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Original article

GIS Based Analysis of Landslide Effecting Factors in the Pyeongchang Area

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Abstract

Most areas in Gangwon-do are mountainous regions where causes heavy damages due to landslides. It is important to analyze basic factors influencing the cause of landslides in order to prevent such landslides. For this study, a landslide occurring site is extracted from aerial images taken after the landslide caused by typhoon 'Ewiniar' in Pyeongchang area 2006. Also, the overlay analysis with the topographic, forest, and soil maps in this area is performed using GIS based methods. In addition, the topographic, forest, and soil characteristics relating to the landslide factors are analyzed. As a result, large numbers of landslides occurred at a slope angle of 20°-40°. In the case of the forest factors, there are close relationships between the artificial pine and larch forests and the frequency of landslides. The low forest density represents a weakness in landslides. In the case of the soil factors, a higher level in the surface soil with a type of sandy loam soil, a higher gravel content in subsoil, and a higher degree of acid rocks in soil parent materials cause higher frequencies in landslides

Keywords : Landslide, Aerial image, GIS, Overlay analysis

1. Introduction

The territory of Korea represents mountainous areas with a curved old phase of topography due to long term erosions and weathering actions. The topographic characteristic causes a sudden increase in rainfall runoff, according to typhoons and torrential rains during June-September of the year that causes huge damages. Also, it includes many steep slopes and shallow soil depth areas, which causes landslides because of sudden changes in soil layers.

In particular, Gangwon-do is located at the middle east section of Korean peninsular and shows a very high probability of presenting landslides, caused by torrential rains because more than 80% of the region are mountainous area. The landslides caused house destructions, casualties, losses of farm lands and roads, and traffic troubles. Also, the damages are repeated by the year with very large scale in its accumulated damages. Landslides caused by torrential rains are usually generated in summer, and are presented as a type of debris flows. In the case of the debris flow, it causes much larger landslides than other usual landslides, since landslide objects are joined to the main steam through valleys(Varnes, 1978).

Factors of landslides, presented in Fig. 1, are classified into internal and external factors. Landslides are generated as these two factors are joined together(Kim *et al*., 2011).

For preventing landslides or reducing damages, it is necessary to predict areas of landslides, causes of landslides, times and scales of landslides, and scales of damages. So, it is important to analyze basic factors(Surface elevation, Slope, Aspect) that affect the landslides(Kwon and Kim, 2010). In landslides, it is generated through the wide areas as well as is initiated from a deep valley. Thus, a remote sensing method and GIS are used to implement studies

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because it is not easy to approach the site. The GIS provides the integration, application, and analysis functions of various information, and is also able to make and evaluate a space prediction model, especially useful to manage and analyze huge space information like landslides (Lee *et al*., 2002; Chae *et al*., 2009; Cho and Chang, 2006). The researches on landslides using a GIS based Heuristic analysis, Statistical analysis and Deterministic analysis method(Table 1) have been widely conducted(Jung *et al*., 2012). Yune *et al*. (2009) analyzed factors of landslides using a GIS method based on the historical data of landslides in Korea, and extracted the relationships between causing factors and landslides using a statistical method. Yang *et al*. (2006) determined vulnerable areas using GIS after investigating and classifying the causing factors of landslides in the southern area of Gangwon-do.

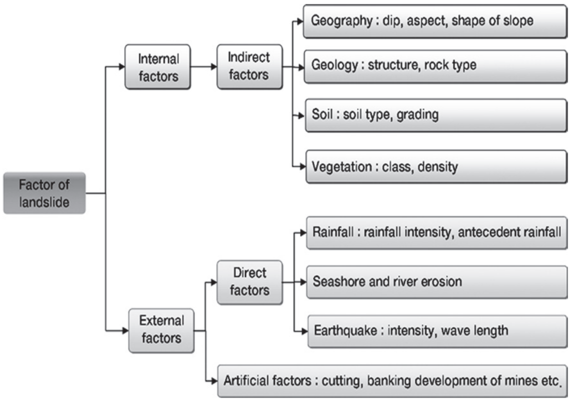


Fig.1 . Factors of landslide (Bromhead, 1998)

In the case of foreign countries, systematical studies on landslides have been conducted for over decades. Dai and Lee (2003) analyzed the characteristics of topology, geology, and rainfall in landslide sites in Hong Kong using GIS and established a prediction model using a logistic regression method. Sezer *et al*. (2011) analyzed the topology, plant, soil in landslide sites in Malaysia and established landslide vulnerable area maps using a fuzzy model.

In this study, the landslides, caused by typhoon 'Ewiniar' in Pyeongchang area in 2006 and its surrounding conditions, are analyzed to verify the characteristics of causing landslides. In addition, factors for landslide analysis models are determined through analyzing the frequency of landslides in the damaged site. GIS based analysis researches for landslide effecting factors have produced similar results

Table 1. Comparisons of main methods to assess landslide hazard based on GIS technology(Wang *et al.*, 2005)

Type of analysis	Technique	Scale of use recommended			Advantages	Disadvantages
		Regional	Medium	Large		
Heuristic analysis	Qualititative map combination	Yes	Yes	No	The degree of hazard is determined rapidly after the fieldwork on the basis of a detailed geomorphological map taking into account a large number of factors as attribute database	The length of operations involved The problem of subjectivity in attributing weighted values
Statistical analysis	Bivariate statistical analysis	No	Yes	No	To map out in detail the occurrence of past landslides	Difficult to prepare data Under no consideration of trigger factor Just susceptibility assessment Not readily be extrapolated to the neighbouring areas
	Multivariate statistical analysis	No	Yes	Restricted use	To collect sufficient information on the variables that are considered to be relevant to the occurrence of landslides Objective in methodology	
Deterministic analysis	Safety factor analysis	No	No	Yes	To permit quantitative factors of safety to be calculated	Data requirements for deterministic models can be prohibitive, and frequently it is impossible to use the models effectively
	Probability of failure	No	No	Yes	External existing models can be used without losing time in programming the model algorithms in a GIS Encourage investigation and measurement of geotechnical parameters in detail	

regardless of various analytical methods (Min *et al*., 2013; Ko *et al*., 2013; Kim *et al*., 2010; Yoo and Choi, 2011). In many previous studies, they used only landslide frequency in each effecting factor. But in case of using only frequency, the class which is a large part in the study area has high probability of falling into the landslide area, on the contrary the class which is a small part in the study area has the low probability. Therefore, we performed comparative analysis of frequency, and frequency per unit area in various landslide effecting factors.

2. Data Acquisition and Method

Pyeongchang area was damaged by torrential rains from typhoon 'Ewiniar' in 2006. Within the boundary of area 8.1km × 4.9km, the data of landslide points (139 points) was obtained from aerial images taken after landslides and the DEM(10m), forest map, and precise soil map were converted to raster data(cell size 10m × 10m). A GIS overlay analysis on both the converted raster data and the location data of landslide points was implemented for obtaining topographic, forest, and soil characteristic data in each points. As in Fig. 2, a lot of landslide occurring points were observed and digitized as point data, which the landsliding effecting factor data is arranged using frequency and frequency per unit area.

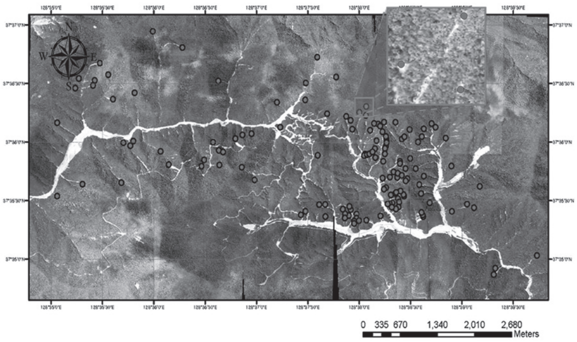


Fig.2 . Landslide occurring points

3. Analysis of Landslides

3.1 Topographic factors

Using the digital topographic map (1:5,000) provided by the National Geographic Information Institute a grid of 10m×10m DEM was made to analyze the slope, aspect, and curvature in landslide points. The topographic factors were analyzed using frequency per unit area. Fig. 3 shows the overlay of the slope and landslide points.

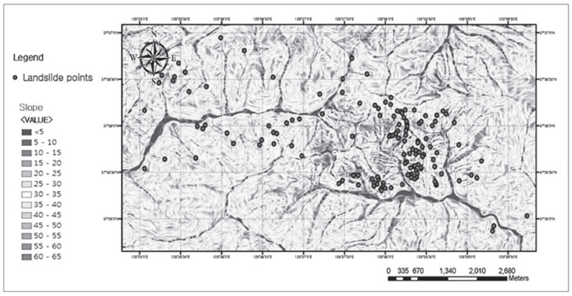


Fig.3 . Overlay of landslide points and slope

The slope was classified with an interval of 5°. There were no points that represented the slopes below 10° and over 50°. As shown in Table 1 and Fig. 4 (a), the points were concentrated at the range between 20° and 40°. It is similar to the study on establishing a landslide vulnerable area map using a GIS method and a causing data analysis (Yune, 2009). Also, the site with a slope of over 60° does not satisfy the basic condition of causing landslides because the site includes steep slopes, thin soil layers, and exposed rock beds to the ground. It is considered that the site with both a slope between 20° and 40° and proper soil layers represents potentials of landslides.

The slope aspect was classified into 9 directions including Flat, N, NE, and so on. In the analysis results, from the W to the SE directions showed the highest risks of causing landslides in Pyeongchang area.

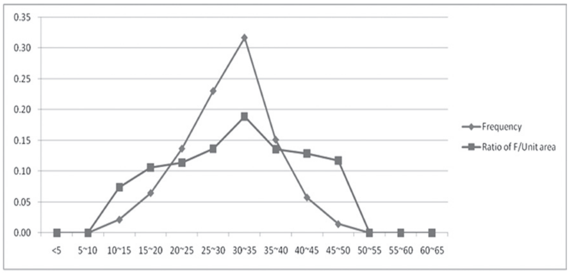
The slope curvature pattern represented 'convex' and 'concave' shapes for approaching '+' and '-' respectively. As shown in Fig. 4 (c), in the case of landslide points it showed many 'convex' shaped areas. Although it was contrary to the conventional study (Yang *et al*., 2006), there were no significant differences in values. So, it is necessary to implement an additional study on causing factors in landslides for larger areas than our study area.

There is a small difference in comparison landslide frequency with landslide frequency per unit area in slope aspect. But there are big differences in slope and curvature. Landslide frequency per unit area is distributed more widely than only landslide frequency.

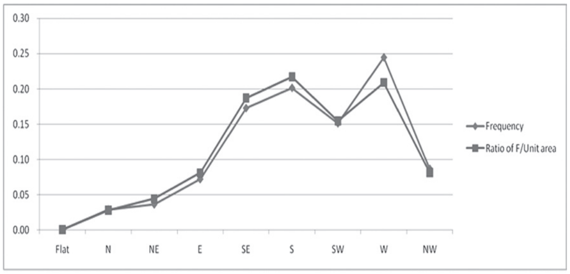
Table 2. Analysis of topographic factors

Slope	Area(㎢)	Frequency	Frequency/ unit area	Aspect	Area(㎢)	Frequency	Frequency/unit area
<5	0.79	0(0.00)	0.00	Flat	0.41	0(0.00)	0.00
5°~10°	0.63	0(0.00)	0.00	N	5.20	4(0.03)	0.03
10°~15°	1.55	3(0.02)	0.07	NE	4.11	5(0.04)	0.04
15°~20°	3.26	9(0.06)	0.11	E	4.49	10(0.07)	0.08
20°~25°	6.39	19(0.14)	0.11	SE	4.64	24(0.17)	0.19
25°~30°	9.00	32(0.23)	0.14	S	4.67	28(0.20)	0.22
30°~35°	8.94	44(0.32)	0.19	SW	4.92	21(0.15)	0.15
35°~40°	5.93	21(0.15)	0.14	W	5.89	34(0.24)	0.21
40°~45°	2.39	8(0.06)	0.13	NW	5.37	12(0.09)	0.08
45°~50°	0.65	2(0.01)	0.12				
50°~55°	0.14	0(0.00)	0.00				
55°~60°	0.02	0(0.00)	0.00				
60°~65°	0.00	0(0.00)	0.00				

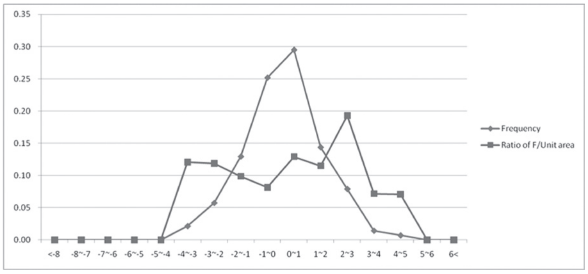
Curvature	Area(㎢)	Frequency	Frequency/unit area	Curvature	Area(㎢)	Frequency	Frequency/unit area
<-8	0.10	0(0.00)	0.00	-1~0	12.61	35(0.25)	0.08
-8~-7	0.08	0(0.00)	0.00	0~1	9.33	41(0.29)	0.13
-7~-6	0.17	0(0.00)	0.00	1~2	5.12	20(0.14)	0.11
-6~-5	0.25	0(0.00)	0.00	2~3	1.68	11(0.08)	0.19
-5~-4	0.46	0(0.00)	0.00	3~4	0.82	2(0.01)	0.07
-4~-3	0.73	3(0.02)	0.12	4~5	0.42	1(0.01)	0.07
-3~-2	1.98	8(0.06)	0.12	5~6	0.27	0(0.00)	0.00
-2~-1	5.36	18(0.13)	0.10	6<	0.33	0(0.00)	0.00



(a) Slope



(b) Aspect



(c) Curvature

Fig.4 . Frequency per unit area of topographic factors

3.2 Forest factors

For analyzing the relationship between landslides and forest factors, the digital forest maps (1:25,000) provided by the Korea Forest Service were used. Fig. 5 shows the density of forest in study area.

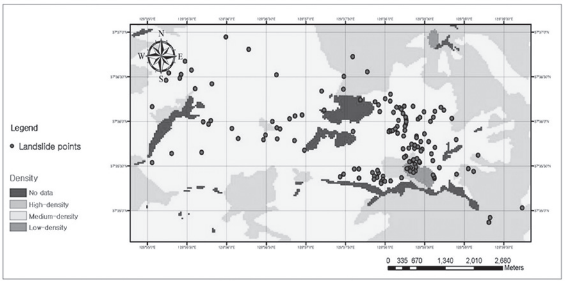


Fig.5 . Overlay of landslide points and forest density

Regarding the forest types in study area, the hardwood (25.41㎢) covered the largest area and the rests of the forest were the mixed forest (8.50㎢), the deciduous forest (2.00㎢), the pine forest (0.85㎢), and the artificial pine forest (0.05㎢). In the frequency per unit area, as shown in Table 2 and Fig. 6 (a) the artificial pine forest and the deciduous forest have represented small occupation areas in the study, but these forests has displayed very high frequencies in landslides. It indicates the artificial pine forest as a high probability in landslides due to its heavy self-weight of trees and its characteristic which spread the in a wide area instead of deep that does not help to improve resistance against landslides (Lee, 2003).

Regarding the diameter of trees, it classifies poles according to diameters of breast hight. The large pole (22.02 ㎢) covered the largest area and the middle (13.09㎢) and small poles (1.08㎢) covered the other area. Considering the frequency per unit area presented in Fig. 6 (b), the small pole has showed the highest vulnerability. It is contrary to the study (Lee, 2003) in which states the increases in diameters of breast height risethe vulnerability of landslides because of increasing the self-weight of trees. Thus, it is required to study further how the diameter interrelated to its size class because the study area includes a very small distribution in small poles.

The age class are classified with age of trees. The class 6 (21.81㎢) has covered the largest area and the class 5 (11.81 ㎢), class 4 (1.48㎢), class 2 (0.72㎢), and class 3 (0.36㎢) covered the other area. The Ages of most trees in this study were ages 40. As represented in Fig. 6 (c), in the frequency per unit area, the class 2 is vulnerable at landslide points, which is considered that a lack of growing roots in slope areas rises the vulnerabilities of landslides due to increases in self-weight of trees. However, additional studies on the age class are needed due to small samples of the class 2 in this study area where the class 5 and 6 cover the most area.

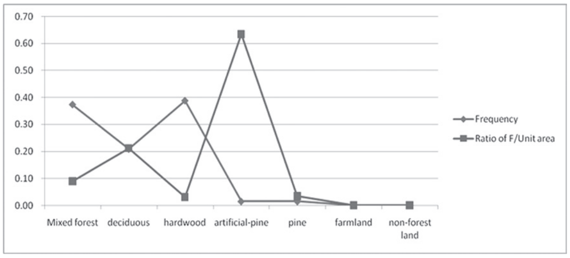
Regarding the density, it classifies the sharing rate of

Table 3. Analysis of forest factors

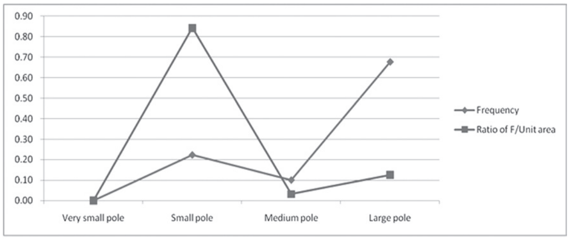
Forest type	Area(㎢)	Frequency	Frequency/unit area	Diameter	Area(㎢)	Frequency	Frequency/unit area
Mixed forest	8.50	52(0.37)	0.09	Very small pole	0.62	0(0.00)	0.00
deciduous	2.00	29(0.21)	0.21	Small pole	1.08	31(0.22)	0.84
hardwood	25.41	54(0.39)	0.03	Medium pole	13.09	14(0.10)	0.03
artificial-pine	0.05	2(0.01)	0.63	Large pole	22.02	94(0.68)	0.13
pine	0.85	2(0.01)	0.03				
farmland	0.19	0(0.00)	0.00				
non-forest land	0.04	0(0.00)	0.00				

Age	Area(㎢)	Frequency	Frequency/unit area	Density	Area(㎢)	Frequency	Frequency/unit area
1	0.62	0(0.00)	0.00	High	13.55	13(0.09)	0.02
2	0.72	31(0.22)	0.89	Medium	22.39	114(0.82)	0.10
3	0.36	0(0.00)	0.00	Low	0.25	12(0.09)	0.89
4	1.48	0(0.00)	0.00				
5	11.81	14(0.10)	0.03				
6	21.81	94(0.68)	0.10				

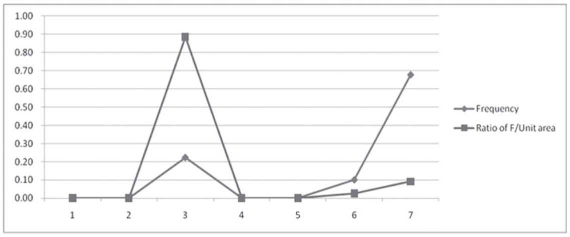
forests into three different levels, high, medium, and low densities, in proportion to areas. The medium density, 22.39 ㎢, covered the largest area and the high (13.55㎢) and low (0.25㎢) densities covered the other area. In the frequency per unit area shown in Fig. 7 (d), the low density represented the highest vulnerable level. It reveals that the roots of trees inhibit landslides and the density of trees is highly related to the probability of causing landslides. There are big differences in comparison landslide frequency with landslide frequency per unit area in forest factors.



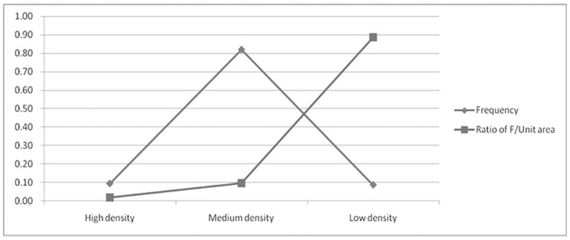
(a) Forest types



(b) Diameters



(c) Ages



(d) Densities

Fig.6 . Frequency per unit area of forest factors

3.3 Soil factors

Soil factors are surface soil texture, drainage class, gravel content, soil texture, effective soil depth and parent material. The soil factors in the study area were investigated using a precise soil map (1:25,000) provided by the Rural Development Administration as shown in Fig. 7 which shows the overlay of drainage class and landslide points.

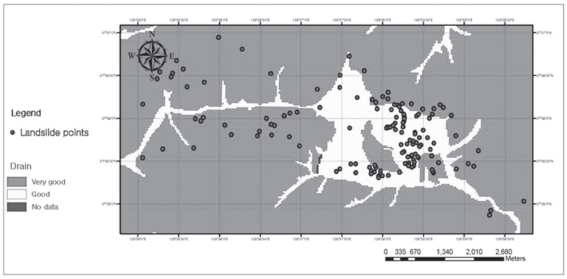


Fig. 7. Overlay of landslide points and drainage class

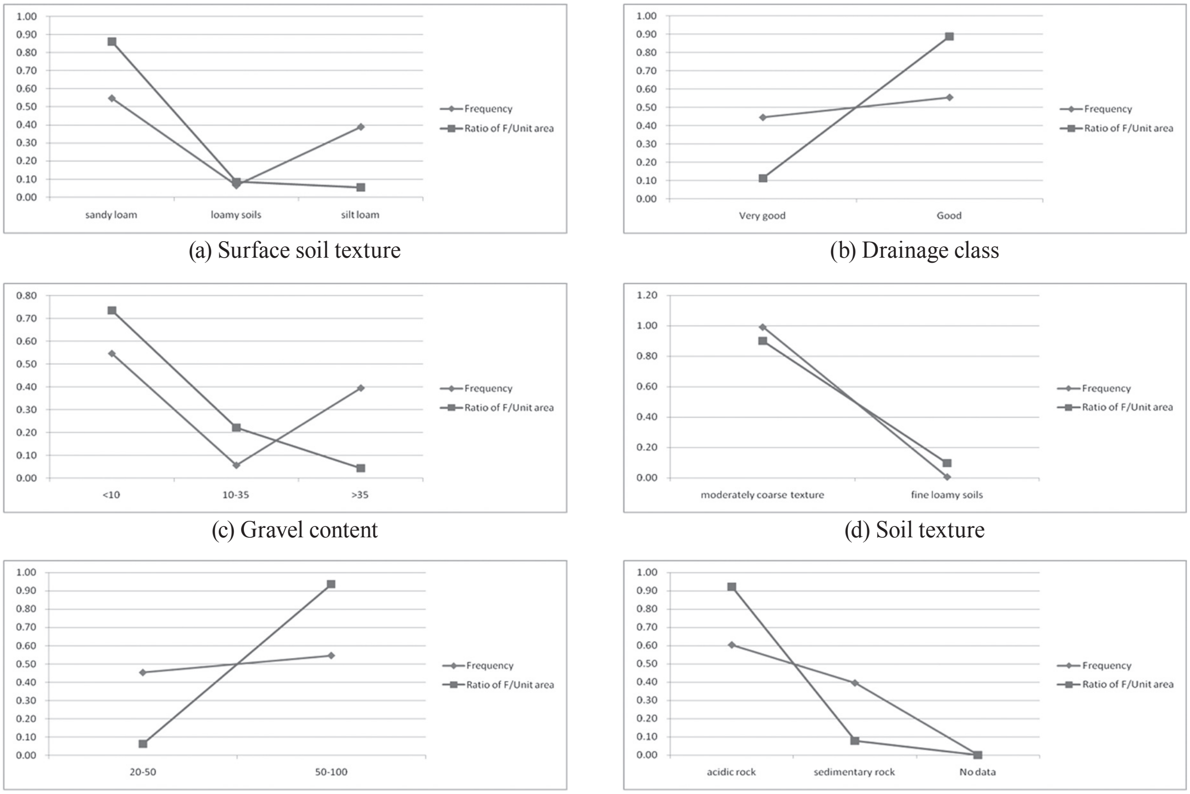
The depth of surface soil is about 15cm and the texture is determined by according to contents of clay, sand, and silt. The silt loam (31.49㎢) covered the largest area and the rests of the study area were the loamy soil (3.31㎢) and the sandy loam (2.78㎢). In the frequency per unit area, the sandy loam has shown the highest vulnerable level to landslides. It is considered that the high frequency is related to the drainage in the site.

The drainage class represents a duration or a frequency of the unsaturation of soil in water and is classified by five classes. Regarding the rate for each section in the drainage class, the very good class (32.46㎢) covered the largest area and the good class (5.12㎢) covered the other area. As shown in Fig. 8 (b), the good class represented a higher vulnerability level in landslides. However, additional studies on the vulnerability of landslides in other areas are required because the study area consists of the very good and good classes only.

The gravel content shows the amount of gravels at the depth of over 20cm from the ground surface and is classified into three levels, such as more than 35%, 10~35%, and less than 10%. The level more than 35% covered the largest area, 33.83㎢, and less than 10% (2.78㎢) and the levels of 10~35% (0.97㎢) were presented in residual areas. In the frequency per unit area, as shown in Fig. 8 (c) the high frequency was

Table 4. Analysis of soil factors

Surface	Area(㎢)	Frequency	Frequency/unit area	Drainage	Area(㎢)	Frequency	Frequency/unit area
Sandy loam	2.78	76(0.55)	0.86	Very good	32.46	62(0.45)	0.11
Loamy soil	3.31	9(0.06)	0.08	Good	5.12	77(0.55)	0.89
Silt loam	31.49	54(0.39)	0.05				
Subsoil gravel	**Area(㎢)**	**Frequency**	**Frequency/unit area**	**soil texture**	**Area(㎢)**	**Frequency**	**Frequency/unit area**
<10	2.78	76(0.55)	0.74	Moderately coarse texture	35.24	138(0.99)	0.90
10~35	0.97	8(0.06)	0.22	Fine loamy soils	2.34	1(0.01)	0.10
>35	33.83	55(0.40)	0.04				
Effective soil depth	**Area(㎢)**	**Frequency**	**Frequency/unit area**	**Parent material**	**Area(㎢)**	**Frequency**	**Frequency/unit area**
20~50	34.80	63(0.45)	0.06	Acidic rock	4.31	84(0.60)	0.92
50~100	2.78	76(0.55)	0.94	Sedimentary rock	33.28	55(0.40)	0.08



(a) Surface soil texture (b) Drainage class

(c) Gravel content (d) Soil texture

(e) Effective soil depth (f) Parent material

Fig. 8. Frequency per unit area of soil factors

presented in the level less than 10%. It shows that the low gravel content shows a high vulnerability level in landslides.

The subsoil is distributed at the depth of about 15cm from the ground surface and the soil texture represents the content of clay, sand, and silt. The moderately coarse texture, 35.24 ㎢, covered the largest area in the study area and other areas were covered by the fine loamy soils, 2.34㎢, where the soils showed a high content of silt and a low content of clay usually. Regarding the frequency per unit area, as shown in Fig. 8 (d) the moderately coarse texture has shown high levels in the landslide points, which represents a vulnerability in landslides.

The effective soil depth means a depth of stretching roots and a distance to a solid soil layer. It is classified into four different levels, such as less than 20cm, 20~50cm, 50~100cm, and more than 100cm. The effective soil depths in the study area were determined by 20~50cm (34.80㎢) and 50~100cm (2.78㎢). As shown in Fig. 8 (e), the level of 50~100cm covered the largest area. It has shown that an increase in the effective soil depth shows increases in the vulnerability of landslides.

The parent material shows rocks and strata during forming soils and is classified into acidic rocks, sedimentary rocks, and so on. The sedimentary rock covered that largest area, 33.28㎢, in the study area and the acidic rock was about 4.31 ㎢. Although the acidic rock covered small areas as shown in Fig. 8 (f), it caused more landslides than the sedimentary rock. There are big differences in comparison landslide frequency with landslide frequency per unit area in various soil factors except for soil texture.

4. Conclusion

In this study, the characteristics of occurring landslides were analyzed using frequency per unit area of landslides. Results are summarized as follows.

First, in the topographic factors the slope of 20°~40° caused most of landslides. In the aspect, from the W to the SE directions showed high risks of causing landslides in the Pyeongchang area. Regarding the curvature, although the convex shape slope represented high frequencies in landslides.

Second, The artificial pine and deciduous forests showed high frequencies in unit area. It reveals that increases in the self-weight of the artificial pine forest and the characteristics of the roots of pine trees are not helpful to increase the resistance to landslides. In the density, the low density showed the highest vulnerability in landslides. It showed that the roots of trees inhibited landslides and the forest density was closely related to the causing factor of landslides.

Third, in the soil factors both the surface soil and the subsoil showed high degrees of causing landslides. Regarding the drainage class, although the class good showed high vulnerability in landslides, it was difficult to determine it as a vulnerable factor because the subject site consisted of just two factors, very good and good.

Fourth, there are big differences in comparison only landslide frequency with landslide frequency per unit area in a lot of factors. So, considering frequency per unit area is necessary for landslide analysis.

In this study the issue of investigating basic factors that affect landslides was conducted and that can be used as basic research data for determining causing factors in landslides. Because the study area is limited in small area and the environments may varies in different area, it is necessary to verify the results with the data obtained in other large area. We think that the further study on calculating the probability of causing landslides using a logistic regression method is needed.

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