Natural Hazards and Earth System Sciences Discussions



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2	Geophysical and Geodetical Investigation of A Landslide Area (Koyulhisar-Sivas,								
3	Turkey)								
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7	Abstract								
8	This study includes geophysical studies carried out in the last section in the close south of Koyulhisar								
9	(Sivas) landslide site. Additionally, the study area is in the most active location where landslide's displacement								
10	amount is the highest. The landslide site basically has been examined geophysics (SRT, GPR) and geodesic								
11	(GNSS) methods. According to the geophysical results, within ~20 m of investigation depth (a) rs with the								
12	average seismic P-wave velocities (V _P) of 0.30, 1.00 and 2.00 km/s have been identified. It has been understood								
13	that the thickness of the first two layers of these layers from top to the bottom is approximately 3 and 6.5 m, and								
14	the last layer with Vp>2.0 km/s is the bedrock. Furthermore, it has been understood that the depth of the sliding								
\bigcirc	surface which is the upper limit of the bedrock varies between \sim 7-10 m, there are loose units on the sliding								
	surface, the type of sliding is planar sliding, and the direction of sliding is S-SE, the tilt of the layer has the same								
17	direction with topography, is SE-oriented and mostly bigger than 5^0 . It was understood that the deformations in								
18	the landslide mass were occured from the geological unit, the layer or topography slope and precipitation and the								
19	landslide activity can continue in the study area. Thus, it has proven that precipitation and deformations within								
20	the layer are effective in triggering the landslide by the geodetic (IDH) observations, and it is understood that								
21	they were compatible with the geophysical results. Therefore, the study area contains the risk and the natural								
22	hazards, and these threatens the settlement area and the buldings and other constructions there.								
23	1 Introduction								
24	(Today, large landslides occurring in Turkey have reached a considerable amount. It is known that a large								
25	landslide occurs in about every 5-10 years in Turkey (Over, 2015). These landslides usually occur in the forms								
26	of mud flow or mass movement. Three of the most effective of these landslides occurred in Koyulhisar (Sivas) in								
2/	19 August 1998, 20 July 2000 and 17 March 2005. Koyulhisar landslide area is one of the important large								
28	landslide areas in the country and occurs in the form of debris or mud flow (Fig. 1 and 8). In addition,								
29	Koyulhisar is an active landslide area, the activity of which has increased for the past 17 years Koyulhisar								
21	landslide area, the subject of this article, is one of the largest landslide areas that significantly lead to serious loss								
20	of lives and property as in throughout Turkey. The large and small landslides in Koyulnisar landslide area have								
3Z 22	mostly occurred due to natural causes until today. Artificial causes mainly constitute the landslides caused by								
33 24	numan interventions (blasting, drilling, improper planting, loading, loss of vegetation cover, etc.). The last large								
34 25	and side occurred with the flow of mud in the north of Koyulnisar landside area in March 2005. Duman et al. (2005) $1 < c$ is $1 < 1 < c$ is $1 < c$ is								
35	(2005) determined that this landslide was in the excessively fast (6 m/sec) class. Demirel vd. (2016), for the								
27	landslide in 2000 year revealed an average of 2.5-7.4 mm/year slip rate. Researchers have stated that these								
ىرى 20	landslides usually have a mechanism involving a circular rotation, this old landslide mass maintains its activity								
30 20	and partial landslides occur on the groundmass (Sendir and Yilmaz, 2001; Duman et al., 2005). Therefore,								
37	Koyunnsar district center is on an old landslide that occurred in the form of circular rotation. The front of this								
4U	iandslide mass is open, it is always active, activity is not massive and usually in the form of local landslides								
41	occurring on the groundmass (Sendir and Yilmaz, 2001).								





<mark>42</mark>	As it is known, landslides, as well as natural processes, may also occur with human-induced interventions
<mark>43</mark>	(during blasting and excavation operations in many studies for roads, tunnels, and mines) performed on or near
<mark>44</mark>	the landslide area (Lazzari, 2006). Therefore, it is important to investigate the reasons that affect the formation
<mark>45</mark>	mechanisms and the formation of landslides Different engineering (geology, geophysics, geodesic, etc.)
46	disciplines have great role and importance especially in decreasing the negative effects. In this context,
47	Koyulhisar landslide area was examined in a wide area with detailed GNSS (Global Navigation Satellite System)
48	methods and the studies of other disciplines (Sendir and Yılmaz, 2002; Tatar et al., 2007; Hatiboğlu, 2009;
49	Hastaoğlu and Şanlı, 2011; Yılmaz, 2009; Hastaoğlu, 2013; Türk, 2013; Topal and Hatiboğlu, 2015; Hastaoğlu,
<mark>50</mark>	2015; Hastaoğlu, 2016). The annual sliding velocity, sliding direction, displacement amounts and natural disaster
51	risk of the landslide have been identified by these studies. In these studies, it has been determined that the
52	displacement amounts of the landslide velocity vary between 1-8.6 cm/year by topography and geological
53	bedding and that the landslide direction is usually S-SE oriented. In terms of geology, some researchers have
54	carried out geological studies on many issues such as geological, tectonic, geotechnical, geochemical and
55	geomorphological studies at the local and regional scale in which the features of the faults, water, hot water, soil
56	and rock on the NAFZ (North Anatolian Fault Zone) and in the region were investigated (Toprak, 1989; Uysal,
<mark>57</mark>	(1995; Sendir and Yılmaz, 2001; Sendir and Yılmaz, 2002; Yılmaz et al., 2005; Gökçeoğlu et al., 2005b; Duman
<mark>58</mark>	et al., 2005; Ulusay et al., 2007; Hatiboğlu, 2009; Yılmaz, 2009; Demirel et al., 2016; Demir, 2018). The results
59	of all these studies have been associated with geophysical results at the interpretation stage in this article.
60	However, the geophysical studies, the subject of this article, were carried out for a limited area and have the
61	distinction of being the first geophysical studies.
62	In the geophysical study, the hazards that would be caused by the landslide geometry of the last section in
<mark>63</mark>	the close south of Koyulhisar landslide area and would affect the settlement area were investigated (Fig. 2 and
<mark>64</mark>	8). The geophysical study was also carried out in this area which is the most active area of the landslide site
<mark>65</mark>	because Hatipoğlu (2009) identified a movement of about 8.6 cm/year in this area. The SRT (Seismic Refraction
66	Tomography) method determining the seismic P-wave velocities $\left(V_{P}\right)$ for seismic applications and the GPR
67	(Ground Penetrating Radar) method for electromagnetic (EM) applications were used in the geophysical data
68	collection in the area. In particular, seismic tomography (SRT, MASW) and ground penetrating radar (GPR)
69	applications are the most commonly preferred methods in landslide studies. The structural geometry of the
70	landslide area was determined by different parameters by assessing the collected geophysical data with
71	appropriate software. These are the seismic V _P velocities, thickness, tilt and tilt direction of the layers. Thus,
72	other features such as the sliding surface depth of the landslide, landslide type, advancement direction and the
73	risk situation were also revealed, and geophysical and other study results were shown to be compatible with each
74	other. The studies carried out by McCann and Forster (1990), Demirağ (1991), Hack (2000), Perrone et al.
75	(2004), Göktürkler et al. (2008) are important in this regard. In addition, Bichler et al. (2004) carried out multi-
76	methodical geophysical studies containing electrical resistivity, GPR and seismic methods in the landslide
77	studies. Otto and Sass (2006) and Ristic et al. (2012) also carried out similar studies on landslide investigation.
78	In these studies, the sliding surface of the landslides and the flow direction properties of the landslide material
79	were generally determined by 2D (two-dimension) and 3D (three-dimension) geophysical sections.
80	It has been observed that the use of the SPT and CDP methods in landelide studies has increased

80 It has been observed that the use of the SRT and GPR methods in landslide studies has increased
81 significantly especially in recent years (Ristić et al., 2012; Timothy et al., 2013; Lissak et al., 2015; Hu and





82	Shan, 2016; Popescu et al., 2016; Su et al., 2016). The parameters which define the landslide such as landslide
83	geometries and bedrock depth (sliding surface depth) have been determined in these studies. Regarding the GPR
84	method, significant studies have been carried out by Davis and Annan (1989) on revealing the soil stratigraphy,
85	by Aldaş et al. (2003), Slater and Niemi (2003) and Green et al. (2003) on the mapping of faults, fractures and
86	cracks and by Benson (1995), Harari (1996), Bano et al. (2000) and Bubeck et al. (2015) on the determination of
87	groundwater levels. However, the accurate determination of the landslide type is also very important as well as
88	landslide elements. Joint studies with geophysics and other disciplines are commonly carried out in determining
89	the landslide type and for different contributions. In addition to these, the seismological history, morphological
90	and topographical features and meteorological data of the study area are always taken into account in the
<mark>91</mark>	landslide analysis. They are largely used in such studies especially for their contribution to interpretation. In this
<mark>92</mark>	article, the information obtained from all these data was used in order to make contributions to the geophysical
<mark>93</mark>	results. For, landslides may develop under various geological, morphological, topographical and physical
<mark>94</mark>	reasons. Thus, through multi-discipline studies, the landslide type can be determined most accurately by
<mark>95</mark>	determining different sliding behaviors (such as the velocity and direction of the landslide, annual amount of
<mark>96</mark>	displacement) varying from region to region. The landslides, which generally occur in the form of sliding, may
<mark>97</mark>	occur with the movements of falling, sliding and flowing or with the combination of a few of these. Therefore,
<mark>98</mark>	accurate determination of the landslide type/kind and the selection of the methods used in the study is very
<mark>99</mark>	important. It may be possible to perform an accurate landslide analysis only if these requirements are met.

100 2 Geology

101 The study area is about 180 km away from Sivas city center and is in the west of Koyulhisar district center which 102 is located in the north of the NAFZ (Fig. 1 and 8). The rocks in the region usually have fractures and 103 discontinuities and are crushed because of the NAFZ which is tectonically active in south of the study area 104 (Tatar et al., 2005). There are also many old and new landslides in the study area depending on the high tilted 105 topography. For these reasons, the directions of movement of the landslides generally threaten the settlement 106 areas (Sendir and Yılmaz, 2001). The geological investigation of Koyulhisar has been carried out regionally or 107 locally by various researchers (Terlemez and Yılmaz, 1980; Toprak, 1989; Uysal, 1995; Sendir and Yılmaz, 108 2002; Duman et al., 2005; Hatiboğlu, 2009). According to these studies, the Plio-Quaternary aged Koyulhisar 109 Formation is the youngest unit in the region. It was stated that the youngest unit consisted of the talus (slope or 110 deposit) and fluvial conglomerates and was seen along the strike-slip faults (Toprak, 1989).

111 Toprak (1989) divided the NAFZ which is represented by a right lateral strike-slip fault zone into five 112 fault sets including the North Anatolian Main Fault, Koyulhisar fault sets, Kelkit fault set, Şıhlar fault set and 113 Kuruçay fault set. But, the Şihlar fault sets affect Koyulhisar district center at the nearest (Fig. 1). Toprak (1989) 114 stated that Koyulhisar section of the NAFZ is still active and a right lateral strike-slip fault zone due to the 115 morphotectonic structures and seismic activities in the region (Fig. 1). As it is seen in Fig. 1, the faults closely 116 concerning Koyulhisar are the NAFZ, which is the main fault extending in the northwest-southeast direction and 117 approximately 2-2.5 km away, in the south, and the Çamlıyaka Fault, which is approximately north-south-118 oriented, in the west. This fault which is the closest one to the study area extends perpendicular to the NAFZ in 119 the south. It was also reported by Tatar et al. (2007) that large and old landslide masses in Koyulhisar landslide 120 area have lower Miocene-aged clay and gypsum levels, Eocene-aged clayey levels and Plio-Quaternary aged 121 sediments.





122	The large and small landslides in Koyulhisar landslide area have mostly occurred due to natural causes
123	until today. The landslides in and near the study area were triggered by old cracks, displacements, and
124	seismotectonic effects over time because they are on the NAFZ (North Anatolian Fault Zone) which is the
125	largest and most active fault zone in Turkey. The geology, morphology and flora features of the study area and
126	its surrounding have also been the other factors that triggered the landslide. Therefore, the studies carried out in
127	the region have shown that active faults triggered the landslides due to the geological and lithologic features of
128	the region.
129	3 Methods
130	3.1 Geophysical surveys
131	The SRT Conduct Refraction Tomography) and GPR (Ground Penetrating Radar) methods which are applied in
132	tomography tormat were used in the geophysical study. Before applying the SRT and GPR methods in the field,
133	the study area was named as A-C and the geophysical measurements were collected separately in these areas
134	(Fig. 2). Then, the geophysical profiles were processed to the satellite map according to the coordinates along
135	with the topographical elevation curves and GNSS measurement locations for the ease of interpretation (Fig. 2a).
136	Geophysical measurements were taken as both NE-SW and NW-SE oriented due to the geologic bedding and
137	topographic features (Fig. 2b-c). However, SRT12-GPR12 profiles were selected as about E-W oriented due to
138	rugged topography in area C. The profile lengths usually range from 40 to 60 m according to the method applied.
139	10 SRT measurements were taken in all areas in the seismic study for geophysical measurements. 10 profile
140	GPR measurements were taken in areas A and C in the electromagnetic study. Drofile shooting technique in
141	the field, hammer and iron plate of 8 kg weight as the source and 12 P geophones of 14 Hz and Geometrics
142	branded seismic device as the receiver were used while collecting the SRT data. In all profiles, the geophone
143	interval was 5 m, offset distance was 2.5 m, sampling interval was 256 ms and the record length was 512 ms.
144	The geophones were respectively fixed on the ground within the selected geophone range and their connections
145	with the seismic device were made. Then, seismic measurements were recorded by starting from the offset
146	distance of 2.5 m, reducing to sledgehammer plate and making at least 5 shots between each geophone,
147	respectively.
148	There are 2 close NE-SW (SRT2, SRT4) oriented seismic SRT profiles and 2 NW-SE oriented seismic
149	SRT profiles in the area defined by A in Fig. 2b. There a total of four GPR profiles on these seismic profiles
150	including NE-SW oriented (GPR2 and GPR4) and NW-SE oriented (GPR3 and GPR5). In area C, there are close
151	E-W oriented SRT10 and SRT11 profiles in the west of the area and GPR10 and GPR11 profiles on these
152	profiles, and SRT9 and SRT14 profiles in the close NE-SW direction in the same area and GPR9 and GPR14
153	profiles located over them (Fig. 2c). There are E-W oriented SRT12 and close NE-SW oriented SRT13 and
154	GPR12 and GPR13 profiles located over them in the east direction of the area.
C	In addition, the landslide cracks on the surface, displacement traces, and structural damages in the study
100	area and its immediate surroundings can be monitored clearly by field observations (Fig. 3). Some landslides in
157	the study area and a portion of the landslide crack traces and the damaging effects of still active or old landslides
158	on buildings can easily be observed in Fig. 3 All damaged structures across the region cannot be used. Therefore,
159	new landslide cracks will emerge over time both on the ground and the existing structures in the region which
160	active in terms of landslide and seismicity, and the formation of new landslides will continue in the area.
1/1	

3.2 Results, analysis and discussion





162	In the evaluation of the SRT data collected in the field, SeisImager program was used for displaying, processing
163	and evaluation of the seismic refraction waves. The marking of the first arrivals of the SRT data was performed
164	using Pickwin, and the evaluation of the first arrival data was performed using Plotrefa module. The GPR data
165	collected on the SRT profiles only in the areas A and C were collected by Ramac2 device using a closed antenna
166	of 250 MHz. The GPR data were processed in Reflexw program. The time-depth sections which were ready for
167	interpretation were obtained by increasing the signal/noise ratios of the signals in the data processing. The
168	geophysical sections were prepared by also making a topographic correction in the inversion operation due to the
169	variability of the topography. Thus, the collected geophysical data were converted into 2D (two-dimension)
170	height-distance and depth-distance sections by being assessed in the appropriate software. Geophysical
171	interpretations were made according to these sections and compared with the results of the other studies.
172	Accordingly, 2D (two-dimension) seismic cross-sections giving seismic V_P -depth information are presented in
173	Fig. 4 and 5. In the seismic data evaluation, the coincidence was provided with RMS (Root Mean Square) errors
174	ranging between 3.4-4.5% in 2D (two-dimension) inversion operation. According to 2D (two-dimension)
175	seismic cross-sections, two or three layers were identified at about 20 m depth. It was understood that the tilts of
176	these layers were southeast oriented, and their tilt was greater than 50 . According to seismic velocities (V_P)
177	calculated, three layers with the layer velocities of 0.30, 1.00 and 2.00 km/s on average were defined from top to
178	bottom. V_{P} values of these layers increase towards the deep. Layer thicknesses range between 3 m and 6.5 m on
179	average from top to bottom due to topographical differences. It was understood that the depth of the sliding
180	surface varied between about 7-10 m, and these depths were the upper bound of the third layer. The units are
181	loose up to this depth according to geological drilling logs (Hatipoğlu, 2009; Hastaoğlu, 2015). This area was
182	considered to have a risk of dislocation due to these loose units, rainfall and tilt conditions. Therefore, the layers
183	with an average of $V_{\rm Pl}{=}0.3$ km/s and $V_{\rm P2}{=}1.00$ km/s over these depths were defined as the layers with the risk of
184	dislocation. The layer with a seismic velocity of greater than $V_{P3}>2.00$ km/s at the lowermost was understood to
185	be the basement layer. On the other hand, the investigation depth was further calculated from the SRT sections
186	compared to the GPR sections due to the differences of geophysical methods in the application. Because GPR
187	sections could be obtained as high resolution for about the first 10 m depth after inversion processing of the GPR
188	data (Fig. 6 and 7). Therefore, it could be said that the GPR and SRT sections are compatible for the first 10 m
189	depth. Besides, the profile lengths of the GPR3 and GPR5 sections in Fig. 7 were evaluated as about 25-35 m.
190	According to the GPR sections in Fig. 6 and 7, there is a layer with a varying thickness of about 3 mm at
191	the uppermost. It is seen that the second layer under this layer proceeds until about 7-10 m depth. These layers
192	are weak, loose and reworked layers with refractions that lost their thickness with low seismic velocity.
193	However, three layers were identified in seismic sections, and their seismic velocity was observed to increase
194	towards the depth (0.30<1.00<2.00< km/s). Accordingly, the fact that the problems seen in the first two layers
<mark>195</mark>	(decreased and ended towards deeper layers (>7-10 m) is understood from the increase in seismic velocities
196	(>2.00 km/s). Therefore, it was understood from the geophysical and geological data obtained for the landslide
197	basement and the layer over it that new landslides may occur over time in the study area due to the tilt and
198	abrasion and transports during precipitation.
199	The electromagnetic wave velocity in the GPR sections is V=0.1 m/ns. This value is generally observed in
200	dry or wet soil, dry or wet clay and sandy environments (Wilchek, 2000; Cardomina, 2002). The high-frequency
201	electromagnetic waves can reach deeper in the environments with low conductivity like sand. However, the







202 conductive units such as clay and shale decrease the penetration depth of the signal transmitted and lead to 203 absorption (Annan et al., 1988; Davis and Annan, 1989). Hatiboğlu (2009) and Hastaoğlu et al. (2015) generally 204 observed two geological units in the wells in the study area. They observed that the upper unit was silty sandy 205 clay and sand interbedded silty clay in some places up to about 10 m, and advanced as sand interbedded silty 206 clay and sand interbedded clay in some places towards deeper than 10 m. Therefore, it was understood that this 207 velocity value was compatible with the units and electromagnetic waves led to rapid absorption due to the layers 208 with clay content. Furthermore, sliding surfaces, landslide furrows, scarps, cracks was observed in the GPR 209 cross-sections, in A and C area (Fig. 6 and 7). In other words, the geological unit, the layer or topography slope 210 and precipitation cause deformations in the loose upper unit. Therefore, these structures may develop or occur in 211 the landslide mass, as shown in Fig. 6 and 7.

212 3.3 Seismological and meteorological data and results

213 The study area is located in an active area in terms of seismicity. The seismological history, the magnitude (M) 214 of which is greater than 2.5, of the examined area and its surrounding between 1900-2015 were investigated for 215 this article (Fig. 8). The map in Fig. 8 was prepared with the seismological data between 1900-2015 (UDIM, 216 2016). Particular attention was paid to the earthquakes before 2005 in the seismological interpretation. This is 217 because the largest and most recent landslide occurred in the area in 2005 and it was aimed to investigate its 218 relationship with displacements and previous landslides. The type of magnitude which is calculated from 219 seismological data is usually the local magnitude. The depths (d) of these earthquakes with higher M>2.5 vary 220 between approximately 5 and 80 km (Fig. 8). According to the seismic data of the years examined, Koyulhisar 221 and its surroundings have always been active seismically. It was observed that this frequency of earthquakes 222 usually occurred on the NAFZ in the south of the study area. Additionally, it has been analyzed the seismic 223 activity of the region at least for the last 112 (1904-2016) years by Demir (2018). In this study, he express that 224 the most notable is probably the relationships between the magnitude of the earthquake to the number of 225 landslides and the area affected by the landslides and between the magnitude and the maximum distance of 226 landslide observations from the epicenter in different geological, topographical, and climatic conditions (Demir, 227 2018).

228 Large earthquakes affecting Koyulhisar district also occurred in the region. These largest earthquakes are 229 in the south of the NAFZ or Suşehri district and a total of three large earthquakes with M≥5.6 occurred there 230 (Över, 2015). Among these, 1992 earthquake is closest to the study area with the least depth but the second 231 largest earthquake (Fig. 8). This earthquake is an earthquake with 6.1 magnitude that occurred 10 km below the 232 ground. The large earthquakes in the south of Suşehri district which is just 13 km away from the study area 233 occurred in 1909 and 1939. 1909 earthquake occurred 60 km below the ground and is the largest and deepest 234 earthquake with a magnitude of 6.3. 1939 earthquake is also deep and the third largest earthquake that occurred 235 50 km below the ground with a magnitude of 5.6 (Över, 2015). In addition, when Fig. 8 is analyzed, it is seen 236 that the magnitudes of the other earthquakes in the north of the NAFZ and the upper elevations of the landslide 237 generally vary between 2.5-4. Similarly, it is seen that the other earthquakes in the south of the landslide area are 238 the earthquakes with a magnitude of greater than 3.6. All these earthquakes may have triggered the landslide 239 mass from time to time in places where sliding surfaces, layers, and topography in the landslide area are more 240 inclined than 5-10 degrees (according to the geophysical cross-sections in this article, when it is considered that





there are loose units and deformations on the sliding surfaces). In particular, they further affected the landslide mass along with the rain and caused large amounts of displacement in the landslide area.

The data regarding the rainfalls with the effects of triggering the landslides are presented in Table 1 and Fig. 9 (MGM, 2016). With these data, the rainfall status of the study area and its surrounding was examined by months as average annual rainfalls and the annual areal amount of rainfall. According to the data obtained between 1950-2015 in Table 1, the rainy periods are generally between October-November-December and January-February-March-April. The highest total daily amount of rainfall in the rainiest years was observed as snowfall in 1950 (110 cm) and as rain in 1991 (55 kg/m²).

249 According to Fig. 9, the annual normal average rainfall value calculated for the years between 1981-2010 250 was calculated as over 483.4 mm. However, 1987-1988 and 1997-1998 were the rainiest years. It is seen that the 251 annual areal amount of rainfall exceeded the normal values and was higher than 550 mm in these rainy years that 252 took place in every 10 years. Similarly, it is also seen that there were high rainfalls for 3-4 years after the years 253 of 1985-1995-2005 with an interval of 10 years. Therefore, annual areal rainfalls were observed to be more 254 before some large landslides like the landslide in 1998. When geological features of the region are taken into 255 account, it is remarkable that the landslide in 1998 and 2000 occurred in the summer months after the winter 256 with a heavy fall of snow. However, the landslide in 2005 occurred during the rainy season. Therefore, rainfalls 257 have always been considered as a factor triggering these landslides in many studies and articles (Tatar et al., 258 2007; Hastaoğlu et al., 2015). Similarly, the authors of this article have always considered rainfalls as a 259 triggering factor in the formation of Koyulhisar landslides. As it is seen, the various studies and the results of 260 this article have proved that Koyulhisar landslides are generally caused by the known reasons that trigger the 261 landslide. Because the seismic activity, the meteorological data and the other conditions mentioned in the 262 landslide area have shown that the landslides could be triggered there.

263 **3.4 Geodetic surveys and results**

264 📶 aoğlu et al. (2015) have carried out multi-disciplinary studies and GNSS studies for many years (about 6 265 years) to determine the deformation and annual sliding amounts especially after the landslides in 1998-2000-266 2005. It was determined that the tension cracks that occurred in the landslides in 1998 and 2000 in the region 267 were filled with the waters consisting of melting snow and rain waters which are the most important component 268 of the hydrological cycle, lakes were formed in the buttress of each sliding mass, and the changes in the 269 groundwater level were the main causes of deformation (Sendir and Yılmaz, 2001; Topal and Hatiboğlu, 2015; 270 Hastaoğlu et al., 2015). The seismological and meteorological data, which were updated by the geodetic (GNSS 271 (DH), geological (IDH (Inclinometer Drilling Holes)) and meteorological data collected in the local study of 272 Hastaoğlu et al. (2015), were reorganized and evaluated. Fig. 2, 9, 10 and Table 1 which were reprepared for the 273 study which is the subject of this article were associated with the results of GNSS studies (Fig. 10). Then, they 274 were compared with geophysical results in interpretation.

The monthly and annual meteorological data should certainly be evaluated particularly within the scope of monitoring activities because the area which is the subject of the study is a landslide area. Hastaoğlu et al. (2015) performed monitoring in IDH wells in the area in 2013-2014 (Fig. 10). If Fig. 2 is examined, there are seven IDH point in the nearest of the geophysical profiles. The graphics in Fig. 10 were prepared from the combined data (unpublished data in the project) and the temperature (⁰C), precipitation (m³) and soil moisture content (cm) were compared in these graphics. Accordingly, the temperature and precipitation were observed to be inversely





proportional during the summer months called as a dry period. It is seen that the soil moisture is changeable apart from the rainy period and has very high water content during the rainy periods. On the other hand, it was understood that the precipitation increased by the decrease in temperatures. It is also seen that the total annual amount of rainfall increased about 2-fold in 2014 compared to 2013 (Fig. 9 and 10). According to all results, rainfalls are considered to be effective in triggering of the landslide because the ground of this landslide area, which is filled with loose units and old cracks, is supersaturated with water due to the rainfalls.

287 Besides, Hastaoğlu et al. (2015) determined that the groundwater level gets close to the surface for 4-6 m 288 on average at the end of the rainy period, to 10 m at the end of the rainy period and decreases up to 25 m in some 289 wells in the area where geophysical study area is also located, and the groundwater flow direction is SW. When 290 this information was associated with topography and in line with the field observations, it was understood that 291 the topography was inclined from the north of the study area towards south, the incline of slope decreased from 292 925 m to 840 m, there was an elevation difference of 85 m, and the amount of slope in the topography increased 293 from south to north $(>5^{0}-10^{0})$ (Fig. 2a). Therefore, it was seen that the geological bedding was compatible with 294 the topographical sloping and the groundwater was compatible with the direction of flow. Hatiboğlu (2009) and 295 Hastaoğlu et al. (2015) observed that the geological units advanced as silty sandy clay from top to bottom and 296 partly sand interbedded silty clay under the topsoil and as sand interbedded silty clay and sand interbedded clay 297 in some places towards deeper than about 10 m in IDH wells in the geophysics study area. Hastaoğlu et al. 298 (2015) estimated with the GPS measurements that the amounts of displacement varied between 1-8.6 cm/year. 299 The geophysical data were collected in the areas where the amount of displacement varied about 8.6 cm/year. 300 The landslide direction was determined to be in the S-SW and SE direction across Koyulhisar (Hastaoğlu et al., 301 2015). It was understood that these directions were compatible with the geophysical sections which were 302 prepared later and that the rainfalls are among the reasons that trigger the landslide.

303 4 Conclusions

304 This study is the first geophysical study carried out in Koyulhisar landslide area. The information provided from 305 many studies (geodetic, geologic, morphologic, seismological, topographic and meteorological) carried out 306 across the region was compared with the geophysical results (SRT and GPR) and found to be compatible. The 307 bedding status of the landslide area, seismic P-wave velocity (V_P) of the layers, the tilt, tilt direction of the 308 layers, depth of the sliding surface and sliding direction and the landslide type could be determined from the 309 geophysical sections. Accordingly, the study area was identified by the layers with the average seismic velocities 310 of $0.30 < 1.00 < 2.00 < \dots$ km/s (or 300, 1000 and 2000 m/sec). The seismic velocity of the landslide basement 311 was found to be higher than 2000 m/sec. According to the geophysical cross-sections, it was understood that the 312 depth of the sliding surface varied between 7-10 m due to the topographical differences. These depths are the depths with low seismic velocities (the average V_P , <0.30 and <1.00 km/s) and defined as loose units which were 313 314 also observed in geological drilling logs. It is understood that sliding surfaces, landslide furrows, collapsed 315 zones, scarps, cracks are observed in the GPR sections. Furthermore, it was understood that the layer tilt was generally more than 5⁰ in all geophysical sections and compatible with the geology and the flow direction of the 316 317 groundwater. It was understood that the landslide type in the area was planar sliding and the direction of sliding 318 was SE.

The geophysical and geodetic study results were found to be compatible because it is known that the landslide direction across Koyulhisar is in S-SW and SE. Consequently, the fact that the depth of the sliding





321	surface over the units is loose, low seismic velocities of the upper layers and the excessive tilt that there is
322	a new risk of landslide in the area. The other factors that trigger the landslide were found to be associated
323	especially with the fact that the area is seismically active, receives heavy rain and has a poor vegetation cover.
324	Furthermore, it was understood that there were deformations in the landslide mass and, observed the sliding
325	surfaces, landslide furrows, collapsed zones, scarps and cracks structures. It was understood that these structures
2	were occured from the geological unit, the layer or topography slope and precipitation. On the other hand, it was
SZT	understood that studies such as blasting and excavation performed by human intervention can trigger the
<mark>328</mark>	landslides and hence the landslide area is a potential area which is open to natural/artificial hazards. As a result,
329	according to all the results, there is still a high landslide hazard in the study area and its surrounding, and this
330	hazard will be also in the future. As a result, the identified risks and natural hazards are also threatened the
331	settlement area and the buildings and other constructions (e.g. roads, walls, parks et al.) there.
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- 446 447

NHESS - Figures



448

449 Figure 1. Geological map of study area arranged from Sendir and Yılmaz (2002) and Hastaoğlu (2016).







450

- 451 Figure 2. (a) Geophysics and geodetic data collection locations in the study area. (b), (c) and (d) geophysics
- 452 profile details.
- 453



Figure 3. Landslide scene photos (landslide, lanslide cracks and constructional damages).

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493 layers).







496 Figure 7. (...contiune) GPR profiles in the C-east area and the deformations in the loose layers (the seismic V_{P1} 497 and V_{P2} layers).



Figure 8. Seismic activity of the study area and its surroundings by the data between 1900-2015 and the 501 landslide areas (UDIM, 2016; MTA, 2018).







Figure 9. Precipitation distribution in between 1981-2015 years of Sivas (MGM, 2016).



Table

Figure 10. Average monthly temperature (T, 0 C), rainfall (m³) and soil moisture content (cm) change graphics of the study area and its surrounding for 2013-2014. It was prepared from the project data (Hastaoğlu et al., 2015).



		-		-			-	-				
SIVAS	January	February	March	April	May	June	July	August	September	October	November	December
The average tempreture (⁰ C)	-3.2	-2.0	2.9	9.1	13.5	17.2	20.2	20.2	16.2	10.8	4.6	-0.6
The average the highest tempreture (⁰ C)	1.0	2.6	8.1	15.3	20.0	24.0	27.9	28.5	24.7	18.4	10.6	3.7
The average the lowest tempreture (⁰ C)	-7.0	-6.2	-1.7	3.4	7.2	9.9	12.0	11.9	8.3	4.4	-0.2	-4.2
The average sunshine duration (hour)	2.3	3.3	4.5	6.2	8.1	10.4	12.1	11.4	9.4	6.3	4.1	2.3
The average number of rainy days	13.0	12.4	13.7	14.0	14.4	8.8	2.5	2.1	4.3	8.0	9.5	12.1
The average monthly total rainfall (kg/m ²)	42.0	40.3	46.0	59.1	60.7	34.8	8.5	5.9	16.9	32.9	41.0	44.2
			The	highest :	and the lo	owest valu	es occurr	ing over ma	ny years (1950	-2015)		
The highest tempreture (⁰ C)	14.6	18.1	25.2	29.0	32.0	35.5	40.0	39.4	35.7	30.5	22.8	19.4
The lowest tempreture (⁰ C)	-34.6	-34.4	-27.6	-10.9	-4.2	-0.3	3.4	3.2	-3.8	-8.1	-24.4	-27.0
Daily total the highest rainfall	2 May 1991	55.0 kg/m ²	Daily the fastest wind		5 Jan. 1996		122.8 km/h	The highest snow		2 Feb. 1950	110.0 cm	