

### **Reply for Anonymous Referee #3**

**Thank you very much for referee's sincere comments.**

**Authors corrected the pre-existing manuscript taking into account the comments. The corrected or additionally incorporated parts in the revised manuscript were underlined and red letters. For the specific comments from anonymous referee #3, authors' corrections are as follows:**

#### **Comment #1**

Most previous papers about GIS-based landslide assessments have been dealt generally with circular slope failures considering slope, rainfall, saturation, vegetation. This paper is about debris flow hazard assessment in a simple way. Even though the framework suggested in this paper is well constructed and operated, the adopted method to assess the hazard level is somewhat unreasonable. Therefore it is required to be revised to be published.

#### **Revision #1**

Authors appreciate referee's sincere review on our manuscript to making the paper near perfect and clarify the novelty of manuscript. Also, the original manuscript was corrected and improved considering the remarks and suggestions from reviewer acting as a referee. So in this response to reviewer comments, the revision of the original manuscript and point-by-point response were prepared. Author's corrections were described in the revisions #1 to #3 for comments.

### **Comment #2**

Basically the assessment method cannot seem to consider various influence factors shown in Table 1, especially vegetation properties and geological properties. In addition, Hazard Classes as shown in Table 3 and Figure 11 are determined only based on rainfall reoccurrence period or accumulated rainfall not considering the susceptibility value and the vulnerability value. That is, the hazard value does not include hydrological properties, vegetation properties and geological properties, which are important influence factors on debris flows. Due to these lacks of considerations in the adopted assessment method, the framework seems to result in poor assessment for the hazard as the authors also agreed in their paper.

### **Revision #2**

Authors appreciate reviewer's sincere recommendation on our manuscript to making the paper near perfect. According to your comments, authors also agreed that the proposed framework (system) can't perfectly distinguish the total Hazard Value differences between occurrences and non-occurrences for the three target areas. Authors developed a simple method (but not limited to its current one) to assess debris flow hazard for expressway management. First of all, this has never been tried in Korea and the method has limitations due to the wide coverage area and usage of available data throughout the whole expressway constructed in Korea. The reason of uncertainty or limitations of proposed framework is constraints of influencing factor and grading standard for determination of debris flow index.

Prediction concerns either where or when debris flow will occur, depending on the type of movement and the scope of the forecasting. Many attributes (geography, rainfall, geology, vegetation, wildfire history, and conditions of existing structures) are related to the mechanism/initiation of debris flows. To obtain information on the influencing factors other than topographical properties (elevation, slope, valley and watershed) and rainfall data, field surveys should be thoroughly conducted throughout entire expressway facility sections. Because the assessment of debris flow hazards in this study is to be applied on a regional scale, the method needed to be simple, and also applicable for the macro-zonation of debris flow hazards. And other factors such as the size and shape of valley along with the variations in slope direction, properties of the subsoil, geological properties, and vegetation also have an influence on the movement of debris-flows.

However, to simplify the method, only the slope information was considered for debris-flow movement possibilities. Considering that obtaining and processing all the attributes stated above in the prediction stage is a time-consuming and difficult task, it was decided that only easily accessible document data (such as digital maps, geological maps, etc.) were to be used in the site-specific assessment process. For example, the spatial correlations (for site-specific micro-scale area) between influence of debris flow and geological or vegetation characteristics was not

perfectly set up in Korea. First of all, since there are mostly occurred macro- or micro-scale debris flow events induced by regional torrential rains, Korea, the application of reliable document data is necessary to immediately evaluate the site-specific debris flow hazard for the wide coverage area. Consequently, the KEC debris flow hazard assessment method was set as a fundamental assessment tool owing to its simplicity. Authors also corrected the original manuscript considering clarification of selection of attributes (influencing factors) offered as following:

[lines 18-31 of page 3]

“To obtain information on the influencing factors other than topographical properties (elevation, slope, valley and watershed) and rainfall data, field surveys should be thoroughly conducted throughout entire expressway facility sections. Because the assessment of debris flow hazards in this study is to be applied on a regional scale, the method needed to be simple, and also applicable for the macro-zonation of debris flow hazards. And other factors such as the size and shape of valley along with the variations in slope direction, properties of the subsoil, geological properties, and vegetation also have an influence on the movement of debris-flows. However, to simplify the method, only the slope information was considered for debris-flow movement possibilities. Considering that obtaining and processing all the attributes stated above in the prediction stage is a time-consuming and difficult task, it was decided that only easily accessible document data (such as digital maps, geological maps, etc.) were to be used in the site-specific assessment process. For example, the spatial correlations (for site-specific micro-scale area) between influence of debris flow and geological or vegetation characteristics was not perfectly set up in Korea. First of all, since there are mostly occurred macro- or micro-scale debris flow events induced by regional torrential rains, Korea, the application of reliable document data is necessary to immediately evaluate the site-specific debris flow hazard for the wide coverage area. Consequently, the KEC debris flow hazard assessment method was set as a fundamental assessment tool owing to its simplicity.”

And the classification of grading standard or weighting function was established based on logistic regression using debris flow case histories at the national-wide expressway area in Korea. Each of the influential factors are given points from 0 to 5 based on the grading standard set considering past debris flow occurrence cases for ten years, and adds up to a total *Susceptibility Value* of 20 points. For the weight considerations of the four attributes, logistic regression was carried out through the Statistical Package for Social Science (SPSS). The occurrence of debris flow is kind of the binary item which is ‘zero’ as happening while as ‘one’ for no occurrence. Hence, the logistic regression is used frequently to carry out the multivariable analysis. Results of about 30 logistic regression analyses showed that the 4 *Susceptibility Value* attributes had weights of 0.27, 0.24, 0.26, and 0.23, respectively. Since the weights showed no

significant difference, the attributes were considered to have identical weights. In the same way, each of the attributes is given points ranging from 0 to 5 based on a grading standard, and these points are added up to provide the total *Vulnerability Value* of 10 points. Thus authors prepared the above mentioned presentation at the revised manuscript:

[lines 16-23 of page 4]

“(…) Each of the influential factors are given points from 0 to 5 based on the grading standard set considering past debris flow occurrence cases for ten years (Table 2), and adds up to a total *Susceptibility Value* of 20 points. For the weight considerations of the four attributes, logistic regression was carried out through the Statistical Package for Social Science (SPSS). The occurrence of debris flow is kind of the binary item which is ‘zero’ as happening while as ‘one’ for no occurrence. Hence, the logistic regression is used frequently to carry out the multivariable analysis (Ohlmacher et al. 2003). Results of about 30 logistic regression analyses showed that the 4 *Susceptibility Value* attributes had weights of 0.27, 0.24, 0.26, and 0.23, respectively. Since the weights showed no significant difference, the attributes were considered to have identical weights.”

In addition, the modifications on framework were considered for three testbed sites according to the clarification of attributes and grading standards. The grading standard was set using all existing data sets of each attribute, and calculating the maximum, minimum, and median values. In order to appropriately represent the differences between debris-flow occurrences and non-occurrences, modifications can be made on the assessment method. Therefore, to modify the grading standards, the average values of each attribute were calculated. When calculating the average values, sites that showed proper outcomes were not taken into consideration. Because the sites in interest were the ones that showed mixed results between occurrences and non-occurrences, only the ones that showed mixed results were considered in the average calculating process. After calculating the average values for each attribute for the occurrence and non-occurrence cases of the three target areas, the each attributes were compared. And a criterion for the grading standard was set based on logistic regression. Through various applications on different criteria, the one which indicated the highest difference between the occurrence and non-occurrence cases was chosen for each attribute. The modified *Susceptibility Value* grading standard was re-established as Table 6. The *Vulnerability Value* grading standard was also modified based on the debris-flow occurrence and non-occurrence cases of the three target areas. Considering the fact that only a very few number of the considered sites had deposit areas with volumes exceeding 2000 m<sup>3</sup>, the grading standard was modified. The highest grading standard was altered from 5000 m<sup>3</sup> to 2000 m<sup>3</sup>, and the other standards were also modified accordingly.

Based on the same condition of application for three target area, the *Hazard Value* and

*Hazard Class* were determined using revised grading standard. The spatial pattern of occurrence case at the scoring chart was distributed on *Hazard Class* of S, A, and B having the high potential of debris flow, as shown in Fig. 12. On the contrary, the points of non-occurrence case were distributed on *Hazard Class* of C, D, and E having comparatively lower potential of debris flow. In addition, the average value of the *Susceptibility Value*, *Vulnerability Value*, and *Hazard Value* of occurrence cases are distinguishable 1.58 times greater than those of non-occurrence cases (Table 7). The difference between *Hazard Value* of occurrence and non-occurrence cases based on revised grading standard are 1.37 times greater than difference (1.15) of application results using existing standard. Moreover, the framework has potential to be upgraded with more data accumulation and more case histories, considering locality of debris flow potential in Korea. Also, attributes other than those regarding the slope should be considered such as watershed size and bending of valley. According to Kim et al. (2014), With larger watershed sizes, both the debris-flow initiation risk and occurrence risk increase. An objective standard was set for the assessment of bending of valley (bending ratio). With larger bending ratios, more debris-flow materials are subjected to sedimentation, lowering the possibility of damage on road structures. Thus, the above modified parts underlined in the manuscript are as follows:

[lines 10-34 of page 11 and lines 1-6 of page 12]

### **“5.3 Modifications on framework”**

The existing KEC method designated points to each attribute according to a grading standard set based on a few case studies of debris-flow occurrences. However, it did not take the non-occurrence cases into consideration. In addition, the grading standard was set using all existing data sets of each attribute, and calculating the maximum, minimum, and median values. In order to appropriately represent the differences between debris-flow occurrences and non-occurrences, modifications can be made on the assessment method. The results of three applications showed the highest number of debris-flow occurrence sites. Therefore, to modify the grading standards, the average values of each attribute were calculated. When calculating the average values, sites that showed proper outcomes were not taken into consideration. Because the sites in interest were the ones that showed mixed results between occurrences and non-occurrences, only the ones that showed mixed results were considered in the average calculating process. After calculating the average values for each attribute for the occurrence and non-occurrence cases of the three target areas, the each attributes were compared. And a criterion for the grading standard was set based on logistic regression. Through various applications on different criteria, the one which indicated the highest difference between the occurrence and non-occurrence cases was chosen for each attribute. The modified *Susceptibility Value* grading standard was re-established as Table 6. The *Vulnerability Value* grading standard was also modified based on the debris-flow occurrence and non-occurrence cases of the three target areas. Considering the fact that only a very few number of the considered sites had deposit

areas with volumes exceeding 2000 m<sup>3</sup>, the grading standard was modified. The highest grading standard was altered from 5000 m<sup>3</sup> to 2000 m<sup>3</sup>, and the other standards were also modified accordingly.

Based on the same condition of application for three target area, the *Hazard Value* and *Hazard Class* were determined using revised grading standard. The spatial pattern of occurrence case at the scoring chart was distributed on *Hazard Class* of S, A, and B having the high potential of debris flow, as shown in Fig. 12. On the contrary, the points of non-occurrence case were distributed on *Hazard Class* of C, D, and E having comparatively lower potential of debris flow. In addition, the average value of the *Susceptibility Value*, *Vulnerability Value*, and *Hazard Value* of occurrence cases are distinguishable 1.58 times greater than those of non-occurrence cases (Table 7). The difference between *Hazard Value* of occurrence and non-occurrence cases based on revised grading standard are 1.37 times greater than difference (1.15) of application results using existing standard. Moreover, the framework has potential to be upgraded with more data accumulation and more case histories, considering locality of debris flow potential in Korea. Also, attributes other than those regarding the slope should be considered such as watershed size and bending of valley. According to Kim et al. (2014), With larger watershed sizes, both the debris-flow initiation risk and occurrence risk increase. An objective standard was set for the assessment of bending of valley (bending ratio). With larger bending ratios, more debris-flow materials are subjected to sedimentation, lowering the possibility of damage on road structures.”

[Table 6]

**Table 6.** Modified points given to attributes according to grading standard of KEC.

Classification			Scoring Criteria	
			Scoring Index	Points
<i>Susceptibility Value</i> (20 Points)	Initiation Assessment (10 Points)	Mean Slope of Watershed (Unit : °)	- Higher than 30°	5
			- 30°~28°	4
			- 28°~26°	3
			- 26°~24°	2
			- 24°~22°	1
			- Under 22°	0
	Movement Assessment (10 Points)	Area Percentage of Watershed with Slopes over 35° (Unit : %)	- Higher than 32%	5
			- 32%~25%	4
			- 25%~18%	3
			- 18%~11%	2
			- 11%~4%	1
			- Under 4%	0
		Mean Valley Slope (Unit : °)	- Higher than 19°	5
			- 19°~17°	4
			- 17°~15°	3
			- 15°~13°	2

			- 13°~11°	1		
			- Under 11°	0		
		Length	- Higher than 67%	5		
		Percentage of Valley with Slopes over 15° (Unit : %)	- 67%~61%	4		
			- 61%~55%	3		
			- 55%~49%	2		
			- 49%~43%	1		
			- Under 43%	0		
		<i>Vulnerability Value</i> (10 Points)	Debris Storage, Sedimentation Availability (5 Points)	Volume of Deposit Area (Unit : m³)	- No accumulation area (0m³)	5
					- 0m³~100m³	4
	- 100m³~500m³			3		
	- 500m³~2,000m³			2		
	- Higher than 2,000m³			1		
	- Excessive volume of deposit area, No damage guaranteed			0		
Debris Passage through Expressway Facilites (5 Points)	Size of Drainage Facility (Unit : Cross-sectional Area, m²)			- Waterway	5	
				- Lateral drains below D1,200	4	
				- Waterway box below B2.0x2.0	3	
				- Waterway box below B4.0x4.0	2	
		- Waterway box below B3.0xD3.0	1			
		- Bridges	0			

[Table 7]

**Table 7. Average of Susceptibility Value, Vulnerability Value, and Hazard Value of occurrence and non-occurrence cases based on modified grading standard.**

	Occurrence case			Non-occurrence case		
	<i>Susceptibility value</i>	<i>Vulnerability value</i>	<i>Hazard value</i>	<i>Susceptibility value</i>	<i>Vulnerability value</i>	<i>Hazard value</i>
Pyeongchang	13.53	9.50	23.03	8.52	5.62	17.00
Deogyu Mountain	14.62	8.52	23.14	9.01	6.92	17.57
Juksan&Geochang	15.31	9.02	24.33	7.12	7.55	17.88
Average	14.47	9.01	23.50	8.22	6.70	14.91

### **Comment #3**

I also found some typos like the first anonymous referee#1. Typos are at; 20th line in page 3, 7th line in page 5, 2nd line in page 6, 17th line in page 6, 24th line in page 6, 1st line in page 7, 29th line in page 8, 20th line in page 10 (not occurred in Class E in Fig. 11) and in figure 2 : necessary to add the process to consider rainfalls. in table 2 : the unit of discharge section area of waterway box Figure 11 is not figure but table.

### **Revision #3**

Thank you for the valuable comments. According to the reviewer's recommendation, typos were corrected and some modifications of figures and tables were conducted. There are some examples of revised part of manuscript.

[lines 13-15 of page 2]

“Assessment of landslides including debris flows has been carried out with GIS techniques combined with statistical analyses and physical-based approaches by various researchers such as [Carrara et al. \(1999\)](#), Dai et al. (2002), Ohlmacher and Davis (2003), [Ayalew et al. \(2003\)](#), Wang et al. (2008), and Kritikos and Davies (2014). (...)”

[lines 21-23 of page 3]

“(...) [And other factors such as the size and shape of valley along with the variations in slope direction, properties of the subsoil, geological properties, and vegetation also have an influence on the movement of debris-flows.](#) (...)”

[lines 26-28 of page 6]

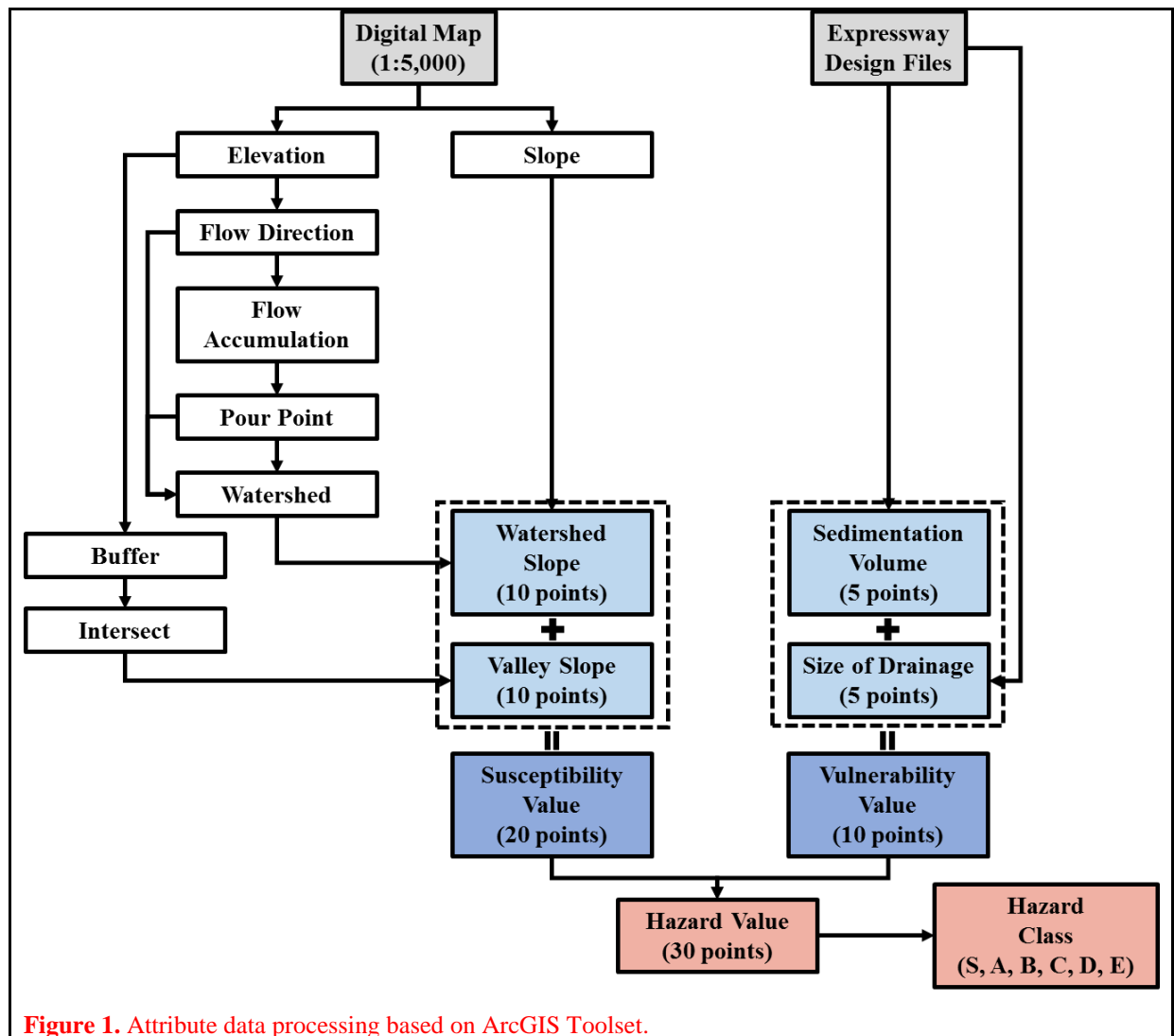
“(...) In order to obtain the valley path points that are positioned inside the 1.5m buffer [zones](#) of the plotted valley path (...)”

[lines 5-7 of page 9]

“In addition, the rainfall values for debris flow hazard assessment are automatically computed based on the monitoring criteria with recurrence periods of rainfall [\(referred to road design in Korea\)](#) (...)”

[Fig. 1]





**Figure 1.** Attribute data processing based on ArcGIS Toolset.