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MONITORING OF URBAN RECONSTRUCTION: A STUDY OF RECOVERY PROCESS IN BAM AFTER THE 2003 EARTHQUAKE

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ABSTRACT: The Bam earthquake in 2003 was one the most devastating disasters occurred in Iran in the recent years that left massive damages to both the population and properties. Today, a decade past from that event, it is important to investigate the city recovery process to evaluate the government's performance in terms of post-earthquake management. This study aims at monitoring the post-earthquake reconstruction and renewals in Bam and discusses the progress and sustainability of disaster management projects. Two sets of satellite images taken immediately after the earthquake in 2004 and eight years later in 2012 from two selected stations were analyzed to make comparison in urban land uses such as vegetation, buildings, open-space etc. We also collected field photos taken in 2004, 2007 and 2014 to observe the performed modifications in the physical environment of the city. In addition, we obtained official statistics and reports regarding the extent of damage to buildings and individuals from the authorities, in order to assess damages and estimate the construction of new buildings. Our results showed that in the partially damaged station, reconstruction process was accomplished however in the severely destructed station, the recovery progress was not desirable.

Key Words: Monitoring, Reconstruction, The 2003 Bam Earthquake, Satellite Image

INTRODUCTION

On 26 December 2003, an earthquake of magnitude 6.6 struck Bam, an old city in the southeast of Iran. Although it lasted for only few seconds, more than 22,391 people were killed (Eshghi et al. 2004). This earthquake damaged almost all the brick buildings, the famous historical construction Arg-e Bam, which is more than 2000-years old, and even modern buildings and city establishments.

Soon after the earthquake, a large amount of research works were carried out on the assessment of the earthquake damages and its impacts (Chiroiu 2005, Gusella et. al 2005, Kohiyama and Yamazaki 2005). However, less works have been done regarding the renewal and reconstruction during the last ten years after the earthquake. Generally, the process of reconstruction is an important part of disaster management that demonstrates the Government's efforts and capability to alleviate the hardship of a disaster and establish satisfaction for survivors (Murao et al. 2013). Therefore, investigating and understanding the process of reconstruction is a valuable measurement for the evaluation of government's performance. Hence in this study, we try to evaluate the renovation and reconstruction of Bam in the post-earthquake interval of ten years, by examining the current situation of the city including residential buildings, public establishments and other city infrastructures.

FRAMEWORK OF THE RESEARCH

The procedure employed in this study is divided into four parts. First, an examination of official statistics and reports provided by the authorities regarding the extent of damage to buildings and fatalities were collected. The status of buildings and their facilities before and after the earthquake, the type of structural frames used in each building before and after the earthquake were also collected. Second, we conducted a field survey of reconstructions based on the sets of field photos taken at three different times after the earthquake from the same locations, in order to compare the landscape and particularly observe performed changes in the physical environment. Following to that, we analyzed and compared two satellite images of the city regions before the earthquake, immediately after the earthquake and the present time to investigate significant changes in buildings, roads, vegetation covers and land use. Finally in the last section, we discussed the obtained results and findings to conclude and acknowledge weaknesses and shortcomings as well as strengths and ratings.

STATISTICAL DATA

Data caving and statistical analyses were conducted based on the data and information prepared by the Bam's Statistical Survey Center under the supervision of Iranian Statistical Center (2004). Urban planning and design of the city in the pre- and post-earthquake times were also evaluated based on the comprehensive and master plans provided by the Bam's municipality. The statistics regarding earthquake victims and damages are presented in Tables 1 and 2, respectively.

According to the information available in the records of Civil Engineering Organization of Bam, starting immediately after earthquake in 2004 up to March 2014, 33126 permissions for construction have been issued and 26540 were executed. Also Iranian Statistical Center (2011) has announced 26708 residential units in 2011. This significant number of units in 2011 indicates the broad extent of reconstructions and the huge amount of budget allocated to this project. Since the Civil Engineering Organization of Bam claimed that they had monitored the construction process, it is expected that these structures show more resistance against similar level of earthquake ground motion in the future.

Table 1. Number of individuals before and after the 2003 earthquake (Source: Bam Earthquake Statistical Survey. 2004)

Before EQ	After EQ				
89145	Dead	Injured	Missing	Temporarily missing	Survivors
	22391	8136	422	3029	55167

Table 2. Number of buildings before and after earthquake (Source: Bam Earthquake Statistical Survey. 2004)

Before EQ	Immediately after EQ in 2004		
28625	Destroyed	Partially Damaged	Intact
	26111	2381	133

FIELD SURVEY

A field survey in Bam was carried out during a research trip by the first author in March 2014. The photos of city reconstructions were collected in different locations by driving and walking in the city. The photo locations were selected based on the reference images that were previously prepared by different groups of investigators during the first month after the earthquake, and in May 2007 by the second author. We tried to match the geographical locations so that the landscape comparison becomes possible.

The field survey revealed four main points.

1. The debris could still be seen in some damaged areas (Fig.1a). In addition in some regions, especially in the center and northern part of the city, debris had been removed, but construction has not been taken place and there are still bare lands. (Fig.1b)
2. Except for a few cases, almost all of the important public buildings, mosques, banks and other governmental offices were reconstructed (Fig. 2).

(a) (b)

Fig.1 (a) Desolate building in the northeast of Bam and (b) bare land in the center of Bam

3. Some of the buildings that have been highly damaged but not destructed, have been renewed and reused with the existing conditions (Fig. 3).
4. New buildings that not exist before the earthquake as a sport stadium, medical university, commercial-administrative complex, library and cultural center, and also a new residential region in the east and southeast of the city. (Fig. 4)

(a) (b)

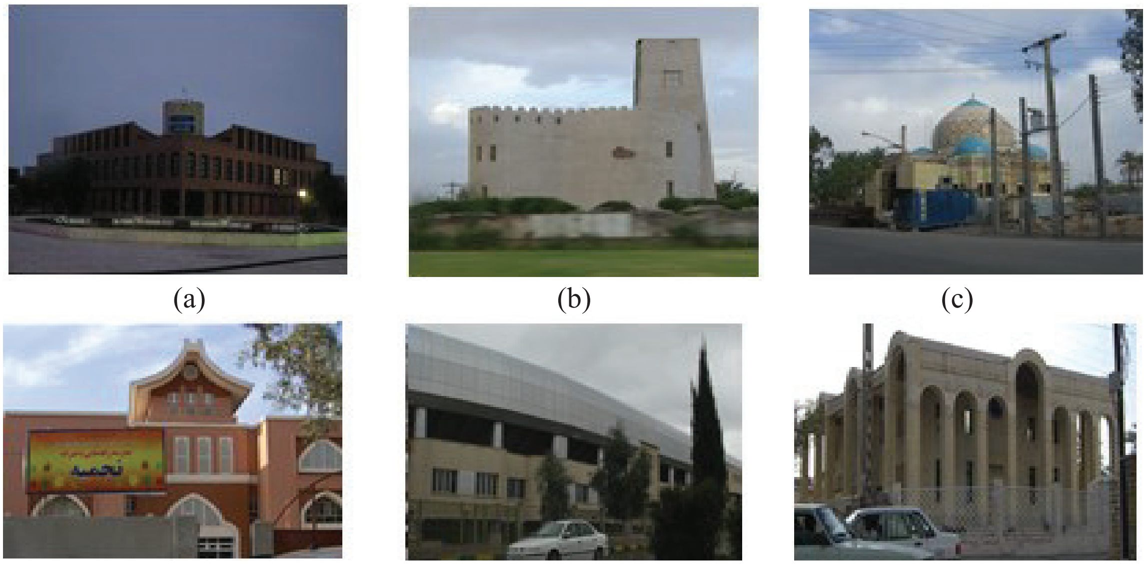
(c) (d)

Fig. 2 Comparison of some reconstructed buildings after the earthquake and in 2014. (a) Fire station of Bam in January 2004 (left) and March 2014 (right). (b) An alley near the Madani Street in the north of Bam in January 2004 (left) and March 2014 (right). (c) ZEYD Mosque in January 2004 (left) and March 2014 (right). (d) MASKAN Bank in January 2004 (left) and March 2007 (right).

(a)

(b)

Fig. 3 A building in south of the city was severely damaged but was still used as in photos taken in (a) January 2004 and (b) March 2014



(a) (b) (c)

(d) (e) (f)

Fig. 4 New set of buildings consisting of (a) medical university in 2014 (b) City hall in 2007 (c) mosque in 2007 (d) a primary school in 2007 (e) sport stadium in 2014 (f) library in 2007 have been constructed in Bam, which did not exist before the earthquake.

SATELLITE IMAGES

We compare two sets of satellite images that captured the area including Bam city by QuickBird on September 30, 2003 and by GeoEye-1 on August 11, 2012. The regions of the city that were covered in this study were selected based on the previous work done by Hisada et al. (2004). They chose eight different aftershock observation stations in the city and evaluated the damages to buildings around the stations based on the EMS-98 criteria, and classified the buildings into five groups, G1 to G5, with respect to the degree of damages.

Out of these stations, two stations (Fig. 5) that were partially damaged (station 1) and severely destructed (station 2) were selected. The estimation of damage in these two stations were consistent with the other studies (Yamazaki et al. 2005, Kohiyama and Yamazaki 2005, Rathje et al. 2005).Then the satellite images around the stations before (2003) and 8 years after (2012) the earthquake were compared to detect the changes in three major urban land covers: *buildings*, *vegetation* and *ground*. Subsequently, we classified the changes in land-covers into ten different categories, that are *old building to new building*, *old building no change* (remained from 2003), *old building to vegetation*, *old building to ground*, *vegetation to new building*, *vegetation no change* (remained from 2003), *vegetation to ground*, *ground to new building*, *ground to vegetation*, and *ground no change* (remained from 2003).

Figure 6 shows the satellite images covering the station 1 in 2003 and 2012. The area and percentage for the three land-covers are presented under each image. A clear increase in the percentage of buildings and a decrease of ground in 2012 can be observed.

Similarly, the changes in land-covers around the station 2 are depicted in Fig. 7. In this area, which was extensively destroyed after the earthquake, the land-covers for buildings and vegetation were decreased and those for ground increased significantly. In this area, located in the north part of the city, the amounts of empty lands are quite large, in other words, reconstruction is slow. Although debris had been removed and the lands were smoothed, reconstruction has not yet started.

Figure 8 shows the changes in land-cover before and after the earthquake in the two study areas. The total areas associated with each of these changes are tabulated in Table 3. The considerable changes of old buildings and ground into new buildings were again confirmed around the station 1. On the other hand, around the station 2, the large amount of land-cover changes from old buildings and vegetation into ground were recognized.

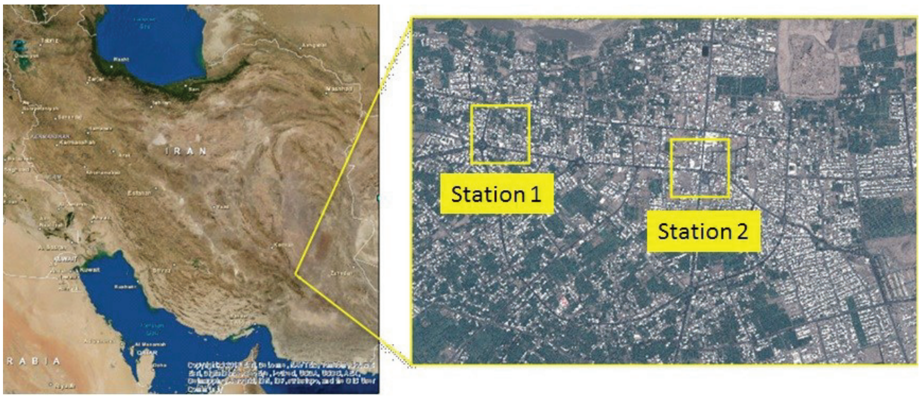


Fig. 5 Location of Bam in Iran and two selected study areas around aftershock stations

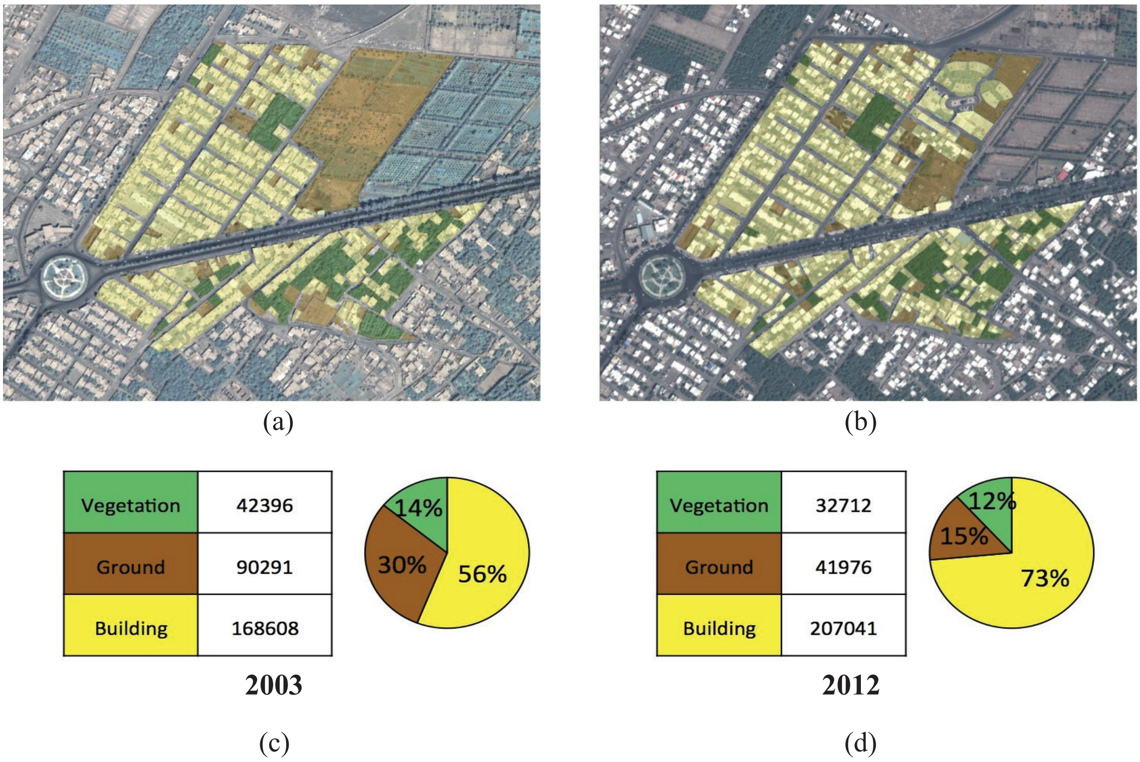
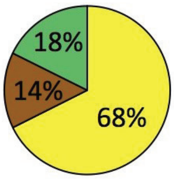


Fig. 6 (a) Satellite image and land-covers at the station 1 in 2003 and (b) those in 2012. The area (m^2) and percentage of *buildings*, *vegetation* and *ground* in (c) 2003 and (d) 2012.

(a)

(b)

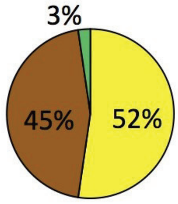
Vegetation	80214
Ground	65809
Building	305946



2003

(c)

Vegetation	9982
Ground	192467
Building	222315

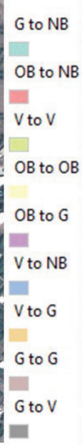


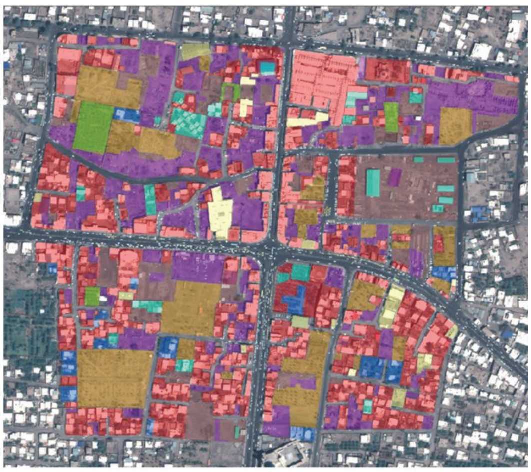
2012

(d)

Fig. 7 (a) Satellite image and land-covers at the station 2 in 2003 and (b) those in 2012. The area (m^2) and percentage of *buildings*, *vegetation* and *ground* in (c) 2003 and (d) 2012.

(a)





(b)

Fig. 8 Changes in land-cover from *old building*, *vegetation*, *ground* in 2003 into *new buildings*, *old buildings*, *vegetation* and *ground* in 2012 are shown in colors at two locations: around (a) the station 1 and (b) the station 2.

Table 3. Corresponding area changes (m^2) from 2003 to 2012 at the two locations

(a) around the station 1

2003 \ 2012	New Building	Old Building	Vegetation	Ground
Old Building	142125	18639	0	4783
Vegetation	6215	----	30108	2485
Ground	36381	----	996	37201

(b) around the station 2.

2003 \ 2012	New Building	Old Building	Vegetation	Ground
Old Building	172395	12486	0	98058
Vegetation	14437	----	8466	61354
Ground	13845	----	0	55013

DISCUSSION

The observation from the field surveys and the satellite images indicated major findings. Firstly, most of the damaged structures have been reconstructed again in the previous locations. Meanwhile some of the buildings that were not seriously damaged were completely renewed. Also, new buildings (such as sport gym, commercial complex and etc.) have been established in the empty lands that provided new land use to the region. In some areas, vegetation and open green spaces have been destructed, most of where no construction has taken place and gardens changed to bare lands.

It can be seen that although the total number of approved and reconstructed units in the city has increased in 2012 compared to 2003 (Table 1) the area of the empty lots and vacant lands, especially around the station 2 has vastly expanded. Despite the statistics there are still many vacant lands in the center and northern part of the city (Fig. 8b) that were previously inhabited however they have been left empty after the earthquake. This can be explained by the increase of unit numbers and population density in reconstructed areas. Most of the old buildings consisted of a single or two units, however after reconstruction, new buildings with more floor levels and units were established. Therefore the total number of constructed units has increased compared to the pre-earthquake time, even though the area of empty lands has also become larger. Specifically at the station 2, the amount of land converted from old buildings (OB) and vegetation (V) to empty ground (G) compared to the total area of vegetation (V), ground (G) and old buildings (OB) that converted to new buildings (NB) was considerably smaller than expected (almost half), which states the fact that reconstruction has not fully taken place.

Furthermore, although parts of vegetation have converted into new buildings (Fig. 8b), the amount of this change is not to that extent to be concerned about. The more concerning issue is the considerable amount of vegetation land that has become empty ground after the earthquake. With regard to the value of farms and gardens and the profits that could be made from these areas, and also considering the fact that most of the destroyed gardens are located in the largely-damaged areas such as (G4+G5)> 70% in Hisada et al. (2004), we can say that probably the owners of these lands were killed in the earthquake and thus nobody can restore and maintain the conditions of these gardens.

CONCLUSION

Urban reconstruction after an earthquake is the most important part of disaster management that is performed by governments. Studying on reconstruction processes is important for the evaluation of government's efforts and achievements. In this paper, the authors conducted a study on the reconstruction of Bam city in two designated areas after the earthquake of 2003, to monitor and evaluate this process. Results showed that at one study area, which was partially damaged, the total area of buildings has increased while the area of empty lands decreased and the area of green space did not changed. We can conclude that this region has not only been fully restored but has also been developed and improved.

On the other hand, at another study area that was severely damaged, the total area of the buildings has decreased after the earthquake while the area of the vacant lands has distinctly increased. This increasing amount of bare lands is due to the destruction of gardens and also due to the lack of reconstruction of new houses.

The results of the comparison between two satellite images taken in 2003 and 2012 indicated that there are significant differences in the reconstruction of the studied areas. This could represent either a miscalculation or a failure in the estimation of damages in the region or it could be due to another factor such as the grants or low-interest loans provided by the government that encouraged citizens to renovate their buildings. The latter seems more probable. In future, further monitoring of other areas of Bam is necessary to discover more details about the recovery process.

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