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Avalanche susceptibility and risk analysis of Eastern Anatolian region using GIS

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Abstract

Turkey faces various natural disasters due to her geographical location. One of these natural disasters is avalanches. Eastern Anatolia Region which covers 21 % of Turkey's land, 163.000 km² surface area is the region where avalanches are the most common. 193 avalanches out of 220 in a 32-year period between 1970-2012 occurred in this region. As a result, 128 individuals were killed, 48 were injured and a total of 17.892 individuals were affected in different ways. This study aims to provide an avalanche susceptibility and risk analysis in Eastern Anatolia Region. Avalanche Susceptibility Analysis and Risk Analysis were undertaken based on Geographical Information Systems (GIS) by following the formulas developed by Mora and Vahrson (1994) and UN Disaster Relief Coordinator (1979) respectively. Global Digital Elevation Model (GDEM) data and official statistics provided by General Directorate of Meteorology and Turkish Statistics Institute were utilized in the study. It was observed that the avalanches occur due to conditions of slope, temperature and precipitation. The impact of this natural disaster will be felt more distinctively in areas with higher population density. Avalanche susceptibility is insignificant and lower in large areas whereas it is high and significant in a small region. Areas with highest susceptibility generally correspond with the frequency of occurrence found in disaster statistics. According to risk values observed to be 11.63 in average, the provinces with the highest risk are Hakkari, Bitlis, Mus, Bingol, Tunceli, Kahramanmaras, Erzurum, Agrı and Van. More detailed avalanche susceptibility identification and planning are called for in the whole region urgently.

Keywords: Geographical Information Systems (GIS); Avalanche; Natural Disaster; Eastern Anatolian Region; Turkey.

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1. Introduction

Avalanche, one of the most complicated atmospheric based natural phenomenons that occurs generally in winter and spring especially on slopes without vegetation where one or sometimes all layers of accumulated snow slide along the incline of the slope with the effect of internal and external forces (Tunçel, 1990; Gürer, 2002; Bacanlı, Özgüler, & Lenk, 2003; Şahin & Sipahioğlu, 2003; Schweizer, Jamieson, & Schneebeli, 2003). It deeply affects the Baltic countries, Italy, America, Canada and some Asian countries, mostly Switzerland, Austria and France. This effect has demonstrated itself in the deaths of more than 2000 people in the past 15 years (DAÖİKB, 2000; Ertürkmen, 2006).

Table 1. Avalanches in Turkey and their results

Province	Number of hazard	Killed	Injured	Affected
Bitlis	31	6	3	3.816
Bingol	27	1	3	4.686
Tunceli	20	13	2	1.679
Hakkari	18	26	1	1.304
Elazıg	15	5	1	1.620
Erzurum	15	7	4	698
Artvin	11	15	1	485
Van	10	10	4	442
Malatya	8	6	1	446
Mus	8	5	1	1.150
Agrı	7	14	10	246
Bayburt	7	59	21	849
Erzincan	5	1	0	406
Adıyaman	5	0	0	707
Trabzon	5	0	0	554
Batman	3	3	2	0
Diyarbakır	3	1	5	65
Giresun	3	1	0	25
Kastamonu	3	4	0	184
Rize	3	5	5	99
Siirt	2	2	1	0
Nigde	2	2	0	0
Gumushane	2	10	7	80
Adana	1	0	0	0
Kars	1	0	0	50
Sırnak	1	2	0	12
Konya	1	1	0	0
Sivas	2	1	2	0
Ordu	1	1	0	0
TOTAL	**220**	**201**	**74**	**19.603**

The effects of avalanches in Turkey are similar to those in the world. The topography and climate conditions of Turkey and the human activities that go along with these conditions result in avalanches that cause large losses in life and property (Taymaz, 2001; Şahin & Sipahioğlu, 2003; Taştekin, 2012). Around 35% percent of Turkish land is exposed to avalanches (Varol & Yavaş, 2006). Regions that are most susceptible to avalanches and that experience the highest number of them are the northern, northeastern and eastern regions and the sloped and hilly parts of the Southeastern Anatolian Region (Şahin & Sipahioğlu, 2003). According to the Turkish Natural Disasters Archive (TNDA) data, 220 avalanches occurred during the 32-year period between 1970 and 2012 in Turkey. 201 people died and 74 people been injured as a result and 19.603 people were affected. The province where the highest number of avalanches occurs in Turkey is Bitlis (31 avalanches). The highest number of dead (59 people) and injured (21 people) were recorded in Bayburt province. The province where the highest number of people was affected by avalanches (4.686) is Bingöl. When these statistical data are evaluated, Eastern Anatolian Region is the region where the highest number of avalanches was recorded with 193 avalanches. As a result of these disasters 128 people died, 48 people were injured and 17.892 people were affected (Table 1).

In this study, an analysis of the avalanche susceptibility and risk in the Eastern Anatolian Region which experienced the highest number of avalanches during the period between 1970 and 2012 was undertaken. A map of the region showing susceptibility of the region and pinpointing risky areas was prepared, and discussed in the context of its effect on humans. Thus data that can be used to analyze the problem and to plan solutions have been produced.

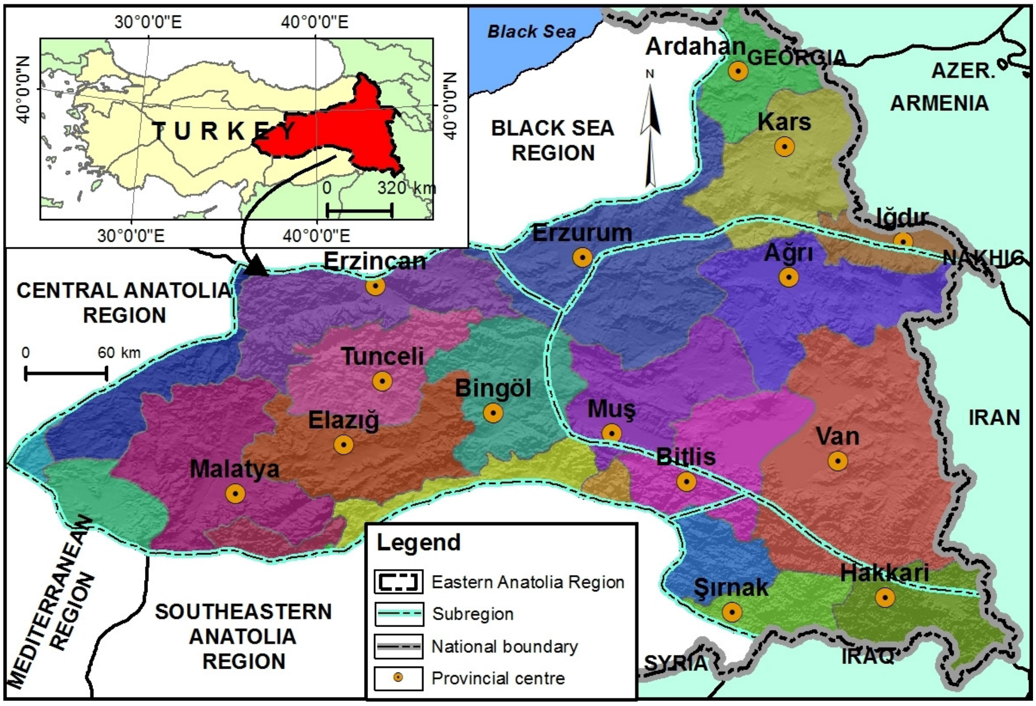

Fig. 1. Location map

2. Description of The Study Area

The Eastern Anatolian Region, which can be defined as the roof of Turkey comprises 21% of Turkey's surface area with its surface area of 163.000 km² (Atalay, 2011) and is the largest of Turkey's geographical regions (Arınç, 2011). The Eastern Anatolian Region, which is made up of 4 divisions and 14 precincts according to the region division principals (Arınç, 2011), is surrounded by the southern region of the Northern Anatolian Mountains in the north, the high south facing slopes of the Taurus Mountains in the south, the watershed of the Fırat and Kızılırmak rivers and the Tahtalı Mountains and Uzunyayla in the west (Atalay & Mortan, 2011), and the country borders on the east. It is situated between the 36° 40' 20" - 41° 42' 07" N latitudes and the 36° 16' 39" - 44° 47' 40" E longitudes according to the geographical coordinate system. Administratively, it covers the entirety of Elazıg, Tunceli, Bingol, Mus, Bitlis, Kars, Igdır, Agrı, Van and Hakkari, and some parts of Artvin, Erzurum, Gumushane, Sivas, Erzincan, Malatya, Diyarbakır, Batman, Siirt, Adıyaman, Sırnak, Kahramanmaras, Kayseri, Sanlıurfa and Ardahan (Fig. 1)

3. Material and Method

Several methods have been developed to eliminate the adverse effect of avalanches (Bacanlı, Özgüler, & Lenk, 2003). The most popular of these in our day are Geographical Information System (GIS) and the Remote Sensing (RS) based modeling (Mejia-Navarro, Wohl, & Oaks, 1994; Furdada, Marti, Oller, Garcia, Mases, & Vilaplana, 1995; Stoffel, Meister, & Schweizer, 1998; Pertigizer, 1998; Mulders, 2001; Huggel, Kaab, & Salzmann, 2004; Ghinoi & Chung, 2005a; Biskupic & Barka, 2010; Önal, 2012). With the help of these models, one can determine to what extent which factors will affect the terrain and where avalanches may occur (Barka & Rybar, 2003; Nadim, Kjekstad, Domaas, Rafat, & Peduzzi, 2006; Biskupic & Barka, 2010). The avalanche susceptibility model developed by (Nadim, Kjekstad, Domaas, Rafat, & Peduzzi, 2006) Mora and Vahrson (Mora & Vahrson, 1994) and supported with the Geographical Information Systems (GIS) was used in this study The formula which contains the factors that cause avalanches were pursued in this stage.

$$H_{avalanche} = (S_r \times 0.4 + D_y \times 0.4 + D_s \times 0.2) \times F$$

Where "Sr" is the slope factor, "Tp" is a factor that depends on precipitation for four winter months (December–March in the northern hemisphere), "Tt"is the temperature factor, and "F" is a factor that depends on the average temperature in winter months (December–March in the northern hemisphere) (F = 0 if average monthly temperature in winter months>2.5°C; F = 1 otherwise).

The slope factor map was prepared using the widely used (Barka & Rybar, 2003; Ghinoi & Chung, 2005b) Global Digital Elevation Model (GDEM) data produced by the Ministry of Economy, Trade and Industry (METI) Earth Remote Sensing Data Analysis Center (ERSDAC) in Japan. The temperature and precipitation maps from the four-month period between December and March were prepared using the official data provided by the General Directorate of Meteorology about average values along a long period of time (1970-2011). The population density map was taken from the data accumulated by the Turkish Statistical Institute's (TSI) Address Based Population Registration System 2011 data. These data was included in the process by using the co-kriging model which is a geostatistical technique to provide interpolation of values obtained from neighboring locations to areas with no data information.

Factor maps for the study were refined and mapped on the ArcGIS/ArcMap 10 package program using the Geographical Information Systems (GIS) techniques and methods. The maps were combined in accordance with formula in the form of 10x10 m grid maps to make an avalanche susceptibility map. The risk evaluation of these avalanche susceptibility maps was undertaken by using the formula defined by UN Disaster Relief Coordinator (UNDRO, 1979):

$$R = H \times Pop \times Vul$$

Where: R = Risk, that is, the number of expected human impacts; H = Annual hazard occurrence probability; Pop = Population living in a given exposed area; and Vul = Vulnerability, depends on sociopolitical-economic context. On the risk evaluation map, "H" is shown by the avalanche susceptibility map, "Pop" is shown by the population density distribution map, whereas the "Vul" value was assigned as 1 because it could not be calculated. The maps used during the application stage of the formula were combined into a 100x100 m resolution risk map.

4. Discussion

The basic elements in the formation of an avalanche are topography and climate conditions (Bacanlı, Özgüler, & Lenk, 2003). For this reason the sloping properties and climate elements like temperature and precipitation must be analyzed in avalanche susceptibility maps which are used to speculate the possibility of an avalanche forming, or in other words, the avalanche risk. The avalanche susceptibility model developed (Nadim, Kjekstad, Domaas, Rafat, & Peduzzi, 2006) by Mora and Vahrson (1994) (Mora & Vahrson, 1994) is a model designed in this capacity. According to this method, the avalanche risk in Eastern Anatolia is as shown below.

The first and most critical parameter of avalanches is the slope (Suk & Klimanek, 2011). Avalanche risk is lower in areas with lower slopes because it is harder for the snow mass to start moving, and in areas with high slopes because there isn't enough snow buildup. Therefore the ideal slopes for avalanches are angled at between 20° - 50° (Şahin & Sipahioğlu, 2003). In this regard the areas with slopes over 25° are in the riskiest category in the Eastern Anatolian region (Fig. 2). These areas are common in mostly mountainous landscapes. As opposed to these; areas with lower slopes such as plateaus and plains are the least risky.

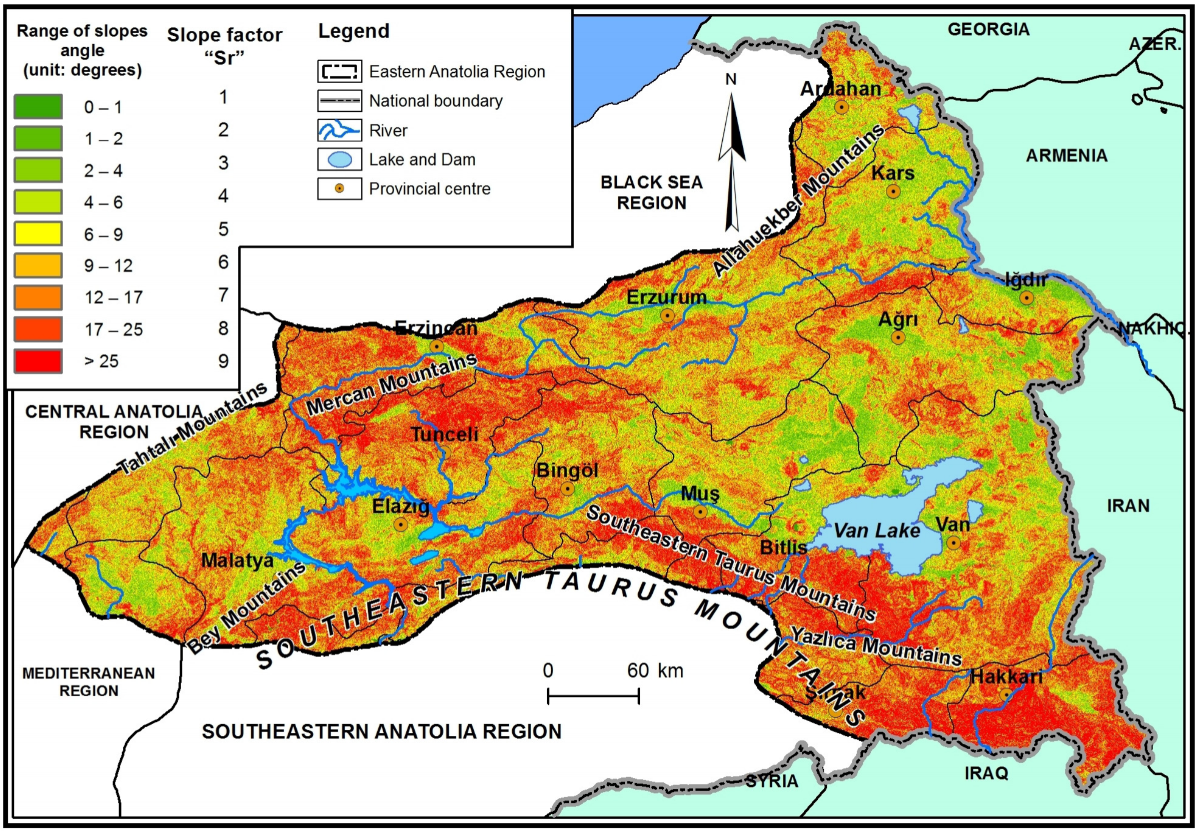

Fig. 2. Slope factor "Sr" map

The second factor in avalanches, which are climatologically caused events (Şahin & Sipahioğlu, 2003), is the climate. The foremost effect of climate shows itself under conditions of precipitation. In this regard, according to the Mora and Varhson (1994) method, the average precipitation data for the four-month period between December and March in the Eastern Hemisphere are used as the basis (Mora & Vahrson, 1994; Nadim, Kjekstad, Domaas, Rafat, & Peduzzi, 2006) since 90% of the avalanches in Turkey take place in these months (Şahin & Sipahioğlu, 2003).

In the four month period between December and March in which the avalanche risk is higher due to climate conditions, the average precipitation is 65.0 mm and it mostly consists of snow. The province with the lowest average precipitation is Iğdır with 16.0 mm, and the province with the highest average precipitation is Bitlis with 159.0 mm. When the level of risk in the areas between December and March are evaluated, the highest level is found to be 3.This situation is caused by lack of over 200 mm of precipitation in these areas in the in the given timeframe. In fact the third factor shows areal expansion in second place (30077.1 km² - 18.5%) in these areas. Due to the fact that precipitation average is between 0-50 mm in most of the area, precipitation factor 1 affects the largest area (104729.9 km² - 64.3%). This is followed by the 50-100 mm classes which affect a smaller area (28193.0 km² - 17.3%) (Table 2; Fig. 3).

Another effect of climate on avalanches is related to temperature conditions. As with precipitation conditions, the basis is the average temperatures taken in the period between December and March in the Northern Hemisphere according to Mora and Vahrson (1994) method (Mora & Vahrson, 1994; Nadim et al., 2006).

Table 2. Classification of precipitation factor "Tp" for avalanche hazard evaluation

Winter Precipitation (mm/year)	Precipitation factor "Tp"	Area	
		km²	%
0-50	1	104729.9	64.3
50-100	2	28193.0	17.3
100-200	3	30077.1	18.5
200-300	4	-	-
300-500	5	-	-
500-750	6	-	-
750-1000	7	-	-
1000-1500	8	-	-
1500->	9	-	-
TOTAL		**163000.0**	**100.0**

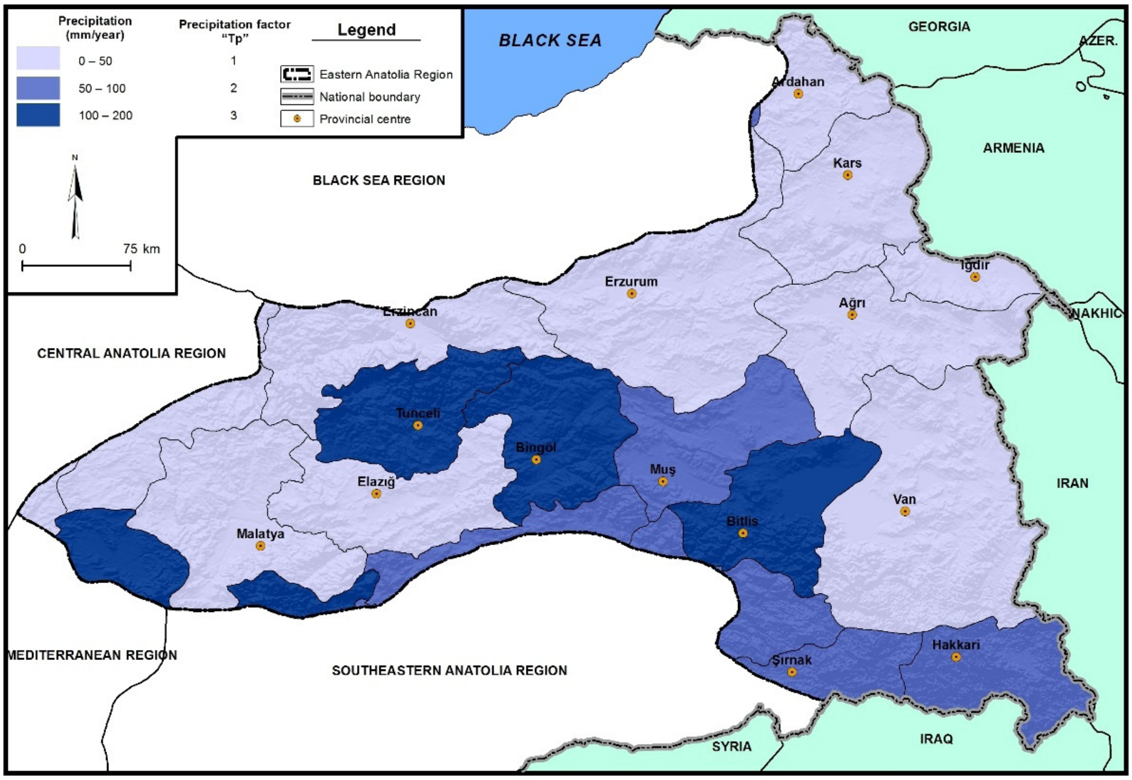

Fig. 3. Precipitation factor "Tp" map

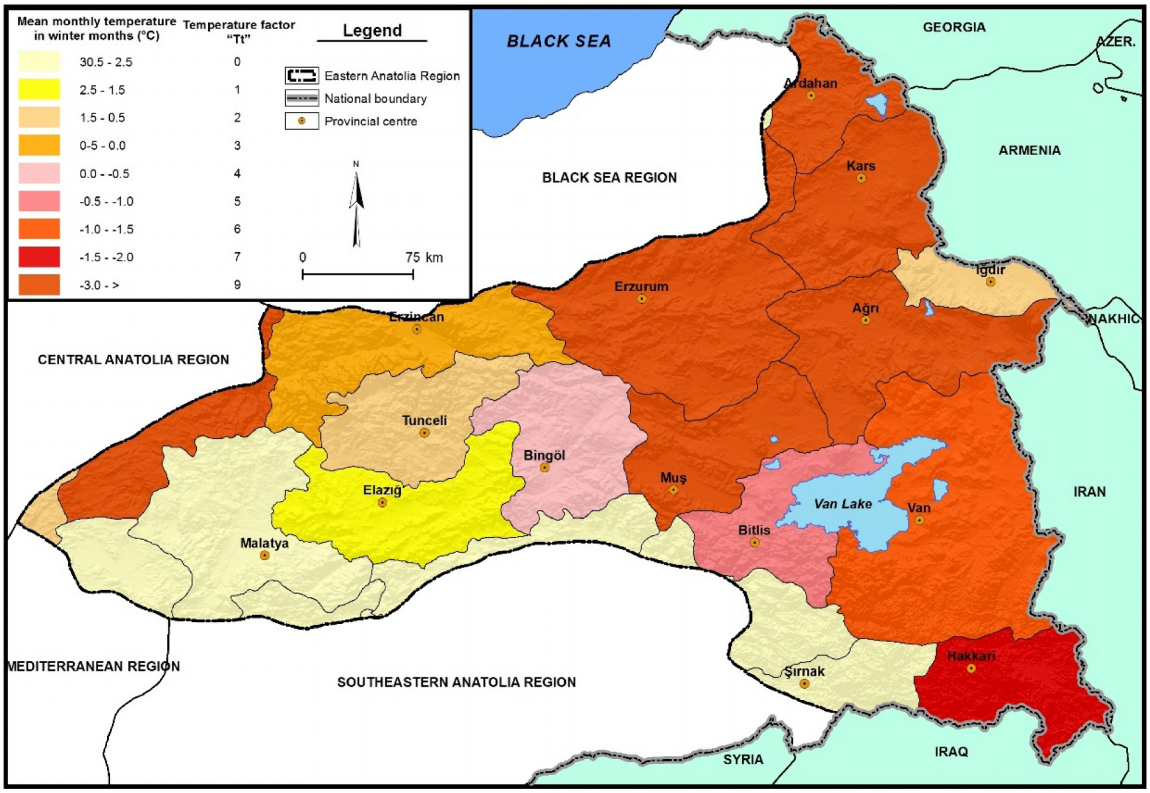

Fig. 4. Temperature factor "Tt"map

Table 3: Classification of snow avalanche hazard potential

Values for $H_{avalence}$	Class	Classification of avalanche hazard potential	Area	
			km²	%
> - 4	1	-	36864.8	22.6
4.1 - 4.5	2	-	16900.0	10.4
4.6 - 5.0	3	-	25400.0	15.6
5.1 – 5.5	4	Negligible	20925.0	12.8
5.6 – 6.0	5	Low	27541.0	16.9
6.0 – 7.0	6	Moderate	21929.5	13.5
7.0 – 7.5	7	Moderate to high	10243.1	6.3
7.5 – 8.2	8	High	3196.5	2.0
8.3- 9	9	Very high	0.1	0.0
TOTAL			**163000.0**	**100.0**

Average temperature distribution in these months is 0.2 °C Eastern Anatolian regions. The province with the lowest average temperature is Ardahan with -8.2 °C and the province with the highest average temperature is Sanlıurfa with 7.8 °C. Temperature changes according to longitude, continentality and elevation in other provinces. Besides the temperature values that are effective in these areas, the distribution of the temperature factor identified according to these temperatures is also effective in evaluating the risk. As opposed to the average precipitation, it is possible to see all the average temperature categories as classified by the Mora and Vahrson (1994) method in Eastern Anatolian region. Accordingly, the riskiest temperature factor value of -3.0 - > °C (9) covers the largest area (56598.8 km² - 34.7%). The smallest area (40.1 km² - 0.0%) is covered by the second riskiest temperature value – with 2.0 and -3.0 °C (8) (Table 3; Fig. 4).

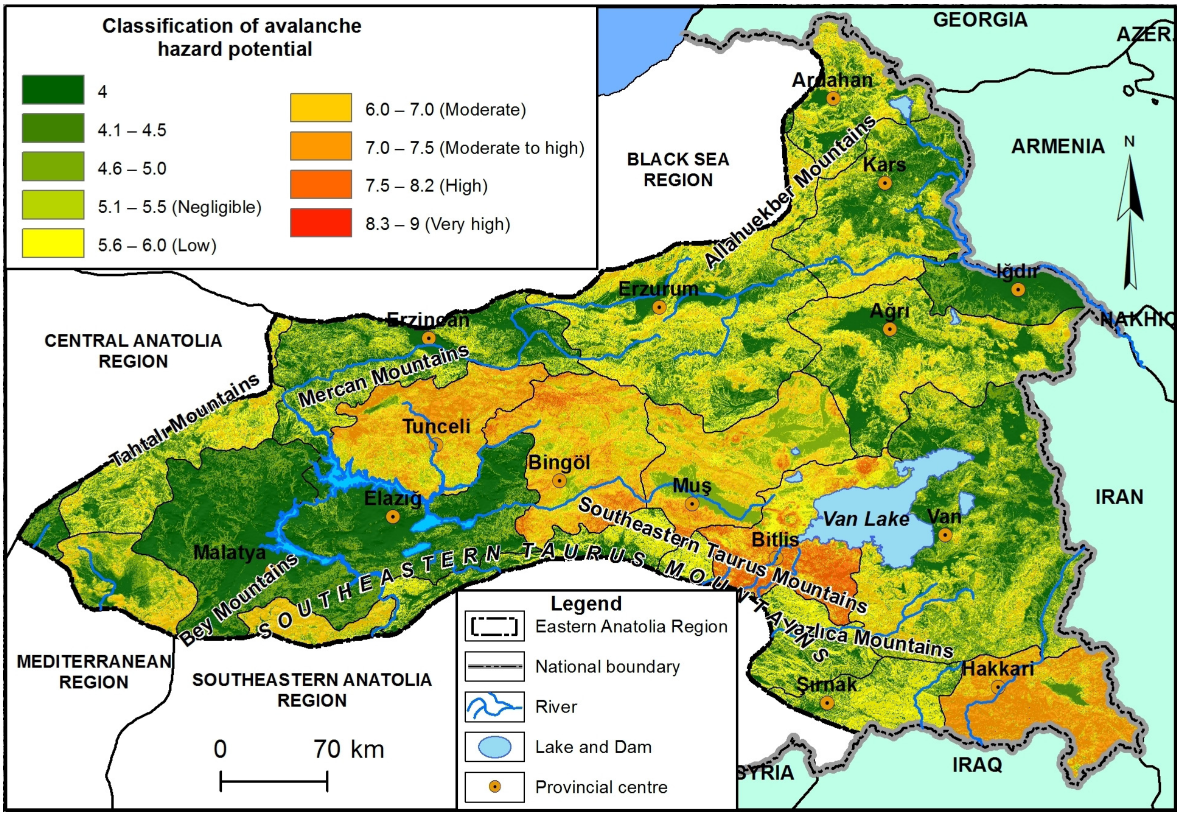

Fig. 5. Map of snow avalanche hazard potential

5. Conclusion

It has been understood that avalanches in the Eastern Anatolian region are caused by sloping, temperature and precipitation conditions. The effects of avalanches will be felt mores strongly in the most densely populated areas. According to the avalanche susceptibility analysis, the susceptibility values are 256.18 on average and the total is 5.386. The areas with highest susceptibility are observed in rather small areas (0.1 km² - 0.0%) in the field where avalanche susceptibility is largely unimportant (20925.0 km² - 10.4%) and the lowest (27541.0 km² - 16.9%). The other susceptibility classes are distributed from lowest to highest are Moderate (21929.5 km² - 13.5%), Moderate to high (10243.1 km² - 6.3%) and High (3196.5 km² - 2.0%). The areas with danger levels values of 1-3 but unidentified due to the fact that they carry insignificant risk are (from highest to lowest) 36864.8 km² - 22.6%; 16900.0 km² - 10.4%; 25400.0 km² - 15.6% (Table 4; Fig. 5).

According to the map obtained at the end of the analysis, the riskiest areas often correspond with event frequency in disaster statistics. In this regard; the provinces with the highest risks in the region are *Bitlis* with the most avalanche cases, *Bayburt* with the highest number of casualties and injured and *Bingol* with the highest number of people negatively affected. When the outcome map was compared with the risk maps prepared for Georgia and for the Middle East in general by using the same method (Nadim, Kjekstad, Domaas, Rafat, & Peduzzi, 2006), the obtained results were largely found to be consistent in the detailed scale. When the obtained information was reorganized according to the risk evaluation formula recommended by UNDRO (1979), the risk values were calculated to be 189.15 in all and 11.63 on average. When these results were compared to the risk map, the provinces with the highest risks were found to be Hakkari, Bitlis, Mus, Bingol, Tunceli, Kahramanmaras, Erzurum, Agrı and Van (Fig. 6).

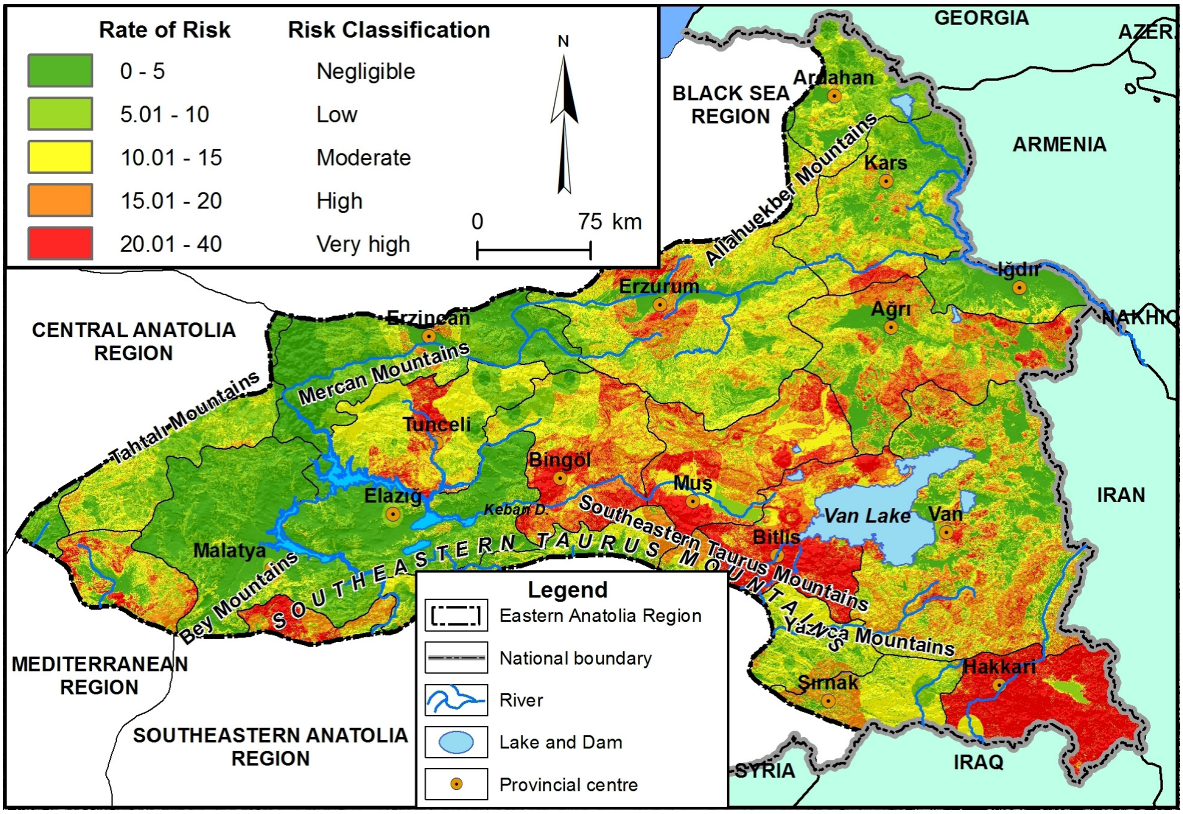

Fig. 6. Map of Risk Assessment

Projects regarding avalanche susceptibility detection and planning need to be started immediately. In this framework, more detailed and effective avalanche risk maps with more effective factors need to be prepared. Detailed climate research into detecting extreme meteorology events in the areas under risk must be undertaken. Early warning systems and planning against avalanches in the settlements in the high risk areas must be developed. In risky areas, avalanche observation stations must be constructed at regular intervals. The current research, another example of an alternative avalanche risk map used in various places in the world with different methods, shows that the given method is applicable to Turkey. It has also shown that the Geographical Information Systems method and techniques can be used in avalanche risk analysis.

References

Arınç, K. (2011). *Doğal, İktisadi, Sosyal ve Siyasal Yönleriyle Türkiye'nin İç Bölgeleri*. 1. Baskı, Biyosfer Araştırmaları Merkezi Coğrafya Araştırmaları Serisi No: 101, Erzurum.

Atalay, İ. (2011). *Türkiye Coğrafyası ve Jeopolitiği*. 8. Baskı, Meta Basım Matbaacılık Hizmetleri, İzmir.

Atalay, İ.; Mortan, K. (2011). *Resimli ve Haritalı Türkiye Bölgesel Coğrafyası*. İnkılap Kitabevi, İstanbul.

Bacanlı, H.; Özgüler, H.; Lenk, O. (Edit.). (2003). *Türkiye Ulusal Meteorolojik ve Hidrolojik Afetler Programı (TUMEHAP)*. Türkiye Ulusal

Jeodezi ve Jeofizik Birliği, Ankara.
Barka, I.; Rybar, R. (2003). Identification of snow avalanche trigger areas using GIS. *Ecology*, 22, Bratislava.
Biskupic, M.; Barka, I. (2010). Spatial modelling of snow avalanche run-outs using GIS. *GIS Ostrava,* 2010: 1-11.
DAÖİKB (2000). *Meteorolojik Kaynaklı Doğal Afetler Alt Komisyonu*. Basılmamış Rapor, Ankara.
Ertürkmen, C. (2006). *Afet Yönetimi*. Basılmamış Yüksek Lisans Tezi, T. C. Ankara Üniversitesi Sosyal Bilimler Enstitüsü Kamu Yönetimi ve Siyaset Anabilim Dalı, Ankara.
Furdada, G.; Marti, G.; Oller, P.; Garcia, C.; Mases, M.; Vilaplana, J.M. (1995). Avalanche mapping andrelated GIS applications in the Catalan Pyrenees. *Surveys in Geophysics,* 16 (5–6): 681–693.
Ghinoi, A.; Chung, C.J. (2005a). Starter: A statistical GIS-based model forthe prediction of snow avalanche susceptibility using terrain features. Application to Alta ValBadia, Italian Dolomites. *Geomorphology*, 66 (1–4): 305–325.
Ghinoi, A.; Chung, C.J. (2005b). Planning with snow avalanche risk: when the Carte de localisation probable des avalanches become sold-fashioned. *Geophysical Research Abstracts*, 7: 1-7.
Gürer, İ. (2002). Türkiye'de Yerleşim Yerlerine Yönelik Kar ve Çığ Problemleri. *TMH - Türkiye Mühendislik Haberleri*, 420-421-422 / 2002/4-5-6: 147-154.
Huggel, C.; Kaab, A.; Salzmann, N. (2004). GIS based modeling of glacial hazards and their interactions using Landsat TM and IKONOS imagery, Norsk Geografisk Tidsskrift-Norwegian. *Journal of Geography*, 58 (2): 61-73.
Mejia-Navarro, M.; Wohl, E.E.; Oaks, S.D. (1994). Geological hazards, vulnerability, and risk assessment using GIS: model for Glenwood Springs, Colorado. *Geomorphology*, 10 (1–4): 331–354.
Mora, S.; Vahrson, W. (1994). Macrozonation Methodology for Landslide Hazard Determination. Bulletin *of theAssociation of Engineering Geologists*, 31 (1): 49–58.
Mulders, M.A. (2001). Advances in the application of remote sensin gand GIS for surveying mountainous land. *International Journal of Applied Earth Observation and Geoinformation,* 3 (1): 3–10.
Nadim, F.; Kjekstad, O.; Domaas, U.; Rafat, R.; Peduzzi, P. (2006). *Global Landslides Risk Case Study. Chapter 2, Natural Disaster Hotspots Case Studies*, Edited by: Margaret Arnold, Robert S. Chen, Uwe Deichmann, Maxx Dilley, Arthur L. Lerner-Lam, Randolph E. Pullen, Zoe TROHANIS, The World Bank Hazard Management Unit, Washington, D. C.
Önal, E. (2012). *26. Katsayı Diyagramı Yönetimi (KDY) ve ArcGIS Programıyla Malatya İlinde Olmuş Afetlerin Analizi ve Haritasal Model ve Simülasyonlarının Gerçekleştirilmesi*. Malatya İl Afet ve Acil Durum Müdürlüğü, 25 Mayıs 2012, Bildiriler Kitabı, s.: 1-13, Malatya.
Pertigizer, F. (1998). Using of GIS technology for avalanche hazard mapping, scale 10.000. *Publikasjon Norges Geotekniske Inst*, 203: 210–214.
Şahin, C.; Sipahioğlu, Ş. (2003). *Doğal Afetler ve Türkiye*. Genişletilmiş 2. Baskı, Gündüz Eğitim ve Yayıncılık, Ankara.
Schweizer, J.; Jamieson, J. B.; Schneebeli, M. (2003). Snow avalanche formation. *Reviews of Geophysics,* 41: 1-25.
Stoffel, A.; Meister, R.; Schweizer, J. (1998). Spatial characteristics of avalanche activity in an Alpine valley: A GIS approach. *Annals of Glaciology,* 26: 329–336.
Suk, P.; Klimanek, M. (2011). Creation of the snow avalanche susceptibility map of the Krkonose Mountains using GIS. *Acta univ. agric. etsilvic. Mendel. Brun.*, 5: 237–246.
Taştekin, A.T. (2012). *Meteroloji ve Çığ*. Meteroloji Genel Müdürlüğü, http://www.mgm.gov.tr/FILES/arastirma/cigdankorunma.pdf, Son Erişim Tarihi: 23.12.2012.
Taymaz, M. (2001). Doğal Afet Zararlarını Azaltma Çalışmaları. *Afet ve Afet İşleri Genel Müdürlüğü Bülteni,* 2: 4-5.
Tunçel, H. (1990). Doğal Çevre Sorunu Olarak Çığlar ve Türkiye'de Çığ Olayları. *Coğrafya Araştırmaları Dergisi*, 2: 43-98.
UNDRO (United Nations DisasterReliefCoordinator). (1979). *Natural Disasters and Vulnerability Analysis in Report of Expert Group Meeting (July 9–12, 1979)*. UNDRO, 49, Geneva.
Varol, N.Ö.; Yavaş, Ö.M. (2006). *Türkiye'deki Çığ Olaylarının Değerlendirilmesi*. 59. Türkiye Jeoloji Kurultayı Bildirileri, TMMOB Jeoloji Mühendisleri Odası, s.: 339, Ankara.