Chapter 5

Rainfall and Landslide Correlation Analysis and Prediction of Future Rainfall Base on Climate Change

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Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/64694

Abstract

The aim of this study is to analyze the quantitative relationship between the volume of rainfall and landslide occurrence in South Korea. To predict future rainfall, a future climate scenario was developed by downscaling the regional climate model (RCM) from the global climate model (GCM) based on the Intergovernmental Panel on Climate Change (IPCC) A1B scenario. In this study, for a quantitative analysis of correlation between rainfall and landslides occurrence, data on rainfall and landslides in Korea in the 2000s was analyzed using the correlation between the occurrence of landslides and rainfall volume (daily and accumulated) and the maximum hourly intensity of rainfall. Daily rainfalls exceeding 164.5 mm is categorized as high risk for landslide. A rainfall that continued for 3 days was found to affect the occurrence of landslide in Korea in the 2000s more than any other number of days during which rainfall lasted. The research area for the future climate change scenarios (A1B) covers the entire area of South Korea. Annual average rainfall had increased by 271.23 mm during 1971–2100. The development of downscaling method using GIS and verification with observed data could reduce the uncertainty of future climate change projection.

Keywords: correlation analysis, rainfall, landslide, climate scenario, statistical downscale, verification

1. Introduction

A landslide occurs when part of a slope suddenly collapses because of rapid changes in nature such as a torrential downpour, a typhoon, or an earthquake. In South Korea, the rainy season, extending from June to September, coincides with the period when landslides occur. Casualties and property damage have been on the increase, and recently, there is frequent localized heavy rain of several hundred millimeters.

The Fourth Report of Climate Change Assessment, published by [1], predicted that climate change would persist for several more centuries due to the greenhouse gases that have already been discharged, even though they could be mitigated by efforts such as a reduction in greenhouse gas emissions. The abnormal climate and localized torrential rain caused by climate change may lead to higher landslide rates. An analysis of the causes of landslides, with a multilateral, holistic view, is needed, given this expected increase in landslides due to climate change. Damage from landslides can be minimized by assessing landslide vulnerability [2].

In order to prevent and reduce landslide casualties and property damage caused by climate change, it is necessary to develop scientific methods for landslide analysis related to future climate change. It is important to predict landslide occurrence caused by future changes in rainfall through an understanding of the correlation between past and future rainfall and landslides and to develop methodologies to quantitatively predict changes in rainfall due to climate change. In addition, necessary is advancement in methods to identify landslide locations and a methodology to analyze and verify the relationship between landslides and climate change [3].

Landslide occurrence factors can be divided into internal and external factors. Internal factors include natural ones such as geological structure, topography, soil quality, and forest, while external factors include natural ones, such as rainfall, erosion of rivers and shores, and earthquakes, as well as artificial ones such as cut-embankment, logging, estate development, and quarrying. Landslides readily occur when a slope with internally adverse factors is subject to adverse external factors. In South Korea, landslides are intensified between June and August with localized torrential rain, a period when landslides occur frequently due to concentrated torrential rainfall. Reference [4] researched types and frequency of landslides by intensified torrential rain, centered on the urban areas of Avigliano. Reference [5] studied the frequency of landslides in Ethiopia by analyzing the relation between rainfall and topography, including landscape and forest distribution. Reference [6] analyzed landslide susceptibility based on the distribution of land moisture.

As mentioned above, studies on climate change and landslides' cause of occurrence have been individually conducted. Analysis of landslide occurrence due to future climate change, by relating the two, is still in its early stages, and awaiting global recognition. This study is one of the first attempts to directly correlate analysis of rainfall and landslide occurrence. Future landslide frequency would increase given the consistent effects of climate changes and with studies into the analysis of prediction of future rainfall based on climate scenario, such as the IPCC A1B scenario.

In this study, relations between landslide and rainfall, domestically from 1991 to 2010, are analyzed, and by linking these data to future climate changes, rainfall pattern is analyzed.

2. Methodology and contents

2.1. Analysis of relation between landslide and rainfall in the 2000s

A database for analyzing the correlation between landslides and rainfall in South Korea in the 1990s and 2000s was assembled. The period of collection is 19 years, from July 1991 to December 2010, the data being for landslides nationwide in South Korea. The references for locations and dates of landslides included newspaper articles, national and local media broadcasts, and reports by the Korea Institute of Geoscience & Mineral Resources (KIGAM) and the Korea Institute of Construction Technology (KICT). There is a great deal of data for landslides in the 2000s from various sources, but data for landslides in the 1990s, sourced from relevant academic articles and national media, are limited. This is why this section focuses on the relation between landslides and rainfall in the 2000s, data from the 1990s being included only for reference.

Locations and dates of landslides were extracted from the collected data. A climate database was assembled using observational data from the Automatic Weather Station (AWS) for the area closest to each landslide over the preceding 5 days. Centered on the date of the landslide, the daily rainfall data from 5 days before to 5 days after the landslide was organized. The total organized data comprised 186 landslide locations and daily rainfall. The 186 landslide spots were not averaged out to be the spot of the landslide but indicate points where landslides occurred *en masse*. The analysis of the relation between landslides and rainfall is conducted by two means. First, rainfall data was collected for the same day of the year as each landslide in order to analyze the correlation between rainfall on the day of landslides and that in the 2000s. Second, daily rainfall was added to each following day in order to analyze the relation between landslides and cumulative rainfall. Additionally, in order to identify the effect of daily rain intensity on landslide occurrence, cumulative rainfall for 1, 3, and 5 days were analyzed.

2.2. Prediction of future rainfall change based on climate scenarios

Abnormal weather and concentrated torrential rainfall are becoming more frequent around the world, with concentrated torrential rainfall predicted to occur consistently with climate change [7]. The prediction of future rainfall changes, reflected in climate change, can be divided into predictions using rainfall probability and predictions using future climate change scenarios. A prediction using rainfall probability is for calculating the frequency of occurrence of the same rainfall by inputting past climate data—a probable statistic method based on past data. It can be used with past extreme climate events such as concentrated torrential rainfall and typhoons and can predict to a certain temperature degree. However, it requires processing of data from the same period in adjacent observation spots with the same method in order to do the interpolation because the calculated results are depicted as points representing the observation spots.

Predictions using future climate change scenarios are conducted after the development of the regional climate model (RCM) by individual research centers of the relevant nation from the global climate model (GCM) presented by the Data Distribution Center (DDC) of the IPCC.

The GCM is to predict the future by using the atmospheric general circulation model (AGCM) and humanistic, economic models, predicting temperature increases and changes in rainfall by the prediction of CO_2 discharge. The GCM has several problems: first, future predictions are dependent on the results of the prediction model; second, its spatial resolution is between 200 and 400 km and it is not appropriate for nationwide studies such as the ones covering South Korea; and third, it cannot predict extreme climate events such as concentrated torrential rainfall and typhoons. In order to avoid these problems of the GCM, a study to develop the RCM with its spatial resolution at the regional scale has been conducted. The RCM is to be built on the basis of the GCM by connection with the GCM and humanistic, economic status at regional levels. RCM can be improved to a spatial resolution of 20–25 km, but it is still dependent on the results of the prediction model of the future climate change, and it is hard to predict changes in extreme climate events. This study, in order to improve its spatial resolution, improved the existing spatial interpolation by applying the temperature and rainfall lapse rate to conduct the specification of the future climate change scenario at scales covering South Korea.

2.3. Spatial statistical downscaling of climate change scenario

As with climate change scenarios, the spatial data used in climate change studies should be connected continuously in space. However, the climate data observed in the past and those for predicting the future consist of representative values in the form of points, and for areas without such representative values, the values should be inferred by spatial statistic interpolation. Interpolation indicates a method by which continuous spatial distribution data is built from the inference of values of nonobserved and adjacent spots from the values of observed spots.

Spatial interpolation has various methods of different characteristics. This study selected Co-Kriging, a geostatistics technique in which eigenvalues for the relevant spots are predicted by the linear combination of already-known adjacent values. In this technique, the adjacent, actually measured values are linearly combined for interpolation, and values are estimated by using such statistical methods. Co-Kriging estimates values by the statistical analysis of many adjacent measured values, indicating that it reflects correlative intensity among the adjacent measured values as well as the distance to actually measured values. Co-Kriging is advantageous for identifying overall trends. The applied Co-Kriging equation is as shown in Eq. (1):

$$Z^*(u) - m(u) = \sum_{\alpha}^{n(u)} \lambda_a [Z(u_a) - m(u_a)] \tag{1}$$

where u, u_a are the locations estimated and locations of known data, $Z(u)$, $m(u)$ are the estimation from adjacent data used, $m(u)$, $m(u_a)$ are the estimated values of $Z(u)$ and $Z(u_a)$, and $\lambda_a(u)$ is the Co-Kriging weighted value (weight).

As mentioned, Co-Kriging is used in this study because it is advantageous for identifying trends across a wide area. To calculate estimated values on nonobserved spots, the effects of observed values of the relevant observed spot are more reflected as the relationship of the adjacent observed spots and the linearity becomes closer. In other words, the types of linearity between nonobserved spots and adjacent observed spots are inferred and reflected as inversely proportional to distance and observed values.

Among the topographical factors, altitude has the greatest effect on changes in rainfall and temperature, as climate elements. Temperature, of the climate factors, is particularly affected by altitude, decreasing as altitude increases under the troposphere [8].

When an interpolation of the general geographic information system is applied, accurate estimation is difficult because of the severe skewness of spatial dependence by other factors. In this study, temperature and rainfall serve as variables, and altitude is a factor damaging spatial dependence. In order to overcome this problem, a form of Co-Kriging with which altitude data can be directly considered is selected over general Co-Kriging. Co-Kriging is a method used to interpolate data in the process of spatial estimation. Temperature and rainfall data has a linear correlation to altitude data [8], and thus altitude data can present additional information to reduce inferred measured values in estimating values for temperature and rainfall in nonobserved spots.

When the data used in all the study areas, including digital elevation data, is used with Co-Kriging, it is known to cause uncertainty in getting a Co-Kriging system weight matrix because the correlativity of adjacent altitude data is larger than that of sample values of temperature or rainfall [9]. In addition, altitude data, existing at or adjacent to estimated locations, may conceal the effects of distant altitude data. In order to reduce such errors, this study used collocated Co-Kriging in which additional data can be used globally in the existing Co-Kriging, limited only by additional data values at estimated locations in Eq. (2):

$$Z_{CK}^{*}(u)=\sum_{a=1}^{n(u)}\lambda_{a}^{ck}(u)z(u_a)+\lambda^{ck}(u)\left[y(u)-m_Y+m_z\right] \tag{2}$$

where $y(u)$: is the altitude value at location u that is not sampled and $m_y + m_z$ is the average value of altitude data and data of temperature or rainfall.

For the altitude data in this study, a digital map (1:25,000) is used as primary data, and the spatial resolution is transformed to digital elevation model (DEM) data (30 m). The locations of the nation's 75 weather stations are plotted on a map, and the land section of the land cover map (1:25,000) is used to build the data for the coastline of South Korea. Because the observed values from the 75 weather observation spots between 1971 and 2000 differ in altitude above sea level and in the heights above surface level of thermometers and rain gauges, a modification equation for the temperature lapse rate was presented by [10]. The temperature lapse rate was based on altitude (Eqs. (3) and (4)). As for rainfall data, the rainfall lapse rate is considered on the basis of altitude [11] (Eqs. (5) and (6)). Eq. (5) shows that the rainfall value should be increased by 74% per 1 km for October-April (Cold Season). For the period May-September (Warm Season), Eq. (6) reflects a 46% reduced rainfall value:

$$|\tau| = 0.00688 + 0.0015\cos 0.0172(i-60) \text{ Average Temperature Lapse Rate} \quad (3)$$

where $|\tau|$ is the absolute value of air temperature lapse rate based on annual dates, and i is the annual date (1/1 day = 1, 12/31 day = 365):

$$\text{T} = T_i + \text{Elevation}(m) \times |\tau| \quad (4)$$

where T : is the temperature corrected by the air temperature lapse rate, and T_i: is the daily temperature (air-temperature lapse rate corrected before the temperature):

$$R = R_i \times (1.74)^{\frac{E}{1000}} \quad (5)$$

$$R = R_i \times (0.46)^{\frac{E}{1000}} \quad (6)$$

where R represents rainfall and E represents elevation (m).

3. Result

3.1. Relation between landslide and rainfall of the day

Figure 1 shows representative types of landslides and rainfall. The *X*-axis averages periods of rain and the *Y*-axis averages periods of occurrence per year as frequent rainfall. Rainfall in the diagram is calculated from the AWS's rainfall data within the areas of landslides.

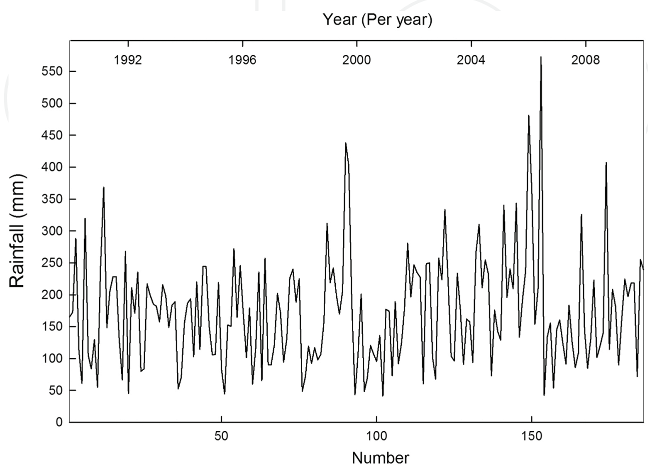

Figure 1. 1-day maximum rainfall of the study area in the 2000s.

Regarding the characteristics of rainfall on days related to landslides in the 2000s, landslide dates are clustered around July 14 and 16, July 22 and 23, August 25 and 26, and September 13 and 16. Examining average rainfall at the time of landslide occurrence, landslides seem to usually occur when rainfall is around 170 mm. Landslides occurring when rainfall was less than 100 mm are considered to result from temporary construction or high cumulative rainfall.

3.2. Relation between landslide and cumulative rainfall

A comparison of cumulative rainfall before landslides with rainfall on the day of landslides was conducted in order to analyze the relation between rainfall on the day of a landslide and cumulative rainfall as a possible cause of landslides. Cumulative rainfall before landslides (1, 3, and 5 days) and rainfall on the day of landslides are compared per year. The horizontal (*X*) axis indicates rainfall on the day of the landslide, while the vertical (*Y*) axis indicates the amount of accumulated rainfall over 1, 3, and 5 days prior to the landslide. **Figures 1–4** show that landslides are caused by rainfall when a region over the 45° central border line is spotted, while they are considered to be caused by cumulative rainfall when a region under the line is spotted. In an analysis of rainfall on the day of a landslide and the cumulative rainfall of 1 day before the landside for the 2000s, landslide spots over and under the 45° central border line are clearly separated. There are 162 spots over and 24 spots under the central border lines (**Figure 2** and **Table 1**). **Figure 2** and **Table 1** include rainfall on the day of the landslide and cumulative rainfall for 3 days before the landslide, where the spots are distributed over and under the 45° central border line, indicating that landslides are equally caused (spots over the border: 86; spots under the border: 80) by rainfall on the day of the landslide. The cumulative rainfall data for 3 days prior is shown in **Figure 3** and **Table 1**. Rainfall on the day of the landslide and cumulative rainfall for 5 days prior are shown in **Figure 4** and **Table 1**. Landslides are spotted more on the area under rather than over the 45° central border line (spots over the border: 56; spots under the border: 130), indicating that landslides are caused by 5-day cumulative rainfall rather than by rainfall on the day of occurrence. Note that 3-day cumulative rainfalls, therefore, may be more indicative of whether landslides are caused by rainfall on the day of occurrence or by cumulative rainfall. Many landslides in the 2000s are closely related

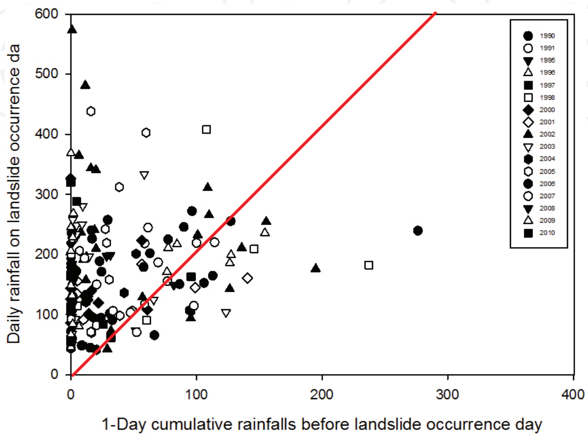

Figure 2. 1-day cumulative rainfall before landslide occurrence day.

to 3-day cumulative rainfall, and thus landslides in the 2000s may be affected more by cumulative rainfall than by rainfall on the day of occurrence. As a result, 1-day rainfall and 3-day cumulative rainfall, rather than cumulative rainfall on other days, had a higher correlation with landslide occurrence.

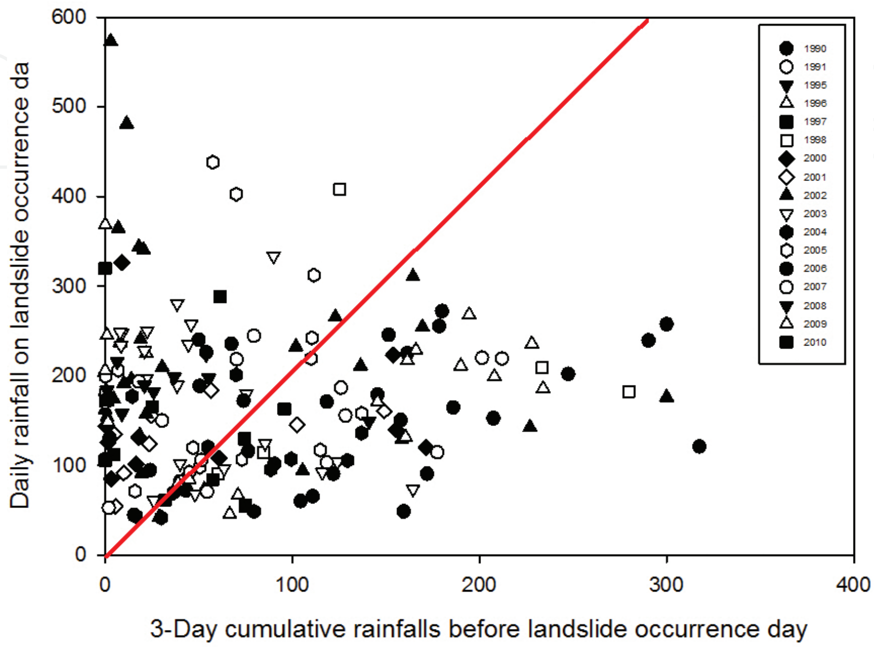

Figure 3. 3-day cumulative rainfall before landslide occurrence day.

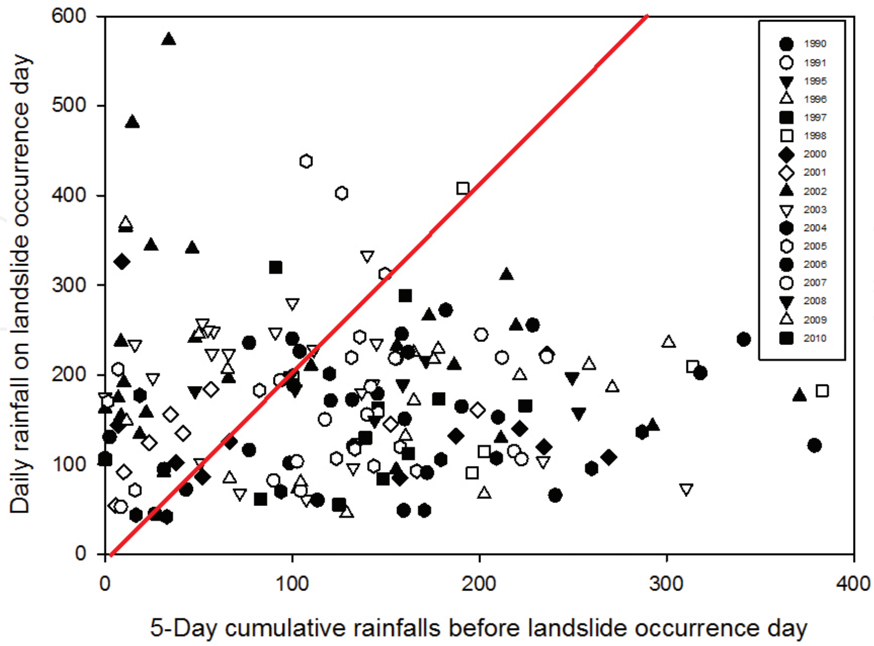

Figure 4. 5-day cumulative rainfall before landslide occurrence day.

Classification	Over	Under
Daily rainfall and 1-day cumulative rainfalls before failure data **(Figure 2)**	162	24
Daily rainfall and 3-day cumulative rainfalls before failure data (**Figure 3**)	86	80
Daily rainfall and 5-day cumulative rainfalls before failure data (**Figure 4**)	56	130

Table 1. Summary of landslide spot counts over and under the 45° central border line (number of spots).

3.3. Scenario for future climate changes in South Korea

The period for the study results built from spatial statistical downscaling of the KMA-RCM is 1971–2100, and average temperature and rainfall per month are produced. Temperature and rainfall are selected from the climate change models because they are the two factors that can express future changes in climate fragmentally and representatively, with higher practical utility (**Figure 5**).

Rainfall was analyzed by accumulation of the monthly average, decreasing from 947.38 mm in Year 1971 to 886.02 mm in Year 2000, a drop of 61.35 mm. Results of future climate change data processing showed that the rainfall estimate increased from 1002.12 mm in Year 2001 to 1218.60 mm in Year 2100, or by 216.48 mm. The annual average rainfall is showed by 271.23 mm from Year 1971 to Year 2100 (**Figure 6**). **Figure 6**, where the *X*-axis is the year and the *Y*-axis is average rainfall, respectively, shows a linear increase.

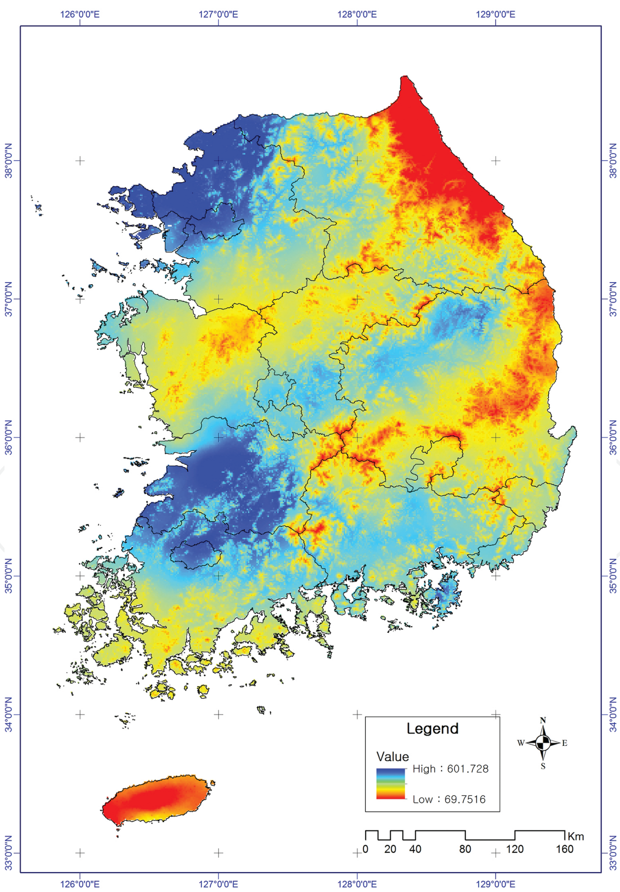

Figure 5. The average rainfall in July 2071 (based on KMA-RCM).

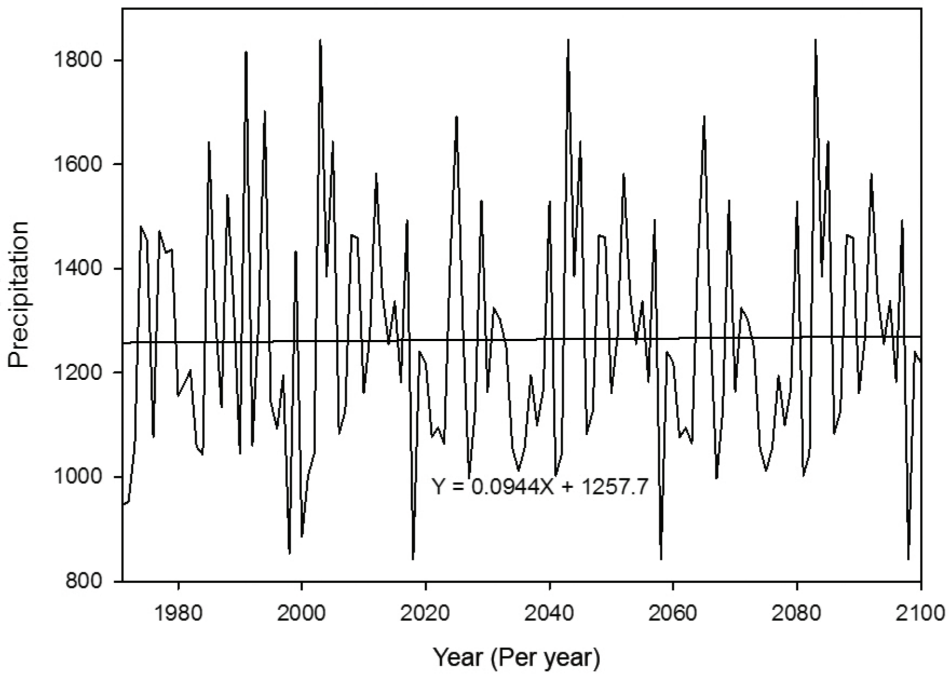

Figure 6. 1971–2100 annual rainfall change in South Korea.

Regarding the annual cumulative rainfall for this 130-year period, 1839.36 mm (2003, 2043, and 2083 year) is the highest, and 847.37 mm (2018, 2058, and 2098 year) is the lowest, a difference of 991.99 mm, while 1817.03 mm (Year 1991) is the second highest, and 853.5 mm (Year 1998) is the second lowest. When years with the same rainfall distribution were organized, 71 are separated. In the distribution maps, built from past climate data, single rainfall is shown as 1817.03 mm and 1701.14 mm. When downscaling based on the KMA-RCM is conducted, the changes in cumulative rainfall as a future change in climate show the repetition of the same distribution with an interval of 40 years, with an overall increase in rainfall [12].

3.4. 1971–2100 annual rainfall change in South Korea: verification of climate change scenario result

In order to reduce uncertainty occurred in the process of spatial statistical downscaling of future climate change scenarios, the analysis of the correlation between this research's results and actual measurements was carried out. Weather data after Year 2000 was selected as the reference year and 75 AWS, which were closest to 75 ground observation points, and data from January 2001 to August 2010 existed was selected and the analysis of correlation between temperature and rainfall data and data obtained through future climate change scenario prediction from 2001 to 2010 was carried out. The data was analyzed and the coefficient of correlation between future climate change scenario prediction data and actual measurements from AWS was over 0.98 on average in the case of temperature and 0.56 in the case of rainfall. This was lower than that of the temperature, but in consideration of uncertainty in rainfall prediction on the climate change scenario, it was a high correlation.

http://dx.doi.org/10.5772/64694

Area	Correlation coefficient	Area	Correlation coefficient	Area	Correlation coefficient
Gangneung	0.41	Busan	0.63	Jangheung	0.49
Ganghwa	0.70	Sancheong	0.53	Jeongu	0.65
Geochang	0.52	Seosan	0.50	Jeongeup	0.65
Goheung	0.49	Seoul	0.64	Jecheon	0.64
Gwangju	0.46	Sokcho	0.45	Jinju	0.48
Gumi	0.62	Suwon	0.62	Cheonan	0.65
Gunsan	0.61	Suncheon	0.61	Cheorwon	0.68
Geumsan	0.60	Andong	0.63	Chupungnyeong	0.67
Namwon	0.57	Yangpyeong	0.62	Chuncheon	0.67
Namhae	0.40	Yeongdeok	0.45	Chungju	0.58
Daegwallyeong	0.59	Yeongwol	0.60	Taebaek	0.57
Daegu	0.49	Yeongju	0.64	Tongyeong	0.39
Daejeon	0.73	Yeongcheon	0.50	Pohang	0.45
Masan	0.45	Ulsan	0.46	Hapcheon	0.49
Mungyeong	0.70	Uljin	0.35	Haenam	0.49
Baengnyeongdo	0.50	Uiseong	0.60	Hongcheon	0.60
Boyeong	0.59	Icheon	0.57	Heuksando	0.50
Boeun	0.76	Incheon	0.64	Yeosu	0.42
Bonghwa	0.66	Imsil	0.66		
Busan	0.29	Jangsu	0.65		

Table 2. Result of correlation between statistical downscaling of future climate change scenario and AWS in Years 2001–2010 (rainfall).

Note that 75 AWS where rainfall data existed from January 2001 to August 2010, 75 observation points were extracted and summarized in **Table 2**. In the case of correlation on rainfall summarized in **Table 2**, most weather stations showed a significantly high correlation, but in some cases of correlation on rainfall shown in **Table 2**, the range of rainfall variability was significantly high depending on the weather station.

In the analysis of correlation on the amount of rainfall, Ganghwa showed a correlation of 0.70, which was significantly high, but Busan showed a correlation of 0.29, which was lower than that of other areas. It was analyzed that generally the correlation between future climate change scenario prediction data and actual measurements was significantly high, but in the case of rainfall, the variability for each year and season was high. South Korea shows abundant rainfall in summer, and the standard deviation of rainfall in summer varies more than two times between regions, and the rainfall variability for each region is also significantly high. In addition, the range of rainfall variability near the coast is higher than that in the inland area in South Korea, and the east coast has the higher rainfall variability than the west coast [13]. In the result of correlation between the rainfall and future climate change scenario prediction data, the bottom 10%, which had the lowest correlation, showed a correlation of less than 0.40, and the corresponding area included Busan, Uljin, Tongyeong, and Namhae. In order to analyze the correlation of relevant area more precisely, the analysis of correlation for each season was carried out additionally. An area with a low correlation was selected because a seasonal change in an area with a low correlation was more closely related with rainfall change [13]. In the analysis result, it was analyzed that the correlation between three regions except for Uljin was lower during summer and winter, with a high range of variance in the meteorological factors (**Table 3**).

Area	Correlation coefficient	Correlation coefficient (summer and winter)	Correlation coefficient (spring and fall)
Busan	0.29	0.24	0.45
Uljin	0.35	0.30	0.16
Tongyeong	0.39	0.37	0.50
Namhae	0.40	0.39	0.43

Table 3. Result of seasonal correlation coefficient between statistical downscaling of future climate change scenario and AWS in Years 2001–2010 (rainfall).

4. Discussion and conclusion

In this study, the pattern of rainfall generating a landslide in the past was analyzed, and the threshold of landslide occurrence by rainfall was also analyzed. Based on the analysis result, the possibility of landslide occurrence in the future was analyzed by analyzing the rainfall of future climate change scenarios.

When the relation between rainfall during the 2000s and landslides in South Korea is quantitatively analyzed, 1-day rainfall and 3-day cumulative rainfall had higher correlations with landslides. Based on this, the landslide occurrence threshold in the study area is defined to be 202 mm for 1-day rainfalls and 449 mm for 3-day cumulative rainfalls. The results of this analysis of rainfall probability show the ratio of the occurrence threshold consistently increases as the target year increases in the study area, the same tendency is seen in the future climate change scenario. Conclusively, the study area has seen increasing rainfall as time passes, and damage, such as that from the 2006 landslide, may increase gradually in the future.

As the target year increases, the accuracy increases for the 202–449 mm thresholds of rainfall probability and the future climate change scenario. In all of the methods applied, the accuracy is higher for the 449 mm threshold than for 202 mm of rainfall probability. A 3-day cumulative rainfall affects landslide occurrence more than a 1-day rainfall in the relation between rain and landslides.

In addition, a rainfall change from Years 1971 to 2100 was analyzed through the analysis of the climate change scenario based on KMA-RCM in this study. The main result of this study can be summarized as follows.

First, the downscaling technique using rainfall lapse-rate technique was developed by using Co-Kriging among geographic information spatial-interpolation techniques. As a research result, the average rainfall between 1971 and 2100 was drawn. The result showed that the average rainfall increased by 271.23 mm.

Second, the analysis of correlation between the average rainfall between 2001 and 2010 and actual measurements from 75 AWSs from regional-scale climate change scenario was carried out. As a result of analyzing the correlation between the future climate change scenario prediction data and actual measurements during the same period, it was concluded that the correlation on the rainfall was 0.56.

A study to downscale KMA-RCM with a spatial resolution of 27 km into the climate change scenario with a spatial resolution of 1 km, which could express the local level climate change, was carried out. In order to reduce the uncertainty in the climate change scenario occurred during this process, the correlation between actual measurements after the reference year entered on the future climate change scenario and research results were analyzed. The result verified that the significance of downscaling of results through KMA-RCM is high, and the average climate pattern (30 years in the past) and the weather pattern from Years 2001 to 2010 were similar. In the case of rainfall, temperature, humidity, and local characteristics (e.g., topography and characteristics of ground surface, etc.) have interacted in the rainfall process complexly, showing a nonlinear relationship [13], and the result of this study was also affected in the same way.

The results of this analysis of correlation between rainfall and landslide show the cumulative rainfall consistently increases in South Korea, the same tendency is also seen in the future climate change scenario.

A result of correlation between rainfall and landslide and the future rainfall change also shows future rain events for quantitative analysis of climate change in South Korea. Changes in rainfall in South Korea are shown to be larger.

The occurrence of landslides is directly caused by intensive rainfall. If there is a change in rainfall, it will lead to a change in the occurrence of landslides.

However, this study is unable to reflect extreme conditions according to climate change, and, even though, the correlation between the result of this study and actual measurements was significantly high, it is necessary to improve the methodology to future climate change scenario prediction continuously. It is necessary to supplement methodologies regarding extreme rainfall and extreme climate events in order to reduce the uncertainty in the future climate change scenario in future studies.

Acknowledgements

This research was supported by Korea Environment Institute funded by the Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education (NRF- 502014R1A1A1002704).

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