Paper:

Post-Disaster Urban Recovery Monitoring in Pisco After the 2007 Peru Earthquake Using Satellite Image

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Pisco was the area most damaged by the 2007 Peru earthquake. The purpose of this research is to develop possibilities of using satellite imagery to monitor post-disaster urban recovery processes, focusing on the urban change in Pisco between 2007 and 2011. To this end, the authors carried out field surveys in the city in 2012 and 2013 and also examined previous surveys to determine that building reconstruction peaked between 2008 and 2009. After analyzing the five-year recovery process, the authors compared its reconstruction conditions by visual interpretation with those by image analysis using satellite image. An accuracy of 71.2% was achieved for the visual interpretation results in congested urban areas, and that for developed districts was about 60%. The result shows that satellite imagery can be a useful tool for monitoring and understanding post-disaster urban recovery processes in the areas in which conducting long-term field survey is difficult.

Keywords: post-disaster recovery process, building damage examination, image analysis, urban development, error matrix analysis

1. Introduction

1.1. Background

In the research field of urban recovery, it is important to monitor urban recovery processes after disasters. Through recovery monitoring, it is possible to understand the recovery process of affected area and to evaluate the urban recovery strategies implemented by governments after disasters. Moreover, quantitative evaluation of the recovery process can lead to suggestions of better recovery strategies for other cities in the future by considering the relationship between recovery process and strategies.

Indices based on the economic recovery level such as gross domestic product or electric power consumption can be used to quantitatively evaluate urban recovery processes. Another type of index is from the perspective of recovery of the physical environment, which is related to infrastructure, building construction, and urban development.

Research groups led by Murao proposed a method for drawing a building recovery curve to quantitatively evaluate urban recovery processes. For example Murao and Nakazato [1] compared regional differences based on permanent housing construction data in Sri Lanka, and Murao et. al [2] clarified national differences in recovery processes among Sri Lanka, Thailand, and Indonesia after the 2004 Indian Ocean Tsunami.

However, such curves were constructed on the basis of statistical data provided by governments or data obtained by the researchers by elaborate field surveys. Thus, collection of proper datasets for construction of these recovery curves is very time-consuming and costly.

As an alternative, remote sensing technology may provide a reasonable method for data acquisition.

This research considers the possibilities of satellite image usage to monitor post-disaster urban recovery processes focusing on urban change in Pisco, which is the area most devastated by the 2007 Peru earthquake.

1.2. Existing Related Research

After an earthquake, building damage estimation would be helpful for emergency response and the subsequent recovery stage. Some research groups have considered usage of satellite images for this purpose.

For example, Koarai et.al [3] analyzed large-scale geological hazards in the case of the Northern Pakistan earthquake, the Middle Java earthquake and the Leyte landslide by using optical high-resolution satellite imagery such as QuickBird, IKONOS, ALOS and SPOT5. According to the research, 1 m-resolution stereo images are necessary to recognize building damages in urban areas.

Matsuzaki et.al [4] performed visual damage interpre-

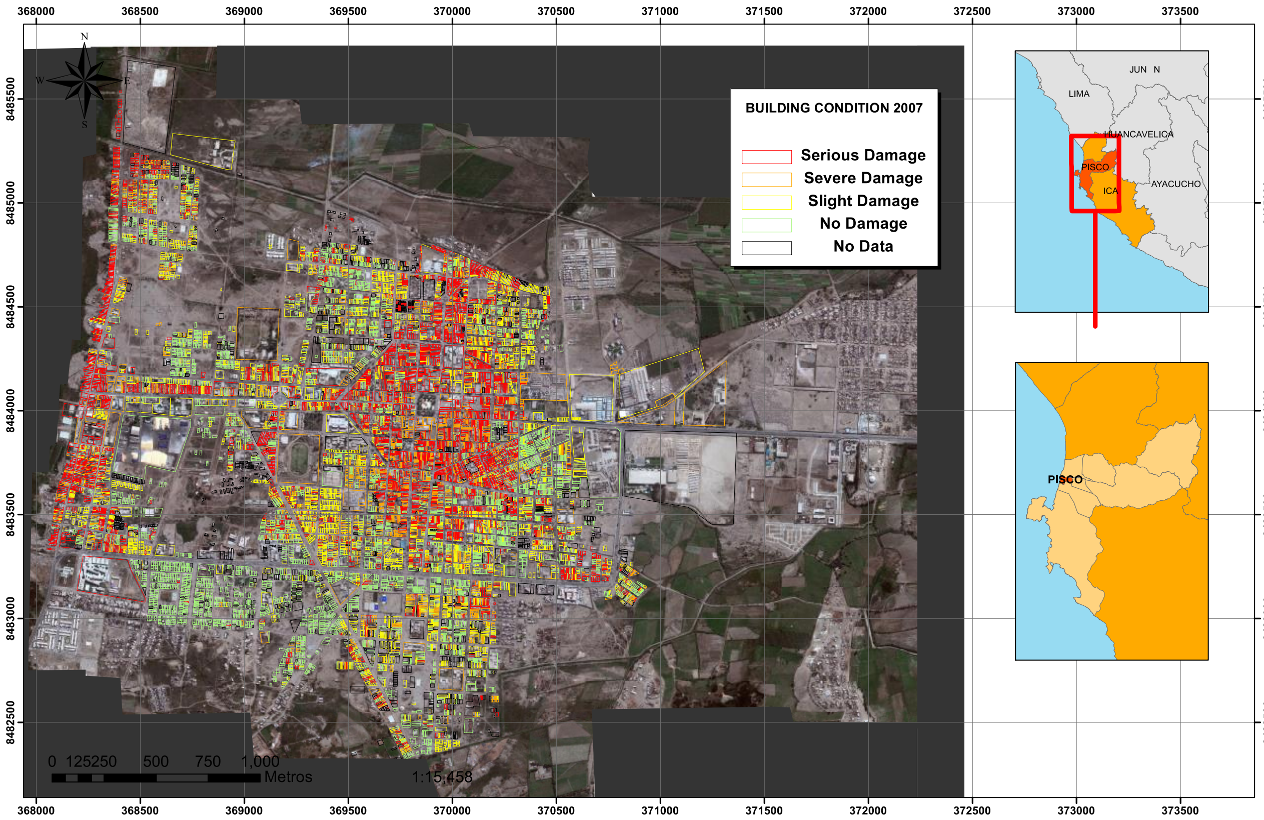

Fig. 1. Building damage conditions owing to the 2007 Peru earthquake, as reported by the Japan–Peru Center for Earthquake Engineering Research and Disaster Mitigation.

tation of buildings in Pisco by using QuickBird satellite Images following the 2007 Peru earthquake and compared the results with that of field survey data. Then, the accuracy of damage inspection was investigated. Finally they reported that the accuracy of the damage grade depends on factors such as the influence of building shadows, differences in the time of data acquisitions, and local building/environmental conditions.

However, few post-disaster recovery processes have been tracked by using image analysis. Nakaoka and Nakao [5] attempted to understand recovery conditions in Kobe after the 1995 Great Kobe earthquake using hue information of satellite images. Higashida et.al used a charge coupled device (CCD) camera to monitor the recovery conditions of some of the areas affected by the 1995 Great Kobe earthquake and the 1999 Chi-Chi earthquake, and they proposed the use of a Recovery Index [6]. However, the areas covered by the method were limited.

1.3. Purpose and Research Method

With a focus on Pisco, this research aims to understand the chronological changes of post-disaster urban conditions and to develop the possibilities of satellite imagery as a useful tool for long-term post-disaster recovery monitoring.

To this end, the following procedure was conducted.

First, an outline of building damage and reconstruction conditions in Pisco as of 2012 are reported based on our field surveys and literature surveys.

Second, the image analysis method is considered by a comparative study of field survey data and satellite images of chronological changes of town blocks from 2007 to 2011. By selecting three characteristic districts, texture analysis is attempted.

Finally, we examine the results of the above method by using accuracy analysis. Then the possibilities of using satellite imagery for monitoring post-disaster urban recovery process are considered.

2. Outline of Building Damage and Reconstruction Conditions in Pisco as of 2012

2.1. Outline of Building Damage in Pisco Owing to the 2007 Peru Earthquake

The Pisco earthquake occurred on August 15, 2007. In the Ica region, which was the area most severely damaged by the earthquake, 134,312 houses were affected. Pisco district is located in the middle of Pisco province in this region. The number of affected houses in the district was 14,008, including 4,106 collapsed buildings [7].

Just after the earthquake, numerous damage surveys were conducted, and damage conditions were reported by some institutes such as the Earthquake Engineering Research Institute (EERI) [8], and the joint investigation group by the Japan Society of Civil Engineers (JSCE) and Japan Association for Earthquake Engineering (JAEE) [9]. **Fig. 1** shows the building damage

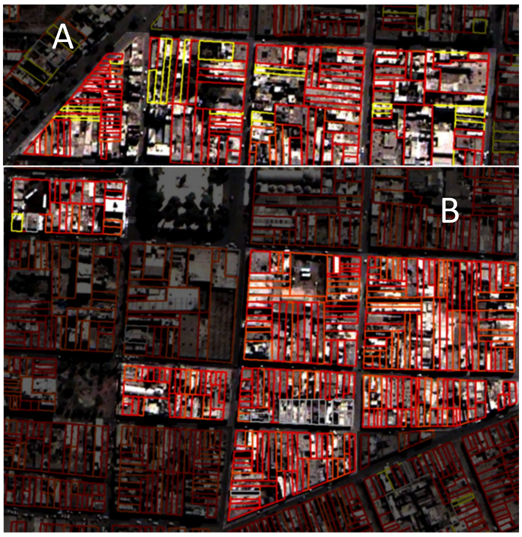

Fig. 2. Blocks included in our field survey. Location of Picture A and Picture B are shown in **Fig. 3**.

Fig. 3. Residential areas selected for hearing survey corresponding to that shown in **Fig. 2**.

conditions investigated by the Japan–Peru Center for Earthquake Engineering Research and Disaster Mitigation (CISMID).

2.2. Recovery Condition as of 2012

The authors conducted a field survey in July 2012 to understand the post-earthquake urban conditions of Pisco. They compared building recovery conditions based on visual interpretation by survey and satellite images from GeoEye captured in 2010 with the damage conditions reported by CISMID [10]. The results indicated that 93.2% of the seriously or severely damaged buildings had been reoccupied and that number of new houses had increased in newly developed areas planned by the government [11].

3. 2013 Field Survey of Recovery Conditions

3.1. Recovery Conditions in Central Districts

The authors carried out another field survey from on July 11 to 15, 2013, to assemble information with more detail.

According to a survey conducted by the Pisco city government, eleven blocks were occupied by mostly adobe-structure buildings [12]. These blocks were characteristic of the central districts of Pisco and were devastated by the earthquake and characteristic of the central districts of Pisco. We assumed that these destroyed buildings had been replaced with new solid-structure buildings such as rain-forced concrete buildings or brick buildings. We then conducted a field survey by visual interpretation to examine the recovery conditions of the town blocks. The eleven blocks that were congested by adobe structures are shown in **Fig. 2**.

According to the CISMID investigation in 2007, 474 land lots contained destroyed buildings in the blocks. Our field survey indicated that the buildings in 471 land lots had been reconstructed, which means that reconstruction ratio in the districts was 99.3%. The structure of 77.8% of the reconstructed buildings was stronger than adobe.

3.2. Hearing Surveys in Residential Areas

City planning has resulted in expanded residential areas [11]. In order to understand the individual recovery processes of different types of residences, we conducted hearing surveys in five residential areas including Leticia, Alto el Morino, Dios Te Ama, Renacer, and La Arborada. **Fig. 3** shows these areas, which correspond to the covered areas in **Fig. 1**. The number of interviewees was three in each area, for a total of fifteen. The Questionnaire contents were about structural type of their houses before and after the disaster, reasons for moving, previous house condition, monetary support by the government and its contents, necessary cost and time for resettlement, and time of moving to new buildings.

Based on the hearing surveys, the following results were revealed:

(1) Three types of housing loan were offered.

(2) Financing and the interest rate were determined by the level of income of creditor.

(3) A residence certificate was necessary for accepting monetary support from the government.

The residents of Pisco included many squatters who lacked residence certificates. Therefore, it was difficult for these people to rebuild even thought the earthquake severely damaged their houses. However, the government granted legal residence after the earthquake to those who had been living illegally in the city for certain period of time. As a result of this policy, many squatters begin to live in the newly developed areas legally.

Residence certificates were examined by Organismo de Formalización de la Propiedad Informal (COFOPRI). **Fig. 4** shows changes in the number of certificates granted from 2007 to 2013 in the Ica region, which includes Pisco province [13]. This chart indicates that illegal residents had gained residence certificates and had been living in

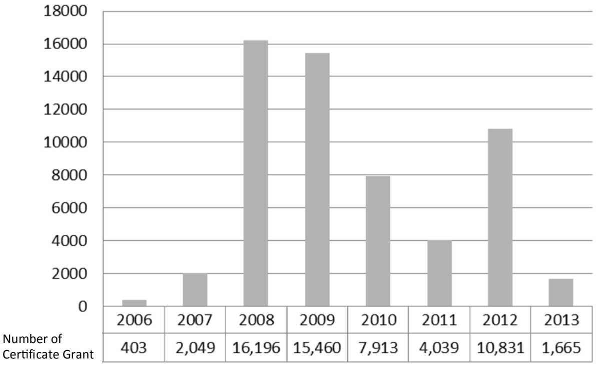

Fig. 4. Changes in numbers of residence certificates granted [13].

Table 1. Satellite image specifications.

Satellite	QuickBird			World View 2	
Sensor	BGIS 2000			WV110	
Date obtained	Dec. 13, 2007	Nov. 9, 2008	July 1, 2009	Aug. 28, 2010	July 15, 2011
Coordinate System	Geographic Lat/Lon				
Projection	WGS-84				
Coordinate	$76-13'18.95''$W, $13-41'54.74''$S				
Image size	7,344 by 4,815				
Resolution	0.6 m			0.5 m	
Off-nadir angle[2]	1.28	11.56	19.99	7.78	17.74

the newly developed areas for two years following the 2007 Peru earthquake. Thus, these statistical data obtained by using satellite images can be objective criteria for evaluating recovery processes.

4. Consideration of Image Analysis Method for Examining the Recovery Process

The aforementioned field survey is a method used for understanding post-disaster recovery processes. However, the economic and temporal expenses are considerable. Therefore, we consider a possibility of using satellite image to understand recovery processes as an alternative measure in this section.

4.1. Satellite Image Used

We obtained panchromatic images with a resolution of about 0.6 m, which are known as high-resolution satellite images, and multi-spectral images with resolutions of 1.84 m–2.62 m captured between 2007 and 2012. The specifications of these images are shown in **Table 1**.

In performing this analysis, pan-sharpened images[1] were produced by superimposing high-resolution images on low-resolution color images and by subdividing pixels. Murakami and Yamashita [14] indicate that people can accurately recognize an object of about 10 times for the resolution in visual observation [14]. Using the pan-sharpened images with a resolution of 0.6 m, visual interpretation for the analysis is possible.

ENVI version 5.0 was used as the application software for the image analysis.

4.2. Examined Districts

Prior to performing the analysis, it was necessary to understand characteristics of the examined area. The following factors were considered:

(1) Characteristics recognized on satellite images

Fig. 5. View of Pisco central district.

- Generally, building roofs appeared as white, and land surfaces including open spaces inside private land lots appeared as black.
- Many buildings had flat roofs.
- Because the observation angle was low, shade was reflected greater in many places.

(2) Characteristics recognized by the survey (**Fig. 5**)

- The target area is basically earthy.
- Most buildings are one- or two-story residential.
- Most streets are unpaved except for main roads.

(3) Social context recognized by interviews

- The percentage of squatters is very high.
- Even in normal times, individual residents often renovate their own houses or build extensions; thus, the building shape is often changed.

The research approach in subsequent sections is based on the above findings.

4.3. Scope of Analysis and Selection of Training Districts

Because it is easier to use simple images for analysis, we used minimum range satellite images covering the

1. Pansharpening is a process to create a high-resolution RGB color image based on a low-resolution RGB color image and a high-resolution monochromic image.

2. Any point not directly beneath a scanner's detectors, but rather off at an angle (ESRI GIS-Dictionary).

Table 2. Basic information of the study area image.

Number of town blocks	Number of pixels	Areas (m^2)
629	9,897,371	3,563,053

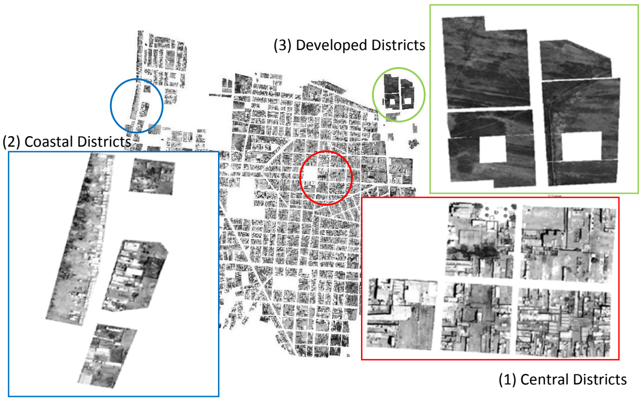

Fig. 6. Scope of analysis and selected training districts.

study area indicated in **Table 1**. **Table 2** shows basic information of the area including the number of blocks, the number of pixels, and the total area.

Prior to image analysis, it was necessary to examine the accuracy of using the images. We selected the following three areas according to damage conditions and locations (**Fig. 6**):

(1) Central districts, commercial with public facilities.

(2) Coastal districts, residential illegally occupied.

(3) Developed districts, residential developed after the 2007 earthquake.

The comparison for understanding the recovery conditions in Section 2 is based on the damage survey conducted by CISMID in 2007, the satellite image from GeoEye captured in 2010, and the field survey conducted in 2012. Then, the satellite images captured in 2007 and in 2011 were used as a training data for the accuracy assessment.

4.4. Types of Change in Land Lots

In order to quantitatively evaluate the recovery processes in the studied districts, the presence of buildings is a significant parameter. The ratio of the buildings to vacant land in each land lot was used for our evaluation.

Regarding changes in land lot usage from 2007 to 2011, four types of changing patterns were identified: (a) vacant land to building area, (b) building area to building area, (c) building area to vacant land, and (d) vacant land to vacant land (**Fig. 7**). An understanding of these four types of building–vacancy patterns is essential for analyzing the chronological recovery transition of individual land lots.

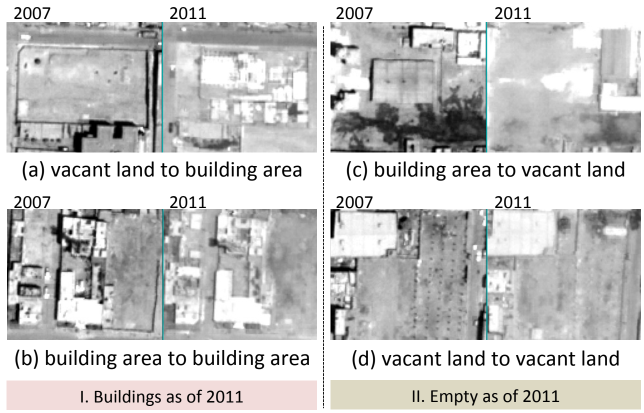

Fig. 7. Four types of changing land lot usage patterns.

Table 3. Characteristics of image analysis methods [15].

Type	Strength	Weakness
Object-based automatic classification	Obtained detailed classification maps, less noise	Complex parameters setting for classification
Pixel-based automatic classification	Relatively obtained homogeneous accuracy without skillful technique	A lot of noise in high-resolution satellite images
Visual interpretation	High classification accuracy	Required skillful technical capabilities, high temporal cost and workload

4.5. Image Analysis Method

4.5.1. Types of Image Analysis Methods

Two types of satellite image analysis methods are in general usage. The first is object-based analysis dealing with vector image data, and the second is pixel-based analysis dealing with raster image data. **Table 3** compares the differences of the methods [15].

In order to decipher building damage or to extract building outlines in high-resolution satellite image analysis, object-based analysis is an effective method, though proper parameters need to be set for data conversion with skillful techniques [14, 15]. We considered the possibility of using pixel-based analysis in our research because we deal with long-term recovery processes that require continuous chronological data, and we aim to establish a laborsaving methodology for urban recovery monitoring in the future.

4.5.2. Analysis Procedure

The analysis procedure we applied in this study is illustrated in **Fig. 8**.

As a common treatment, we first superimposed each band of individual images on one layer after geometric correction, indicated as "image superposition" in the figure. By comparing the images, we recognized no difference in the urban fabric or shapes of town blocks. Then

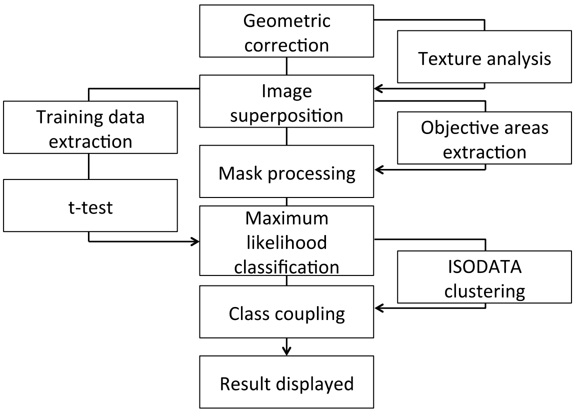

Fig. 8. Analysis flowchart used in this study.

we eliminated most areas except the focus districts by mask processing.

Second, we selected remarkable changing patterns as training data and calculated fundamental statistics to evaluate statistical significance using pixel-based analysis and texture analysis.

Finally, as evaluated by the t-test, we conducted maximum likelihood classification based on the training data and classified changing pattern. Unclassifiable areas with shadows were eliminated by Iterative Self-organizing Data Analysis Technique (ISODATA) clustering.

4.6. Extraction of Pixels Regarding Changing Patterns as Training Data

No ground truth data for the objective areas existed. Then, we identified changing areas by visual observation on the superimposed images as of 2007 and 2011. **Table 4** shows the numbers of pixels regarding changing patterns.

Checking spectrum separation by calculating fundamental statistics reveals that the scatter plot area for buildings and that for vacant land overlapped (**Fig. 9**), which indicates that the spectrum separation performance was not very high for this analysis.

Next, we used fundamental statistics based on entropy, or the texture information of the images, to reduce misclassification caused by using only pixel-based classification. The higher the level of tint, the more entropy increases. Entropy decreased in the area surrounded by the red circle in **Fig. 10**. As shown in **Fig. 11**, a building existing in 2007 was removed in 2011. On the contrary, entropy increased in that surrounded by the blue circle in **Fig. 10**, which indicates new building construction. Therefore, we can classify the patterns in listed in **Table 4** by using this method.

4.7. Setting Window Size

By setting the window size at more than one pixel, we can obtain texture information. One pixel on a 0.6 m resolution image covers about 60 cm^2 in the real world. The proper window size for this analysis was that slightly covering the area of a building. Because of a lack of building outline polygon data, we extracted 100 buildings at random on the image and calculated their average length and width. Although the lengths of the building varied, their width was almost 7 m. Therefore we set the window size at 13 pixels by 13 pixels for texture analysis, which equals 7.8 m^2.

Table 4. Numbers of pixels regarding changing patterns.

a	b	c	d	Total
Vacant land to building area	Building area to building area	Building area to vacant land	Vacant land to vacant land	
13,303	10,359	3,036	11,745	38,443

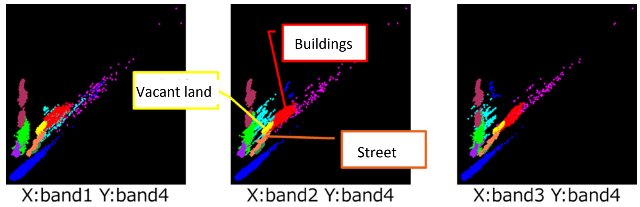

Fig. 9. Spectrum separation conditions.

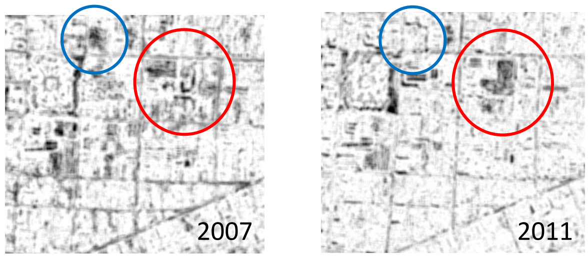

Fig. 10. Comparison on image represented by entropy.

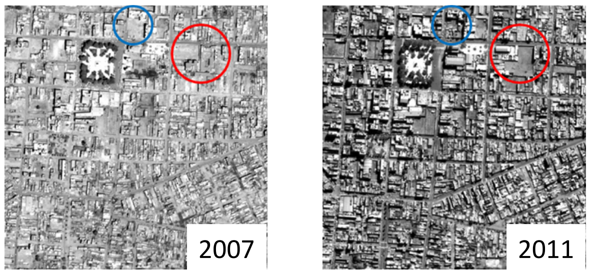

Fig. 11. Comparison of satellite images.

5. Examination of Recovery Process Analyzed by the Method

5.1. Combination of Target Time

The target times for examining the changing conditions include the following combinations: (1) 2007 and 2011, (2) 2007 and 2008, (3) 2008 and 2009, (4) 2009 and 2010, and (5) 2010 and 2011.

5.2. Recovery Process Analyzed by Our Method

The method described in Section 4 was applied to the objective area. The images in **Fig. 12** show the chronological changes in Pisco from 2007 to 2011 as determined by this analysis.

Each image presents differences detected between spans of one year. Buildings are presented in black, and vacant land is in gray. It is possible to recognize building density conditions and transitions of housing construction in these images. For example, the area surrounded by the red square in each image shows obvious changes in the districts since 2007.

5.3. Examination of Proposed Analysis Method

Three training districts were previously selected, as shown in **Fig. 7**. We used the results of the analysis for these districts to examine the accuracy of the method proposed in the present study.

5.3.1. Changes in Central Districts

Changes in the central districts as determined by satellite images captured in 2007 and 2011 in addition to the results of the analysis are shown in **Fig. 13**. It appears that some empty lots remained in the image of 2007 where collapsed buildings had been removed. The analysis results verified relatively large sites with some buildings became vacant lots as of 2011. Large buildings were effectively extracted from the images, though some boundaries between buildings and open space may have been misclassified.

5.3.2. Changes in Coastal Districts

Changes in coastal districts are shown in **Fig. 14**. These districts were severely damaged by the 2007 Peru earthquake. The government provided temporary housing to the victims in the districts. However, many squatters reconstructed their houses without government aid. As a result of the analysis, the remaining foundations of such damaged buildings were misclassified as sound buildings.

5.3.3. Changes in Developed Districts

Changes in the developed districts are shown in **Fig. 15**. This area, which was a wasteland in 2007, was developed by the government as a permanent housing area following the earthquake. Although this change is obvious through visual observation, misclassification often occurred in the analysis. Such results may be attributed to changes in the components on the ground owing to the development. In particular, concrete that replaced the soil in the new residential area was recognized in the analysis as the same material used for building roofs.

Fig. 12. Changes in the entire area of Pisco.

5.4. Accuracy Assessment of Analysis Results

Because no building polygon data was available for the focus area, we used the training data for accuracy assessment. By overviewing the images for 2007 and 2011, we deciphered changes in individual land lots by visual interpretation based on the four types of classification listed in **Table 4**, and we calculated the number of changed pixels.

Next, error matrix analysis was used for accuracy as-

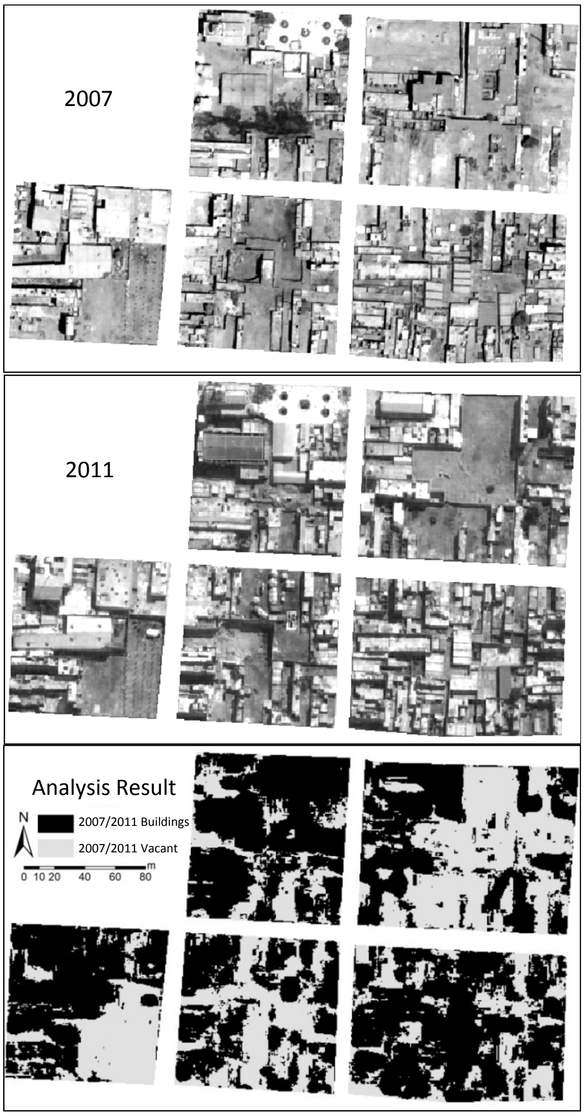

Fig. 13. Changes in central districts in 2007 and 2011.

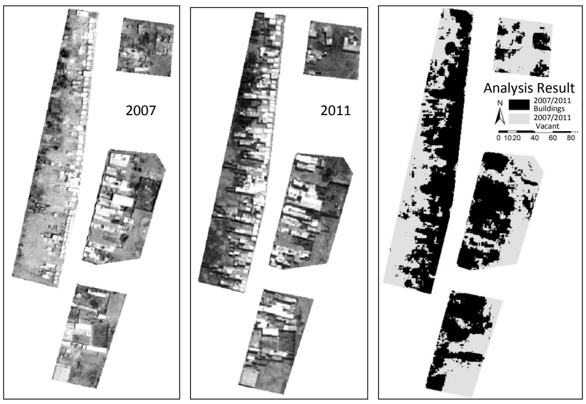

Fig. 14. Change of coastal districts (2007 and 2011).

sessment of the image analysis, as show in **Table 5**. Each column in the table indicates the number of pixels based on visual interpretation, and each row indicates that determined by the image analysis. C_{11}/C_{31} and C_{22}/C_{32} are

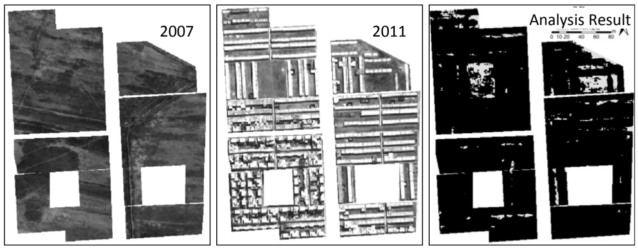

Fig. 15. Changes in developed districts in 2007 and 2011.

used for producer's accuracy to indicate the accuracy rate of visual interpretation. Conversely, C_{12}/C_{13} and C_{22}/C_{23} are used for user's accuracy to indicate the accuracy rate of image analysis results. $(C_{11}+C_{22})/C_{33}$ is used as indicate overall accuracy for a comprehensive evaluation. The producer's low accuracy presents extraction failure by misclassifications. On the contrary, the user's low accuracy indicates low accuracy of the results obtained by image analysis.

As shown in **Tables 6–8**, overall accuracy for the central districts was more than 70%; that for coastal and developed districts was about 65% and 60%, respectively.

Koshimura et al. conducted research on post-tsunami image analysis in Banda Aceh. They reported that accuracy by pixel-based analysis was about 67%, and that by object-based analysis was about 71% [16]. Matsuzaki et al. reported analysis results in Pisco at about 70% [4]. Our research obtained comparable results in the central districts.

The user's accuracy for vacant land was relatively higher than that for buildings in all districts. It is considered that the spectral information of a vacant lot is more stable than that of buildings.

5.5. Quantification of Recovery Processes

Quantitative evaluation of the recovery processes in Pisco requires calculation of buildings. However, the individual building outlines in the images and maps used in this research were not clear. Therefore, the building area in each land lot was estimated using the map developed by CISMID, as shown in **Fig. 1**. By using 1% land lot sampling of the entire area, the average building coverage ratio per lot was calculated. Then, the total building area of the focus area of Pisco was defined as the initial value for evaluating the recovery processes.

Figure 16 shows a quantitative recovery process of Pisco as a result of this effort. Compared with the conditions present four months after the earthquake in 2007, the building ratio increased slightly in 2008. The ratio sharply increased between 2008 and 2009 and rose slightly in 2011. The building ratio in 2010, however, was lower than that in 2009 and in 2011. It is inferred that the high observation angle for the satellite image of 2009 affected to the analysis by increasing the ratio of building shadows.

A comparison of the number of certificates granted (**Fig. 4**) with the recovery process tendency (**Fig. 16**) revealed the actual post-earthquake recovery situation in

Table 5. Table of error matrix analysis.

		Visual interpretation			
		Building	Vacant	Total	UA
Image Analysis	Building	C_{11}	C_{12}	C_{13}	C_{12}/C_{13}
	Vacant	C_{21}	C_{22}	C_{23}	C_{22}/C_{23}
	Total	C_{31}	C_{32}	C_{33}	-
	PA	C_{11}/C_{31}	C_{22}/C_{32}	-	SA: $(C_{11}+C_{22})/C_{33}$

UA: user's accuracy, PA: producer's accuracy, SA: system accuracy

Table 6. Analysis results for central districts.

		Visual interpretation (Pixels)			
		Building	Vacant	Total	UA
Image Analysis (Pixels)	Building	66,701	38,454	105,155	63.4%
	Vacant	10,277	53,850	64,127	84.0%
	Total	76,978	92,304	169,282	-
	PA	86.6%	58.3%	-	71.2%

UA: user's accuracy, PA: producer's accuracy, SA: system accuracy

Table 7. Analysis results for coastal districts.

		Visual interpretation (Pixels)			
		Building	Vacant	Total	UA
Image Analysis (Pixels)	Building	21,720	36,202	57,922	37.5%
	Vacant	2,189	49,838	52,127	95.8%
	Total	23,909	86,140	110,049	-
	PA	90.8%	58.0%	-	65.1%

UA: user's accuracy, PA: producer's accuracy, SA: system accuracy

Table 8. Analysis results for developed districts.

		Visual interpretation (Pixels)			
		Building	Vacant	Total	UA
Image Analysis (Pixels)	Building	89,057	65,715	154,772	57.5%
	Vacant	550	7,815	8,365	93.4%
	Total	89,607	73,530	163,137	-
	PA	99.4%	10.6%	-	59.4%

UA: user's accuracy, PA: producer's accuracy, SA: system accuracy

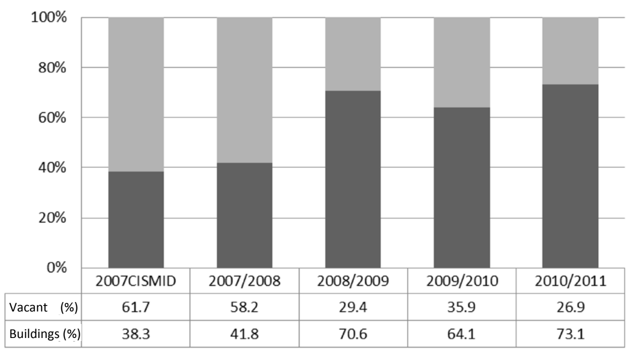

Fig. 16. Quantitative recovery process.

Pisco. In general, the issuance of the certificate by the government triggered reconstruction activities by residents.

6. Conclusions

Pisco was the area most damaged by the 2007 Peru earthquake. The purpose of this research was to explore the usage of satellite imagery for monitoring post-disaster urban recovery processes, focusing on the urban changes in Pisco between 2007 and 2011. To this end, the authors conducted field surveys in the city in 2012 and 2013 and reviewed literature surveys. It was determined that building reconstruction peaked between 2008 and 2009.

Following an understanding the five-year recovery process, the authors compared the reconstruction conditions by visual interpretation with those by satellite image analysis. An accuracy of 71.2% was achieved by the visual interpretation results in congested urban areas. Although post-earthquake urban recovery in Pisco was relatively low until 2008, the activity increased substantially in 2009. This tendency was likely affected by the issuance of certificates by the government to prove legal residence in Pisco.

The research results also demonstrates that satellite imagery can be a useful tool in the monitoring and understanding of post-disaster urban recovery processes in areas in which long-term field surveys are difficult to conduct because of temporal/economic costs and heavy workloads. However, satellite images need to be carefully selected by considering such parameters as observation angle.

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