LANDSLIDE HAZARD ANALYSIS

I- NATIONAL LANDSLIDE INVENTORY

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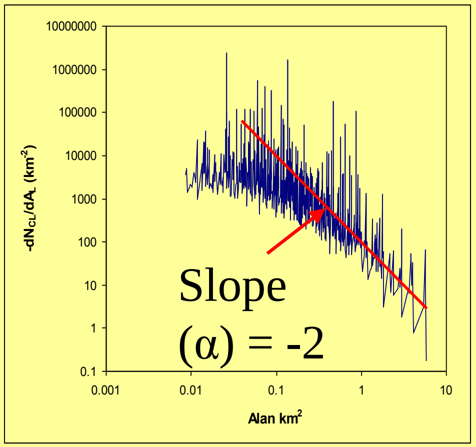
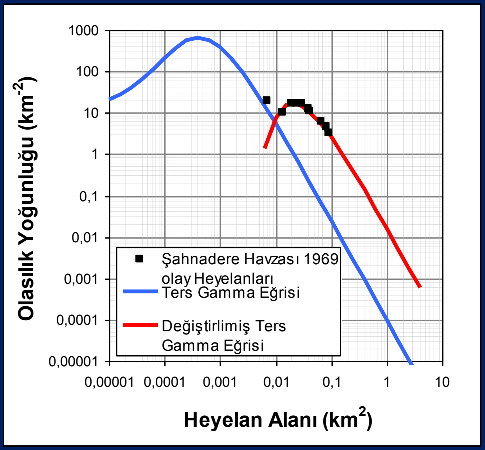
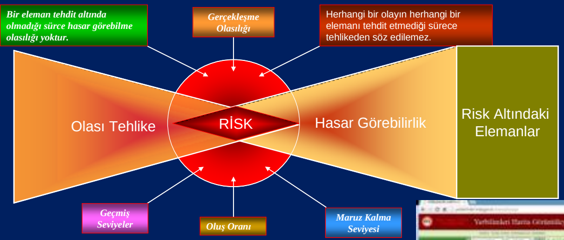
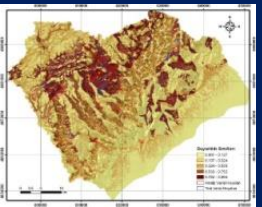
TALK LAYOUT

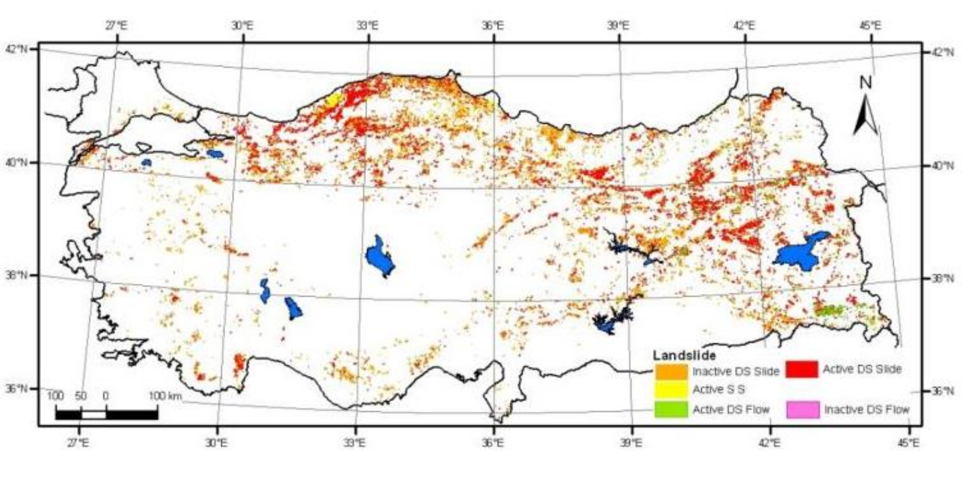
- Introduction
  - Natural Hazards / (UN! Natural Disasters)
  - General terminology in landslide inventory, hazard and risk assessment
- Archive and Historical Landslide Inventories of Turkey
  - Standards and medium, regional & national scale landslide inventory maps, MTA Geosciences Web Portal
- Quantitative landslide hazard and risk assessment
  - Spatial probability
  - Temporal probability
  - Probability of landslide size

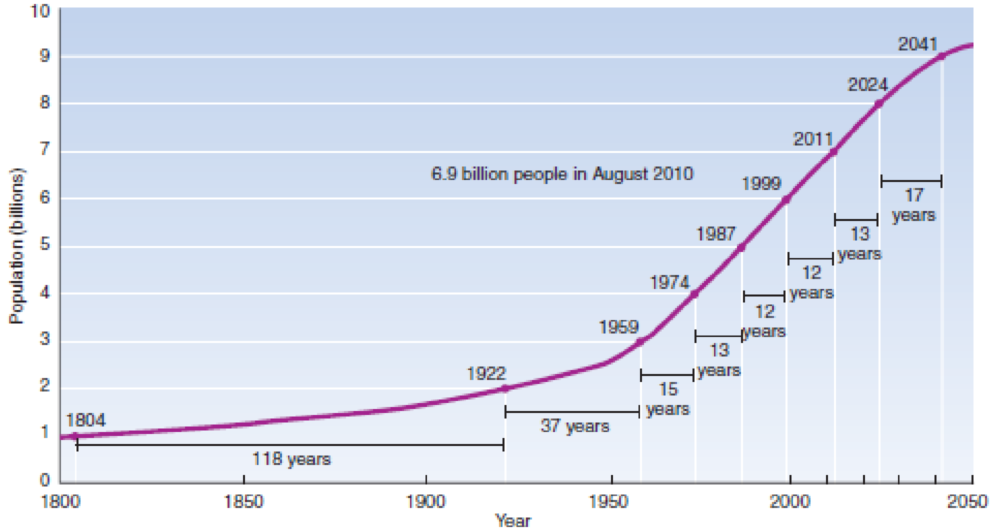




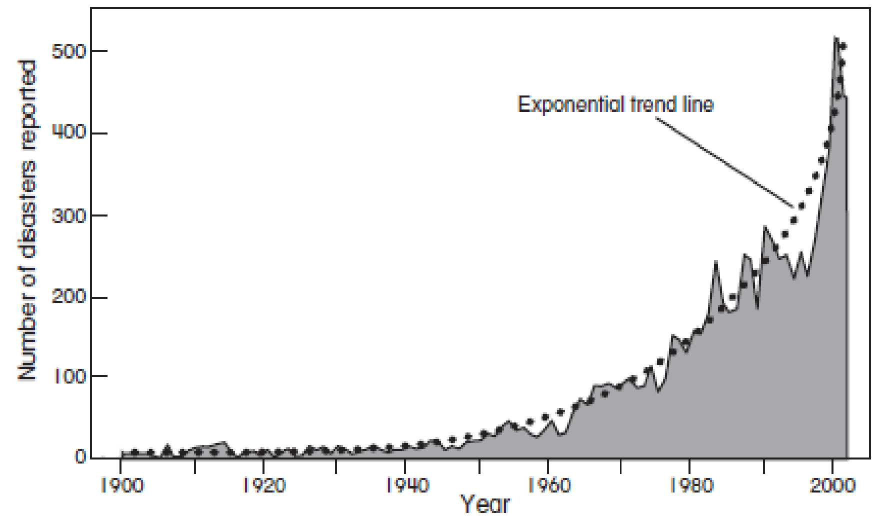






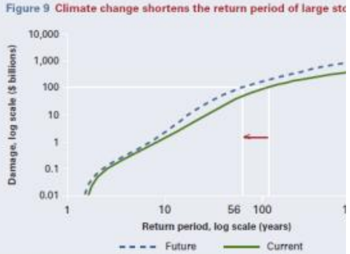


RE 1.11 Growth of the world population of humans. Notice how the time to add another billion people has decreasec
t is projected to start increasing in the future.
S Census Bureau.



Reporting incidence of natural hazards over time 1900–2001 (based on CRED, 2002).

Figure 9 Climate change shortens the return period of large sto



Note: The figure shows the return period for tropical cyclones of different intensi specific climate model (MIROC). A $100 billion storm is estimated to happen on States given the current climate. With a future warmed climate, it is expected to h
Source: Mendelsohn, Emanuel, and Chonabayashi 2010a.

TABLE 1.6

World Population Data, Mid-2010

	Population (millions)	Birth Rate (per 1,000)	Death Rate (per 1,000)	Yearly Growth %	Doubling Time (in years)	Projected Population in 2050 (millions)
World	6,892	20	8	1.2	58	9,485
More-developed countries	1,237	11	10	0.2	350	1,326
Less-developed countries	5,656	22	8	1.4	50	8,159
Least-developed countries	857	35	12	2.3	30	1,710
Africa	1,030	37	13	2.4	29	2,084
Asia	4,157	19	7	1.2	58	5,424
Europe	739	11	11	0	—	720
Northern America	344	13	8	0.6	115	471
Latin America	585	19	6	1.3	50	729
Oceania	37	18	7	1.1	63	58

Source: World Population Data Sheet (2010).

TABLE 1.2

The 40 Deadliest Natural Disasters, 1970–June 2010

Fatalities	Date/Start	Event	Country
300,000	14 Nov 1970	Hurricane	Bangladesh
255,000	28 Jul 1976	Earthquake (Tangshan)	China
245,000	26 Dec 2004	Earthquake and tsunami	Indonesia, Sri l
230,000	12 Jan 2010	Earthquake	Haiti
140,000	2 May 2008	Hurricane Nargis	Myanmar
140,000	29 Apr 1991	Hurricane Gorky	Bangladesh
88,000	8 Oct 2005	Earthquake	Pakistan
87,500	12 May 2008	Earthquake	China
66,000	31 May 1970	Earthquake and landslide (Nevados Huascaran)	Peru
50,000	21 Jun 1990	Earthquake (Gilan)	Iran
35,000	Aug 2003	Heat wave	Europe
27,000	26 Dec 2003	Earthquake (Bam)	Iran
25,000	7 Dec 1988	Earthquake	Armenia
25,000	16 Sep 1978	Earthquake (Tabas)	Iran
23,000	13 Nov 1985	Volcanic eruption and mudflows (Nevado del Ruiz)	Colombia
22,000	4 Feb 1976	Earthquake	Guatemala
20,103	26 Jan 2001	Earthquake (Gujarat)	India
19,118	17 Aug 1999	Earthquake (Izmit)	Turkey
15,000	19 Sep 1985	Earthquake (Mexico City)	Mexico
15,000	1 Sep 1978	Flood (monsoon rains in north)	India
15,000	29 Oct 1999	Hurricane (Orissa)	India
11,000	22 Oct 1998	Hurricane Mitch	Honduras
10,800	31 Oct 1971	Flood	India
10,000	15 Dec 1999	Flooding and mudslides	Venezuela
10,000	25 May 1985	Hurricane	Bangladesh
10,000	20 Nov 1977	Hurricane (Andhra Pradesh)	India
9,500	30 Sep 1993	Earthquake (Marashtra state)	India
8,000	16 Aug 1976	Earthquake (Mindanao)	Philippines
6,425	17 Jan 1995	Earthquake (Kobe)	Japan
6,304	5 Nov 1991	Typhoons Thelma and Uring	Philippines
5,778	21 May 2006	Earthquake	Indonesia
5,422	30 Jun 1976	Earthquake (West Irian)	Indonesia
5,374	10 Apr 1972	Earthquake (Fars)	Iran
5,300	28 Dec 1974	Earthquake	Pakistan
5,112	15 Nov 2001	Floods and landslides	Brazil
5,000	23 Dec 1972	Earthquake (Managua)	Nicaragua
5,000	5 Mar 1987	Earthquake	Ecuador
4,800	23 Nov 1980	Earthquake (Campagna)	Italy
4,500	10 Oct 1980	Earthquake (El Asnam)	Algeria
4,000	24 Nov 1976	Earthquake (Van)	Turkey
1,975,036 Total deaths			

Source: Data after *Swiss Reinsurance Company* (2009).

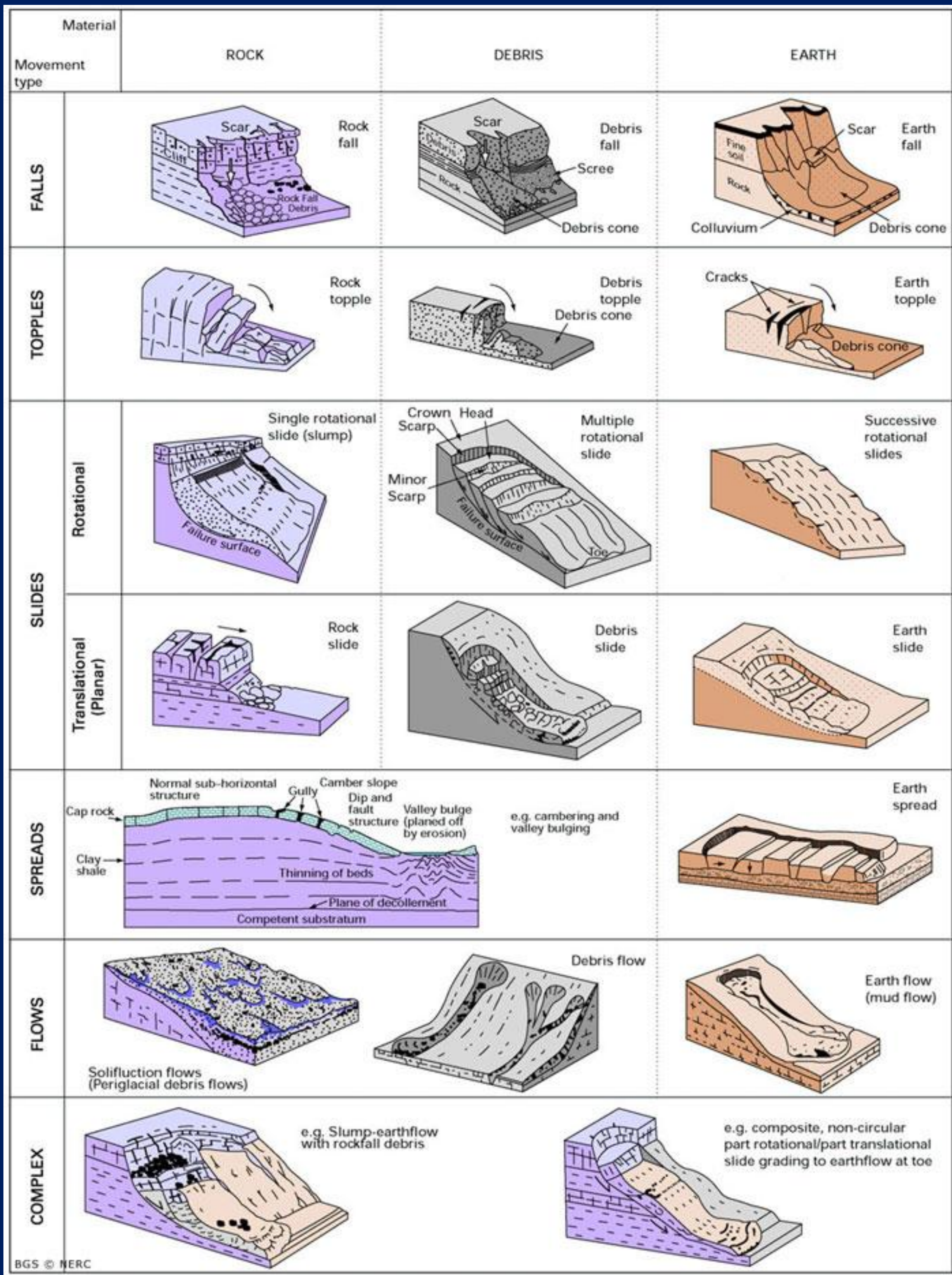
TABLE 1.3

The 40 Most Costly Insurance Disasters, 1970–2008

Losses in Millions of 2008 US$	Fatalities	Date/Start	Event	Country
71,300	1,836	29 Aug 2005	Hurricane Katrina	USA
24,552	43	24 Aug 1992	Hurricane Andrew	USA
22,835	2,982	11 Sep 2001	Terrorist attack	USA
20,337	57	17 Jan 1994	Earthquake (Northridge)	USA
20,000	136	6 Sep 2008	Hurricane Ike	USA
14,680	124	2 Sep 2004	Hurricane Ivan	USA
13,847	35	16 Oct 2005	Hurricane Wilma	USA
11,122	34	20 Sep 2005	Hurricane Rita	USA
9,176	24	11 Aug 2004	Hurricane Charley	USA
8,926	51	27 Sep 1991	Typhoon Mireille	Japan
7,940	71	15 Sep 1989	Hurricane Hugo	USA
7,695	95	25 Jan 1990	Winter Storm Daria	Europe
7,497	110	25 Dec 1999	Winter Storm Lothar	Europe
6,328	54	18 Jan 2007	Winter Storm Kyrill	Europe
5,866	38	26 Aug 2004	Hurricane Frances	USA
5,860	63	17 Oct 1989	Earthquake (Loma Prieta)	USA
5,855	22	15 Oct 1987	Storm	Europe
5,258	64	26 Feb 1990	Winter Storm Vivian	Europe
5,222	26	22 Sep 1999	Typhoon Bart	Japan
4,663	600	20 Sep 1998	Hurricane Georges	USA, Caribbean
4,382	41	5 Jun 2001	Tropical Storm Allison	USA
4,334	3,034	13 Sep 2004	Hurricane Jeanne	USA, Haiti
4,087	45	6 Sep 2004	Typhoon Songda	Japan
4,000	135	26 Aug 2008	Hurricane Gustav	USA
3,752	45	2 May 2003	Tornadoes	USA
3,648	70	10 Sep 1999	Hurricane Floyd	USA, Bahamas
3,642	167	6 Jul 1988	Explosion on Piper Alpha offshore oil rig	UK
3,540	59	4 Oct 1995	Hurricane Opal	USA
3,493	6,425	17 Jan 1995	Earthquake (Kobe)	Japan
3,102	45	27 Dec 1999	Winter Storm Martin	France
2,925	246	10 Mar 1993	Storm (East Coast)	USA
2,763	38	6 Aug 2002	Floods	Europe
2,688	26	20 Oct 1991	Fire—into urban area, drought	USA
2,675	—	6 Apr 2001	Storms (tornado/hail)	USA
2,583	4	25 Jun 2007	Flood	UK
2,548	30	18 Sep 2003	Hurricane Isabel	USA
2,495	39	5 Sep 1996	Hurricane Fran	USA
2,462	20	3 Dec 1999	Winter Storm Anatol	Europe
2,455	4	11 Sep 1992	Hurricane Iniki (Hawaii)	USA
2,369	—	12 Sep 1979	Hurricane Frederic	USA
$342,902 Billion	16,938 Total deaths			

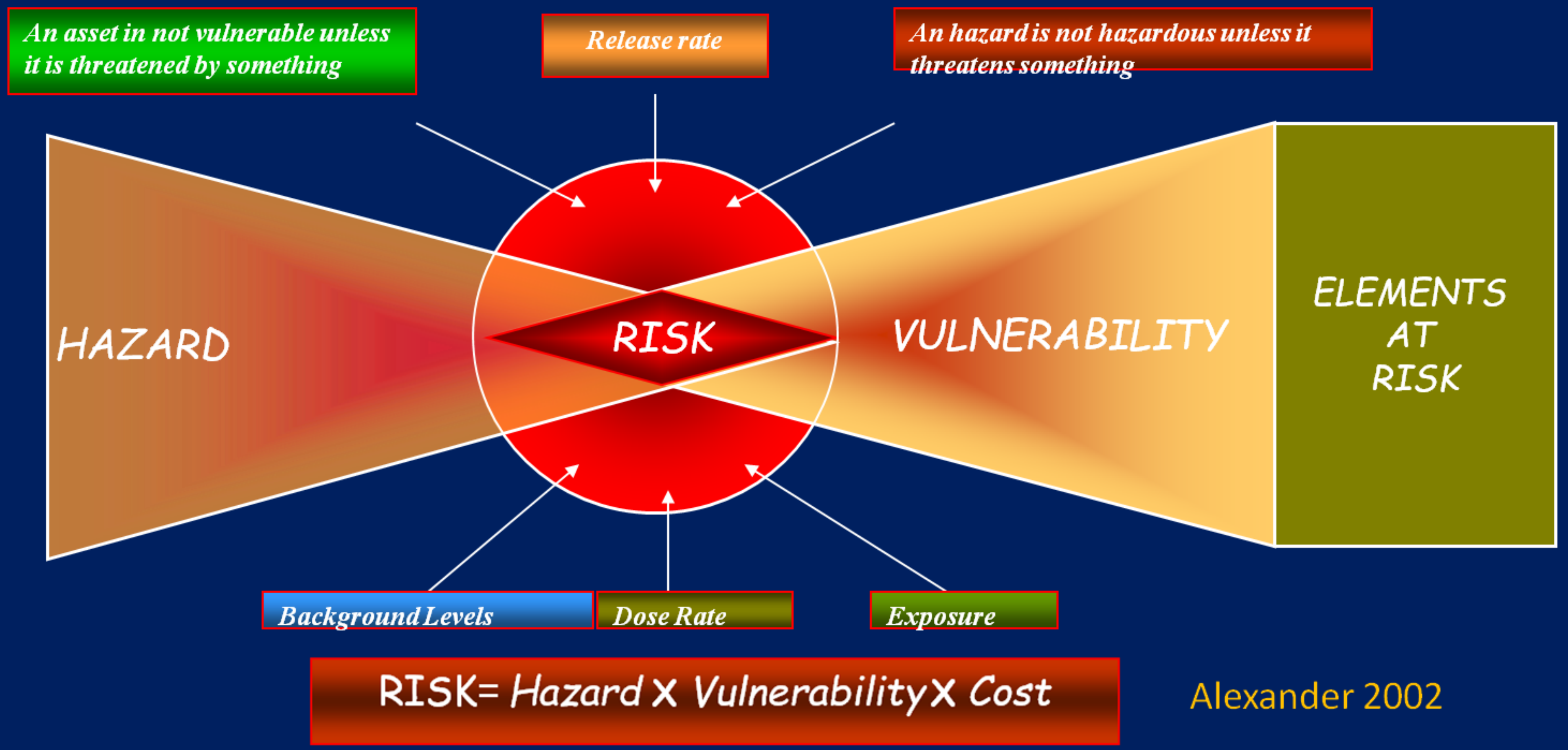
Source: Data after *Swiss Reinsurance Company* (2009).

A "landslide" is the movement of rock, debris, or earth material down a slope, under the influence of gravity (Cruden and Varnes, 1996).



Large and small landslides occur almost every year in nearly all regions of the world. However, the number of landslides is difficult to ascertain, and even the number of landslide-caused casualties is not correctly counted worldwide. Most casualties caused by rain-induced landslides are included in those tabulated for hurricane or storm disasters, and casualties caused by earthquake-induced landslides are often included in those for earthquake disasters. Thus, the casualties due to landslide disasters are often extremely underestimated. (Sassa et al. 2007)

Velocity Class	Description	Velocity (mm/sec)	Typical Velocity	Probable Destructive Significance
7	Extremely Rapid			Catastrophe of major violence; buildings destroyed by impact of displaced material; many deaths; escape unlikely
		5×10^{3}	5 m/sec	
6	Very Rapid			Some lives lost; velocity too great to permit all persons to escape
		5×10^{1}	3 m/min	
5	Rapid			Escape evacuation possible; structures; possessions, and equipment destroyed
		5×10^{-1}	1.8 m/hr	
4	Moderate			Some temporary and insensitive structures can be temporarily maintained
		5×10^{-3}	13 m/month	
3	Slow			Remedial construction can be undertaken during movement; insensitive structures can be maintained with frequent maintenance work if total movement is not large during a particular acceleration phase
		5×10^{-5}	1.6 m/year	
2	Very Slow			Some permanent structures undamaged by movement
		5×10^{-7}	15 mm/year	
1	Extremely SLOW			Imperceptible without instruments; construction POSSIBLE WITH PRECAUTIONS



Natural Hazard (H) means the probability of occurrence within a specified period of time and within a given area of a potentially damaging phenomenon.
Vulnerability (V) means the degree of loss to a given element(s) at risk resulting from the occurrence of a natural phenomenon of a given magnitude.
Risk (R) means the expected degree of loss due to a particular natural phenomenon (hazard) (Varnes 1984).

1. Which event? → Typology (L inventory)
2. Where? → Spatial probability (susc
3. When? → Temporal Probability
4. How large? → Prob. Landslide Size
5. Who, what, how? → Damages
6. How much? → Value

Hazard

Vulnerability

Cost

Landslide hazard maps portray the probability of occurrence of a given landslide size within a specified time period and within a given area.

The wide spectrum of landslide events and the complexity and variability of their interactions with the environment both natural and man-made make the acceptance of a single definition of landslide hazard unsuitable. Very large, fast-moving landslides e.g., rock avalanches are probably the most destructive and hazardous mass movements. Slow-moving, deep-seated failures rarely claim lives but can cause high property damage. Fast-moving flows triggered by intense rainfalls are extremely destructive, causing widespread damage and casualties. Each type of landslide pose different threats and may require a separate assessment, based on distinct definitions of landslide hazard.

Landslide inventory maps document the extent of landslide phenomena in a region, and show information that can be exploited to investigate the distribution, types, recurrence and statistics of slope failures, to determine landslide susceptibility, hazard, vulnerability and risk, and to study the evolution of landscapes dominated by mass-wasting processes.

- **Landslide archive inventory**
  Collecting historical information on landslide events from scientific, technical and any kind of reports. Consequences and location.

- **Event landslide inventory**
  Landslide triggered by a single event, ex. Earthquake or rainfall induced

- **Multi-temporal landslide inventory**
  The most advanced form of LI. Continuous effects of many events over a period (multiple sets of aerial photographs, HRSI.

- **Historical (Geomorphological) landslide inventory**
  Includes all landslides recognized by the time of mapping.

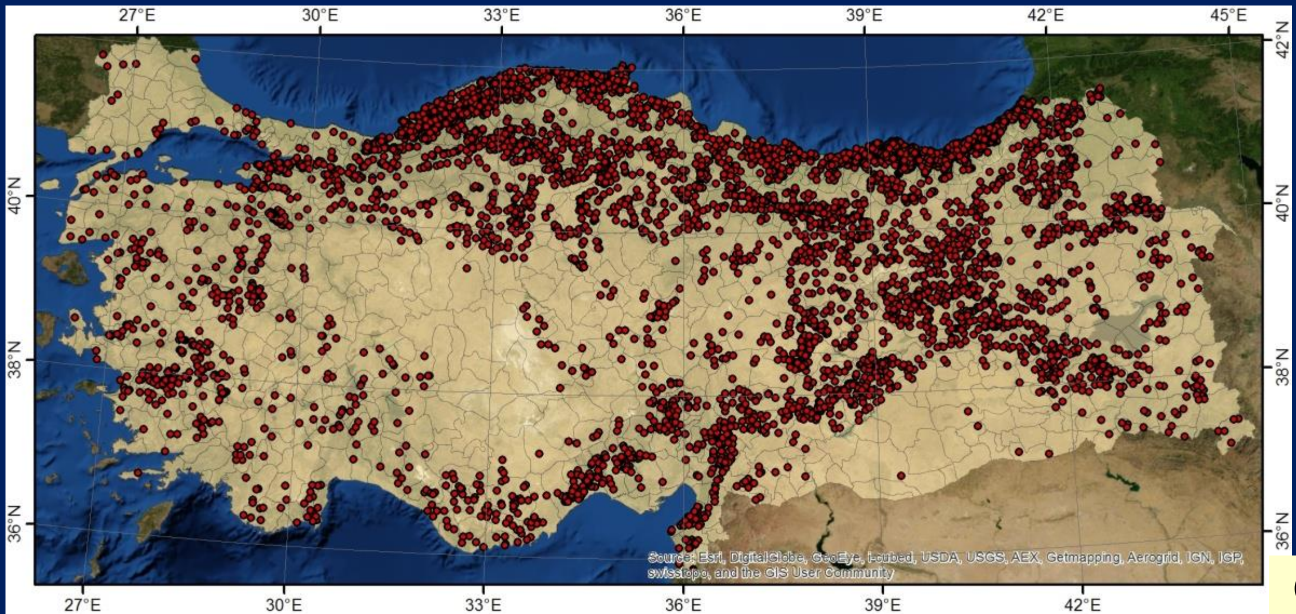
The information shown on landslide inventories can be used for a variety of analyses,

- investigating landslide spatial abundance, through the production of landslide density maps;
- comparing inventory maps obtained from different sources (e.g., archive and geomorphological) for the same area;
- evaluating the completeness of the inventories;
- ascertaining landslide geographical persistence, by comparing event and geomorphological inventories;
- estimating the frequency of slope failure occurrence, by analyzing historical catalogues of landslide events or multi-temporal inventory maps;
- obtaining the statistics of landslide size;
- ascertaining landslide susceptibility and hazards, including the validation of the obtained susceptibility and hazard forecasts;
- determining the possible impact of landslides on built-up areas or the infrastructure; and
- contributing to establish levels of landslide risk.

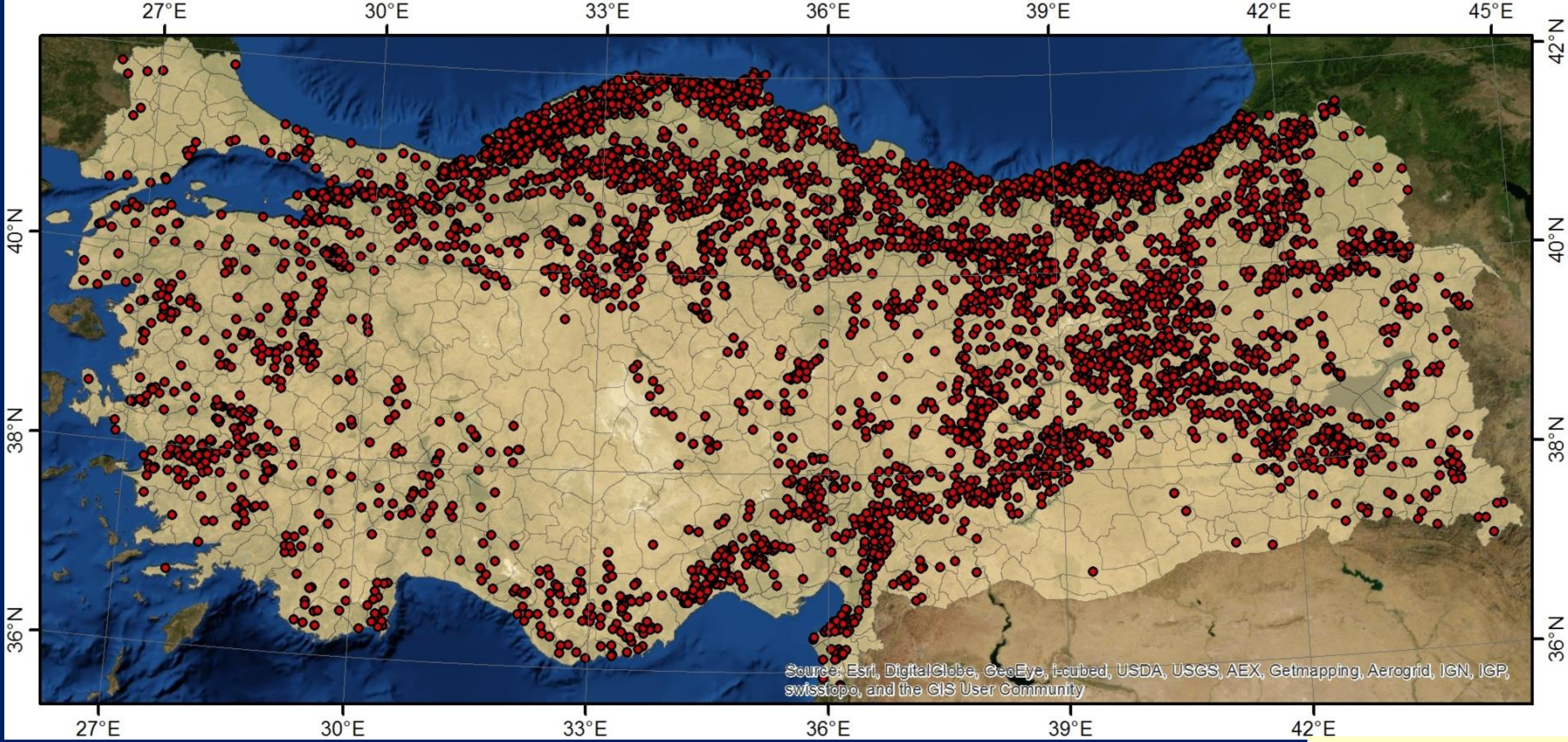
The quality and reliability of the different analyses obtained from a landslide inventory depend largely on the quality and completeness of the original landslide map.

Landslide Archive Inventory of Turkey

The one of the nationwide study on landslides in the context of "Disaster Inventory Project" was prepared by AFAD (Turkish Disaster and Emergency Management Presidency) under the former establishment namely The General Directorate of Disaster Affairs for the years 1950 to 2008. The database was built up by evaluating 29.807 disaster reports on earthquake, landslide, rockfall, flood and avalanche events and then stored in GIS database by point features including date, settlement name, number of event and victim of disasters. Accordingly, the landslide archive inventory encompasses 16.450 (2956 for the rockfalls) disastrous landslide events with 78.762 victims.

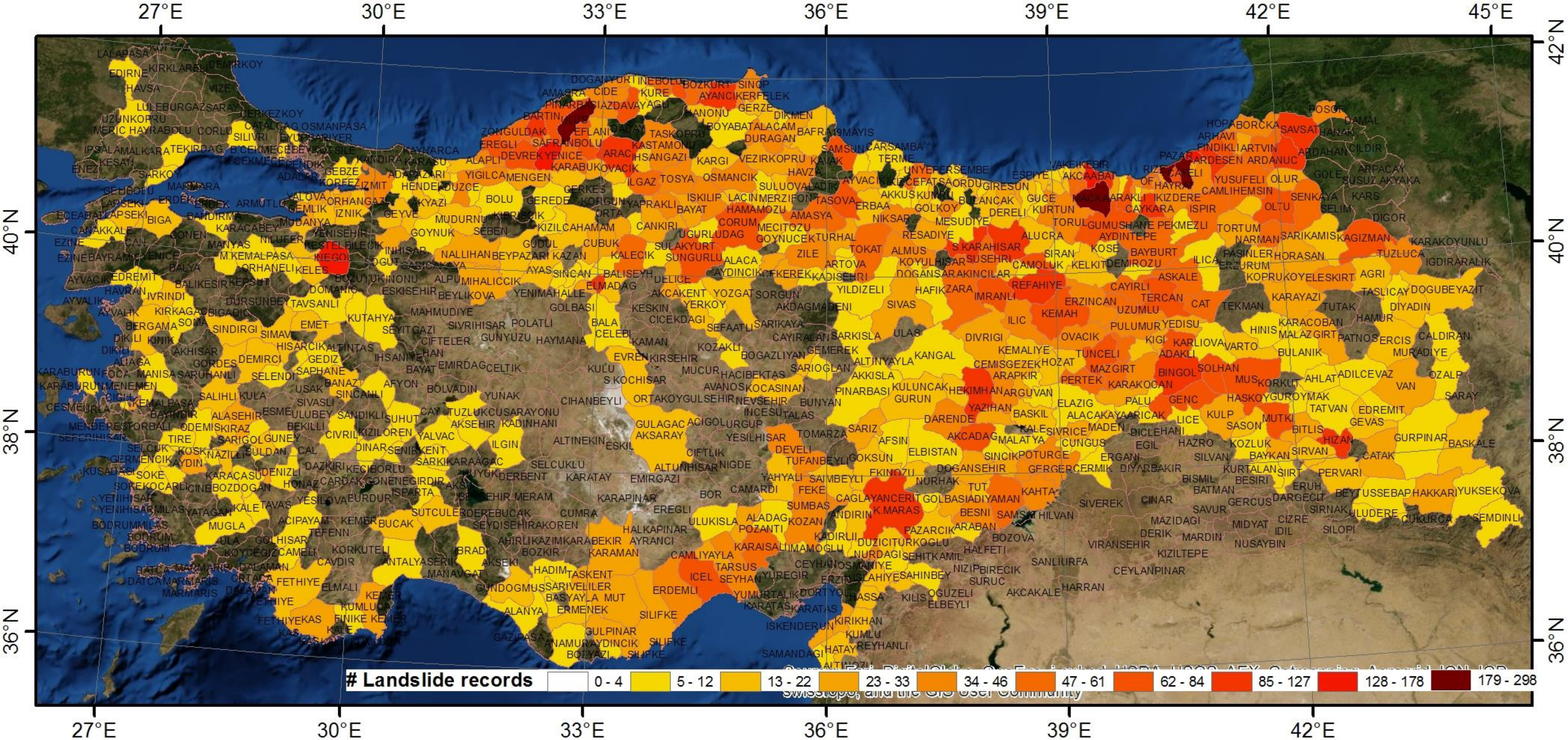


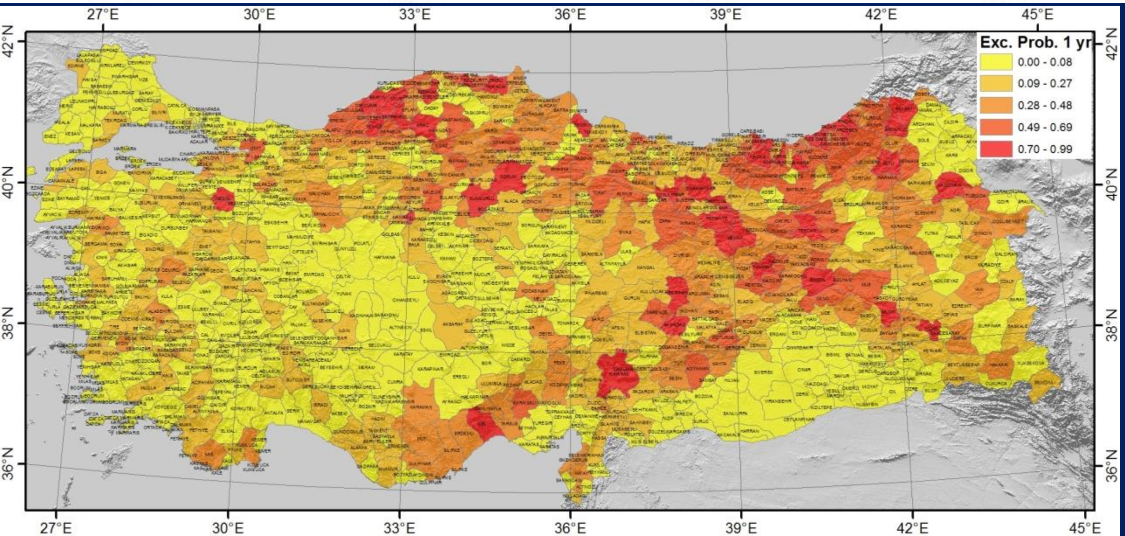
(Gökçe et al. 2006)

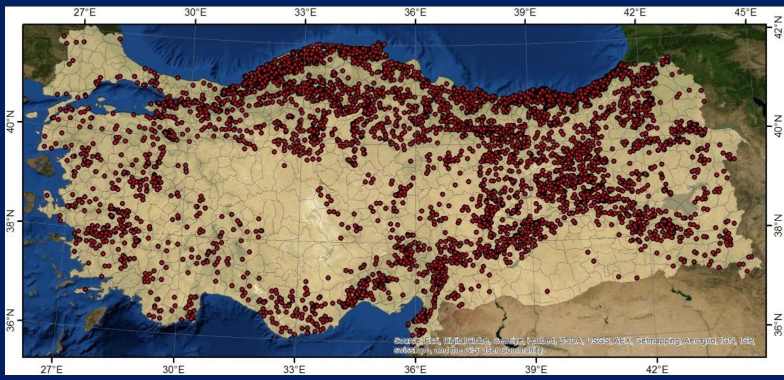


(Gökçe et al. 2006)

Settlements affected by natural hazards between 1950-2005 in Turkey							
Natural Hazard Type	Affected Settlements		Events		Evacuation required events	Evacuated residences	
	Count	%	Count	%		Count	%
LANDSLIDES	5060	41.6	15563	51.9	7714	84805	33.7
FLOODS	1861	15.3	3873	12.9	2249	26081	10.4
EARTHQUAKES	2952	24.3	5267	17.6	4807	106838	42.4
OTHERS	2299	18.9	5304	17.7	2712	34137	13.6
TOTAL	12172	100	30007	100	17482	251861	100







Second-order administrative division

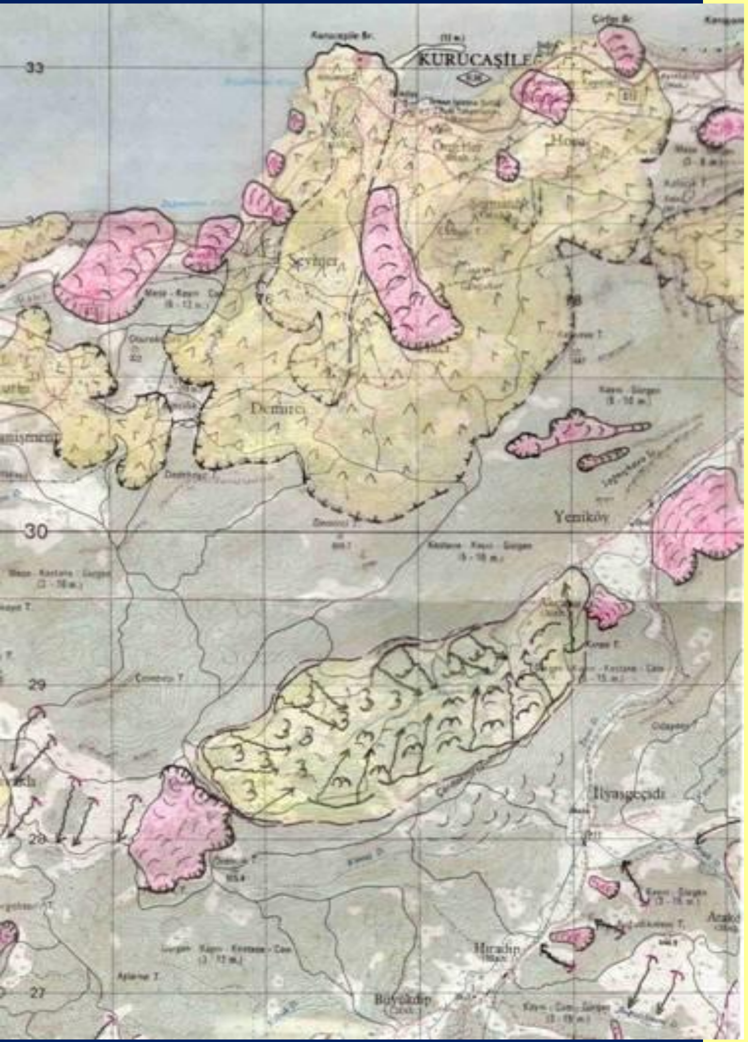
MTA Landslide Database of Turkey

The General Directorate of Mineral Research and Exploration (MTA) started the 'Turkish Landslide Inventory Mapping Project' in 1997

to improve understanding of regional and national landslide processes
to establish landslide inventory maps at medium (1/25.000), regional (1/500.000) and national 1/1.500.000) scales

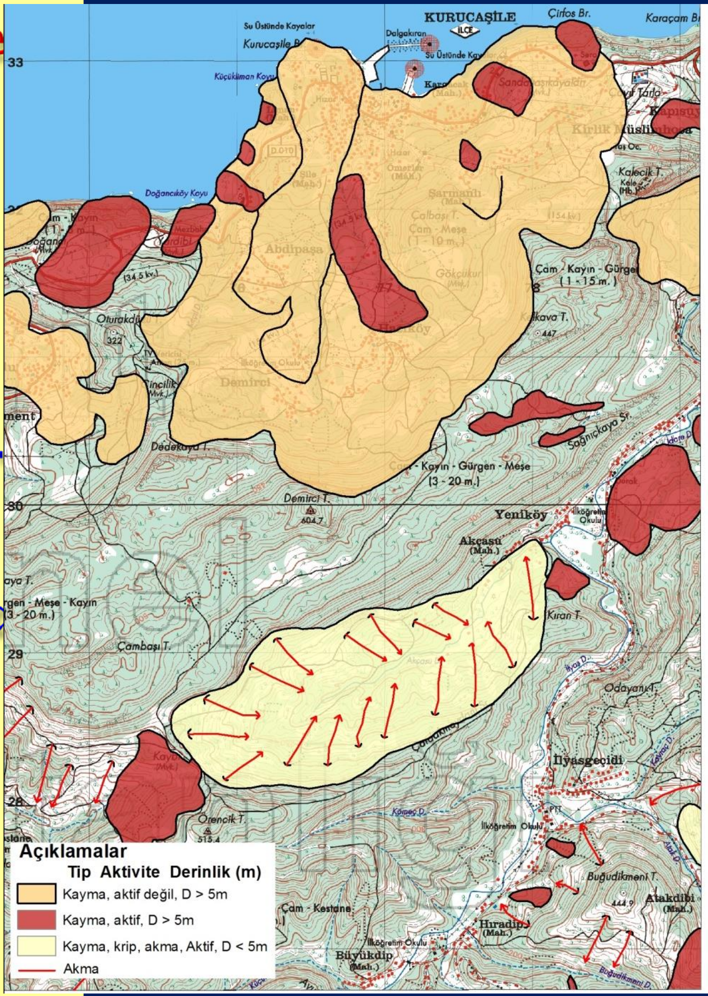
Depicting the type and spatial distribution, landslide inventory maps,

- facilitate understanding of regional landslide phenomena,
- assist to target areas where more detailed investigations are required and
- provide basic requirements for landslide hazard assessment studies.



Type of Landslide
(Varnes, 1978)
1- Flow
2- Slide
.
.
State of Activity
(UNESCO, WP/WLI.
1993)
Active
(Active, Suspended
reactivated..)
Inactive
(relict)

Relative depth
1-Deep d>5 m,
2-Shallow d<5 m



1:25.000 scale

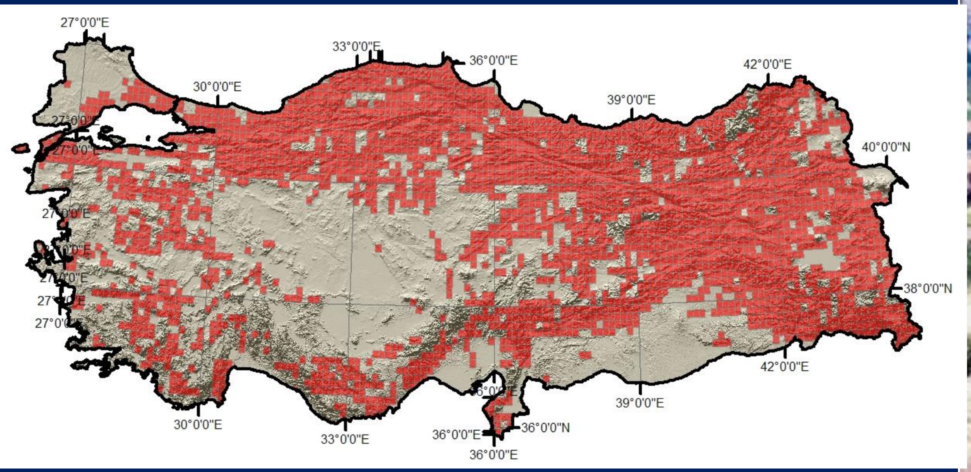
Active landslide

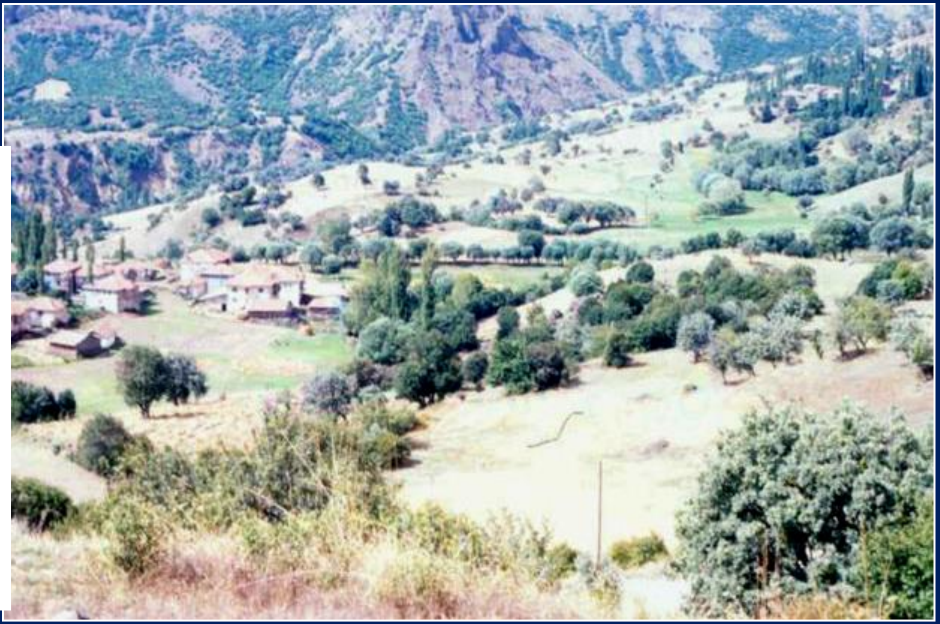
Inactive slide

Shallow landslide

INACTIVE LANDSLIDES

2945/5547





TÜRKİYE HEYELAN ENVANTERİ HARİTASI / *LANDSLIDE INVENTORY MAP OF TURKEY*

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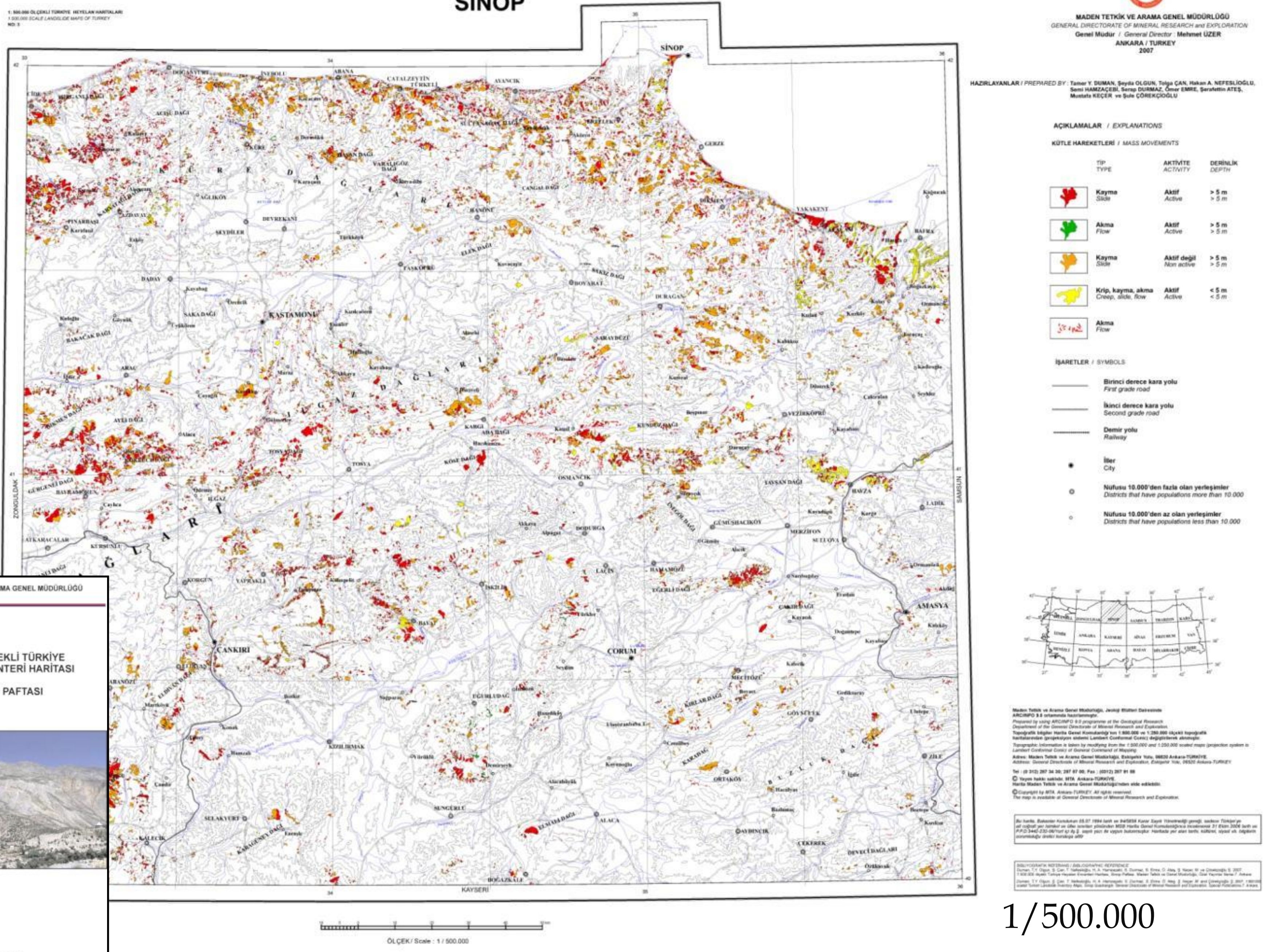
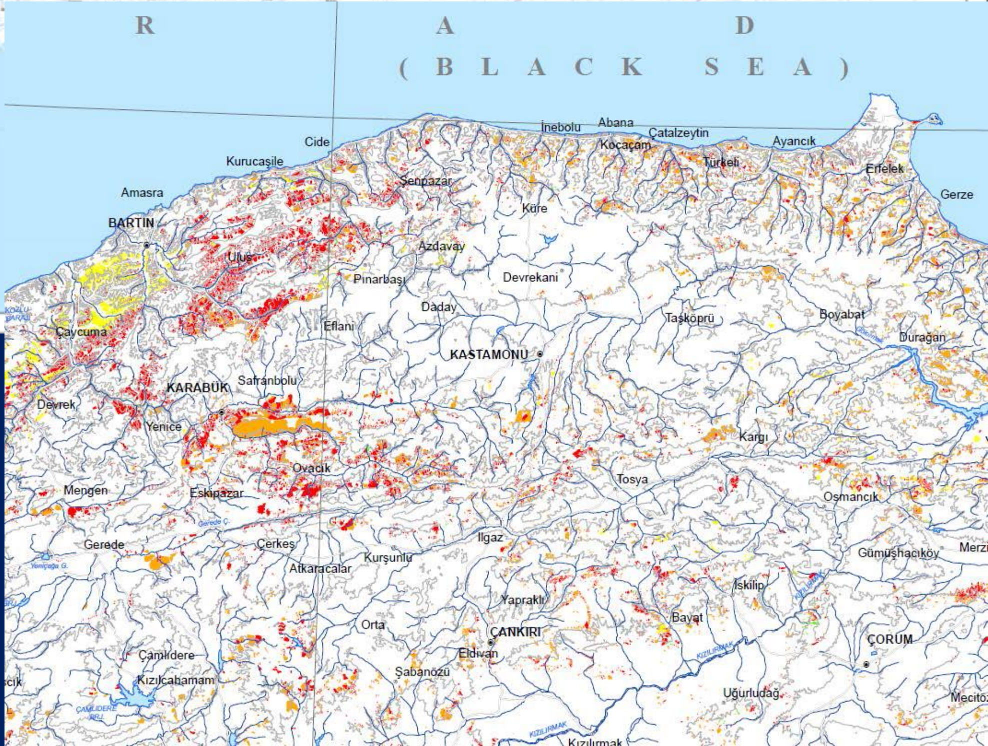



MADEN TETKİK VE ARAMA GENEL MÜDÜRLÜĞÜ

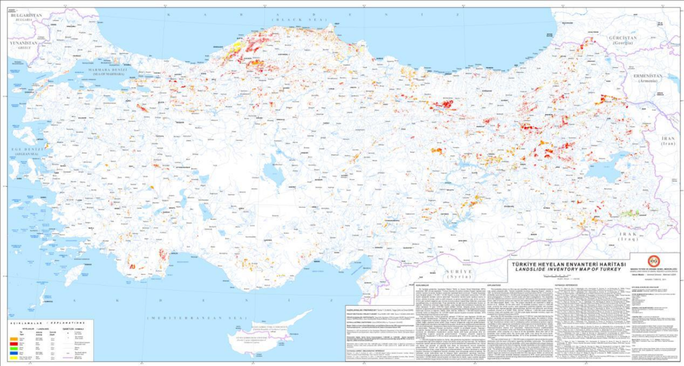
1/500 000 ÖLÇEKLİ TÜRKİYE
HEYELAN ENVANTERİ HARİTASI

TRABZON PAFTASI

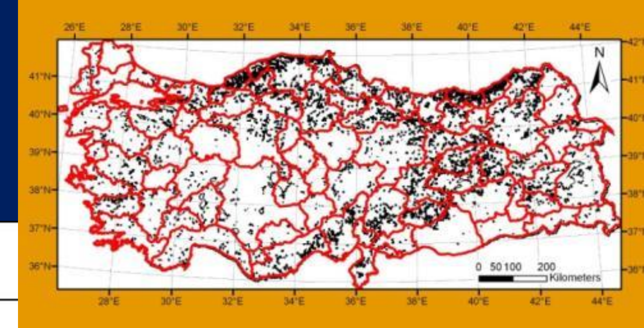
1/500.000

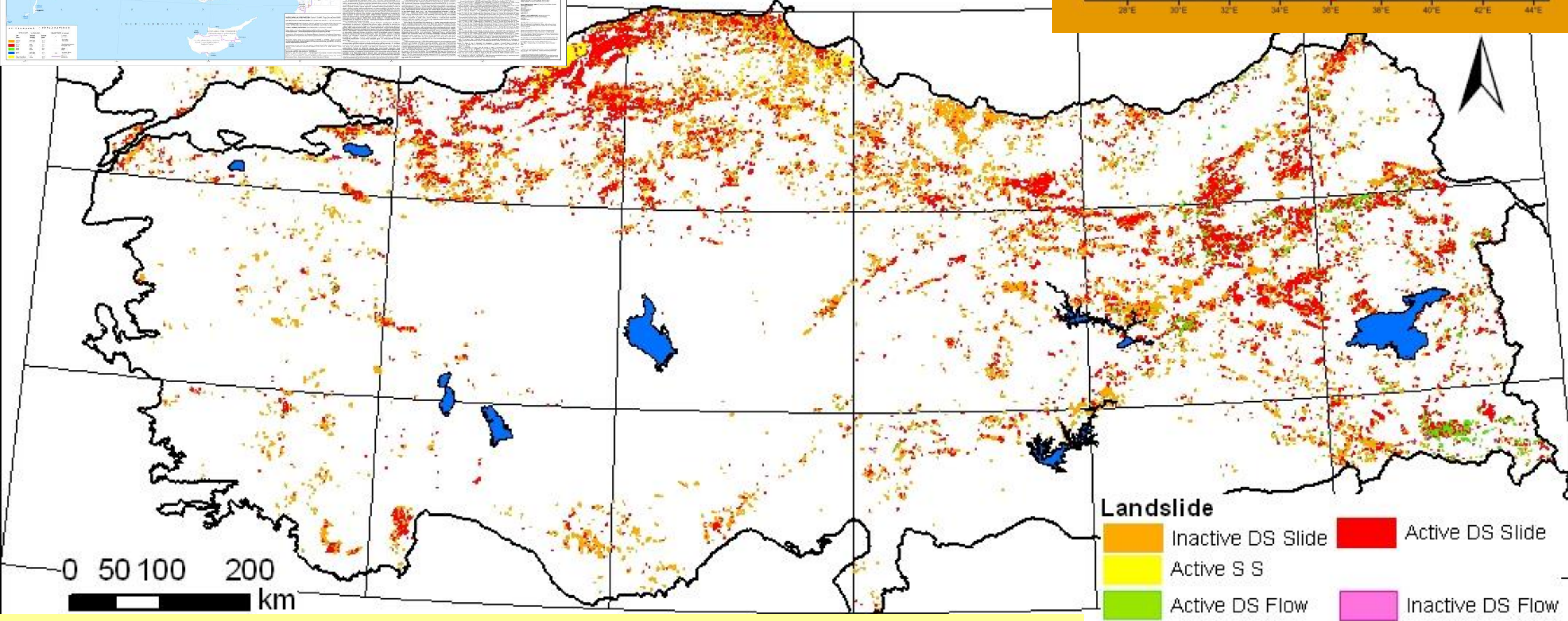


1/1.500.000 scale

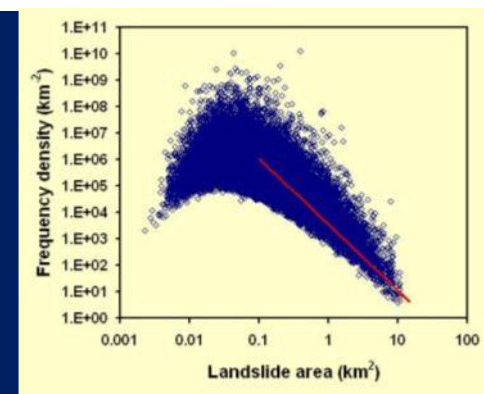


Landslide Inventory





	Deep-Seated				Shallow-Seated		
	Slide inactive	Slide active	Flows active	Flow inactive	Slides	Flows	Total
Count	20959	39822	4836	112	1032	18286	85047
Mean (km^2)	0.38	0.20	0.13	0.23	0.64		
Max (km^2)	101.01	44.2298	7.80	2.35	66.14		
Min (km^2)	0.004	0.002	0.007	0.02	0.02		
Total Area (km^2)	7919.43	7837.75	627.66	26.1014	661.65		17072.59
% Area	46.39	45.91	3.68	0.15	3.88		100.00



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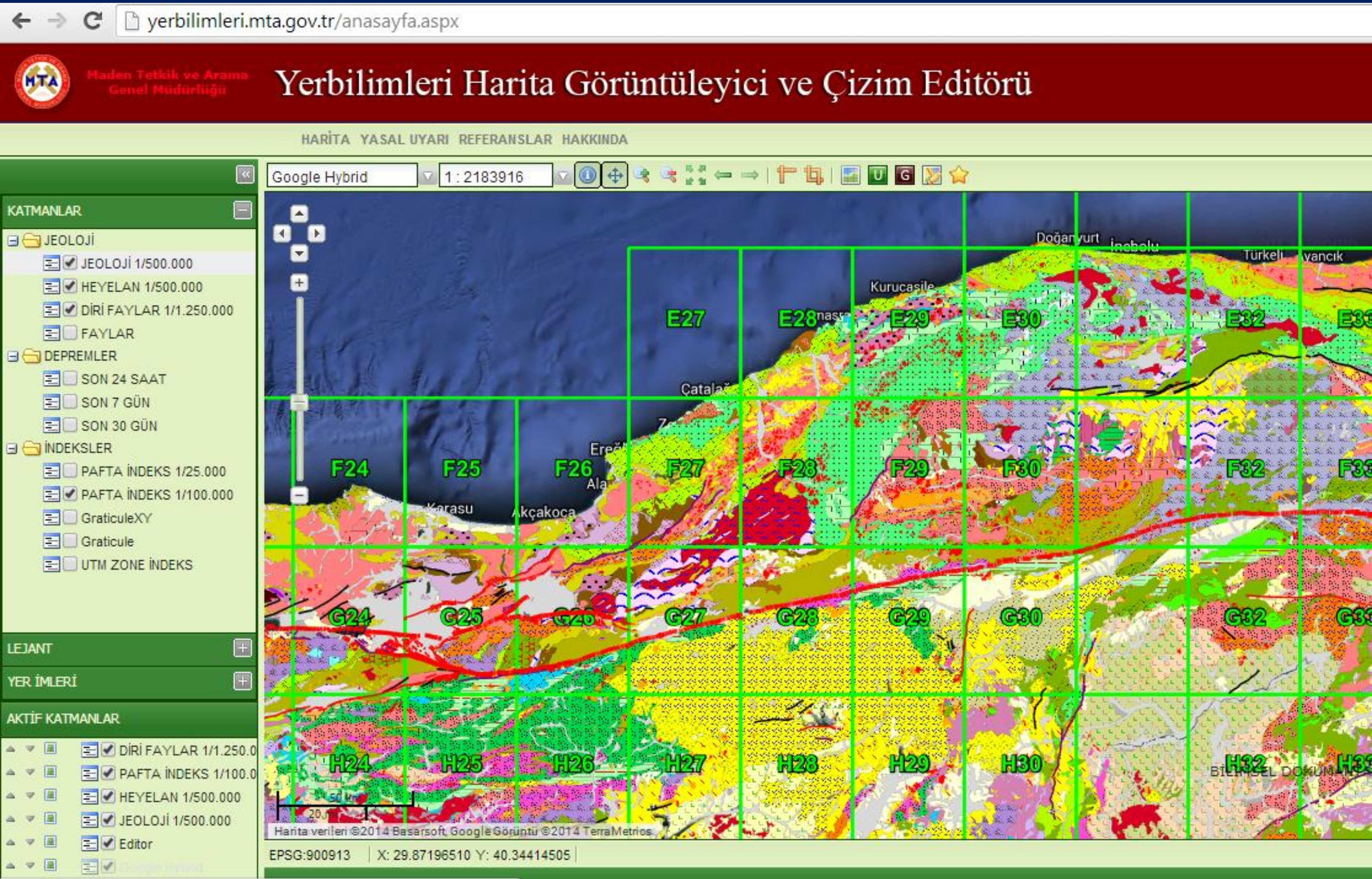

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DEPREMLER
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SON 7 GÜN
SON 30 GÜN
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PAFTA İNDEKS 1/25.000
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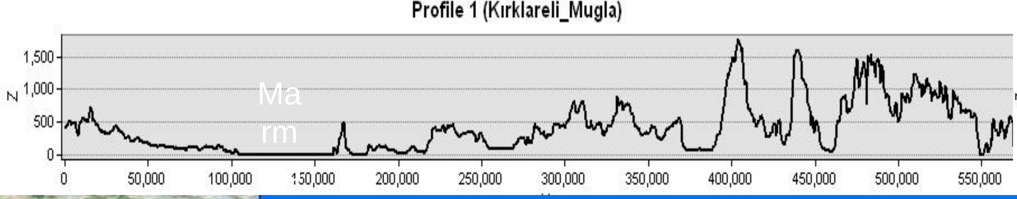
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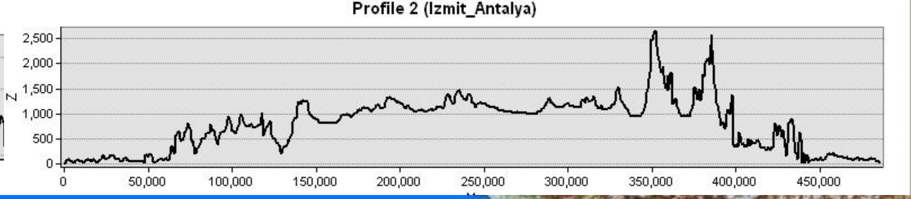
Profile 2 (Izmit_Antalya)


BLACK SEA
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PLATEAU
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ANATOLIA
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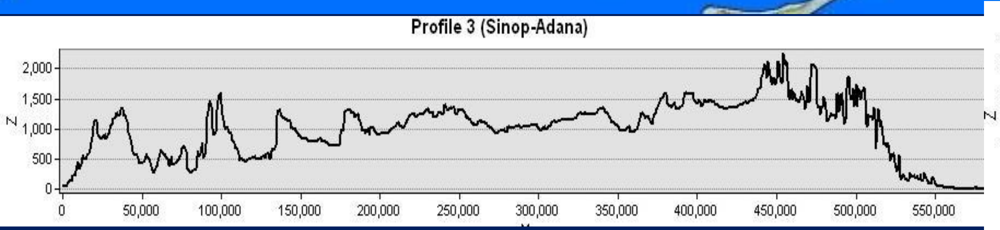
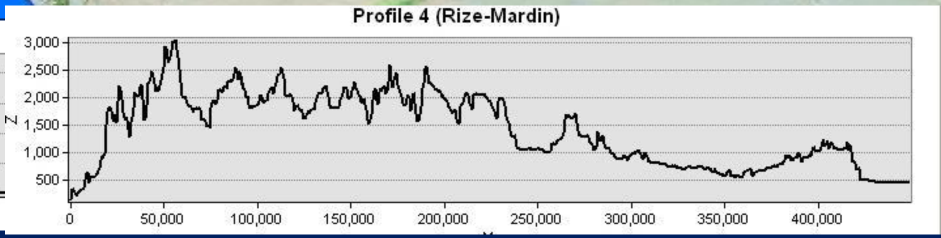
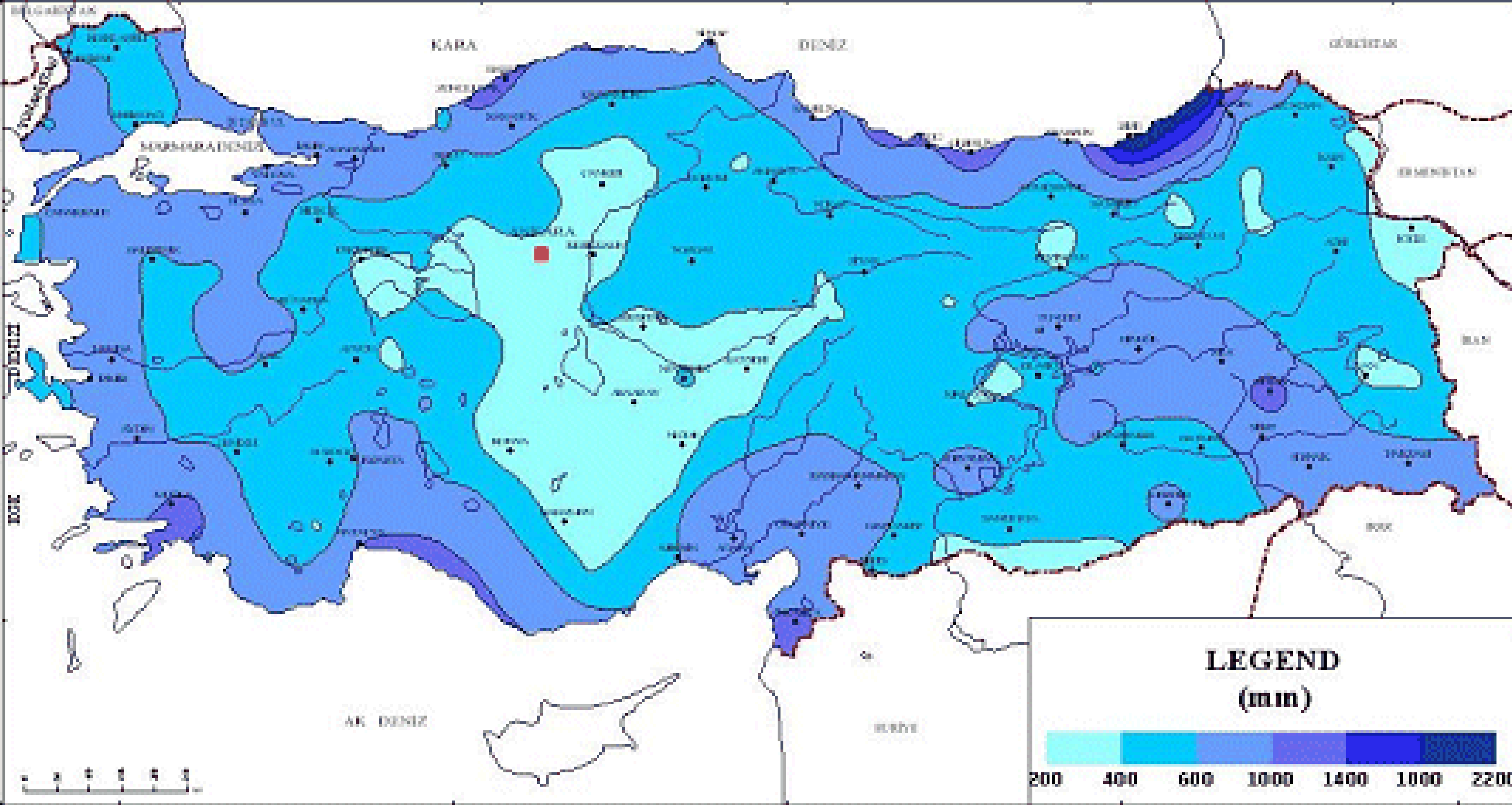
ANATOLIA
TORIDRELIEF GROUP
Antalya
ARABİC PLAIN
MEDİTERRANEAN


Profile 3 (Sinop-Adana)


Profile 4 (Rize-Mardin)



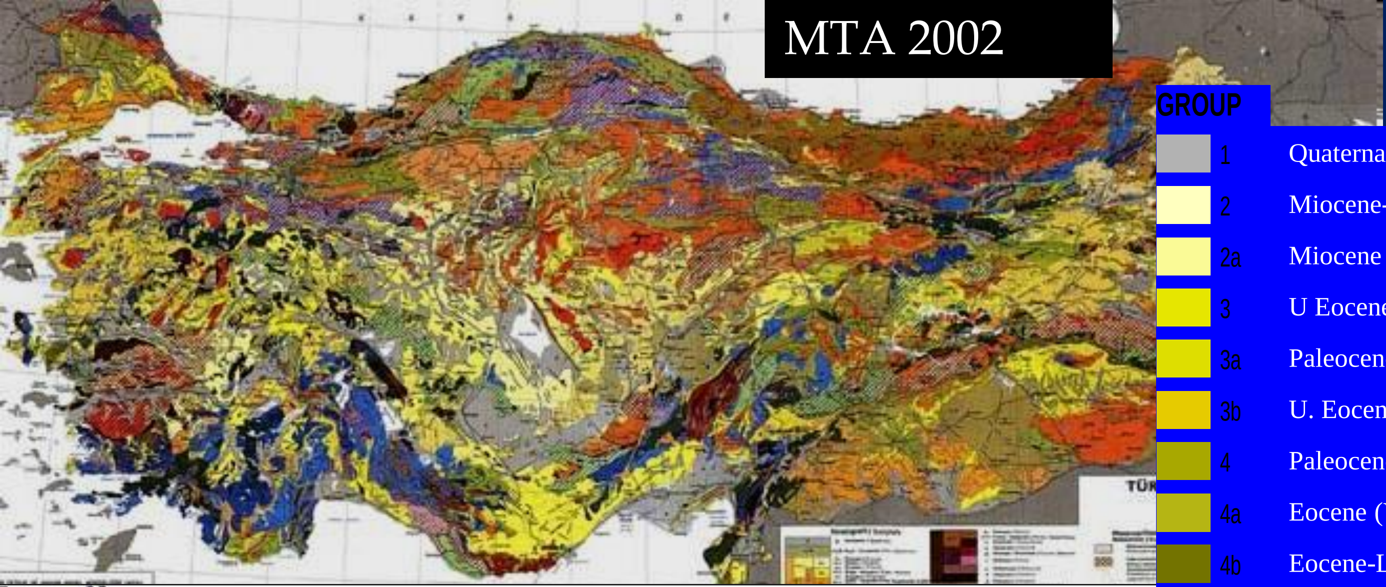
The Black Sea coastlands are the wettest region, with rain throughout the year and a winter maximum. Annual totals exceed 800mm, reaching 2,400mm in the east.

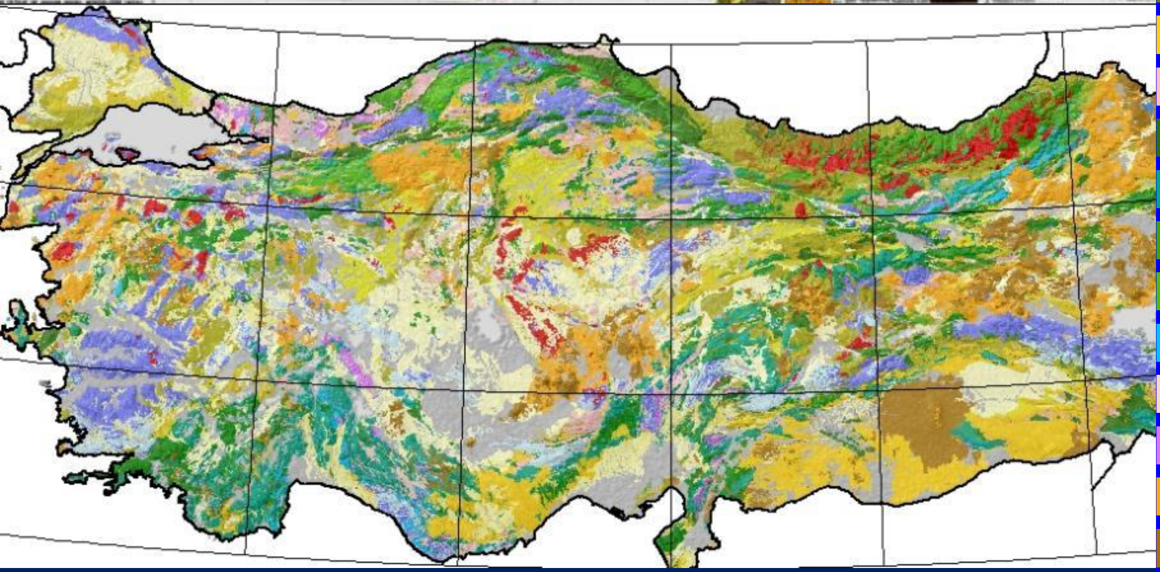
Thrace and Marmara are influenced by winter depressions passing through the straits, but summers are drier than along the Black Sea. The Aegean coastlands have a Mediterranean regime. Annual precipitation 600 to 900 mm.

The inner Anatolia i has a semicontinental climate with a large temperature range, annual rainfall < 400mm.

East Anatolia 600-1000mm, duration of snow cover are more than 4 mounth in mountaneous areas. The south eastern anatolia(300-600mm).

MTA 2002

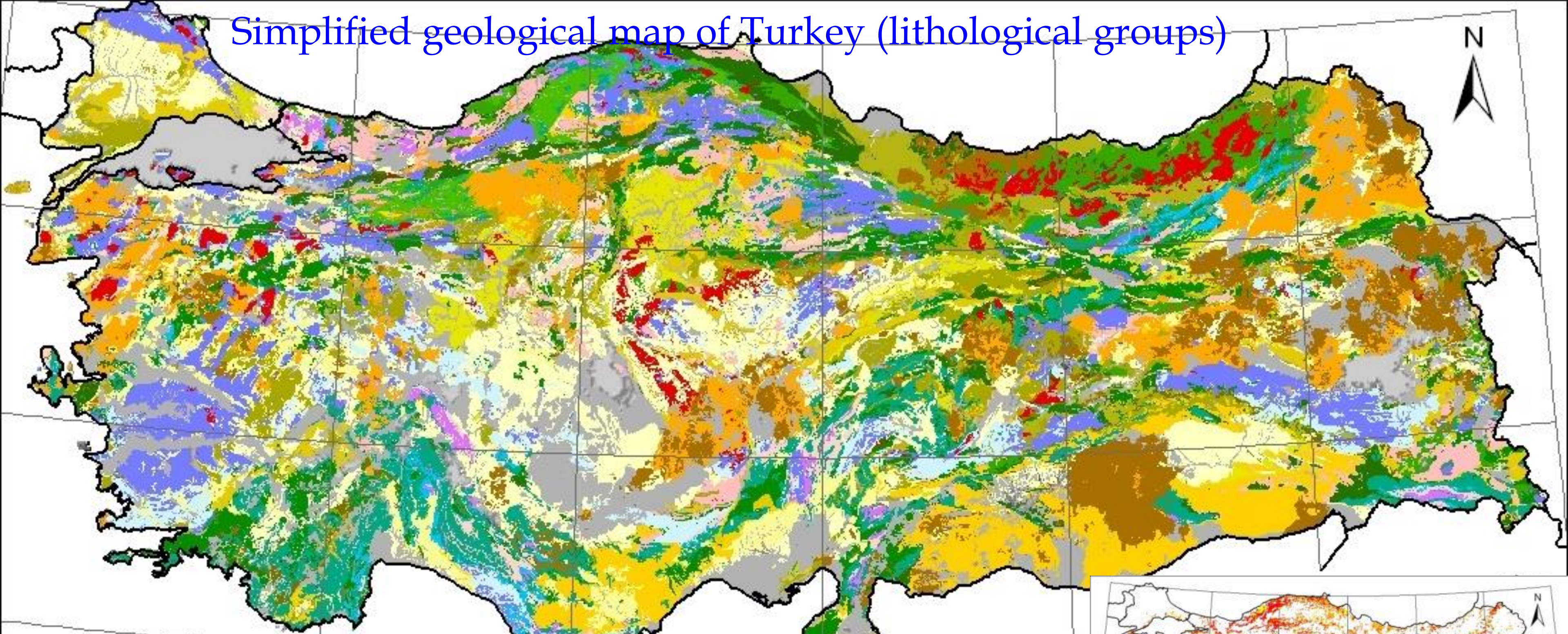


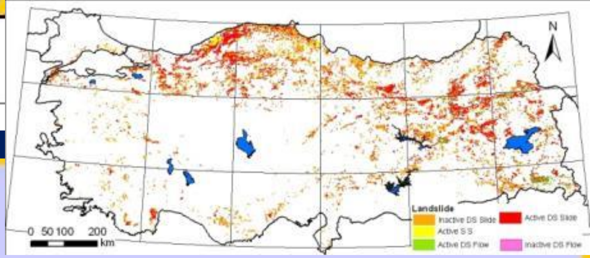


GROUP	
1	Quaternary – Pleistocene (Undifferentiated)
2	Miocene-Pliocene (Undiff. Continental Clastics)
2a	Miocene (Undiff. Continental Clastics)
3	U Eocene-Pliocene (Evaporitic rocks)
3a	Paleocene- L. Miocene (Volcanic sediments)
3b	U. Eocene- L.Miocene (Continental Clastics)
4	Paleocene- Pliocene (Continental clastics and Carbonates)
4a	Eocene (Volcanic and sedimentary rocks)
4b	Eocene-L. Miocene (Carbonates- clastics)
5	U. Paleocene-L .Pliocene (Neritic Limestones)
6	U.Paleocene – Eocene (Clastics and carbonates)
7	U.Cretaceous – Eocene (Clastics and carbonates)
8	Cambrian-Paleocene (pelagic limestones)
9	M.Triassic -Eocene (Volcanic and sedimentary rocks)
10	Cretaceous (Clastics and carbonates)
11	L. Cretaceous- U. Jurassic (Carbonates and clastics)
12	L. Cambrian- Permo-Triassic (Carbonates and clastics)
13	Precambrian- L. Lias (Carbonate and clastics)
14	Paleocene- Quaternary (Undifferentiated volcanics)
15	L. Jurassic-Quaternary (Riodasit, basalt, andesite etc.)
16	Mesozoic (Ophiolitic rocks)
17	Precambrian-Miocene (Granatoids)
18	Cretaceous (Meta gabbro-amphibolite)
19	Precambrian - Eocene (Metamorphic rocks)
20	Precambrian - Cretaceous (marble, calcschist, rec. limeston

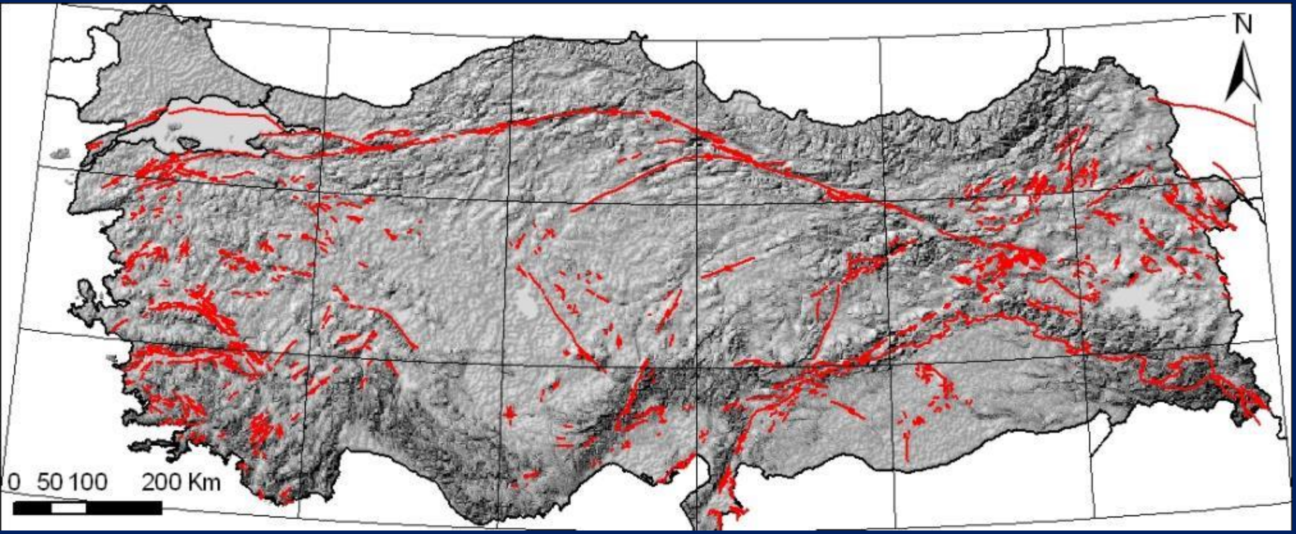
Gological maps

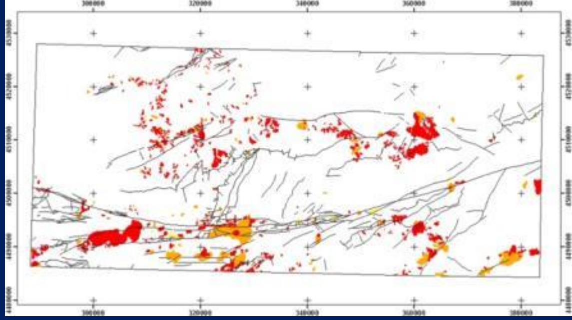
Simplified geological map of Turkey (lithological groups)





Group	
2	Miocene-Pliocene (Undiff. Continental Clastics)
201	Miocene (Undiff. Continental Clastics)
4	Paleocene- Pliocene (Cont. Clastics and carbonate)
6	U.Paleocene – Eocene (Clastics and carbonates)
7	U.Cretaceous – Eocene (Clastics and carbonates)
14	Paleocene- Quaternary (Undifferentiated volcanics)
15	L. Jurassic-Quaternary (Riodasit, basalt, andesite etc.)
16	Mesozoic (Ophiolitic rocks)



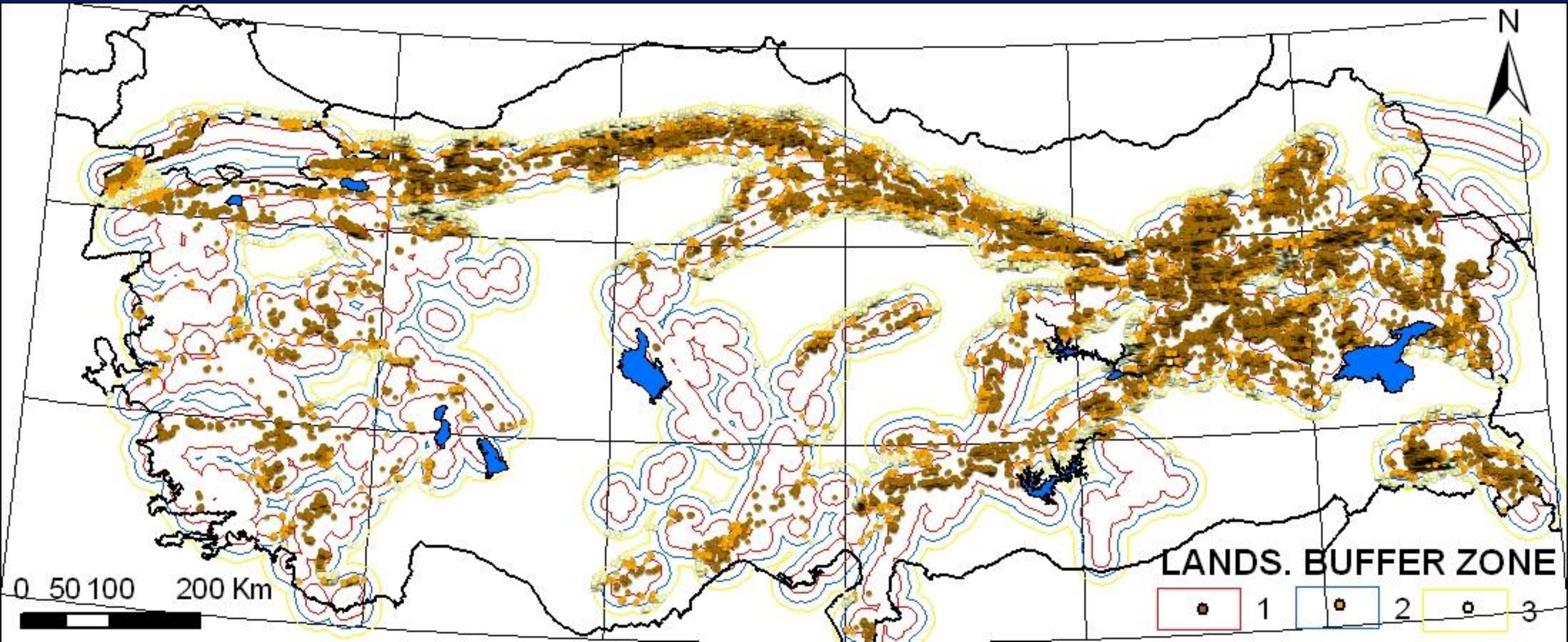


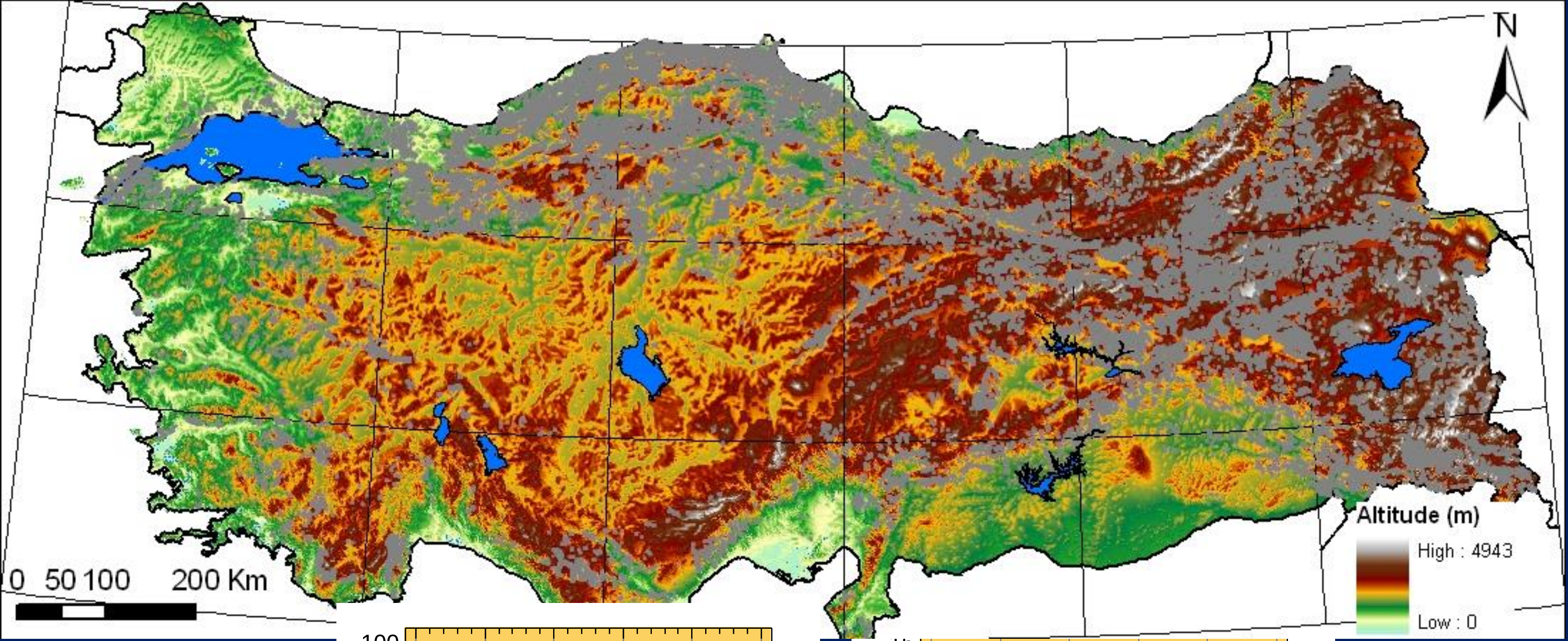
BZ interval 10km

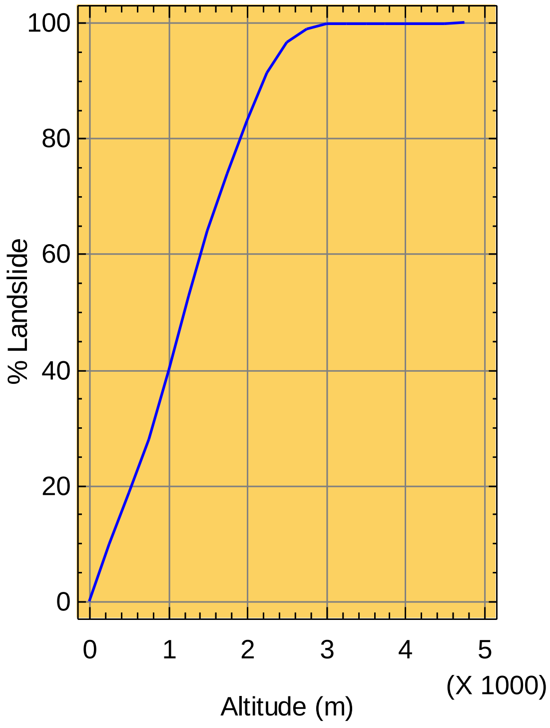
BZ 1= %35 Landslides

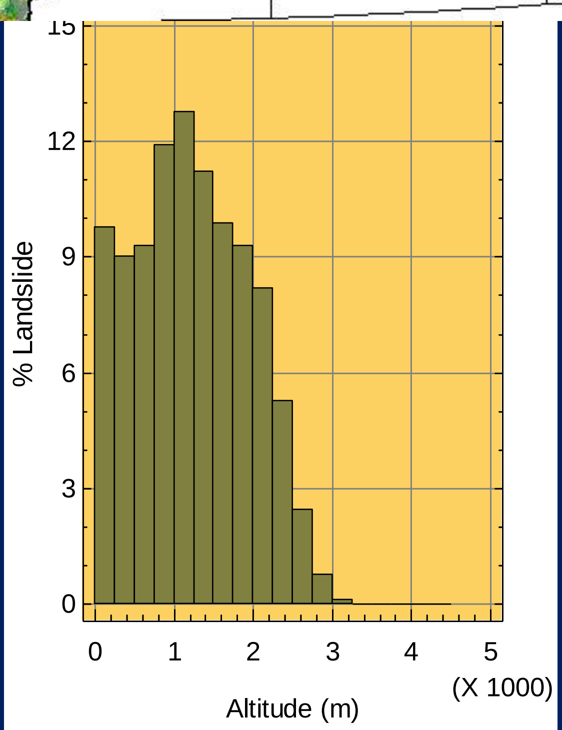
BZ 2= %18 Landslides

BZ 3= %12 Landslides



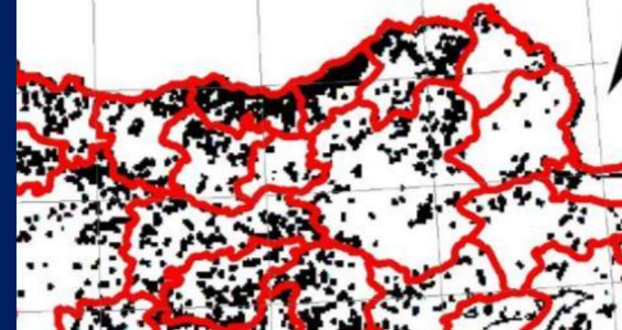

N
0 50 100 200 Km
Altitude (m)
High : 4943
Low : 0

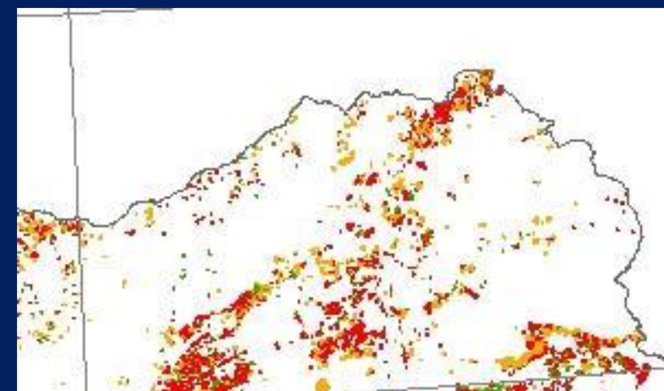

% Landslide
Altitude (m)
(X 1000)
0
20
40
60
80
100
1
2
3
4
5


% Landslide
Altitude (m)
(X 1000)
0
3
6
9
12
15
1
2
3
4
5



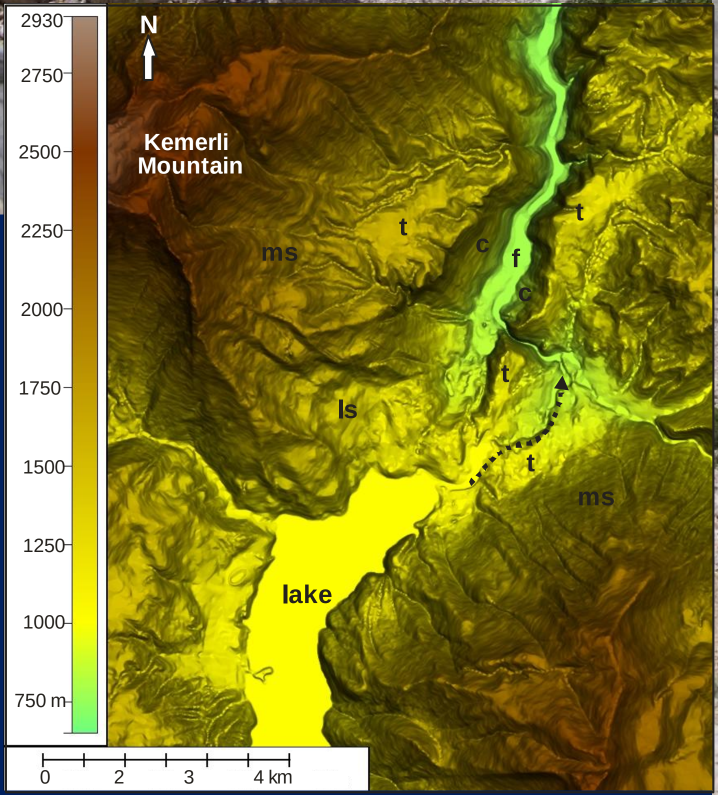

Eastern Black sea



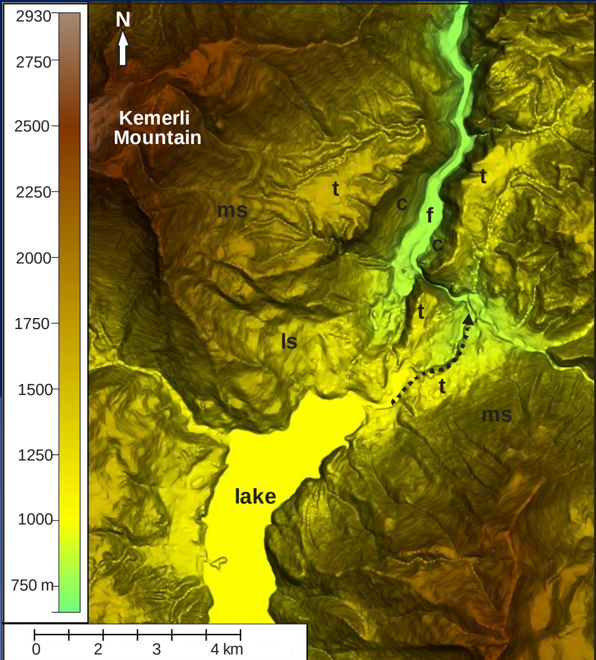




LANDSLIDE DAMS (TORTUM)



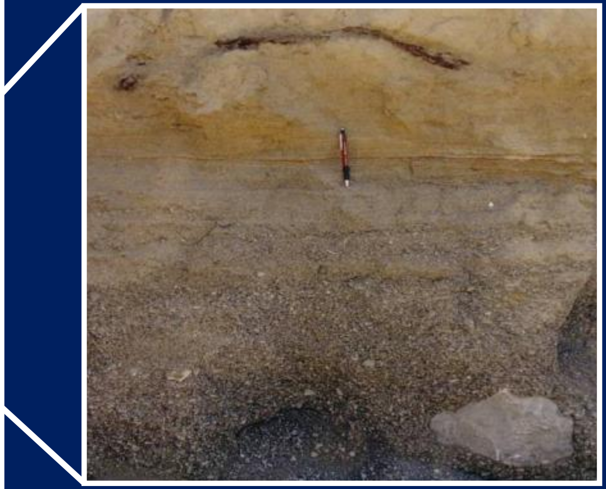
Lake area: 6.77 km^2
Displaced mass: 223 million m^3
drainage area 1820 km^2 ,
Volume of the lake: 538 million m^3



Tortum landslide

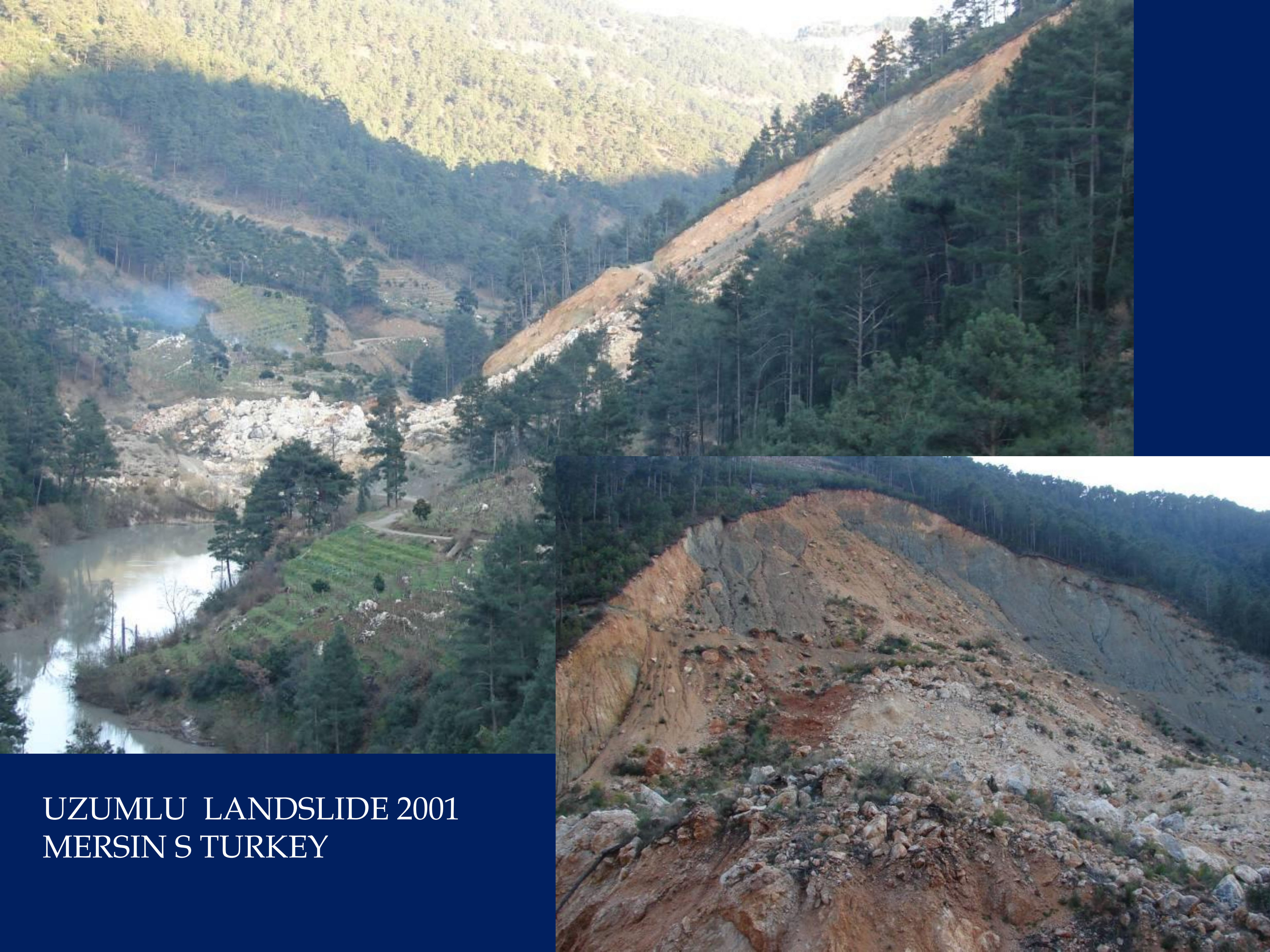
1680+-40 ad

C_{14} method



Lichenometric dating

- Posof _çoruh river
- 2210+-50 Bp
- 2260+-40 Bp



UZUMLU LANDSLIDE 2001
MERSIN S TURKEY

Landslide around the dam reservoirs

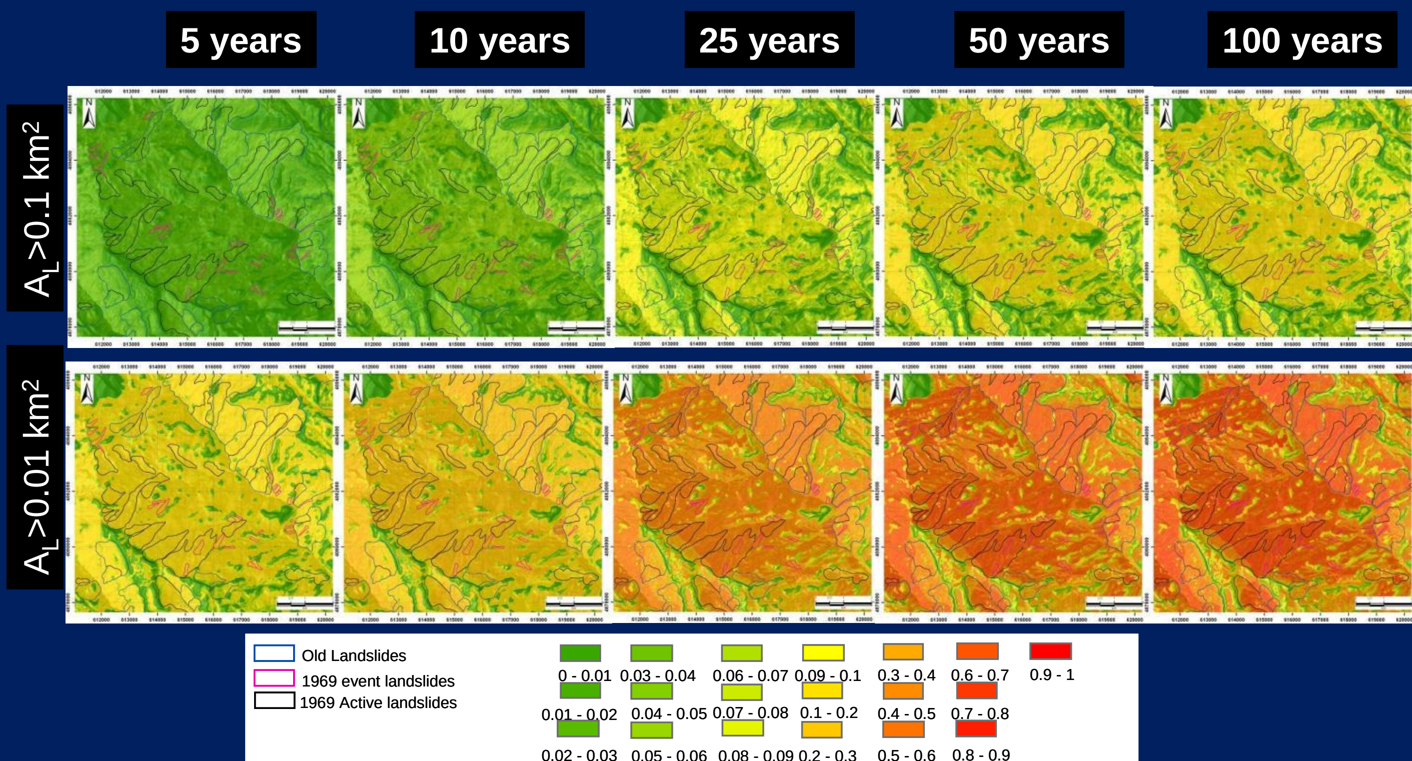
Conclusion

- Reliable inventory data has primary importance and influence, for any land use planning procedure particularly in early stages and for subsequent hazard evaluation process. The inventory maps produced by MTA will compensate for the basic deficiencies on the regional and national landslide processes evaluating with major geological, tectonic, geomorphologic and climatic conditions that control the extent and spatial distribution of them.

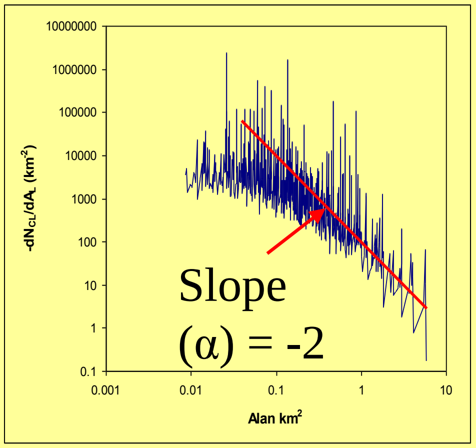
QUANTITATIVE LANDSLIDE HAZARD AND RISK ASSESSMENT BETWEEN MERSIN AND ERDEMLI REGION (SOUTHERN TURKEY)

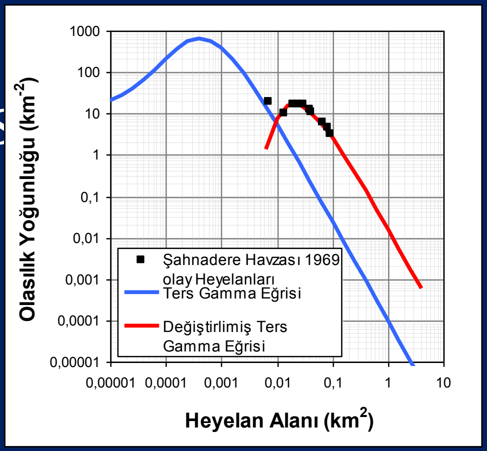
[1]Tolga ÇAN, [2]Tamer Y. DUMAN, [1]Engin ÇİL, [1]Tolga MAZMAN

[1]Çukurova Üniv. Dept. of Geology, TR-01330 Adana, TURKEY
[2]General Directorate of Mineral Research and Exploration (MTA), TR-06520 Ankara, TURKEY

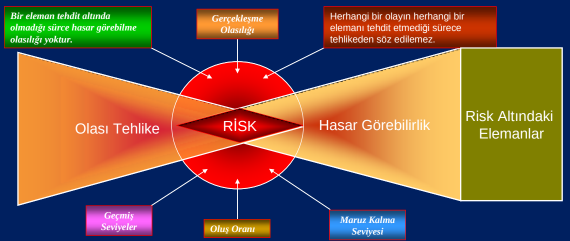


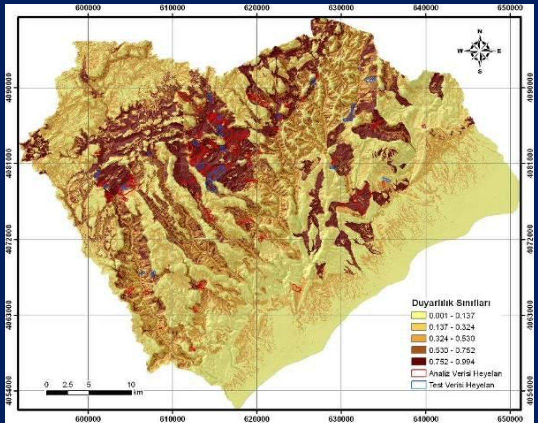
TALK LAYOUT

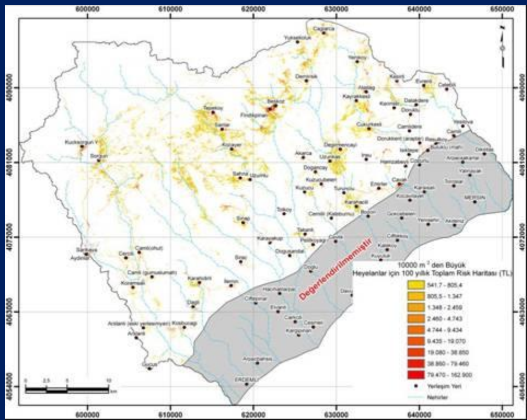


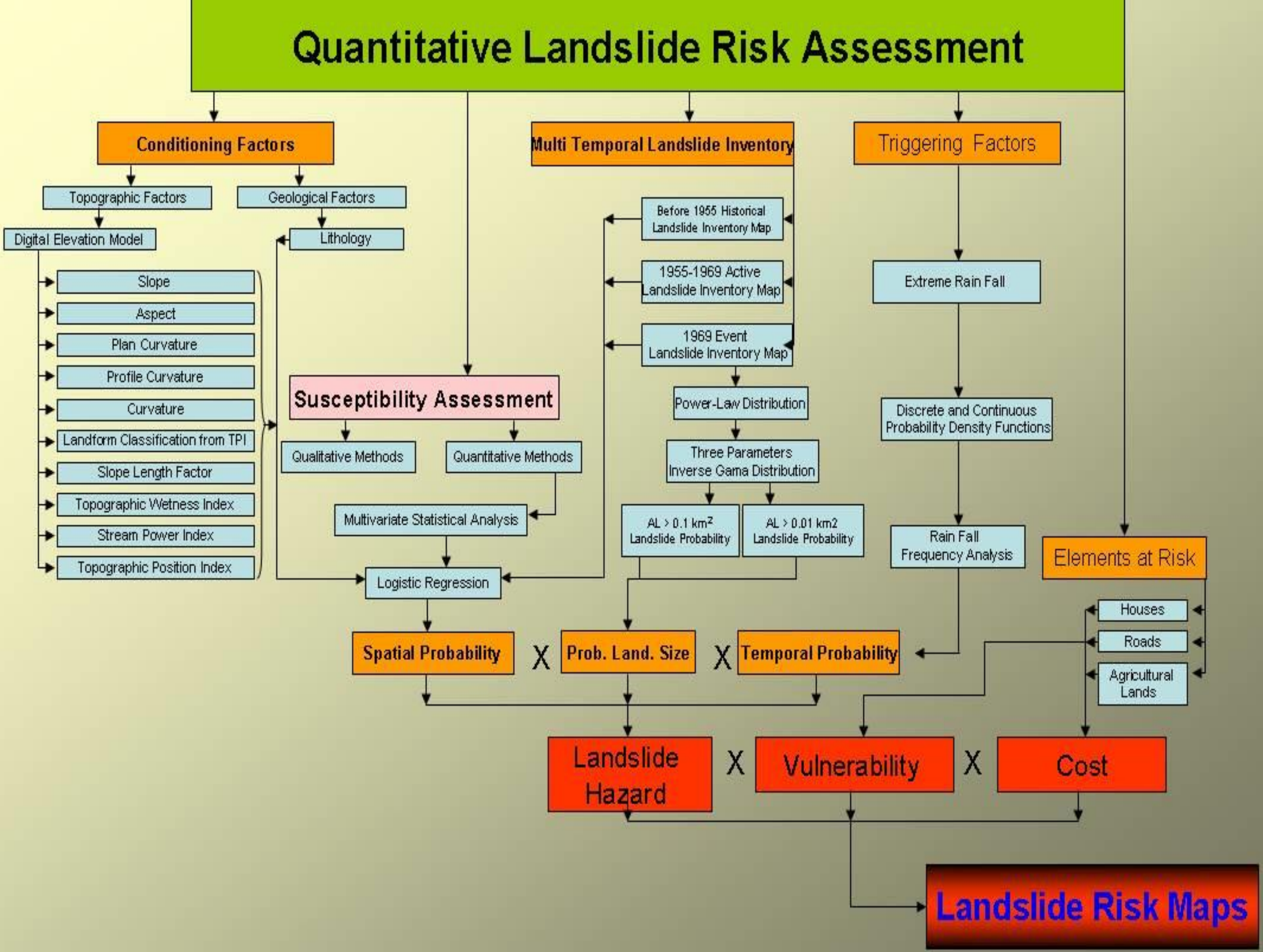


- *Introduction*
- *Landslide Hazard Assessment*
  -Spatial probability (Conditioning factors)
  -Temporal probability (trigering factors)
  -Probability of landslide size (MTLI)
- *Elements at risk, vulnerability and cost*
- *Landslide risk maps*
- *Conclusions*

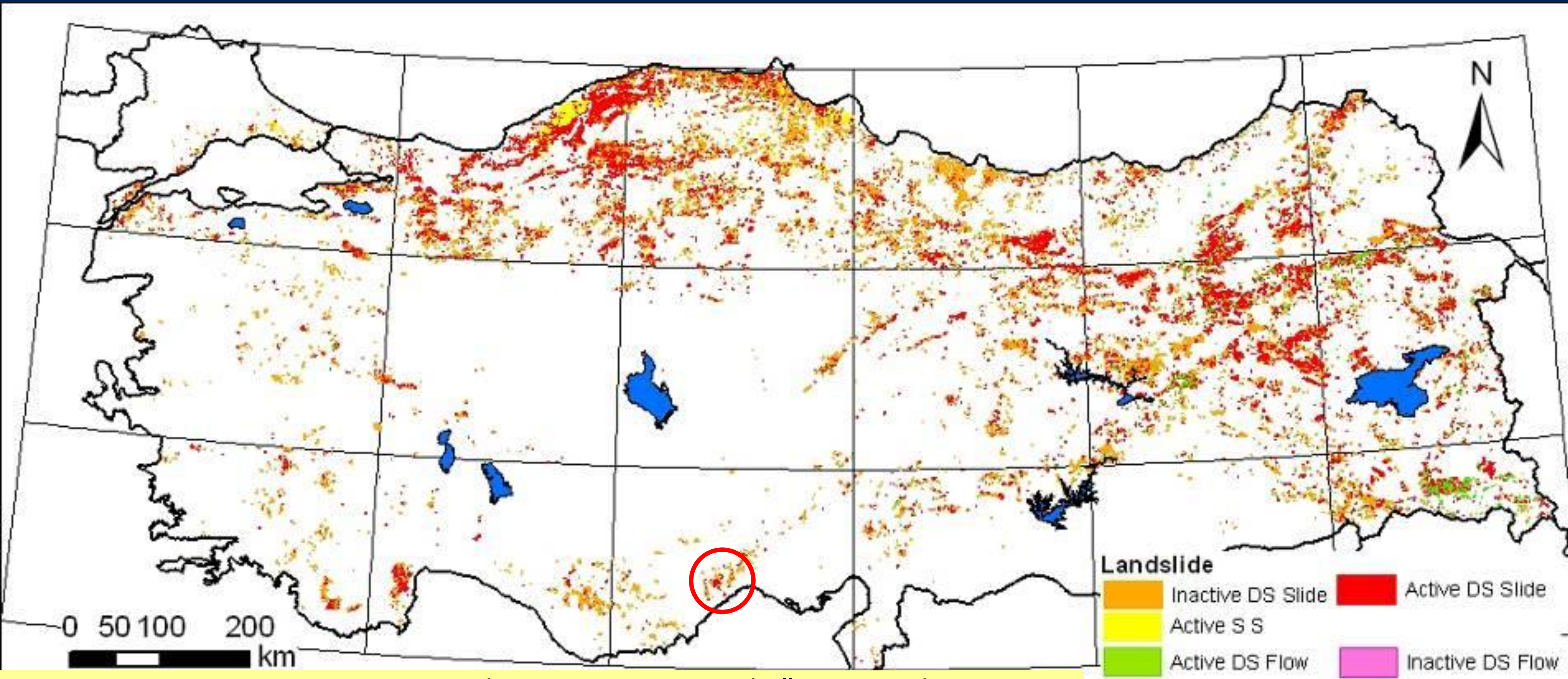




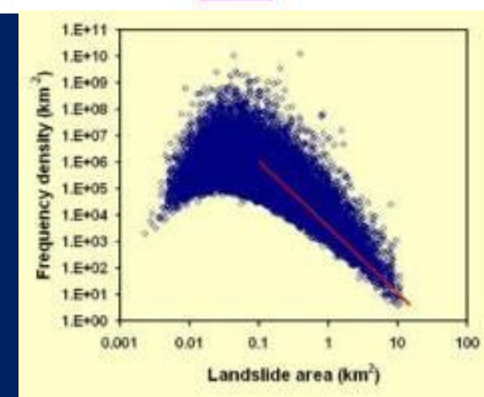


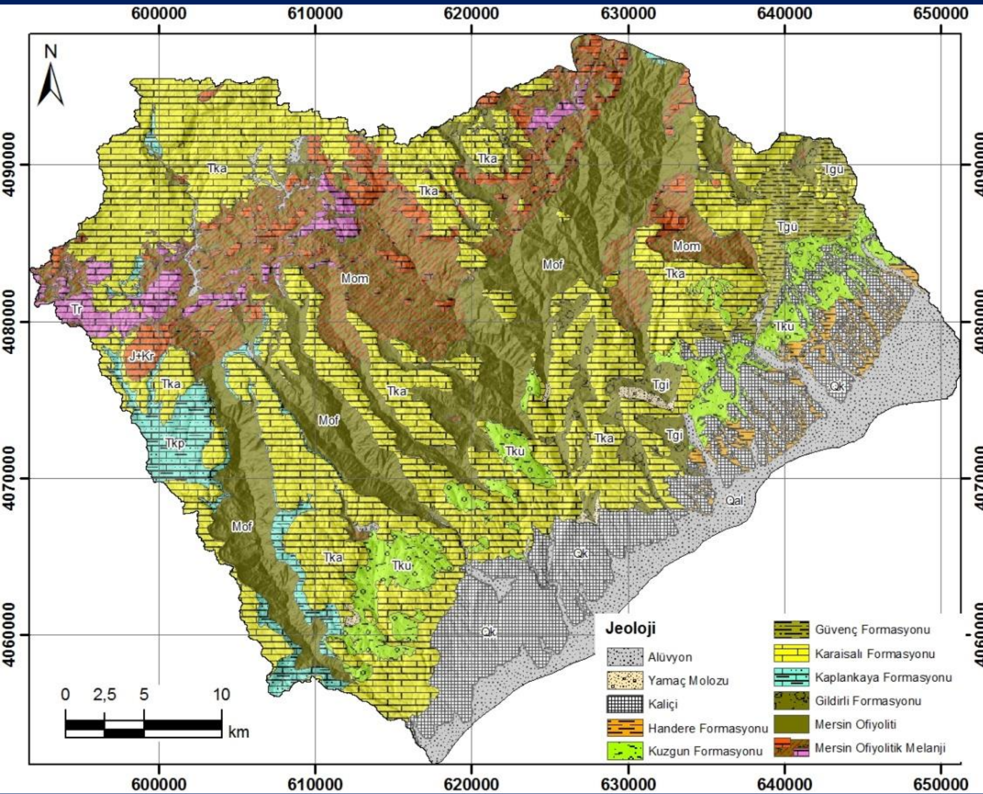

Quantitative Landslide Risk Assessment
Conditioning Factors
Multi Temporal Landslide Inventory
Triggering Factors
Topographic Factors
Geological Factors
Digital Elevation Model
Lithology
Before 1955 Historical Landslide Inventory Map
1955-1969 Active Landslide Inventory Map
1969 Event Landslide Inventory Map
Extreme Rain Fall
Slope
Aspect
Plan Curvature
Profile Curvature
Curvature
Landform Classification from TPI
Slope Length Factor
Topographic Wetness Index
Stream Power Index
Topographic Position Index
Susceptibility Assessment
Qualitative Methods
Quantitative Methods
Multivariate Statistical Analysis
Logistic Regression
Power-Law Distribution
Three Parameters Inverse Gama Distribution
AL > 0.1 km2 Landslide Probability
AL > 0.01 km2 Landslide Probability
Discrete and Continuous Probability Density Functions
Rain Fall Frequency Analysis
Elements at Risk
Houses
Roads
Agricultural Lands
Spatial Probability
X
Prob. Land. Size
X
Temporal Probability
Landslide Hazard
X
Vulnerability
X
Cost
Landslide Risk Maps

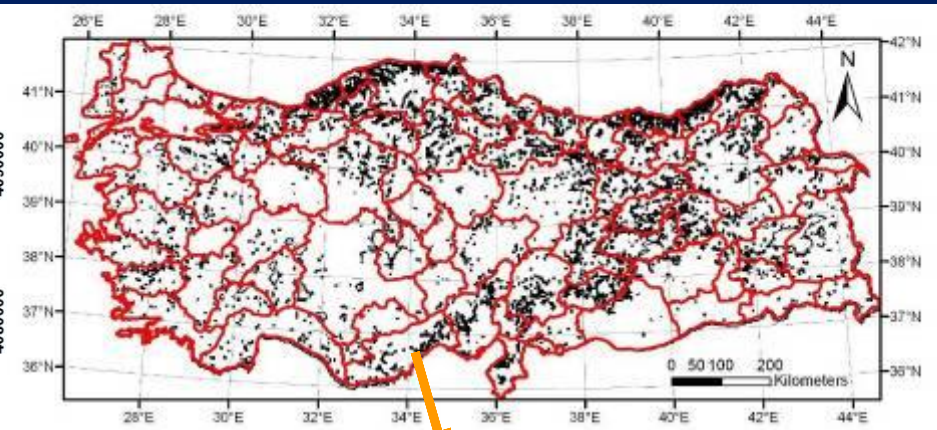
Historical Landslide Inventory of Turkey

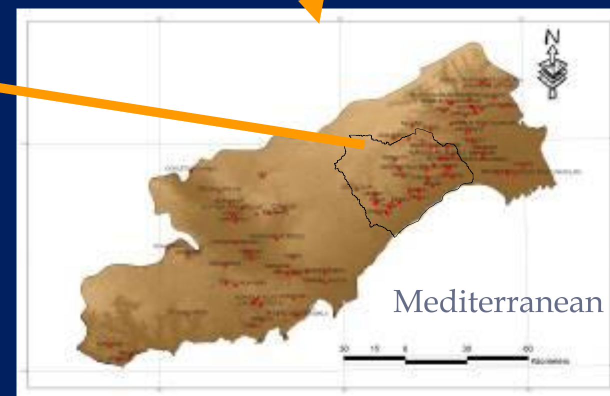


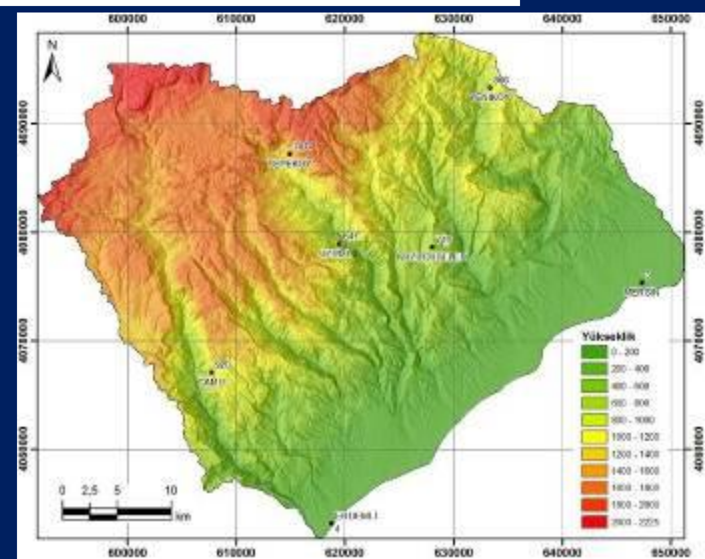
	Deep-Seated				Shallow-Seated		
	Slide inactive	Slide active	Flows active	Flow inactive	Slides	Flows	Total
Count	20959	39822	4836	112	1032	18286	85047
Mean (km^2)	0.38	0.20	0.13	0.23	0.64		
Max (km^2)	101.01	44.2298	7.80	2.35	66.14		
Min (km^2)	0.004	0.002	0.007	0.02	0.02		
Total Area (km^2)	7919.43	7837.75	627.66	26.1014	661.65		17072.59
% Area	46.39	45.91	3.68	0.15	3.88		100.00



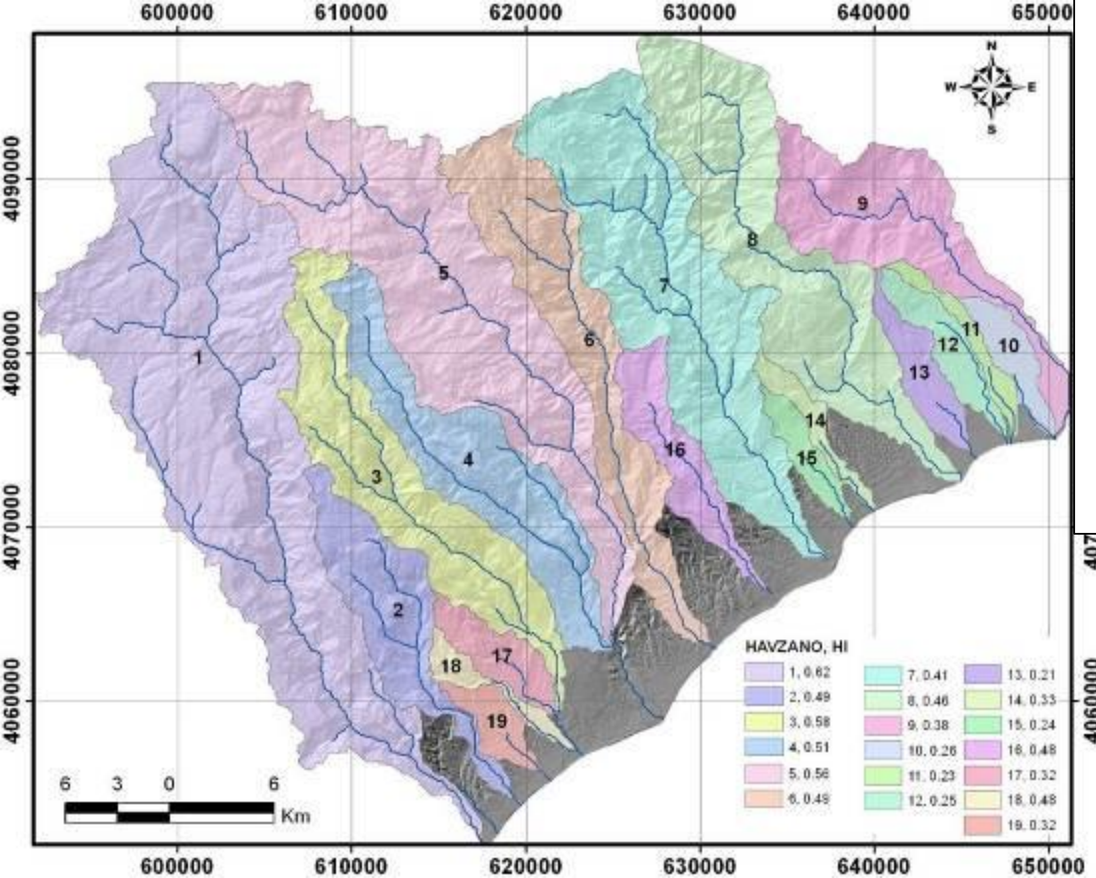


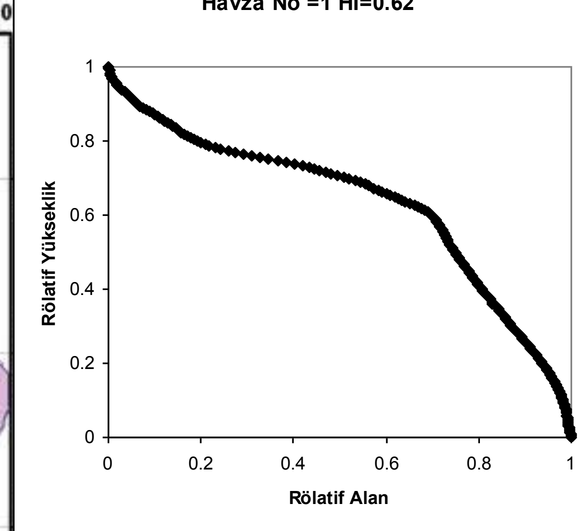


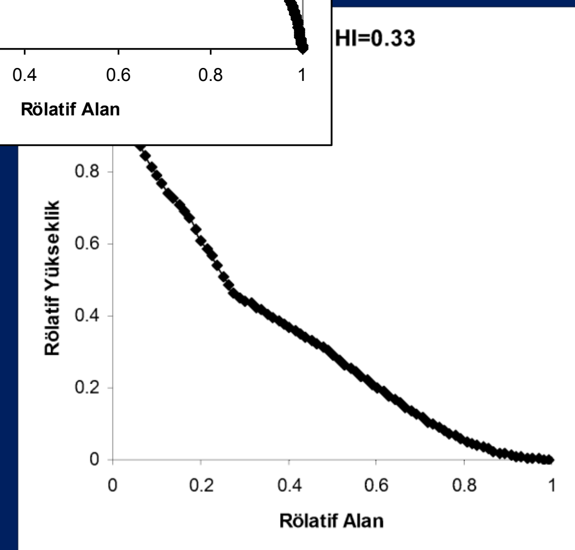




1285 and 338 residences were either collapsed or heavily damaged in Mersin city, due to the landslides triggered by excessive rainfall in 1969 and 2001, respectively.







Convex shaped hypsometric curves indicate that the watershed is stabilized and the concave hypsometric curves indicate more proneness of watershed to the erosion processes

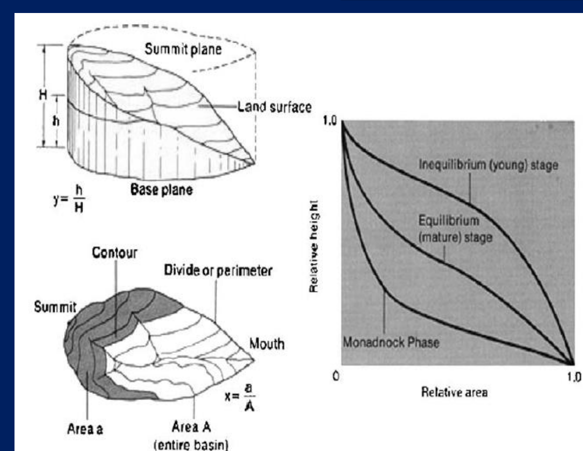
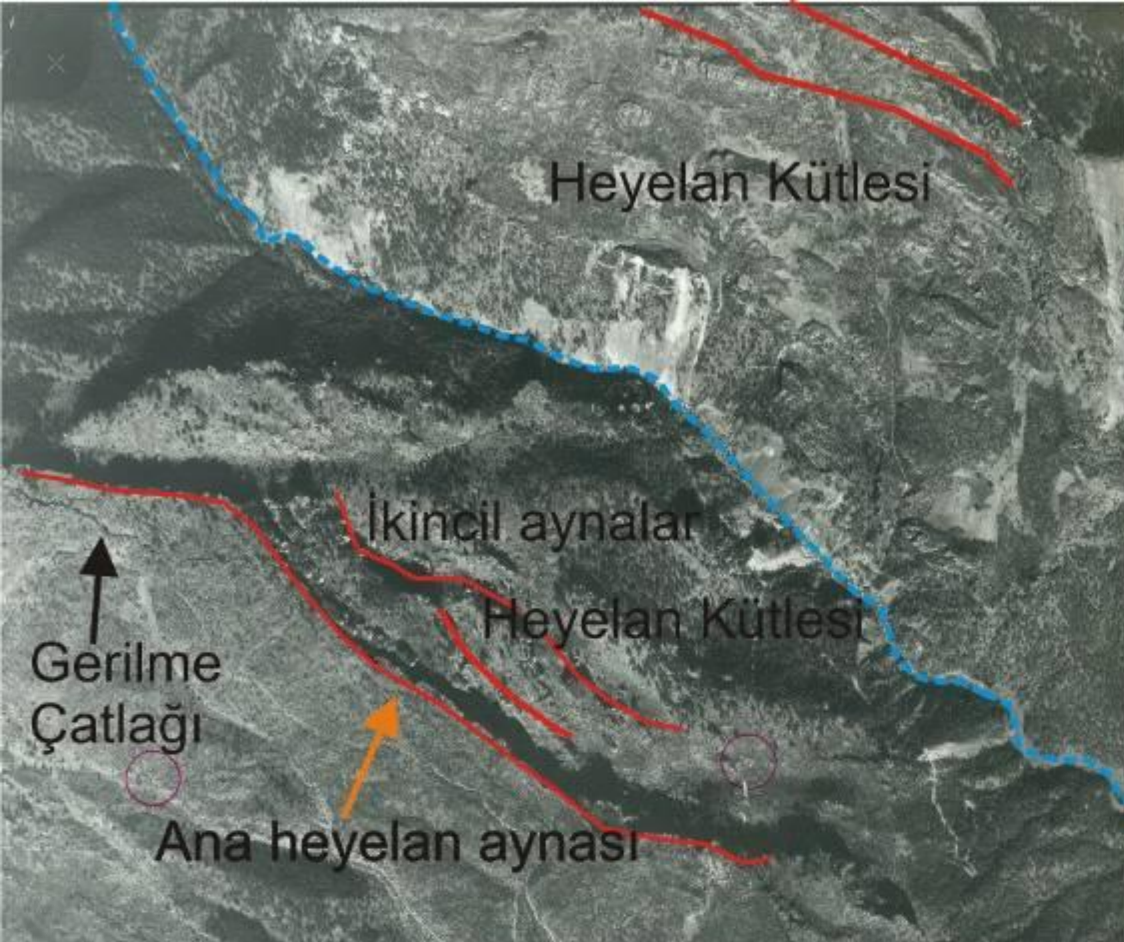
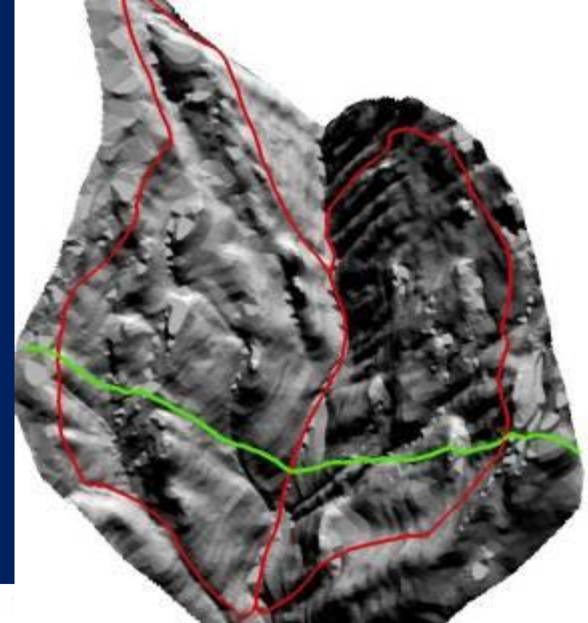
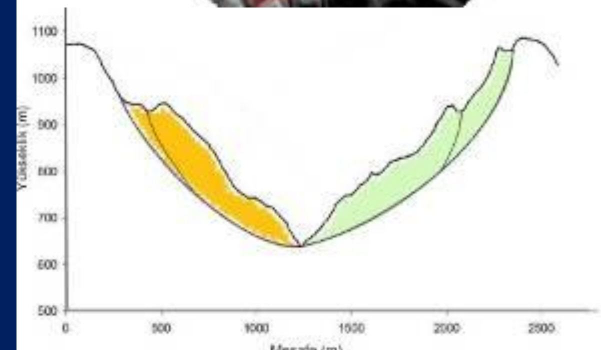


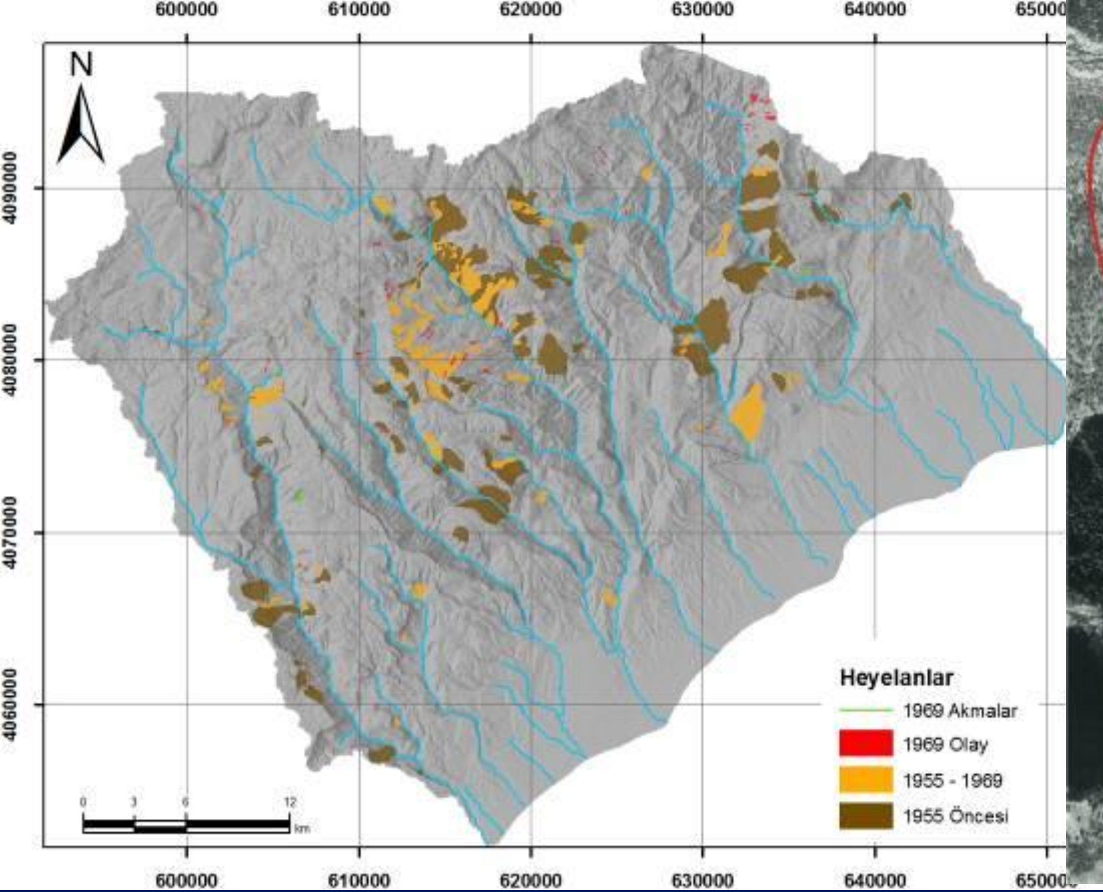
Fig. 1 The concept of hypsometric analysis and the model hypsometric curves (Ritter et al. 2002)

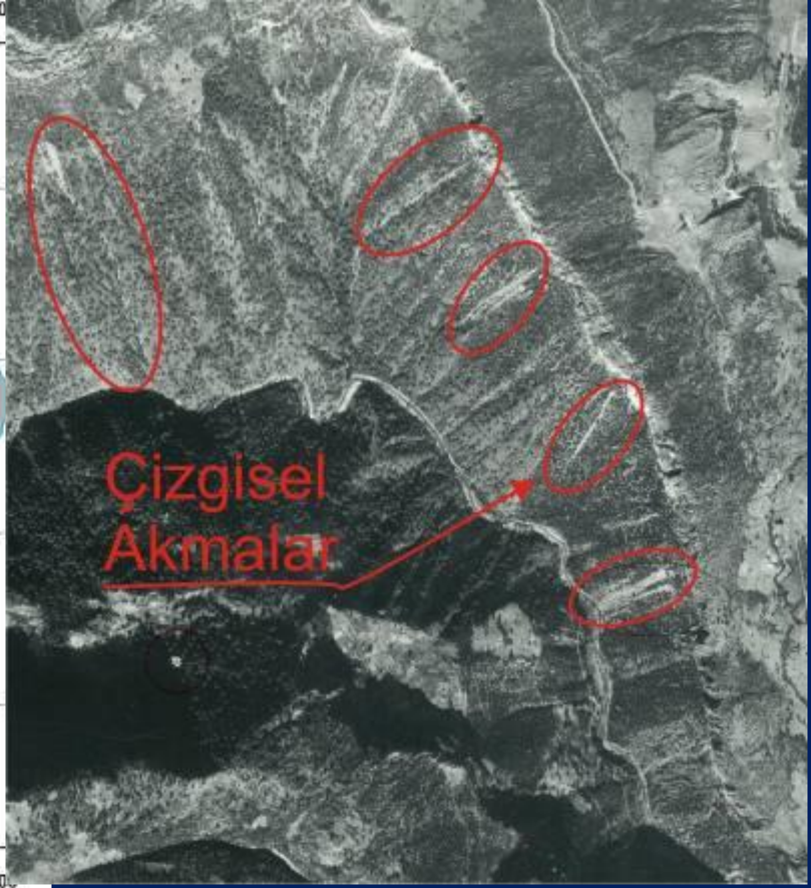

Heyelan Kütlesi
İkincil aynalar
Heyelan Kütlesi
Gerilme
Çatlağı
Ana heyelan aynası




Yükseklik (m)
Mesafe (m)
1100
1000
900
800
700
600
500
0
500
1000
1500
2000
2500

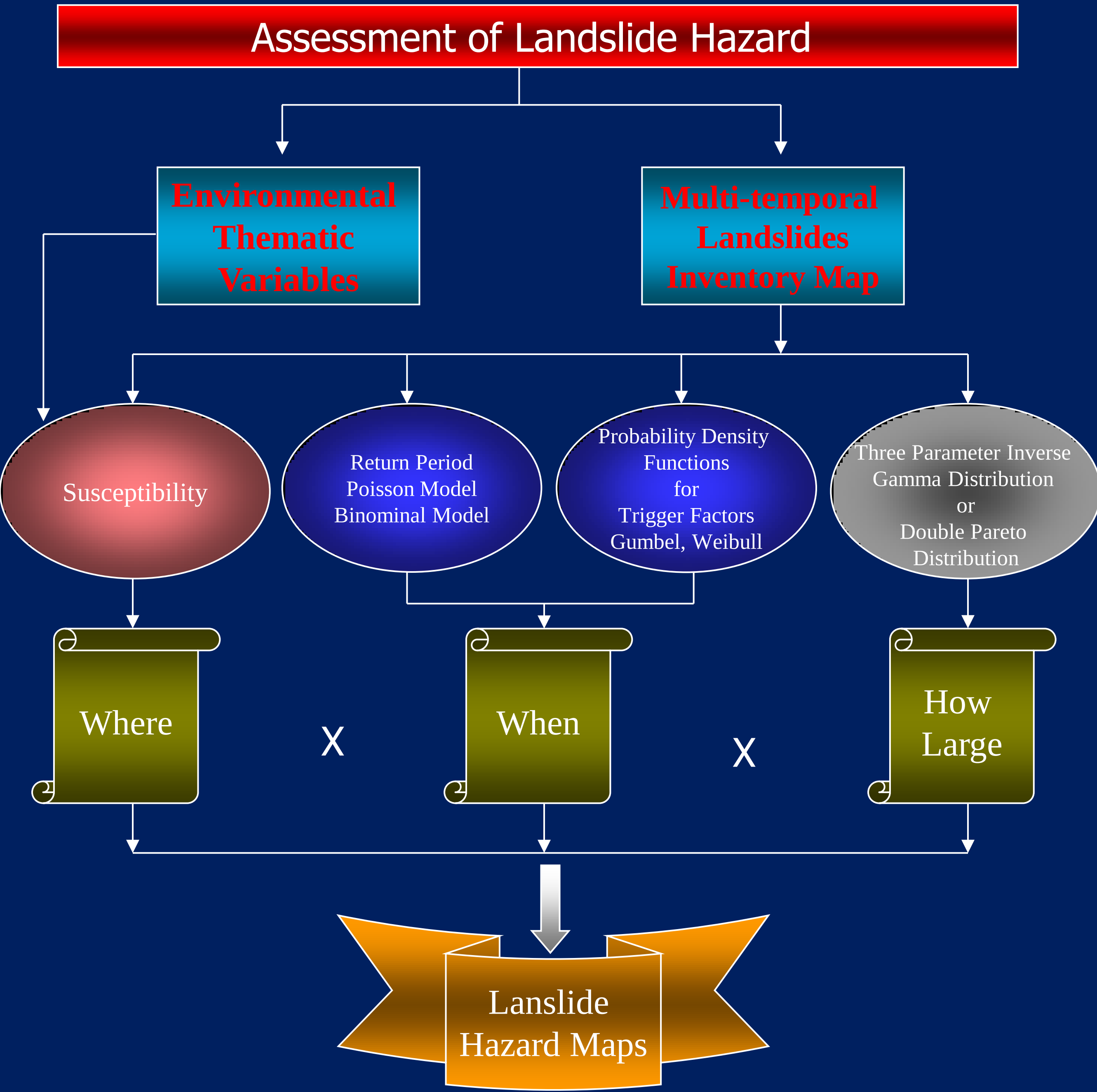






	Landslide Type			
	Circular Failure	Complex	Flow (Area)	Flow (Linear)
Number	**177**	**103**	**24**	**53**
Mean (km^2)	**0.19**	**0.74**	**0.02**	**-**
Max. (km^2)	**2.95**	**3.98**	**0.08**	**-**
Min. (km^2)	**0.005**	**0.013**	**0.005**	**-**
Total (km^2)	**33.28**	**75.93**	**0.48**	**-**

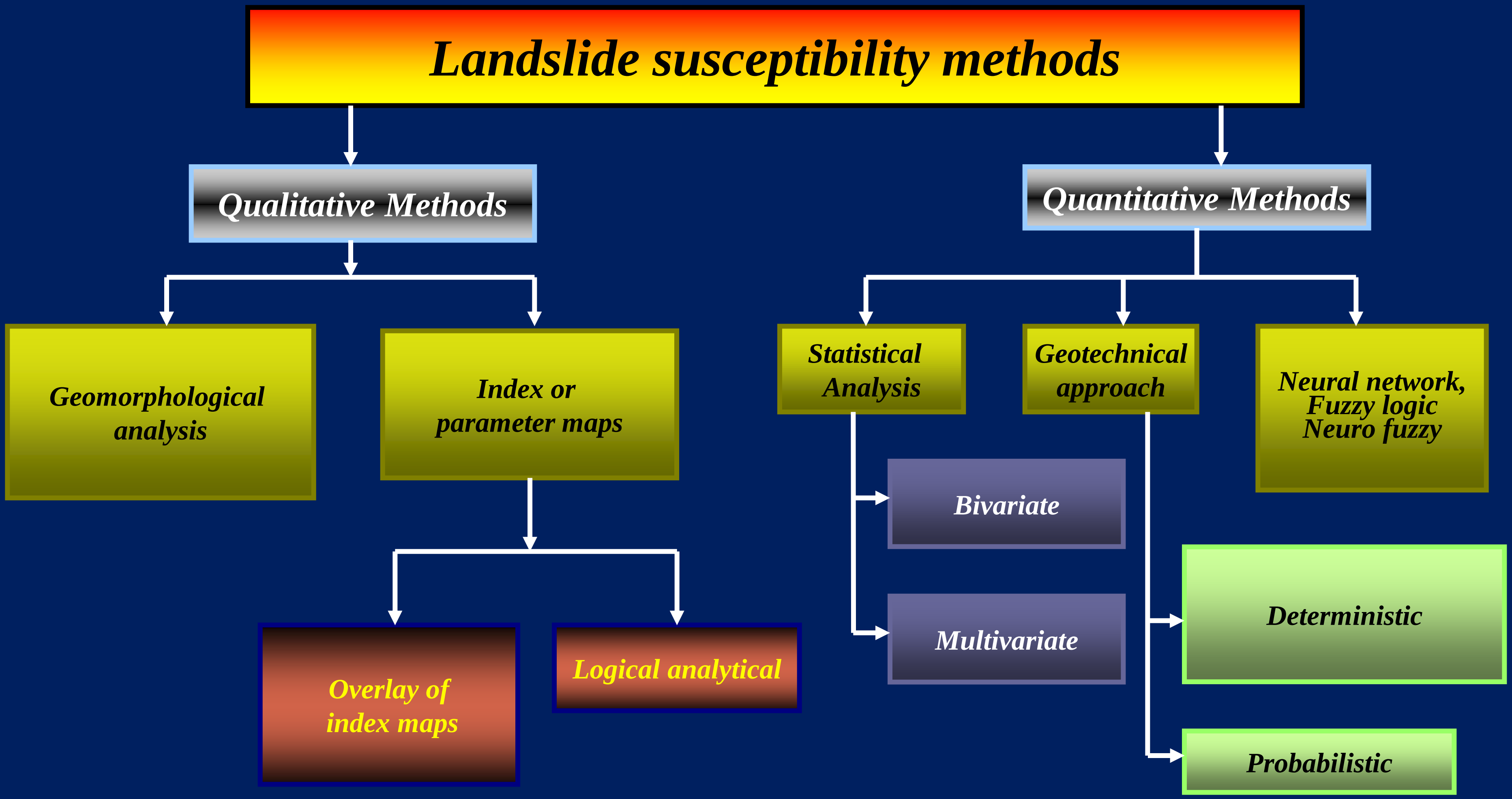
	Multi-temporal Landslide Inventory		
	Before 1955	1955-1969	1969 Event
Number	**77**	**108**	**109**
Mean (km^2)	**0.98**	**0.28**	**0.029**
Max. (km^2)	**4.03**	**3.98**	**0.13**
Min. (km^2)	**0.059**	**0.017**	**0.005**
Total (km^2)	**75.30**	**30.92**	**3.15**



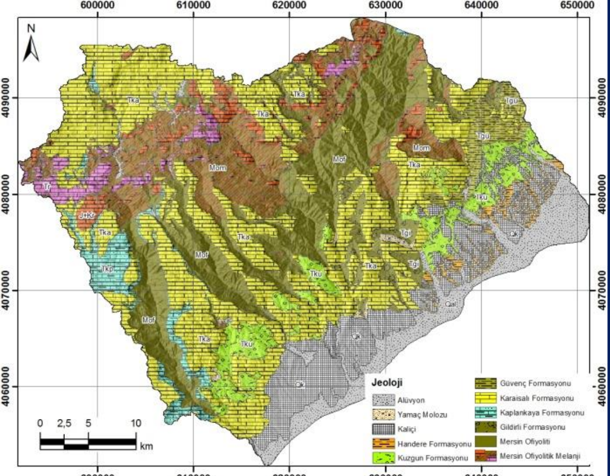
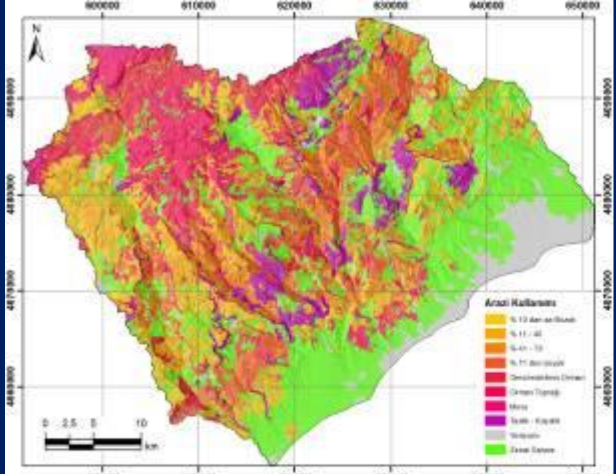
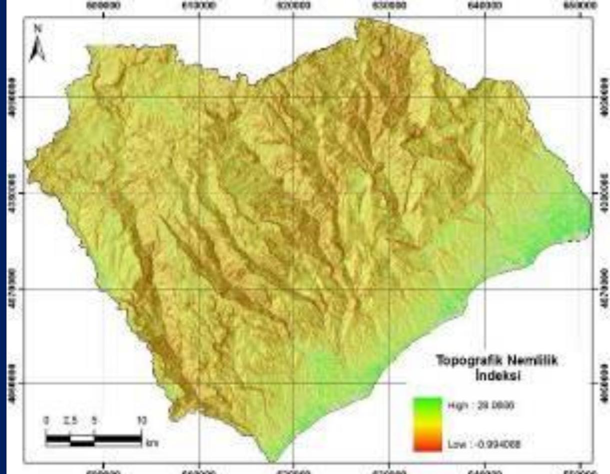
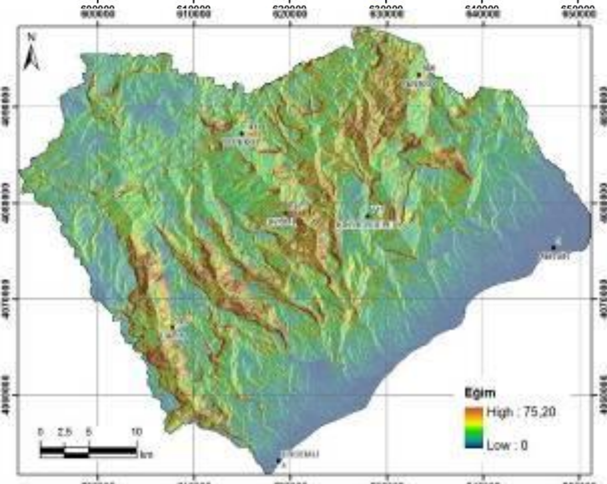
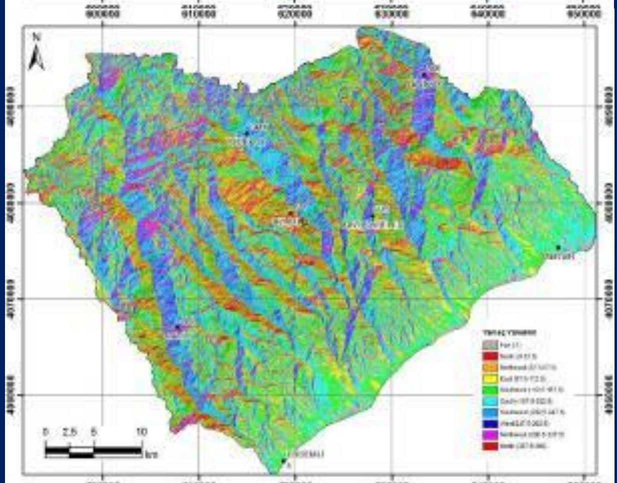
RISK= *Hazard* X *Vulnerability* X *Cost*

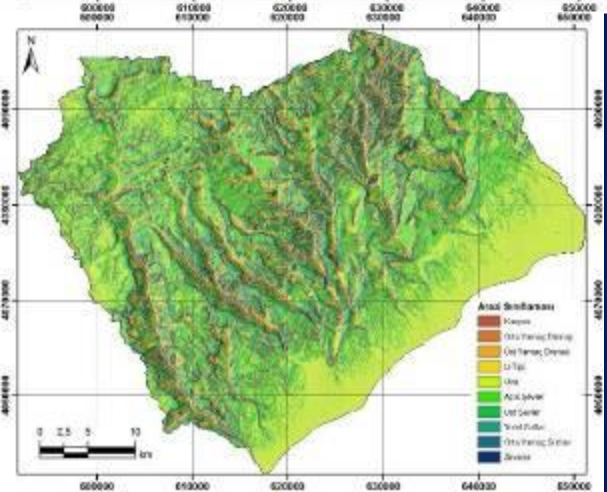
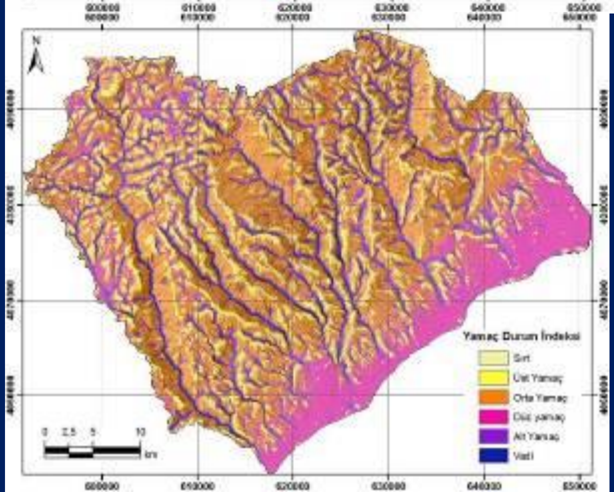
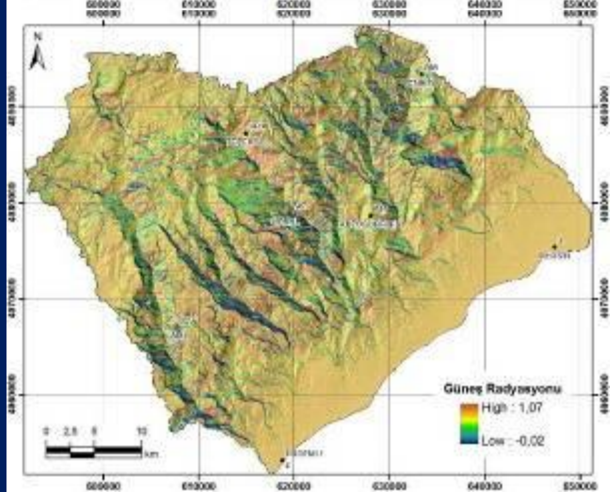
- the probability of occurrence of a given landslide size within a specified time period and within a given area

Guzzetti vd, 2005



Aleotti ve Chowdhury 1999


Jeoloji
Alüvyon
Yamaç Molozu
Kaliçi
Handere Formasyonu
Kuzgun Formasyonu
Güvenç Formasyonu
Karaisalı Formasyonu
Kaplankaya Formasyonu
Gildirli Formasyonu
Mersin Ofiyoliti
Mersin Ofiyolitik Melanji
0 2,5 5 10
km

Arazi Kullanımı

Topografik Nemlilik İndeksi
High
Low

Eğim
High : 75,20
Low : 0


Nehir Aşındırma İndeksi
High
Low : 0

Arazi Sınıflaması

Yamaç Durum İndeksi
Sırt
Üst Yamaç
Orta Yamaç
Düz yamaç
Alt Yamaç
Vadi

Güneş Radyasyonu
High : 1,07
Low : -0,02

Logistic regression

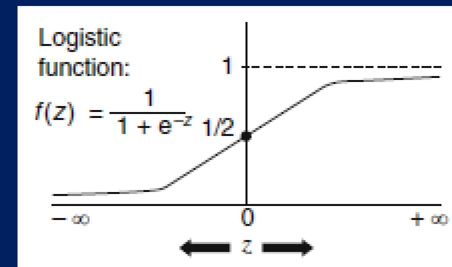
In quantitative terms, the relationship between the occurrence of landslide and various causative factors can be expressed as:

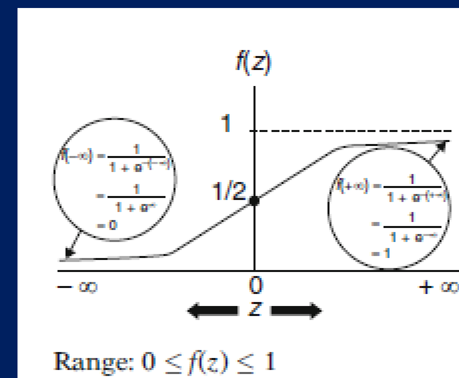
$$p = \frac{1}{1 + e^{-z}}$$

where p is the estimated probability of landslide occurrence based on the influence of causative factors.
The probability varies from 0 to 1 on an S-shaped curve (Kleianbum 1994) and z is the linear combination varies from −∞ to +∞. z can be expressed as a summation of some constant value, which is the intercept of the model (α) and products of independent variables (Xi) and their respective coefficients (βi).

$$z = \alpha + \sum_{i=1}^{n} \beta_i X_i$$

The model estimates the regression parameters consisting of a constant (α) and the coefficients of the independent variables (βi), based on the values of independent variables and the status of the dependent variable in the sample cells, using a maximum likelihood method (Mathew et al. 2009). Logistic regression makes an attempt to estimate α and βi by finding a best fit function to describe the relationship between the status of the dependent variable (presence or absence) and a set of independent variables for the sample locations. Using the model-derived estimates based on the selected samples, the probability of slope failure may be calculated on a cell by cell basis.





$$z = \alpha + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_k X_k$$

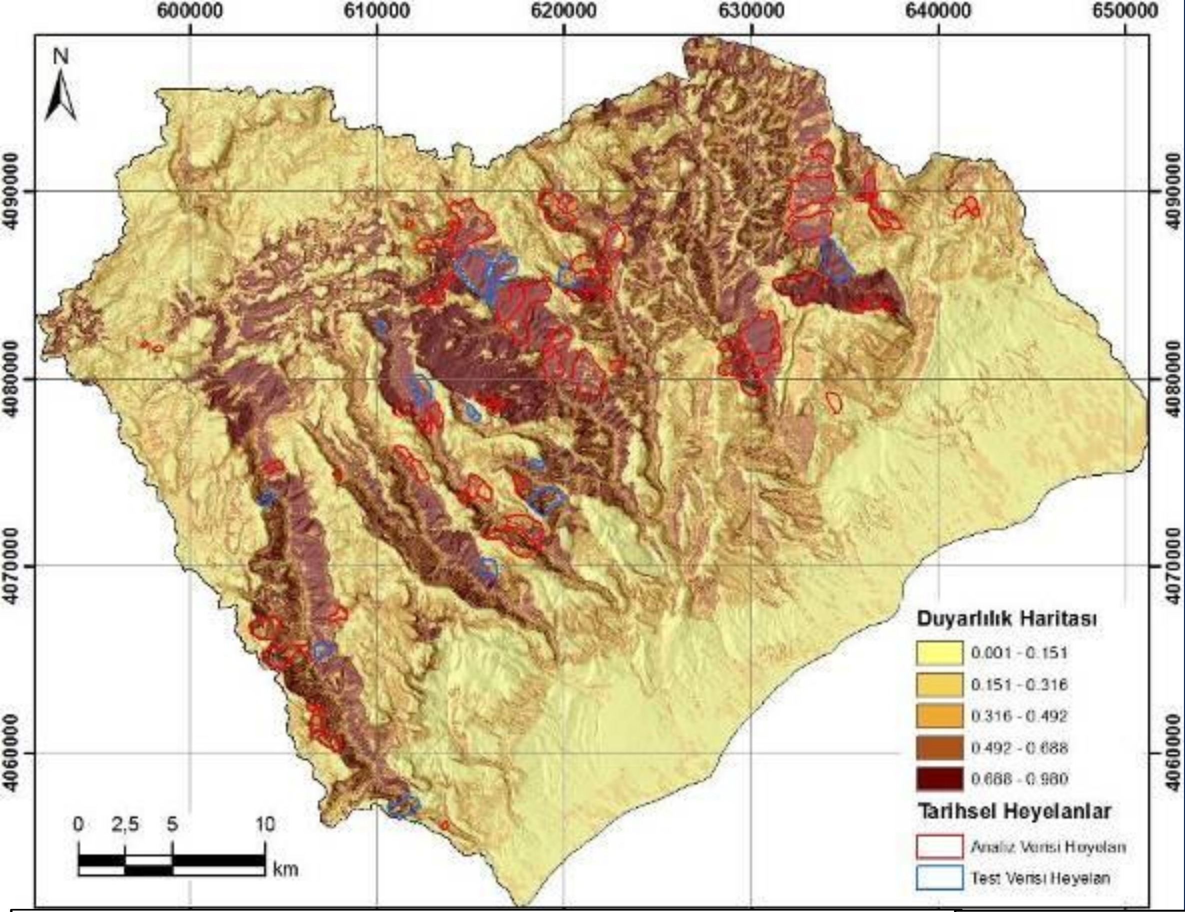
$$f(z) = \frac{1}{1 + e^{-z}} = \frac{1}{1 + e^{-(\alpha + \sum \beta_i X_i)}}$$

Değişken	β	S.E.	Wald	df	Sig.	Exp(B)
yuksek	-0.0001	0.000	74.674	1	0.000	1.000
egim	0.021	0.001	1,113.148	1	0.000	1.021
sp1 (Sırt)	-0.779	0.055	199.214	1	0.000	0.459
sp3 (Orta Yamaç)	1.660	0.017	9,100.227	1	0.000	5.259
sp5 (Alt Yamaç)	0.475	0.021	489.986	1	0.000	1.609
tpi1 (Kanyon)	0.968	0.021	2,074.064	1	0.000	2.632
tpi2 (Orta Yamaç Diranajı)	0.254	0.020	157.699	1	0.000	1.289
tpi3 (Üst Yamaç Diranajı)	1.031	0.060	295.559	1	0.000	2.803
jeo2 (Mof)	0.759	0.020	1,500.934	1	0.000	2.135
jeo3 (Mom)	1.684	0.020	7,063.088	1	0.000	5.385
jeo5 (Qka)	-1.922	0.054	1,265.640	1	0.000	0.146
jeo7 (Tgi)	0.549	0.032	295.643	1	0.000	1.732
jeo10 (Tka)	-0.283	0.020	200.360	1	0.000	0.753
jeo11 (Tkp)	0.246	0.033	56.338	1	0.000	1.279
jeo12 (Tku)	-3.076	0.091	1,145.587	1	0.000	0.046
jeo14 (Tr)	-0.631	0.052	148.699	1	0.000	0.532
baki3 (Kuzey Doğu)	0.315	0.017	323.820	1	0.000	1.370
baki6 (Güney)	0.516	0.016	979.163	1	0.000	1.675
baki7 (Güney Batı)	0.844	0.016	2,813.610	1	0.000	2.325
baki8 (Batı)	0.719	0.018	1,569.042	1	0.000	2.053
tpi10 (Zirveler)	0.524	0.029	333.565	1	0.000	1.689
tpi4 (U-Tipi)	1.138	0.019	3,518.789	1	0.000	3.120
Constant	-2.495	0.025	9,882.359	1	0.000	0.083

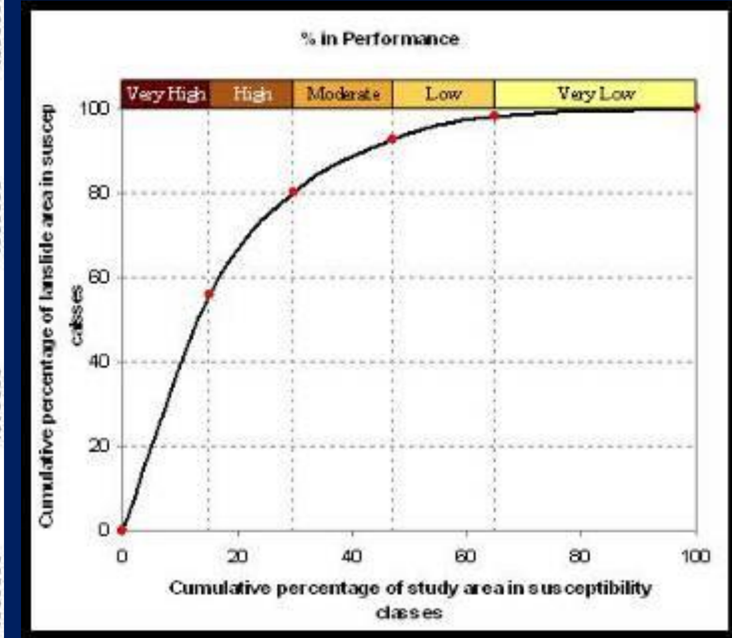
Gözlenen		Tahmin Edilen		
		Heyelan		Doğruluk (%)
		0	1	
Heyelan	0	69044	28074	71,1
	1	18780	78338	80,7
Genel (%)				75,7

Area Under the Curve

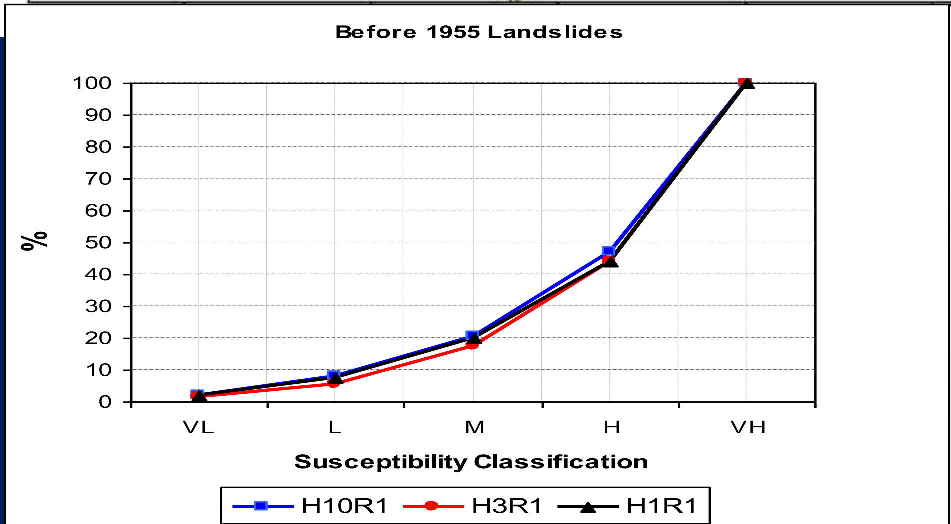
Test Result Variable(s)	Area	Std. Error(a)	Asymptotic Sig.(b)	Asymptotic 95% Confidence Interval	
				Upper Bound	Low er Bound
H1R1 (1955 Tarihsel)	0,836	0,000	0,000	0,835	0,837
H3R1 (1955 Tarihsel)	0,849	0,000	0,000	0,848	0,850
H10R10 (1955 Tarihsel)	0,844	0,000	0,000	0,843	0,845
H7R1 (1955-1969 Aktif)	0,870	0,001	0,000	0,869	0,871
H6R1 (1955-1969 Aktif)	0,869	0,001	0,000	0,867	0,870
H10R1 (1955-1969 Aktif)	0,865	0,001	0,000	0,863	0,866

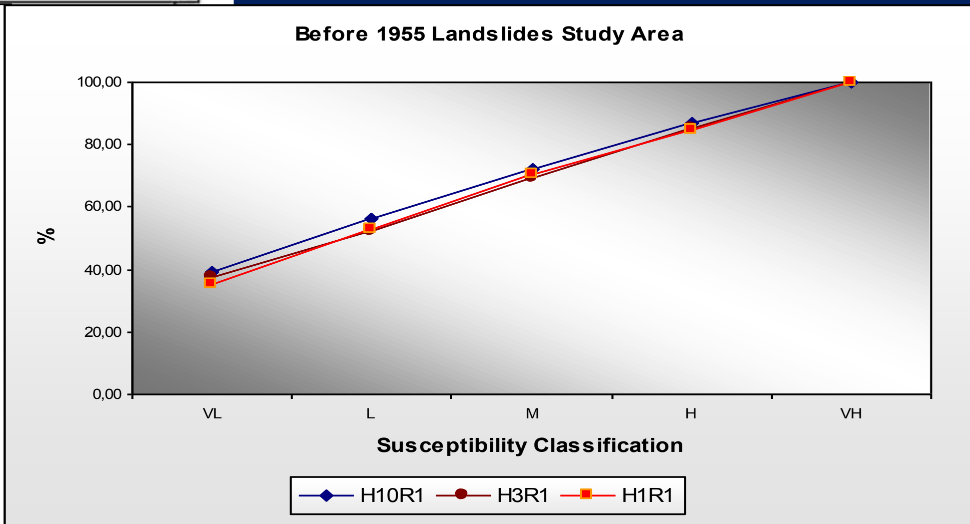


Before 1955



H1R1





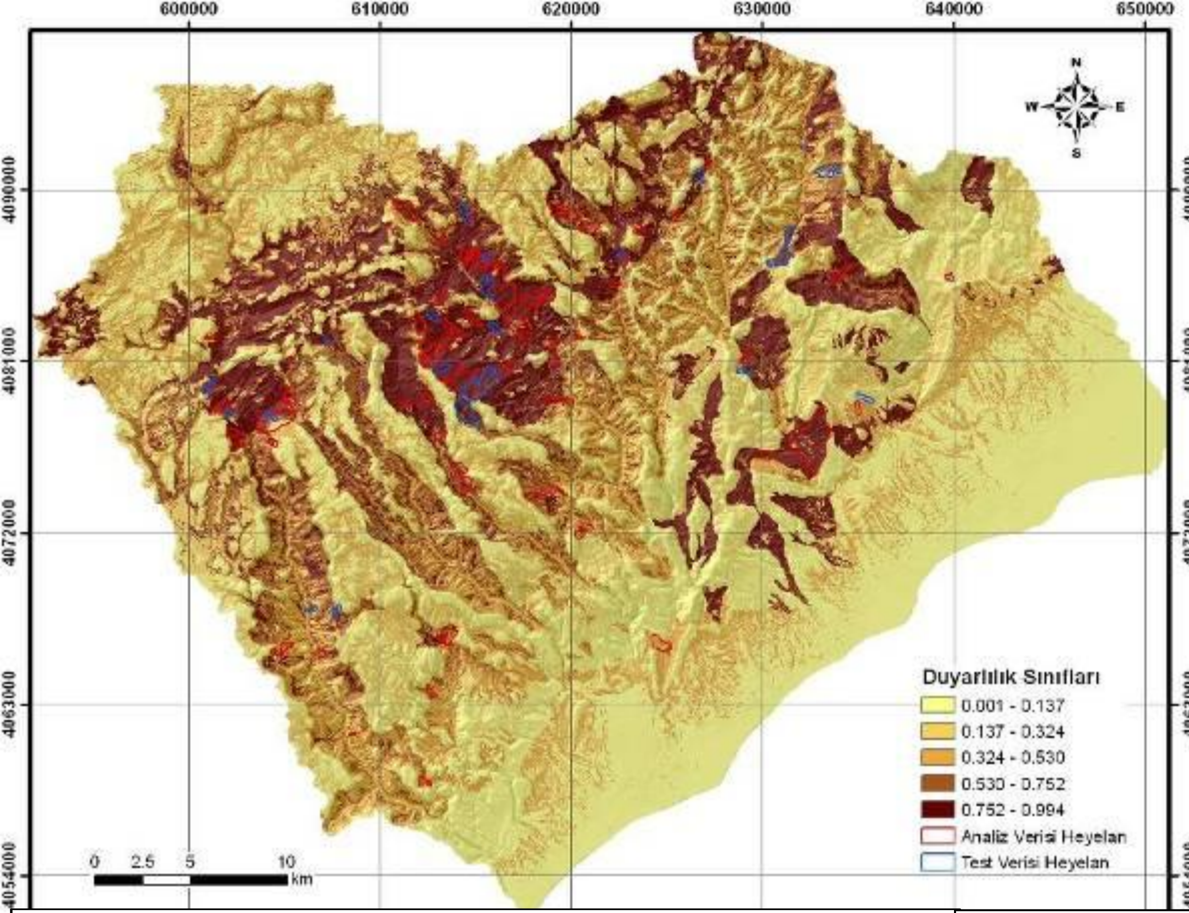
1955- active

Değişken	β	S.E.	Wald	df	Sig.	Exp(B)
egim	-0.016	0.001	176.944	1	0.000	0.984
yuksek	0.001	0.000	772.283	1	0.000	1.001
sp1 (Sırt)	-2.143	0.153	196.307	1	0.000	0.117
sp2 (Üst Yamaç)	-1.057	0.063	284.207	1	0.000	0.348
sp3 (Orta Yamaç)	0.735	0.034	476.797	1	0.000	2.086
sp6 (Vadi)	-0.565	0.042	178.506	1	0.000	0.569
tpi1 (Kanyon)	0.792	0.040	384.457	1	0.000	2.207
tpi4 (U-Tipi)	1.268	0.035	1,338.962	1	0.000	3.553
tpi5 (Ova)	-1.840	0.062	892.607	1	0.000	0.159
tpi8 (Yerel Sırt)	0.962	0.075	166.385	1	0.000	2.616
tpi9 (Orta Yamaç Sırtları)	-0.740	0.042	304.757	1	0.000	0.477
tpi10 (Zirveler)	-1.149	0.094	148.074	1	0.000	0.317
jeo3 (Mom)	1.431	0.024	3,610.385	1	0.000	4.185
jeo7 (Tgi)	2.176	0.041	2,811.853	1	0.000	8.809
jeo8 (Tgü)	-1.258	0.100	157.763	1	0.000	0.284
jeo10 (Tka)	-1.607	0.033	2,419.284	1	0.000	0.200
jeo13 (Tkuk)	2.157	0.073	879.196	1	0.000	8.649
jeo14 (Tr)	-1.459	0.093	245.009	1	0.000	0.232
baki5 (Güney Doğu)	-0.441	0.029	230.871	1	0.000	0.643
baki7 (Güney Batı)	0.423	0.025	278.005	1	0.000	1.527
Constant	-1.176	0.044	708.907			

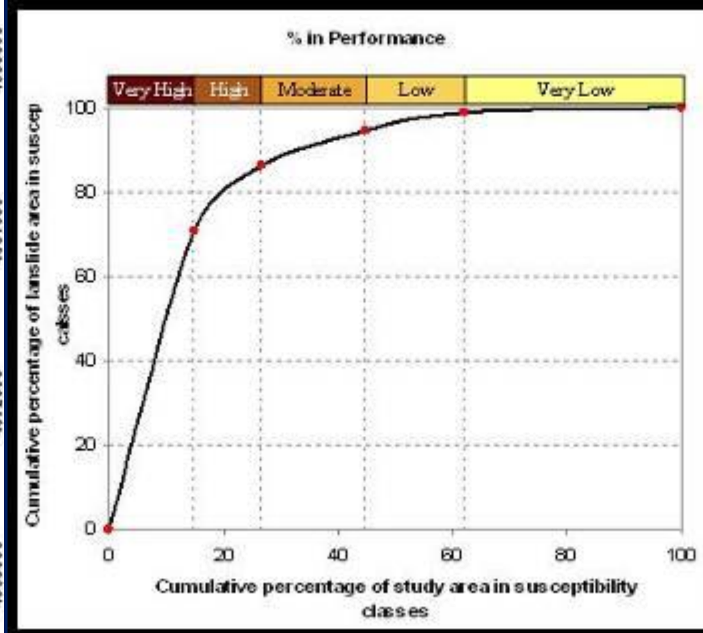
Gözlenen		Tahmin Edilen		
		Heyelan		Doğruluk (%)
		0	1	
Heyelan	0	30433	8415	78,3
	1	6858	31990	82,3
Genel (%)				80,3

Area Under the Curve

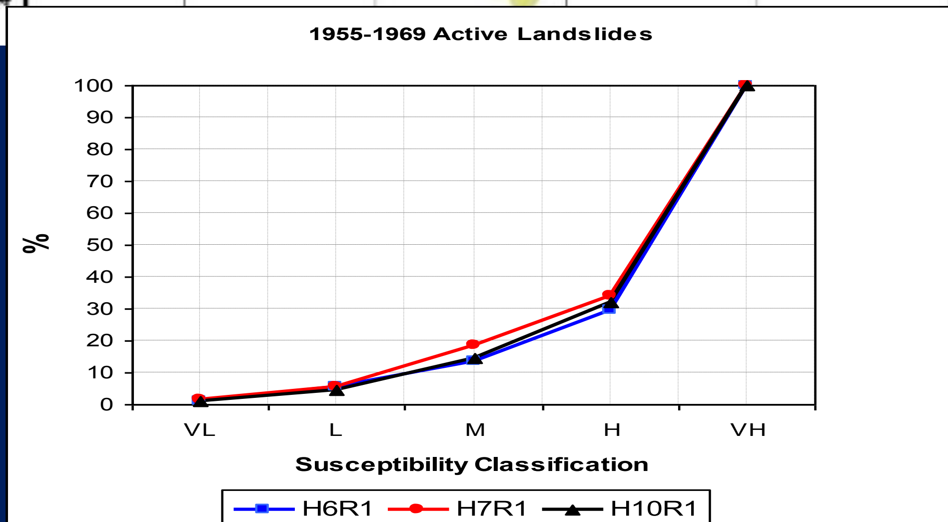
Test Result Variable(s)	Area	Std. Error(a)	Asymptotic Sig.(b)	Asymptotic 95% Confidence Interval	
				Upper Bound	Lower Bound
H1R1 (1955 Tarihsel)	0,836	0,000	0,000	0,835	0,837
H3R1 (1955 Tarihsel)	0,849	0,000	0,000	0,848	0,850
H10R10 (1955 Tarihsel)	0,844	0,000	0,000	0,843	0,845
H7R1 (1955-1969 Aktif)	0,870	0,001	0,000	0,869	0,871
H6R1 (1955-1969 Aktif)	0,869	0,001	0,000	0,867	0,870
H10R1 (1955-1969 Aktif)	0,865	0,001	0,000	0,863	0,866

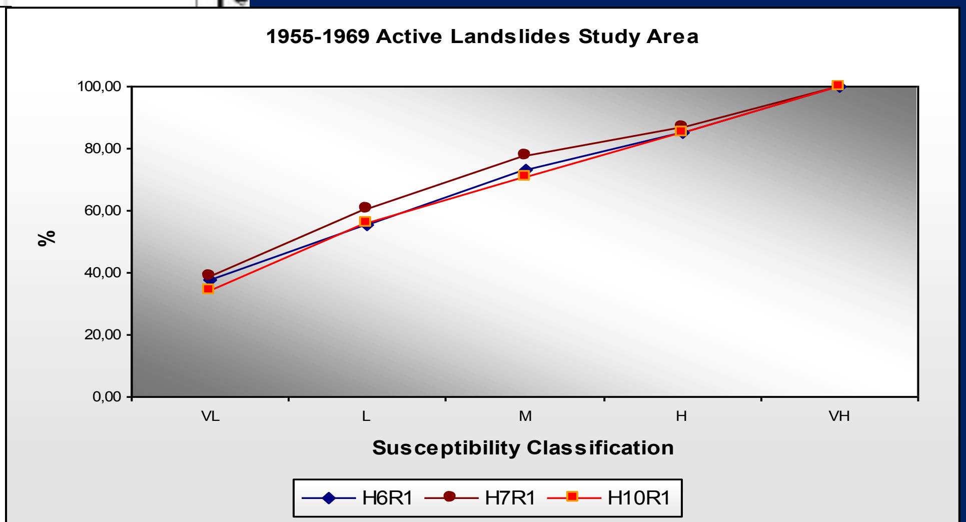


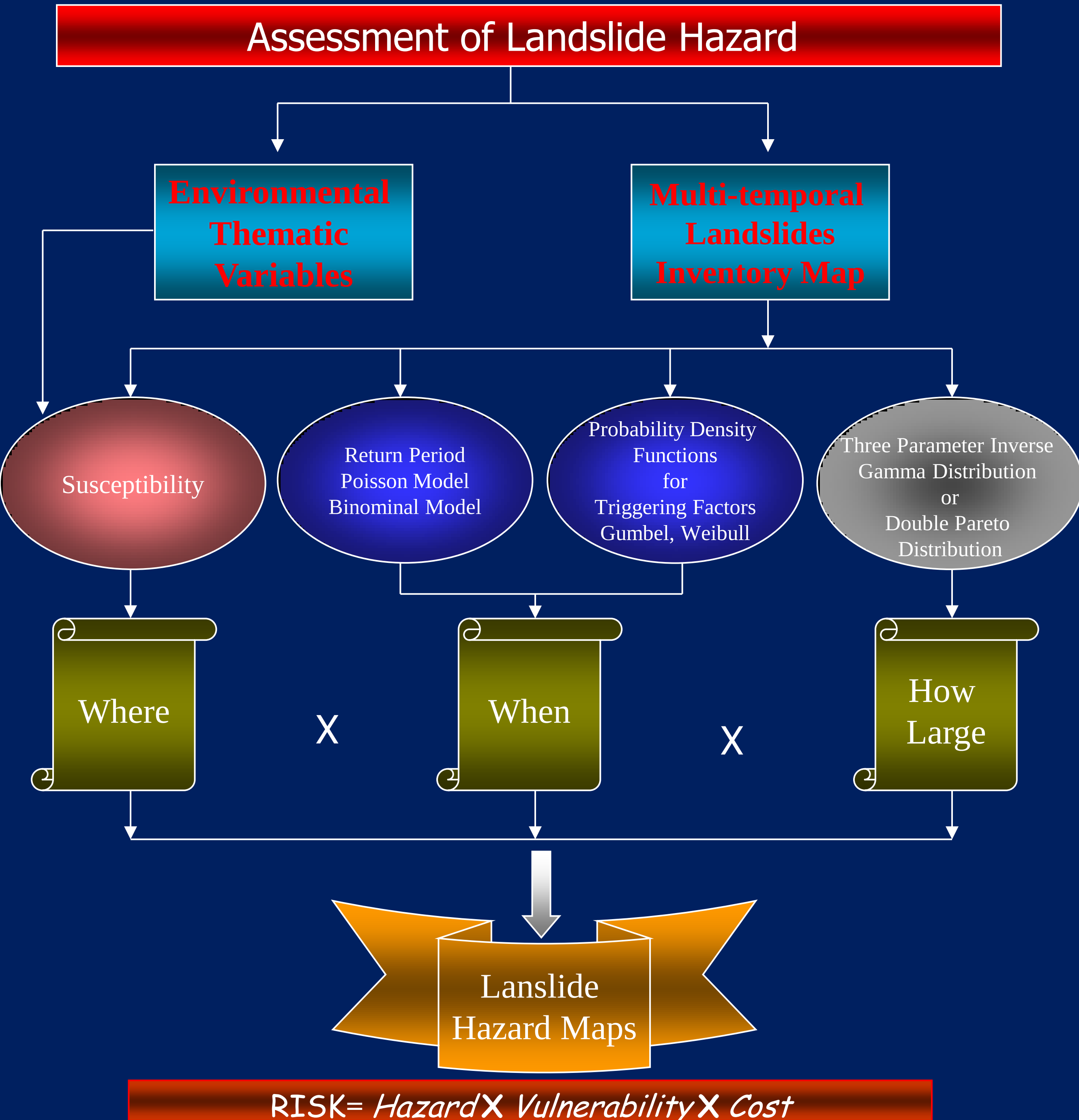
1955- active



H6R1

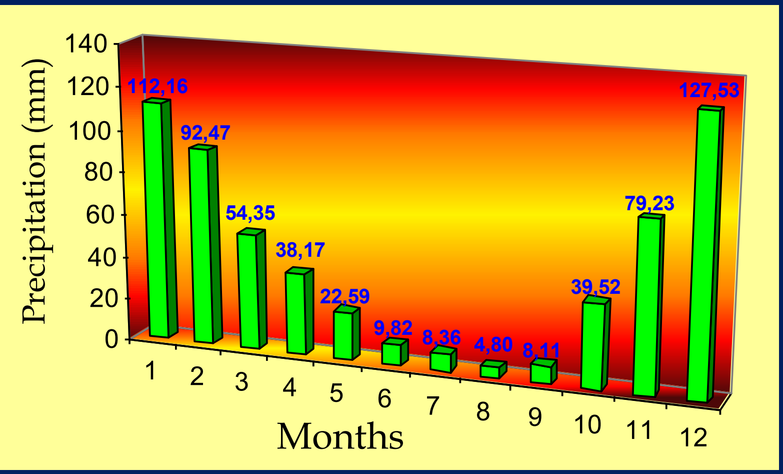




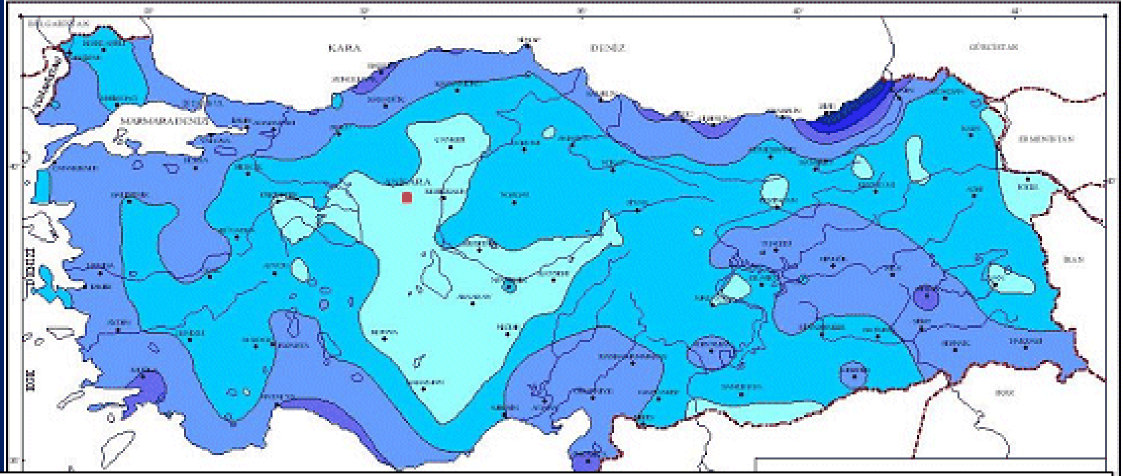


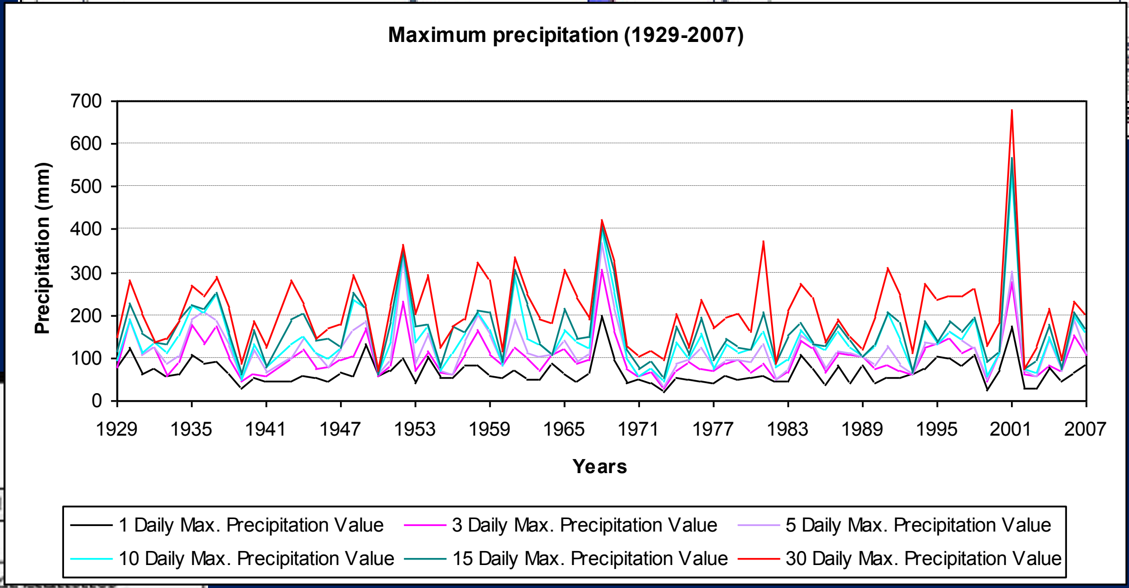
Guzzetti vd, 2005

Rainfall

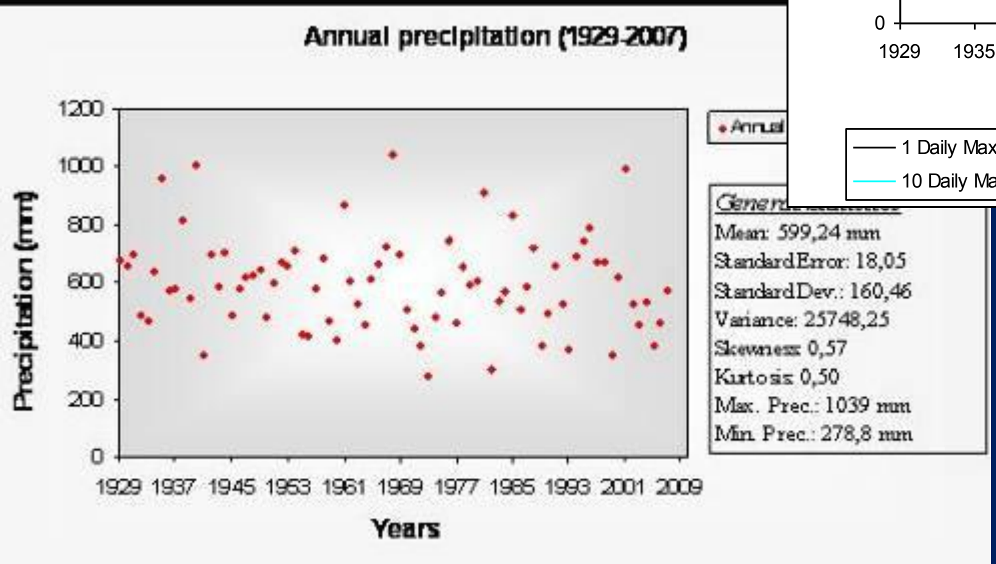


Precipitation (mm)
140
120
100
80
60
40
20
0
112,16
92,47
54,35
38,17
22,59
9,82
8,36
4,80
8,11
39,52
79,23
127,53
1
2
3
4
5
6
7
8
9
10
11
12
Months

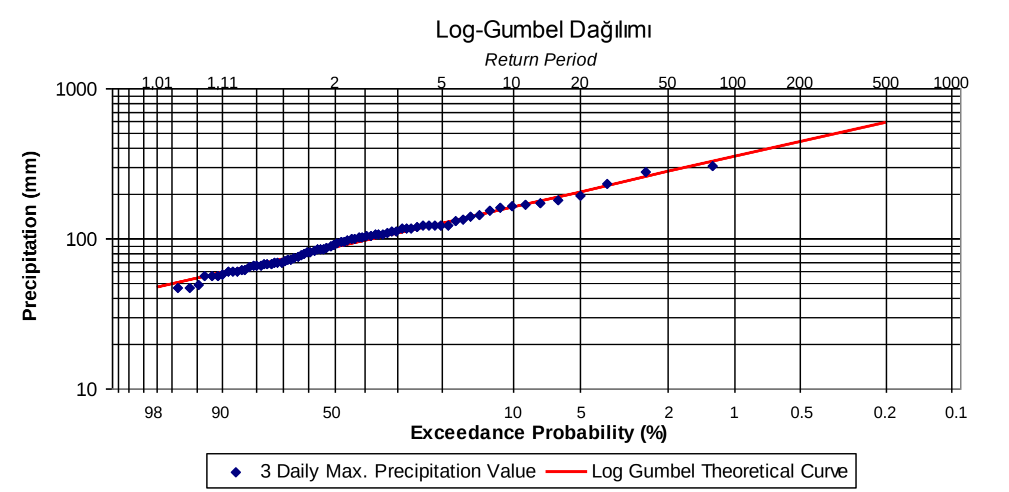


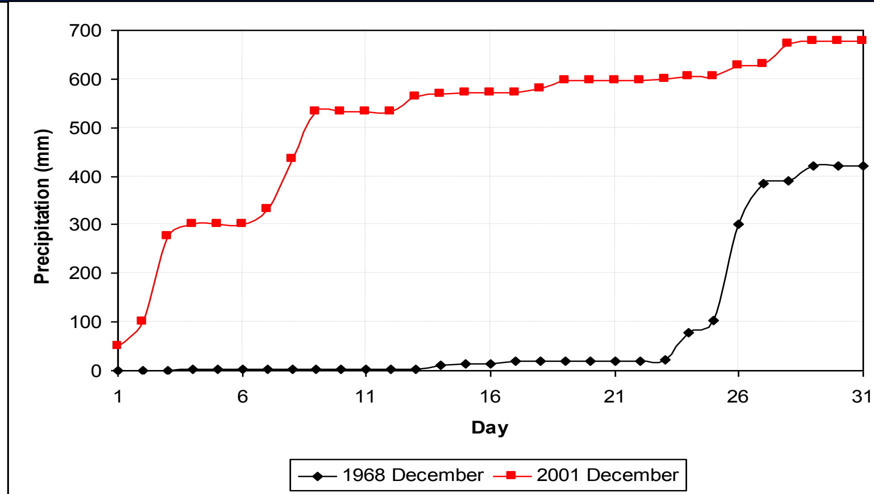


Maximum precipitation (1929-2007)
Precipitation (mm)
700
600
500
400
300
200
100
0
1929
1935
1941
1947
1953
1959
1965
1971
1977
1983
1989
1995
2001
2007
Years
1 Daily Max. Precipitation Value
3 Daily Max. Precipitation Value
5 Daily Max. Precipitation Value
10 Daily Max. Precipitation Value
15 Daily Max. Precipitation Value
30 Daily Max. Precipitation Value



Annual precipitation (1929-2007)
Precipitation (mm)
1200
1000
800
600
400
200
0
1929
1937
1945
1953
1961
1969
1977
1985
1993
2001
2009
Years
Annual
Genera
Mean: 599,24 mm
Standard Error: 18,05
Standard Dev.: 160,46
Variance: 25748,25
Skewness: 0,57
Kurtosis: 0,50
Max. Prec.: 1039 mm
Min. Prec.: 278,8 mm



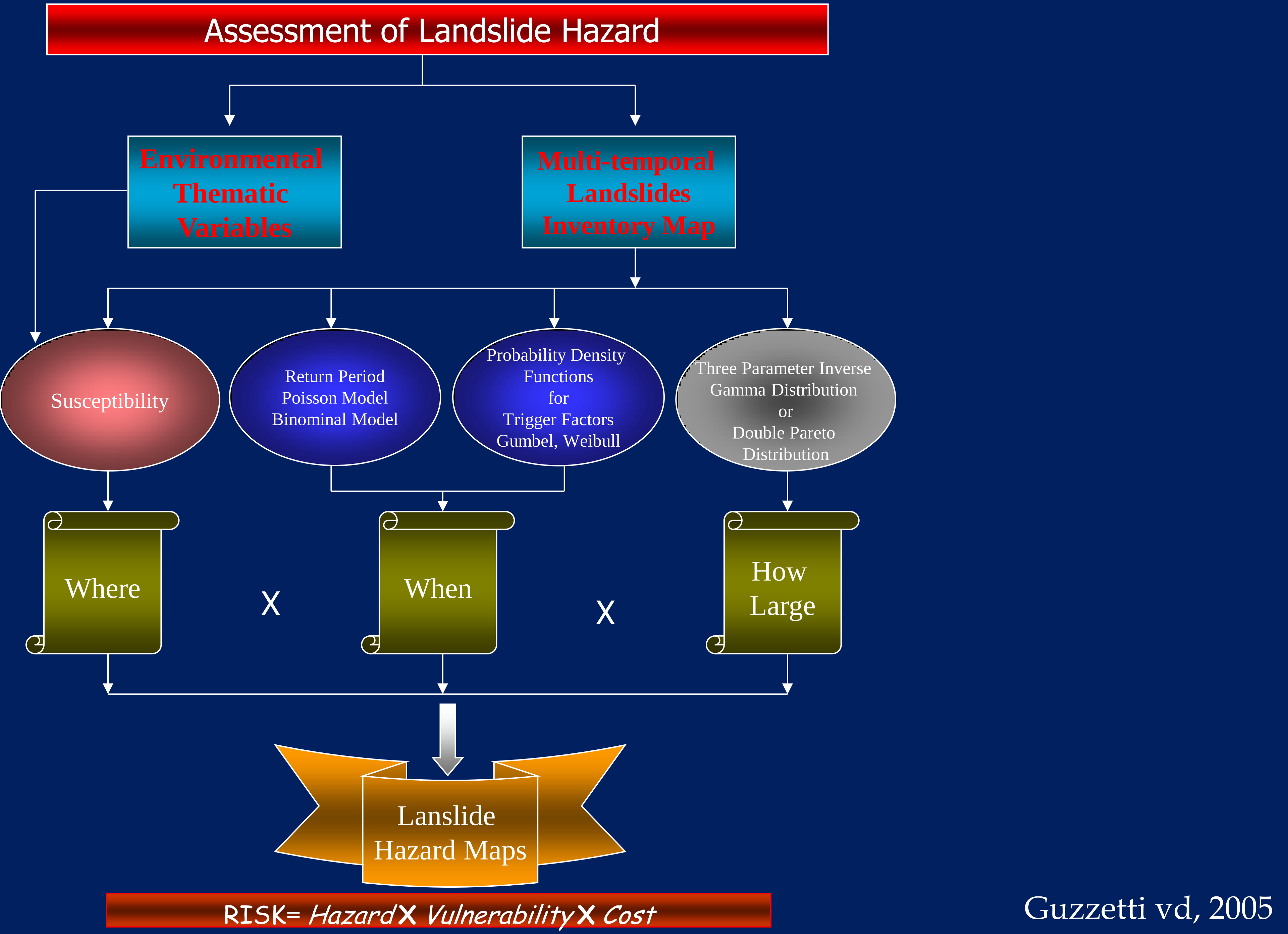


Maximum precipitations	26 December 1968	3 December 2001
1 Day	**199,50**	**175,40**
R.P. (Year) Gumbel	477,40	170,20
3 Day	**280,60**	**276,60**
R.P. (Year) Log-Gumbel	51,82	49,50
5 Day	**282,40**	**277,70**
R.P. (Year) Gumbel	55,50	50,26
10 Day	**287,40**	**314,40**
R.P. (Year) LP3	20,21	29,48
15 Day	**298,00**	**376,50**
R.P. (Year) LP3	16,48	52,02
30 Day	**432,10**	**391,50**
R.P. (Year) LP3	42,21	23,82

K-S Test

1 Daily Max.	Gumbel
3 Daily Max.	Log Gumbel
5 Daily Max.	Gumbel
10 Daily Max.	LP3
15 Daily Max.	LP3
30 Daily Max.	LP3

Years	Exc. Prob.
5	0.095
10	0.181
25	0.393
50	0.632
100	0.865



Assessment of Landslide Hazard
Environmental Thematic Variables
Multi-temporal Landslides Inventory Map
Susceptibility
Return Period
Poisson Model
Binominal Model
Probability Density Functions for Trigger Factors
Gumbel, Weibull
Three Parameter Inverse Gamma Distribution or Double Pareto Distribution
Where
X
When
X
How Large
Lanslide Hazard Maps
RISK= Hazard X Vulnerability X Cost
Guzzetti vd, 2005

Power-law frequency-area statistics

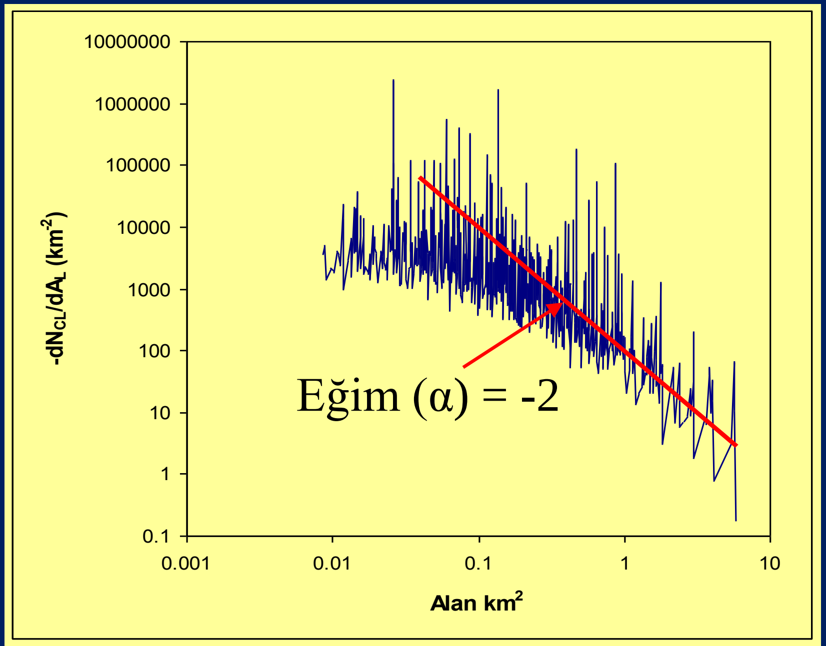
Malamud vd. 1999

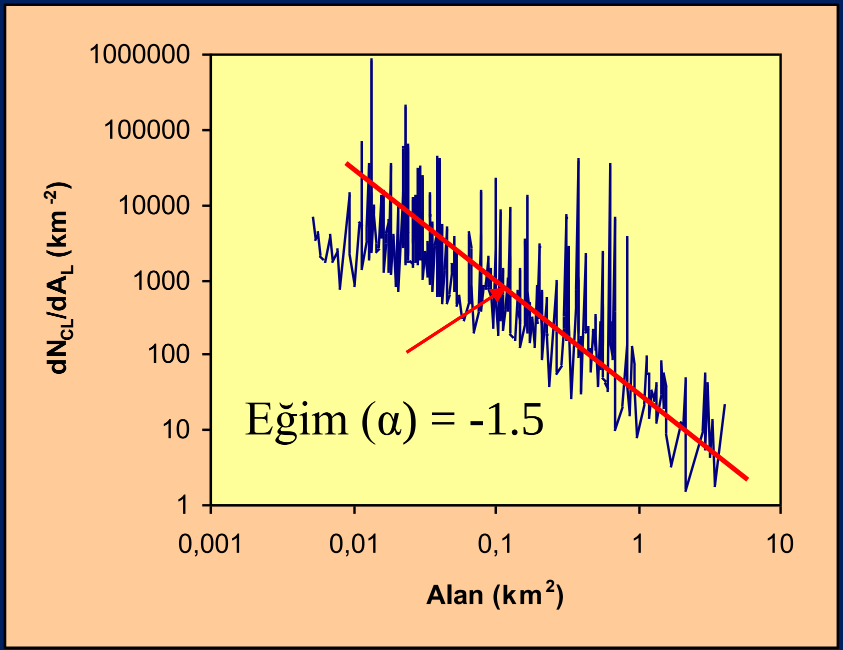
$$N_{CL} = C' A_L^{-\alpha} = \frac{dN_{CL}}{dA_L}$$

where N_{cl} is the Cumulative number of landslides, C intercept, Al landslide area, -α slope that control the medium and large landslide.

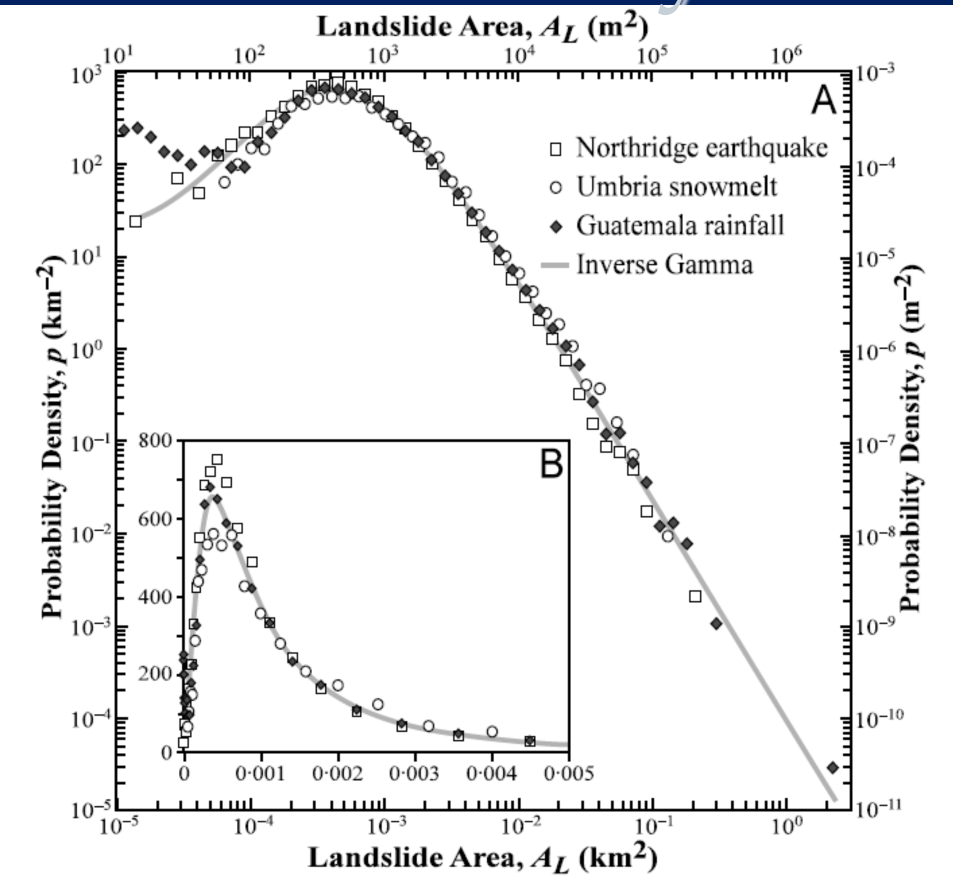
dN_{cl} is the number of landslides with areas between A_L and $A_L + dA_L$.

The noncumulative number of landslides, $-dN_{CL} / dA_L$, with area A_L, is given as a function of A_L.





Probability of the landslide size



$$P(A_L; p, a, s) = \frac{1}{a\Gamma(p)}\left(\frac{a}{A_L - s}\right)^{p+1} \exp\left(-\frac{a}{A_L - s}\right)$$

$a = 1.28x10^{-3}\, km^2$ $\qquad \Gamma(1.4) = 0.88726$

$s = -1.32x10^{-4}\, km^2$ $\qquad R^2 = 0.965$

$p = 1.4$ $\qquad A_L = Landslide\ area$

$a =$ location of maximum probability.

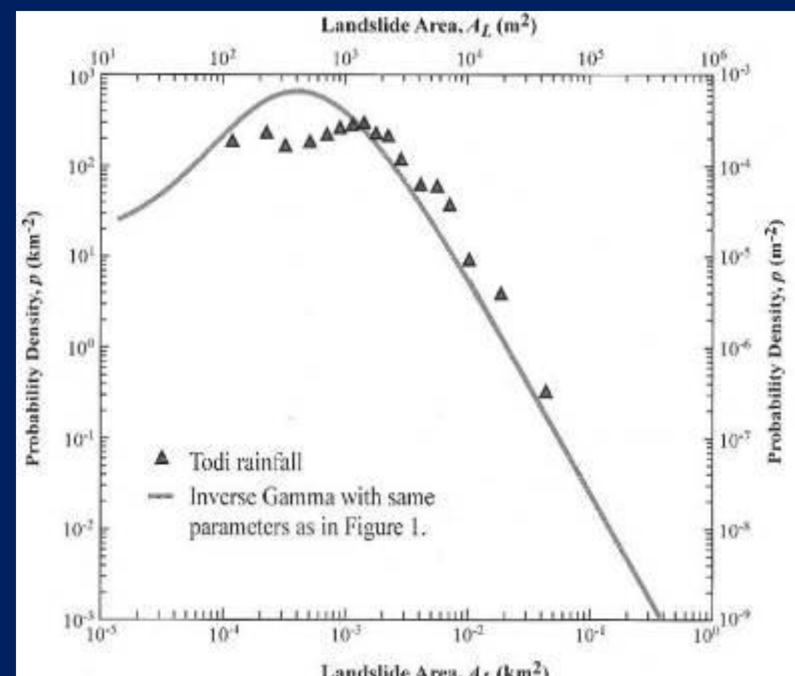
$s =$ exponential rollover for small landslides

$p =$ power - law decay for medium and large landslide

Notrhridge: 11111
Umbria: 4233
Guatemala: 9594

Medium and large values of A_L

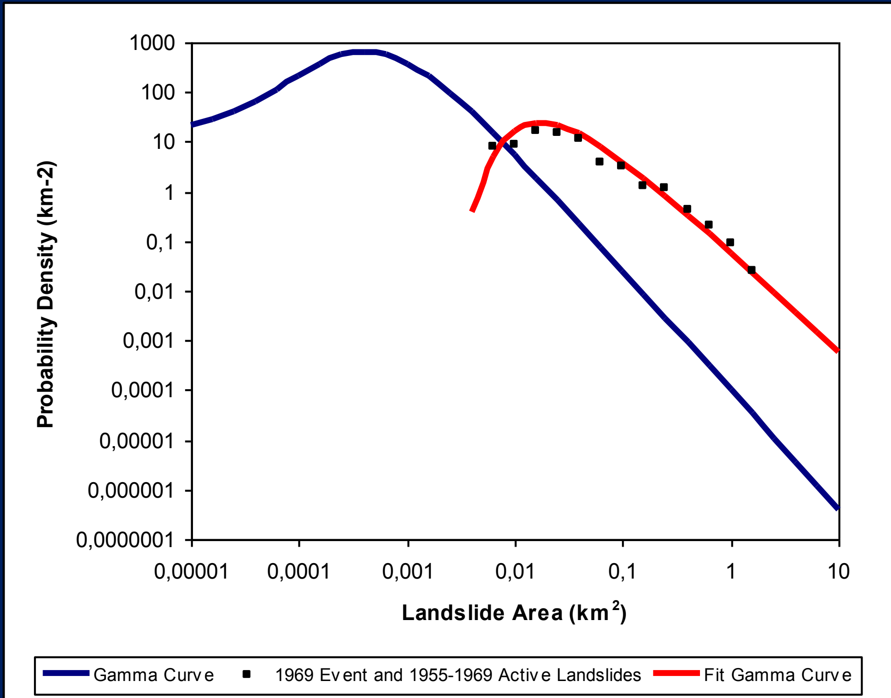
$$P(A_L) \approx \frac{1}{a\Gamma(p)}\left(\frac{a}{A_L}\right)^{p+1}$$

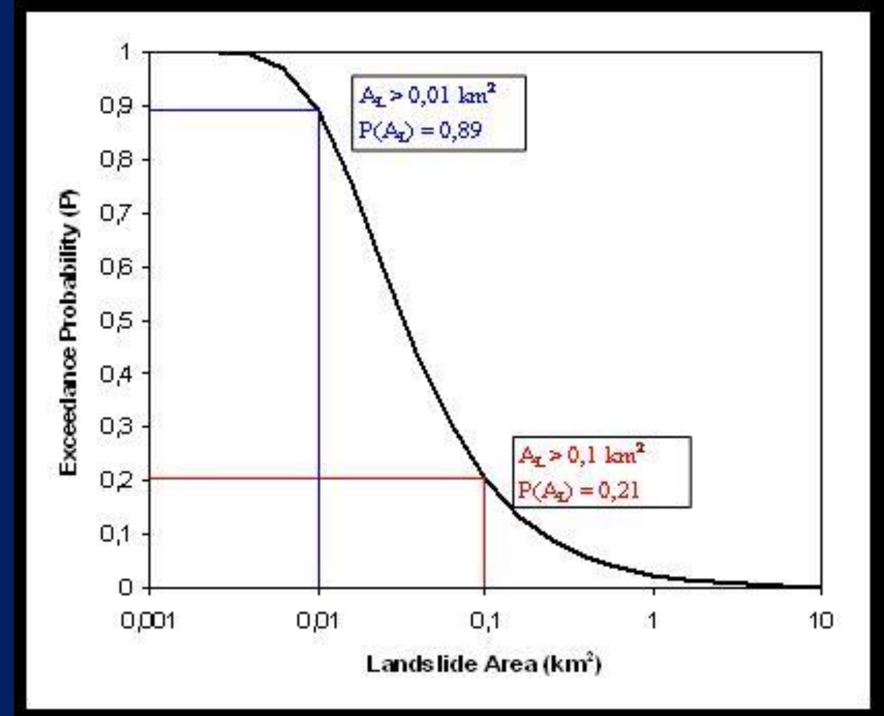


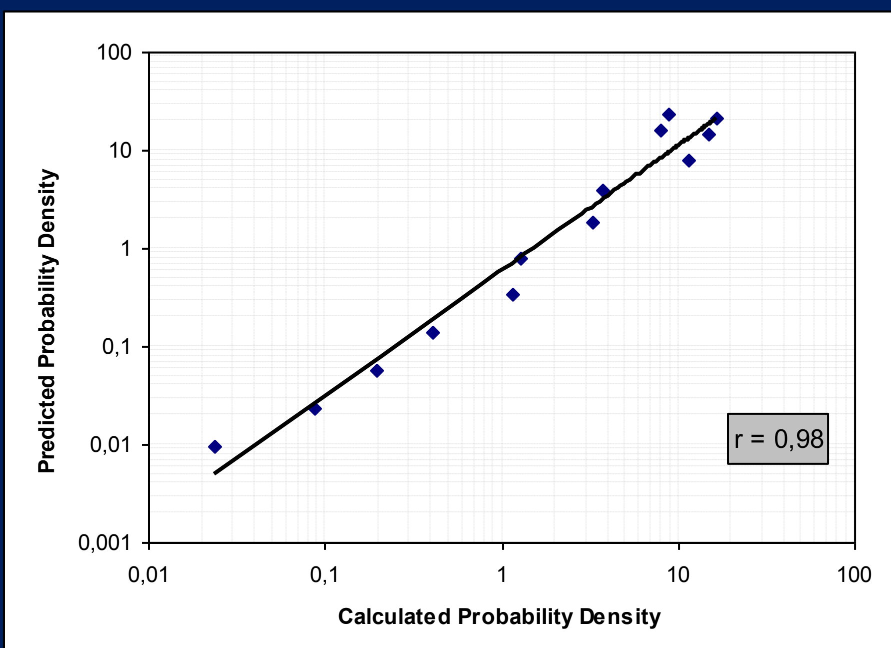
Malamud vd. 2004

Todi:165

Turcotte vd. 2006







$$P(A_L) = \int_{a_L}^{\infty} \frac{1}{a\Gamma(p)} \left(\frac{a}{A_L - s} \right)^{p+1} \exp\left(-\frac{a}{A_L - s} \right)$$

$a = 0.022\ km^2$

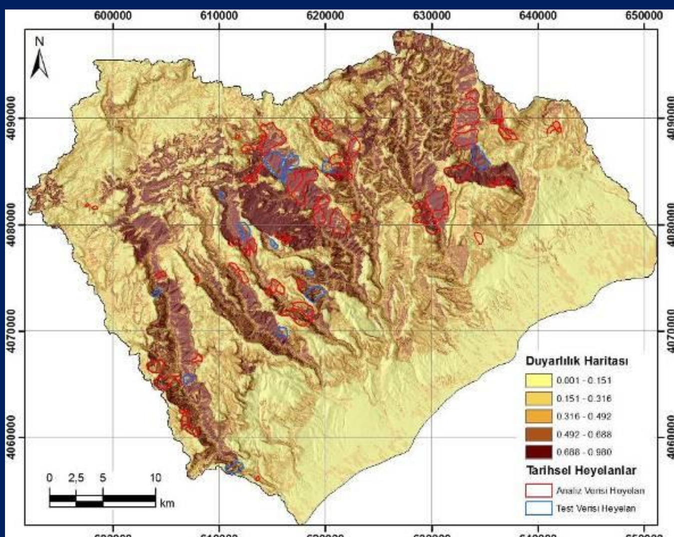
$s = -1x10^{-4}\ km^2$

$p = 0.98$

$\Gamma(0.98) = 1.01195$

$A_L = Landslide\ \ Area$

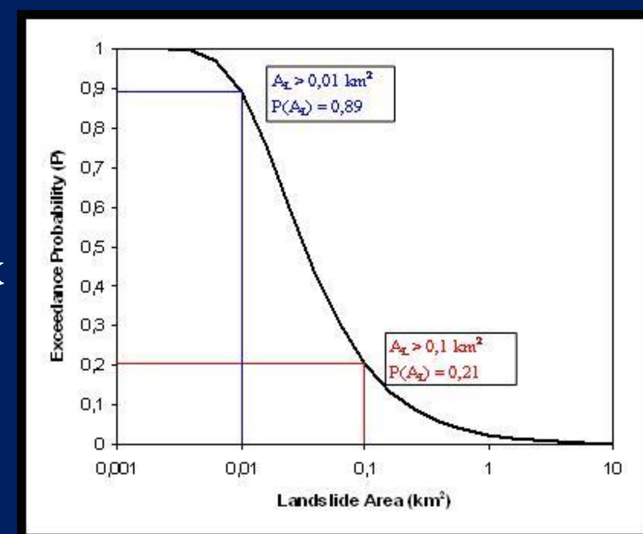
Landslide hazard= Ps * Pt * Pls

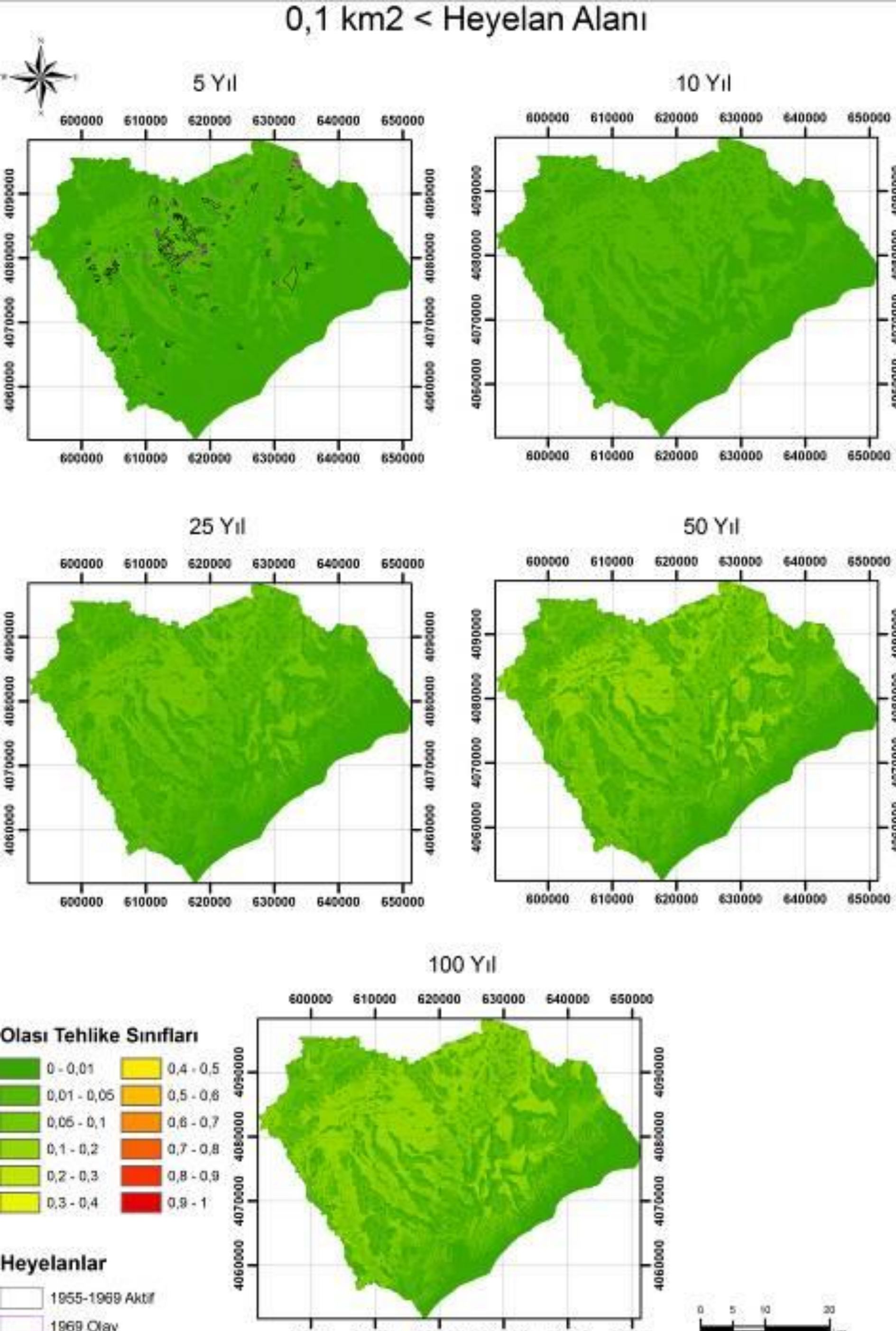


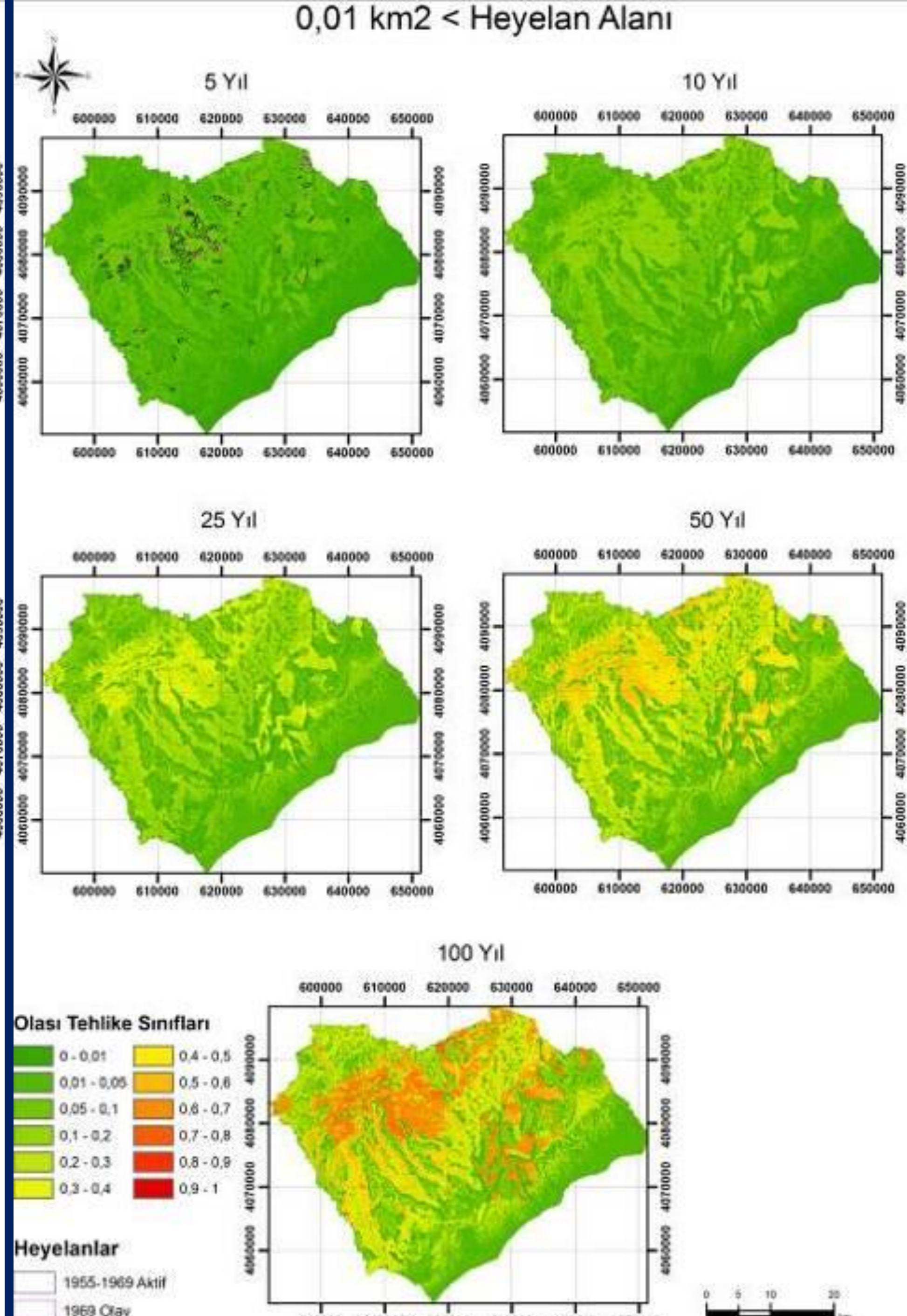
x

Years	Probabilty
5	0,095
10	0,181
25	0,393
50	0,632
100	0,865

x



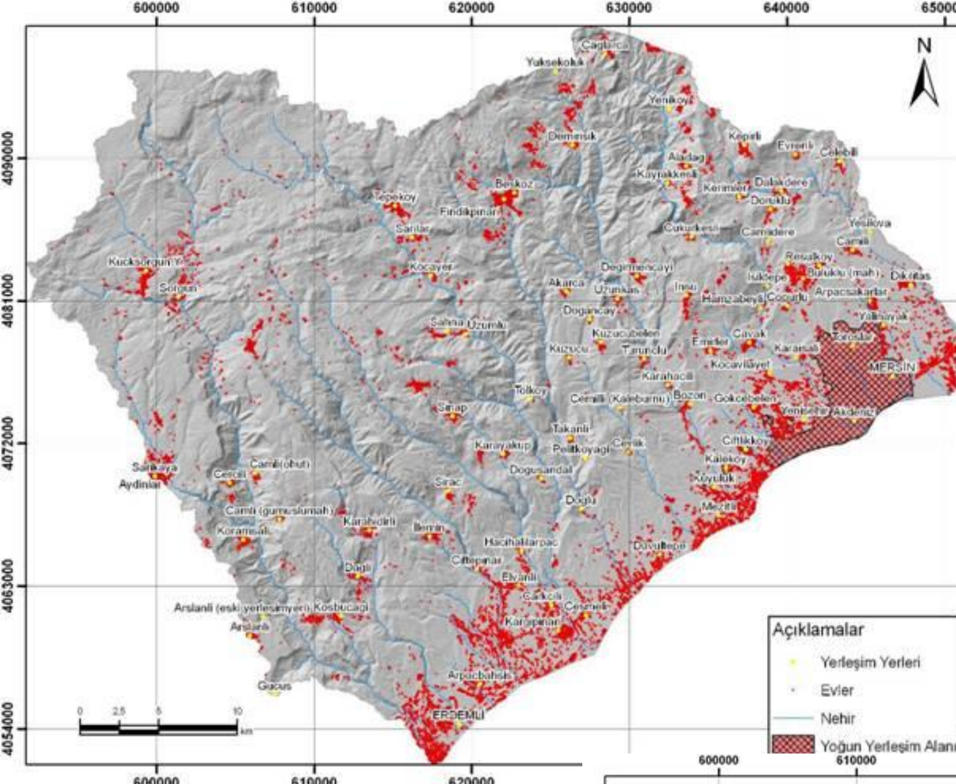

0,1 km2 < Heyelan Alanı
5 Yıl
10 Yıl
25 Yıl
50 Yıl
100 Yıl
Olası Tehlike Sınıfları
0 - 0,01
0,01 - 0,05
0,05 - 0,1
0,1 - 0,2
0,2 - 0,3
0,3 - 0,4
0,4 - 0,5
0,5 - 0,6
0,6 - 0,7
0,7 - 0,8
0,8 - 0,9
0,9 - 1
Heyelanlar
1955-1969 Aktif
1969 Olay


0,01 km2 < Heyelan Alanı
5 Yıl
10 Yıl
25 Yıl
50 Yıl
100 Yıl
Olası Tehlike Sınıfları
0 - 0,01
0,01 - 0,05
0,05 - 0,1
0,1 - 0,2
0,2 - 0,3
0,3 - 0,4
0,4 - 0,5
0,5 - 0,6
0,6 - 0,7
0,7 - 0,8
0,8 - 0,9
0,9 - 1
Heyelanlar
1955-1969 Aktif
1969 Olay

Elements at Risk (Roads)

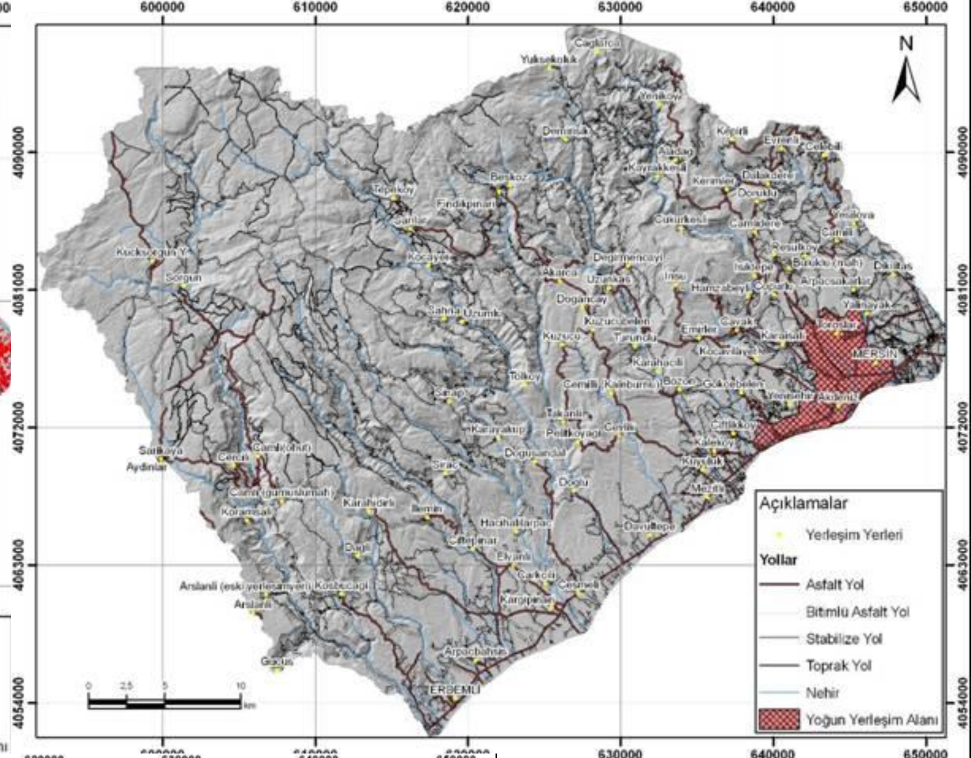
Elements at Risk (Houses)


Agricultural lands



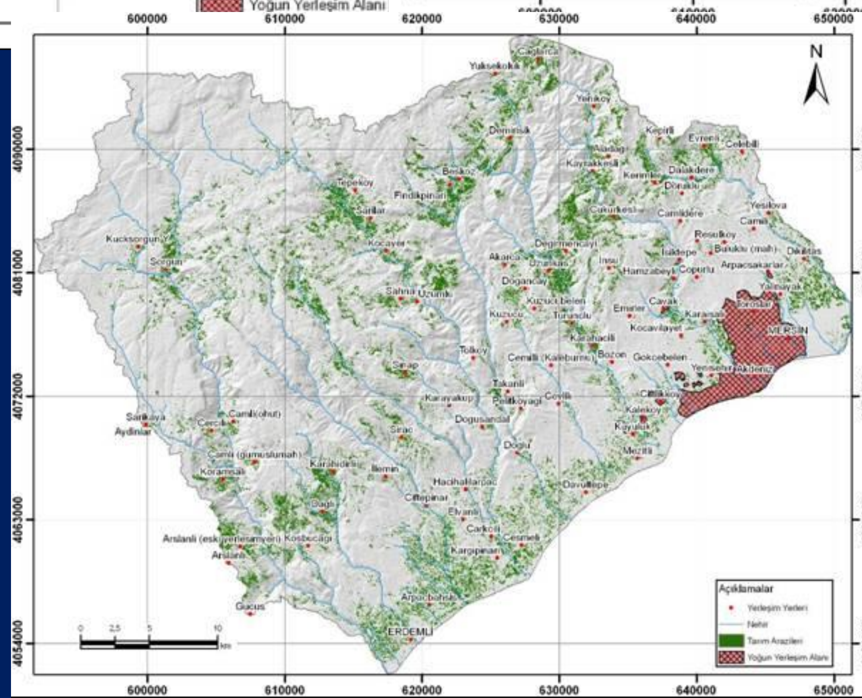
Settlements

26420 / 13780 houses



Transportation

2916km



Agricultural land 169 km^2

Bayındırlık ve İskan Bakanlığı, 2009 yılı III sınıf, A Grubu yapılar için yapı yaklaşık birim maaliyeti(Resmi gazete, 9 Mart 2009)

III. SINIF, A GRUBU YAPILAR	Birim Maliyet
○ Okul ve mahalle spor tesisleri (Temel eğitim okullarının veya işletme ve tesislerin spor salonları, jimnastik salonları, semt salonları) ○ Katlı garajlar ○ Hobi ve oyun salonları ○ Ticari bürolar (üç kata kadar -üç kat dahil- asansörsüz ve kalorifersiz) ○ Alışveriş merkezleri (semt pazarları, küçük ve büyük hal binaları, marketler. v.b) ○ Basımevleri, matbaalar ○ Soğuk hava depoları ○ **Konutlar (dört kata kadar- dört kat dahil - asansörsüz ve kalorifersiz)** ○ Benzin istasyonları ○ Kampingler ○ Küçük sanayi tesisleri (Donanımlı atölyeler, ticarethane, dükkan, imalathane, dökümhane) ○ Semt postaneleri ○ ve bu gruptakilere benzer yapılar.	**437,00 m2/TL**

TRANSPORTATION NETWORK

10m width asphalt road =160000 km/TL

Unit price/pixel

4000TL asphalt

2000TL bit. asfalt

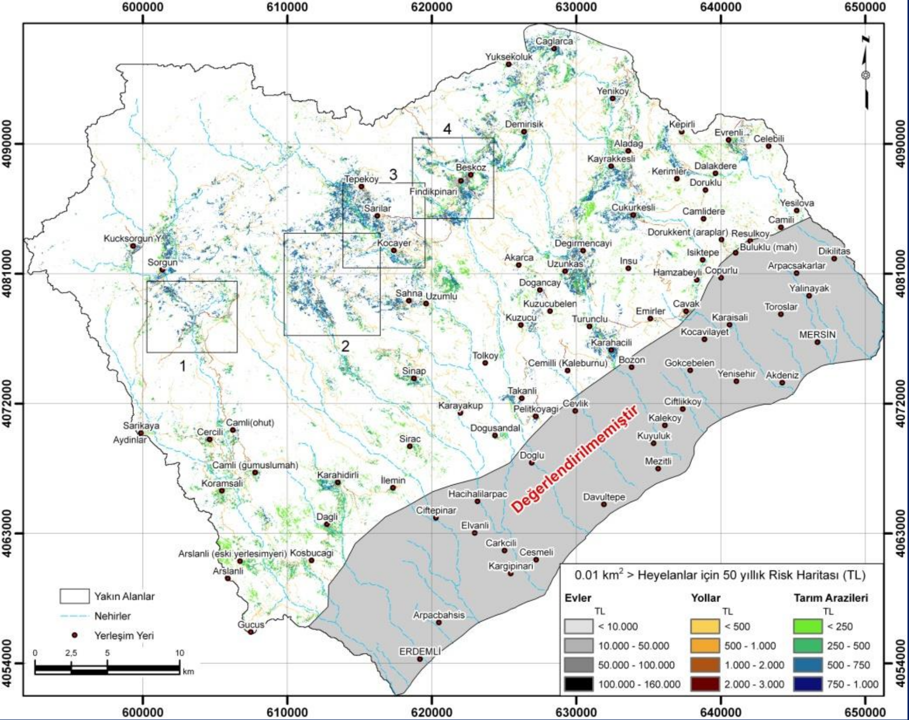
1000TL stabilized

500TL earth

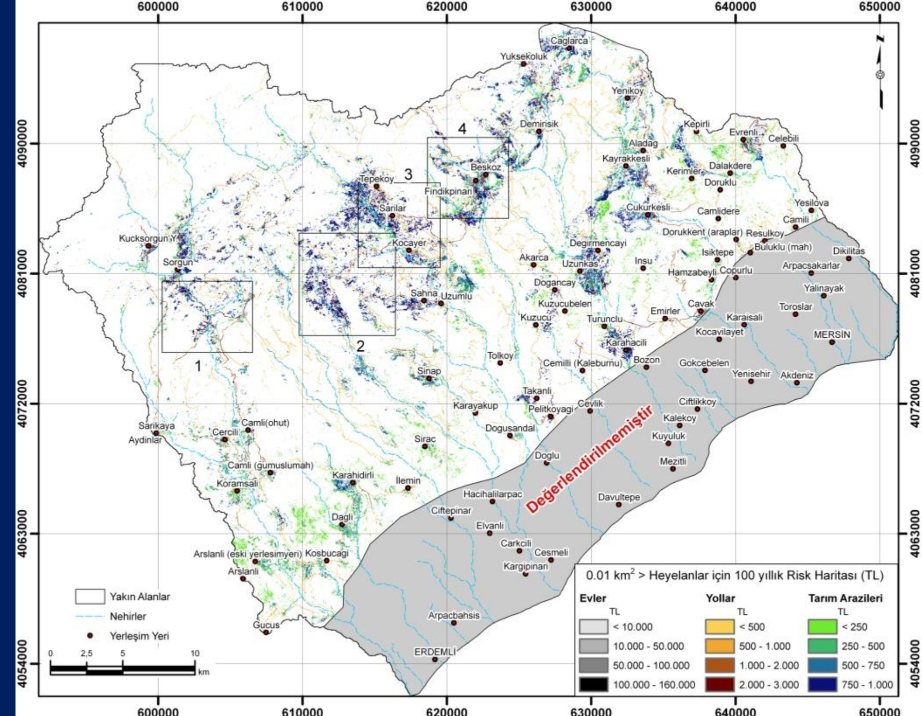
AGRICULTURAL LAND

1 pixel=2000TL

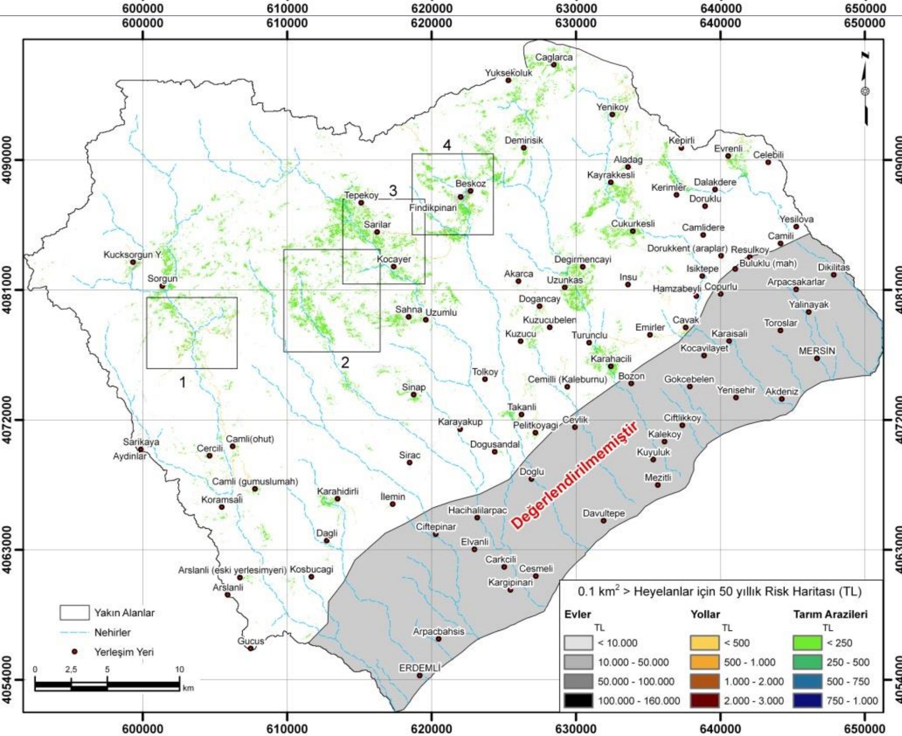
VULNERABILITY 1 0.6



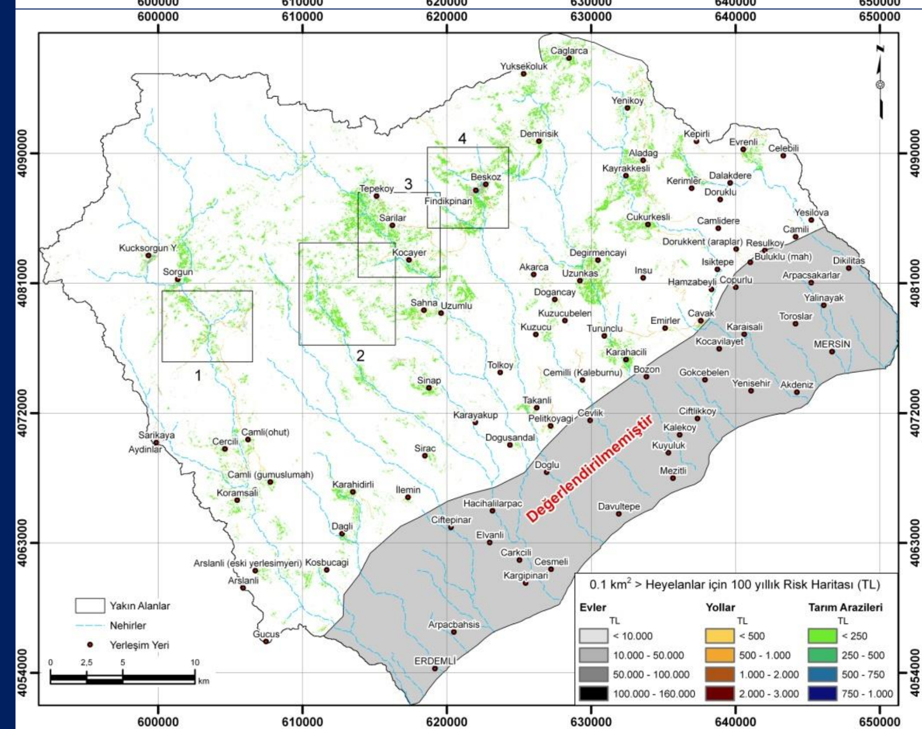
0.01 km² > Heyelanlar için 50 yıllık Risk Haritası (TL)
Yakın Alanlar
Nehirler
Yerleşim Yeri
Evler
TL
< 10.000
10.000 - 50.000
50.000 - 100.000
100.000 - 160.000
Yollar
TL
< 500
500 - 1.000
1.000 - 2.000
2.000 - 3.000
Tarım Arazileri
TL
< 250
250 - 500
500 - 750
750 - 1.000
Değerlendirilmemiştir



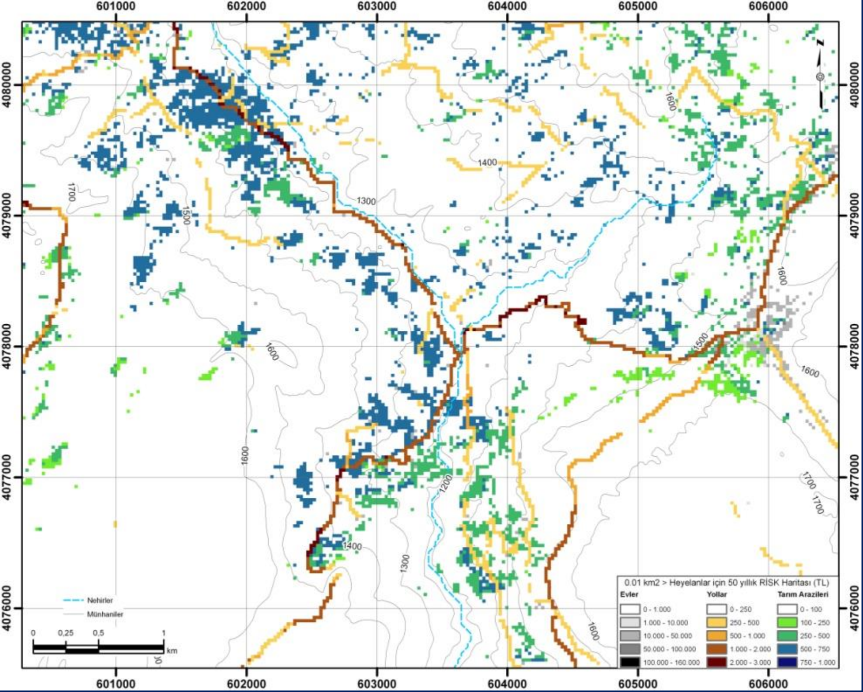
0.01 km² > Heyelanlar için 100 yıllık Risk Haritası (TL)
Yakın Alanlar
Nehirler
Yerleşim Yeri
Evler
TL
< 10.000
10.000 - 50.000
50.000 - 100.000
100.000 - 160.000
Yollar
TL
< 500
500 - 1.000
1.000 - 2.000
2.000 - 3.000
Tarım Arazileri
TL
< 250
250 - 500
500 - 750
750 - 1.000
Değerlendirilmemiştir



0.1 km² > Heyelanlar için 50 yıllık Risk Haritası (TL)
Yakın Alanlar
Nehirler
Yerleşim Yeri
Evler
TL
< 10.000
10.000 - 50.000
50.000 - 100.000
100.000 - 160.000
Yollar
TL
< 500
500 - 1.000
1.000 - 2.000
2.000 - 3.000
Tarım Arazileri
TL
< 250
250 - 500
500 - 750
750 - 1.000
Değerlendirilmemiştir

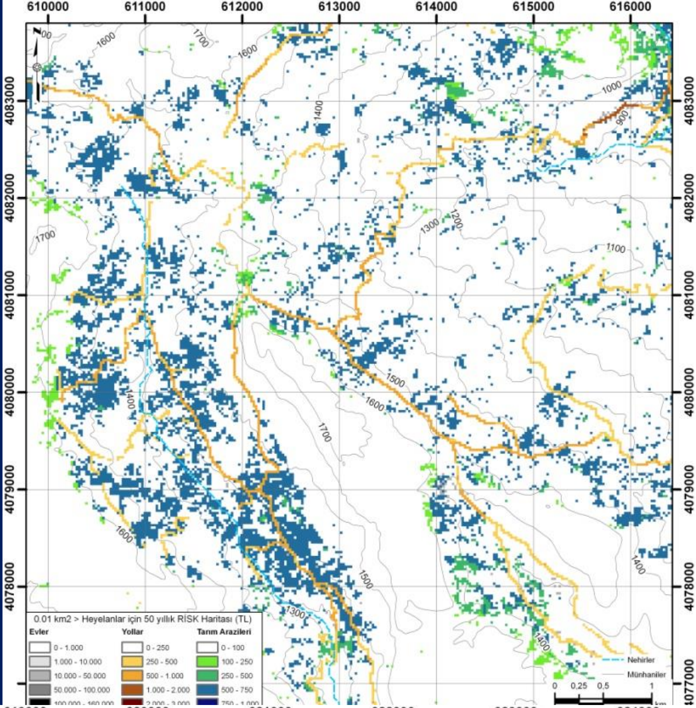


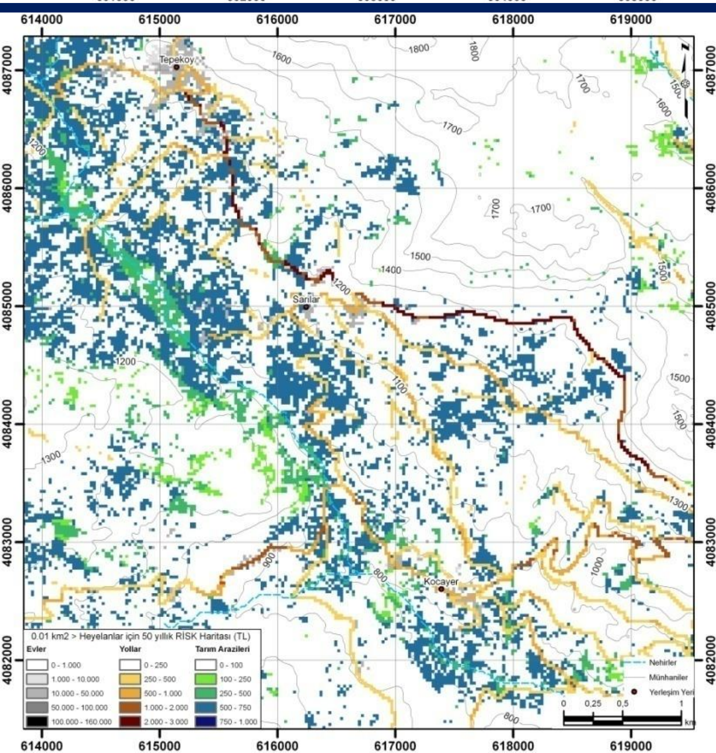
0.1 km² > Heyelanlar için 100 yıllık Risk Haritası (TL)
Yakın Alanlar
Nehirler
Yerleşim Yeri
Evler
TL
< 10.000
10.000 - 50.000
50.000 - 100.000
100.000 - 160.000
Yollar
TL
< 500
500 - 1.000
1.000 - 2.000
2.000 - 3.000
Tarım Arazileri
TL
< 250
250 - 500
500 - 750
750 - 1.000
Değerlendirilmemiştir


0.01 km2 > Heyelanlar için 50 yıllık RİSK Haritası (TL)
Evler
0 - 1.000
1.000 - 10.000
10.000 - 50.000
50.000 - 100.000
100.000 - 160.000
Yollar
0 - 250
250 - 500
500 - 1.000
1.000 - 2.000
2.000 - 3.000
Tarım Arazileri
0 - 100
100 - 250
250 - 500
500 - 750
750 - 1.000
Nehirler
Münhaniler
km

1

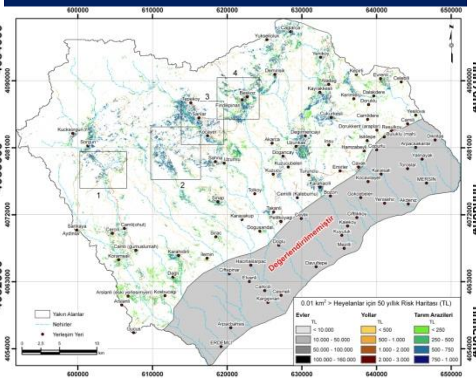
2

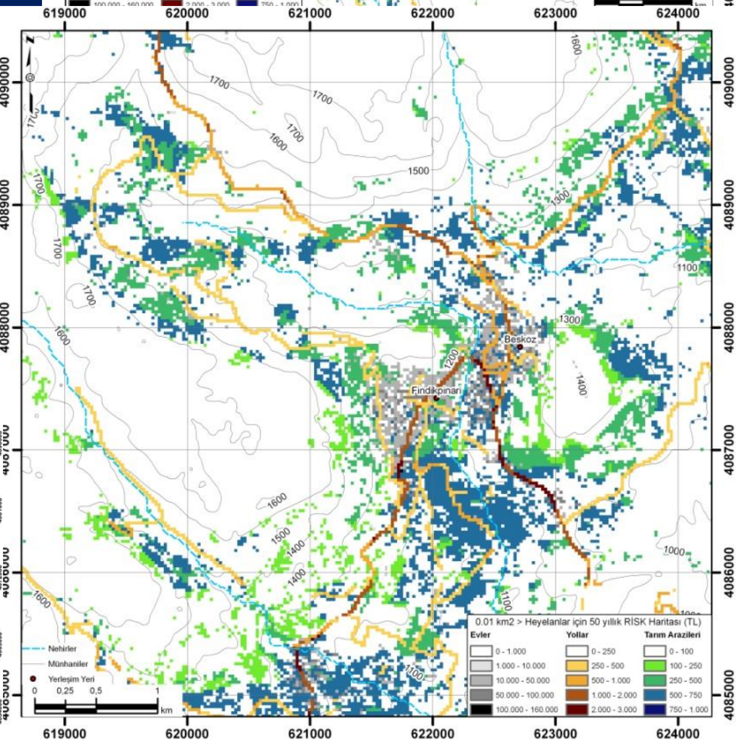

0.01 km2 > Heyelanlar için 50 yıllık RİSK Haritası (TL)
Evler
0 - 1.000
1.000 - 10.000
10.000 - 50.000
50.000 - 100.000
Yollar
0 - 250
250 - 500
500 - 1.000
1.000 - 2.000
Tarım Arazileri
0 - 100
100 - 250
250 - 500
500 - 750
Nehirler
Münhaniler

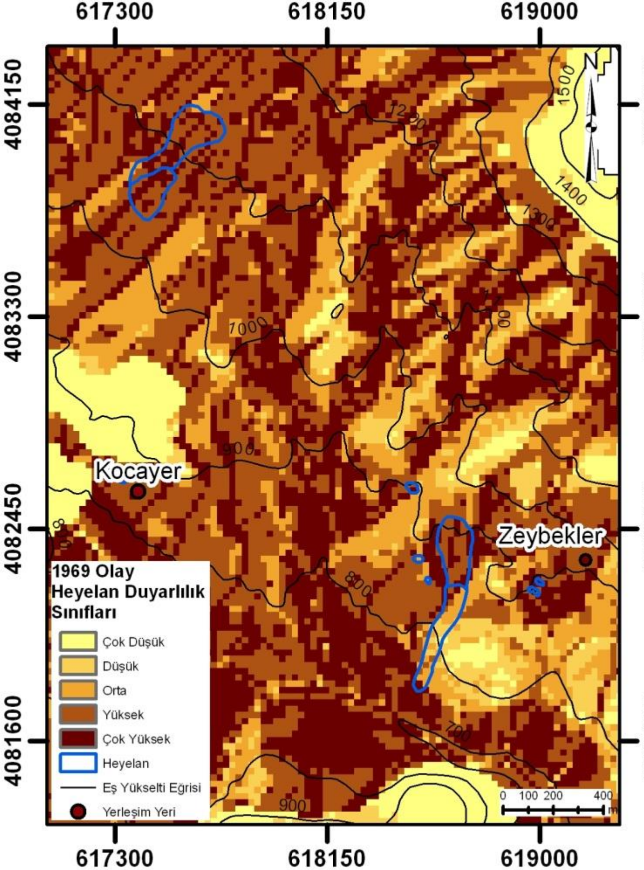

Tepeköy
Sarılar
Kocayer
0.01 km2 > Heyelanlar için 50 yıllık RİSK Haritası (TL)
Evler
0 - 1.000
1.000 - 10.000
10.000 - 50.000
50.000 - 100.000
100.000 - 160.000
Yollar
0 - 250
250 - 500
500 - 1.000
1.000 - 2.000
2.000 - 3.000
Tarım Arazileri
0 - 100
100 - 250
250 - 500
500 - 750
750 - 1.000
Nehirler
Münhaniler
Yerleşim Yeri
km

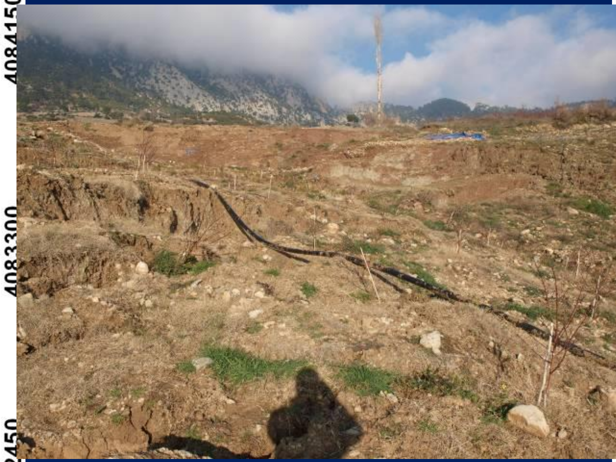
3

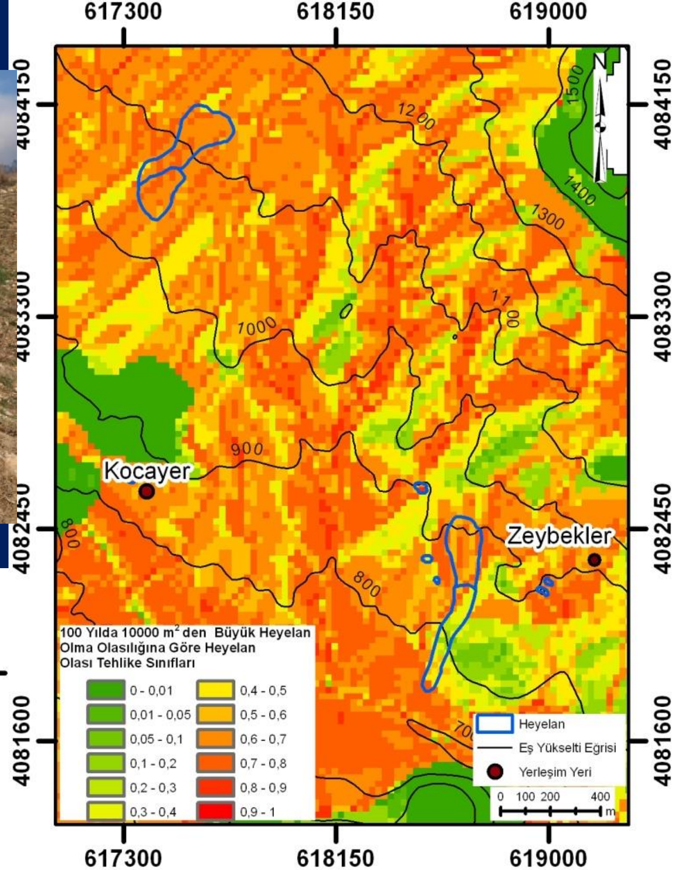
4

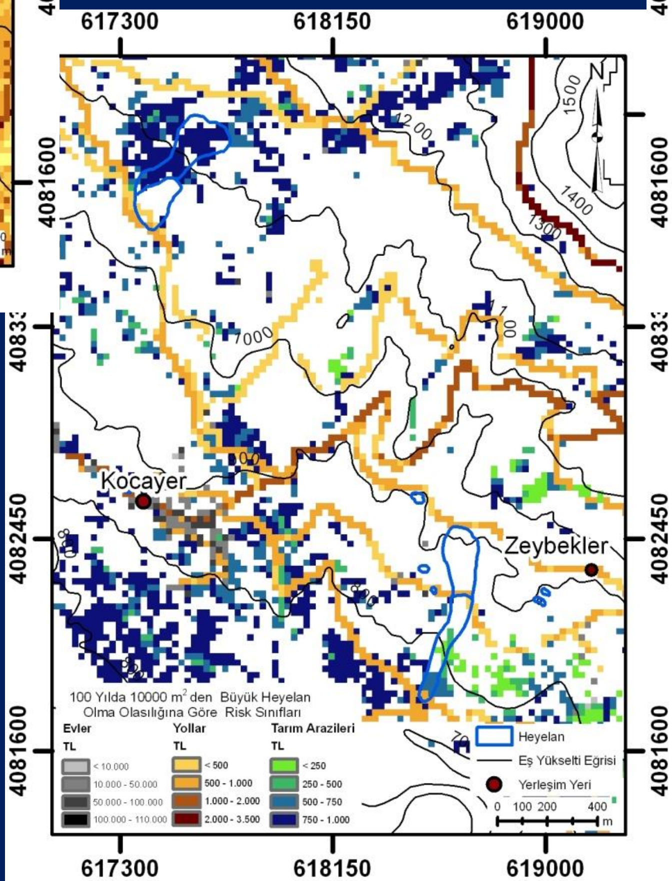

Değerlendirilmemiştir
Yakın Alanlar
Nehirler
Yerleşim Yeri
0.01 km² > Heyelanlar için 50 yıllık Risk Haritası (TL)


Beşkoz
Fındıkpınarı
Nehirler
Münhaniler
Yerleşim Yeri
0.01 km2 > Heyelanlar için 50 yıllık RİSK Haritası (TL)
Evler
0 - 1.000
1.000 - 10.000
10.000 - 50.000
50.000 - 100.000
100.000 - 160.000
Yollar
0 - 250
250 - 500
500 - 1.000
1.000 - 2.000
2.000 - 3.000
Tarım Arazileri
0 - 100
100 - 250
250 - 500
500 - 750
750 - 1.000
km


617300
618150
619000
4084150
4083300
4082450
4081600
Kocayer
Zeybekler
1969 Olay
Heyelan Duyarlılık
Sınıfları
Çok Düşük
Düşük
Orta
Yüksek
Çok Yüksek
Heyelan
Eş Yükselti Eğrisi
Yerleşim Yeri
0 100 200 400
m
1500
1400
1300
1200
1000
900
800
700




617300
618150
619000
4084150
4083300
4082450
4081600
Kocayer
Zeybekler
100 Yılda 10000 m² den Büyük Heyelan
Olma Olasılığına Göre Heyelan
Olası Tehlike Sınıfları
0 - 0,01
0,01 - 0,05
0,05 - 0,1
0,1 - 0,2
0,2 - 0,3
0,3 - 0,4
0,4 - 0,5
0,5 - 0,6
0,6 - 0,7
0,7 - 0,8
0,8 - 0,9
0,9 - 1
Heyelan
Eş Yükselti Eğrisi
Yerleşim Yeri
0 100 200 400
m
1500
1400
1300
1200
1000
900
800


617300
618150
619000
4082450
4081600
Kocayer
Zeybekler
100 Yılda 10000 m² den Büyük Heyelan
Olma Olasılığına Göre Risk Sınıfları
Evler
TL
< 10.000
10.000 - 50.000
50.000 - 100.000
100.000 - 110.000
Yollar
TL
< 500
500 - 1.000
1.000 - 2.000
2.000 - 3.500
Tarım Arazileri
TL
< 250
250 - 500
500 - 750
750 - 1.000
Heyelan
Eş Yükselti Eğrisi
Yerleşim Yeri
0 100 200 400
m
1500
1400
1300
1200
7000

CONCLUSION

Effective landslide hazard mitigation perspective requires understanding the complex nature of the mass movements and their main conditioning and triggering factors, in detail.

THANK YOU