Environmental impacts of a large catastrophic landslide, in Sivas northeast of Turkey

CANDAN GOKCEOGLU[1], TAMER Y. DUMAN[2], HARUN SONMEZ[3] & HAKAN A. NEFESLIOGLU[4] , TOLGA CAN[5]

[1] *Hacettepe University. (e-mail: cgokce@hacettepe.edu.tr)*
[2] *MTA. (e-mail: tduman@mta.gov.tr)*
[3] *Hacettepe University. (e-mail: haruns@hacettepe.edu.tr)*
[4] *MTA. (e-mail: hanefesliglu@mta.gov.tr)*
[5] *Cukurova University. (e-mail: tolgacan@cukurova.edu.tr)*

Abstract: Landslides are common natural hazards in the seismically active North Anatolian Fault Zone. Channel incisions, seismic activity, heavy rainfall and anthropogenic effects are the main triggers of landslides. However, on March 17 2005, a catastrophic large landslide, the Kuzulu landslide, was triggered by snow melting without any precursor in Sivas, the northeast of Turkey. The initial failure of the Kuzulu landslide was rotational. Following the rotational failure, the earth material in the zone of accumulation exhibited an extremely rapid flow caused by steep topography and high water content. The Agnus creek valley, where the Kuzulu village is located, was filled by the flowed earth material and a landslide lake having an area of 6900 m^2 was formed in the upper part of the Agnus creek. The distance from the toe of the rotational failure down to the toe of the earthflow measured more than 1800 m, with about 12.5 million m^3 displaced earth material. The velocity of the Kuzulu landslide was extremely fast, approximately 6 m/sec. The main goal of this study is to describe the factors governing the Kuzulu landslide and to put forward its environmental impacts. The main environmental impacts of landslides are loss of human lives, destroying residential and industrial developments, damaging agricultural and forest lands, negative impacts on the quality of water in rivers and streams. During the Kuzulu landslide, almost all negative impacts of landslides on the environment occurred. 15 people (villagers) were buried under the displaced material, because of the extremely high velocity. This is the most important impact of the Kuzulu landslide. A total of 34 houses and 1 mosque were demolished, completely, and an important farming area was destroyed. The rotational failure is located in a gigantic paleolandslide area and the regolith zone of the volcanic units. Depending on these factors, the main failure surface was about 100 m. For this reason, the forest cover did not have a positive effect on the stability. Due to the landslide, an important forest cover of 47000 m^2 was completely destroyed. The Agnus creek discharges to the Kelkit River, one of the important rivers of Turkey. Over a period of 4 days, approximately 5.3 million m^3 earth material was transported by the Agnus creek and this material reached the Kelkit River. Adding this material to the Kelkit River caused a decrease in water quality and an increase in the sediment load in the river bed. Considering the field observations, retrogressing landslide activity is expected and the other parts of the Kuzulu village are under the threat of the subsequent landslide hazard.

Résumé: Les glissements de terrain sont des aléas naturels fréquents dans la zone de faille nord anatolienne. Les incisions de canaux, l'activité sismique, les fortes précipitations et les effets anthropiques sont les principaux facteurs déclencheurs des glissements de terrain. Or, le 17 mars 2005, un grand glissement de terrain catastrophique, le glissement de terrain de Kuzulu a été déclenché par la fonte des neiges sans aucun signe annonciateur à Sivas, au nord-est de la Turquie. La rupture initiale du glissement de terrain de Kuzulu a été circulaire. Suivant la rupture circulaire, les matériaux de la zone d'accumulation ont présenté un flux extrêmement rapide causé par une topographie abrupte et une forte teneur en eau. La vallée du ruisseau Agnus où se situe le village de Kuzulu a été comblée par les matériaux transportés et un lac de glissement de terrain d'une surface de 6900 m² a été formé dans la partie supérieure du ruisseau Agnus. La distance du talon du glissement circulaire jusqu'au talon du flux de sols a mesuré plus de 1800 m, avec quelques 12,5 millions de m^3 de sols déplacés. Le glissement de terrain de Kuzulu a été extrêmement rapide, approximativement de 6 m/s. Le but principal de cette étude est de décrire les facteurs régissant le glissement de terrain de Kuzulu et de mettre en lumière ses impacts environnementaux. Les principaux impacts environnementaux des glissements de terrain sont les pertes de vies humaines, la destruction de sites résidentiels et industriels, l'endommagement de terrains agricoles et forestiers, les impacts négatifs sur la qualité de l'eau des rivières et ruisseaux. Le glissement de terrain de Kuzulu a eu presque tous les impacts négatifs des glissements de terrain sur l'environnement. 15 personnes (des villageois) ont péri sous les sols déplacés en raison de leur rapidité extrême. C'est l'impact le plus important du glissement de terrain de Kuzulu. Un total de 34 maisons et une mosquée ont été totalement démolis et une importante zone fermière a été détruite. La rupture circulaire est située dans une vaste zone de paléo-glissement de terrain et dans la zone régolithe de l'unité volcanique. En fonction de ces facteurs, la principale surface de rupture a été d'environ 150 m. C'est pour cette raison que la couverture forestière n'a pas eu d'effet positif sur la stabilité. En raison du glissement de terrain, une importante couverture forestière de 47 000 m² a été totalement détruite. Le ruisseau Agnus se jette dans la rivière Kelkit, une des plus importantes rivières de Turquie. Durant 4 jours, quelques 5,3 millions de m^3 de sols ont été transportés par le ruisseau Agnus jusqu'à la rivière Kelkit. Cet apport de sols à la rivière Kelkit a causé une baisse de la qualité de l'eau et une augmentation de la charge de sédiments dans le lit de la rivière. Considérant les observations de terrain, un glissement de terrain rétrograde est attendu et les hautes parties du village de Kuzulu sont sous la menace d'un glissement de terrain subséquent.

Keywords: environmental impact, failures, geological hazards, geomorphology, mass movement, weathering.

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INTRODUCTION

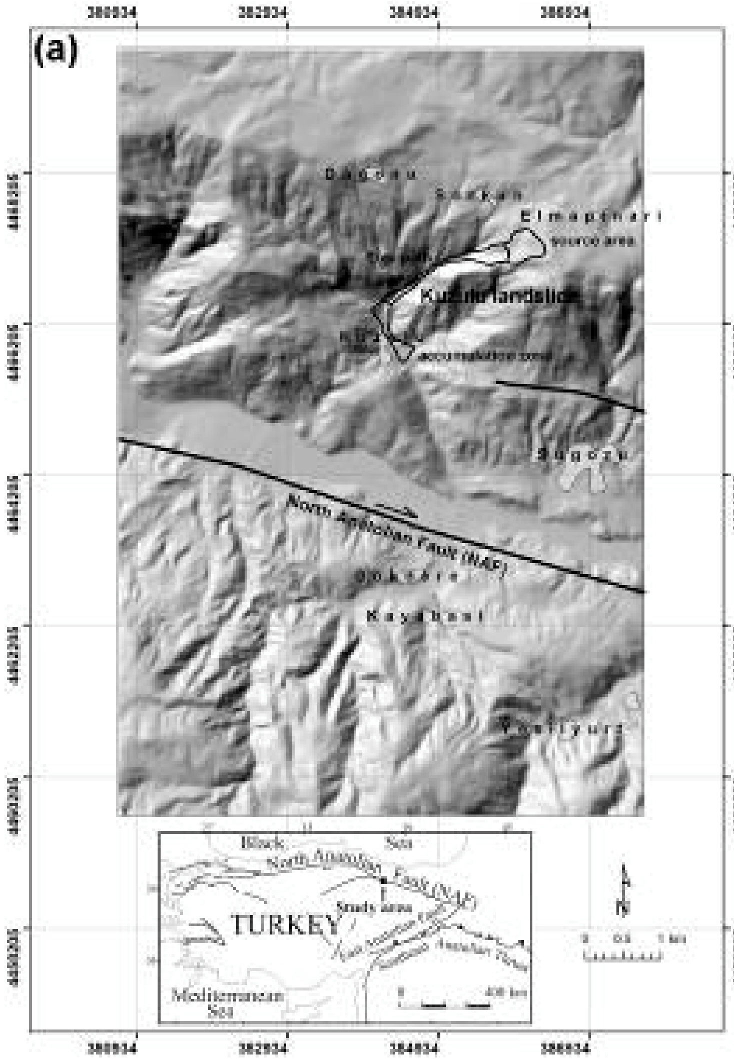
In Turkey, landslides are one of the important natural hazards. In the period of 1959–1994, landslides damaged 76995 buildings throughout Turkey (Ildir, 1995) in addition to death of people, destroyed farming lands and roads etc. Sometimes, landslides can have extremely high velocities with large volume and some catastrophic effects of such landslides on humans and environment occur. Following a period of rapid snowmelt, such a large and catastrophic landslide, the Kuzulu landslide, occurred in the Central Anatolian Region of Turkey, north of Sivas, on March 17, 2005, without any trigger except the melting snow. The main environmental impacts of landslides are loss of human lives, destruction of residential and industrial developments, damage to agricultural and forest lands, and negative impacts of the quality of water in lakes, rivers and streams (Schuster and Fleming, 1986). The detailed papers on the mechanism of the Kuzulu landslide (Gokceoglu et al., 2005a and b) and landslide susceptibility zoning its close vicinity (Gokceoglu et al., 2005a) have already been published. The purpose of this study is only to put forward the environmental impacts of this catastrophic event because, during the Kuzulu landslide, almost all negative impacts of landslides on the environment occurred..

GENERAL CHARACTERISTICS OF THE LANDSLIDE AREA

The Kuzulu landslide is located in the Central Anatolian Region of Turkey, north of Sivas and west of Koyulhisar (Figure 1a) and the distance between the Kuzulu landslide and the North Anatolian Fault Zone is approximately 3 km. For this reason, the landslide area and its close vicinity show typical active fault-zone morphology. In other words, throughout the east-west direction, which is the main direction of the North Anatolian Fault Zone, there is a valley. The topography exhibits steep slopes and high elevations linked to the North Anatolian Fault (Figure 1b). The valley, having an east-west direction and an elevation of about 580 m, forms the bed of the Kelkit River, one of the more important streams of Turkey. The secondary streams at the northern and southern parts of the study area are tributary to the Kelkit River. In the landslide area, sedimentary and volcanic units crop out. The Maestrichtian limestones crop out at the lower elevations of the area and form steep slopes; the earth-flow part of the Kuzulu landslide is located in this unit. The higher elevations of the area are covered by volcanic units such as Pliocene basalts and tuffs (Figure 1b). These units are highly susceptible to weathering. A considerable part of these units show paleolandslide morphology, such as hummocks and old scarps. Parallel drainage is dominant in the landslide area and its close vicinity.

Some thematic DEM derivative maps such as slope, aspect, topographic-wetness index and stream-power index maps have been produced for evaluation of the morphological characteristics of the landslide area. In the area, the surface elevation varies between 580 and 1830 m. Depending on the high variation in the elevations, the slope values are also high (Figure 2a). In the area, the slope ranges from between 0-64 degrees. However, in the zone of paleolandslides where the Kuzulu landslide occurred, the slope are about 20 degrees, while that of the transportation channel is extremely high, over 35 degrees. Depending on the North Anatolian Fault Zone, the main physiographic trend of the area is approximately east-west (Figure 2b). However, the aspect of the slope with the Kuzulu landslide varies from northwest to southwest.

Primary topographical attributes such as slope and aspect are calculated from the directional derivatives of a topographic surface (Wilson and Gallant, 2000). The secondary topographical attributes are computed from two or more primary attributes. According to Wilson and Gallant (2000), the majority of these secondary attributes comes from describing patterns as a function of process. In this study, two well-known secondary topographical attributes are considered. One of them that is topographic-wetness index (TWI) (Moore et al., 1991) has been used extensively to describe the effect of topography on the location and size of saturated source areas of runoff generation. The topographic-wetness index map of the landslide area is produced in Figure 2c. When observing Figure 2c, the topographic-wetness index values are higher around the Kelkit River bed and the paleolandslide area than in other parts of the area. This is based on the fact that the paleolandslide area, located in the northern part of the study area, includes numerous surface depressions, and these depressions prevent surface runoff, allowing infiltration of surface water from various sources, such as rainfall and snowmelt. This finding is supported by field observations. Especially, many springs exist at lower elevations. Infiltration of water to slope-forming material results in increased pore-water pressure in the material and to decrease in its shear strength. The other topographical index parameter, stream power index (SPI) is important because the earth-flow part of the Kuzulu landslide run out more than 1800 m. This long run out distance can be explained two ways: viscosity of the material and steepness of the topography. The stream-power index map of the study area is given in Figure 2d. The stream-power index values for the secondary channels of Agnus Creek are very high, approximately 9. This shows that these channels have a high potential for earth-flows with high velocities.


(a)
380934
382934
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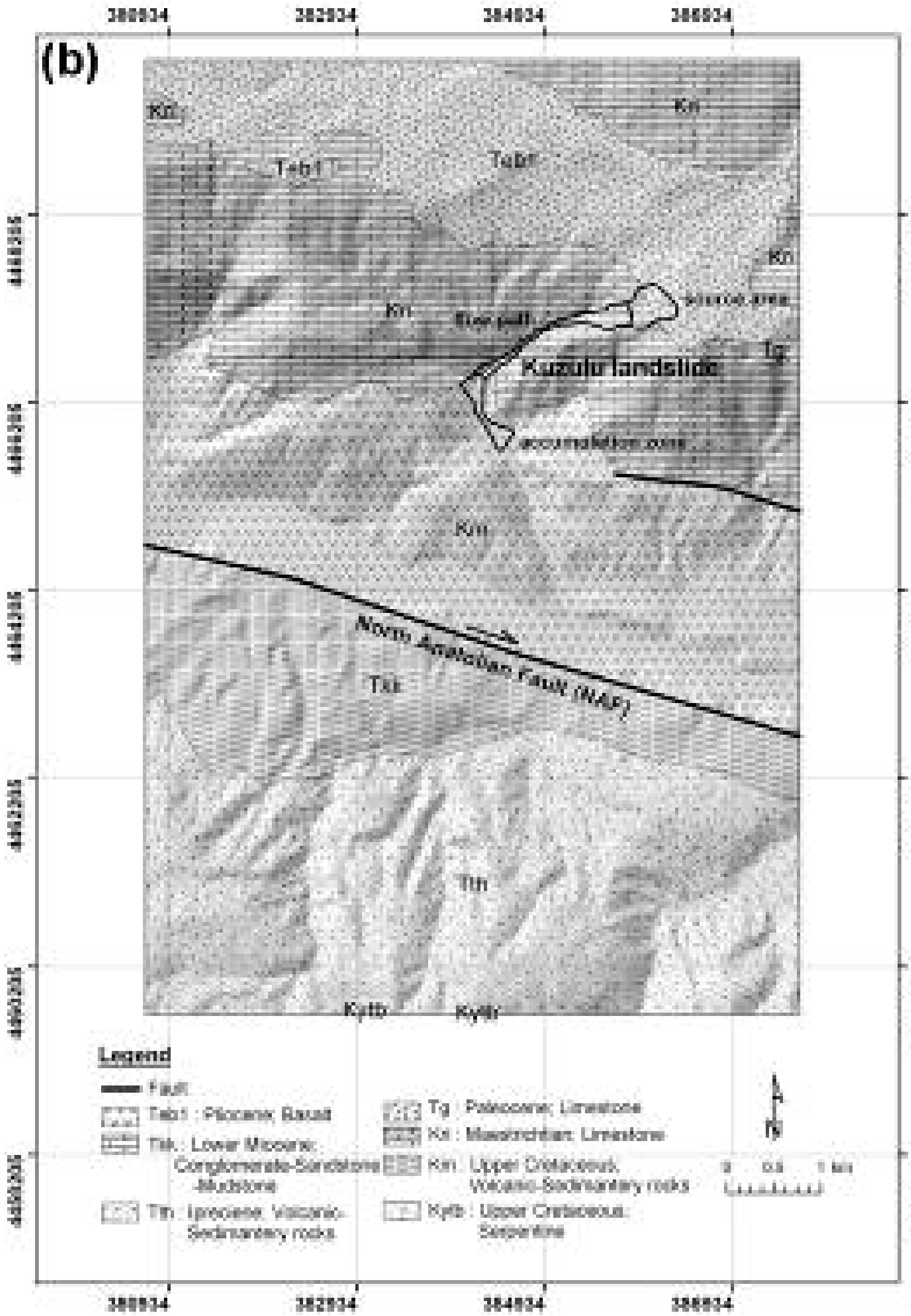

Figure 1. Location map (a) and geological map (b) of the study area.

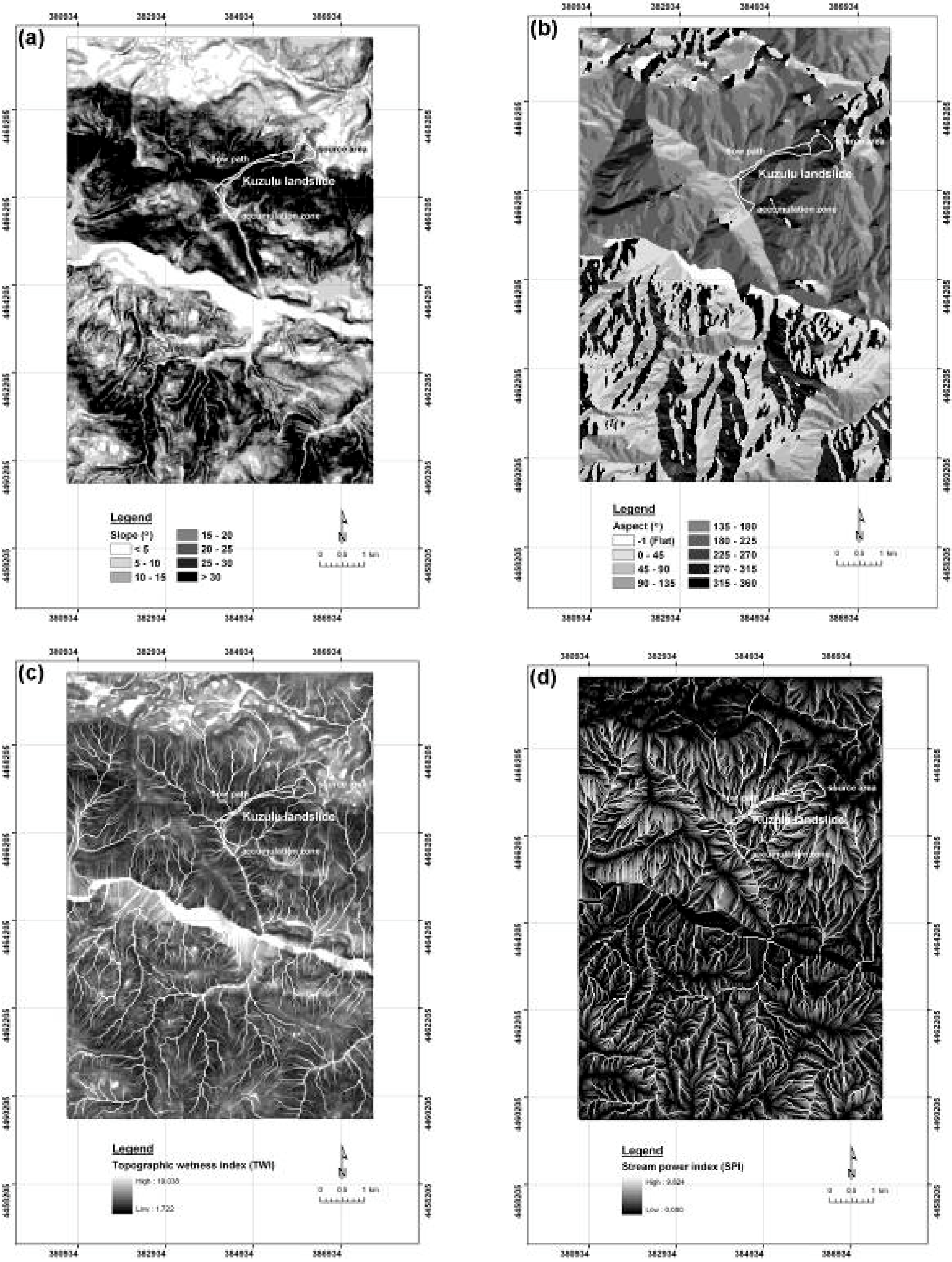

Figure 2. Slope map (a), aspect map (b), topographic wetness index (TWI) map (c), and stream power index (SPI) map (d) of the study area.

MECHANISM AND ENVIRONMENTAL IMPACTS OF THE LANDSLIDE

On March 17, 2005, the Kuzulu landslide, in the thick regolith zone of the volcanic units, was triggered by snowmelt without any precursor. The initial failure of the Kuzulu landslide was rotational. Following the rotational failure, the earth material in the zone of accumulation was transformed into an extremely rapid flow caused by steep topography and high water content. The Agnus Creek valley, where Kuzulu village is located, was filled by the earth-flow and a landslide dam having a surface area of 6900 m^2 and a depth of 30 m was formed on the headwater of Agnus Creek (Figure 3). The distance from the toe of the rotational failure down to the toe of the earth flow was more than 1800 m, with about 12.5 million m^3 of displaced earth material. The velocity of the earth-flow part of the Kuzulu landslide was extremely fast, approximately 6 m/sec. Fifteen villagers were buried under the displaced material, because of its extremely high velocity. This was the most important impact of the Kuzulu landslide. In addition, thirty-four houses (Figure 4) and a mosque were demolished, and an important agricultural area was destroyed. As mentioned above, the main failure was located in a large paleolandslide area and in the regolith zone of the volcanic units. Because of the geology, the depth of maximum failure surface was about 100 m (see Figure 3). For this reason, the forest cover did not have a positive effect on the stability. Due to the landslide, an important forest cover having an area of 4.7 ha was completely destroyed. Agnus Creek discharges into Kelkit River, one of the more important rivers of Turkey. During a 4 day period, approximately 5 million m^3 of earth material was transported to the Kelkit River by Agnus Creeek. This material caused a decrease in water quality of the Kelkit River and an increase in its sediment load. Considering the field observations, retrogressive landslide activity is expected; thus, other parts of Kuzulu village are under threat of future landslide activity. Although the distance between the main failure and Kuzulu village was approximately 2 km, the earth-flow reached the village. In fact, prediction of runout distances of earth-flows is very difficult, although many hypotheses have been presented to predict runout. Some detailed empirical calculation on runout distance of the Kuzulu landslide was given by Gokceoglu et al. (2005a and 2005b).

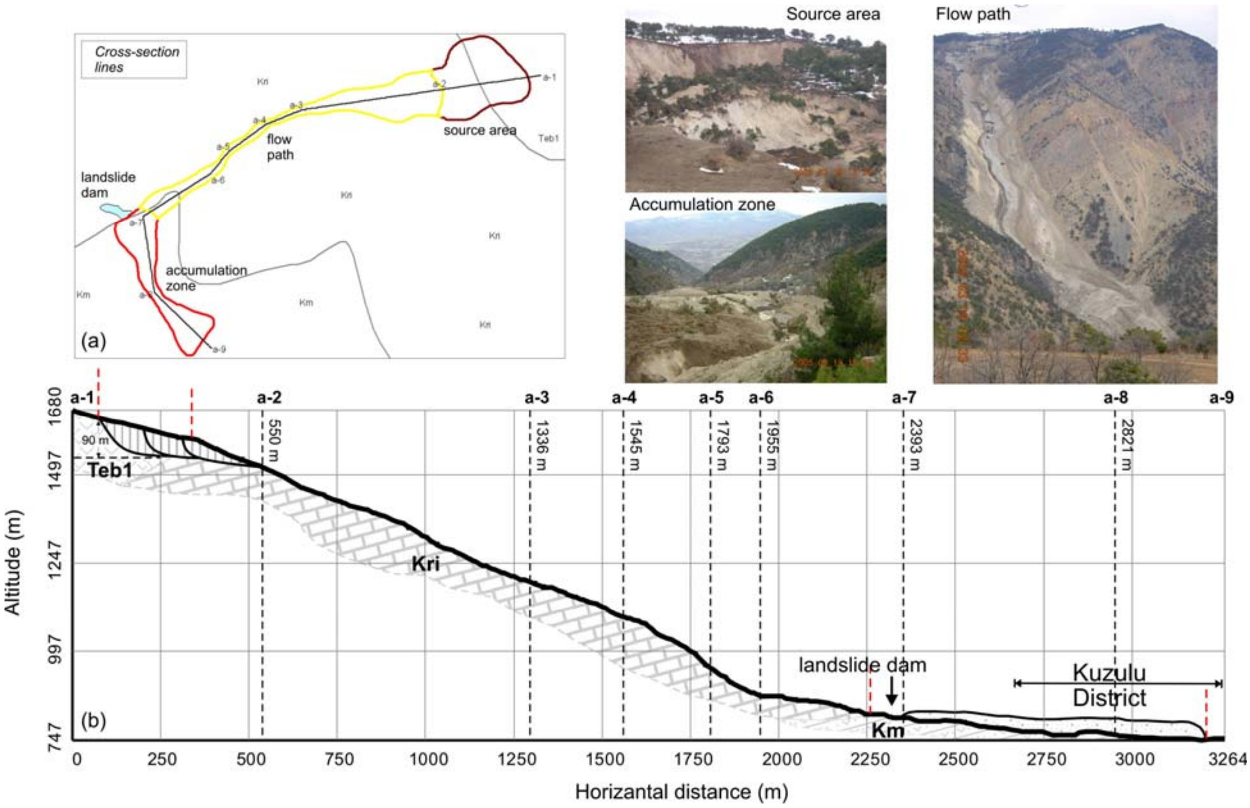

Figure 3. Plan view (a) and coss-section (b) showing the mechanism of the landslide, and photos (c) from source area, flow path and accumulation zone of Kuzulu landslide (Gokceoglu et al., 2005a).

Figure 4. Damaged houses.

RESULTS AND CONCLUSIONS

On March 17 2005, a catastrophic large landslide, the Kuzulu landslide, was triggered by snow melting without any precursor in Sivas, the northeast of Turkey. The main mechanism of the landslide is complex because it contains two movement types. The initial failure of the Kuzulu landslide was rotational. Following the rotational failure, the earth material in the zone of accumulation exhibited an extremely rapid flow caused by steep topography and high water content.

The Agnus creek valley, where the Kuzulu village is located, was filled by the flowed earth material and a landslide lake having an area of 6900 m^2 was formed in the upper part of the Agnus creek. The distance from the toe of the rotational failure down to the toe of the earthflow measured more than 1800 m, with about 12.5 million m^3 displaced earth material.

During the Kuzulu landslide, all negative impacts of landslides on the environment occurred. 15 people (villagers) were buried under the displaced material, because of extremely speed velocity, approximately 6 m/s. This is the most important impact of the Kuzulu landslide. A total of 34 houses and 1 mosque were demolished, completely, and an important farming area was destroyed. Due to the landslide, an important forest cover an area of 47000 m^2 was completely destroyed.

The Agnus creek discharges to the Kelkit River, one of the more important rivers of Turkey. During 4 days, approximately 5.3 million m^3 of earth material was transported by the Agnus creek and this material reached the Kelkit River. Adding this material to the Kelkit River caused a decrease in water quality and an increase in the sediment load in the river bed.

As a conclusion, considering the field observations, retrogressing landslide activity is expected and the other parts of the Kuzulu village are under the threat of the subsequent landslide hazard.

Corresponding author: Dr Candan Gokceoglu, Hacettepe University, Beytepe Campus, Ankara, 06532, Turkey. Tel: +90 312 297 77 35. Email: cgokce@hacettepe.edu.tr

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