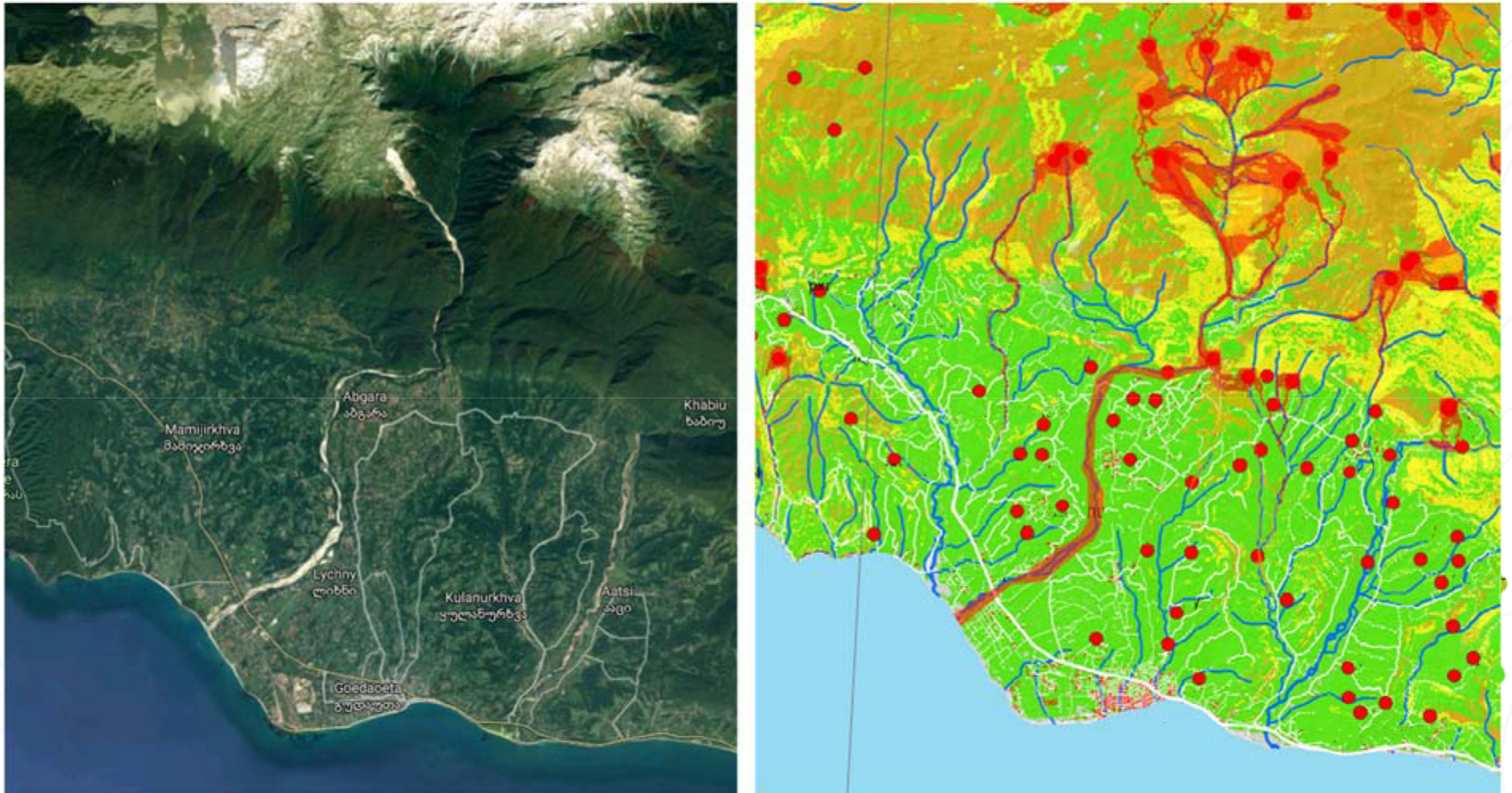


FIGURE 15: DETAIL OF THE LANDSLIDE SUSCEPTIBILITY MAP, SHOWING THE AREA AROUND ABGARA, WITH ACTIVE LANDSLIDES AND RECENT DEBRIS FLOW DEPOSITS. LEFT: GOOGLE EARTH IMAGE, RIGHT: SUSCEPTIBILITY MAP.



# Landslide hazard map of Abkhazia (Combining landslide initiation and debrisflow/mudflow runout)

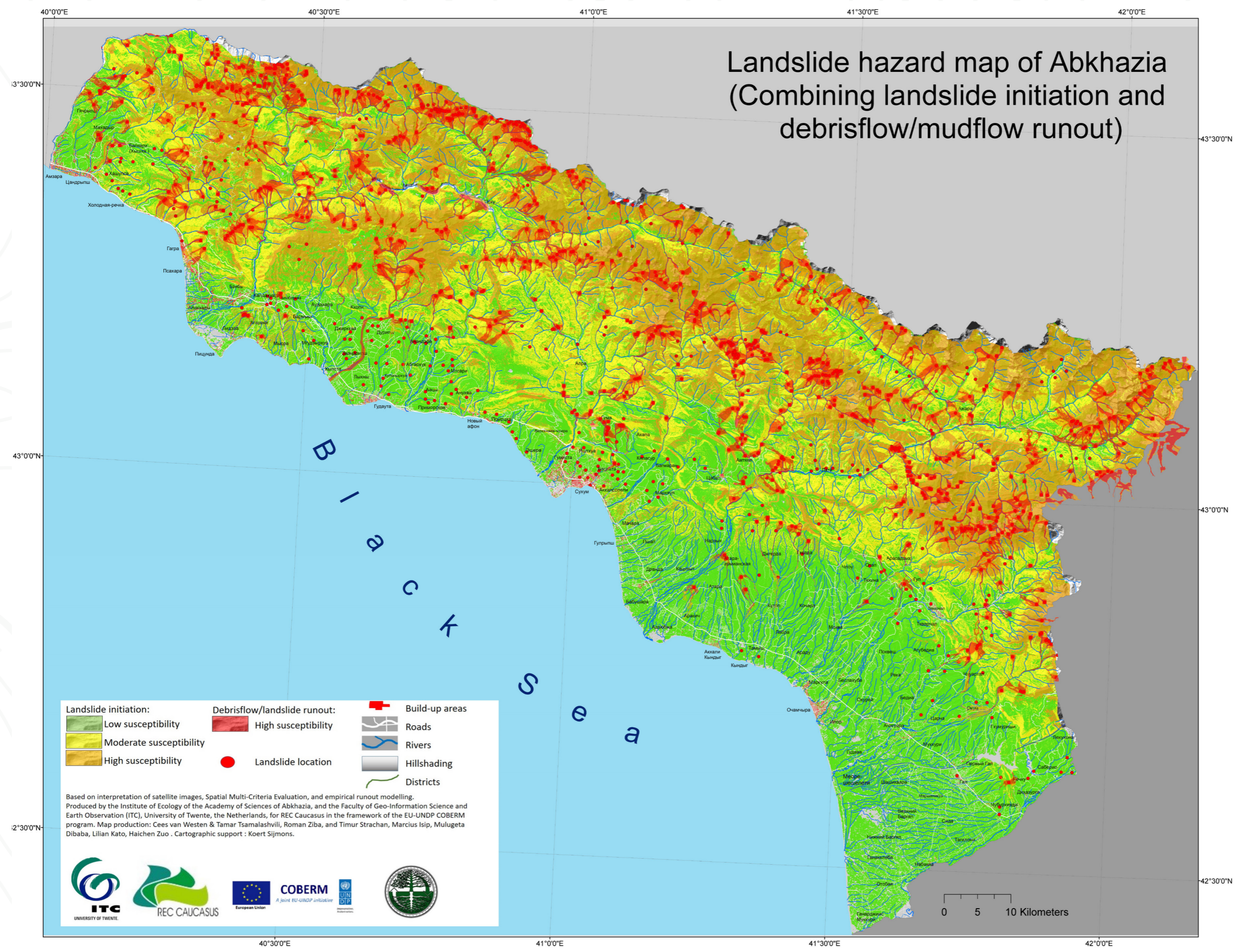


FIGURE 16: LANDSLIDE HAZARD MAP FOR ABKHAZIA



# FLOODS

## HISTORICAL DATA COLLECTION

We collected the available historical data available on floods from the various authorities. Figure 17 shows the distribution of all hazard events and flood events in Abkhazia.

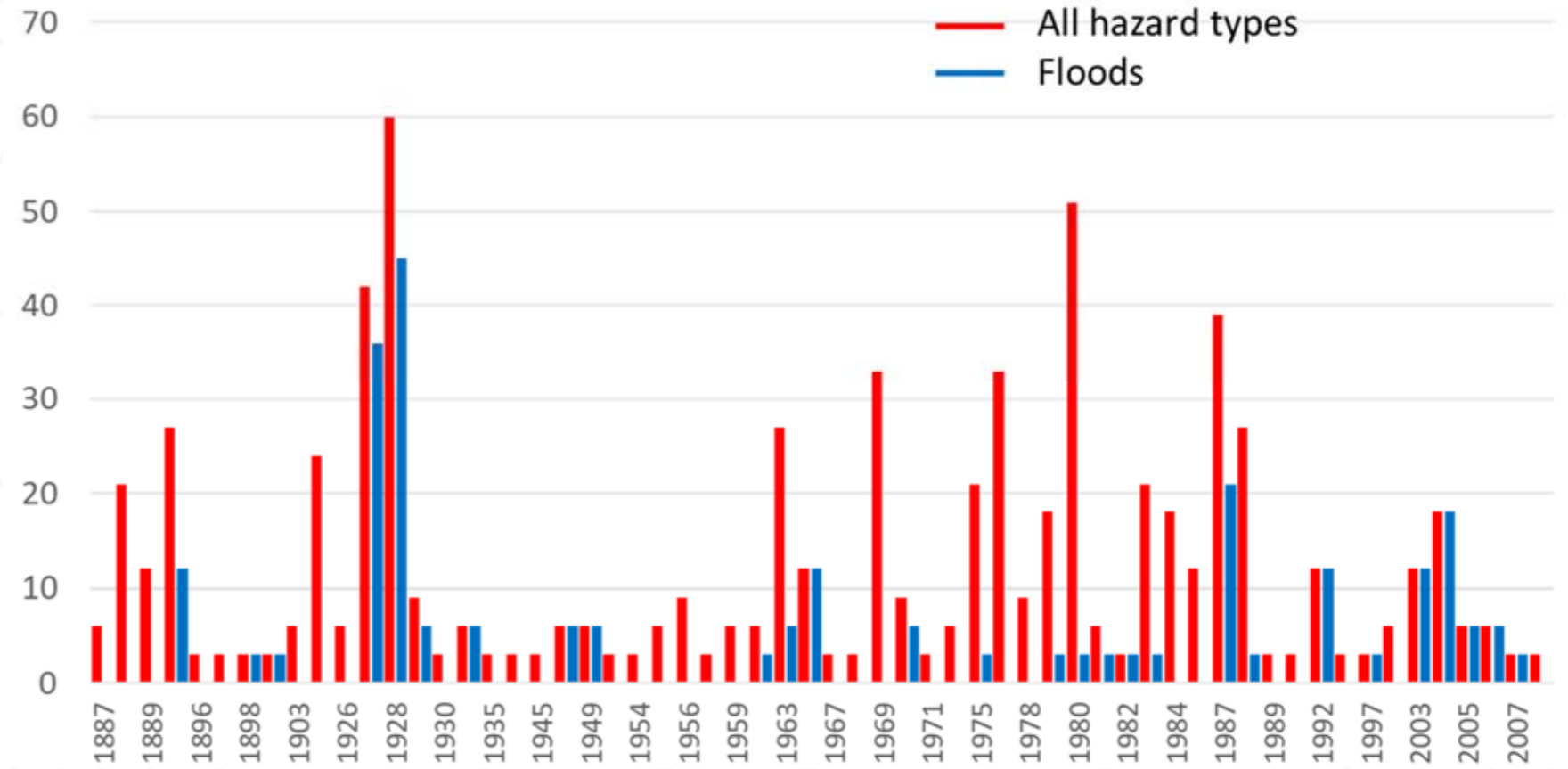


FIGURE 17: HISTORICAL INFORMATION ON FLOOD EVENTS FOR ABKHAZIA.

FIGURE 18 SHOWS THE DISTRIBUTION OF HAZARDOUS EVENTS OVER THE VARIOUS COMMUNITIES

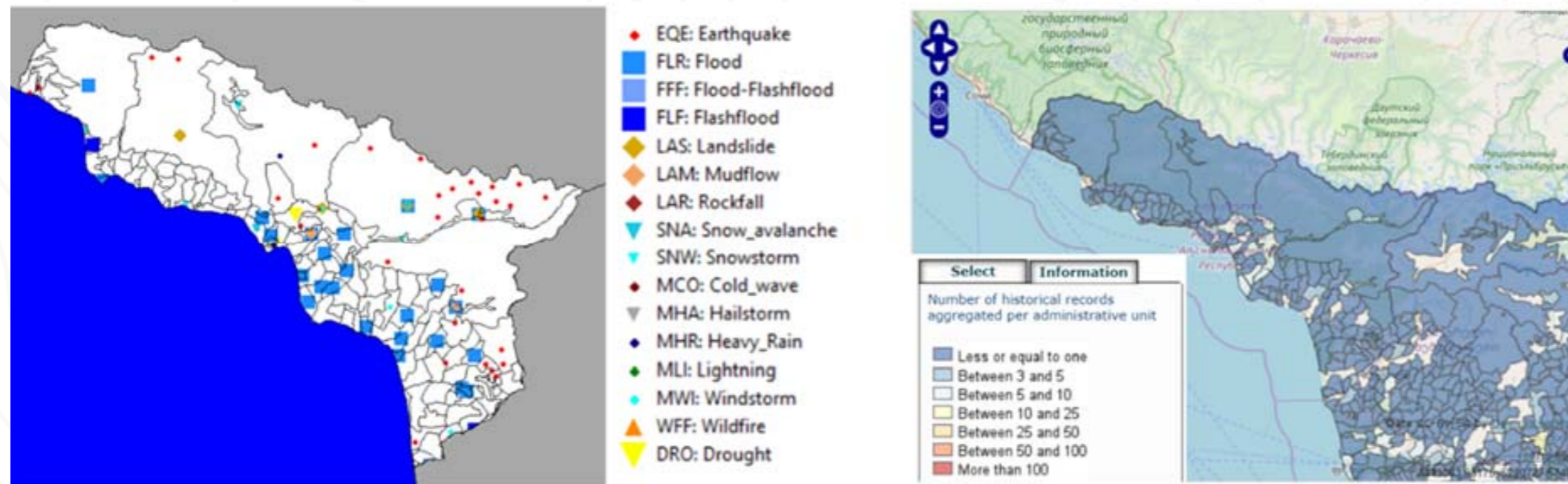


FIGURE 18: LEFT: HISTORICAL HAZARD EVENTS IN ABKHAZIA, WITH FLOOD EVENTS AS BLUE SQUARES. RIGHT: NUMBER OF FLOOD EVENTS PER COMMUNITY (FROM [HTTP://DRM.CENN.ORG](http://drm.cenn.org) )

WE WERE NOT ABLE TO COLLECT ANY INFORMATION ON HISTORICAL FLOOD EXTENTS AS MAPS FOR VALIDATION PURPOSES. FIGURE 19 SHOWS THE AVAILABLE FLOOD INFORMATION ON SOME INTERNATIONAL FLOOD PORTALS (E.G. UNOSAT FLOOD PORTAL AND DFO FLOOD PORTAL).

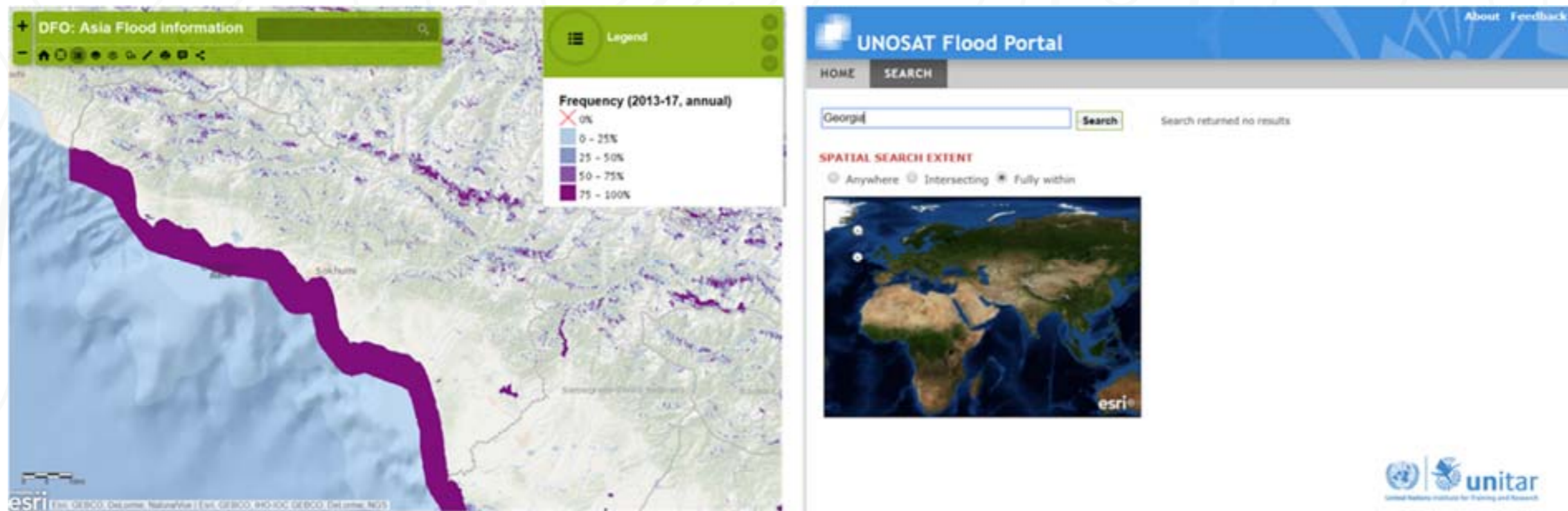


FIGURE 19: POOR HISTORICAL DATA ON INTERNATIONAL FLOOD MAPPING PORTALS. LEFT: DARTMOUTH FLOOD OBSERVATORY WEB PORTAL ([HTTPS://DILUVIUM.COLORADO.EDU/ARCGIS/APPS/VIEWER/INDEX.HTML?APPID=508E429FC82443098BC087F00CD7FA77](https://diluviu.colorado.edu/arcgis/apps/viewer/index.html?appid=508E429FC82443098BC087F00CD7FA77)) RIGHT: UNOSAT FLOOD PORTAL ([HTTP://FLOODS.UNOSAT.ORG/GEOPORTAL/CATALOG/SEARCH/SEARCH.PAGE](http://floods.unosat.org/geoportals/catalog/search/search.page))

## FLOOD SUSCEPTIBILITY ASSESSMENT

The procedure for flood hazard assessment makes extensive use of dynamic modelling tools. An example is the algorithm developed by the Joint Research Center of the European Union for flood hazard and risk mapping at the pan-European scale (de Roo et al., 2007 ). A first estimate of the flood hazard is determined from the height above the river. It computes the elevation difference between a specific grid-cell and its closest neighbouring grid-cell containing a river, while respecting the catchment tree-structure: in this way a grid cell can never be linked to a river in another (sub)-catchment. The method is defined by the following main steps: (1) determination of the river network derived from the digital elevation model, (2) define the river as ‘pits’ – outlets of individual small local catchments. For each of those pits, the local catchment draining into this pixel is defined using the ‘catchment’ function, (3) the elevation of the river pixel (the pit) is given to this entire sub-basin: the river pixel is assigned the elevation from the DEM. Finally, the difference between the original DEM and the DEM with the local river altitude is estimated as the height above the river. This local height difference is sliced into susceptibility.

We have used the flood hazard maps that have been generated for the Global Assessment Report (GAR), which are based on global datasets, including 30 m resolution SRTM DEMS. The resulting flood maps are shown in Figure 20. As these maps are very general, we also interpreted the hill shading image of the 12.5 m Alos Palsar DEM, in combination with the Google Earth Images, and digitized our own version of the flood susceptibility map (See Figure 21 ).



# Flood hazard maps for Abkhazia (based on flood modelling)

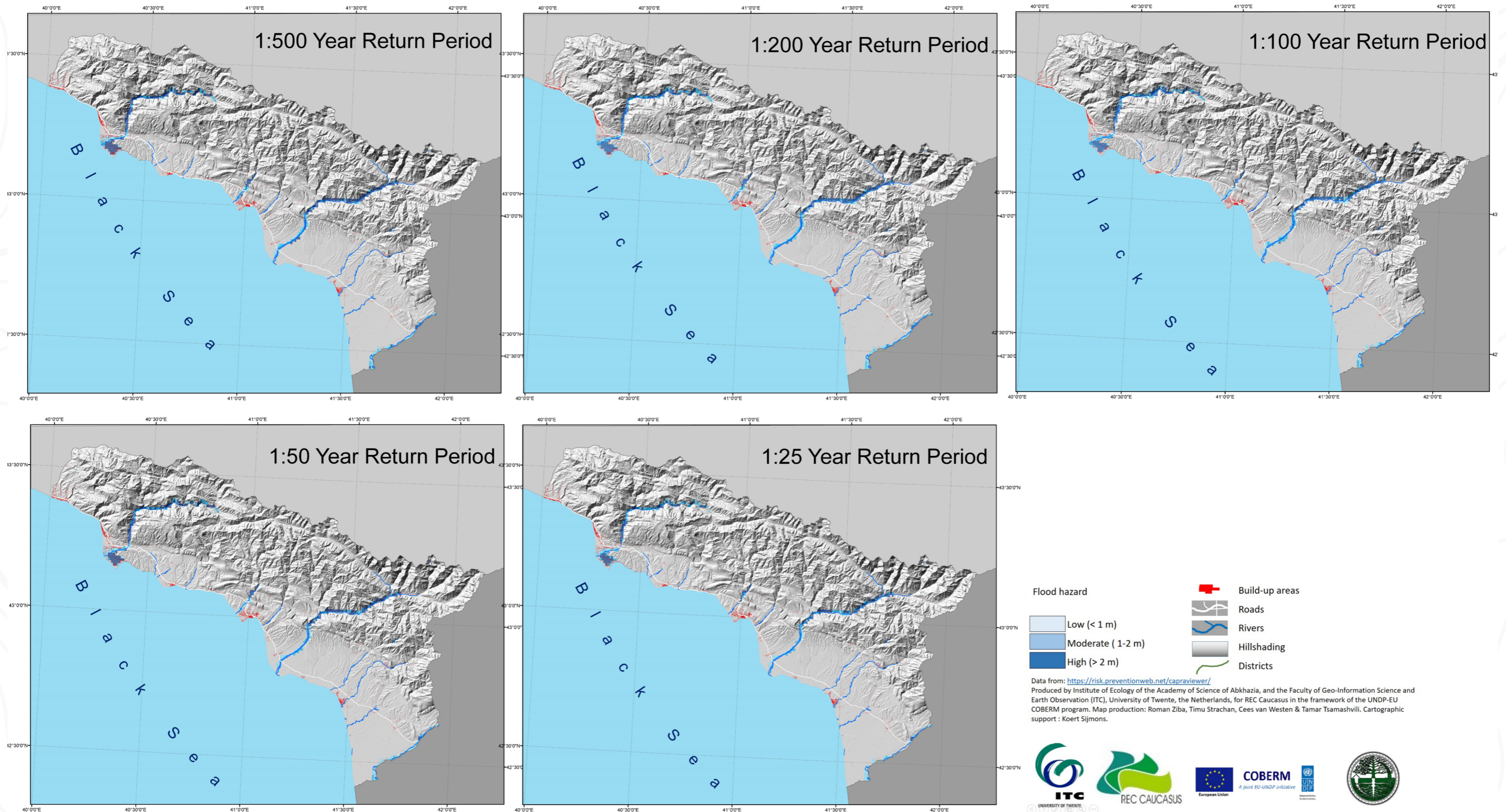


FIGURE 20: FLOOD HAZARD MAPS FOR ABKHAZIA FROM GAR (GLOBAL ASSESSMENT REPORT) DATA PORTAL.



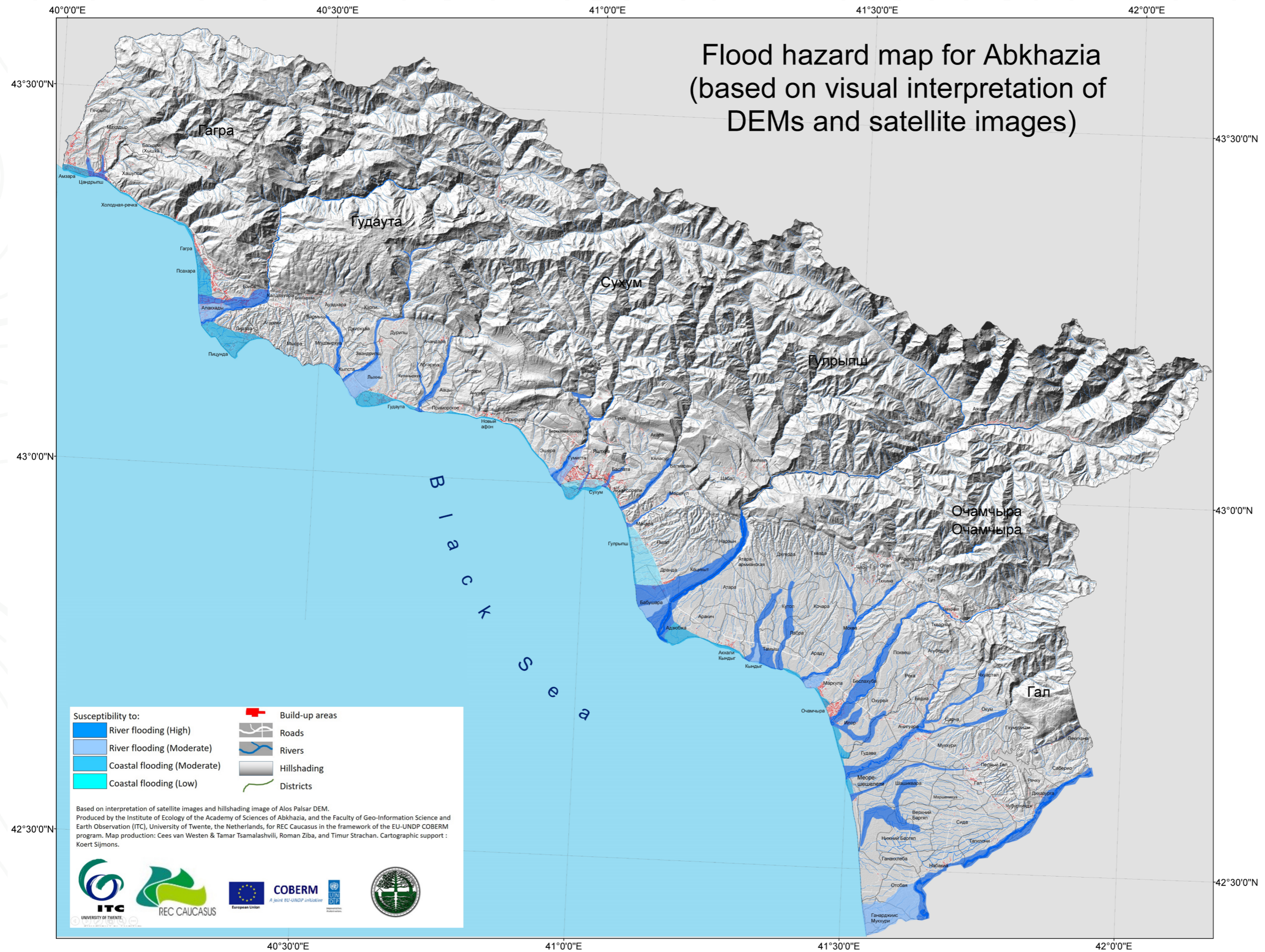


FIGURE 21: FLOOD HAZARD MAPS FOR ABKHAZIA, GENERATED BY INTERPRETATION OF HILL SHADED DEM AND SATELLITE IMAGES.



# WILDFIRES

## HISTORICAL DATA COLLECTION

Historical information on Wildfires was not available from organisation in Georgia or Abkhazia. We therefore also searched for other data on historical wildfires in Abkhazia. The best source of information was GlobalFireWatch (<https://fires.globalforest-watch.org/>). “This uses NASA Fire Information for Resource Management System (FIRMS) near real time (NRT) active fire data from the MODIS and VIIRS satellites to map fire locations. The sensors on these satellites detect the heat signatures of fires from the infrared spectral band. When a fire is detected, the system indicates the area where the fire occurred with an “alert.” Because each satellite orbits the earth twice per day, these alerts can be provided in near-real time. Fire alerts are posted on the NASA FIRMS website within 3 hours of detection by the satellite. The accuracy of fire detection has improved greatly since fire detection systems were first developed for the MODIS satellites. Fire data from the MODIS satellite are approximately 1km resolution and VIIRS satellite data has a resolution of 375m. Today, the rate of false positives is 1/10 to 1/1000 what it was under earlier systems first developed in the early 2000s. The algorithm used to detect fires includes steps to eliminate sources of false positives from sun glint, water glint, hot desert environments and others. When the system does not have enough information to detect a fire conclusively, the fire alert is discarded. In general, night observations have higher accuracy than daytime observations.”

DISTRIBUTION OF FIRE ALERTS 1 JAN 2013 - 19 JUL 2018

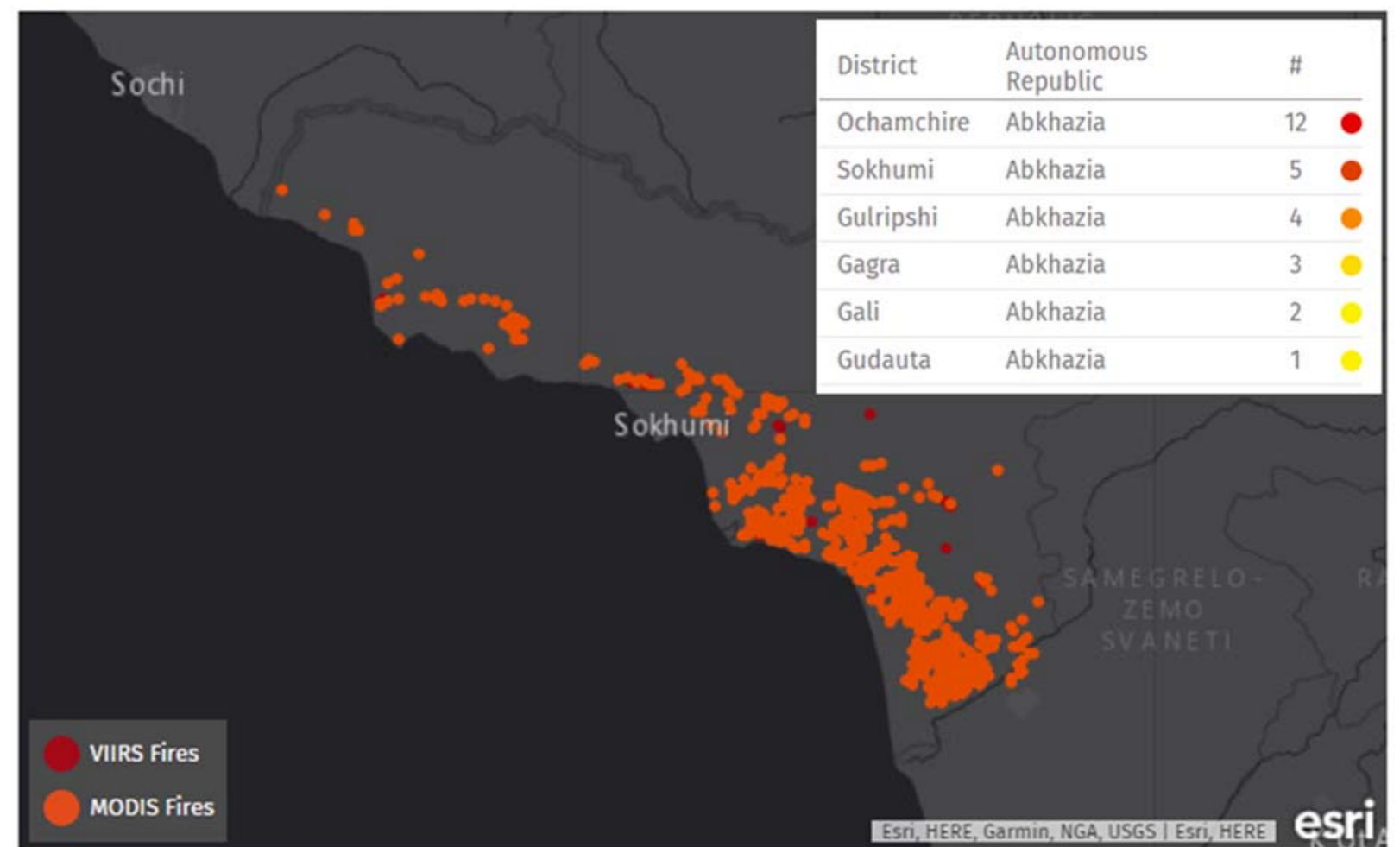


FIGURE 22: WILDFIRES IN ABKHAZIA REPORTED THROUGH SATELLITE OBSERVATIONS BETWEEN 2012 AND 2018 (WWW.GLOBALFIREWATCH.ORG)



### FIRE ALERT COUNT JAN 1, 2012 - PRESENT

#### MODIS fire alerts

Click and drag in the plot area to zoom in

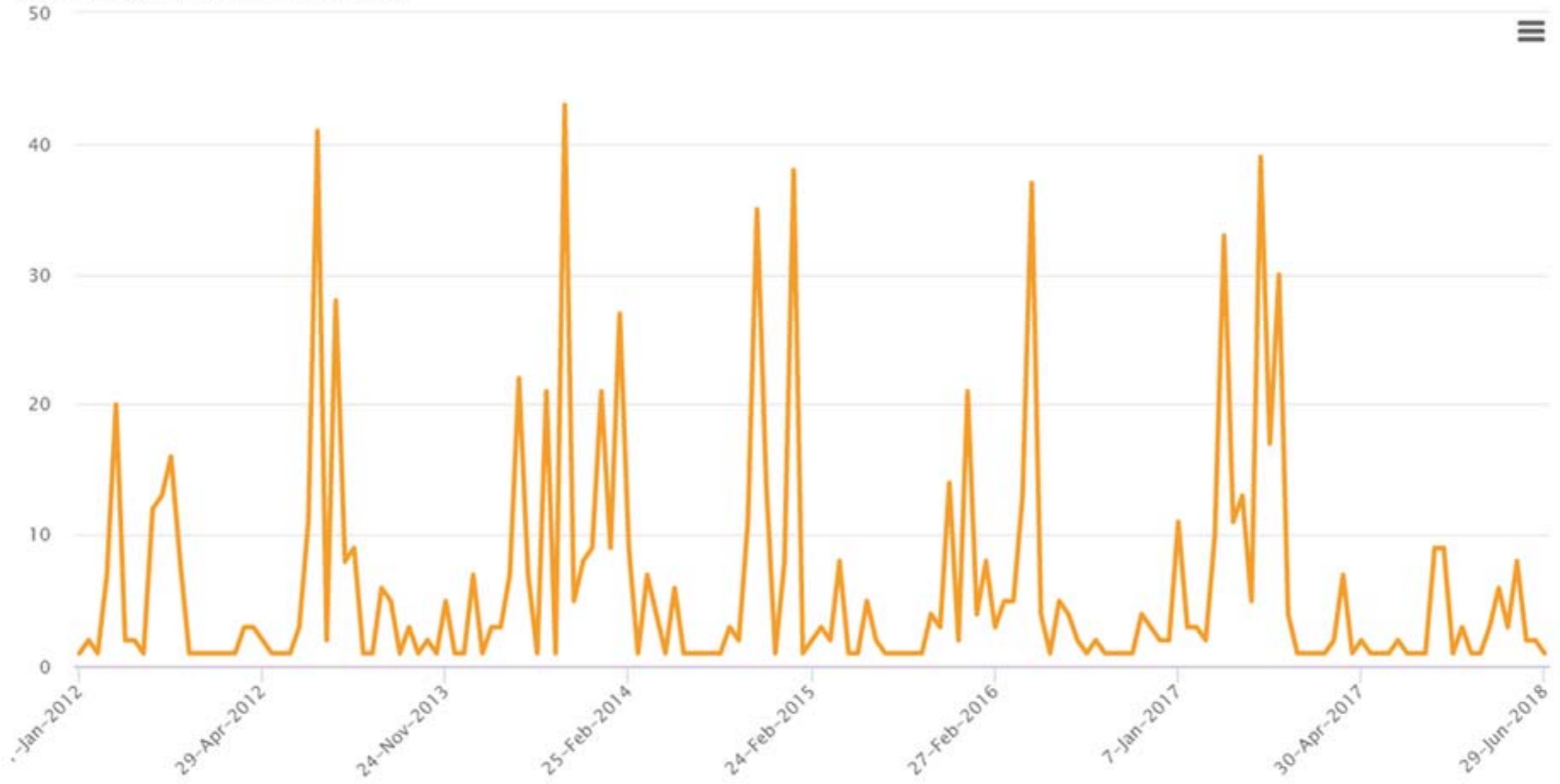


FIGURE 23: FIRE ALERT COUNT REPORTED THROUGH SATELLITE OBSERVATIONS BETWEEN 2012 AND 2018 (WWW.GLOBALFIREWATCH.ORG)

According to the Global Forest Watch ([www.globalforestwatch.org](http://www.globalforestwatch.org)) Abkhazia, with a total area of 881,246 ha, had a very limited loss of forested areas (with >30% canopy density) of 854 ha in the period 2001-2017, and a gain of 377 ha. The total forested area in 2000 was 584,980 ha. This shows that deforestation does not seem to be a major problem in Abkhazia and apparently also not a lot of forested areas are lost because of forest fires.

## WILDFIRE SUSCEPTIBILITY ASSESSMENT

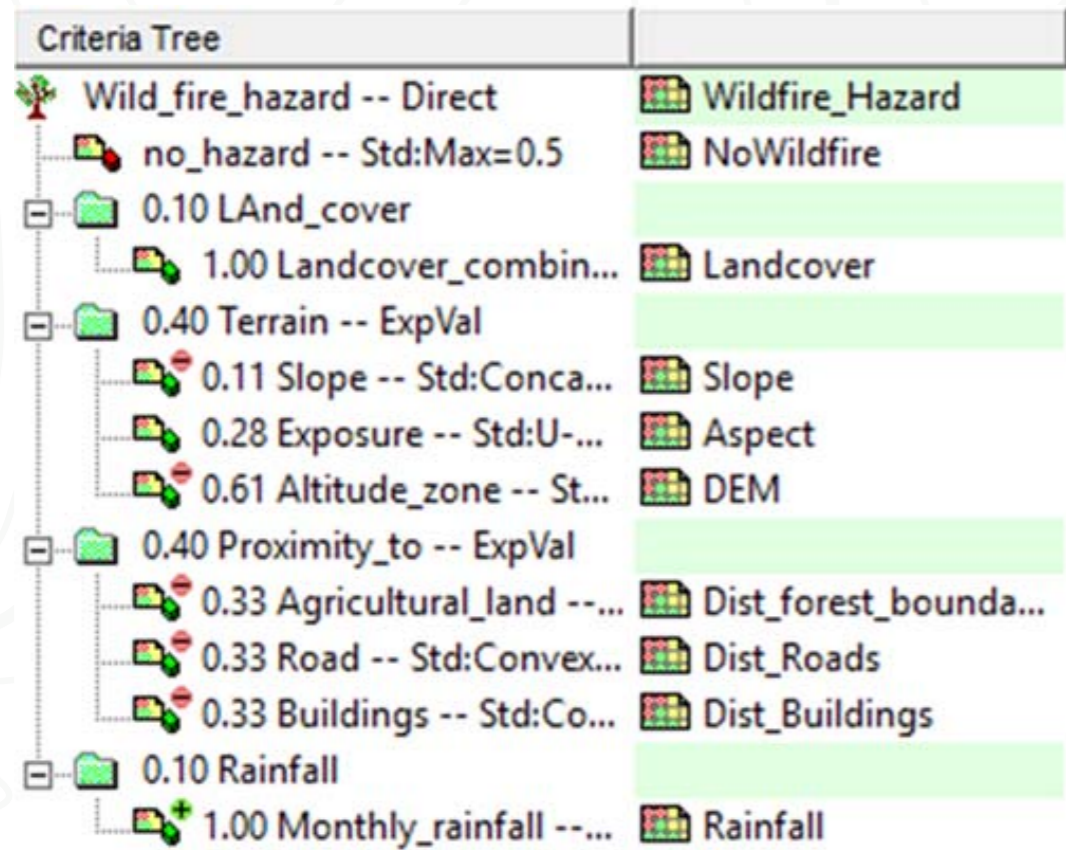
For the wildfire susceptibility assessment we decided to apply the Spatial Multi-Criteria Evaluation method, in which a number of indicators are combined that determine the level of susceptibility to wildfire. Figure 24 shows the criteria tree used for the wildfire hazard assessment. Based on the historical wildfire occurrence we assume that wildfires can occur in the following conditions.

**Landcover.** We used two landcover maps that were available to us. The first one was a polygon map of landcover classes, without any metadata. So we didn't know who made this map, with which method and in which year. When comparing this map with the Google Earth images, it was clear that this map contained quite some inconsistencies. The second landcover map was a satellite derived land cover map generated by the (British geological survey, 2017) for the European Space Agency (ESA). However, this map had larger pixel size and also contained unclassified areas and used as one of the factor maps in SMCE. We assigned susceptibility values to the various landcover classes, as shown in

**Terrain parameters.** Based on the DEM from Alos Palsar, we calculated slope steepness, exposure (slope direction) and altitude, and standardized these values according to the graphs shown in Figure ?. We assume that steeper slopes are less favourable for wildfires, and that south oriented slopes are more susceptible due to drier conditions. We also assume that higher zones are less susceptible than lower zones.

**PROXIMITY TO ....** We assume that most of the wildfires in Abkhazia occur as a result of human consequences. This is supported by the overview of the historical wildfire events shown in Figure 22. We assume that wildfires may occur due to different reasons: burning of agricultural products that run out of control, thrown cigarette buds, open fires nearby buildings etc. Therefore we used several distance maps that represent these situations. A distance map was made of the contacts between agricultural land and forest/shrub land. Another distance map was made from the distance to roads (including also footpaths) and a third distance map for the distance to build-up areas. Figure 25 shows the standardization values used.

**RAINFALL.** Of course drier areas will be more susceptible to wildfires, and therefore we used available average monthly rainfall distribution pattern as indicator. We didn't give it a high weight because the map doesn't show a large spatial variation, and also because this factor is more important as a time prediction factor, rather than a spatial factor.



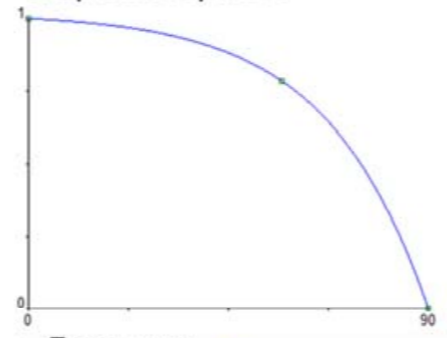
The resulting map was classified into three zones: high, moderate and low. The high susceptible zones occur in the areas that are forested, or have shrubs or mixed agricultural and forest/shrub land in the lower part of Abkhazia.

FIGURE 24: CRITERIA TREE FOR THE WILDFIRE HAZARD ASSESSMENT, USING FOUR GROUPS OF INDICTORS RELATED TO LANDCOVER, TERRAIN, PROXIMITY TO OBJECTS AND RAINFALL.

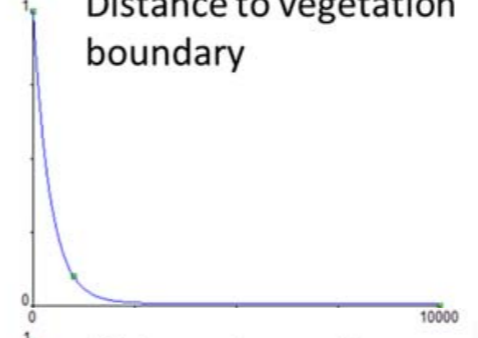
Landcover

| Landuse     | Suitability |
|-------------|-------------|
| Bare        | 0           |
| Cropland    | 0           |
| CropsForest | 0.6         |
| Forest      | 0.9         |
| Grassland   | 0.2         |
| Shrubs      | 1           |
| urban       | 0           |
| water       | 0           |

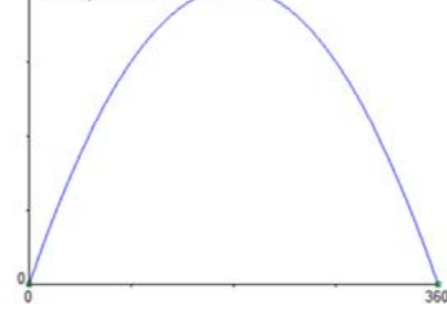
Slope steepness



Distance to vegetation boundary



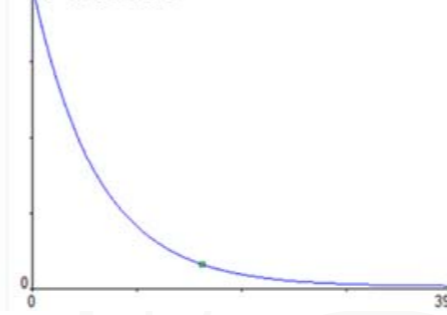
Exposure



Distance to roads



Altitude



Distance to buildings



FIGURE 25: STANDARDIZATION FOR THE MAIN INDICATORS



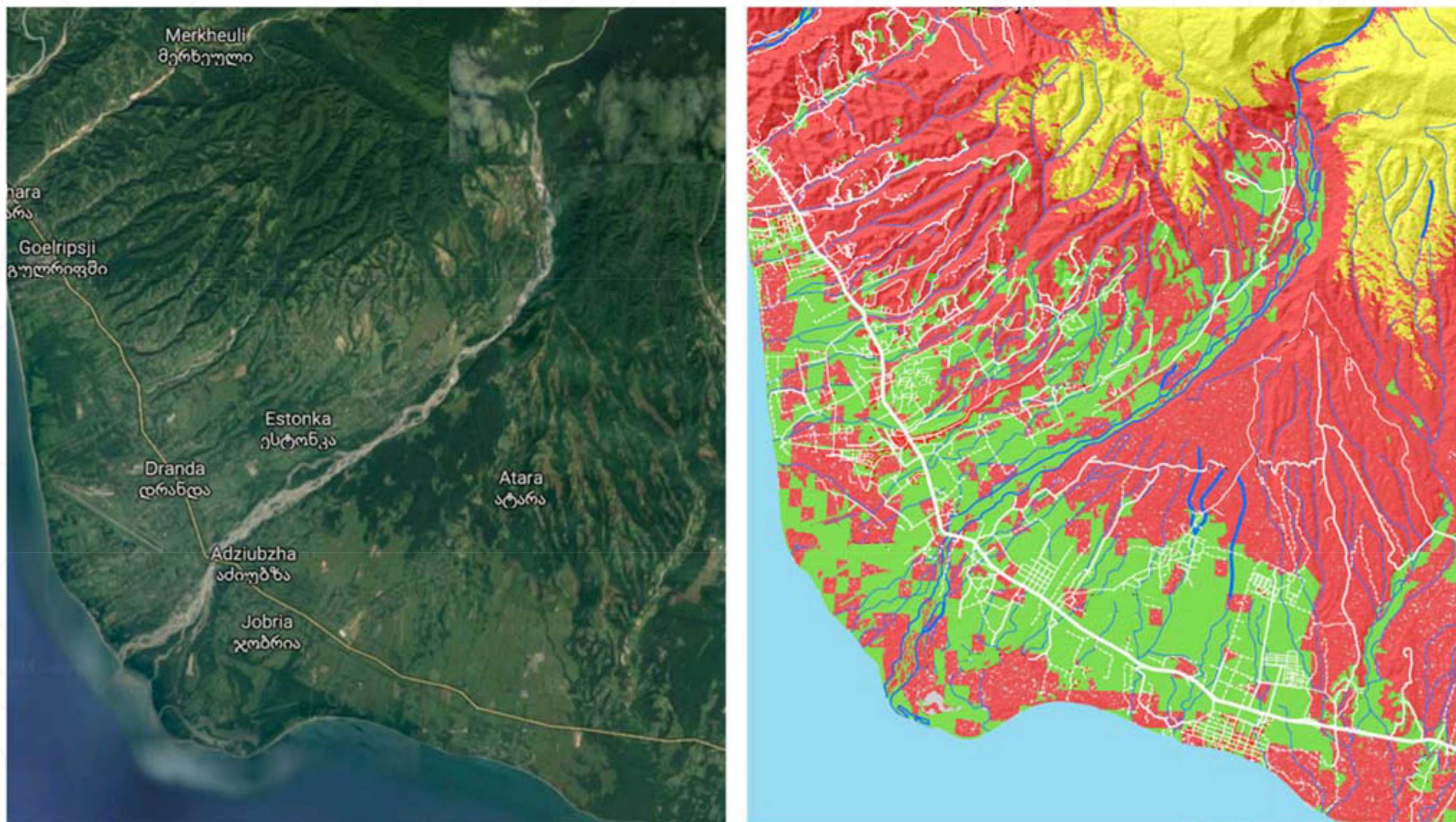


FIGURE 26: WILDFIRE HAZARD MAP: COMPARING GOOGLE EARTH IMAGE WITH WILDFIRE HAZARD MAP FOR A PART OF ABKHAZIA. PROBLEMS WITH AVAILABLE LANDCOVER MAP ARE OBVIOUS.



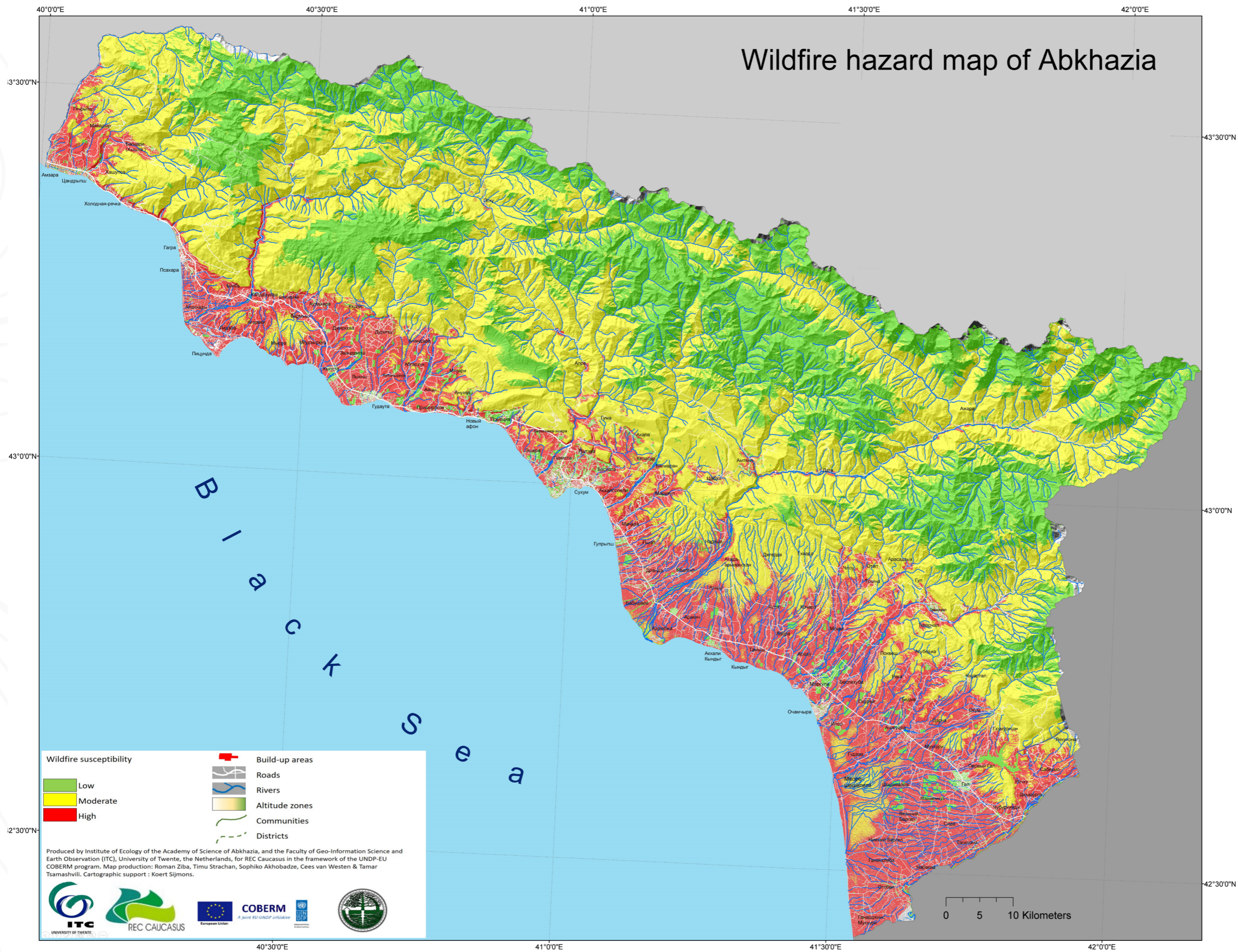


FIGURE 27: WILDFIRE HAZARD MAP.



# EARTHQUAKE HAZARD

## HISTORICAL DATA COLLECTION

Historical earthquake data for Abkhazia was collected from various sources. The 2014 Earthquake Model of the Middle East (EMME14) is the latest seismic hazard model, developed within the Earthquake Model of the Middle East (EMME) Project between 2010 and 2014. (<http://www.efehr.org/en/Documentation/specific-hazard-models/middle-east/overview/>). The model spans across region across eleven countries: Afghanistan, Armenia, Azerbaijan, Cyprus, Georgia, Iran, Jordan, Lebanon, Pakistan, Syria and Turkey. This region is one of the most seismically active regions on Earth because of complex interactions between four major tectonic plates i.e., Africa, Eurasia, Arabia and India and one minor tectonic block - Anatolia. Destructive earthquakes frequently occur within this region with great loss of life and properties, as shown by major earthquake disasters in modern human history 1939 Erzincan (Turkey), 1988 Spitak (Armenia), 1990 Manjil (Iran), Izmit (Turkey, 1999), Bam (Iran, 2003), Kashmir (Pakistan, 2005), Van (Turkey, 2011), and Hindu Kush (Afghanistan, 2015) (Erdik et al., 2012; Giardini et al., 2016). However, Abkhazia did not experience devastating earthquakes in historic times. The EMME project focused on establishing the catalogue of seismicity for the area, using all historical (pre-1900), early and modern instrumental events up to 2006. After removal of duplicate events, foreshocks and aftershocks, and converting all magnitude to Mw scale, 27,174 main events remain from 1250 B.C. through 2006. Homogenization of the catalogue was achieved using regional conversion equations between mb, Ms, ML and Mw and by converting all magnitudes to Mw scale. The primary catalogue presents the events with origin time, longitude, latitude, magnitude and depth (Zare et al., 2014). Figure 28 shows the number of events for magnitudes larger than 3.5 in Abkhazia and surrounding areas.

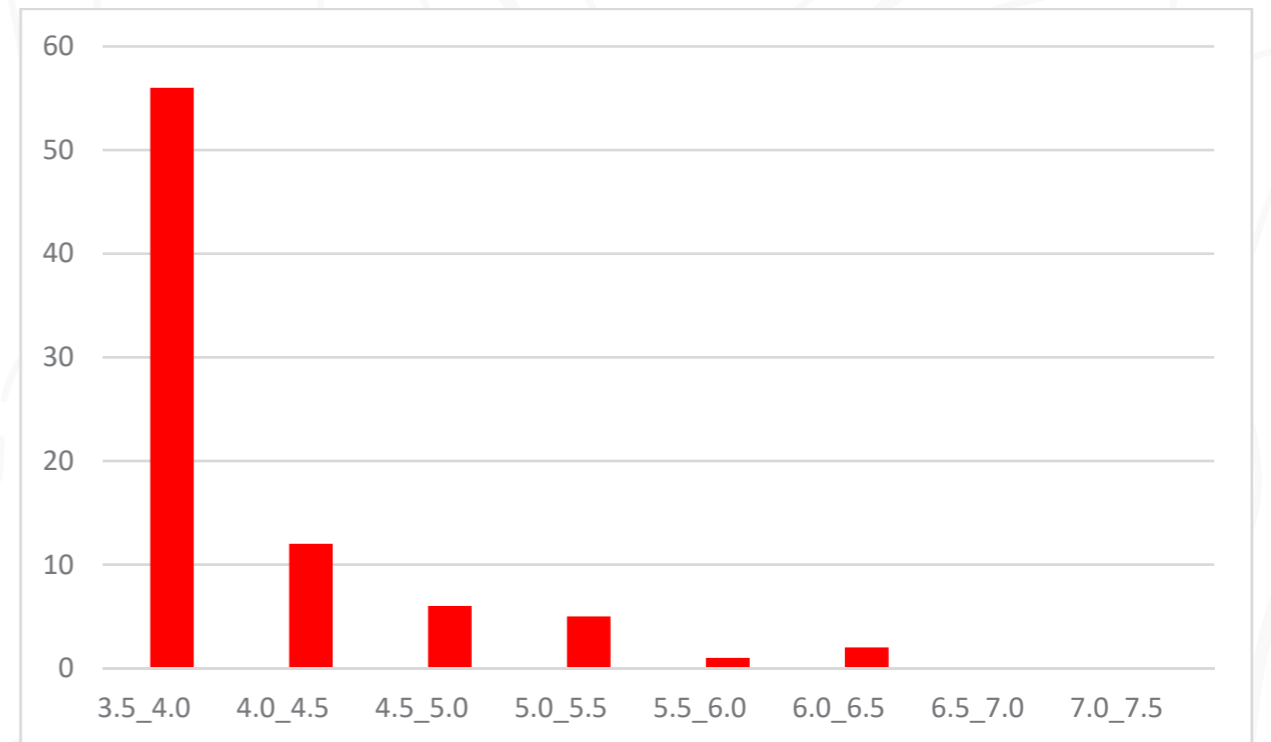


FIGURE 28: NUMBER OF EARTHQUAKES PER MAGNITUDE CLASS.

The most recent earthquake hazard assessment for Abkhazia was carried out as part of the EMME14 project. The following text is derived from their website (EMME14, 2017). “The source model combines well-known identified faults with seismogenic segments or sections compiled within the region. Not all the compiled faults were used to derive the fault source model. From the entire dataset the selection was based on the following criteria:

- Active in Quaternary (1 million years) with a slip-rates of about 0.1mm/year
- Late Quaternary active faults (observed or assigned fault movement during the last 50000 to 130 000years)
- Geological feature (section, segment or faults) have a slip rate at least 0.10mm/year corresponding to 1m in Holocene (~10 000years).
- Maximum magnitude equal to 6.20

The faults were ranked based on the information availability, accuracy and confidence. Top ranked faults were used for hazard assessment. The fault source map presents the selected faults as a function of their slip-rate as well as their 3D geometry. Each fault source is defined as a composite source; they are fully parameterized, including parameters of geometry, slip rate, moment rate etc. together with uncertainties, defined as maximum and minimum values. Activity on fault sources is computed by converting the geological slip rates into seismicity” (Gülen et al., 2014).

For the preparation of the seismic hazard model for the Caucasus the following harmonized inputs and data base were developed (Danciu et al., 2017).

- EMME14 earthquake catalogue (The historical catalogue includes more than 2,000 records for the time period 2000 BC to 1899. The instrumental catalogue covering the time period from 1900 to 2010 includes 6,102 records with  $M_w \geq 5$  )
- EMME14 neo-tectonic model (A digital active tectonic map of the Middle East region has been generated. A total of 3,397 active fault sections are defined and faults with a total length of 91,551 km have been parameterized.)
- EMME14 area, fault source and background models
- Ground Motion Prediction Equations (GMPEs) and logic tree. A comprehensive regional strong motion dataset was compiled. Testing methods were used in ranking the candidate GMPEs and to select the final set for the logic-tree application in regional seismic hazard estimates.

The seismic hazard for the EMME region was computed using OpenQuake (Pagani et al 2014).

Figure 29 gives the Peak Ground Acceleration maps for different return periods (from GAR data platform), and Figure 30 shows the most commonly used version: PGA with 10% exceedance probability in 50 years (= 475 year RP).



# Earthquake hazard maps for Abkhazia (for different return periods)

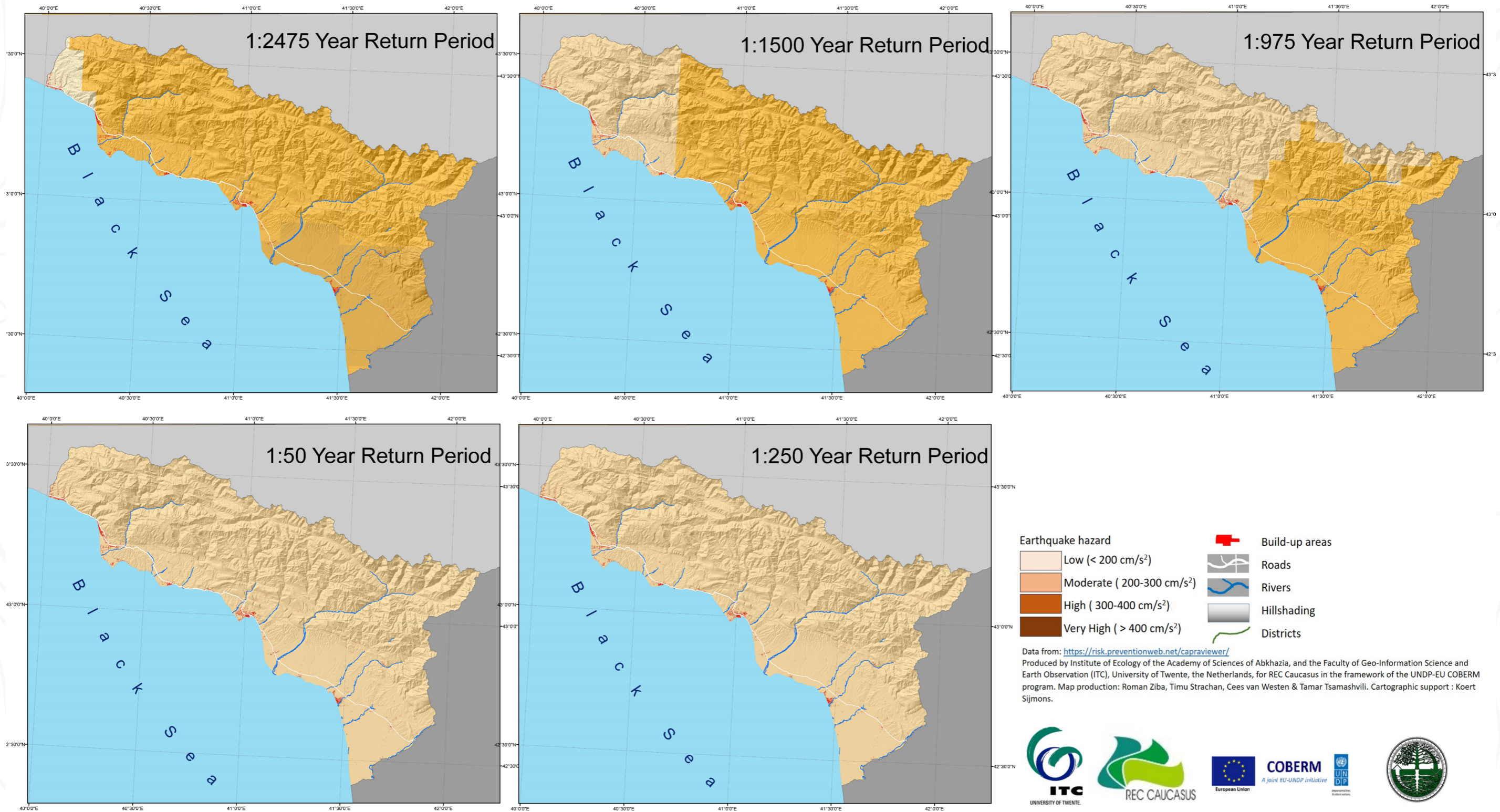


FIGURE 29: PEAK GROUND ACCELERATION MAPS FOR DIFFERENT RETURN PERIODS (FROM GAR DATA PLATFORM: [HTTPS://RISK.PREVENTIONWEB.NET/CAPRAVIEWER/MAIN.JSP?COUNTRYCODE=G15](https://risk.preventionweb.net/capraviewer/main.jsp?countrycode=G15))





### Earthquake hazard map for Abkhazia (PGA levels with 10% probability of exceedance in 50 years)

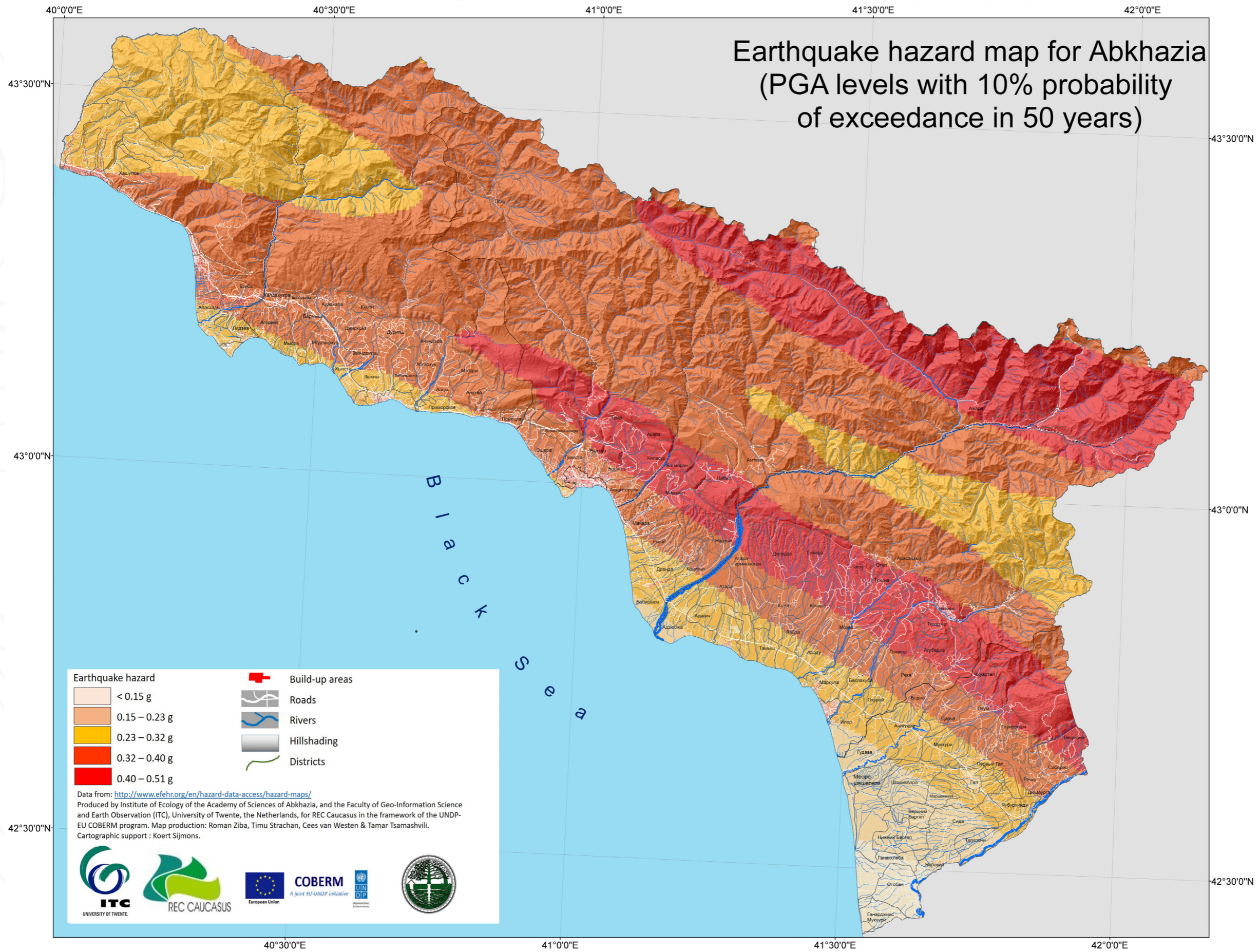


FIGURE 30: PEAK GROUND ACCELERATION MAP WITH 10% EXCEEDANCE PROBABILITY IN 50 YEARS (= 475 YEAR RP) FROM EMM14 PROJECT.



# COASTAL HAZARDS

## HISTORICAL INFORMATION

Whereas in Soviet Union period, the Black Sea's coastline was considered as the "Red Riviera", the waterfront of Sukhumi and Gagra has now many problematic zones, which is leading to the enhanced destabilisation process of the coast. Also the extraction of rock and sand from the river-beds in Abkhazia have a negative impact on the environment. Abkhazia's beaches are formed by sediment gravel and sand from its rivers. Parts of the coastal zone of Gagra, Sukhumi and Promoskoye are under the threat of erosion (Sutcliffe, 2018). There are very few published studies on coastal dynamics of the Black Sea coast.

Zenkovitch (1973) analyses the conditions existing on beaches on the north coast of the Black Sea. The way in which beach material is moved by waves set up by winds from various directions is discussed. Expensive sea-walls and groins have been built. Some underwater investigations as to movement of material were made, and the varying gradients of the sea floor along this coast are significant. In the eastern part of the coast submarine canyons present a special problem. One example is Cape Pitsunda. In the 1960s, the resort town of Pitsunda was built on the eastern side of the peninsula, between its southern point and the mouth of the Bzyb River. The group of residential and office buildings was built as close as possible to a concrete embankment protecting them from the sea. Pitsunda's pine forests and mild climate made it an ideal resort. However, in January 1969, a storm broke out; it lasted 80 hours, damaged the sea wall, flooded the ground floor of the residential buildings, and washed away the shingle beach. A month later, another storm completely demolished the concrete embankment, since the beach no longer offered any protection Yakushenko, O. (2014).

## COASTAL HAZARD MAPPING

We used Google Earth historical images to detect changes in the coastline of Abkhazia. The use of multi-temporal images is standard practice for mapping changes in shoreline (e.g. Aydin and Uysal, 2014), Li et al. 2001). We used Google Earth images from 2003 to 2018. We based the analysis on the results obtained in the EnvironGrids project. The best data related to coastal changes for the Black Sea region can be found on [http://blacksea.grid.unep.ch/layers/geonode:blacksea\\_beaches](http://blacksea.grid.unep.ch/layers/geonode:blacksea_beaches) (Allenbach et al.,2016).

A complete database of Black Sea beaches have been digitalized in Google Earth Pro Application. The dataset are in shapefile format and contain an attribute table with a brief description of the surrounding environment (geometry of the beach, information on images used, presence or absence of wave and/or river, and an appreciation of the sediment size) and percentages of beach's surface loss estimated by the lowest and the highest retreat prediction for three level rise scenarios (0.5 m, 0.82 m and 1 m).

Beach erosion vulnerability has been assessed by combining Black Sea beaches geodatabase with coastal retreat prediction



induced by sea level rise scenarios. Coastal retreat was estimated using an ensemble of 6 analytical (Edelman, 1972; Brunn, 1988; Dean, 1991) and numerical (Larson and Kraus, 1989; Leont'yev, 1996; Roelvink (Xbeach), 2010) models for a vast range of environmental condition, to better reflect the entire Black Sea basin (Allenbach et al., 2016). We used a map /database of the beaches of the entire Black Sea area. The map shows the maximum beach's surface loss in percentage induced by a sea level rise of 0.5 m (max. retreat prediction of 21.4 m). The map contained the following attributes:

**NAME:** Code name of the beach 3 first letters are the country followed by a clock-wise numbering

**ORIENT:** Calculated orientation of the beach in degree

**LENGTH:** Calculated length of the beach in meters

**MAX:** Calculated maximum width of the beach in meters

**MEAN:** Calculated mean width of the beach in meters

**AREA:** Calculated area in square meters

**B\_NAME:** Name of the beach when available

**P\_CODE:** Code for protection description

1: Groynes, breakwaters, headlands

2: Natural coves

3: Natural beach without protection

4: Training wall

5: Seawall and revetments

**FRONT:** Simplified code for coast description

1 presence of vegetation

2 presence of urban

3 presence of dunes

4 presence of cliff

5 presence of agriculture

6 presence of marshlands

7 presence of water

ex: 123 presence of vegetation-urban-dune

**RIVER:** presence 1 or absence of river 0

**G\_CODE:** Sediment size appreciation (Google photographs)



0 not available

1 Fine (only sand)

2 Medium (sand-pebble-shells)

3 Coarse (only pebble)

**C2: Front beach description (coast) categories**

11 Vegetation and sand mixture

12 Grass vegetation

13 Shrub vegetation

14 Tree vegetation

21 Buildings

22 Road

23 Wall

24 Seawall and revetments

31 Dune

32 Dune with vegetation

41 Vegetation on steep slope

42 Little vegetated escarpment

43 Steep rocky slope

51 Agriculture

61 Marshes

71 Lake, Lagoon

72 River

**WAVE: Presence 1 or absence of waves in the image**

**DATE: Date of the satellite image used**

**SLR1min: minimum % of the beach surface loss by a coastal retreat of 4.1 meters induce by a SLR of 0.5 m**

**SLR1max: maximum % of the beach surface loss by a coastal retreat of 21.4 meters induce by a SLR of 0.5 m**

**SLR2min: minimum % of the beach surface loss by a coastal retreat of 6.9 meters induce by a SLR of 0.82 m**

**SLR2max: maximum % of the beach surface loss by a coastal retreat of 31.6 meters induce by a SLR of 0.82 m**

**SLR3min: minimum % of the beach surface loss by a coastal retreat of 8.5 meters induce by a SLR of 1 m**

**SLR3max: maximum % of the beach surface loss by a coastal retreat of 37.3 meters induce by a SLR of 1 m**



# Coastal hazard maps of Abkhazia (from EnvironGRIDS project)

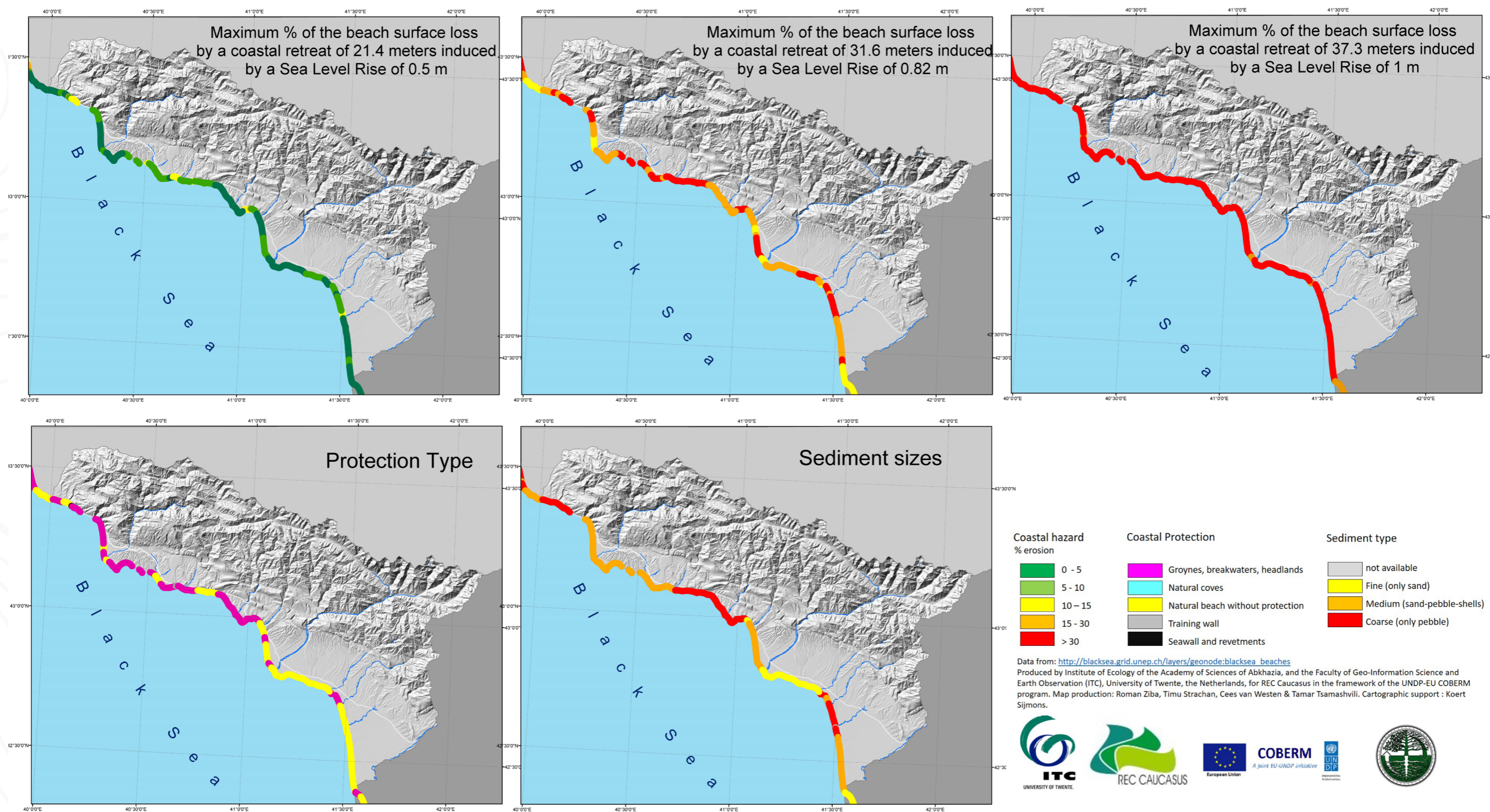


FIGURE 31: COASTAL HAZARDS IN ABKHAZIA, DERIVED FROM THE ENVIRONGRIDS PROJECT (HTTP://BLACKSEA.GRID.UNEP.CH/LAYERS/GEONODE:BLACKSEA\_BEACHES)



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