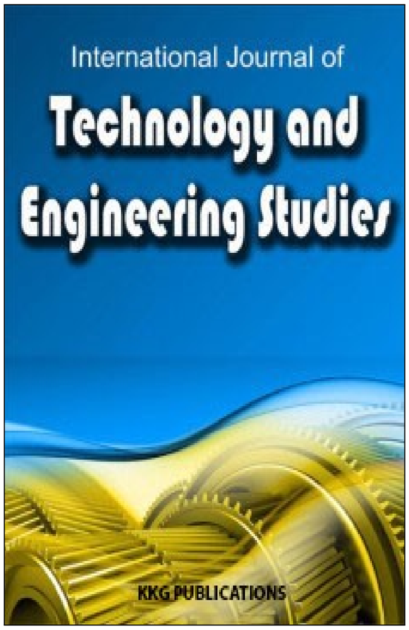

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A Study on the development of Priority Estimation Process for Supporting Damage Investigation

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A STUDY ON THE DEVELOPMENT OF PRIORITY ESTIMATION PROCESS FOR SUPPORTING DAMAGE INVESTIGATION

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Abstract. This study aims to provide a solution to decrease the large amount of time consumed during the damage investigation. Therefore, this study suggests a priority estimation process of the damage investigation that calculates the damaged areas caused by the natural disaster and estimates the damage investigation priority according to the size of the damaged area. The estimation process comprises four steps: preprocessing, damaged area calculation, priority estimation, and information provision. The preprocessing ensures that the pre-and post-satellite images of the damage and GIS thematic maps have identical coordinates and locational information. The damaged area calculation accompanies automatic calculation using the Change Vector Analysis (CVA), Differential Normalized Difference Vegetation Index (DVI), and Tasseled Cap Transformation (TCT) algorithms. The priority estimation can be done according to the size of the damaged areas of individual administrative boundaries. The last step of the information provided is to provide necessary information such as land cover and cadastral data within the damaged area through the overlay analysis of land cover maps and continuous cadastral maps. The priority estimation process developed in this study is expected to be helpful for more effective dispatching of local government personnel and supporting early response and recovery for the residents within the damaged area. Furthermore, a follow-up study for developing the system to operate the priority estimation process established in this study is required.

INTRODUCTION

Recently, damage caused by natural disasters has been occurring frequently and globally. Such damage occurs accidentally owing to abnormal climates. Moreover, the scale of the damage is increasing.

Currently, in Korea, public investigators who are local government officials are sent to investigate damage caused by natural disasters. Investigating this type of damage requires a significant amount of time and a large number of investigative personnel. Therefore, it is necessary to effectively use the limited number of local government personnel.

Furthermore, Information Technology (IT) and remote sensing are rapidly becoming more sophisticated. There is an increasing need to develop damage investigation techniques in the field of disaster control. There is also active research on the use of satellite imagery of extensive natural disaster areas to explore the damage [1].

However, most of the studies on the exploration of damaged areas using satellite imagery use supervised classification by remote sensing experts, and unsupervised classification with low classification accuracy. These methods are difficult for the person directly involved in damage investigation to use because damaged areas are identified inaccurately or an expert's intervention is necessary. Therefore, it is necessary to perform a study to identify damaged areas accurately based on satellite images, and to utilize these for worksite operations related to damage investigation.

In addition, the use of the GIS is increasing day by day. GIS is used in various fields such as facility management, environmental management, national defense, city planning, and disaster control based on location information, as well as remote sensing. In particular, the utilization of GIS is essential for disaster control, which requires general damage information as well as accurate location information [2].

Therefore, this study uses satellite imagery and GIS without specialized knowledge related to satellite images to identify damaged areas owing to natural disasters, and proposes a priority estimation process to investigate damaged areas within administrative boundaries.

LITERATURE REVIEW

Currently, research is being conducted on using satellite imagery in the detection of damaged areas resulting from natural disasters. [3], using Landsat 7 ETM+ images, proposed a method to analyze changes in land coverage of the Namdae stream basin in Gangneung, Korea. The changes were caused by typhoon RUSA. This study uses a DNDVI algorithm. DNDVI algorithm is difference in Normalized Difference Vegetation

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Index (NDVI) indicating the activity of vegetation. The algorithm then computes the difference between the pre and post-satellite images of the damage. Using these difference values, the algorithm identifies waterlogged ground and areas damaged by the typhoon.

[4] used Landsat TM images to conduct a study of changes to the downstream area of the Nakdong River in Gyeongsangna-do, Korea, which is an area that was significantly damaged by typhoon RUSA. This study uses the TCT algorithm to obtain various land cover information from satellite images and to extract brightness, moisture, and components of vegetation. Then, the procedure applies CVA, an algorithm that detects changes in images across two different time periods, to generate the components that will be extracted later to detect changes. Finally, the procedure compares the findings from the application of Principal Component Analysis (PCA) and an image difference approach with those generated by the CVA algorithm. As a result of this comparison, the CVA algorithm appears to be the most appropriate for detecting changes in waterlogged ground. As an example that shows a system buildup, [5] developed a damage history visualization system that identifies and captures damage history from a map of the damage inflicted in Busan, Korea. This area was severely impacted by heavy rainfall in 2009, and later by typhoon Maemi in 2003. This system was designed to search for damage history data by type of disaster as specified by content of damage, cause of damage, and classification of damage. Moreover, the National Institute for Disaster Prevention [6] developed a damage investigation system to compute the scale of damage caused by a disaster. This system computes the estimated damage by allowing users to read pre and post-damage satellite images for a visual interpretation, and then providing users with damage information that defines affected areas of cropland and the affected number of buildings.

Based on these previous research studies, it was found that there are limitations when applying damage investigation techniques that analyze on-site work operations in progress.

Simply identifying the damaged area, visualizing previous damage, or visually inferring a damage assessment is not sufficient. To overcome these limitations, this study develops a priority estimation process that considers the spectral characteristics of pre and post-damage satellite images to identify damaged areas and damaged areas of investigation within the boundaries of a unit of administration.

METHOD AND MATERIALS

Study Area

This study examines Geumjeong-gu, Busan-si, an area of 19.47 km^2 that was severely impacted by heavy rainfall during August 2425, 2014, as the area of study (Figure 1). During this time, Geumjeong-gu suffered from heavy rain that caused landslides and flooding.

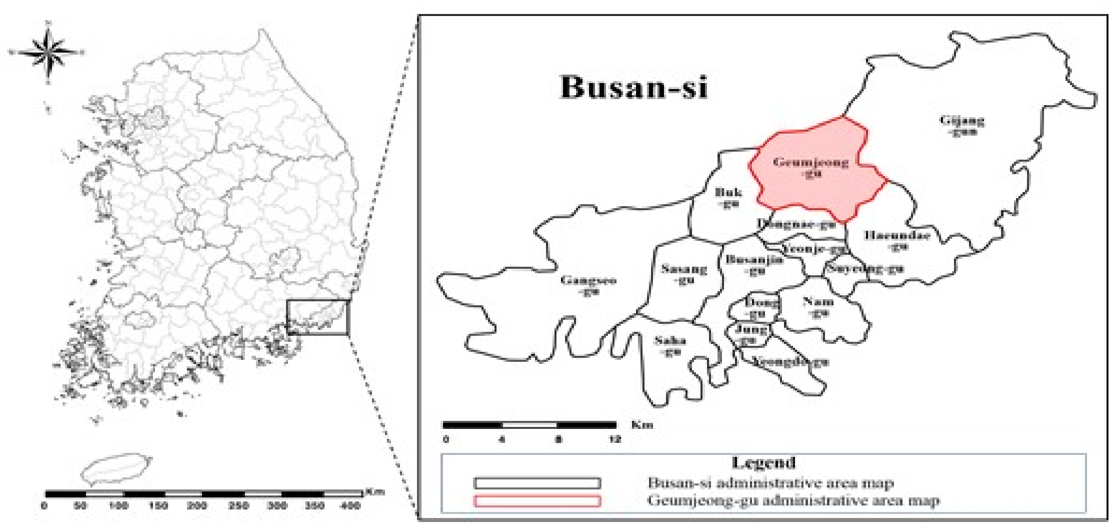

Fig. 1. Geumjeong-gu within Busan-si

Data Collection and DB Establishment

In this study, damaged areas are identified from all areas stricken by a natural disaster. To prioritize damaged areas by administrative boundary, Landsat-8 satellite images, serial cadastral maps, land cover maps, and political maps are obtained to establish the set of DBs. This set of DBs is partitioned into (1) an image DB and (2) a GIS DB. The image DB is used to establish pre and post-damage images collected during the priority estimation process and with Landsat-8 images including the Busan-si shot executed on May 16, 2014. Satellite images of the same area captured on September 5, 2014, are also obtained (Figure 2, Table 1). The image DB is used to locate damaged areas by applying a change detection algorithm. The GIS DB is established from serial cadastral maps, land cover maps, and political maps (Table 2). The resultant GIS DB is used to prioritize damaged areas by the units of administrative boundaries, and then compute cadastral and land cover information.

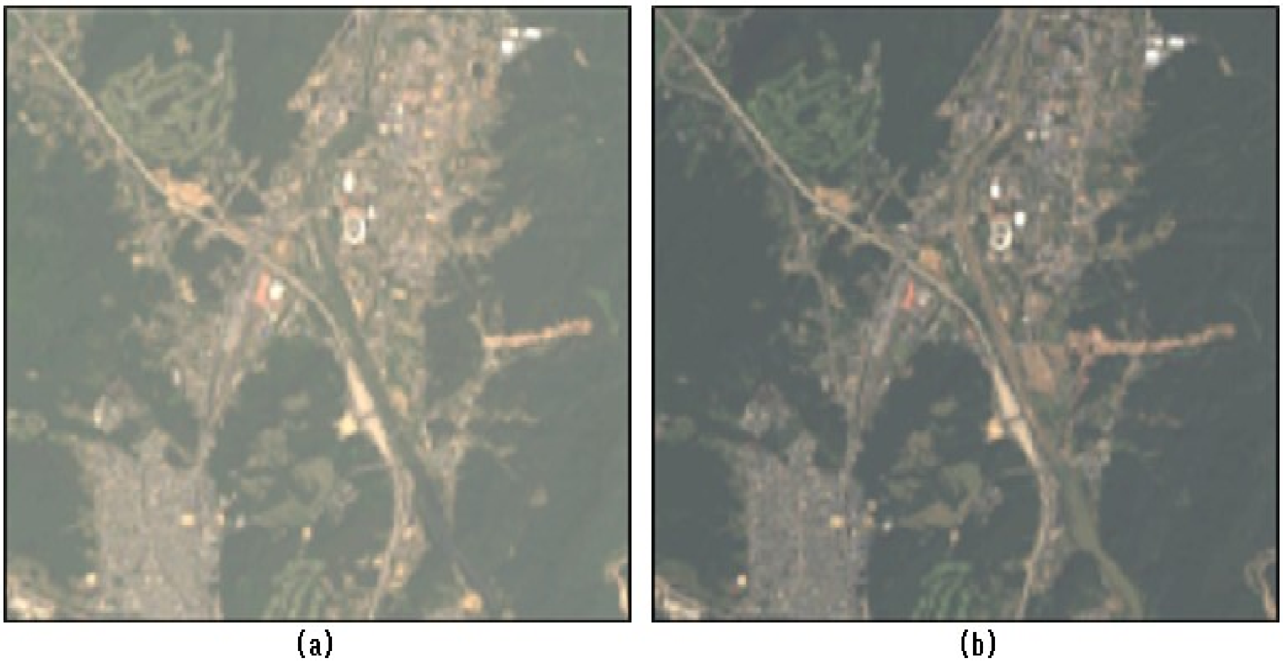

Fig. 2. (A) 2014.05.16 Satellite imagery (B) 2014.09.05 Satellite imagery

TABLE 1
IMAGE DB

Spatial Data	Data Type	Source Agency	Spatial Resolution	Time	Date
Landsat-8 satellite image	Raster	United State Geological Survey, National Aeronautics and Space Administration	Panchromatic : 0.50-0.68μm, Coastal Aerosol : 0.43-0.45μm, Blue : 0.45-0.51μm, Green : 0.53-0.59μm, Red : 0.64-0.67μm, Near IR : 0.85-0.88μm, SWIR1 : 1.57-1.65μm, SWIR2 : 2.11-2.29μm, Cirrus : 1.36-1.38μm, TIRS1 : 10.60-11.19μm,	Before damage	2014.05.16
			TIRS2 : 11.50-12.51μm,	After damage	2014.09.05

Priority Estimation Process Developed

In this study, damaged areas from natural disasters are identified by using satellite image and the GIS DB. An estimation process to prioritize damaged areas in the unit of an administrative boundary is developed. The priority estimation process consists of four steps: preprocessing, identification of damaged areas, priority estimation, and information provision (Figure 3). Each of the steps is summarized below:

TABLE 2
GIS DB

Spatial Data	Data Type	Source Agency	Scale	Content	
Cadastral map	Shape file	Local government	1:500 1:6,000	Crop land, Paddy land, Orchard, Pasture land, forest land, Ground water land, Saltern, Cultural facilities, Industrial land, School land, Parking lot, Warehouse land, Road, Railroad land, Levee, River, Ditch, Water gathering land, Fish farm, Water treatment plants, Park, Physical training site, Recreation park, Religious facilities, Historic sites, Cemetery, Miscellaneous land	
Land cover map	Shape file	Ministry of environment	1:25,000	Urban & Arid	Residential
					Industrial
					Commercial
					Recreational
					Transportation
					Public facilities
				Agriculture	Rice fields
					Crop fields
					Green house
					Orchard
					Miscellaneous
				Forest	Broadleaved forest
					Coniferous forest
					Mixed forest
				Grassland	Natural grasslands
					Artificial grasslands
				Wetland	Inland wetlands
					Coastal wetlands
				Open Space	Nature
					Miscellaneous
				Water	Inland water
					Coastal
Political map	Shape file	Statistics Korea	1:5,000	Administrative boundaries(Si-Do, Si-Gun-Gu, Eup-Myon-Dong)	

Step 1: The preprocessing step obtains pre- and post-damage satellite images from the United States Geological Survey (USGS) and unifies a common coordinate system shared by the serial cadastral maps, land cover maps, and political maps. In the case of Landsat-8, preprocessing creates a common coordinate system to support the WGS 1984 ellipsoidal UTM 52N coordinate system without geometric correction. This is because USGS provides images whose geometric correction is completed in the form of Level 1.

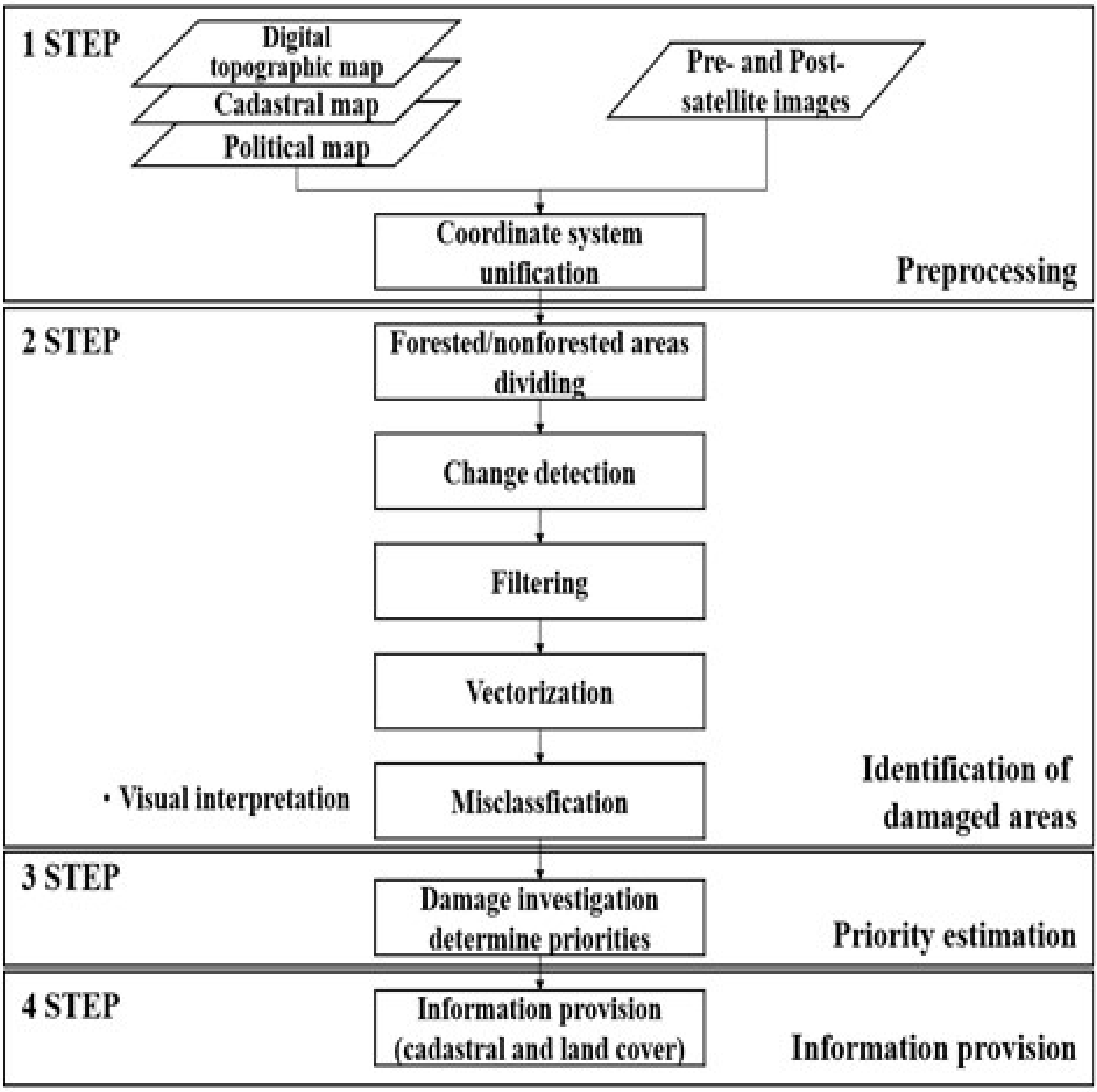

Fig. 3. Priority estimation process

Step 2: The identification of damaged areas for identifying damaged areas from natural disasters is accomplished using pre and post-damage satellite images. In this process, pre and post-damage satellite images are superimposed over land cover maps.

Then, each area is divided into forested areas and non-forested areas. Any changes to the area are identified by applying a change detection algorithm. Subsequently, the final damaged area is identified by using filtering techniques and then removing any misclassifications.

The TCT change detection algorithm is used to obtain land cover information. This is followed by applying the CVA algorithm to detect changes in the area. Then, the DNDVI algorithm is applied to identify differences in the vegetation index at various points in time. For each band of a Landsat-8 satellite image, the TCT algorithm applies a conversion factor to transform attributes of the image such as brightness, vegetation, and moisture.

TCT applies a conversion factor to each band of a Landsat-8 satellite image to enable conversion into meaningful information such as brightness, vegetation, and moisture. The TCT algorithm makes it possible to provide a qualitative computation of soil information, vegetation index, and soil moisture information (Table 3).

The CVA algorithm is a change detection technique designed to estimate the change in pixel vectors obtained at two different times [7].

In the CVA algorithm, if the change in each pixel in the pre- and post-damage image is greater than the threshold, which is the basis for determining the damage, it is considered to be the changed pixel owing to the natural disaster. Using this changed pixel, the changed area can be identified.

The DNDVI algorithm detects the vegetation zone that has changed by using the difference in period in the NDVI developed by [8]. In the case of non-forested areas, TCT is applied to the pre- and post-damage satellite image to obtain brightness, vegetation, and moisture information. Then, the CVA algorithm is applied to identify the changed area.

Among the changed areas after identification, the area where vegetation increases can be considered to be the changed area because its spectral characteristics differ significantly despite the fact that it is not a damaged area.

Therefore, when applying the DNDVI algorithm, if vegetation increases in the post-damage image compared with that in the pre-damage image, the area is excluded from the changed area.

Then, a conversion to vector data is performed to enable overlapping with the GIS data. The vectorized changed area includes misclassified areas instead of areas changed by natural disasters. This also includes changes to clouds and time series.

It is impossible to remove such misclassified areas automatically by using current remote sensing and GIS technology. Therefore, removal of misclassified areas is accomplished manually through the visual interpretation of the user.

The changed area, after the misclassified area is removed, is regarded as the damaged area resulting from natural disasters. To identify the changed area in a forested area, the Blue band, Green band, Red band, SWIR1 band, and SWIR2 band of Landsat-8 pre-and post-damage satellite images are applied to the CVA algorithm.

Since damaged areas are overestimated when the NIR band (which reacts sensitively to moisture information) was used to identify damaged areas in a non-forested area, a conversion into vector data was performed, and misclassifications were removed to identify the damaged areas in a forested area.

Step 3: The priority estimation step can be used to determine priorities using administrative boundaries by overlapping the identified damaged areas with a political map. Then, by using the size of the damaged area, this step prioritizes the administrative boundary that includes more damaged areas.

Step 4: The information provision step provides cadastral and land cover information by administrative boundary. Computed damaged areas are superimposed over serial cadastral maps and land cover maps. This information was used to influence the user's decision-making process when determining areas to be investigated for actual damage.

TABLE 3
TCT TRANSFORM COEFFICIENTS FOR LANDSAT-8

Division (Information)	Band2 (Blue)	Band3 (Green)	Band4 (Red)	Band5 (NIR)	Band6 (SWIR1)	Band7 (SWIR2)
Brightness	0.3029	0.2786	0.4733	0.5599	0.508	0.1872
Greenness	-0.2941	-0.243	-0.5424	0.7276	0.0713	-0.1608
Wetness	0.1511	0.1973	0.3283	0.3407	-0.7117	-0.4559

RESULTS AND CONSIDERATION

This study defined a priority estimation process, which was then applied to a specified area of study. This study obtained pre- and post- satellite image and GIS data for study areas.

Then, the satellite images and GIS data were used to establish a common coordinate system. Next, a change detection algorithm was applied to pre- and post-damage satellite images to identify damaged areas.

In order to identify a damaged area using a change detection algorithm, it is necessary to determine the threshold, which is a measure that is the basis for determining change.

Threshold values that define change vary by area, and the extent of the damage must be determined empirically [9]. However, since the amount of damage resulting from natural disasters that occurred within the area of study is limited, there are restrictions on determining accurate threshold values.

To compute a reasonable threshold value, other damaged areas included in pre- and post-damage satellite images were identified. Their areas of study, along with regional areas, were included to determine a threshold value.

A change detection algorithm was the primary method used to compute threshold values. This algorithm was divided into two methods. The first method consisted of applying the

TCT algorithm, followed by applying the CVA algorithm. The second method consisted of applying the CVA algorithm to Blue band, Green band, Red band, SWIR1 band, and SWIR2 band frequencies of pre- and post-damage satellite images.

The defined change detection algorithm was applied to a total of eight regions. The eight regions represented two areas of cropland, two forests, two residential, and two rivers that were included in pre- and post-damage satellite images. To determine the threshold value to be used by the change detection algorithm, an error matrix was used to calculate a threshold-specific classification accuracy in damaged areas.

An error matrix was used to compare the classification accuracy of two images in a tabular format [10] (Table 4). To obtain a classification accuracy by using the error matrix, measured values of actual damaged areas are necessary. For this reason, actual information about damaged areas was requested from the local government, but these data did not exist. Accordingly, this study assumed that the affected area was identical to the area where changes were detected, and damage identification was conducted by visual interpretation. Next, two algorithms were applied to the damaged areas, and the thresholds representing the highest accuracy were computed (Table 5).

As a result, it was found that the first method that applied the CVA algorithm after application of the TCT algorithm appeared to result in a high level of accuracy for all damaged areas except for one residential area. However, it was found during study that there were many misclassifications in the forested area that was not damaged when applying the first method.

To better understand this behavior, three random undamaged forested areas in the satellite image (pre- and post-damage) were selected (Table 6). Then, both the first and the second methods were applied to the applicable areas. In this case, it was found that the second method achieved high accuracy. In forested areas, the second method was applied, and a threshold value of 15 was determined, indicating the highest accuracy. At the same time, when the second method was applied to the forested area, the classification accuracy was approximately 84.91% on average.

In the case of the non-forested areas, TCT was applied, and then the CVA algorithm was applied. In this case, the threshold value was computed to be 25, which is very close to the average of the values showing the highest accuracy in the areas (excluding forested areas). At the same time, when the first method was applied to the areas (excluding forested areas), the classification accuracy was approximately 82.71% on average. When computing the classification accuracy, areas of increased vegetation determined by applying DNDVI were removed, image noise was removed by filtering, usage of vectorization was added, and misclassifications were removed.

Next, an algorithm application method was defined for the areas of study, and the threshold value previously determined was used. In the case of non-forested areas, the TCT algorithm was applied, and then the CVA algorithm was applied with a threshold value of 25. In forested areas, the CVA algorithm using five bands was applied with a threshold value of 15 to identify each damaged area. The damaged area at the administrative boundary was identified by superimposing the damaged areas identified for the areas of study over political maps.

The administrative boundary under study included a total of three dongs: Seon-dong, Dugu-dong, and Nopo-dong. They have damaged areas of 139,229.7 m^2, 57,905.0 m^2, and 10,800.0 m^2, respectively. Next, cadastral and land cover information was computed by superimposing the damaged area of Seon-dong that included the most affected areas over serial cadastral maps and land cover maps (Table 7). Based on these findings, the order of priority was as follows: Seon-dong, Dugu-dong, and Nopo-dong. In addition, it can be concluded that, when using cadastral and land cover information, it is possible to support the damage investigators decision-making in determining the damage in the investigated areas.

TABLE 4
ERROR MATRIX

CVA Result Visual Reading	Damaged Area	Undamaged Area	Total
Damaged area	A1	B1	D1
Undamaged area	B2	A2	D2
Total	C1	C2	T

TABLE 5
CLASSIFICATION ACCURACY OF DAMAGED AREAS

Division	Damaged Area	CVA (Blue, Green, Red, SWIR1,SWIR2)		TCT-CVA (Band2-Band7)	
		Threshold	Classification Accuracy(%)	Threshold	Classification Accuracy(%)
Cropland	Namji-eup, Changnyeong-gun, Gyeongsangsam-do	17	77.45	23	87.37
	Jangan-eup, Gijang-gun, Busan-si	21	70.95	27	78.49
Forest	Jindong-myeon, Changwon-si, Gyeongsangsam-do	15	88.18	21	90.91
	Dugu-dong, Geumjeong-gu, Busan-si	15	81.63	21	80.61
Residential	Samseong-dong, Yangsan-si, Gyeongsangsam-do	25	91.51	27	92.81
	Pyeongsan-dong, Yangsan-si, Gyeongsangsam-do	27	81.34	27	72.04
River	Jangan-eup, Gijang-gun, Busan-si	21	83.33	23	89.71
	Hwamyeong-dong Buk-gu, Busan-si	21	75.09	25	75.83

TABLE 6
CLASSIFICATION ACCURACY OF UNDAMAGED FORESTED AREAS

Division	Damaged Area	CVA (Blue, Green, Red, SWIR1,SWIR2)		TCT-CVA (Band2-Band7)	
		Threshold	Classification Accuracy(%)	Threshold	Classification Accuracy(%)
Undamaged forested area	Jindong-myeon, Changwon-si, Gyeongsangsam-do	15	85.23	27	48.62
	Gupo-dong, Buk-gu, Busan-si		94.02		59.83
	Hwamyeong-dong Buk-gu, Busan-si		99.13		63.20

TABLE 7
SEON-DONG, GEUMJEONG-GU, BUSAN-SI, INFORMATION (CADASTRAL AND LAND COVER)

Cadastral Information	Damaged Area(m^2)	Land Cover Information	Damaged Area(m^2)
Crop land	9,542.3	Transportation	47.4
Paddy land	49,051.9	Crop fields	49,524.0
Forest land	59,301.1	Coniferous forest	77.619.6
Cultural facilities	2,142.6	Mixed forest	12,038.7
Road	8,152.2	-	-
River	6,995.5	-	-
Ditch	2,342.2	-	-
Water treatment plants	1,701.9	-	-

The following section will conclude the study and highlight the recommendations for future.

CONCLUSION AND RECOMMENDATIONS

This study developed an estimation process to prioritize damaged areas partitioned by administrative boundaries in identified areas that were damaged by natural disasters. The priority estimation process consists of four steps. Step 1 is preprocessing, Step 2 is the identification of damaged areas, Step 3 is priority estimation, and Step 4 is information provision. To conduct a study, pre- and post-damage satellite images and GIS data were obtained from the areas of study to establish the image DB and GIS DB.

Step 1 (preprocessing) defined a common coordinate system between pre- and post-damage satellite images and the GIS DB.

Step 2 is the identification of the damaged area. This divides the area into forested areas and non-forested areas, and determines the damaged areas by applying each algorithm. The non-forested area is determined by applying the TCT algorithm followed by the CVA algorithm. The forested area was determined by applying the CVA algorithm to the Blue band, Green band, Red band, SWIR1 band, and SWIR2 band frequencies of pre- and post-damage satellite images.

Step 3 implements the priority estimation that identifies the damaged area within an administrative boundary by superimposing an identified damaged area over appropriate political maps. Then, the damaged areas are prioritized by size in the administrative boundary.

Step 4 is information provision, which provides cadastral and land cover information for the administrative boundary with the highest priority. This supports a user's decision-making when determining the areas to investigate for damage.

In order to verify that the damaged areas identified by the process described herein represent an accurate reflection of the actual damage, the same area was visually interpreted on a manual basis to identify the true values of the damaged areas. It was found that the accuracy of damage in an area, as computed through the process described herein, was 84.91% accurate in non-forested areas and 82.71% accurate in forested areas. Therefore, by applying the priority estimation process developed in this study to the damaged areas affected by natural disasters, it is possible to identify a rough scale of the damage by identifying the damaged areas. Prioritization of damaged areas by administrative boundary and cadastral and land cover information can be used to dispatch personnel who select prioritized damage-investigation areas and perform the damage investigation. Follow-on studies will develop a system to support damage investigations based on the process presented in this study.

Declaration of Conflicting Interests

No conflict of interests is present in the current study.

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— This article does not have any appendix. —