論 文 の 内 容 の 要 旨

論文題目　GIS-based Susceptibility Analysis and SAR-based Detection for the Landslides Triggered in 2018 Hokkaido Eastern Iburi Earthquake
(2018年北海道胆振東部地震の土砂災害に関するGISを用いた危険度評価とSARを用いた検出に関する研究)

氏　　名　葛　平兰

The 2018 Hokkaido Eastern Iburi Earthquake induced a special landslide event, in which extensive densely distributed small-sized shallow landslides occurred in the soil types of pyroclastic fall deposits near the towns of Atsuma, Mukawa, and Abira. This disaster brought valuable data, experience, and lessons, while causing big casualties and damage in Eastern Iburi area of Hokkaido prefecture, Japan. This research aimed to make full use of these data and experience to understand the landslide event, learn from it, and to suggest a procedure benefiting future landslide disaster management. Spatial data and previous reports and studies concerning the landslides were analyzed and studied to understand the landslide event. GIS-based susceptibility analysis and SAR-based detection for the landslides were carried out to benefit pre-event and post-event landslide management, respectively. Based on these analyses, some lessons were learned and a procedure was suggested for landslide disaster management in the future. To systematically introduce these analyses, studies, and lessons, seven chapters were arranged in this thesis, of which the details were described as follows:

Chapter 1 introduced the basic information of this research, including research background, problem statement, research objective, research methodology, and the structure of the research. The special landslide event caused by 2018 Hokkaido Eastern Iburi Earthquake reminded us to learn from it and to make a management procedure corresponding to landslide process for reducing casualties and damage. Considering the purpose of emergency application and the actual situation of landslide disaster, GIS-based landslide susceptibility and SAR-based landslide detection were determined, even though there were several problems to be solved for their application in such cases. To explain how to use these analyses to achieve these objectives systematically and clearly, seven chapters were written orderly and logically.

Chapter 2 described the important concepts and terminologies used in this research, including landslide, GIS, RS, SAR, disaster, and disaster management. The definition, causes, types, and impacts of landslides were first introduced to provide an understanding of the research subject. The concepts, basic knowledge, important terms, and advantages of GIS, RS, and SAR were then presented to explain the major technologies and tools applied in this research and why they were applied. The definition, classification, and impacts of disaster as well as the procedure and cycle for disaster management were finally described to help understand this research in a big picture of disaster study.

Chapter 3 analyzed the characteristics of the landslides by collecting spatial data of landslide inventory and conditioning factors (topography, geology, soil, surface vegetation, precipitation, and ground motion), and studying previous reports and research concerning this landslide event. These landslides were densely distributed in a region of the transition zone from Hidaka Mountains to Ishikari Depression in the north of the earthquake epicenter within a distance of 25km from the epicenter. Most of them were small-sized shallow landslides with a slip surface above the basement complex, moving down several meters' pyroclastic fall deposit layers with long run-out and high mobility. These landslides mainly occurred in valley topography and planar slopes with several types, leaving the landslide upper surface exposed as brownish patches. The slope gradient of the landslides was smaller comparing with the general value of other landslides, which might due to the special soil types here (porous pyroclastic fall deposits) and the inundation of the soil by previous rainfall. The earthquake was the direct trigger and the combinational impact of several conditioning factors (especially soil, rainfall, and earthquake) was the real cause of the landslides. The general mechanism of most landslides might be that the shear force of the earthquake ruptured the soft porous pyroclastic fall deposit layers that have already been inundated by the previous accumulated rainfall from the hard bedrock.

Chapter 4 executed suitable GIS-based landslide susceptibility analysis using the collected spatial data to facilitate pre-event landslide disaster management in the future. Landslide inventory and conditioning factors were used as dependent and independent variables in the analysis, respectively. All collected data, either in a raster format or in a vector format, were converted into the same format-10m raster cells for analysis. Effectiveness, correlation, and multicollinearity problems of the conditioning factor indicators were analyzed by the area under the ROC curve, Pearson's correlation, TOL, and VIF, to find the relatively effective indicators and to exclude the correlated indicators for model construction. Several different ratios of landslide presence and absence were tested to find a favorable one for statistical analysis, as there were much more non-landslide cells than landslide cells. A landslide susceptibility model was finally constructed using the selected indicators under the determined ratio by a logistic regression. 70% of the data were used for training and 30% of the data were used for validation to construct and check the model. Applying the constructed model, a landslide susceptibility map was generated in the study region, which showed certain consistency with actual landslides. It was expected to provide some information for future landslide occurrence by updating the changed terms, such as ground motion.

Chapter 5 explored favorable SAR-based landslide detection approaches by analyzing different features in captured SAR data to benefit post-event landslide disaster management in the future. Two pre-event and one post-event ALOS-2 SLC SAR products with a high resolution were applied. Potential parameters that could be derived from these products and had the ability to measure ground changes were selected and calculated based on radar reflection mechanism. Considered parameters included the absolute value of intensity difference, co-event correlation coefficient, correlation coefficient difference, co-event coherence, and coherence difference. Qualitative and quantitative analyses of these parameters were carried out to understand and compare their performance for landslide and non-landslide pixel distinguishment. Favorable parameters were explored for identifying landslide pixels by the optimal thresholds. A joint application of several parameters for landslide detection was also investigated by a linear discriminant analysis, using three relatively favorable parameters with one in each type. A simple exploration and comparison of the free Sentinel-1 SAR products for the landslide detection was also performed to provide some reference for future application.

Chapter 6 investigated an additional application of landslide susceptibility map or landslide conditioning factors to the SAR-based landslide detection. Landslide susceptibility map was constructed by a series of landslide conditioning factors and could provide the dangerous condition of landslide occurrence in different areas. For areas with such a map, the additional application of it to the SAR-detected landslides could help improve the landslide detection results, limit the scope of SAR image for processing, draw attention to dangerous areas, and provide more reasonable information for rescue and response operations. For areas without such a map, the landslide conditioning factors can be applied to improve the SAR-based landslide detection results. Exterior conditioning factors (e.g., ground motion and precipitation) can be used to eliminate irrelevant areas and narrow target areas for analysis. Interior conditioning factors (e.g., slope gradient and land use) can be applied to exclude areas of no interest or areas where landslides are unlikely to occur (e.g., flats and waters).

Chapter 7 summarized the main conclusions, recommendations, limitations, and possible directions for future study. The special characteristics of the landslide event reminded us to pay attention to the dynamic characteristics of pyroclastic fall deposits. Moreover, areas with special characteristics should also be taken seriously, when landslide triggers occur even with a low intensity, as the combinational impact of several conditioning factors that are not very significant might cause a severe landslide event. According to GIS-based landslide susceptibility analysis and SAR-based landslide detection, a following landslide management procedure can be applied corresponding to a disaster process: before landslide occurrence, updating the predicted or actual rainfall and/or earthquake terms in the landslide susceptibility map according to actual situation, to understand the dangerous condition of landslide occurrence in different areas and to remind local people for better preparation; after landslide occurrence, detecting the landslides rapidly by suggested SAR features and combining them with the updated landslide susceptibility map to provide information for rescue and response operations; after that, when available and applicable, analyzing optical remote sensing images and carrying out field survey to obtain more detailed information of the landslide event from other aspects. The obtained information, data, experience, and lessons can then be used to improve the developed models and approaches in the previous procedures. There were several limitations in the research that can be studied further, such as the detailed physical mechanism of the landslide occurrence, the dynamic characteristics of the pyroclastic fall deposits, and the polarimetry information in SAR data for landslide detection.