A GIS and RS-BASED QUANTITATIVE VULNERABILITY ASSESSMENT FOR RAINFALL TRIGGERED LANDSLIDES

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Abstract – Quantification of landslide risk requires computation of landslide hazard and consequences. Computation of landslide consequences should be determined in terms of loss in a quantitative manner. The analysis of consequences involves determination of elements at risk and vulnerability of elements at risk. The vulnerability of elements at risk depends on the understanding of the interaction between a given landslide and the affected elements. In this study, a quantitative approach for mapping landslide vulnerability was developed for property at local scale. The approach focused on determination of quantitative vulnerability values for each element at risk by considering temporal and spatial impacts by adopting a "damage probability matrix" approach. The spatial vulnerability of buildings were determined by modeling the landslide velocity. As a result risk to property was obtained by considering the roads and buildings on local scale.

Keywords: Vulnerability, loss estimation, risk, building, road

1. INTRODUCTION

Landslide risk assessment is of crucial importance in decreasing the potential losses. However, attempts to determine qualitative and/or quantitative risk assessment seems to be fewer (e.g. Aleotti and Chowdhury, 1999; Bell and Glade, 2004; Remondo et al. 2008) which might be due to the difficulties in obtaining data. It is of fundamental importance to collect data about consequences of landslides for landslide risk assessment. Vulnerability is fundamental component in the evaluation of landslide consequence analysis (Leone et al., 1996). In this study, the use of run-out modeling opens a new possibility to assess the vulnerability values quantitatively on local scale. The velocity values were evaluated with the number of inhabitants per house to evaluate the spatial vulnerability of building and road. The vulnerability of buildings and road were estimated by adopting the damage probability matrix approach (Düzgün, 2008). In this approach, the elements at risk on local scale were considered separately by damage probability matrix. As a result, quantitative risk maps were produced on a continuous scale where numerical values indicate the distribution of risk including the annual probability of expected loses in TL per pixel.

2. STUDY AREA

Hepler is a small district located on a hillside. The Hepler region exhibits mountainous topographical features, and is frequently subject to heavy precipitation. Due to these adverse effects, the region is prone to extensive and severe landslides (Ercanoğlu and Gökceoğlu, 2002). Depending on the reports of the General Directorates of Disaster Affairs of Bartın, the region is settled down on an old landslide mass. Landslide mass is identified in lithologic units of Upper Cretaceous age Flysch, which is named as the Ulus formation. The Flysch formation is saturated due to extreme snowmelt in the winter and rainy season in the spring. As the terrain becomes saturated with water, landslide and mud flows occur. In 1967, 1985 March, 1998 May, and 2000 June, devastating landslide events occurred in Hepler village. 1985 and 1998 slides were reported to be a flow type slide.

3. CONSEQUENCE ANALYSIS

Consequence study involves determination of spatial impact, vulnerability and elements at risk.

3.1. Probability of Spatial Impact

The vulnerability of property were predicted depending on their exposure to slide velocity. Therefore, the effect of run-out distance was considered for probability of spatial impact. To define the flow depositions produced from the landslides, a two–dimensional Flo2D model (O'Brein et al., 1993) was applied in the study. Flo 2D is a two dimensional finite difference model developed by O'Brien (O'Brien, 1999) used to simulate clear water, flood hazards, mud flows, and debris flows. The objective of this model is to estimate the probable range of flow properties in terms of velocity and depth to predict a reasonable area of inundation (O'Brein et. al., 1993). Assuming that the same rainfall situation that produced slides in the past will produce the same effects in the future, an event like the one in 1998 was simulated. A low intensity but continuous rainfall occurred between May 1 and May 19, with a total amount of 45.4 mm in the study region. Rainfall intensity increased between the days May 20-22. The Bartın station reported that during these three days a total precipitation of 166.3 mm. occurred. Then, torrential rainfalls over a three-day period (May 20-22) spawned landslides throughout the upper slopes of the terrain. Slide surges destroyed most of the houses in Hepler. According to local reports, 25 houses moved after the devastating event. For simulation studies, the 7-day (1998, May 17-23) hourly data was acquired from Bartın station. In order to create a storm distribution, the relative accumulation was computed by using the hourly records of 7-day precipitation (Figure 1). This data was then used to be input to compute the hydrograph, which would then be used as input for simulation. In other words, the storm distribution was used to compute the discharge (Q m^3/s) in each cell in the selected region.

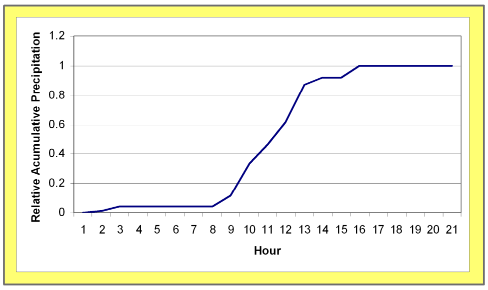

Figure 1.Rainfall distribution at Bartın Station May 17-23, 1998.

To create a FLO-2D grid system and model, the following steps were completed for the analysis. The DTM data (terrain data) with 1-m resolution was exported to Ascii grid file to be input for the Grid Developer System (GDS) and a 10-m square grid system was prepared (Bertolo and Wieczorek, 2005). The channel geometry was estimated through the data collected from the fieldwork, visual inspection of remote sensing images and also the slope unit model. Then, the shape file slide boundary was imported to the system and the simulation area (computational domain) for the FLO-2D model was determined based on this boundary. The elevation data was interpolated and FLO-2D grid element elevations were assigned to each grid cells. The Manning's roughness (n-value) was not present for the study region; hence some general assumptions provided by O'Brien 1999 were used. By the field surveys, the region was observed to have dense grass and vegetation; therefore, the overland flow manning's n roughness value was considered as 0.32 depending on the physical surface type. After the determination of outflow nodes, the FLO-2D simulated the flooding by routing the flood hydrograph. For each cell of the analyzed data, FLO-2D returns volume concentration, velocity, discharge and depth during all times in the simulation (Garcia et al., 2004). The velocity map of the simulated slide changes with the volume concentration and ranges between 0.01 and 1.55 m/s (Figure 2). The spatial variation of velocity values over the study region and the distribution of houses are also illustrated in Figure 2. The velocity map was used for further vulnerability estimation.

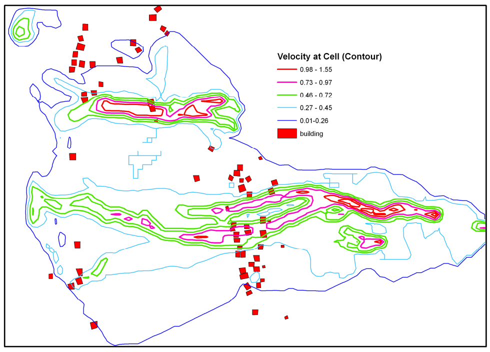

Figure 2.The velocity map of the simulation result (m/s)

3.2. Vulnerability Assessment

The damage to property can be estimated by adopting a damage probability matrix (Yücemen, 2002; Düzgün, 2008). This approach was used in structural earthquake engineering for evaluating the damage for a given building stock at a given earthquake intensity (Ko Ko et al., 2004). In this approach, instead of building blocks, the buildings and the road were considered separately by damage probability matrix. The existing elements at risk (building and road) in the area were identified by the developed algorithm. The theoretical background of the developed algorithm was presented in detail in the Aytekin et al., 2010. Therefore it is not presented in this study.

Damage to the buildings and the road was categorized into four groups based on the level of damage. Damage state (DS) was considered in four levels, changing from none to destruction, in which none and destruction stands for no and completes damage. RDR is the range of damage ratio for each damage percentage. RDR is defined as 0, 0-10, 20-40 and 50-100 (Table 1) (Düzgün, 2008). Central Damage Ratio (CDR) is defined as the mean value of RDR. SPD is the probability of observing damage state for the given temporal condition (season in a year and time in a day). The properties (such as buildings, roads, etc.) are always exposed to threats for all the time. Hence the temporal probability is not considered for the vulnerability analysis of properties. SPD is computed by considering the spatial vulnerability of buildings, which is determined by modeling the landslide velocity using Flo 2D. The velocity ranges between 0.01 and 1.55 as obtained from the simulation. Hence, in the first step the velocity was normalized to 0 and 1. In the second step, the velocity map was classified into four different classes depending on the natural break method. Finally, the percentage area of each property on each level of landslide velocity was computed by the overlay of velocity map with buildings and roads respectively. The SPD is the percentage ratio of each feature computed for buildings and roads on each velocity level (Table 1, Table 2).

Table 1. Damage Probability Matrix for Building

DS	RDR (%)	CDR (%)	SPD
None	0	0	0.23
Light	0-10	0.05	0.52
Moderate	20-40	0.3	0.12
Destruction	50-100	0.75	0.11
Mdr (%)			15.00

Table 2.Damage Probability Matrix for Road

DS	RDR (%)	CDR (%)	SPD
None	0	0	0.71
Light	0-10	0.05	0.11
Moderate	20-40	0.3	0.19
Destruction	50-100	0.75	0.00
Mdr (%)			6.08

The MDR is computed for each damage state by sum of the multiplication of CDR and SPD values as presented in Eq. 1

$$MDR = \sum_{j=1}^{4} CDR_j x SPD_j \qquad (1)$$

Where j is the level of damage state that ranges between 1 and 4, in which 1=None, 2=Light, 3=Moderate and 4= Destruction

4. RISK ANALYSIS

The hazard maps produced for Kumluca region which was expresses as annually probability of landslide occurrence probability for each pixel were used to obtain the hazard values for Hepler district. A detailed description of the hazard mapping procedure can be provided extensively in the Erener and Duzgun, 2010. Risk to property was obtained for Hepler by considering the roads and buildings. The cost of buildings, which was determined from the General Directorate of Disaster Affairs of Bartın, was used to assign the economical value, which is 23,600 TL/Pixel. The cost of roads was obtained from the General Directorate of Transportation for provincial type, which is 751,100 for one km and computed as 15,022 TL for per pixel.

The risk was computed for each property (building and road) separately. Then the total risk map was obtained by overlaying all risk maps. The risk computation involves multiplication of each property value with MDR values and then multiplication by hazard value.

$$Risk_{Porp} = R_{Building} + R_{Road} \qquad (2)$$

As a result, for the assumed damage probability matrix in Table 1, Table 2 the annual risk to Hepler was estimated for TL/pixel cost of damage. Figure 3 illustrates the spatial variation of risk values for risk to property.

The risk maps for loss of property provide a low risk values for road (Figure 3); however, the risk values vary for houses and provide medium and high levels of risk for houses. The houses at the northern part provide higher risk values compared to the southern part of the region which might be due to the physical properties of the terrain and depend on the slope.

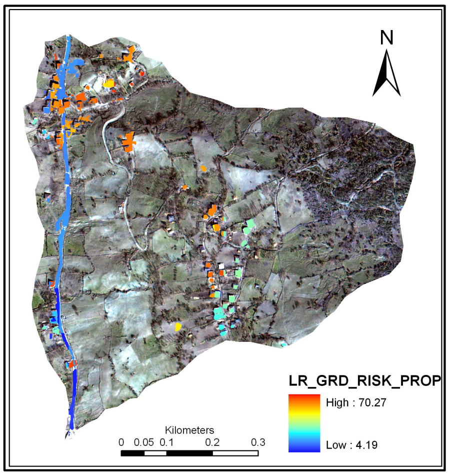

Figure 3.Risk to property (TL/Pixel)

5. CONCLUSION

There is not a common method of vulnerability assessment in landslide risk mapping. The vulnerability approach designed for this study is based on damage probability matrix and run-out velocity, which may bring a new possibility to assess the vulnerability values quantitatively. The use of the velocity value of run-out is new for vulnerability assessment and several issues such as rheology computation and model calibration are needed to be incorporated into the analysis. In addition to temporal impact, which is considered in the vulnerability approach, the probability of being in run-out zone for elements at risk, the construction type, the replacement cost of particular buildings etc. may also be considered for further vulnerability assessment studies.

Landslide risk assessment is still in its developing stage, and most countries do not have a standardized landslide risk assessment programme. In Turkey, there are even no studies for risk mapping for landslides. Therefore, this study contributes to the literature by designing a loss estimation approach for quantitative risk assessment. The risk maps were obtained by the evaluation of hazard and consequence maps for each element at risk. A combined landslide risk map was obtained by adding risk for each element at risk. As a result, quantitative risk maps were produced on a continuous scale where numerical values indicate the distribution of risk including the annual probability of expected loses in TL per pixel.

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