Snow Avalanche Risk Assessment

21-Dec-11

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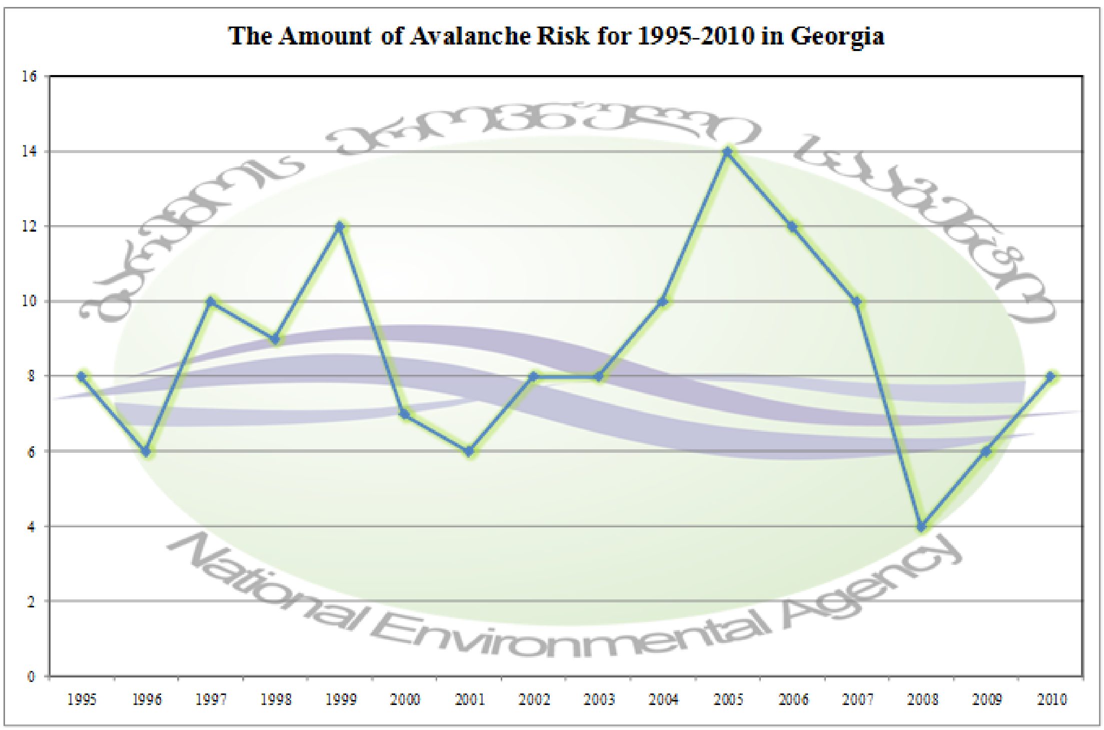
1. Introduction

Due to complicated topography, different climate conditions and hydrographic situation (dense network of rivers), the natural catastrophes, such as landslides, mudflows, floods and avalanches are frequent in Georgia.
One of the main disasters, which challenges human catastrophes and loss amounted hundreds of millions of US dollars is Avalanche.
There are 5000 avalanche catchment areasidentified in Georgia. More than 1100 endanger settlement, communication, road, electricity and etc. Annually from each avalanche catchment fixed 1-10 occurrence.[1]
The most sensitive zones are the western and the central part of Caucasus. And the most damaged regions are: Svaneti, mountain Adjara, Tusheti, Kazbegi and Dusheti.[2]
In Winter 1970-71 while the catastrophic snowfalls identify 39 human losses, in winter 1975-78 – 42, in winter 1986-87 – 80. The material damage reached 60, 200 and 500 mln USD respectively. About 20 000 inhabitant were forced to change dwelling.[3]



This graphic is done by NEA where is shown statistical data from 1995-2010 of the amount of avalanche risk. The numbers are showing the amount of occurred avalanche, which challenged a serious damage.

Snow avalanches are gravity mass flows that occur only in mountainous terrain of sufficient inclination and at altitudes. For this reason, their occurrence is more spatially restricted than for other hydrogeological hazards such as debris flows and floods, and it is more temporally limited than for rock avalanches and landslides. However, essentially all mountain slopes steeper than about 30^0 receiving sufficient snow precipitationare potentially avalanche-prone.

[1] NEA information
[2] NEA information
[3] NEA information

Terrain is an essential factor and the only factor that is constant over time. A slope angle of $>30^0$ is usually required for dry snow slab avalanches.With digital terrain models (DTM) and geographical information systems (GIS) potential starting zones can be identified and their characteristics compared to avalanche occurrence. However, this approach is only reliable if the DTM resolution andaccuracy are not larger than 20 –30 m, and even then they do not indicate small-scale variations in slope anglethat are of interest for avalanche forecasting.[4]

Forests inhibit avalanche formation. In dense forests (>200 trees of diameter >16 cm ha^{-1}) the snow cover is too irregular to produce avalanches[5].

For large (catastrophic), new snow avalanches, precipitation is the strongest forecasting parameter and is closely related to avalanche danger. Accumulation of a new snow depth of about 1 m within a storm is considered critical for the initiation of extreme avalanches; about 30–50 cm is critical for naturally released avalanches in general.[6]

Wind contributes to loading and is often considered the most active contributing factor after new snow.Loading by wind-transported snow can be fast and produces irregular deposits with locally increased loading rates. Variations in wind speed and snow drift form
layers of different density or hardness, creating stress concentrations within the layered snowpack. Proposed that the wind transforms the snow into a more brittle material and that wind-deposited snow layers are more prone to avalanching.[7]

Temperature is a decisive factor contributing to avalanche formation, particularly in situations withoutloading. Its effect on snow stability is complex sincechanges in air temperature affect snow stability in variousways.. Rising temperature during a storm and rapid temperature increaseshortly after a storm contribute to instability. Changes in air temperature primarily affect surface layers, i.e., the slab, whereas the weak layer is relatively unaffected because of the generally low thermal conductivity of snow.[8]

Snow cover stratigraphy is recognized as the keycontributing factor for dry snow slab avalanche formation. Any loading by new or wind-driven snow or any temperature increase has no effect on snow stability if no weakness exists in either the old snow or at the old snow surface underlying the new snow. Therefore the weak layer or interface is a necessary prerequisite but not sufficient condition for avalanche formation.[9]

The rain plays a complex role in snow metamorphism. Generally, for dry snow, a small increase in the liquid water content (LWC<0.5%) does not significantly affect the mechanical properties ofsnow. However, heavy rain induces a rapid and noticeable increase in LWC, which results in a

[4]Jürg Schweizer, J. Bruce Jamieson, Martin Schneebeli – Snow Avalanche Formation [13], [16]
[5]Frey et al., 1987; Gubler and Rychetnik, 1991; Schneebeli and Meyer-Grass, 1993
[6]Jürg Schweizer, J. Bruce Jamieson, Martin Schneebeli – Snow Avalanche Formation [19]
[7]Jürg Schweizer, J. Bruce Jamieson, Martin Schneebeli – Snow Avalanche Formation [24]
[8]Jürg Schweizer, J. Bruce Jamieson, Martin Schneebeli – Snow Avalanche Formation [30]
[9]Jürg Schweizer, J. Bruce Jamieson, Martin Schneebeli – Snow Avalanche Formation [35]

drop in the shear stress strength. This situation leads towidespread avalanche activity (wet snow avalanches).[10]

The orientation of slopes with respect to the sun has a strong influence on the day-to-day stability of the snowpack. For instance, in winter, shady slopes receive little incoming radiation from the sun and conversely lose heat by long-wave radiation. It is generally observed that for these slopes, the snowpack is cold and tends to develop weak layers (faceted crystals, depth hoar). Many fatalities occur each year in such conditions. In late winter and in spring, the temperature increase enhances stability of snowpacks on shady slopes and instability on sunny slopes.[11]

There are lots of other factors of snow avalanche formations: snow thickness, snow density, ground surface roughness, ground shape and curvature, altitude etc.

[10]Christophe Ancey - Cemagref, unite Erosion Torrentielle, Neige et Avalanches, Domaine Universitaire, 38402 Saint-Martin-d'Heres Cedex, France. p. 3

[11]Christophe Ancey - Cemagref, unite Erosion Torrentielle, Neige et Avalanches, Domaine Universitaire, 38402 Saint-Martin-d'Heres Cedex, France. p. 3

2. Research Methodology

The first step is to determine snow avalanche starting zones and to classify them according to occurrence risk. Altitude, slope, plan curvature, aspect, temporal and spatial snow extend, snow depth and forest maps were created and reclassified according to their importance for avalanche formation. Each map has integer values 1, 2 and 3 (the higher value means the better conditions for snow avalanche formation). All maps play positive role in forming of snow avalanche. The only exception is forest map. Forest is braking factor for snow avalanche, but forested landscape doesn`t exclude avalanche. As far as we do not have information about forest type, their density etc. only two value classification was done. If forest presents value is -3, if it doesn`t – 0.
Sum operation of all seven maps gives us raster with snow avalanche starting zones classified by the level of hazard from 6 to 18. It will be reclassified to 3, 4 or 5 level as soon as we decide which one to use.This map has been validated using snow avalanche shapefile provided by NEA.
The next step is to determine track and runout zone of snow avalanche in order to assess all possible damage.

3. Baseline Data and Preprocessing

3.1. Data Sources

We collected necessary data from different sources. They are:

- **National Environmental Agency of Georgia (NEA)**

  Data:

Database of already occurred snow avalanches (2009y) for the part of western and eastern Georgia;
Shapefile of some snow avalanches for different regions of Georgia;
Books and articles;
Avalanche risk map of Georgia (scale 1:2000000) done by NEA.

- **National Resources Agency of Georgia**

  Data:

Shapefile of forest cover of Georgia. Database isn`t full;
Shapefile of protected areas of Georgia.

- **Terra Satellite**

  Data:

Aster GDEM v2;
Modis Snow Cover.

- **Landsat Satellites**

  Data:

Landsat TM 4-5 spectral images.

- **Climate catalog book of USSR**

  Data:

Maximal (sometimes average) snow depth from 193 stations (middle of XX century).

- **Historical data from media**

It was important to analyze historical data, about already occurred snow avalanche in Georgia. Source was archived newspapers from National Library of Georgia, this data was starting from 1860s.

3.2. Data Description and Preprocess

3.2.1 Aster GDEM v2

The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model (GDEM) was developed jointly by the U.S. National Aeronautics and Space Administration (NASA) and Japan's Ministry of Economy, Trade, and Industry (METI).

The ASTER GDEM covers land surfaces between 83°N and 83°S and is comprised of 22,702 tiles. Tiles that contain at least 0.01% land area are included. The ASTER GDEM is distributed as Geographic Tagged Image File Format (GeoTIFF) files with geographic coordinates (latitude, longitude). The data are posted on a 1 arc-second (approximately 30–m at the equator) grid and referenced to the 1984 World Geodetic System (WGS84)/ 1996 Earth Gravitational Model (EGM96) geoid.

Updates in GDEM Version2[12]:

- Finer horizontal resolution - The elevation is calculated by image matching of ASTER stereopair. The kernel size for image correlation matching is changed to 5 by 5 pixel from 9 by 9 pixel.
- Water body detection - GDEM ver. 1 could detect lakes larger than about $12km^2$. This improves to $1km^2$ in version 2.
- New observed data - GDEM version 2 incorporates new ASTER data observed afterSeptember 2008. The voids and artifacts caused by lack of ASTERdata will be improved.
- Resolution improves to 70m from 110m (version 1).
- Offset reduces to -0.7m from -6m (version 1).
- Voids in northern area decrease.
- Artifacts mostly disappear.
- Lakes are perfectly flat.

While the ASTER GDEM 2 benefits from substantial improvements over GDEM 1, users are nonetheless advised that the products still may contain anomalies and artifacts that will reduce its usability for certain applications, because they can introduce large elevation errors on local scales. The data are provided "as is" and neither NASA nor METI/ERSDAC will be responsible for any damages resulting from use of the data.[13]

According to our quality check process between Aster GDEM v2 and topographic maps 25k and 50k, also digitized point elevations from 50k topo map, Aster GDEM v2 elevation was very close to elevation points from 25k topo map. 50k map (paper and digitized) had relatively big errors.[14]

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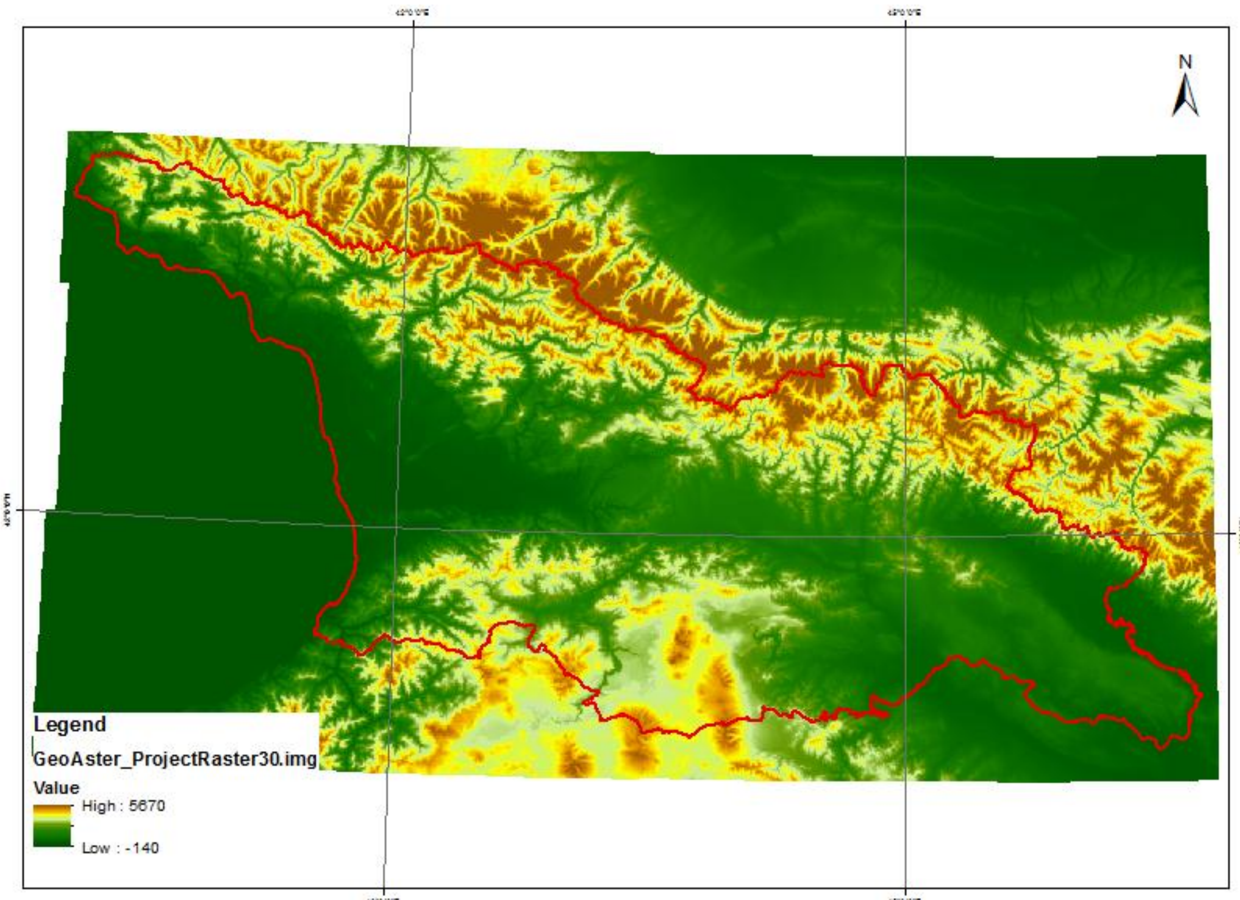
[12]Tetsushi Tachikawa, Masami Hato, Manabu Kaku, Akira Iwasaki - Characteristics of ASTER GDEM Version 2
[13]https://lpdaac.usgs.gov/content/view/full/11033
[14] See additional file "Which Dem Is Better"

ASTER Global DEM (GDEM) data are subject to redistribution and citation policies. Before ordering ASTER GDEM data, users must agree to redistribute data products only to individuals within their organizations or projects of intended use, or in response to disasters in support of the GEO Disaster Theme. When presenting or publishing ASTER GDEM data, users are required to include a citation stating, "ASTER GDEM is a product of METI and NASA."

We decided to use Aster GDEM v2. This DEM was downloaded from http://demex.cr.usgs.gov/DEMEX/

Downloaded data represents whole Caucasus region and by default was divided into three parts. We used ArcGis Data management tool "mosaic to new raster" and received one raster from three.

Figure 1: 30 m pixel size DEM



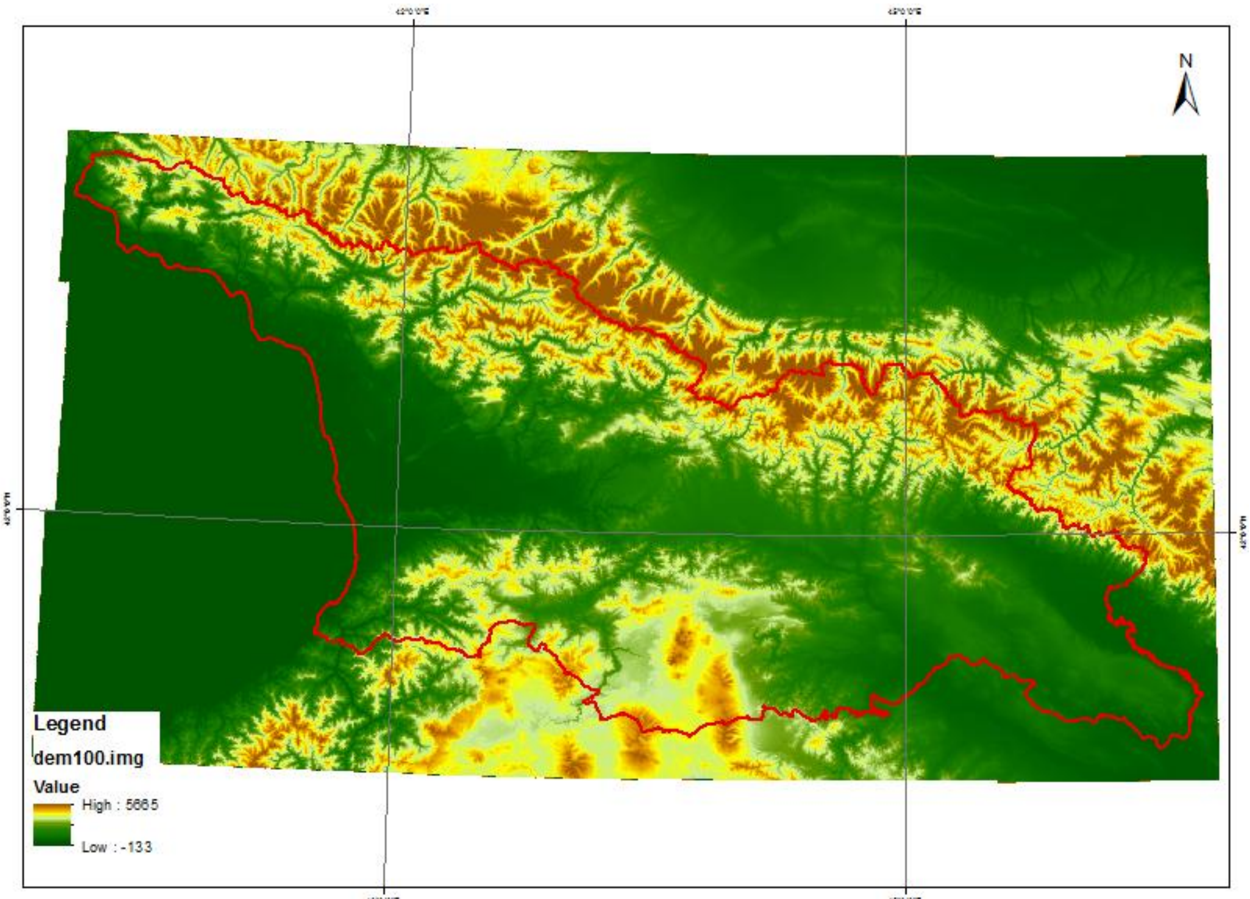
The min. elevation value from our DEM is -140m. Of course, -143m is anomaly but these errorsare in the Black Sea area and also on the most NE part of DEM. When we extracted DEM using Georgia`s state boundary contour we have got 0m as minimal elevation.

The max. elevation value is 5670m, it represents the highest mountain peak of Caucasus - Ialbuzi (Elbrus), It`s elevation is 5642m[15]. Offset is 28m.

[15] The World Book Encyclopedia—Page 317 by World Book, Inc

DEM was resampled to 30m pixel and reprojected to WGS 84, N38. Later we resampled it from 30m to 100m pixel size. On all steps resampling technique was “cubic”.

Figure 2: 100m pixel size DEM



3.2.2 Modis Snow Cover

The MODIS/Aqua Snow Cover Monthly L3 Global 0.05Deg CMG (MYD10CM) data set, new for Version 5 (V005), contains snow cover and Quality Assessment (QA) data in Hierarchical Data Format- Earth Observing System (HDF-EOS) format, and corresponding metadata. This data set consists of 7200 column by 3600 row global arrays of snow cover in a 0.05 deg Climate Modeling Grid (CMG). MODIS snow cover data are based on a snow mapping algorithm that employs a Normalized Difference Snow Index (NDSI) and other criteria tests. Monthly average snow cover is calculated from the daily global products for the month.

These data are offered free of charge. You may use these data freely, provided that you cite NSIDC as the source, and provide an acknowledgment in any published papers.

The following example shows how to cite the use of this data set in a publication:
List the principal investigators, year of data set release, data set title and version number, dates of the data you used (for example, December 2003 to March 2004), publisher: NSIDC, and digital media.
Hall, Dorothy K., George A. Riggs, and Vincent V. Salomonson. 2006, updated monthly. MODIS/Aqua Snow Cover Monthly L3 Global 0.05Deg CMG V005, [list the dates of the data used]. Boulder, Colorado USA: National Snow and Ice Data Center. Digital media.

Snow Cover Monthly CMG Field Coded Integer Values	
Value	**Description**
0 - 100	percent of snow in cell
211	night
250	cloud
253	no decision
254	water mask
255	fill

Data was ordered by http://reverb.echo.nasa.gov/reverb/

According to list of snow avalanches occurred in Georgia in 2009[16] and European experience (mainly alpine) dangerous periods for snow avalanche is from November till April. That's why we decided to order 6 Modis images per year (season) for last 6 years. So we ordered and received 36 images.

[16] Provided by NEA

Season 1:
MYD10CM.A2005305.005.2008084212423.hdf – 11.2005;
MYD10CM.A2005335.005.2008094202839.hdf – 12.2005;
MYD10CM.A2006001.005.2008067164053.hdf – 01.2006;
MYD10CM.A2006032.005.2008081164725.hdf – 02.2006;
MYD10CM.A2006060.005.2008099190711.hdf – 03.2006;
MYD10CM.A2006091.005.2008113204647.hdf – 04.2006.

Season 2:
MYD10CM.A2006305.005.2008133193925.hdf – 11.2006;
MYD10CM.A2006335.005.2008142173855.hdf – 12.2006;
MYD10CM.A2007001.005.2007052080752.hdf – 01.2007;
MYD10CM.A2007032.005.2007071105847.hdf – 02.2007;
MYD10CM.A2007060.005.2007121035613.hdf – 03.2007;
MYD10CM.A2007091.005.2007134211715.hdf – 04.2007.

Season 3:
MYD10CM.A2007305.005.2007344044828.hdf – 11.2007;
MYD10CM.A2007335.005.2008008184258.hdf – 12.2007;
MYD10CM.A2008001.005.2008036190548.hdf – 01.2008;
MYD10CM.A2008032.005.2008067205530.hdf – 02.2008;
MYD10CM.A2008061.005.2008094172451.hdf – 03.2008;
MYD10CM.A2008092.005.2008126182135.hdf – 04.2008.

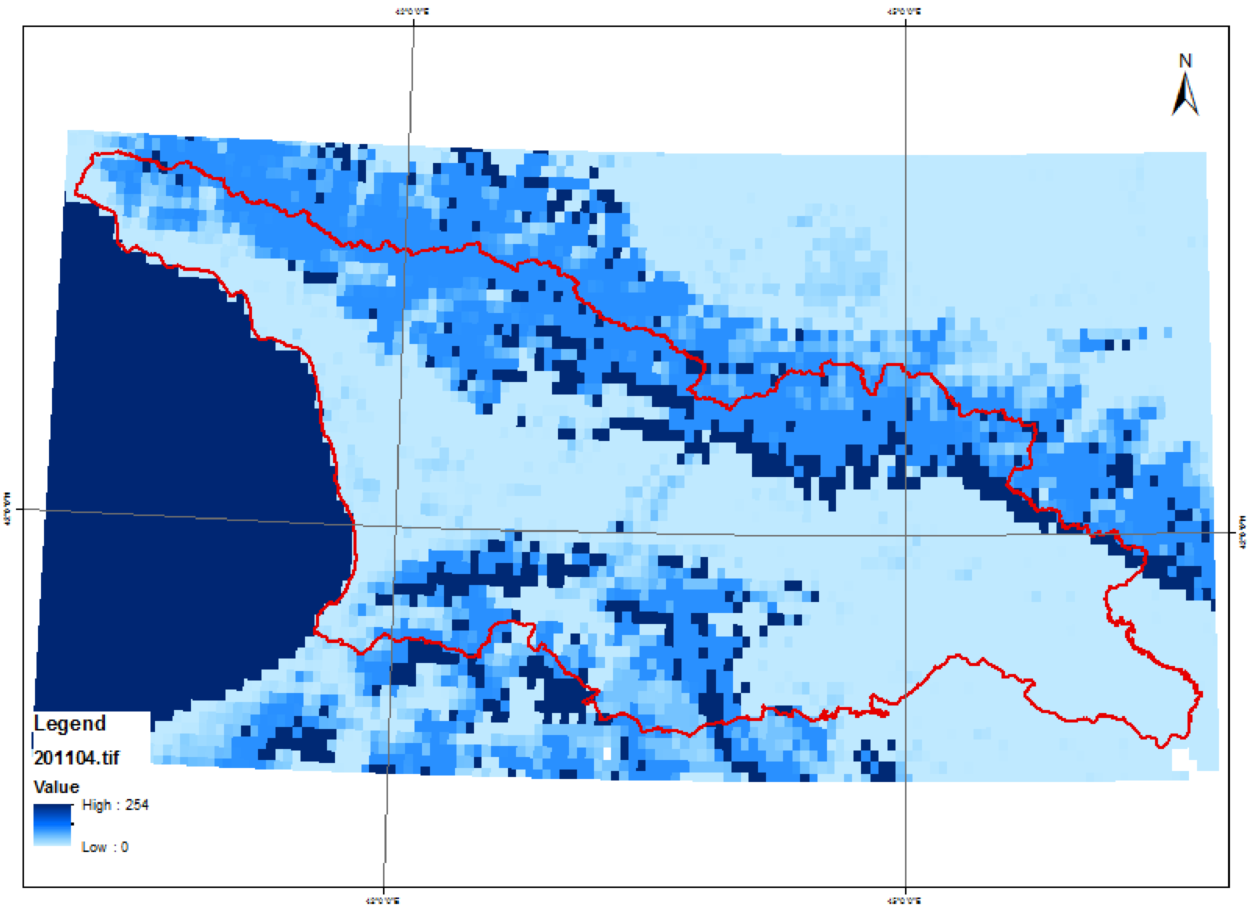
Season 4:
MYD10CM.A2008306.005.2008340141244.hdf – 11.2008;
MYD10CM.A2008336.005.2009033163301.hdf – 12.2008;
MYD10CM.A2009001.005.2009040134844.hdf – 01.2009;
MYD10CM.A2009032.005.2009065133001.hdf – 02.2009;
MYD10CM.A2009060.005.2009100130245.hdf – 03.2009;
MYD10CM.A2009091.005.2009126063025.hdf – 04.2009.

Season 5:
MYD10CM.A2009305.005.2009354191924.hdf – 11.2009;
MYD10CM.A2009335.005.2010011135427.hdf – 12.2009;
MYD10CM.A2010001.005.2010040151341.hdf – 01.2010;
MYD10CM.A2010032.005.2010062181601.hdf – 02.2010;
MYD10CM.A2010060.005.2010103144512.hdf – 03.2010;
MYD10CM.A2010091.005.2010133130146.hdf – 04.2010.

Season 6:
MYD10CM.A2010305.005.2010343161635.hdf – 11.2010;
MYD10CM.A2010335.005.2011005160514.hdf – 12.2010;
MYD10CM.A2011001.005.2011038164217.hdf – 01.2011;
MYD10CM.A2011032.005.2011062112942.hdf – 02.2011;
MYD10CM.A2011060.005.2011116141319.hdf – 03.2011;
MYD10CM.A2011091.005.2011123002919.hdf – 04.2011.

As Modis image represents whole world all 36 scenes were extracted (in ArcGis) using Aster GDEM v2 file.

Figure 3: One example of extracted Modis Snow Cover. Image represents April of 2011.



3.2.3. Database of Already Occurred Snow Avalanches

NEA provided us database of already occurred snow avalanches (2009y) for western and eastern Georgia. This Excel file has the following data fields:

- Number or name of snow avalanche;
- Date - when happened snow avalanche;
- Sort of snow avalanche;
- Start zone elevation;
- Elevation of toe of snow avalanche;
- Snow avalanche track length;
- Snow avalanche surface characteristics;
- Avalanche snowshed area;
- Slope degree of starting zone;
- Snow average density at the moment of very start of snow avalanche;
- Snow avalanche morphometry;
- Snow avalanche snow density;
- Comment

Figure 4: Screenshot of snow avalanche database from NEA

ჩამოსული ზვავების უწყისი

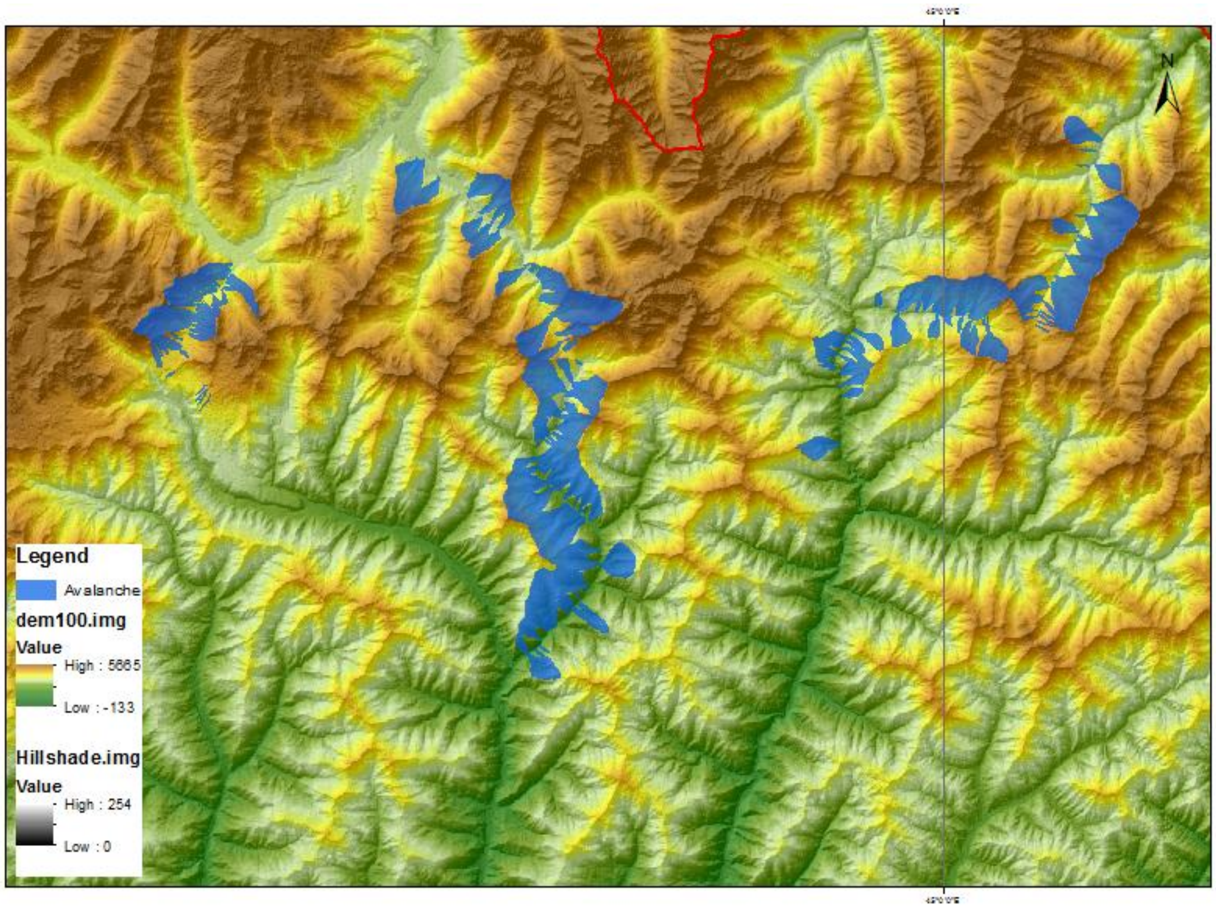
რგ №	№ ან ზვავის დასახელება	ზვავის ჩამოსვლის დრო და რიცხვი	ზვავების ტიპები მორფოლოგიისა და გენეზისის მიხედვით	ზვავების მოწყვეტის ზონის სიმაღლე ზღვიდან მ-ში	ზვავების დაცემის სიმაღლე ზღვის დონიდან მ-ში	განვლილი გზის სიგრძე	ჩამოსული ზვავების ზედაპირის დახასიათება	ზვავშემკრები აუზის ფართობი ათასეულ კმ²-ში	დახრილობის კუთხე მოწყვეტის მხრიდან	თოვლის საშუალო სიმკვრივე მოწყვეტის დროს	ზვავების კონუსის ზომები				ჩამოსული ზვავების სიმკვრივე გ/სმ³	შენიშვნა
											სიგრძე მ-ში	სიგანე მ-ში	საშუალო სიმაღლე მ-ში	მოცულობა მ³-ში		
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
გუდაური-კობის მონაკვეთი																
1	66(ტრანშეინაია)	02-11-09	ხ.ზ.-2-ს/ამ	3100	770	1550	სუფთა თოვლი	0.25	45^0	0.10	60	18	3.0	3240	0.54	გადაკეტა გზა
2	65(მოსტოვაია)	02-11-09	ხ.ზ.-2-ს/ამ	2900	560	1250	,,----,,	0.08	40^0	0.10	56	13	2.5	1820	0.55	,,------------------,,
3	92	02-11-09	ხ.ზ.-2-ს/ამ	2250	90	220	,,----,,	0.12	45^0	0.12	70	25	2.5	4375	0.53	გადაკეტა გზა

Database doesn`t have any coordinates but anyway It is very valuable data for getting some local characters of snow avalanche and for validation also.

3.2.4. Snow Avalanche Shapefile

There are 621 snow avalanche shapes (in some estimates it is just 5% of all snow avalanches) with the following attributes:
Avalanche code number;
Place name (sometimes);
Perimeter;
Snow avalanche surface area.

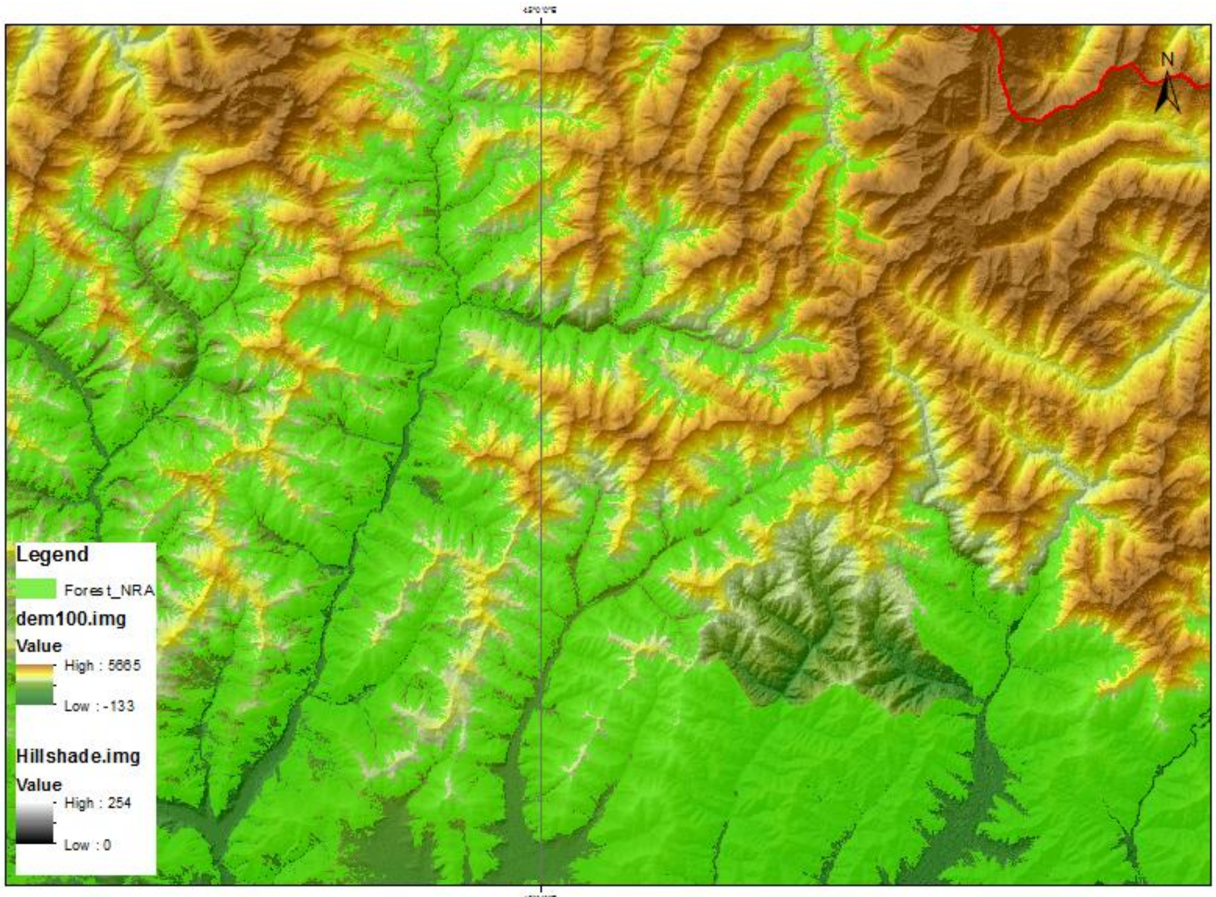
Figure 5: Visualization of snow avalanche shapefile



3.2.5 Shapefile of Forest Cover of Georgia

Database is useful to get information about forested areas, nothing more. Database isn`t complete and doesn`t represent forests of protected areas, some local forest areas and there is no information from region of Abkhazeti (the most north western Georgia).

Figure 6: Visualization of forest cover shapefile

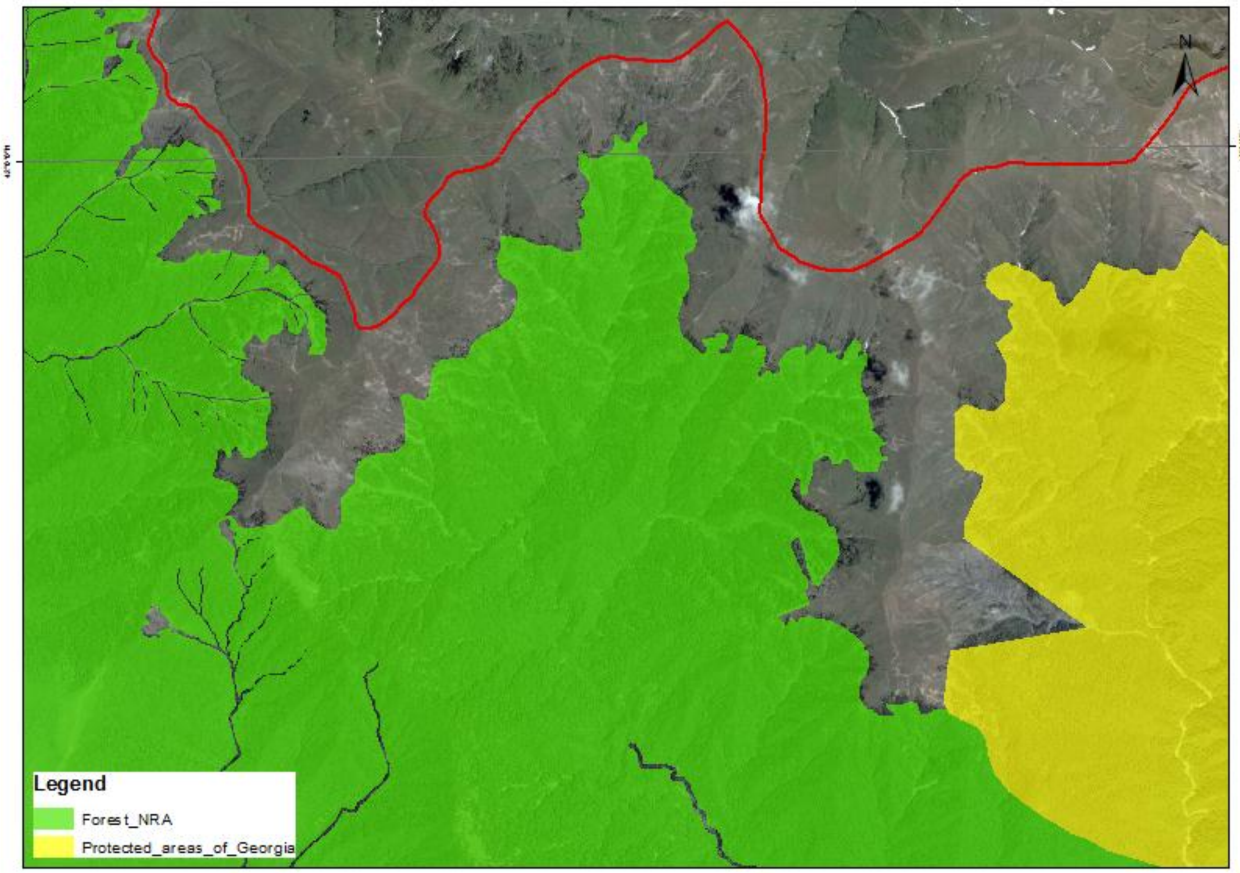


Shapefile was converted to 100m pixel size raster.

3.2.6. Shapefile of protected areas of Georgia

Shapefile represents all protected areas of Georgia. It was useful for creating full forest cover map, because sometimes protected areas shape was coincided with forest areas. Sometimes shapes were manually corrected according forests seen in Bing Areal Maps from ArcGIS 10.

Figure 7: Visualization of reshaped protected areas shapefile with forest shapefile. Base image is Bing Areal Image.



Protected areas shapefile was reshaped and now it represents forests that are in protected areas. Later it was converted to 100m pixel size raster and joined entire forest raster.

3.2.7. Landsat TM 4-5 spectral images

The Landsat Thematic Mapper (TM), a sensor carried onboard Landsats 4 and 5, has acquired images of the Earth nearly continuously from July 1982 to the present with a 16-day repeat cycle.

Landsat TM image data files consist of seven spectral bands (band designations). The resolution is 30 meters for Bands 1-5, and Band 7. Band 6 resolution (thermal infrared) is a collected 120 meters, but is resampled to 30 meters. The approximate scene size is 170 km north-south by 183 km east-west (106 mi by 114 mi).
The following scenes were ordered and downloaded from http://reverb.echo.nasa.gov :

LT51730302007178MOR00 – Acquisition date 2007-06-27, 07:55:34. Cloud cover <5%;
LT51720302006280MOR00 – Acquisition date 2006-10-07, 07:49:36. Cloud cover <5%.

Origin "Image courtesy of the U.S. Geological Survey".

Level of correction: L1t - provides systematic radiometric and geometric accuracy by incorporating ground control points while employing a Digital Elevation Model (DEM) for topographic accuracy. Geodetic accuracy of the product depends on the accuracy of the ground control points and the resolution of the DEM used: Ground control points used for Level 1T correction come from the GLS2005 data set. DEM sources include SRTM, NED, CDED, DTED, and GTOPO 30.

These scenes were used to derive forest layer for Abkhazeti region.

3.2.8. Climate Catalog Book of Georgian SSR

From Climate Catalog Book of Georgian SSR (pub. 1970), we took the data of maximum snow depth for 193 stations. This data represents maximal snow depth during observation period. Unit is centimeters. For some stations maximal snow depth data was missing and for such cases we have used average snow depth data. This data was digitized and geodatabase was created.

Figure 8: Geodatabase screenshot

FID	Shape *	Id	StationI	Station	Elevation	X	Y	Snow_max
0	Point	1	236	Abastumani	1265	42.832015	41.753439	96
1	Point	1	308	Abuli	1984	43.609001	41.401348	40
2	Point	1	344	Avadxara	1600	40.647215	43.516081	242
3	Point	2	147	Agara	638	43.817549	42.040479	115
4	Point	1	260	Adigeni	1185	42.701894	41.675873	76
5	Point	1	55	Ambrolauri HMS	544	43.152478	42.518854	71
6	Point	2	375	Amtkeli	320	41.323754	43.035463	98
7	Point	1	199	Anaseuli	130	41.980393	41.911726	110
8	Point	2	316	Didi arakali	1900	43.661226	41.304919	30
9	Point	2	297	Arakva	1650	43.492609	41.487411	42
10	Point	1	286	Aspindza	1098	43.251265	41.573218	40
11	Point	2	200	Ateni	716	44.092389	41.912848	12
12	Point	2	306	Akha	1300	44.10407	41.451965	12
13	Point	2	193	Akhaldaba	724	43.487447	41.931589	42
14	Point	1	307	Akhalkalaki HMS	1716	43.490172	41.410197	113
15	Point	1	276	Akhaltsikhe	982	42.986812	41.638435	76
16	Point	1	155	Akhmeta	567	45.207935	42.035045	23
17	Point	1	145	Atsana	196	42.064039	42.049425	61
18	Point	2	240	Atskuri	970	43.159103	41.729651	55
19	Point	1	175	Babi	700	43.335328	41.975917	177
20	Point	1	347	Bagnari	220	40.155717	43.428385	11
21	Point	1	243	Bakuriani Agro	1665	43.518445	41.739875	114
22	Point	2	242	Bakurianis Andeziti	1538	43.471901	41.734521	120

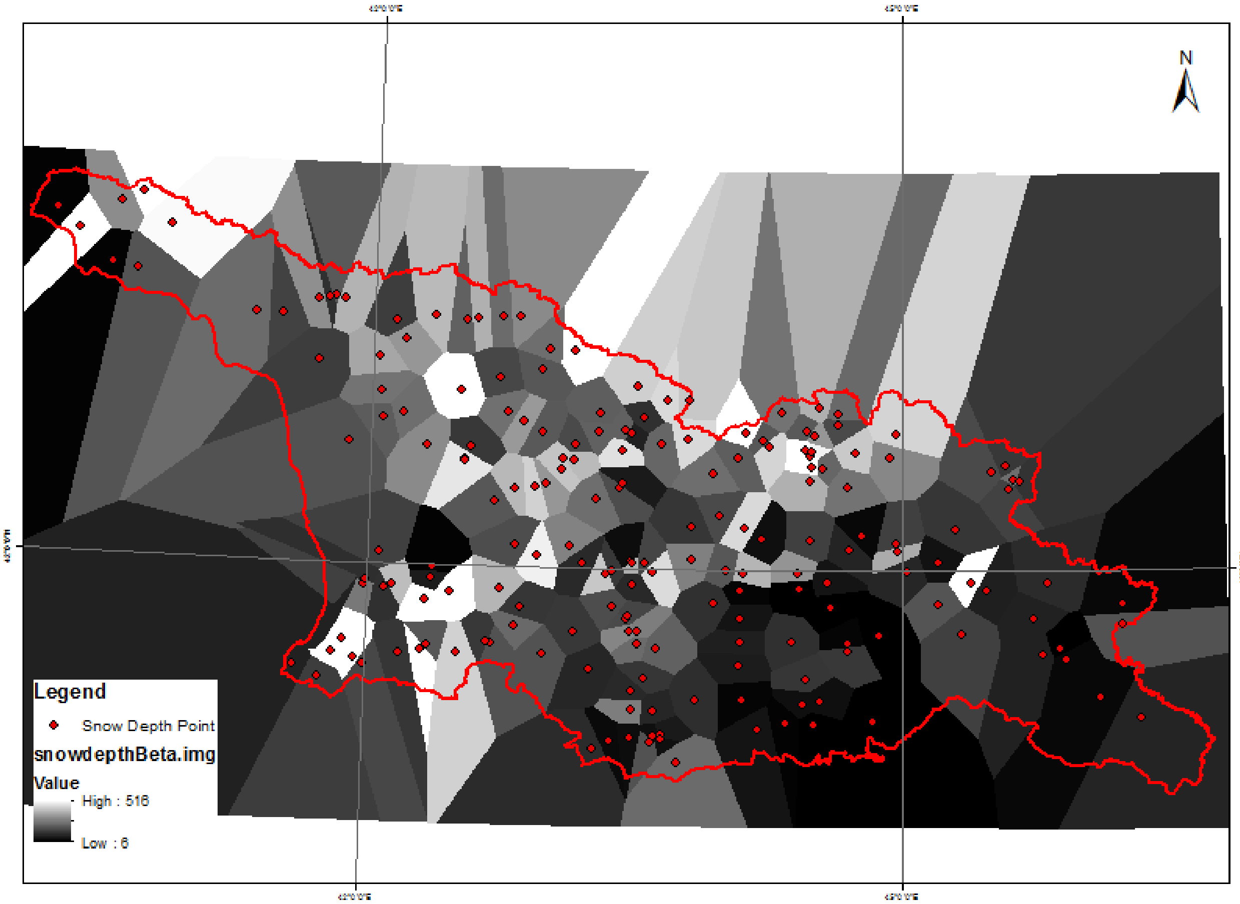
Fields in geodatabase:
Id – 1. meteo station; 2. meteo post;
StationID – Old ID code of meteo station/post;
Station – Station name (place name as well);
Elevation – Altitude of meteo station/post;
X an Y – Coordinates of meteo station/post;
Snow_max – Snow Depth. Unit: cm.

It was necessary to interpolate this point data. We have read several articles and according one of them[17] was decided to interpolate observations from the stations in ArcGIS using an inverse distance weighted interpolation. We have used following settings: Power – 0.5; Number of Points – 1. Result was fine, just one problem was identified. It was in Atchara region: snow

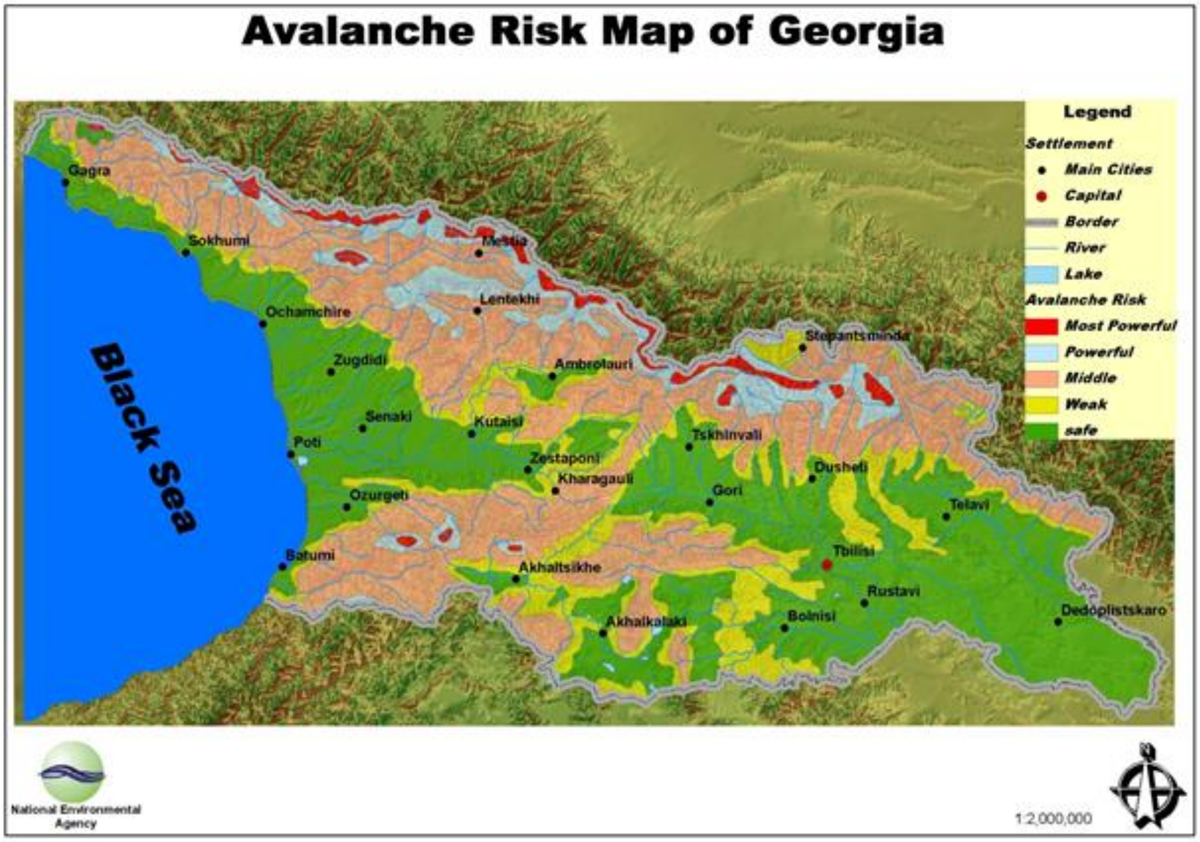
[17] Avalanche Terrain Modeling in Glacier National Park, Canada - Donna M. Delparte, University of Calgary. p.60

depth from mountainous areas were spread to the seashore. One barrier was added for that region and problem was solved.

Figure 9: Snow depth points interpolation by IDW method



3.2.9. Avalanche risk map of Georgia (scale 1:2000000) done by NEA

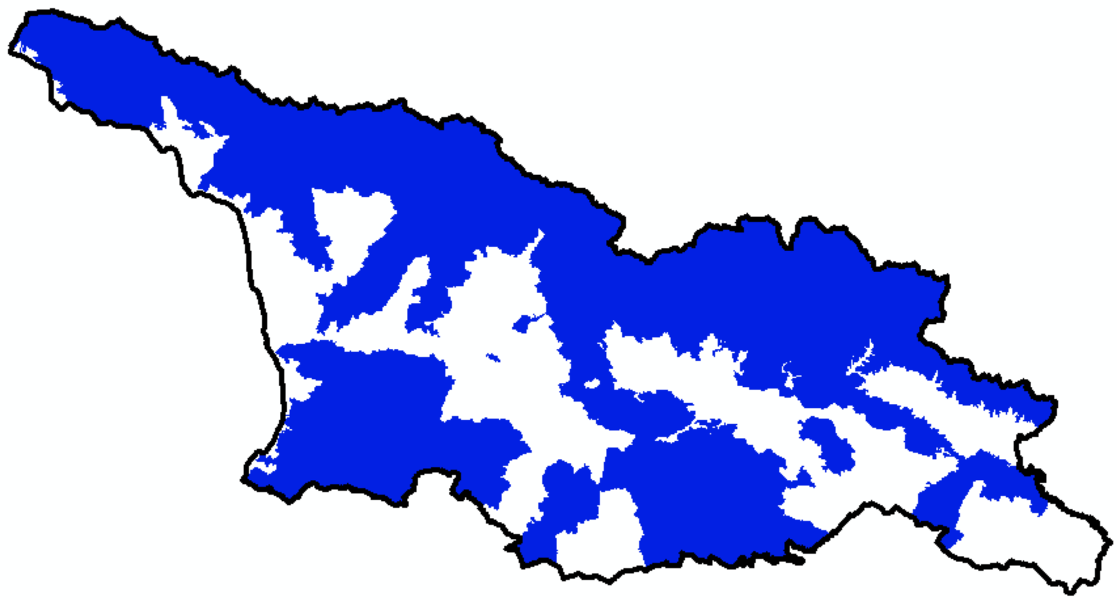


As far as we know this map is done manually and later was digitized. It represents polygons on areas where snow avalanche may happen. Negative point is that areas are represented by polygons and that's why it covers also that areas that are not danger but are situated in the middle of danger areas. Also another negative factor is maps scale (1:2000000). Positive is that we can compare average areas of snow avalanches from our results.

3.2.10. Historical Data from Media

Data was collected in MS Access file. Fields are describing location of hazardous event by community, district and regional level. On second stage we used database of settlement based on 1:50000 scale topographical map and joined polygonal shape file of communities with historical snow avalanche database. Database was converted to 100m pixel size raster.

Figure 10: Raster based on historical data from media



4. Data Processing

Some preface: All maps are calculated/based on AsterGDEM v2. Original DEM is reprojected from Geographic Coordinate system WGS84 to Projected Coordinate System WGS84, N38. Original pixel size was 1 arc-second (about 27.4m for Georgia). It was resampled to 30m, and later to 100m. So, basic DEM has PCS WGS84, N38 and pixel size- 100m. These and all other operations were done with resampling technique Cubic Convolution.

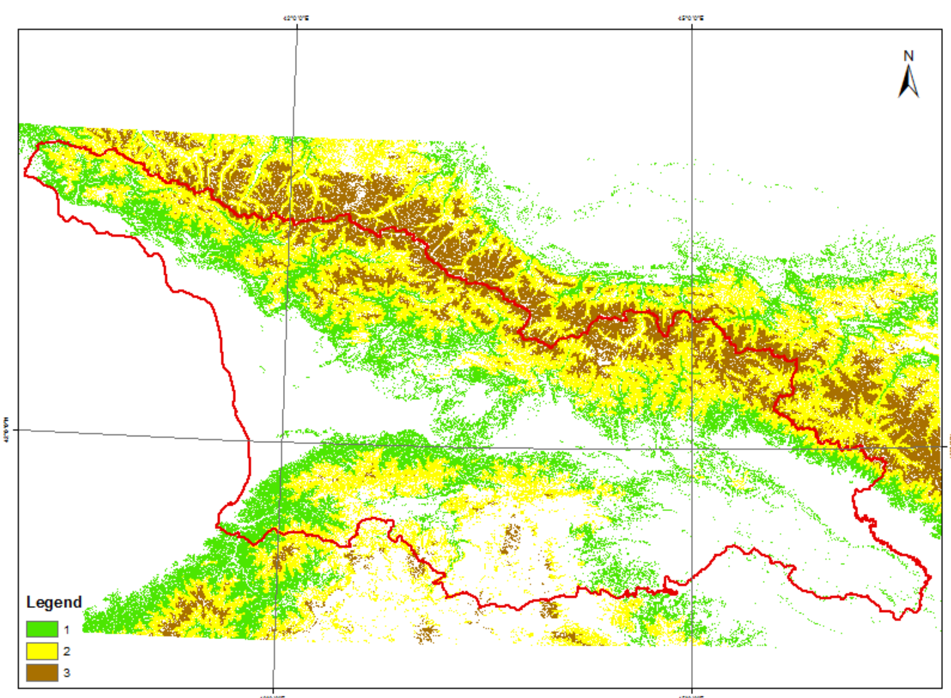
4.1. Altitude

According to Moscow State University Faculty of Geography[18] altitude distribution of registered snow avalanches on Greater Caucasus Range are:
1000m and below – 2.2%;
1000-1500m – 10.3%;
1500-2000m – 13.9%;
2000-2500m – 19.5%;
2500-3000m – 31.5%;
3000m and more – 22.1%.

Another case is the lowest altitude where the snow avalanche happens. Based on M. Salukvadze`s work "Avalanche Hazard in Zemo (Upper) Svaneti" (published in 2011 as a book, provided by NEA) we decided to take 270m a.s.l. as the lowest border for snow avalanche hazard zone.DEM classification for altitude is:
270m and below – NoData
270-1500m – 1;
1500-2500m – 2;
2500m an more – 3.

All areas below 270m a.s.l. is removed from altitude map.

Figure 11: Altitude map



[18]http://www.geogr.msu.ru/avalanche/regions/caucasus/kavkaz.doc/odyframe.htm

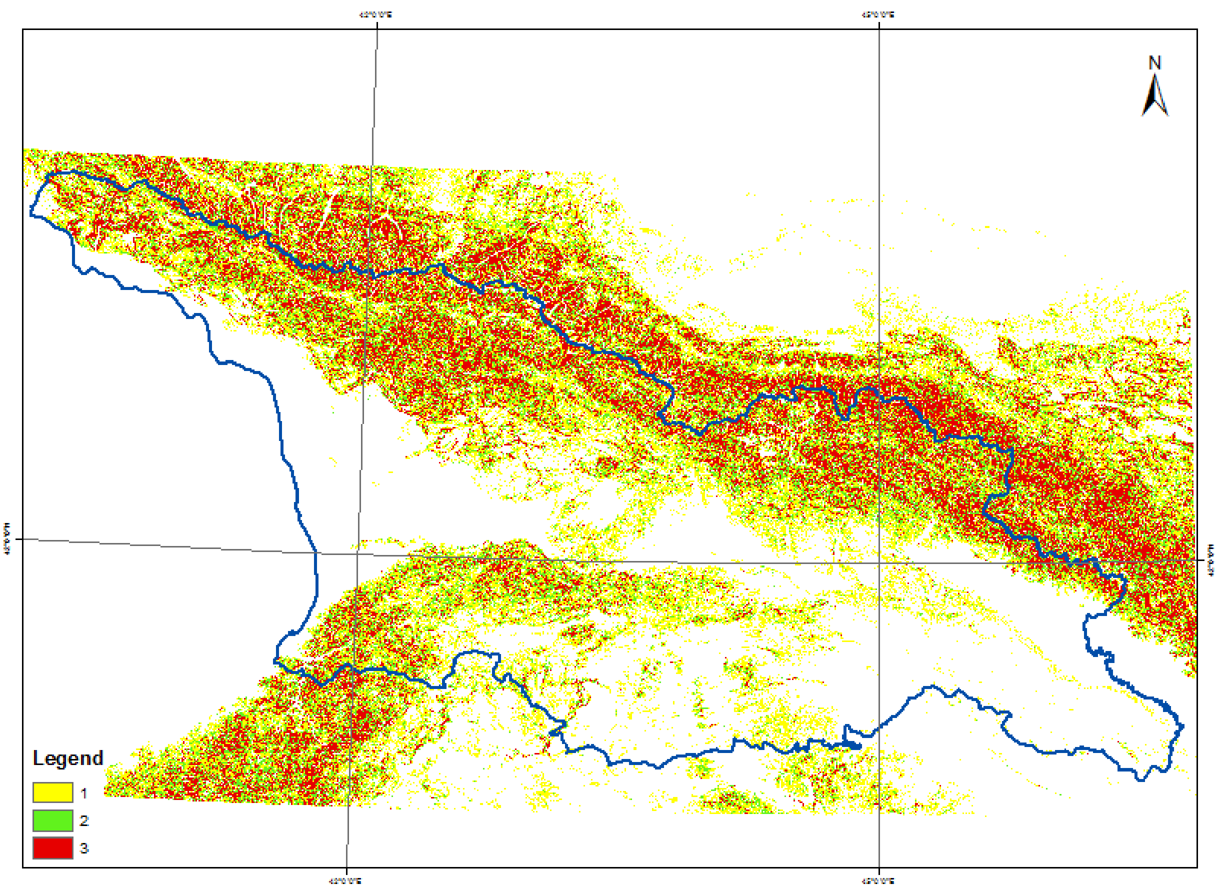
4.2. Slope

Avalanches most frequently occur on slopes of 30^0 to 45^0, but they may occasionally release from either gentler or steeper terrain[19].

In most cases, the average inclination of starting zones ranges from 27^0 to 50^0. On rare occasions, avalanches can start on gentle slopes ofless than 25^0,but generally the shear stress induced by gravity is not large enough tocause failure. For inclinations in excess of $45^0$to 50^0, many slides occur during snowfalls.Slopes more gentle than 15^0 degrees has no avalanches and slopes above 60^0often do not build up significant quantities of snow because they are too steep. This information is confirmed by the database of already occurred snow avalanches (provided by NEA). All areas with 0-15^0 and 60 and more inclination are removed from map, also areas below 270m a.s.l. Our slope classification is following:

Slope (degree)	**Value**	**Comment**
0-15, 60 and more	0 (NoData)	Safe
15-25, 50-60	1	Low risk
25-30, 45-50	2	Middle risk
30-45	3	High risk

Figure 12: Classified slope map



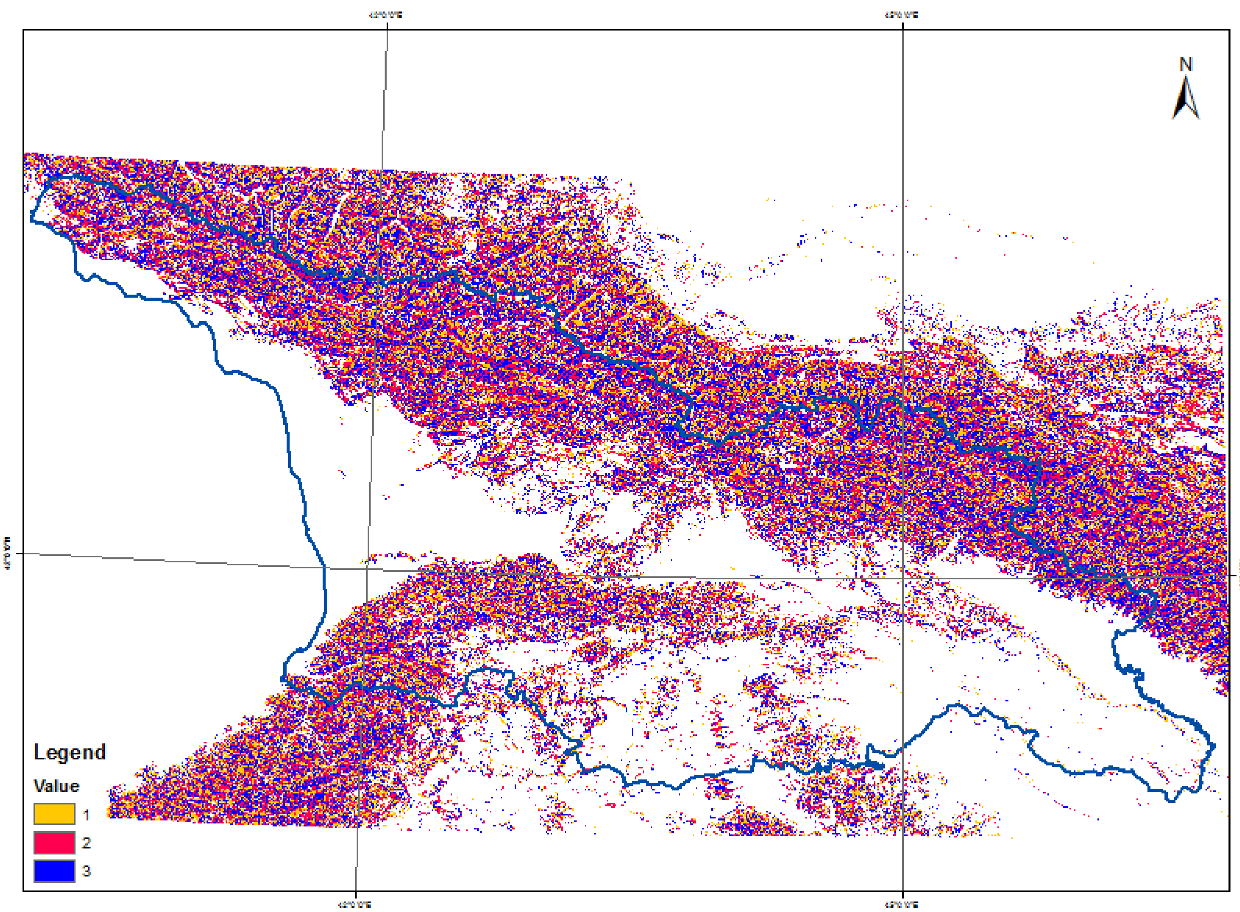
[19] Basic Principles for Avoiding and Surviving Snow Avalanches – Lance Yang, P

4.3. Aspect

We have read lots of articles about aspect influence on snow avalanche formation, but this is a case that highly defends on local circumstances. Thats why we decided to use experience of people who are working on avalanches during tens of years. We asked NEA experts to make a classification of aspects. Here is a result:

NW, NE – 1;
N, SW, SE -2;
S, W, E – 3;
Flat – NoData.

Figure 13: Classified Aspect map



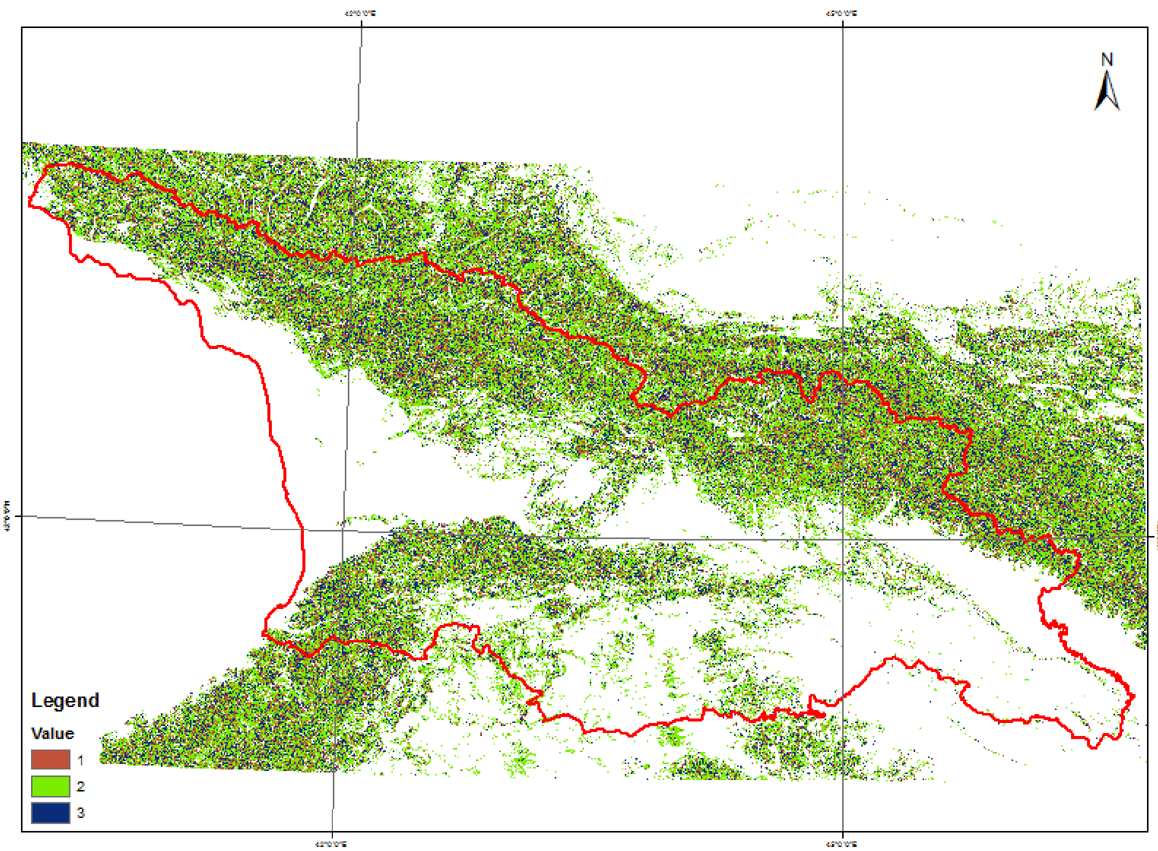
All areas with flat aspect, altitude less than 270m a.s.l. and slope 0-15^0,>60^{0}are removed from map.

4.4. Curvature

ArcGIS command "curvature" computes the curvature of the slope separated into two orthogonal components where the effects of gravitational processes are either maximized (profile curvature) or minimized (plan curvature). For the definition of the snow avalanche potential release areas the plan curvature is used to separate concave areas from flat and convex ones[20].
Classification of relief forms was taken from article "Avalanche risk assessment in the Tatra Mts., Kasprowy Mt. region, Poland" done by Pawel Chrustek, Jagiellonian University, Krakow, Poland. Convex – 10, Flat – 8, Concave – 6. Aslo, according to first mentioned article (footnote 16) concave is represented by the values - <-0.2; Flat - +0.2 to -0.2; Convex - >+0.2.

Relief form	Value	Weight value
concave	<-0.2	1
flat	+0.2to-0.2	2
convex	>+0.2	3

Figure 14: Classified plan curvature map



All areas with flat aspect, altitude less than 270m a.s.l. and slope 0-15^{0},>60^{0}are removed from map.

[20]Definition and characterisation of potential avalanche release areas - Margherita Maggioni, Urs Gruber and Andreas Stoffelhttp://proceedings.esri.com/library/userconf/proc02/pap1161/p1161.htm

4.5. Snow Extend

After Modis images were extracted, resampled to 100m pixel size and reprojected to PCS WGS84, N38 we reclassified it:

As far as original pixel size was about $25km^{2}$, in order to avoid extremely small snow cover areas, pixels with less than 10% of snow cover were considered as `no snow` and set to No Data; Pixels with values 10-100 were set to 1 (snow presents). Pixels above 100 value were set to No Data, because they do not represent snow. As a result we have 36 Modis images with just two values: 1- snow; and, 0- no snow;

November, March and April (warmer months) 18 images were reclassified and value 1 was adjusted to value 10. December, January and February (colder months) another 18 images were reclassified and value 1 was adjusted to value 1000. Then all 36 images were summed. As a result we have one image, but its nomenclature tells us amount of cold and warm months in pixel. for example, let`s take the maximum value – 18 180. As far as colder months` value was 1000 and warmer ones` 10, we can say that pixel with value 18180 means: there was snow for 18 month in cold period and 18 months in warmer. Another example: value 14090. It means, there was snow for 14 months in cold and 9 months in warmer period.

And the final classification: Values were divided to 1000 and result was divided into three equal parts.

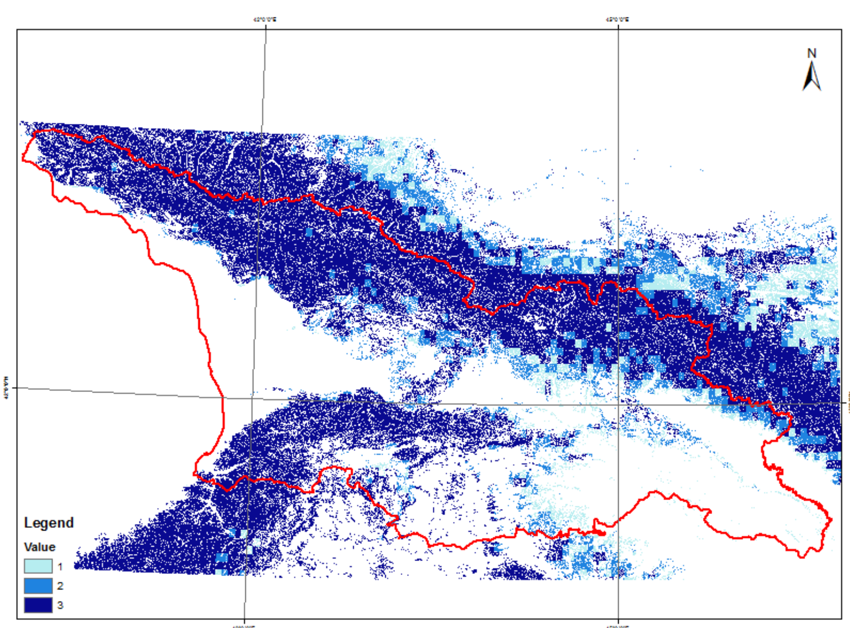
cold/warm	Value
0.1-6.6	1
6.7-12.12	2
12.13-18.18	3

How to read this chart: Value 1 – minimal snow load of pixel is just 1 month during 6 years. Maximum load is 6 cold months and 6 warm months during 6 years;

This classification is just conditional and isn`t based on any scientific calculations.

All areas with flat aspect, altitude less than 270m a.s.l. and slope $0-15^0$,$>60^0$are removed from map.

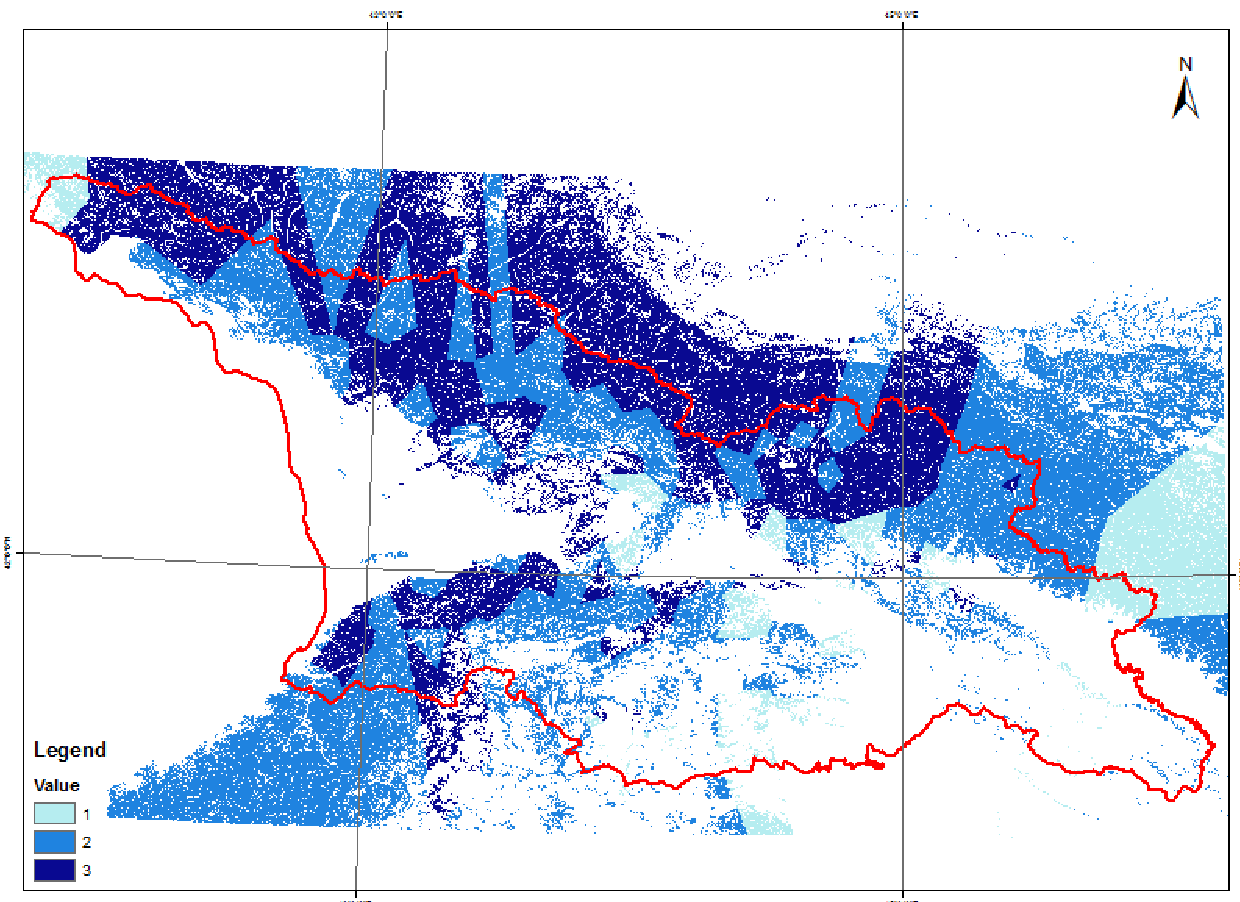
Figure 15: Modis snow cover classified map



4.6. Snow Depth

Snow depth map that represents IDW interpolated point data from observation stations was modified by the following ways:
As far as, this data represents maximum (and sometimes average) snow depth, all values that are below 10cm were considered as nonimpact factor for snow avalanche formation and were removed from map[21]. Others were classified by the following:
0-10cm – NoData;
10-30cm – 1;
30-100cm – 2;
100cm and more – 3.

Figure 16: Classified snow depth map.



All areas with flat aspect, altitude less than 270m a.s.l. and slope 0-15^0,>60^{0}are removed from map.

[21] Determining the Critical New Snow Depth for a Destructive Avalanche by Considering the Return Period - Jürg Schweizer*, Christoph Mitterer and Lukas Stoffel, P.293

4.7. Forest

We have forest raster made from forest shapefile (provided by Natural Resources Agency of Georgia). Also, we have forest raster created from Protected areas shapefile modification. And the only region we miss in our database is Abhazeti. Forest raster for this region was done using Landsat TM 4-5 scenes. In ArcGIS 10 we have calculated Normalized Difference Vegetation Index (NDVI) by the following formula:

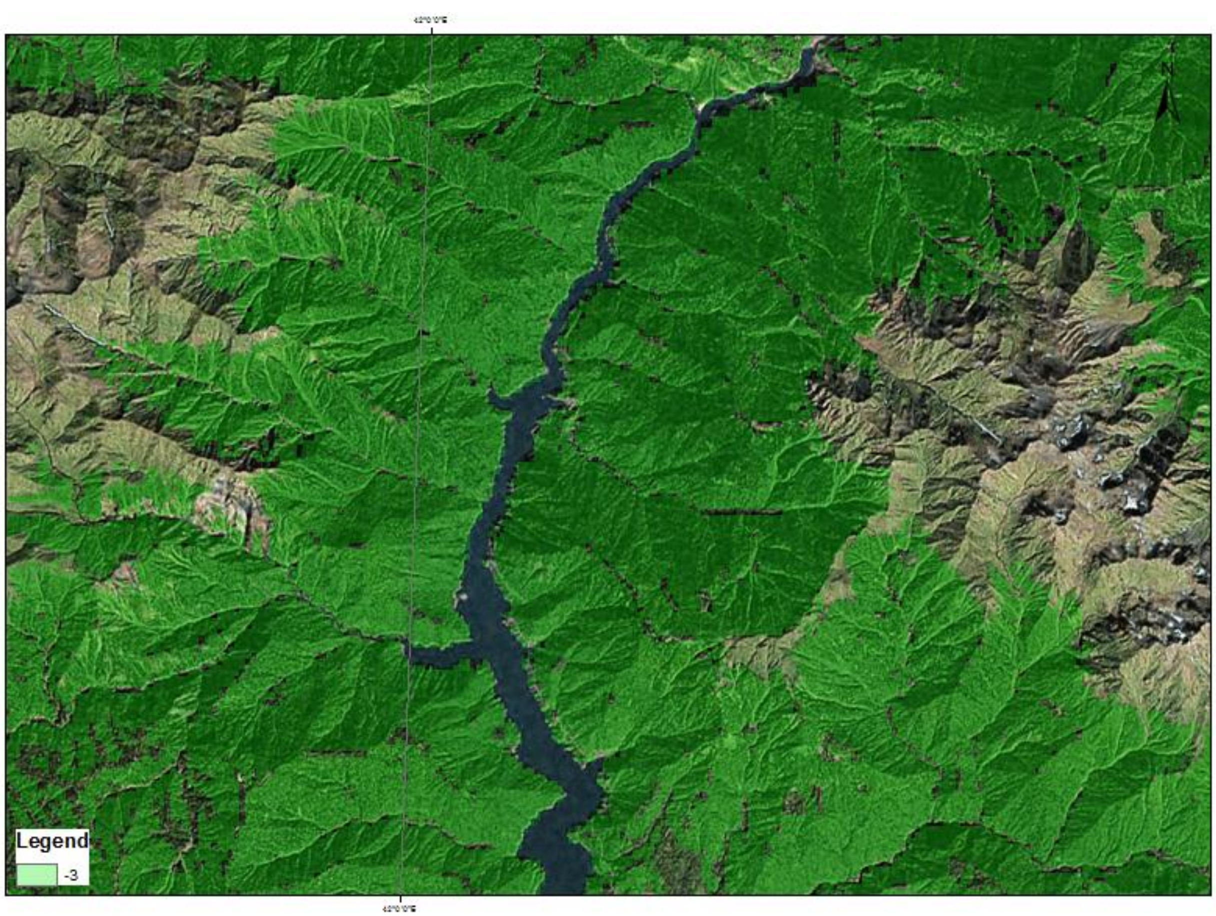
NDVI = (near IR band - red band) / (near IR band + red band)

For Landsat TM NIR band is 3 (0.63-0.69 µm) and Red band is 4 (0.76-0.90 µm), so in ArcGIS 10 Raster Calculator was written the following:

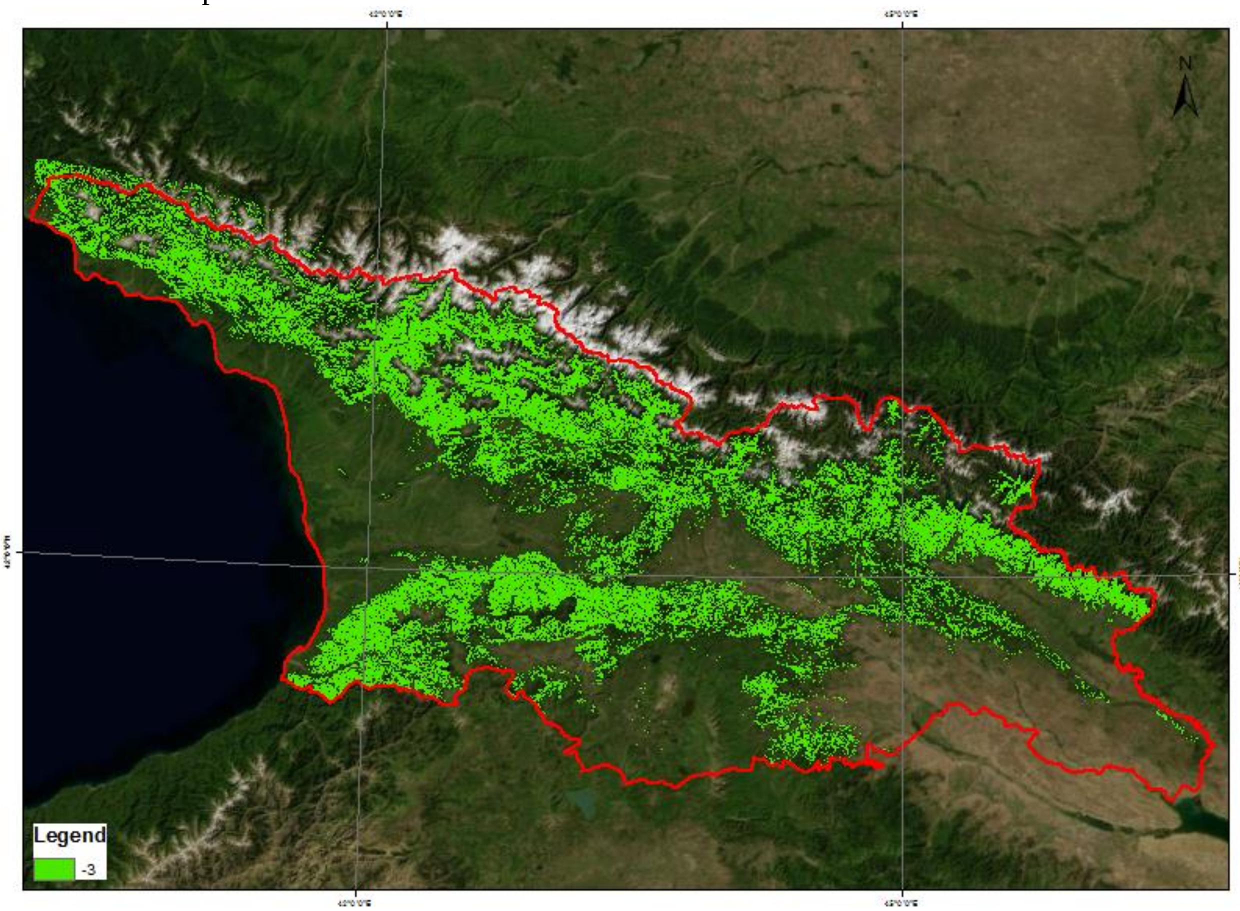
float(band 4 - band 3) / float(band 4 + band 3)

NDVI values are from -1 to 1. We have used Bing Aerial Maps from ArcGIS 10 to determine the "forest interval" in this value range.
For scene LT51730302007178MOR00 forest started after 0.68 value;
For scene LT51720302006280MOR00 forest started after 0.5 value.
Finally all rasters for whole Georgia were combined to new raster and forest raster maps was ready.
Pixel size – 100m; Datum – PCS WGS, N38; All areas with flat aspect, altitude less than 270m a.s.l., slope 0-15^0,>60^{0}and snow depth <10cm were removed from forest map.

Figure 17: Comparison of Landsat forest raster with Bing Areal Maps from ArvGIS 10.



Forest cover can not prevent snow avalanche but is represents deterrent factor[22]. We decided to reclassify this layer by following:
If forest presents – value is -3;
I forest doesn`t present – value is 0.

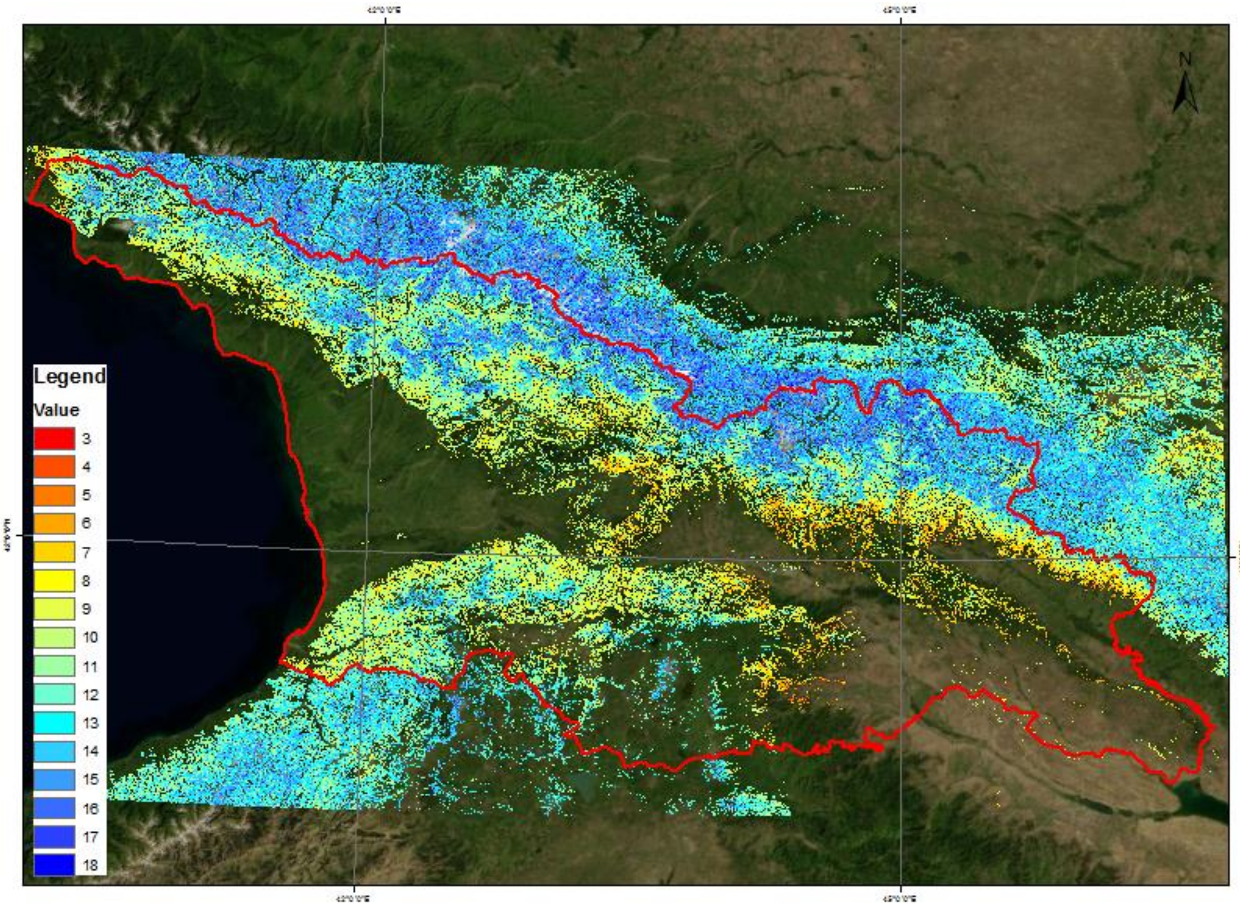


[22] Avalanche Hazard in Zemo (Upper) Svaneti – M. Salukvadze

5. Data Combining and Result

After all seven maps are ready, their values were summed using ArcGIS 10 Raster Calculator:
"altitude.img" + "slope.img" + "plancurvature.img" + "aspect.img" + "snowextend.img" + "snowdepth.img" + "forest.img"
Result:

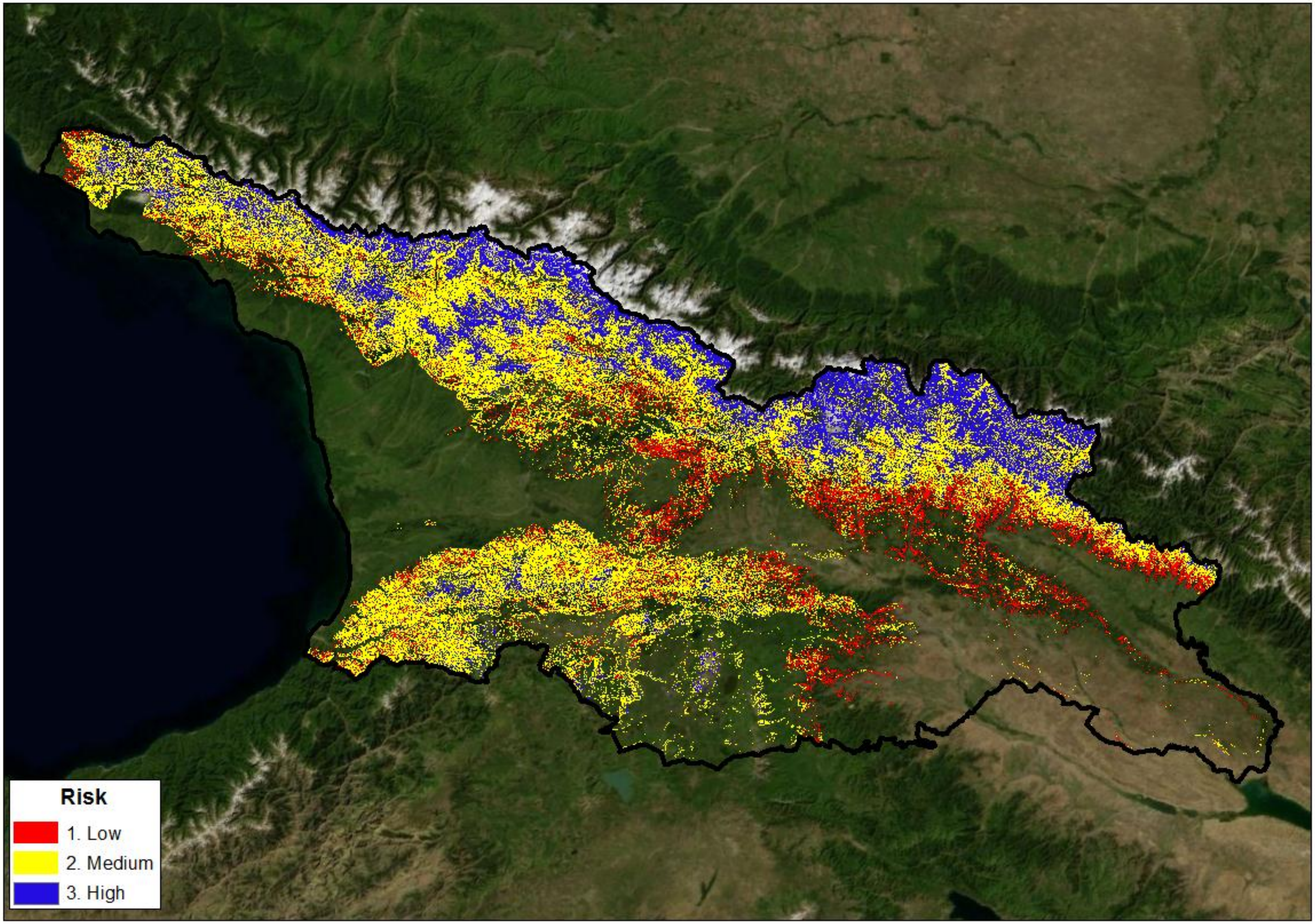
Figure 18: Snow Avalanche Starting Zone map without classification.



The final classification was done using equal interval technique.

1- low possibility of snow avalanche formation;
2- medium possibility of snow avalanche formation;
3- high possibility of snow avalanche formation.

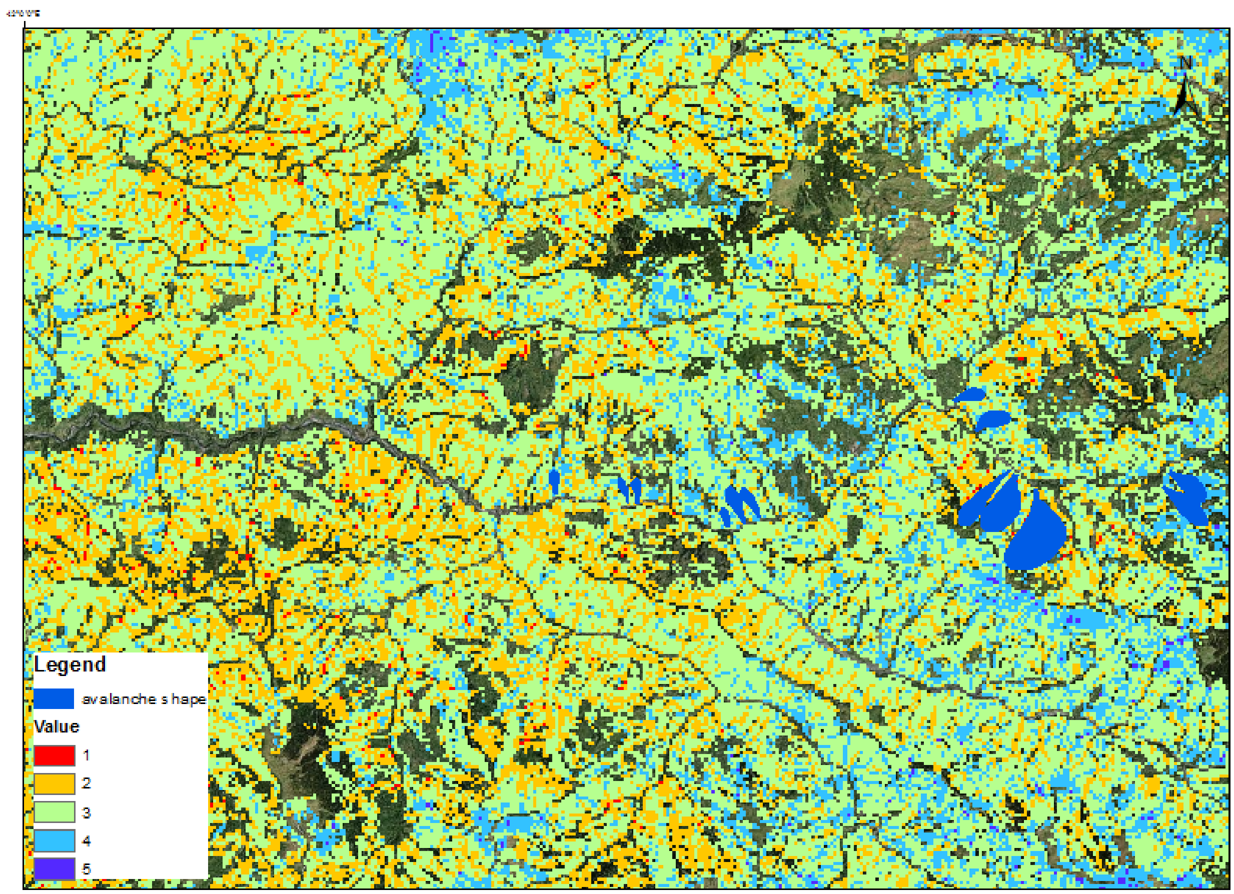
Final map:


Risk
1. Low
2. Medium
3. High

6. Validation

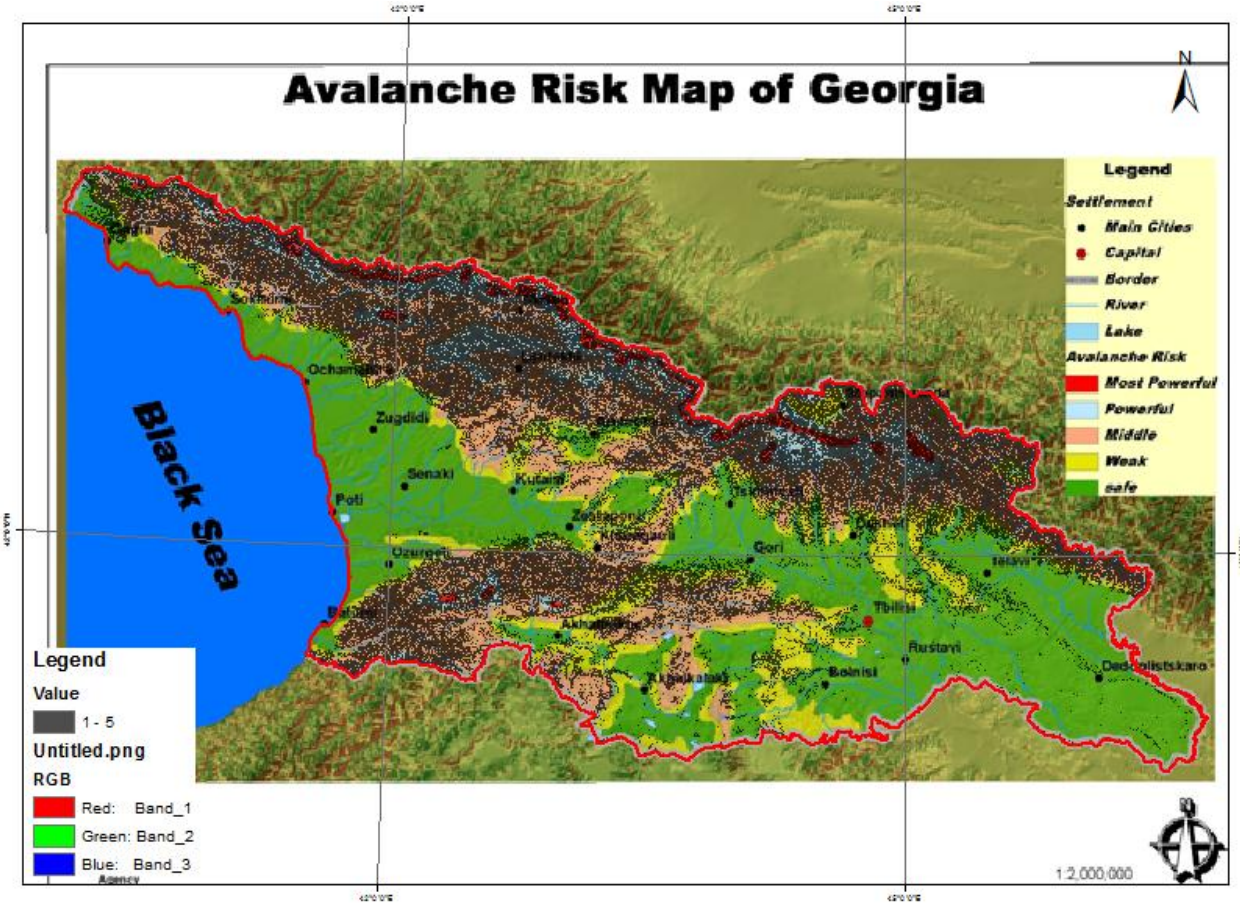
Validation was done using NEA provided snow avalanche shapefile and 2000000 scale snow avalanche hazard map.
Because of data specification only visual check was possible.
Almost all avalanches from shapefile are in the area of snow avalanche starting zone map.

Figure 19: Snow Avalanche Starting Zone map and NEA avalanche shape



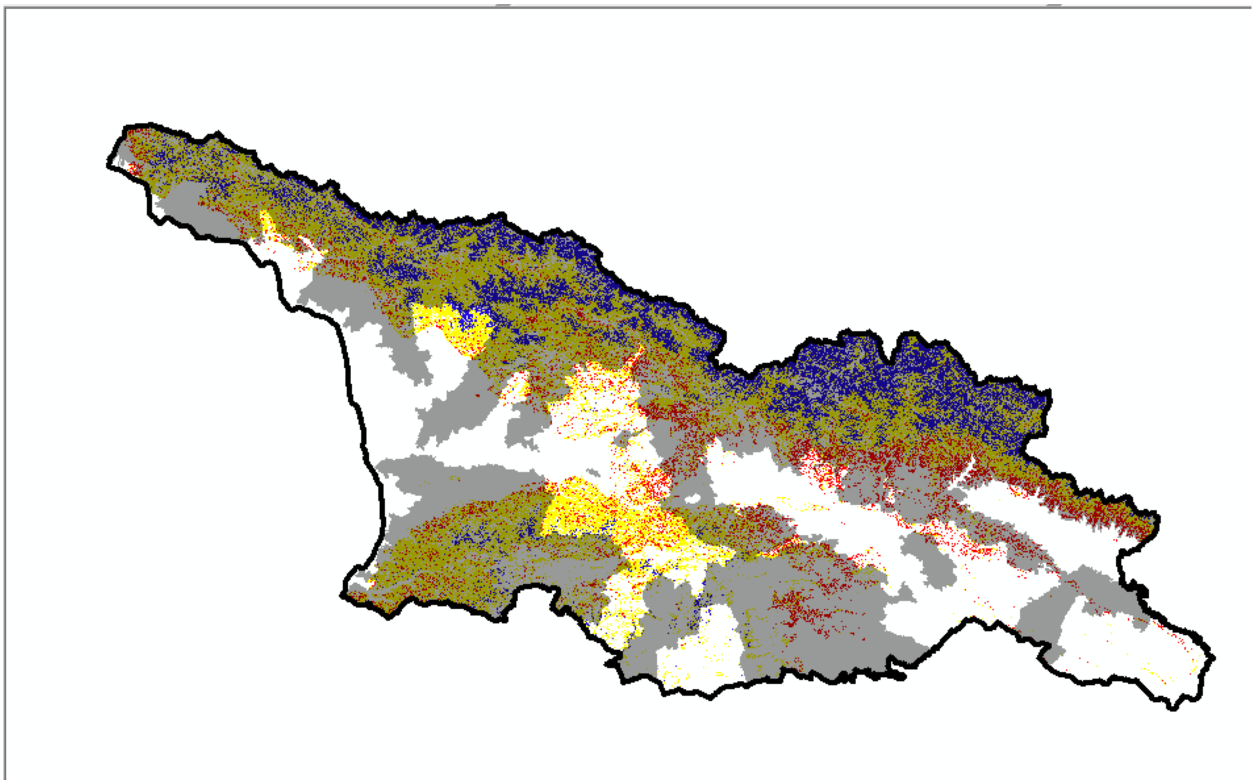
The second validation source is 1:2,000,000 scale NEA avalanche map. Because of scale only snow avalanche areas and sometimes hazard stage can be compared.
Visual comparison went ok, very often even risk section were the same.

Figure 20: NEA Avalanche Risk Map and our map (black overlay)



Another source of validation is raster made by historical data from media. Validation was done by visually and results were ok. (see fig. 21)

Figure 21: Transparent black layer- Historical data; base map- snow avalanche starting zone map



7. Runout zone (?)

ArcGIS Spatial Analyst flow accumulation tool was used to determine snow avalanche runout trajectory. Input weight raster was snow avalanche starting zone map. Strahler stream order was used to filter flows and just first 3 orders were left.

Figure 22: "Runout" zone map

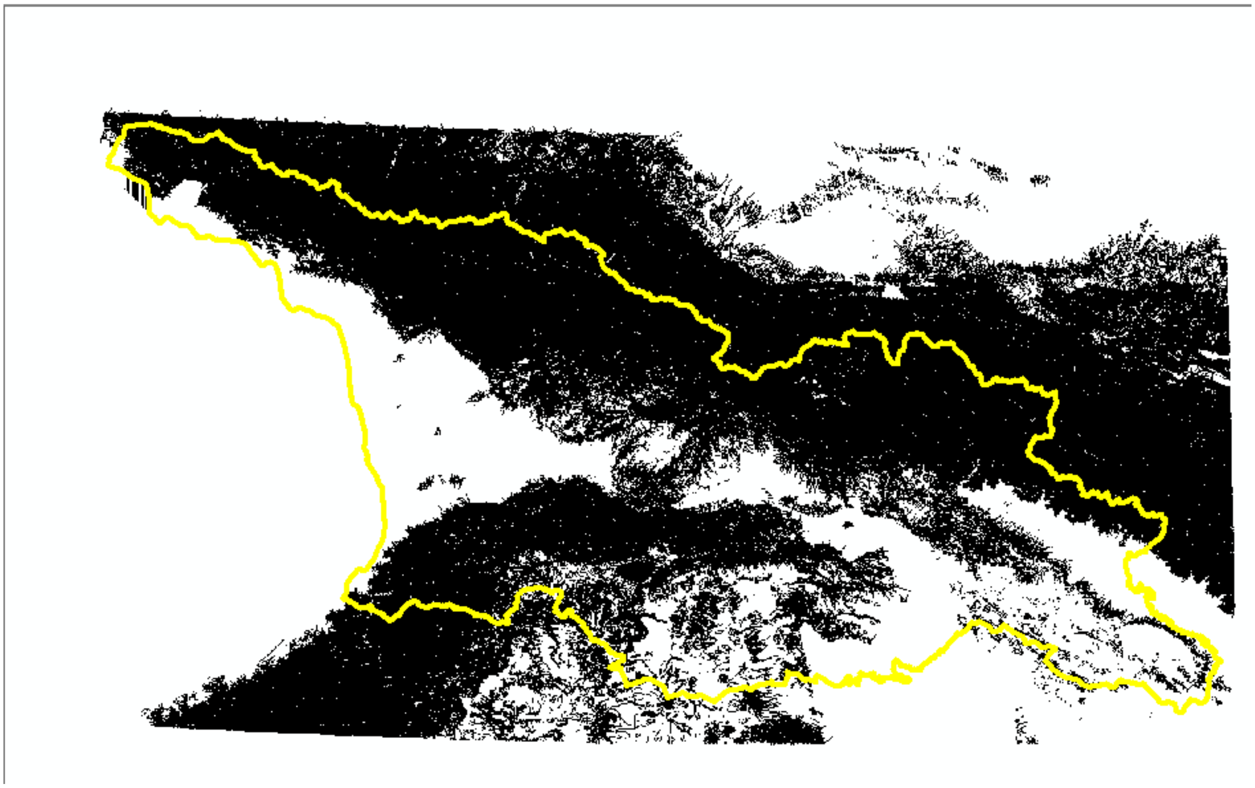


Figure 23: Starting zones, avalanche shapes and "runouts" (black)