UNIVERSITÄT SALZBURG

MONITORING RECOVERY AFTER EARTHQUAKES THROUGH THE INTEGRATION OF REMOTE SENSING, GIS AND GROUND OBSERVATIONS: THE CASE OF L'AQUILA (ITALY)

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MONITORING RECOVERY AFTER EARTHQUAKES THROUGH THE INTEGRATION OF REMOTE SENSING, GIS AND GROUND OBSERVATIONS: THE CASE OF L'AQUILA (ITALY)

MSc. DIANA MARÍA CONTRERAS MOJICA

PROFESSOR Dr. THOMAS BLASCHKE

Dr. DIRK TIEDE

B. Eng. MARIANNE JILGE

INTERFACULTY DEPARTMENT OF GEOINFORMATICS – Z_GIS

UNIVERSITY OF SALZBURG.

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ACRONIMS

CBD	Central Business District.
CNL	Cognition Network Language.
ESA	European Space Agency.
ESRIN	European Space Research Institute.
GIS	Geographic Information Systems.
GO	Ground observations.
GLCM	Grey Level Co-occurence Matrix
GLDV	Grey Level Difference Vector
GPS	Global Positioning System.
GUI	Graphical User Interphase.
INGV	Istituto Nazionale di Geofisica e Vulcanologia,
LIDAR	Light detection and ranging
LOS	Line of sight.
LST	Land use surface temperature.
LULC	Land use/land cover.
MLSC	Maximum Likelihood Supervised Classification.
MOVE	Methods for the improvement of vulnerability assessment in Europe.
NDVI	Normalised differenced vegetation index.
OBIA	Object-based image analysis.
OOA	Object-oriented image analysis.
PDNA	Post-disaster needs assessment.
RADAR	Radio detection and ranging.
RS	Remote sensing.
SAFER	Services and applications for emergency response.
SAR*	Synthetic radar aperture.
SAR*	Search and rescue.
InSAR	Synthetic aperture radar interferometry.
S	Standard Deviation
SCT	Sub-pixel Correlation Technique.
UHI	Urban heat islands.
TRIAMS	Tsunami recovery and impact assessment and monitoring system.
UNDP	United Nations Development Program.
VNRI	Visible near infrared

* Different meaning according to the context.

1. INTRODUCTION

1.1. BACKGROUND

On April 6th of 2009, an earthquake with a magnitude of 6.3 M_W, at a depth of 10 km and at an epicenter located 34 km to the Southwest of the city of L'Aquila in Italy struck the city (population 728.000). L'Aquila is the capital of the province by the same name, and a major center of the *Abruzzo* region. Its location, and the map of ground motion intensity during the earthquake are displayed in figure 1-1.

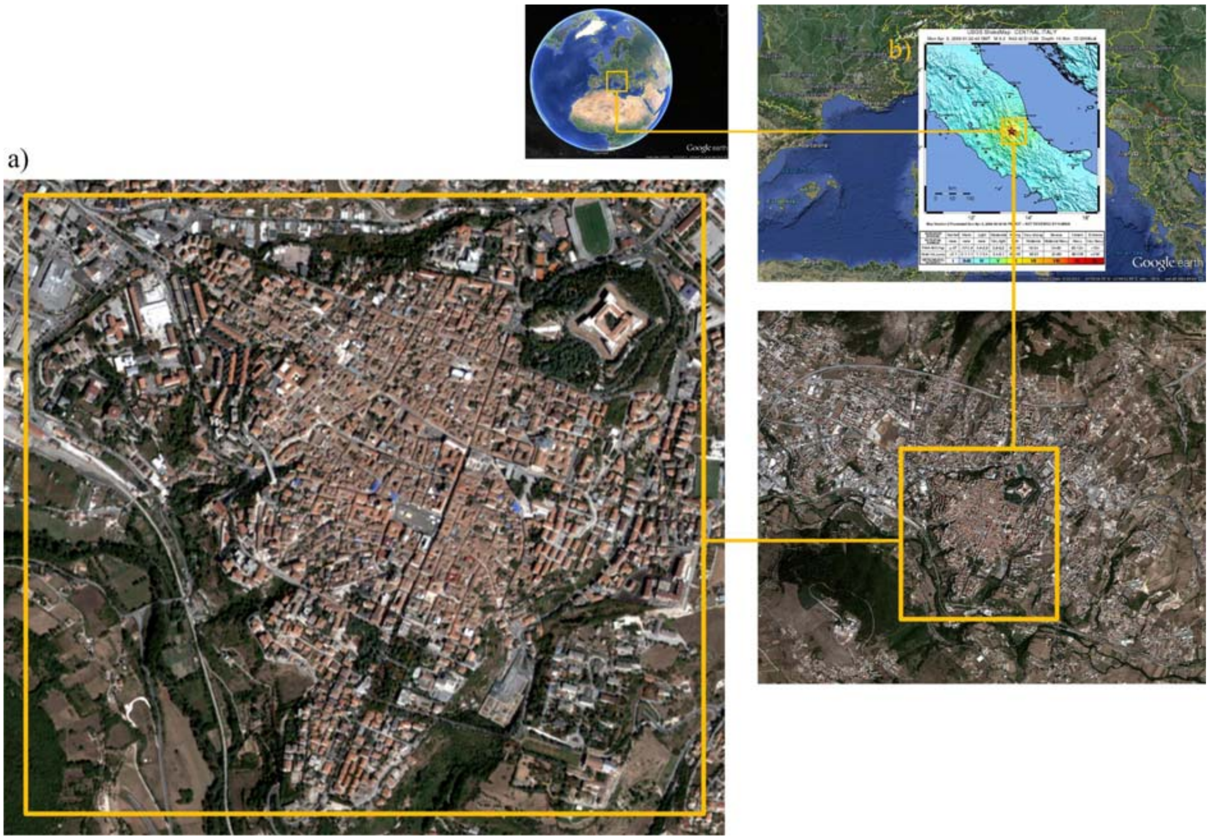

Figure 1-1 Case study area: L'Aquila (Italy).
a) Location. Source: *Google Earth – Quickbird/Digitalglobe*, distributed by *European Space Imaging* on 11 September 2011; and b) Map of the ground motion intensity during the earthquake in L'Aquila (Italy). Sources: USGS.

The historical city was destroyed, 1.500 people were injured, 202 of them seriously, 308 lost their lives, 67.500 became homeless [1], and between 3.000 and 10.000 buildings were damaged. Some academic sources stated that between 1.5 and 3 million tons of waste (70-80% a combination of aggregates, masonry and concrete) were generated [2][3], while other sources state that between 4 and 5 million tons [4]. The cost of the damage was estimated to be 16 billion Euros [5]. More than four years later, some of the most affected areas in the city center of L'Aquila [7] still remain off limits to citizens [6], and plenty of the historic buildings are supported by electro-solded buttresses.

1.2. RESEARCH PROBLEM

The usefulness of remote sensing imagery for developing indication maps of damages after earthquakes in urban areas has already been proven in the cases of Carrefour in Haiti, and Concepción in Chile. Now the research question is: if and how Remote Sensing (RS), as well as Geographical Information Systems (GIS) integrated with ground observations (GO) can serve to efficiently monitor the recovery process, not only during the emergency, but also in its subsequent phases: early recovery, recovery, and development phase.

Monitoring the progress of the recovery is a holistic process. It implies knowledge about the existing vulnerability before the earthquake, and the extraction of indicators in the physical, social, economic, institutional, cultural and ecological dimensions, in order to avoid impending vulnerability and assessing resilience.

This proposal corresponds to the second specific objective of the PhD research entitled: Spatial vulnerability indicators applied to recovery and risk reduction after earthquakes: The case of L'Aquila (Italy). The first step of this project is to establish spatial variables of recovery after earthquakes that can be integrated to indicators, as well as defining an index of progress for every recovery phase in the physical, social, economic, institutional, cultural and ecological dimensions. After identifying the variables and indicators for each recovery phase, it will be necessary to design a methodology based on geospatial tools and techniques (RS, GIS and GO), in order to use these variables and indicators by combining them to a recovery index to measure the progress of an affected urban area in this aspect.

Between 2009 and 2013 we have been combining GO, GIS and RS, in a lesser proportion, in order to complete the map indicating the degree of damage, and to monitor the changes in the land use in L'Aquila (Italy), after the earthquake. This time, the main reason for formulating this project is the possibility of exploiting the capabilities of geospatial tools and techniques, in order to efficiently monitor recovery, regarding time and cost.

1.3. JUSTIFICATION

Several indices have been developed to measure vulnerability, but only few studies yielded a recovery index, which is the least studied phase in the cycle of disaster management [8]. The recovery of Kobe (Japan) is the most well documented and successful recovery process in history, which reached the development phase in less than 10 years.

To monitor the recovery of a city after a disaster, it is necessary to collect fine scale data, in order to map the composition of the urban area under study, and for assessing not only the changes in the urban morphology, but also the patterns of the urban landscape, in which buildings were built and people are living. Nowadays besides the PDNA (Post-Disaster Needs Assessment) by UNDP, and TRIAMS (Tsunami Recovery and Impact Assessment and Monitoring System) , there are no standards to evaluate recovery [9].

In the past, the approach for urban analysis using remote sensing imagery was mainly a pixel-based approach. This approach has several limitations regarding the accuracy of the data obtained, and it does not offer the complete context that is necessary for extracting proxy indicators in the social and economic dimension. In our project, we propose a method which integrates RS, GIS and GO to measure the progress of the recovery of an urban area after an earthquake using the Object-Based Approach, known as OBIA. This object-oriented analysis technique is useful for deriving physical and proxy socio-economic indicators in the spatial context at the local level and with a higher accuracy [8, 10-12]. OBIA is also compatible with GIS, allowing the aggregation of information, as well as multi-scale representation, offering the possibility of a more holistic assessment of the recovery progress in each phase. GO account for fine scale data, used to validate the information derived from RS and integrated through GIS.

Currently, remote sensing tools (Satellite imagery and/or aerial photography) allow a quick identification of the most affected areas in a city after an earthquake. During the emergency, GO methods such as field surveys are carried out, in order to determine the degree of safety of the buildings in the city, and to develop a map of the degree of damage [13]. However, this exercise cannot be carried out again three, five or ten years later, in order to keep a record of the post-disaster phases and monitor the achievements in the recovery process, mainly due to its costs. The result of our research will provide a method based on spatial indicators, derived from geospatial techniques, to monitor the different phases of a city's recovery, a task which would otherwise be time consuming, expensive, and the observations difficult to be documented.

Monitoring the recovery will allow us to keep the emergent causal factors of vulnerability under control, in order to avoid reproducing the pre-existing conditions that caused the disaster in the city. It will provide data to assess the resilience of a community, and encourage the formulation of pre-impact recovery plans and the improvement of recovery plans going on around the world.

1.4. RESEARCH OBJECTIVES

The purpose of this report is to present a methodology, which draws upon spatial indicators, to monitor a post-disaster recovery process after an earthquake, by integrating remote sensing using OBIA, GIS tools and GO methods. This methodology shall integrate spatial indicators that can be monitored not only during the relief or emergency phase, but also during the early recovery, recovery and development, if there is one. The integration of these methods and techniques will provide indicators in the physical dimension, from which it will be possible to derive proxy indicators in the social, economic, and ecological dimensions.

1.4.1 Sub-objectives:

- To demonstrate the capabilities of OBIA for monitoring a post-disaster recovery process beyond the emergency or relief phase.

- To design a monitoring model integrated by indicators to be assessed according to each recovery phase, and the suitable tools and techniques to carry out this task.

- To integrate a framework of spatial indicators to monitor and assess a recovery process after an earthquake in the physical, social, economic and ecological dimension.

2. LITERATURE REVIEW

2.1. POST-DISASTER RECOVERY PROCESS

In the concept of the present report, recovery is defined by the authors as a complex multidimensional long-term process of planning, financing and decision making after a disaster, in order to restore sustainable living conditions of a community or an area, strongly influenced by vulnerable conditions in the physical, social, economic, institutional, cultural and ecological dimensions existing before the event [14].

The recovery process must address the interaction among a variety of groups and institutions, with the aim to rebuild people's lives and livelihoods, besides reconstructing buildings and infrastructure, restoring cultural assets and ecological conditions [15]. The recovery is maybe the phase of the disaster management cycle that better reflects the idiosyncrasy of a population. More vulnerable areas will have longer recovery phases [16, 17] and each recovery case is special due to the vulnerability conditions existent before disasters.

In spite that this uncertain and conflict-laden process is not linear, and it does not have a clear boundary, it is usually divided into four phases. In the present research, we will adopt the name of the recovery phases established by the United Nations Development Programme (UNDP): relief, early recovery, recovery and development. A summary of the denominations for each recovery phase according to different authors is presented on figure 2-1.

2.2 INDICATORS – SPATIAL INDICATORS

The assessment of the recovery process should be based on indicators in order to guarantee objectivity and comparability [18]. Indicators are qualitative or quantitative measures resulting from systematically observed facts [19] which describe the characteristics and allow the assessment of certain phenomena.

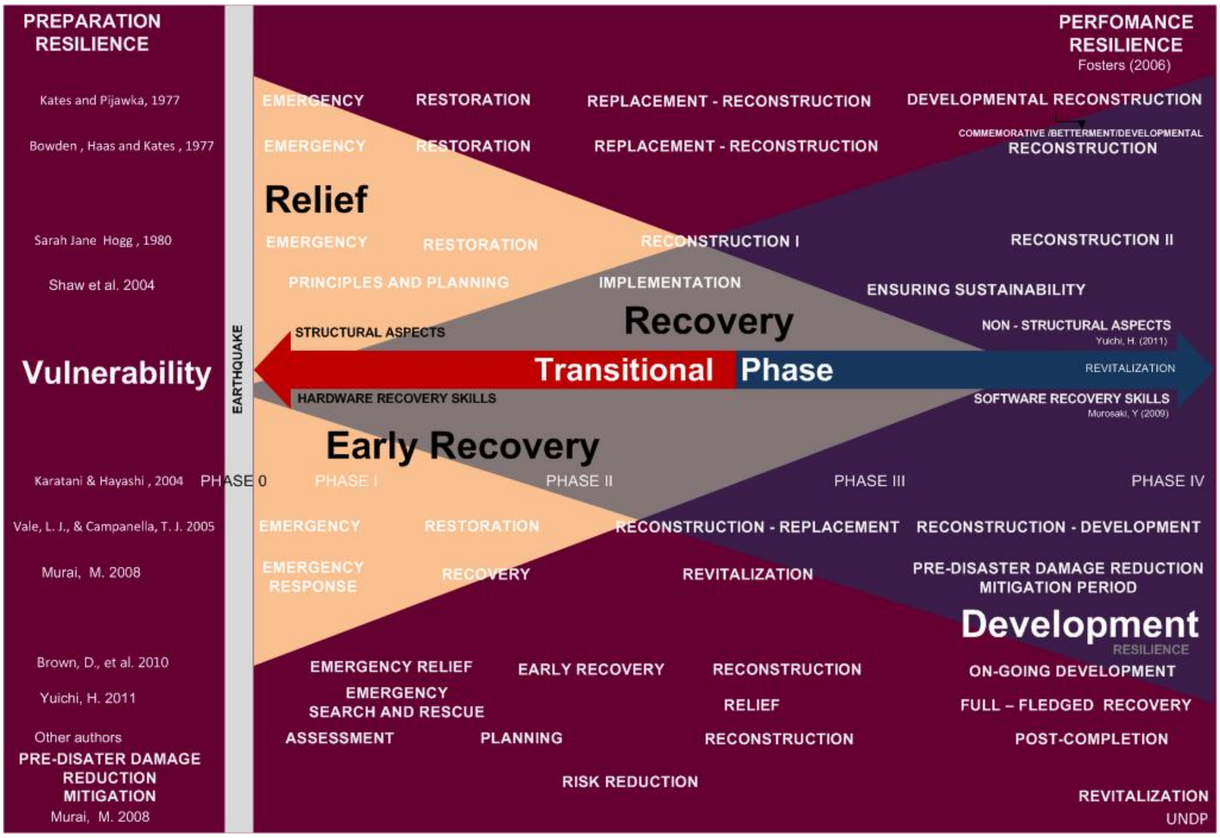

Figure 2-1 Post-disaster recovery phases according to different authors
Adapted from: UNDP Policy on Early Recovery [10].

Several indices have been developed to measure vulnerability, but only Yuka Karatani & Hayashi [20], [21]; Shohei [18]; Chang [22] yielded a recovery index, and only Brown et al. [23] have considered the use of spatial indicators. Measuring the spatial component of recovery is important, since both the disastrous event as well as the recovery process to follow, take place in an explicit spatial context. Spatial indicators are visible measures of the stage, at which the recovery process is progressing, making it easier to design a recovery plan at earlier stages, and to evaluate it in a participatory way later. Bearing these reasons in mind, it is difficult to understand why the spatial aspect of recovery is rarely considered, as it was proved by Mills in 2008 [8].

Brown et al. identified twelve recovery indicators with some spatial component: road condition, accessibility analysis, reconstruction of bridges and transport facilities, presence of vehicles; removal and construction of buildings, change in urban land use and morphology, quality of dwelling and reconstruction; temporal dwellings and shelters, location of population; administration, education, healthcare and religious facilities, power, water and sanitation;

change in land cover and public open space and recovery of livelihoods. This set of indicators was aggregated to 6 sectors: transport, building /shelter, transitional shelters and IDPs, services, environment and livelihoods [9].

2.3. MONITORING

Monitoring is defined as the activity to observe a process for a period of time in order to discover the rules, which drive it. In disaster management, the rules which drive the post-disaster recovery process vary from one society to another, according to their levels of vulnerability. We believe, that the purpose of monitoring recovery processes must be orientated towards accumulating knowledge, and establishing lessons learnt, which later allow us to develop an index to measure not only the progress towards the restoration of the existing situation before the event, but also to encourage going beyond it.

2.3.1 RS and GIS

The usefulness of remote sensing imagery for developing indication maps of damages after earthquakes in urban areas during the relief phase has already been proven in the cases of central Jave in Indonesia [11, 24], L'Aquila in Italy [25, 26], Carrefour in Haiti [27, 28], Conception in Chile [28], and Fukushima in Japan [29], through deriving indicators in the physical dimension during the relief or early phase of the post-disaster time. The advance of remote sensing technologies turns satellite images into a valuable method for collecting data of urban change in a post-disaster phase [30].

In May 2010, Bevington et al [31] made an attempt to monitor, the progress in the early recovery phase after the earthquake in Haiti (Januar 2010) combining remote sensing and ground observations collected through interviews, community meetings and other methods, to test the correlation between socio-economic disruption and degree of physical damage. In this research, the authors found that despite the limitations of remote sensing for explaining the changes in the post-disaster landscape, the doubts are elucidated with the information collected through ground observations.

Considered as a direct observation tool by Brown, D., et al., the main advantages of using high resolution satellite images is the accuracy and reliability of the data collected, while the drawback is that some aspects of recovery are not evident in satellite images. Although, this disadvantage can be overcome by combining imagery analysis with ground observations [9].

Anyway, satellite imagery needs to be transformed into information that can be combined with other data sets, whereby GIS plays the integrating role [10].

2.3.1.1 Ground/surface deformation:

The project of Services and Applications for Emergency Response (SAFER) analyzed the ground deformation in the Abruzzos region (Italy), due to the earthquake in L'Aquila. The objective was to thoroughly understanding the seismic activity, and identify the areas prone to landslides as secondary effects due to the earthquake. To achieve this objective, they used *ENVISAT* images processed in *DIAPASON* software. The results were the milimetric measurements of the ground deformations produced by the earthquake in L'Aquila. The outcome was 9 zones , identified by different colours, equivalent to minimum displacement of 25 cm [32], as it is possible to observe in figure 2-2.

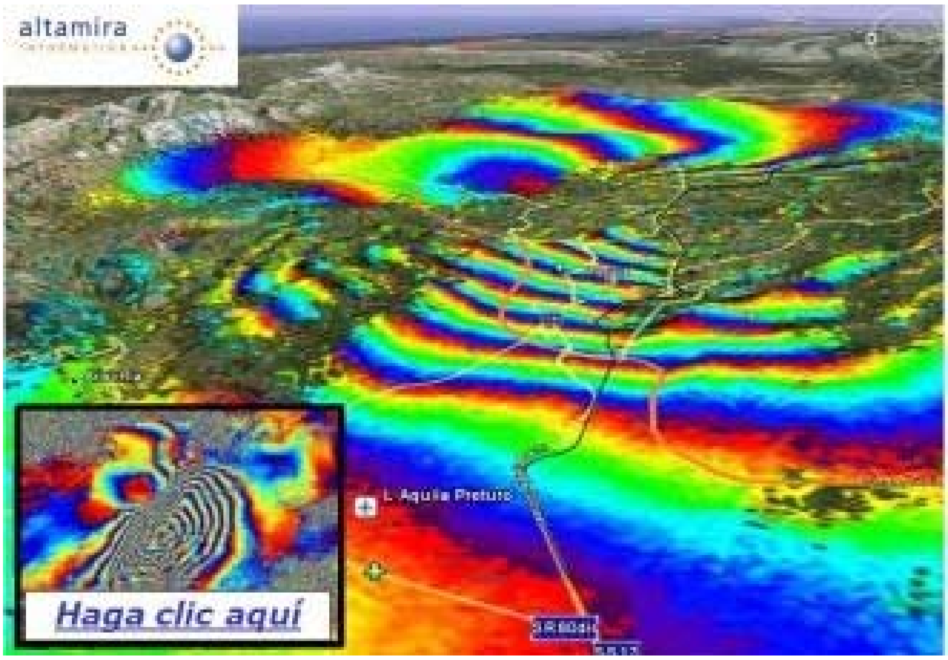

Figure 2-2 Ground deformations in Abruzzos region.
SAFER. "Estudio de caso:Terremoto de L'Aquila " Estudio de caso. Retrieved March 15th, 2013, 2013, from http://www.altamira-information.com/html/3-18782-ESTUDIO-DE-CASO-Terremoto-en-L-Aquila-Italia.php.[32]

Synthetic Aperture Radar Interferometry (InSAR) and Sub-pixel Correlation Technique (SCT) were used by Goudarzi, M. A., et al. in 2012 to also measure ground surface deformation in the satellite line of sight (LOS). To determine direction and deformation, two separate interferometric pairs of ENVISAT ASAR and ALOS PALSAR data sets were taken into account. Additionally, the SCT was utilized to investigate the horizontal displacement in the area. Two separate pairs of *ENVISAT ASAR* and *ASTER* optical image data sets were used, and horizontal displacements un Range/Azimuth and in West-east/south-north directions were also studied. They found a maximum of 28.1 cm subsidence in LOS direction on the descending interferogram of the *ENVISAT ASAR* data set to the north-west of Onna village, figure 2-3 shows both, the ascending and the descending interferograms. The post-seismic relaxation occurred after April 7th, towards the South and South-east of the main epicentre. The horizontal displacement was not significant on the surface, as it was observed in the results from SCT [33].

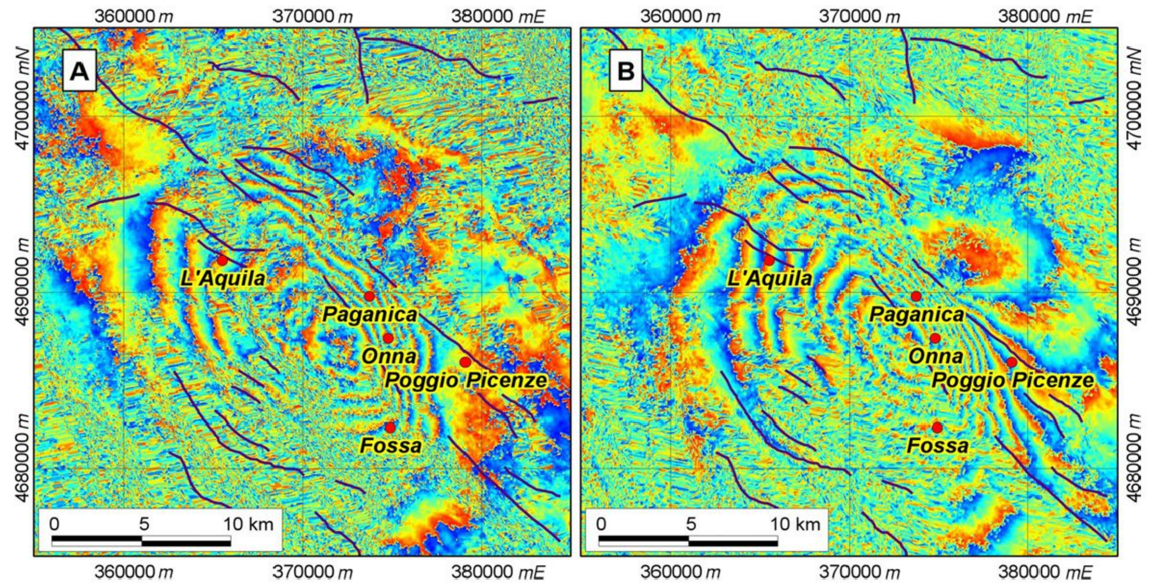

Figure 2-3 ENVISAT ASAR interferograms of the L'Aquila area.
(A) the ascending (2009/04/15-2009/03/11) and (B) descending (2009/04/12 - 2009/02/01) pairs in the UTM coordinate system (zone 33). Major faults are shown in black lines. Goudarzi, M. A., et al. (2011). "Surface deformation caused by April 6th 2009 earthquake in L'Aquila (Italy): A comparative analysis from ENVISAT ASAR, ALOS PALSAR and ASTER." International Journal of Applied Earth Observation and Geoinformation **13**(5): 801-81.[33].

2.3.1.2. Change detection in Buildings and vegetation

Brown, D., et al applied a pixel-based approach and the maximum likelihood algorithm to classify impervious surfaces and extract information about removal and construction of buildings [9]. Regarding land cover and urban green space, the same authors applied a series of semi-automated methods: normalised differenced vegetation index (NDVI) and maximum likelihood supervised classification (MLSC). The land cover indicators studied were: erosion and degradation, deforestation and construction. Brown, D., et al argues that monitoring environmental recovery or degradation must include non-urban land cover classes such as vegetation-based habitats (sparse vegetation, thick vegetation) and water bodies, and also urban (bare ground, impervious surfaces and buildings). The classification work was done using *ENVI* software suite, and change detection.

In the past, the approach of using remote sensing imagery for urban analysis was mainly a pixel-based approach. This approach has several limitations especially in analyzing VHR images and it does not offer the complete context that is necessary for extracting proxy indicators in the social and economic dimension. In 2010, Blaschke claimed that the pixel paradigm was coming to the end, and the object-based image analysis (OBIA) or GEOBIA methods were gaining ground in the context of spatially explicit information extraction workflows, which is also, according to the author the most suitable for spatial planning and monitoring programs [10].

Nevertheless, the discussion about the advantages of the OBIA approach, compared with the pixel analysis approach started several years ago. In 2001, Blaschke and Strobl pointed that while pixel-based analysis is based on the spectral values of the pixels, OBIA takes into account spatial concepts or relationships of the objects under analysis such as location distances, topological connectivity, directional characteristics, neighbourhood context, multiple scales, spatial patterns [34], shape, compactness, boundaries and so on.

OBIA builds on concepts that have been used in remote sensing image analysis since several years, such as: segmentation, edge-detection, feature extraction and classification concepts [10]. Its offers a bridge between spatial concepts applied in landscape analysis, GIS, and GIScience, providing synergy between image-objects and their radiometric characteristics and analyses in Earth Observation data. In 2006, Arbiol asserted that high resolution aerial images at coarse scales can detect fields or forest stands, and on the finer ones trees or plants [10]. In order to detect damages in buildings in L'Aquila, Uprety and Yamazaki in 2010 used high-resolution Synthetic Radar Aperture (SAR) imageries from *TerraSAR-X* (X-band, wave length of 3.1 centimeter) along with high-resolution *QuickBird* optical images [26]. They have two sets of data: one pre-sismic, and one post-seismic. Their idea for damage detection using microwave radar technology is based on the hypothesis that damaged buildings give a weak backscatter return to the satellite receiver compared to not affected buildings. The red colour pointed out the possible changes after the earthquake. A low correlation value and a large backscattering difference indicates a possibly damaged building, as it is displayed in figure 2-4 [26]. They also estimated the NDVI from the post-event *QuickBird* image (multispectral, four bands), as it is observed in figure 2-5.

An automated approach based on OBIA for deriving indications for damaged buildings in L'Aquila was applied by Tiede in 2010 [25]. The author based their change detection analysis, in the difference of the shadows casted by buildings before and after the earthquake, and it is mainly oriented to the detection of partially or totally collapsed buildings [27]. This methodology also requires also pre- and post-disaster images with similar recording angles. The change detection analysis was carried out through rule sets for information extraction written in *Cognition Network Language* (CNL), in the *eCognition 8* software (Trimble Geospatial). An automated spatial comparison (size, shape, etc.) of extracted shadow objects before and after the earthquake was done, the size of missing "shadow-objects" serves as an additional indicator for damage impact.

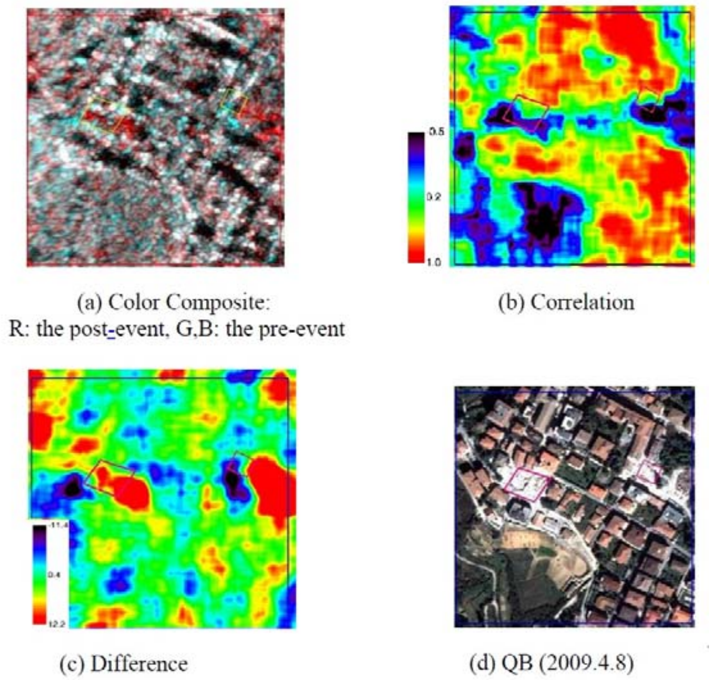

Figure 2-4 Correlation and difference map of a damaged area in L'Aquila (Italy).
Uprety, P. and F. Yamazaki (2010). Damage Detection using High Resolution TerraSAR-X Imagery in the 2009 L'Aquila Earthquake. 8th International Workshop on Remote Sensing for Disaster Management Tokyo, Japan, Tokio Institute of Technology**:** 9 [26]

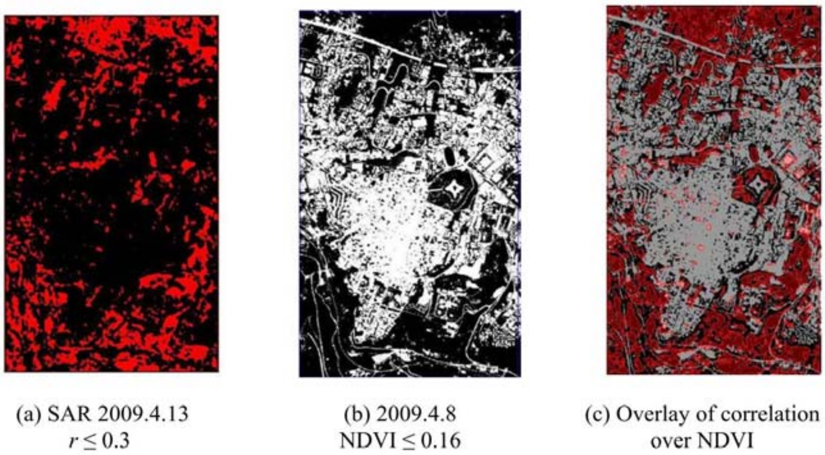

Figure 2-5 NDVI an correlation map of the central L'Aquila city.
Uprety, P. and F. Yamazaki (2010). Damage Detection using High Resolution TerraSAR-X Imagery in the 2009 L'Aquila Earthquake. 8th International Workshop on Remote Sensing for Disaster Management Tokyo, Japan, Tokio Institute of Technology**:** 9 [26].

The likely damaged buildings were visualized applying *Kernel* density methods and weighted according to the difference in the sizes of the missing shadow objects in the post-disaster image, as it is presented in figures 2-6 and 2-7. In these figures, the red tones highlighted damage hot spots, and the size of the circles are proportional to the change in the size of the shadows, therefore to the probable magnitude of the damage [25].

Figure 2-6 Damage indication after the earthquake in L'Aquila (Italy).
Tiede (2010). Experiment on the "L'Aquila Area Earthquake", with VHR images before and after the date of the event (April 6, 2009) Salzburg, Centre for Geoinformatics (Z_GIS), Salzburg University: 6 [25].

Figure 2-7 Damage indication map after the earthquake in L'Aquila (Italy).
Tiede (2010). Experiment on the "L'Aquila Area Earthquake", with VHR images before and after the date of the event (April 6, 2009). Red tones indicate high impact, yellow tones low impact. Salzburg, Centre for Geoinformatics (Z_GIS), Salzburg University: 6 [25].

2.3.1.3. Change detection in the socio-economic dimensions

In 2009, Ebert, A. et al used object-oriented image analysis (OOA) approach to extract proxy variables from high resolution images, and laser scanning data, combined with elevation and hazard data. The information derived was applied to the assessment of vulnerability in the social dimension in a case study area of Tegucigalpa (Nicaragua). In their research, the authors concluded that OOA was a valuable tool for extracting proxy variables, which were not directly mappable [35].

In the research done by Ebert, A., et al in 2009, to estimate vulnerability in the social dimension, the indicator of socio-economic status had the parent proxy of: settlement type and topographic location. The supporting proxies of the settlement type were: proportion of built-up and vegetated area, road conditions, roof type, available infrastructure and texture. The supporting proxies of topographic location were slope position and proportion of buildings in hazard zone. The indicator of commercial and industrial development had building heights as the supporting proxy, and the indicator of distance or lifelines had the distance measures as the supporting proxy [35]. The results are depicted in figure 2-8.

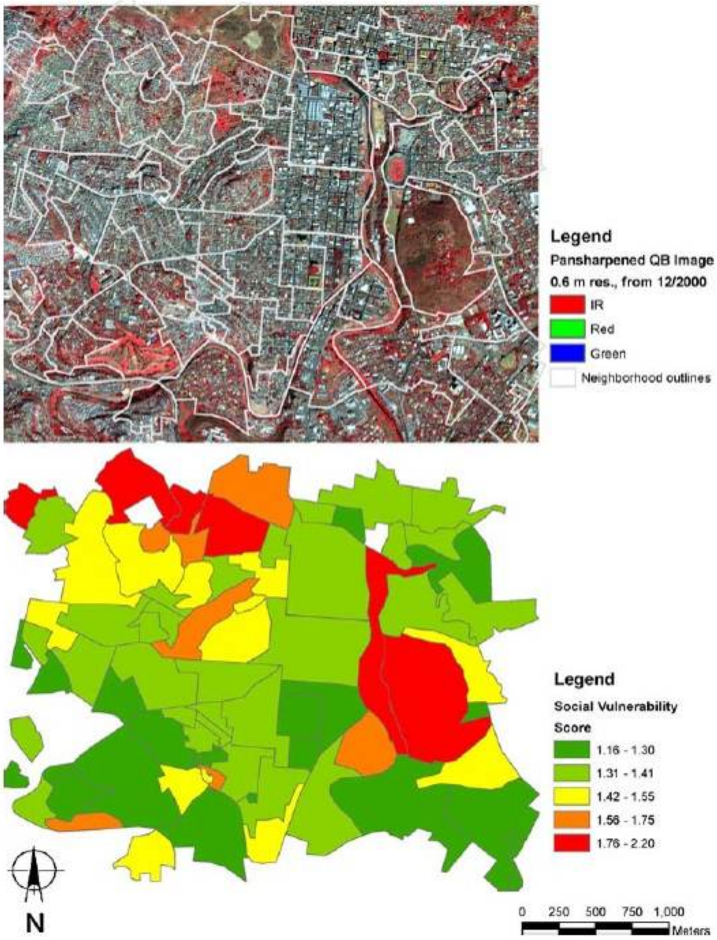

Figure 2-8 Scores from the social vulnerability index per neighborhood.
Ebert, A., et al. (2009). "Urban social vulnerability assessment with physical proxies and spatial metrics derived from air- and spaceborne imagery and GIS data." Natural Hazards **48**(2): 275-294 [35].

According to Brown, D., et al. particular buildings such as commercial, education facilities, factories, health facilities, houses and hotels can be identified using satellite images, by observing the shape and the structure of a building, and its surrounding environment [25], which is particularly useful for monitoring the progress in the socio-economic dimension in the post-disaster recovery time.

Another indicator for monitoring progress in a post-disaster recovery process is the VNRI radiance [36], or night-time light (radiance intensity and duration). They are used to monitor the removal and reinstallation of power, economic activity, CO_2 emissions, and provision of electricity [9].

2.3.2 GO and GIS

Before the fifth and the tenth anniversaries after the earthquake in Kobe (Japan), two comprehensive recovery assessments were carried out in 1999 and 2003, respectively. The first time, the object of the survey was to check the progress of the post-disaster recovery in regard to: daily-life recovery, safe and secure city development, housing and urban reconstruction, and economic/port recovery. Five years later, the objective was the same but focused on: civic life, urban activities, housing and community development, and safety and security. The purpose of these assessments was to collect opinions from citizens, in order to achieve a grass-roots assessment. Nevertheless, they found that it was difficult to monitor the progress of the recovery plan due to the absence of numerical targets. Therefore they created the *Citizen-Happines Index*. Eventually, after twelve workshops, they found the seven critical elements of recovery, named according to the weight allocated by the citizens: a) housing, b) social ties, c) community rebuilding, d) physical and mental health, e) preparedness, f) economy, g) livelihood, and economic and financial situations, and g) relationship to government [37]. Unfortunately, these opinions were not georeferenced in order to discover the spatial patterns of these findings.

A combination of direct observations (remote sensing and ground observations) and social-audit (focus group meetings, household surveys, and key informant interviews) was implemented by Brown et al. [9] to monitor and evaluate recovery in the cases of the 2004 Indian Ocean tsunami, and 2005 Pakistan earthquake.

According to Brown, D., et al. in 2010, ground observations can be part of the direct observations as ground survey using GPS video, or part of the social-audit tool to measure recovery through focus meetings, household surveys, and key informant semi-structured interviews, methods which complement each other and should be combined. These tools allow the collection of accurate qualitative data about the subjective perceptions, and the reasons behind the citizens satisfaction levels, as well as offering insight into the occupancy and maintenance level of the buildings, the progress and quality of the reconstruction work, the prosperity and attractiveness of an area, and the functionality of local shops, hospitals, churches, commemorative features, and even estimate how long the reconstruction will take[9] .

Ground observations contribute to validate the findings in satellite imagery, and to solve any queries about building use or degree of damage. In 2010 Brown, D., et al used geo-coded imagery, photographs taken by a GPS camera, and video linked to the VIEWS^{TM} (Visualizing Earthquakes with Satellites) system [9].

The opportunity of carrying out ground observations also brings the chance to collect official reports, publications and statistics[9], as well as the occasion to experience the progress and difficulties of the different post-disaster phases. The documents collected must be carefully checked, because sometimes very little of the information contained in them is relevant and/or useful, or it is not in the required scale[9], or may have political bias. Another drawback of this method lies in the fact that it is expensive and time consuming.

The GPS video or geospatial video was also used by Mills et al in 2010 to study the recovery process at neighborhood scale after the 2007 firestorm in Southern California, and to document cultural resources in the Holy Cross neighborhood of New Orleans after Hurricane Katrina. Two different systems were used in each case: the Spatial Video Acquistion System (SVAS), and Red Hen Systems VMS 300, to integrated as videos into ArcGIS with the Geovideo Toolbar. Geospatial video was considered by the same authors as the most suitable tool to collect qualitative and quantitative data at a fine scale in the dynamic post-disaster environment, not only in the spatial, but also in the temporal dimension [8]. Another advantage of this method lies in the possibility of simultaneously recording the comments of the community about their satisfaction level with the post-disaster recovery process [8].

In 2009, Ebert, A., et al. proposed a method for addressing the high cost and limited spatial coverage of ground surveys. The figure 2-19 portrays the cost-benefit concept of an integrated approach technology for the assessment of social vulnerability. The information collected through remote sensing, represented in solid lines, is efficient, easy to repeat, and low cost per mapping unit, but not detailed enough for the assessment of vulnerability in the social dimension. In contrast, ground surveys are more expensive and time-consuming, but highly detailed [35].

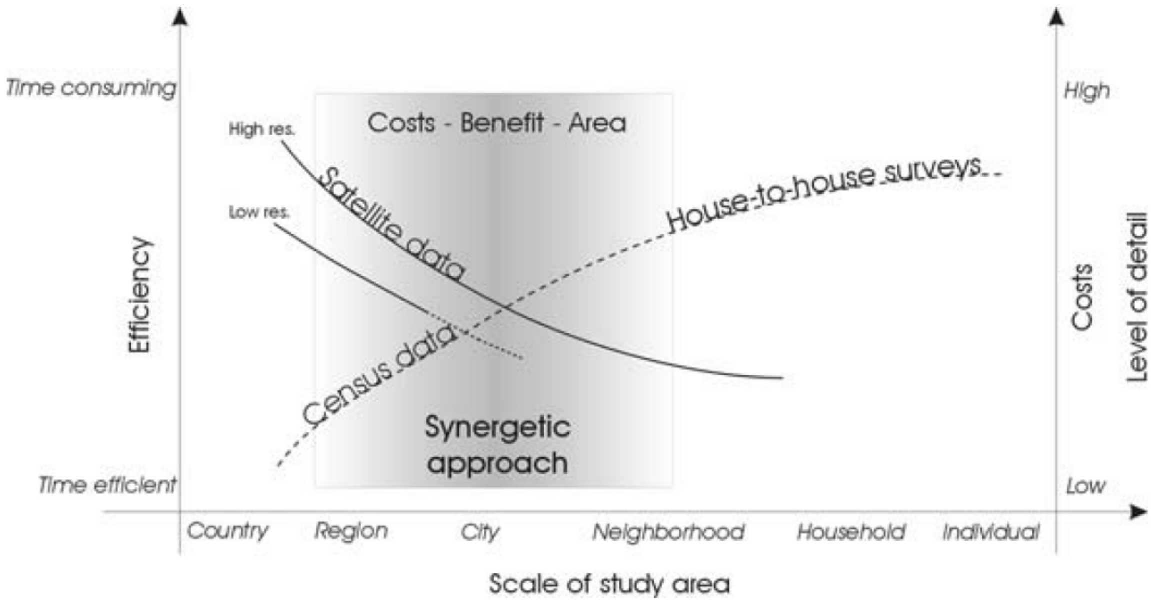

Figure 2-9 Cost-benefit integrated approach: GO, RS and GIS.
Ebert, A., et al. (2009). "Urban social vulnerability assessment with physical proxies and spatial metrics derived from air- and spaceborne imagery and GIS data." Natural Hazards **48**(2): 275-294[35].

3. METHODOLOGY

3.1. SELECTION OF INDICATORS

The list of recovery indicators was derived from several sources. Firstly, in order to have a benchmark in the post-disaster phase, we consider it suitable to use some indicators from the list of vulnerability indicators identified in the MOVE project. This project was carried out between 2008 and 2011, with the aim of creating knowledge, and innovate frameworks and methods for the assessment of vulnerability to natural hazards in Europe. The indicators of post-disaster recovery were aggregated in the same dimensions of susceptibility and fragility considered in the MOVE project.: physical, ecological, social, economic, cultural, and institutional [38] as it is represented in figure 3-1.

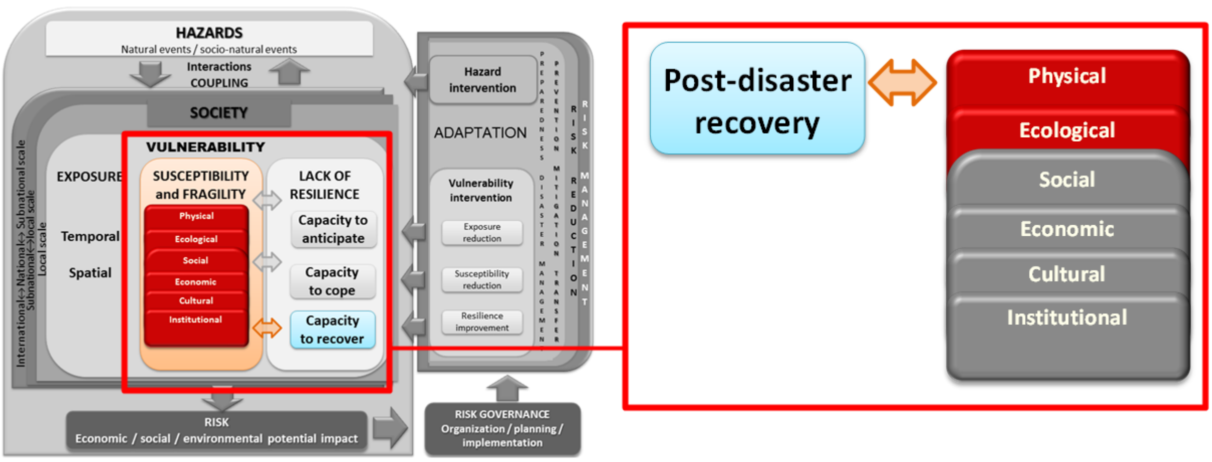

Figure 3-1 MOVE vulnerability framework adapted to post-disaster recovery assessment.
Vinchon, C., et al. (2011). Assessing vulnerability to natural hazards in Europe: From Principles to Practice. Development of outcomes. MOVE: 47.

The second source were scientific publications which address the cases of Kobe, some cities in Italy and L'Aquila; third, the periodical situation reports from Haiti and Chile issued by OCHA; fourth, the Magazine "Noi Abruzzo" published by the commissioner of the reconstruction in

L'Aquila (Italy), which is the case study area of the present research [38]; and fifth, the web sites which address the cases of the earthquake in L'Aquila and the Tsunami in Fukushisma (Japan).

The second step is an analysis to identify which of these indicators are based on spatial variables, or which ones can be spatially mapped; the third step is to find the common variables among the subsets of spatial variables from vulnerability indicators and the spatial variables from recovery indicators. The fourth is an investigation of the availability of data to carry out spatial and statistical analyses and, subsequently, to determine the most suitable techniques in both cases. The available data was already collected through remote sensing (automated and visual analysis) and ground observations, and were integrated using GIS.

3.2 SAMPLING AREA

The sampling area will be the historical center of L'Aquila as a district and node, limited by the roads or paths: via XX Settembre, viale Luigi Rendina, Vico di Picenze, via sfinge, via Fortebraccio, via Marinucci, via Santa Maria a Forfona, via Panfilo Tedeschi, via Signorini Corsi, via Zara, viale Tagliacozzo, viale gran Sasso D'Italia, viale Nizza, via Duca degli Abruzzi, Viale Papa Giovanni XXIII. In spite that the blocks along the road viale Crispi do not belong to the historical center, they are included because in the sampling area this road ends in Porta Napoli, which together with Porta Castello and Porta Romana constitute nodes in the district. The sampling area is delimited in figure 3-2.

The city center was selected as a sampling area, not only because it was the most affected area after the earthquake, but also because it is the most representative district of the city [39]. According to Brown, D., et al. a 10% sample will provide enough data [9].

Figure 3-2 Sampling area (City center) of the case study in L'Aquila (Italy).

3.3. MONITORING PROGRAM

As an essential part of the research, a monitoring schedule was defined, which included the tools to collect the data. This plan was formulated since the beginning, but adjusted according to the availability of means, resources and data of the research. The monitoring program is detailed in table 1.

TIMELINE		REMOTE SENSING (RS)			GROUND OBSERVATIONS		GEOGRAPHIC INFORMATION SYSTEM (GIS)	
Nr.*	**YEAR**	**MONTH**	**SENSOR**	**SOFTWARE**	**MONTH**	**TOOLS**	**MONTH**	**TOOLS**
0	2006	September	Quickbird					
	2009	April	Quickbird					
1	2010			eCognition 8 Arc GIS 10	April	GPS Analogue maps interviews	July December	GPS- pictures -analogue maps - publications Google maps/Earth Arc GIS 9.3-10
	2011	September	Quickbird				Januar Februar	
3	2012				September	GPS Analogue maps voice records	September Februar	GPS- pictures Google maps/Earth (3D) Arc GIS 10.1
	2013	Not available		eCognition 8 Arc GIS 10.1			Enero July	
5	2014**				April	GPS Analogue maps		GPS- pictures Google maps/Earth (3D) Arc GIS
10	2019**	April	Quickbird	eCognition Arc GIS	April	GPS Analogue maps interviews		

Table 1 Monitoring schedule of the post-disaster recovery progress in L'Aquila (Italy).
*Number of years after the earthquake, and ** fieldwork planned.

3.4 DATA COLLECTION

3.4.1 Remote sensing

3.4.1.1. Visual analysis

The visual inspection or manual interpretation of satellite images in order to detect changes applies only to buildings and vehicles, not to vegetation. The first tool used to visualize the damages after the earthquake was the application developed by the *Servizio per l'Informazione Territoriale e la Telematica – Ufficio Sistema Informativo Geografico*, in which volunteers were able to compare the high resolution images before (left side) and after the earthquake (right side), as it is displayed in the example in figure 3-3.

Figure 3-3 Damages - Crossroads of Via XX Settembre and Viale Crispi – Corso Federico II.

For the present research, the visual inspection is done by first comparing, the satellite images before (2006) and after the earthquake (2009) to detect the parcels with damages. Later, the image after the earthquake (2009) is also compared with the satellite image form 2011, to inspect if there is some progress. To carry out this inspection, we use the GIS tool *Image Analysis/Swipe* layer showed in figures 3-4 and 3-5. When a change or progress in the reconstruction process is detected, then it is compared again with the satellite image of 2006 and 2011, to be sure about the change.

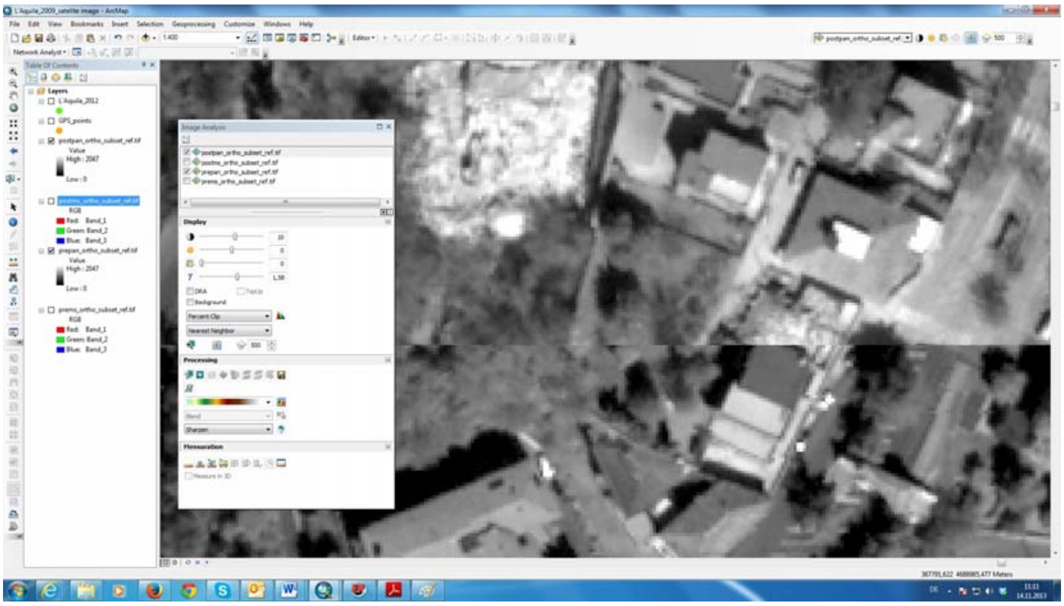

Figure 3-4 GIS tool Image Analysis/ Swipe layer - changes between 2006 and 2009.

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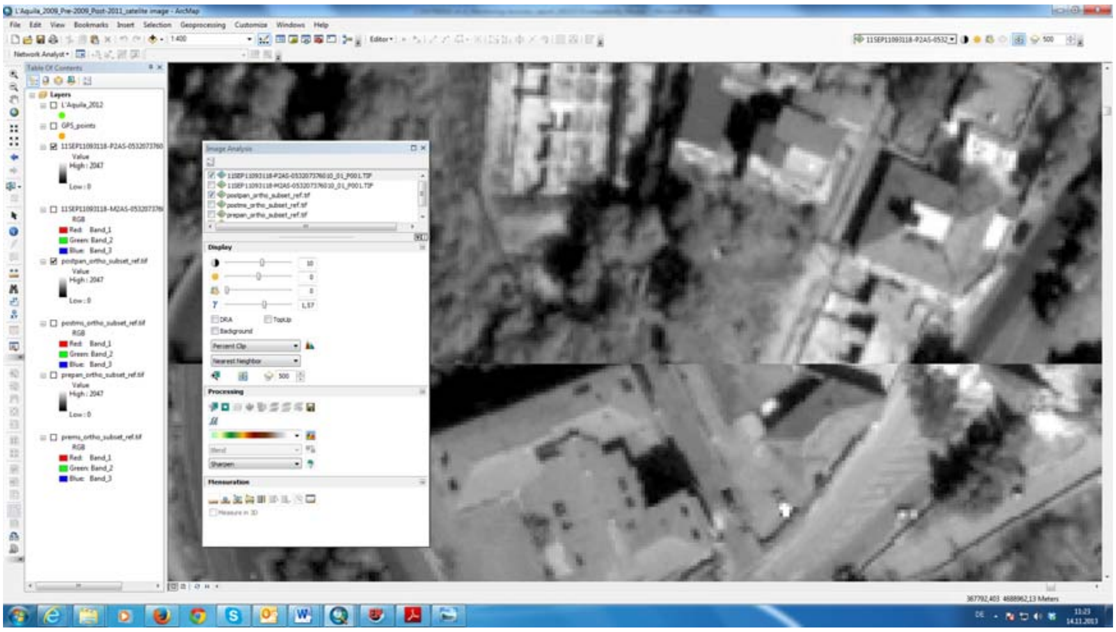


Figure 3-5 GIS tool Image Analysis/ Swipe layer - changes between 2009 and 2011.

The search for changes in the images between 2009 and 2011 is supported by the use of *Google Earth–3D*, the damage indication maps produced by Tiede in 2010 [25], the publication *Noi Abruzzo* [40], the damage degree map produced by us, which integrates the other maps, as well as the damages detected thanks to the tool developed by the *Servizio per l'Informazione Territoriale e la Telematica Ufficio Sistema informative Geografico*, unfortunately, this tool is not longer online.

3.4.1.2. Semi - automated analysis

Tiede (2010) took part in the experiment *L'Aquila Area Earthquake*, organized by the European Space Research Institute (ESRIN), and European Space Agency (ESA), in order to compare automated damage assessment algorithms [27] with the results from other research institutions. Within this experiment, *QuickBird* images were provided by Dr. Salvatore Stramondo, from the *Istituto Nazionale di Geofisica e Vulcanologia* (INGV). The results were already presented in figures 2-6 and 2-7. The analysis is semi-automated due to the integration of expert knowledge into the decision rule-set, in order to detect changes and refine the results targeted to the specific data available. A fully automated analysis, on the other hand, would use a predefined algorithm which is applicable without additional interaction, but lacking the specifics of the current situation which is in emergency situations and the limited data availability usually not very successful.

The approach of detecting changes in the built environment during the early recovery, and recovery phase, is different from the approach of detecting changes in the relief or emergency phase, due to the different priorities and the indicators in each of these phases as well as the traditional data availability.

During the relief or emergency phase, the priority is identify the most affected areas as soon as possible to save the lives of people who could be under the debris. Therefore, the algorithm to detect collapsed buildings based on the changes in the size of the shadows between pre-and post-event data, as well as rubble detection will be an effective method to locate damages, as it was previously demonstrated in the cases of L'Aquila [25], and Haiti [27].

To detect changes in the early recovery and recovery in L'Aquila, we acquired a *Quickbird/Digitalglobe* image of 2011, which is a multi-band image displayed with a composite of red, green, blue and near infrared as well as the panchromatic band in higher resolution as it is presented in figure 3-6. According to the color reflectance values presented in figure 3-7, different features such as changes in buildings, impervious surfaces (roads, squares,etc) and vegetation can be detected in the image.

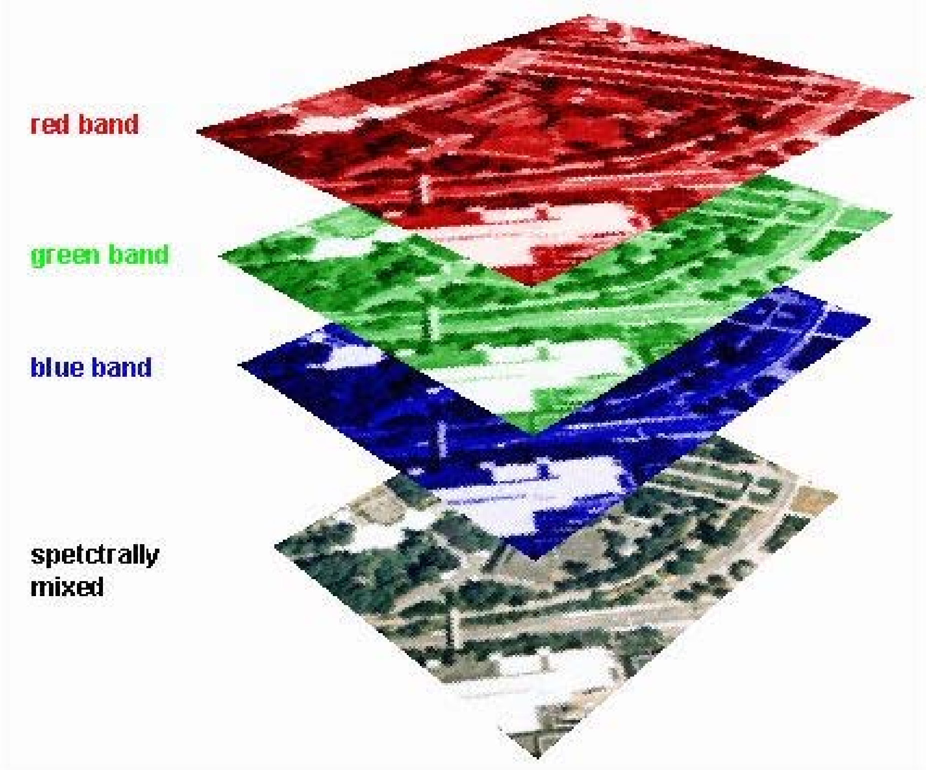


Figure 3-6 Red, green, and blue bands merged together on the bottom as a color composite image.

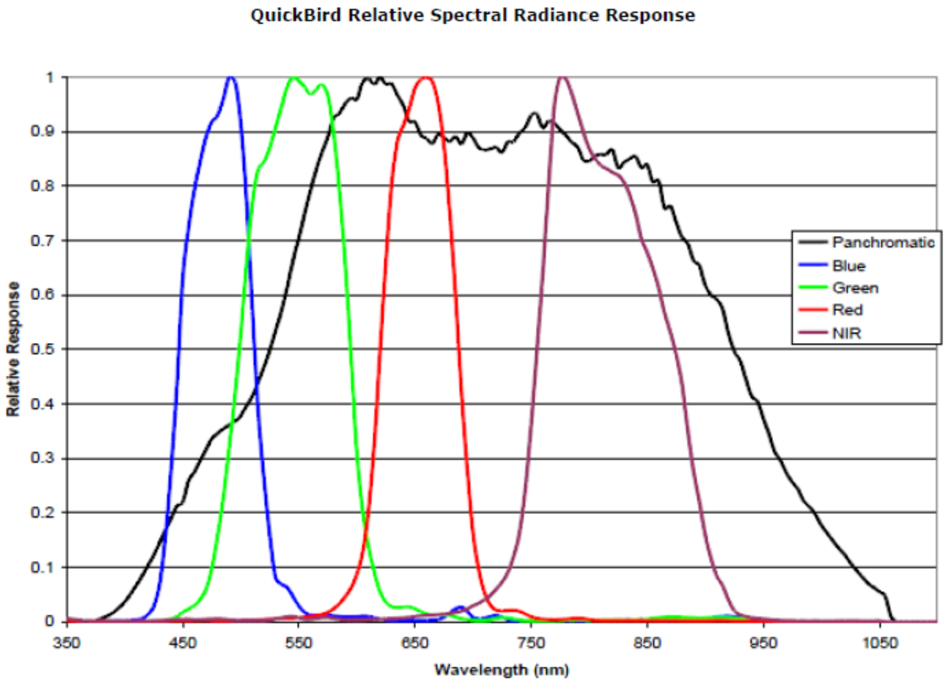


Figure 3-7 QuickBird relative spectral radiance response for the blue, green, red and near infrared band as well as for the panchromatic band. (source: digitalglobe.com).

For the detection process of changes in buildings, impervious surfaces and vegetation, a set of decision rules and parameters must be written in *Cognition Network Language* (CNL), in the *eCognition 8 software (Trimble Geospatial).* The graphical user interface (GUI) to detect changes in buildings and impervious surfaces is displayed in figure 3-8, and for detecting changes in vegetation in figure 3-9. In both figures, some of the parameters and decision rules applied can be observed in the *process tree* window.

3.4.2. Ground observations

Two fieldwork visits were conducted in L'Aquila in the period from 2009 until this year, one in 2010 (one year after the earthquake), and one in 2012 (three years after the earthquake). Another visit is scheduled for April 2014, exactly five years after the earthquake.

The main activities during fieldwork in 2010 and 2012 comprised the following: first, a visit to the restricted area and surroundings to take geo-tagged pictures and map the building condition and the building use. Second, visit the new settlements around L'Aquila. Third, collect spatial datasets to integrate the information in GIS; and fourth, interviews with community members who lived in the temporal shelters and staff members of civil protection.

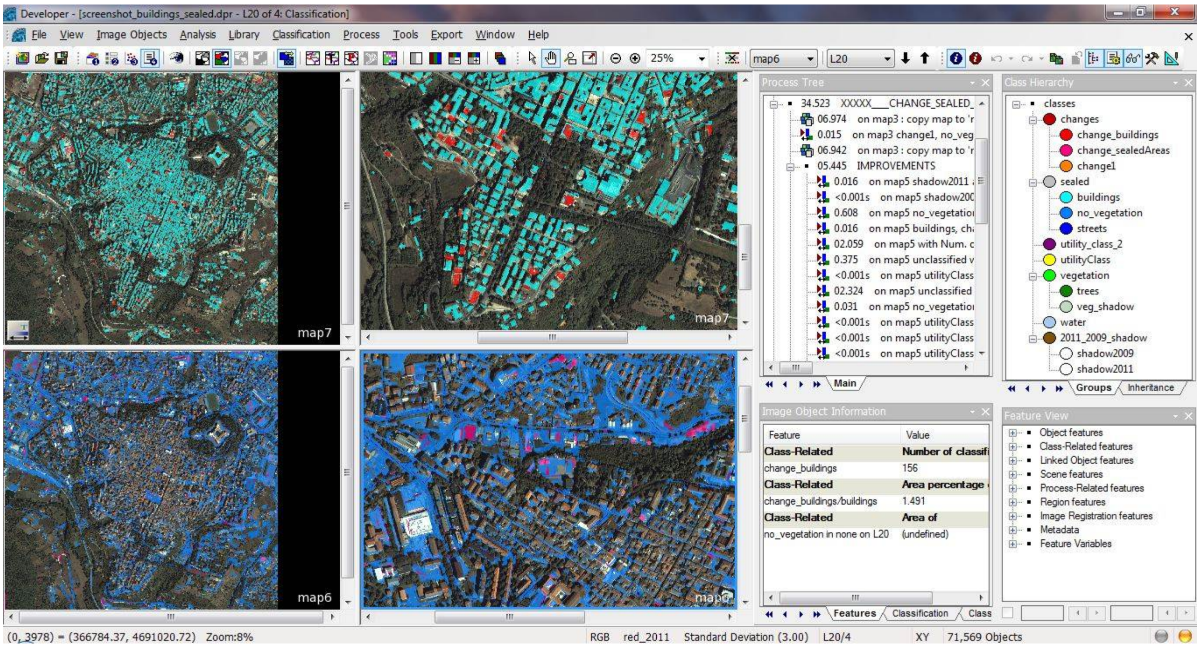


Figure 3-8 GUI to detect changes in buildings and impervious surfaces.

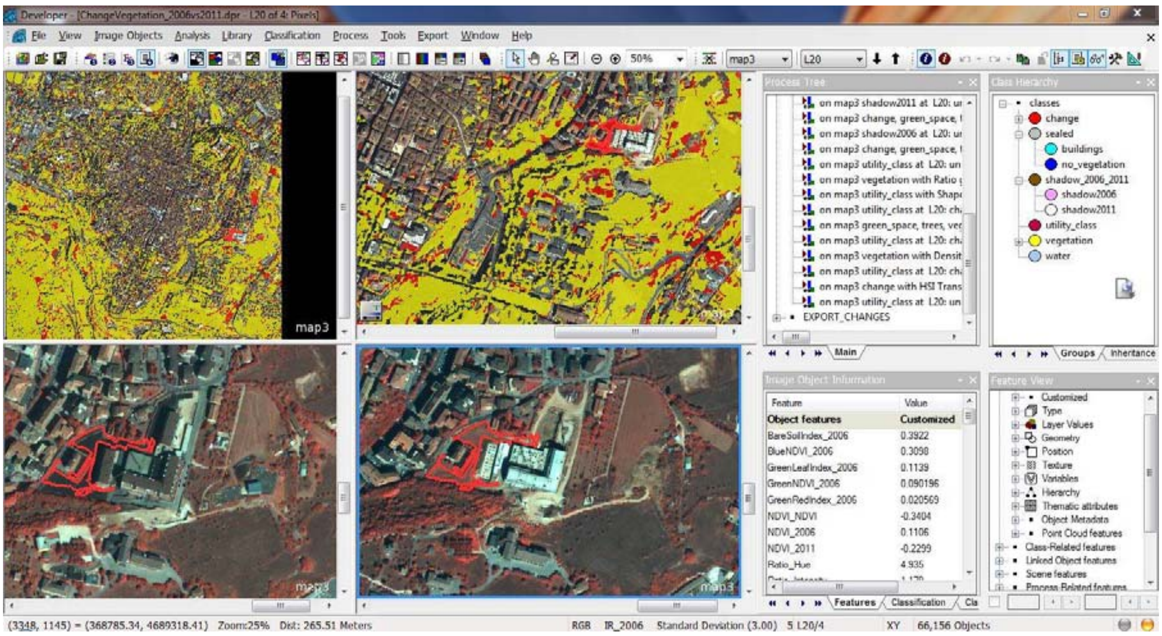


Figure 3-9 GUI to detect changes in vegetation.

In 2012, it was necessary to expend more time in the city center, that the planned initially, because it was reduced the size of the cordoned off area, and the controls to have access to it were less strict. Therefore, we had the opportunity to observe the conditions of buildings that it was not possible to observe in 2010.

3.5. DATA INTEGRATION – GIS

GIS is used to integrate the fieldwork observations from 2010 and 2012, as well as the information obtained from the documents about the reconstruction: Magazine *Noi Abruzzo* [40], collected during fieldwork, the report of MICRODIS project, a project with the aim to study the epidemiological, social and economic effects of the earthquake [42]; and the results from the automated analysis carried out by Tiede in 2010 [25], it was possible to create a geospatial database of damage degree, land use restriction and building condition, and the building use classification as it indicated in figure 3-10.

This database was used to monitor the changes in these aspects in 2010 and 2012, with respect to 2009. We reconstructed the land use map of L'Aquila before the earthquake, by integrating the information available in *Google maps* in 2009-2010, and the 3D model of the city of L'Aquila in *Google Earth*, which includes pictures of L'Aquila before and after the earthquake. Another source was the observation of the announcements in the GPS-tagged photographs taken during the fieldwork [43]. The integration and the analysis of the information collected is done through GIS, as it is depicted in figures 3-10.

This time each category of the identified changes through the visual and automated analysis will be later integrated into the framework of spatial recovery indicators formulated by Contreras et al. in 2013 [43]. Each category of change gets a value according to its contribution to the whole post-disaster recovery process. Aspects such as the presence of a new building, the removal of debris, the closing of temporary shelters, the appearance of a small pathway, the removal a soccer field, or the planting of new trees do not contribute equally to the recovery process of a city.

Regarding the assessment of the progress in the socio-economic dimension, Contreras, D., et al. in 2013 [43] reconstructed the land use of L'Aquila before the earthquake by using analogue or printed maps, *Google maps*, as well as the photographs available in the 3D model of the city of L'Aquila in *Google Earth*.

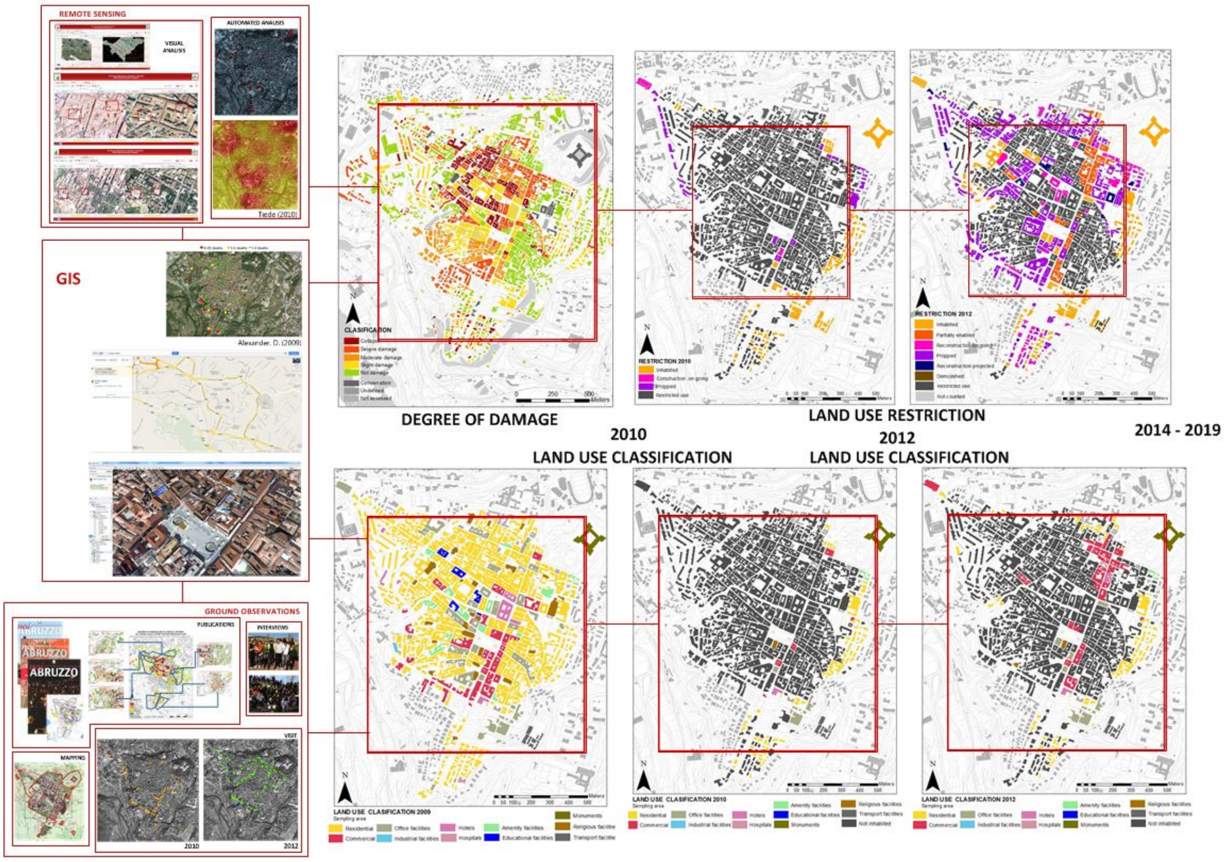


Figure 3-10 Integrated monitoring scheme to assess recovery in L'Aquila (Italy).

The return to the former building use after the earthquake is counted as a progress in the socio-economic dimensions, because land/building use involves both dimensions. The weighting of the contribution to the recovery process according to the building condition, or the building use was carried out through expert judgment, taking into account the descendant ranking of elements, that meant recovery for citizens in Kobe (Japan) [37]. Another ranking considered was the importance allocated to some particular building use, by people located in the new settlements in L'Aquila, the result of this survey was published in the final results of MICRODIS project [42]. The last rank considered was the top five indicators that the user needs survey identified in the study carried out by Brown, D., et al. in 2010, for the cases of the recovery after the 2004 Indian Ocean tsunami, in Ban Nam Khem (Thailand), and after the earthquake in 2005 in Chella Bandi, Muzaffarabad (AJK Pakistan). The results of the progress assessment of the post-disaster recovery process in L'Aquila in 2012 will be published in this year.

The scheme of the complete methodology applied in the present research can be observed in figures 3-11 (next page).

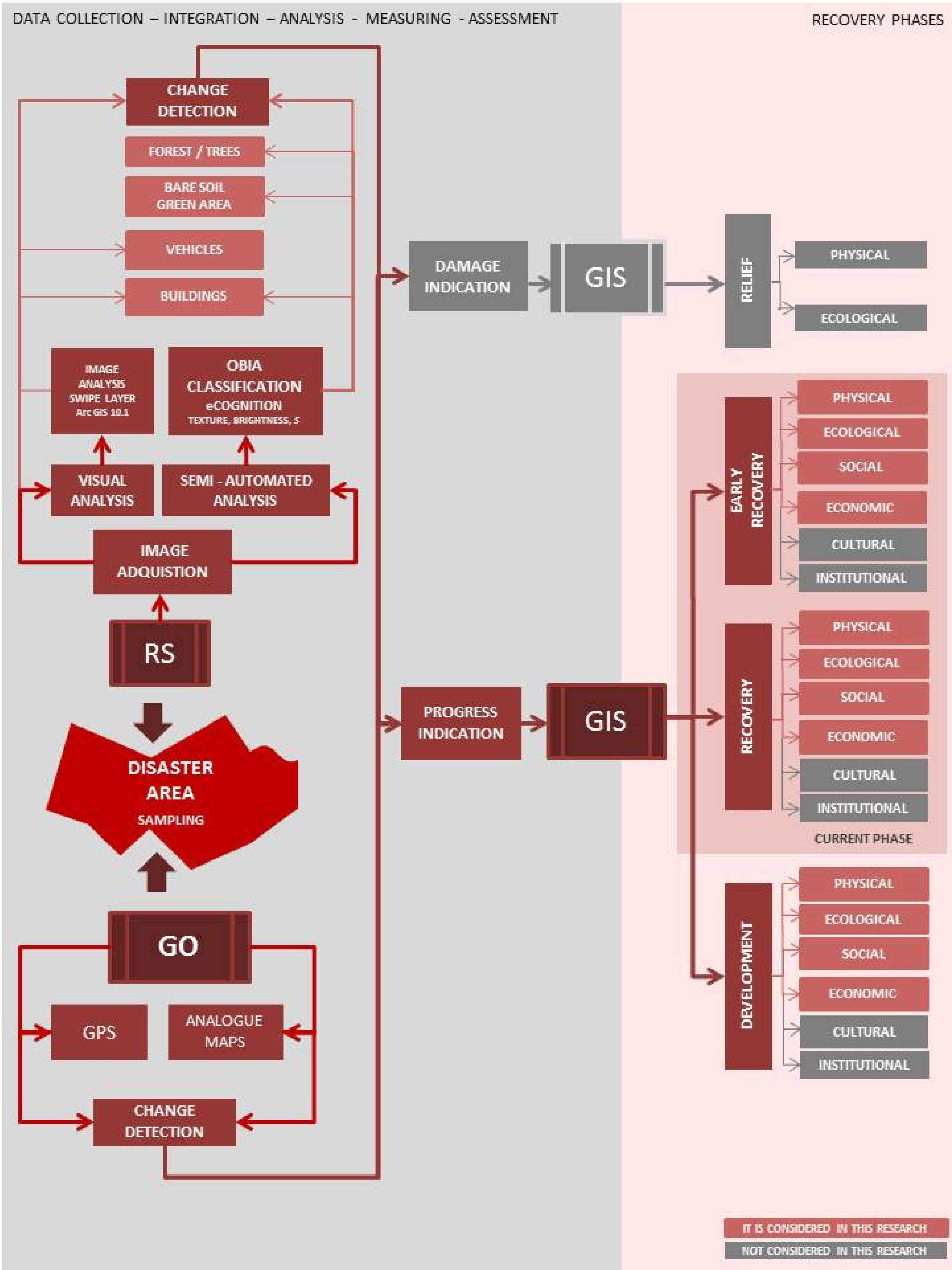


Figure 3-11 Methodology to monitor recovery phases integrating RS, GIS and GO.

4. RESULTS

4.1. OBIA CAPABILITIES

4.1.1 Visual analysis – manual interpretation

The locations of the changes identified by visual analysis are pointed out in figure 4–1 in magenta color, on the satellite image from 2011. The result of visual analysis shows76 changes, distributed mainly in new buildings (21), debris removed (12), roof repaired (8) and temporary shelters removed (7); followed by building demolished (4), earthworks (5), parking removed (3), new parking (2), roof deteriorated (2), roof disassembled (2), new settlement (1), soccer field removed (1), building reconstructed (1), new roof (1), reconstruction on-going (1), temporary structures removed (1), new pathway (1), and forest (1). Figure 4-2 shows and compares the categories of changes in the city center of L'Aquila (Italy) in the period between 2009 and 2011.

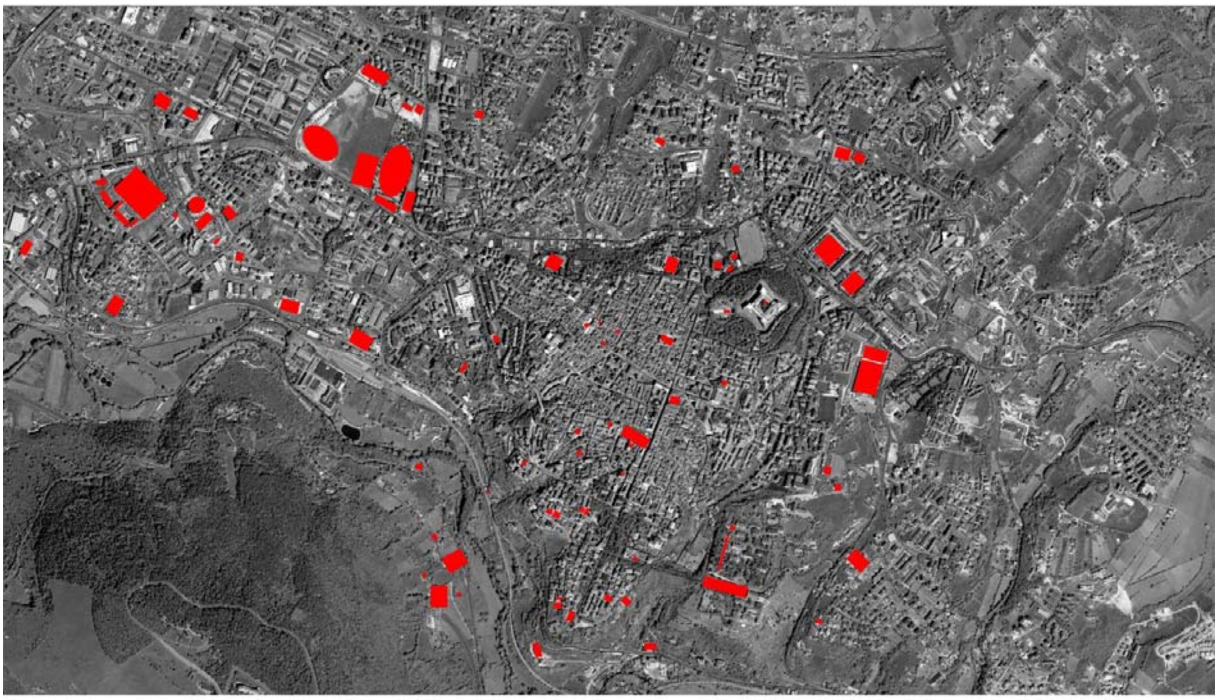


Figure 4-1 Result of visual analysis of changes in L'Aquila (Italy) between 2009 and 2011.

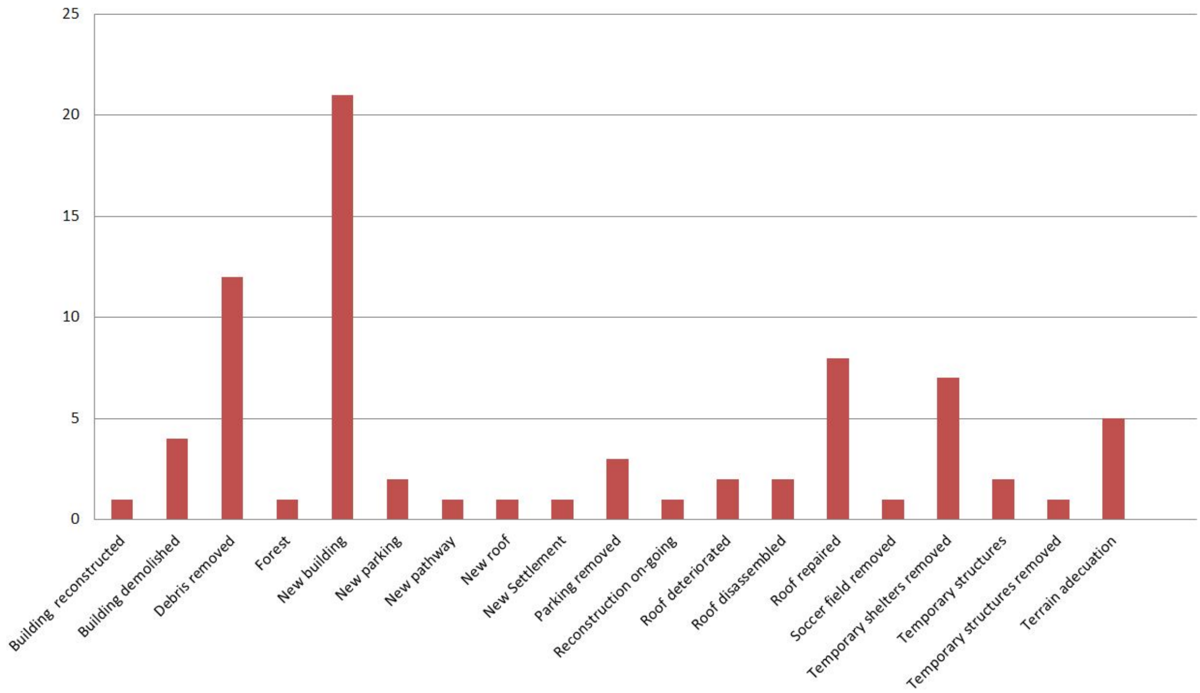
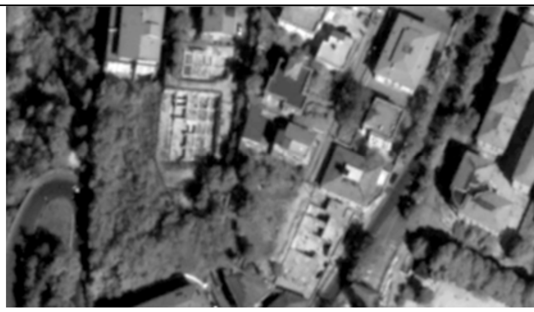
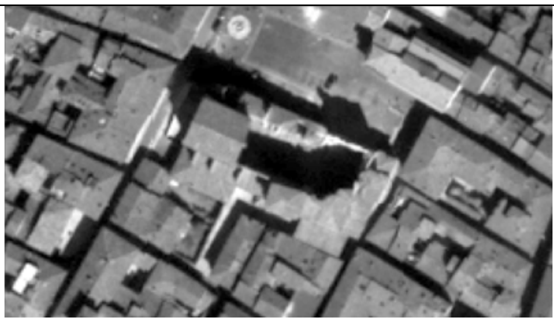
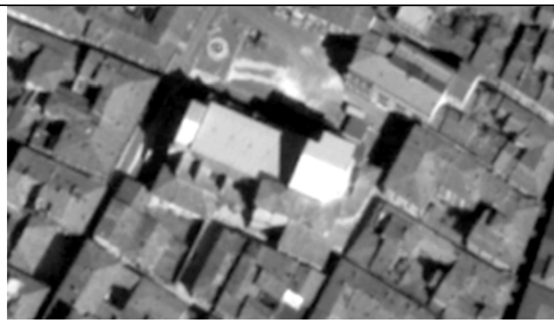
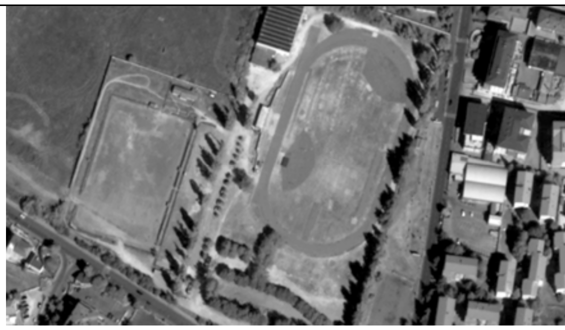
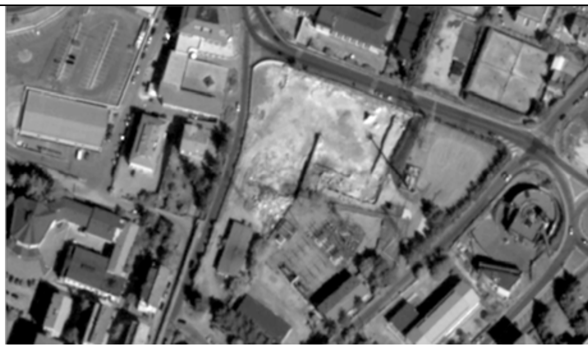
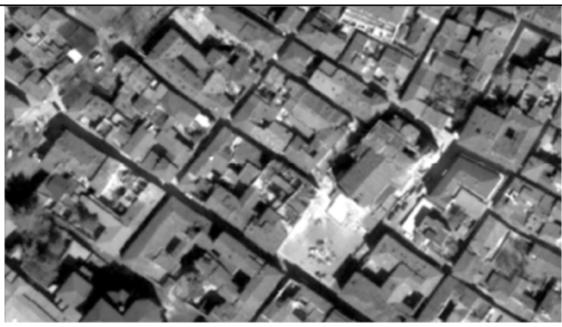
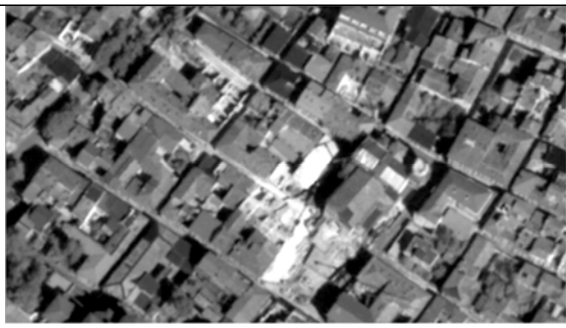
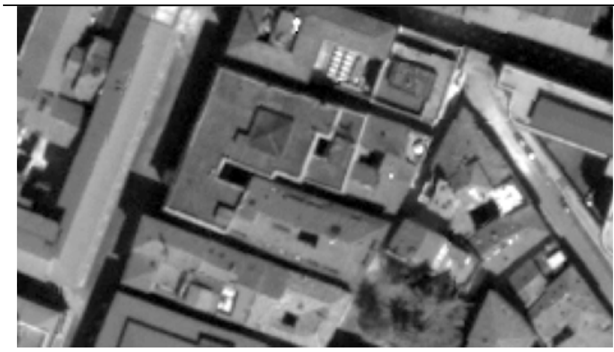
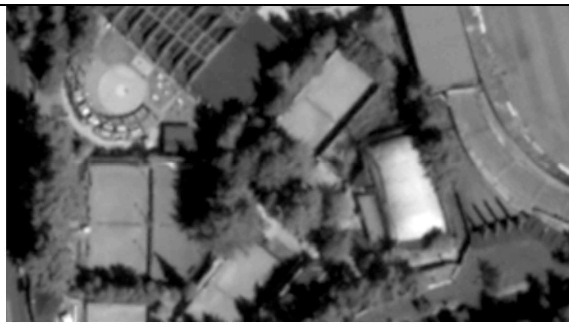
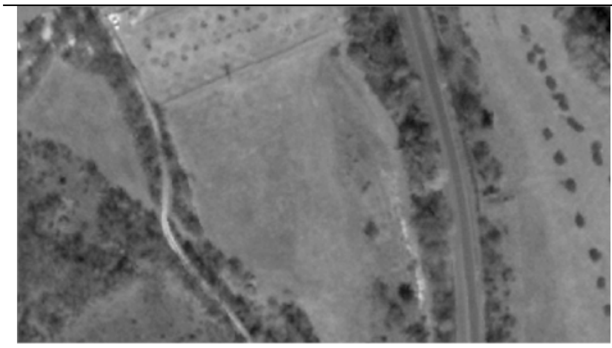
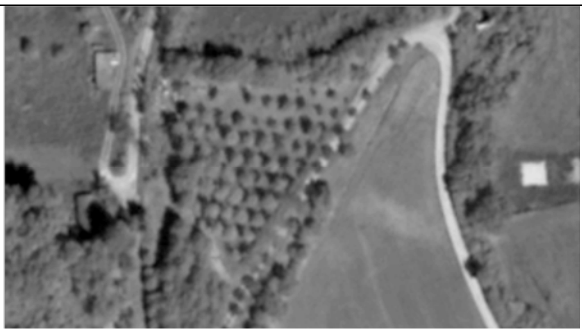
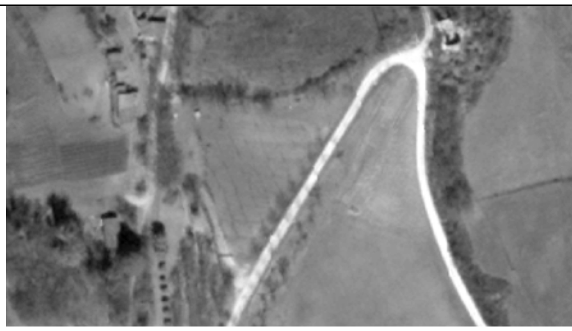


Figure 4-2 Categories of changes in the city center of L'Aquila (Italy), between 2009 – 2011.

2009	**2011**
NEW BUILDINGS	
	
DEBRIS REMOVED	
	

2009	2011
ROOF REPAIRED	
	
TEMPORARY SHELTERS REMOVED	
	
BUILDING DEMOLISHED	
	
EARTHWORKS	
	

2009	2011
PARKING AREAS REMOVED	
	
ROOF DETERIORATED	
	
ROOF DISASSEMBLED	
	
ROOF REMOVED	
	

2009	2011
BUILDING RECONSTRUCTED	
	
NEW PATHWAY	
	
NEW TREES	
	
NEW SETTLEMENT	
	

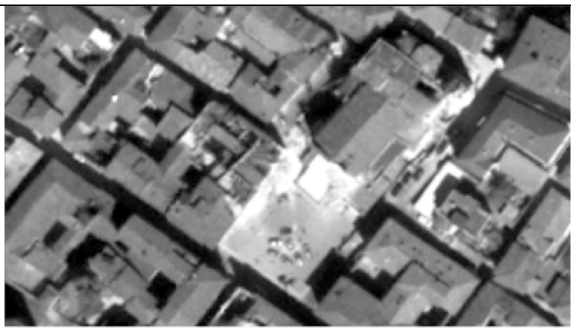
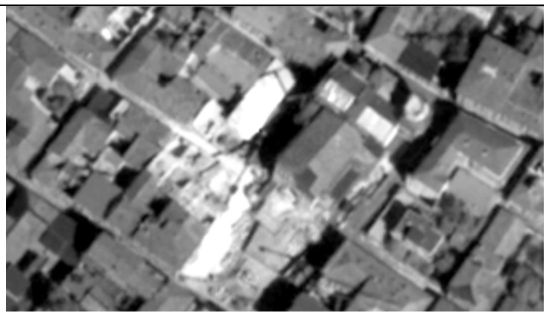
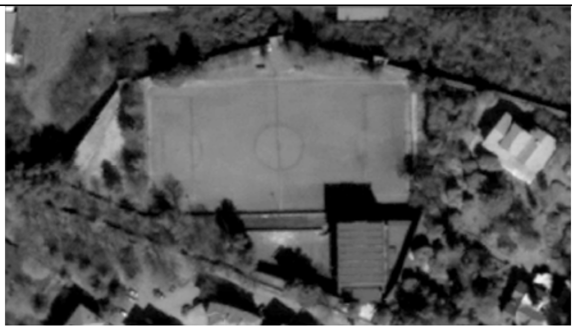
2009	2011
RECONSTRUCTION ON-GOING	
	
SOCCER FIELD REMOVED	
	
TEMPORARY STRUCTURES INSTALLED	
	
TEMPORARY STRUCTURES REMOVED	
	

Table 2 Examples of each category of changes in the city identified through visual analysi

4.1.2 Semi - automated analysis

The locations of changes in buildings, impervious surfaces and green spaces after the earthquake in L'Aquila (Italy) between 2009 and 2011 are pointed out in figures 4–3, 4-4, and 4-5, respectively. By using semi - automated analysis 148 changes were identified regarding buildings, 72 (49%) more than with the visual analysis.

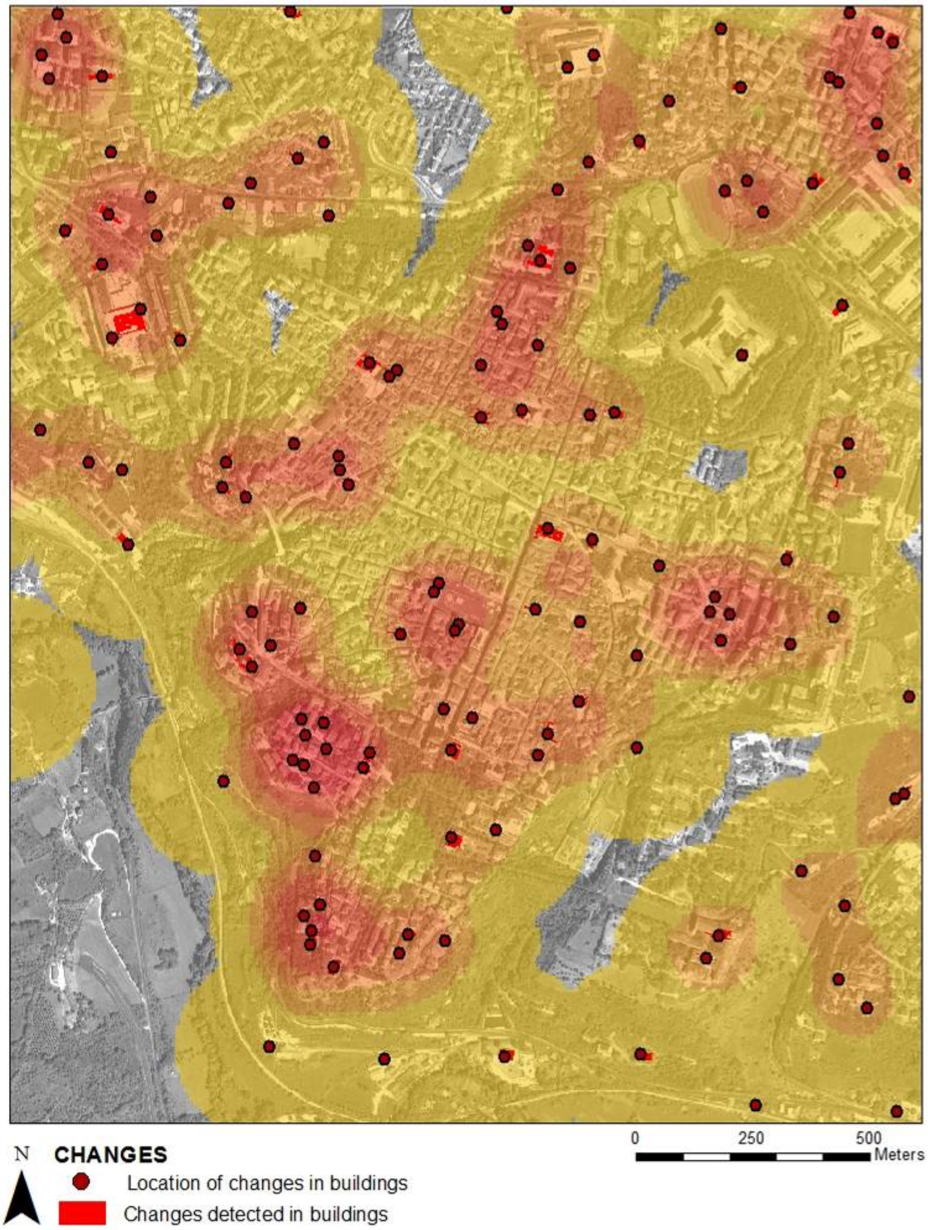


Figure 4-3 Heat-location map of changes in buildings after the earthquake in L'Aquila (Italy) between 2009 and 2011.

Moreover, 1775 changes in impervious surfaces were detected as it is displayed in figure 4-4. Changes consist of debris removed, temporary shelters removed, earthworks, parking areas removed, new pathways, and so on.

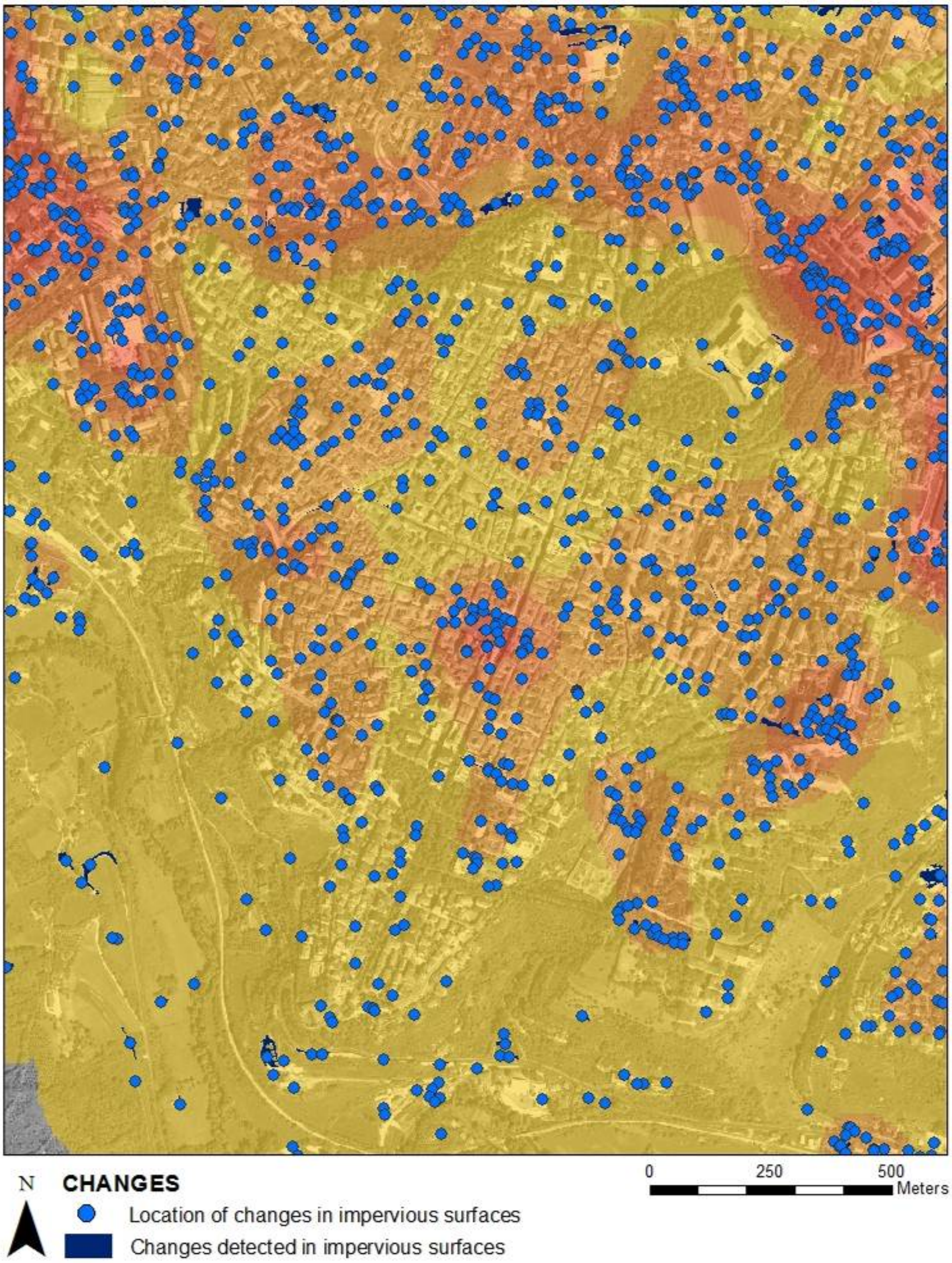


Figure 4-4 Heat-location map of changes in impervious surfaces after the earthquake in L'Aquila (Italy) between 2009 and 2011.

Regarding vegetation 3556 changes were identified, and depicted in figure 4-5. Changes in vegetation should not be mapped as a heat map since it is not single tree analysis or similar.

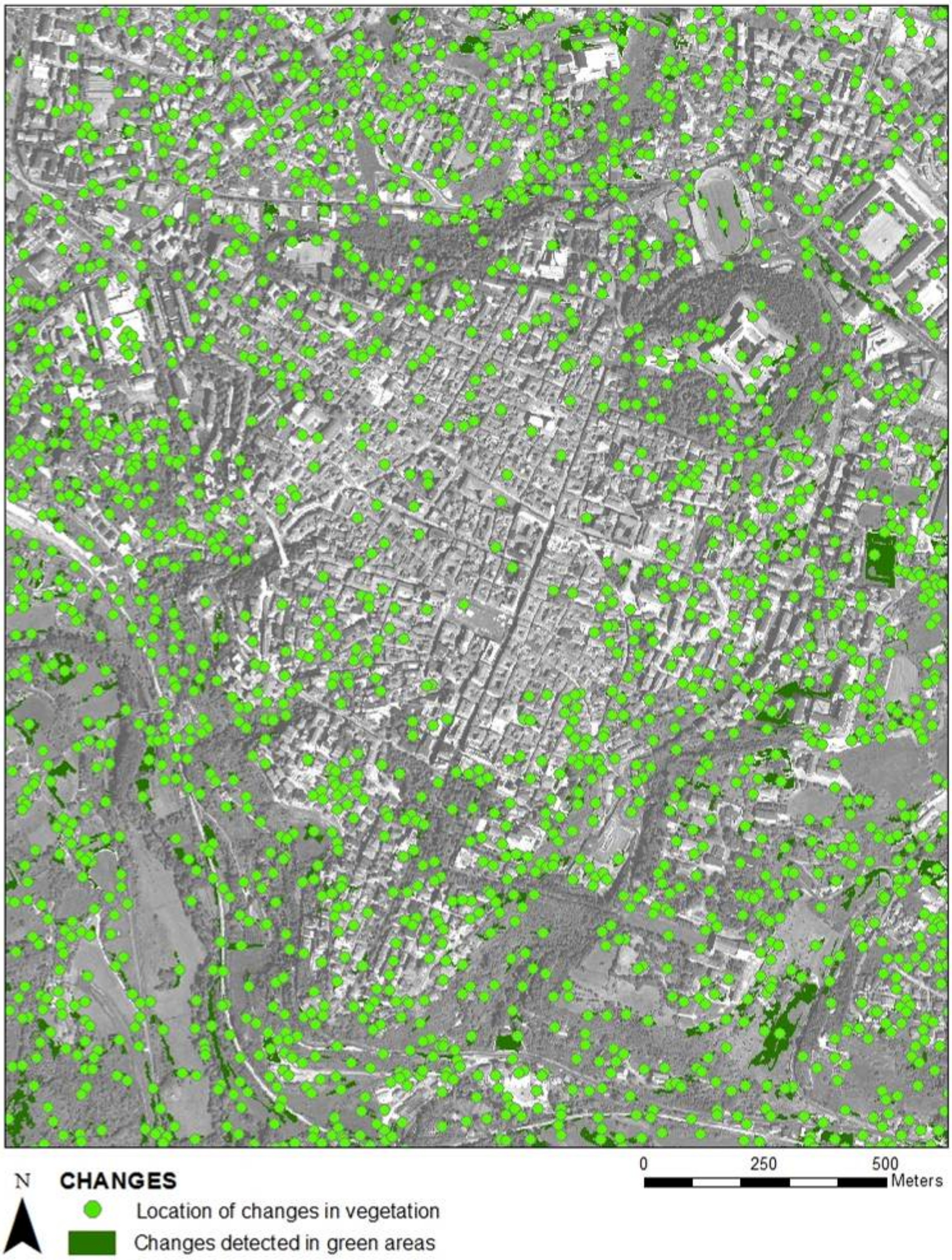


Figure 4-5 Map of changes of changes in vegetation after the earthquake in L'Aquila (Italy) between 2009 and 2011.

4.2. MONITORING PROCESS MODEL

The proposed monitoring process model presented in figure 4-6 integrates RS, GIS and GO. The indicators, tools and techniques highlighted in colors were particularly addressed in this research; however, this monitoring process model including all indicators, tools and techniques, can be applied to monitor any post-disaster recovery process after an earthquake in the world, based on spatial indicators.

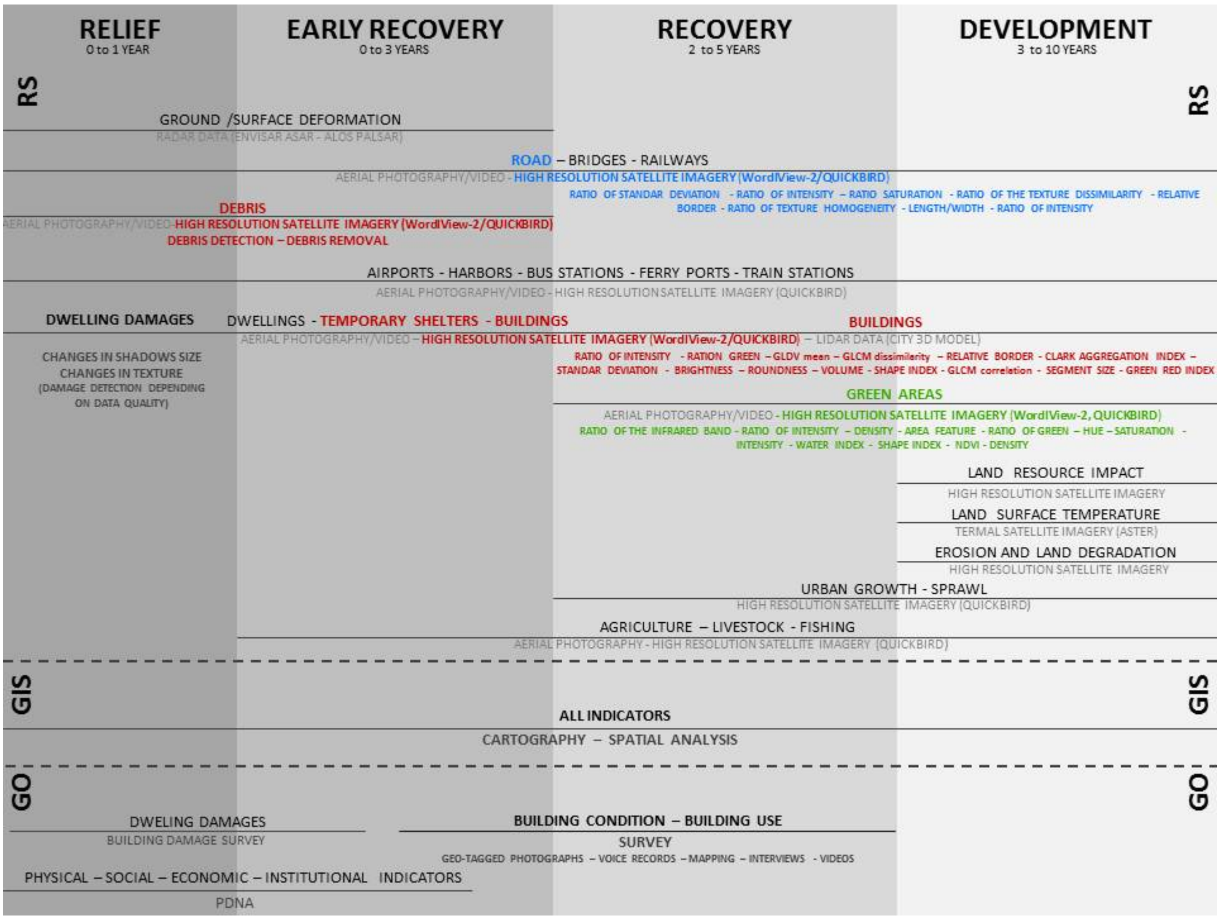


Figure 4-6 Integrated monitoring model of RS-GIS-GO to assess post-disaster recovery.

The spatial results of the application of the monitoring process model can be appreciated in figure 4-7.

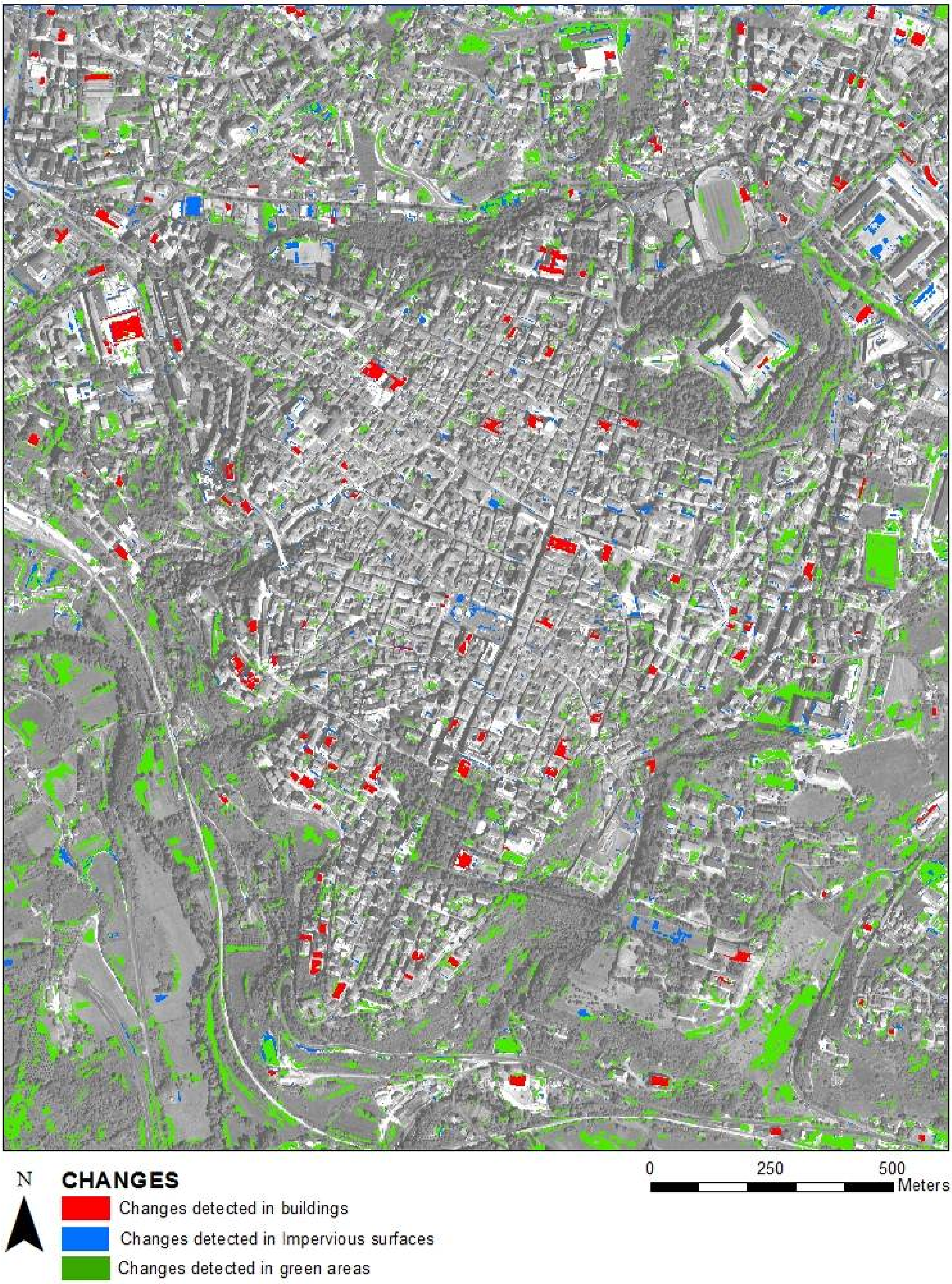


Figure 4-7 Changes detected in buildings, impervious surfaces and green areas.

4.3. POST-DISATER SPATIAL RECOVERY INDICATORS

The 20 identified categories of changes through the visual, and automated analysis were integrated into the framework of spatial recovery indicators formulated by Contreras et al. in 2013 [43], as it is depicted in table 3 .

NEW CATEGORIES	EXISTING CATEGORIES
New building	New building
New Settlement	
Roof repaired	Construction on-going
Roof disassembled	
Building reconstructed	Building reconstructed
New roof	
Reconstruction on-going	Reconstruction on-going
Roof deteriorated	Propped
Building demolished	Demolished
Temporal structures	Temporary structures
Temporal structures removed	
Debris removed	INFRASTRUCTURE
Earthworks	
New pathway	
Temporary shelters removed	LAND USE AND DWELLING
Parking removed	Transport facilities
New parking	
Soccer field removed	Sport facilities
Forest	ECOLOGICAL DIMENSION
Grassland	

Table 3 Integration of categories of changes identified through the visual and semi-automated analysis to the framework of spatial recovery indicators.

A more comprehensive framework made up of 30 variables, 5 indicators, and 3 dimensions to monitor and evaluate the progress of post-disaster recovery is constructed, based on the categories identified through the visual and semi-automated analysis, in this research. Later, each category will get a value according to its contribution to the recovery. This value should be allocated by the affected community in a workshop, because according to the vulnerability conditions existing before, the allocated importance to each category will change from one community to another, as it is demonstrated by the differences in the frameworks formulated by Brown et al. in 2010 [9], and Honjo in 2011 [37]. Nevertheless, this exercise is out of the scope of the present research, and the category values were allocated by a group of academic experts. These experts are also responsible for the subsequent weighting of each indicator and dimension, in a scale that goes from 10 to 0, which is presented in table 4. This process is currently on-going, but the values allocated by the experts are already presented in table 5, and plotted in figure 4-8.

VALUE	MEANING
10	Excellent/ideal contribution to recovery
9	Very high contribution to recovery
8	High contribution to recovery
7	Important contribution to recovery
6	Good contribution to recovery
5	Middle contribution to recovery
4	Contributes to recovery
3	Somehow contributes to recovery
2	low contribution to recovery
1	Very low Contribution to recovery
0	Not contribution at all to recovery

Table 4 Scale to allocate a value according to the contribution of some categories to the progress of the post-disaster recovery after an earthquake.

D	IND	VARIABLE	WEIGHTS						NORMALIZED WEIGHTS						
			EXPERTS						EXPERTS						Av
			1	2	3	4	5	6	1	2	3	4	5	6	
PHYSICAL	BUILDING CONDITION	New building	10	10	**9**	3	8	**9**	0,11	0,11	0,08	0	0,1	0,085	0,08
		Construction on-going	8	8	8	8	8	8	0,09	0,09	0,07	0,1	0,1	0,075	0,08
		Partially enabled	9	8	8	5	6	8	0,10	0,09	0,07	0,1	0,1	0,075	0,08
		Building reconstructed	10		10	8	9	10	0,11	0,00	0,09	0,1	0,1	0,094	0,08
		Reconstruction on-going	8	9	9	8	8	8	0,09	0,10	0,08	0,1	0,1	0,075	0,09
		Reconstruction projected	6	6	8	7	6	6	0,07	0,06	0,07	0,1	0,1	0,057	0,07
		Propped	4	6	6	3	3	5	0,04	0,06	0,05	0	0	0,047	0,05
		Inhabited	10	8	3	8	5	7	0,11	0,09	0,03	0,1	0,1	0,066	0,07

D	IND	VARIABLE	WEIGHTS						NORMALIZED WEIGHTS						
			EXPERTS						EXPERTS						Av
			1	2	3	4	5	6	1	2	3	4	5	6	
		Restricted use	0	1	8	2	4	5	0,00	0,01	0,07	0	0	0,047	0,03
		Demolished	1	2	8	4	2	2	0,01	0,02	0,07	0	0	0,019	0,03
		Temporary structures	0	3	6	2	6	5	0,00	0,03	0,05	0	0,1	0,047	0,04
	INFRASTRUCTURE	Debris removed	10	10	10	10	10	10	0,11	0,11	0,09	0,1	0,1	0,094	0,10
		Earthworks	3	7	7	5	6	7	0,03	0,08	0,06	0,1	0,1	0,066	0,06
		New pathway	3	9	6	5	6	7	0,03	0,10	0,05	0,1	0,1	0,066	0,06
	DWELLING	Temporary shelters removed	10	6	10	4	6	9	0,11	0,06	0,09	0	0,1	0,085	0,08
		TOTAL	92	93	116	82	93	106	1	1	1	1	1	1	1
SOCIO - ECONOMIC	LAND USE	Commercial	9	8	9	8	8	8	0,11	0,10	0,10	0,10	0,10	0,09	0,10
		Transport facilities	9	9	9	8	9	9	0,11	0,11	0,10	0,10	0,11	0,10	0,11
		Amenity facilities	5	5	6	8	7	5	0,06	0,06	0,07	0,10	0,08	0,06	0,07
		Religious facilities	6	5	5	5	5	7	0,07	0,06	0,05	0,06	0,06	0,08	0,07
		Hospitals	7	8	9	8	7	10	0,08	0,10	0,10	0,10	0,08	0,11	0,10
		Office Facilities	8	7	8	6	6	7	0,10	0,09	0,09	0,08	0,07	0,08	0,08
		Educational facilities	7	8	8	8	7	8	0,08	0,10	0,09	0,10	0,08	0,09	0,09
		Hotels	4	6	6	5	7	5	0,05	0,08	0,07	0,06	0,08	0,06	0,07
		Industrial facilities	8	7	8	8	8	8	0,10	0,09	0,09	0,10	0,10	0,09	0,09
		Monuments	5	2	3	3	2	4	0,06	0,03	0,03	0,04	0,02	0,05	0,04
		Sport facilities	6	3	6	4	6	5	0,07	0,04	0,07	0,05	0,07	0,06	0,06
		Residential	10	10	10	8	9	10	0,12	0,13	0,11	0,10	0,11	0,11	0,11
		Not inhabited	0	2	4	0	2	2	0,00	0,03	0,04	0,00	0,02	0,02	0,02
		TOTAL	84	80	91	79	83	88	1	1	1	1	1	1	1
ECOLOGICAL	Green areas	Forest	5	5	3	6	6	4	0,63	0,50	0,50	0,50	1	1	0,57
		Grassland	3	5	3	6	2	3	0,38	0,50	0,50	0,50	0	0	0,43
		TOTAL	8	10	6	12	8	7	1	1	1	1	1	1	1

D Dimension

IND Indicator

Av Average of normalized weights for variables

Table 5 Value allocated by experts according to the contribution of each category to the progress of the post-disaster recovery after the earthquake in L'Aquila (Italy).

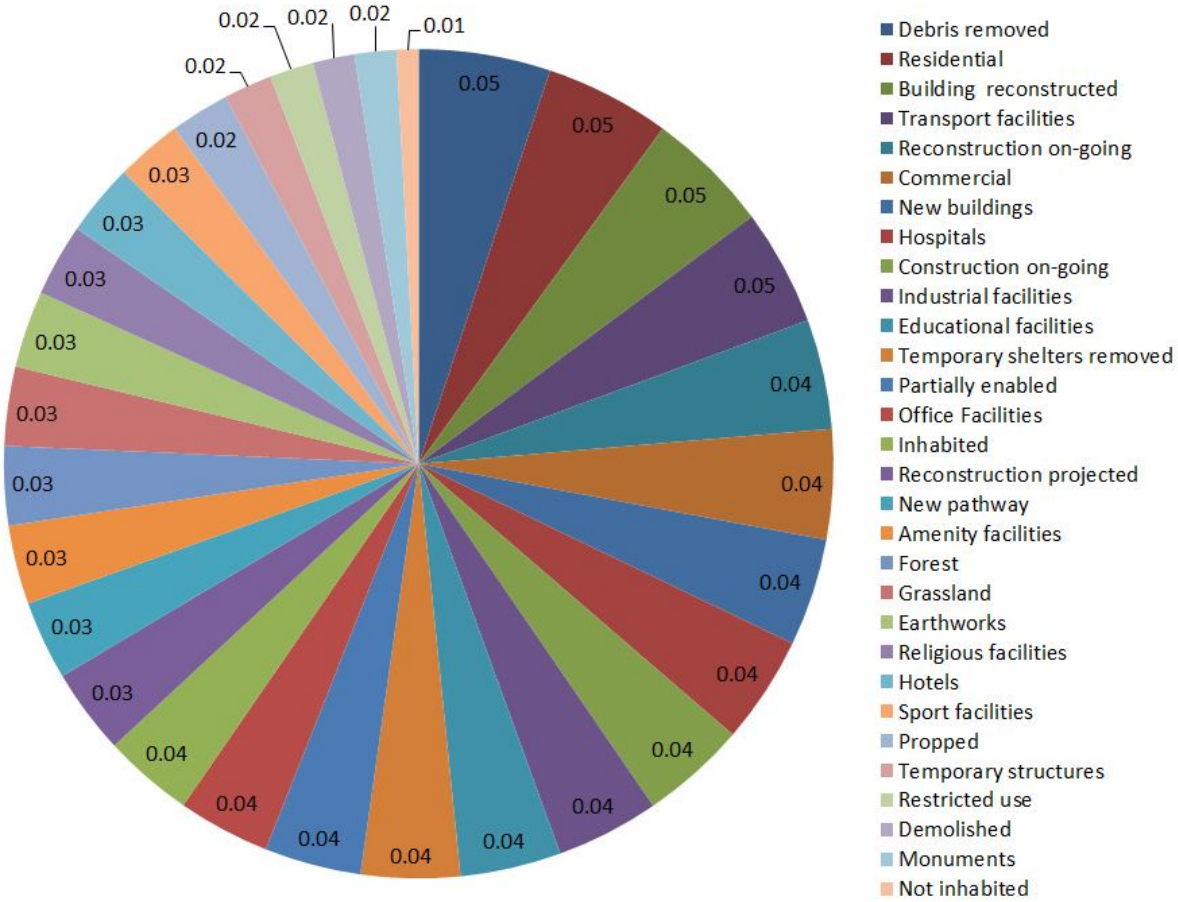


Figure 4-8 Results of expert allocation values to each category, according to their contribution to the progress of the post-disaster recovery after the earthquake in L'Aquila (Italy).

The experts allocated the highest contribution values to the categories: *debris removed, residential, building reconstructed* and *transport facilities*; followed by *reconstruction on-going*, *commercial building use, new buildings, hospitals, construction on-going, industrial* and *educational facilities, temporary shelters removed, partially enabled buildings, office* and *inhabited* as *building use*. Other categories with a considered medium contribution were also listed in the order: reconstruction projected, new pathway, amenity facilities, forest, grassland, earthworks, religious facilities, hotels and sport facilities. The categories with less contribution to the post-disaster recovery according the experts are *propped buildings*, *temporary structures*, *restricted use*, *demolished*, *monuments*, *not inhabited* buildings.

The spatial result of the allocated contribution values of each category will produce a map similar to the one presented in figure 4-9, but it will cover a broader area thanks to the use of remote sensing tools, and techniques. In this case, the map was produced based on the data collected through ground observations done on fieldwork 2012.

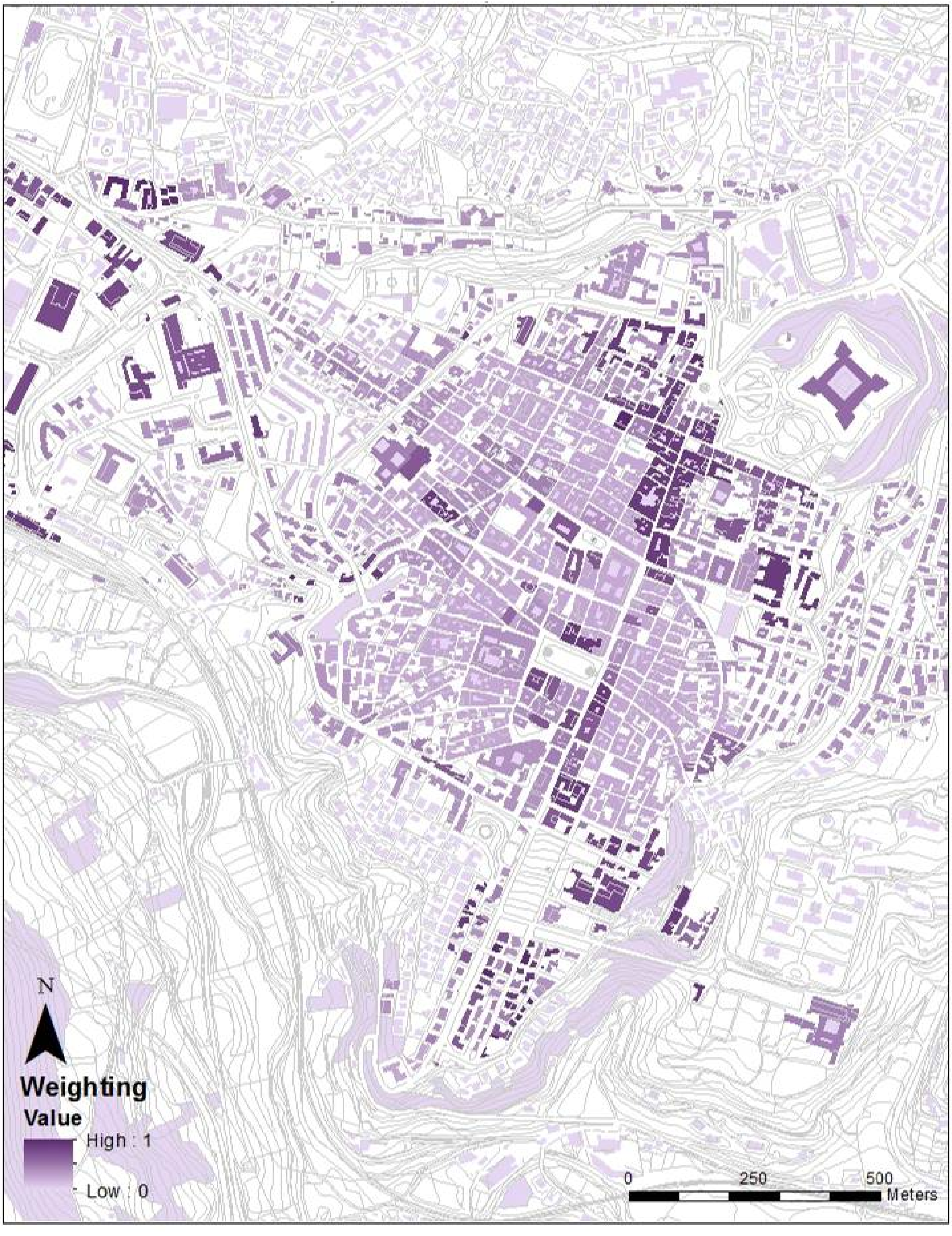


Figure 4-9 Hotspots of recovery identified by ground observations in the city center in L'Aquila (Italy) in 2012.

5. DISCUSSION

The difference of our post-disaster recovery index with others previously formulated lies in the fact that our index stems from the MOVE vulnerability framework [44], therefore the recovery indicators are grouped in the same dimensions: physical, environmental, social, economic, cultural and institutional. Maybe other recovery indices have not considered the institutional and cultural dimensions, because of agreement difficulties about the concept, in the case of the cultural dimension, and to collect data in the institutional dimension. Those are the main reasons for including these dimensions in our list of recovery indicators, but not in the estimation of the progress of the recovery process in L’Aquila.

The post-disaster phases provide a great opportunity to improve buildings, infrastructure, governance and economy [45], but should also be an opportunity to reduce the impact of the urban expansion on the environment. We agree with other authors who formulate post-disaster recovery indicators in the ecological dimension, that green areas help to regulate urban surface temperature, as well as providing habitats for biodiversity, clean air, water and contributing to the mental and physical well-being of the population, while at the same time that increasing the attractiveness of an area, and therefore the prices of the land [9].

One indicator considered by Brown, D., et al. is the presence of vehicles as a sign of recovery, because their presence on the roads means that the roads condition is suitable, and that there are urban facilities open [8]. These authors opted for a visual inspection by manually counting the amount of vehicles in their case study area. We also considered the possibility of including this indicator, but the available satellite data was not suited for this task. Especially the different days of acquisition was hampering this idea (e.g. we cannot compare the traffic in a peak hour during a working day, with the traffic on Sunday afternoon). The total drop in the number of cars in the surroundings of the city center of L’Aquila, can be appreciated in the differences between the images 5-1 (2008), and 5-2 (2010). In the case of L’Aquila, the fall in the numbers of cars is not related to the condition of the roads. It stems from the fact that some streets were still included in the restricted area in 2010. The gradual returning of cars to Via Fonteseco, three years later is depicted in figure 5-3.

Figure 5-1 Vehicles in Via Fontesecco in L'Aquila (Italy), between 2008, 2010 and 2012.
A) August 2008 (before the earthquake). Photo by Google Earth; b) 2010, one year after the earthquake, and c) 2012, three years after the earthquake. Photos by: Diana M. Contreras M.

In 2010 Brown, D., et al. casts a doubt on the effectiveness of using high resolution imagery to collect data about other dimensions besides the physical and the environmental ones [9]. However, authors such as Ebert, A., et al. in 2009, were able to demonstrate the utility of using satellite images to derive proxy indicators for assessing vulnerability [35]. This research and previous work [43] aims to demonstrate the utility of the information extracted from remote sensing to derive proxy indicators in the social and economic dimensions during the early recovery, recovery and development, validated and complemented with ground observations. Another disadvantage mentioned by the same authors is the cost of the images, however, these are still less expensive than deploying a ground survey in the affected area one year, three, five or ten years later, to collect data about the progress of the recovery process, and in this way accumulate knowledge and experience about this kind of processes.

One disadvantage found by us constitutes the availability of high resolution images of L'Aquila (Italy), almost five years later. An updated image from 2013 is not available in the archive, it would need to be tasked. Nevertheless, not only the price for asking a new image was a constraint, it is necessary to keep in mind that the image of the requested area could potentially entail clouds (up to 20% not knowing where the clouds are located), making it entirely useless for change detection analysis. That was the main reason for selecting the available cloud free image of L'Aquila in September 2011, and not 2013, as was our initial intention.

Another problem lies in the season of the available image, which is an essential aspect regarding change detection in buildings and vegetation. Regarding buildings, the seasonal difference between the *Quickbird* data from 2006 (September) and the *Quickbird* data from 2009 (April) caused some problems in shadow change detection, to determine the location of collapsed buildings, using a semi-automated method [25] during the relief phase. The different foliation of the vegetation, as it is possible to observe in figure 5-2 a) and b), causes some problems in change detection of buildings, which could be tackled by introducing rules for the detection of vegetation shadow (proximity and direction of vegetation and shadow objects), but still some false positives are wrongly detected [25].

Figure 5-2 Foliation near to buildings on the road via XX Settembre in L'Aquila (Italy).
A) April 2010, and b) September 2012.

The same concern applies to change detection in vegetation. The *Quickbird* data from 2006 and 2011 was taken in September (late summer), while the *Quickbird* data from 2009 was taken in April (Spring), where the trees do not have foliation yet, as it is portrayed in figures 5-2 a) and 5-3 a). Therefore we considered that vegetation change detection is only meaningful for the images from September 2006 and 2011.

Figure 5-3 Difference in foliation on the road Via XX Settembre in L'Aquila (Italy).
A) Abril 2010, and b) September 2012.

In the exercise of visual detection of changes, the foliation of trees hampered the counting of vehicles, in the satellite imagery in September 2006 and in September 2009.

Since one of the problems with the visual and automated analysis of changes using *QuickBird* images is that only buildings with damages or modifications to the roof can be counted as a change. It would have been necessary to have data from digital aerial images [46], or lidar and/or radar data [47] to detect the difference of buildings heights between pre- and post-event models, but even with these data sets we are not able to detect damages in the building structure/façade which do not result in a (partly) collapse of the building or the building roof.

The advantage of using *QuickBird* or/and *Worldview satellite imagery* stems from the fact that the satellite can be programmed to wherever is needed, such to the affected area after an earthquake, and the images obtained are high-resolution images ideal for the OBIA approach for detecting changes in buildings, impervious areas and vegetation, such in this research.

Since the building use, and occupation in the city center of L'Aquila (Italy) changed dramatically after the earthquake, another indicator proposed to be considered was land use surface temperature (LST), used by Feizizadeh and Blaschke to identify urban heat islands (UHI), and to prove their relationship to land use /land cover (LULC) and air pollution [48]. Nevertheless, we decided not considered this indicator, taking into account that it can be more significant in really crowded central business districts (CBD), and the city center of L'Aquila was not like that before the earthquake. However, in other case study areas of post-disaster recovery, land use surface temperature (LST) can be an indicator to monitor in the long term.

Another indicator to monitor progress in a post-disaster recovery process is the VNRI radiance [36], or night-time light (radiance intensity and duration) [9]. They are used to monitor the removal and reinstallation of power, economic activity, CO_2 emissions, and provision of electricity [9]. In the case of L'Aquila the indicator of VNRI radiance [36], or night-time light[9] would have been interesting to monitor, particularly with respect to the city center. It would be possible to observe the drop in the economic activity in 2009 after the earthquake, in this zone of L'Aquila, and the subsequent light increase in activities between April 2009, and November 2013, when this report is written. However, the difficulty stems from the fact that the civilian night-time data is only available at a resolution of 0.5 – 2.7 Km [9], and to monitor the city center of L'Aquila (Italy), we would require a much higher resolution. Night-time light in Central Europe is show in figure 5-4, but only big cities such as Rome or Naples in Italy are somehow identifiables.

It is true that the use of the satellite images to detect changes, and therefore assess the progress in the post-disaster recovery is less expensive than to deploy several survey teams on the whole case study area every one, three, five or ten years later. However, there is also the need to take into account that using remote sensing is also an expensive process (in less amount), not only due to the prices of the images, but also because, much time is required in order to process, interpret and programming rule-sets for automated feature extraction.

Figure 5-4 Night-time light in Central Europe.
NASA (2000). Visible earth. Land_lights_16384, NASA. 40634 KB.

In the ground surveys carried out in 2010 and 2012, we observed many buildings severely damaged by the earthquake, and then deteriorated by the lack of maintenance, since they still remained uninhabited, but this condition cannot be appreciated in the visual analysis of the satellite image from 2011.

6. CONCLUSIONS

Recovery is increasingly regarded as a crucial part in the whole ‘disaster cycle’. Monitoring the recovery processes aims to control the emergent causal factors of vulnerability, and to avoid reproducing pre-existing conditions that caused the disaster in the city. Ultimately, a monitoring process shall provide data to assess the resilience of a community, and encourage the formulation of pre-impact recovery plans, and the improvement of recovery plans going on around the world.

RS is effective to monitor changes mainly in the physical and ecological dimension, in spite that it is also possible to extract proxy indicators in the social, economic, institutional and cultural dimensions from the imagery. These indicators can be validated later on through ground observations, and integrated through the use of GIS.

The results and the information extracted depend on the kind of data available. The lack of updated satellite images in affected areas by earthquakes or any other disaster in the past constitutes an obstacle to monitor recovery processes, and accumulate knowledge about recovery mechanisms in population and communities, as it was argued by Hayashi in 2003 [20].

Remote sensing and ground observations are tools to collect data, and GIS is a tool to integrate the data collected through them. Ground observations are more than simply a tool to validate the interpretation of the images collected through remote sensing. They provide information about the social, economic, institutional, and cultural aspects, while at as the same time validating the observations in the physical and environmental dimension. The integration of this information allowed the authors to determine the recovery hotspots in L’Aquila city in the spatial context.

On-line application such as the ones created by the Servizio per l’Informazione Territoriale e la Telematica Ufficio Sistema informative Geografico to visualize the damages due to the earthquake in L’Aquila (Italy) in 2009 help not only experts, but also community, who do not have access to satellite images to be aware of the magnitude of the damages and the changes in the territory due to the earthquakes.

Detecting changes in buildings requires the integration of semi-automated analysis and visual or manual interpretation. The semi-automated analysis demonstrated not only to be more effective than the visual analysis or manual interpretation regarding the number of changes in buildings detected, but also the perfect tool to detect changes in impervious surfaces and vegetation after earthquakes. Though, the visual analysis is compulsory to determine the categories of the changes, and their contribution to the progress of the whole recovery process.
In the semi-automated analysis, we are interested in the number, the location, and the spatial distribution, more that in the detail of change. The category of the change will be determined in the detailed visual analysis.

In the semi-automated analysis, the most effective parameters to detect changes in buildings were: *ratio Intensity, texture GLDV mean, texture dissimilarity and brightness*. In the case of change detection in impervious surfaces, the most effective parameters were *ratio standard deviation of red, ratio intensity, ratio texture dissimilarity red (2009, 2011), ratio texture homogeneity red (2009, 2011), ratio standard deviation blue (2009, 2011)*. To detect changes in vegetation through the semi-automated analysis, the most effective parameters were ratio *IR 2011 (pixel-based)*, and *ratio Intensity*.

The detection of changes was particularly difficult in the case of buildings, due to not only the lack of an updated cadastral map used for classification, but also the difference in the viewing angles and illumination between the images from 2009 and 2011, for which more strict decision rules were formulated. The opposite case was the detection of changes in impervious surfaces, which was easier than expected. Nevertheless, we still had the problem that different positions in cars were detected as change.

With the help of ratios and texture parameters as well as the brightness and saturation of segments it is possible to detect changes between two or more images. However sometimes strict rules are necessary to improve the result and to reduce errors in the classification.

The visual analysis and the semi-automated analysis disclosed that changes in buildings are spread throughout the whole city center, there is no a concentration in a particular zone. The changes in impervious surfaces are mainly distributed around the city center. The changes are made up mainly of roads, sidewalks, open spaces and sports facilities where the temporary shelters were located after the earthquake. A small concentration of changes in impervious surfaces were identified in a few zones within the city centre as well. In regard to changes in vegetation, only very few changes were observed in the city centre, because the green areas in the city center are limited to small internal yards in the buildings. However, around the city center many changes are observed. Concluding, most of the changes in buildings, impervious surfaces and vegetation detected through the semi-automated analysis are happening around the city centre, not inside. This urban dynamic contributes to the image of stagnation of the post-disaster recovery in the whole of L’Aquila (Italy), because the historical city centre is the most representative, and symbolic area of whatever city in the world, and L'Aquila is not an exception.

The conclusions from the changes detected through the visual analysis or manual interpretationare on the same line. They are located around the city centre of L'Aquila but very few in the inner city, giving the image of a stagnated recovery. Most of the changes located exclusively in the city centre are related with debris removed (12), which is more an activity of the early recovery than the recovery, then followed by roof repaired (6), temporal structures installed (2), roof deteriorated (2), temporary structures removed (1); which does not contribute significantly to the recovery. Only one new building (1), and only one (1) building with a reconstruction on-going, were detected in the changes, which is a discouraging result. This summary of changes brings us to the same conclusion as the findings obtained through the semi-automated analysis and previous research [43], which argued that the post-disaster recovery progress in L’Aquila is not stagnated, but the progress is very slow.

The limitations in RS regarding satellite imagery resolution and semi-automated analysis to extract the number of vehicles on the streets in the post-disaster area can be solved by the observations on fieldwork, as it was demonstrated by the photos 5-1 b) and c) taken during fieldwork 2010 and 2012, respectively. These images show the gradual return of the cars to the city center of L'Aquila, without manually counting the number of vehicles circulating in each of its streets.

The contribution of remote sensing not only offers the possibility to easily identify the changes in buildings, impervious surfaces and vegetation, but also to reduce or delimitate more efficiently the amount of area to cover on fieldwork when to carrying out ground observations. Through the integration of the data collected on ground observations (fieldwork), and remote sensing by using GIS, it is also possible to extend the number of categories to construct a post-disaster recovery index, to identify which categories encourage the progress of the recovery process, and identify the hot-spots of recovery in an area affected by a disaster.

7. RECOMENDATIONS

The damage indication maps based on high resolution imagery constitute a tool for decision-makers to decide where to deploy search and rescue task forces, and buildings inspection groups during the relief post-disaster phase. During the early recovery, recovery and development, they are still a tool to decide which areas must still be monitored, which of them request a special focus, and if it is still necessary, deploy a ground survey after one, three, five or ten years, without expending resources to monitor the whole affected area.

Remote sensing is an efficient tool during the emergency or relief phase to identify the areas with a high degree of damage in a damage indication map. But during the early recovery, recovery and development, where a high level of detail is required to monitor progress in the social, economic, institutional and cultural dimension, although it is still possible derive information from high resolution images through the use proxy indicators, it is better to opt for ground surveys to ensure a high degree of reliability in the information collected.

The semi-automated analysis should be followed by the visual analysis or manual interpretation, in order to determine the categories of the changes in the buildings and their contribution to the post-disaster recovery process.

Countries, cities and towns must be proactive in respect to keeping cadastral data updated, because this data combined with satellite imagery is essential during the post-disaster recovery phase, to carry out damage indication maps in the emergency or relief phase, and to produce change detection maps in the early recovery, recovery and development.

When the accurateness of the data is a major concern, then it is necessary to opt for a ground survey. The disadvantages regarding the cost and time can be reduced, by focusing the survey in the specific points identified from the damage indication maps.

If the recovery process progresses according to a plan, it is expected that the number of points for which to carry out a ground survey will drop in the coming years, otherwise if the number of points or areas with problems remains constant, it could be an indicator that there is stagnation in progress of the post-disaster recovery, like in the case of the city center of L'Aquila.

The satellite images to be compared, in order to detect changes in the built environment, and to count vehicles either in visual or automated analysis must be taken at the end of autumn, when the foliation of the trees is already gone, and until mid-spring when the foliation in the trees starts to appear again. The opposite happens with the images to detect changes in vegetation, because the useful images must be taken by the satellite in a period between the end of the spring, and not later than the beginning of autumn, before the foliation of trees starts to fall.

Another tool for visual analysis is time series, available for free in Google Earth and displayed as an icon with a clock with a green arrow in the GIU of Google Earth. It shows the satellite imagery through the time in the case study area, by moving the time slider between the different acquisition dates. It will not only indicate the changes or the progress in a post-disaster recovery process of the case study area, but also about the availability of imagery in the zone. Unfortunately, sometimes this can be the only free tool to identify changes using satellite images, due to the prices and the use restrictions of the satellite images.

We partially agree with the suggestion from Brown, D., et al. in 2010, about constructing a pre-disaster database of high risk urban areas [9]. Though more a database of high risk urban areas, we consider more important to keep updated information about the vulnerability condition of population in the hazard zones. It will constitute a benchmark to monitor the post-disaster recovery process, in case an event happen.

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