Indicators for Measuring, Monitoring and Evaluating Post-Disaster Recovery

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Abstract— **This paper introduces *the Recovery Project*, which aims to identify indicators of post-disaster recovery using satellite imagery, internet-based statistics and advanced field survey techniques. This paper reviews the recovery literature as a means of introducing the recovery process and the considerations that must be made when evaluating recovery. This is followed by an introduction to the Recovery project and its two case study sites: 1. Ban Nam Khem, Thailand and 2. Muzaffarabad, Pakistan. A review of the recovery process at Ban Nam Khem is presented along with a diagram of potential indicators obtained from the literature research. The paper concludes with a short discussion on how remote sensing may be used to monitor some of these indicators.**

I. Introduction

A. Recovery

Recovery may be thought of as an attempt to bring a post-disaster situation to a level of acceptability [1] through the rectification of damage and disruption that has been inflicted upon an urban system's built environment, people and institutions [2]. Such perturbations may be caused to an urban system by either natural or man-made disaster events, such as flooding, tsunamis, earthquakes or explosions.

Early research identified a linear sequence of recovery phases that a community was thought to undergo following a disaster. The classic text, *Reconstruction following disaster*, described reconstruction as "ordered, knowable and predictable" [3]. More recently, Comerio noted that the Federal Emergency Management Agency in the United States used three temporal phases to describe their response to a disaster: 1. Emergency response phase (24 hours to 2 - 3 weeks) 2. Relief phase (a week to half a year) and 3. Recovery phase (several weeks to 10 years) [4].

B. Recovery as a dynamic process

Recovery is now increasingly conceptualized as a dynamic process with no clear endpoint [5]. The use of recovery phases is thought to oversimplify the recovery process and mask how in reality, the various roles overlap and interact with each other. Literature has since focussed on the inequalities that are created by disasters and the recovery process. Recovery has been shown to vary over time and space due to socio-economic and political factors, and because of a multitude of decisions that are made before, during and after a disaster [6].

Miles & Chang noted the potential similarities between recovery and social vulnerability theories, which suggest that vulnerable groups may be more susceptible to losses and have more difficulty recovering [7]. A lack of finance is one of the most significant factors preventing reconstruction. This may arise due to a shortage of capital, a lack of government support or a complex application process for funding. The method used to allocate aid and resources to the affected communities may also affect the recovery trajectory. A comparison of three earthquakes found that the relief phases were very similar, but the provision of temporary shelters varied dramatically [8]. In Japan, rental housing was provided to the poor, whilst in Turkey the Government constructed new "public houses" and in Taiwan, economic subsidies were provided to rebuild and purchase new houses.

It is now considered critical that citizens are involved in decision making throughout the recovery process. Social capital and community organisations with strong leadership are crucial to ensure a fast recovery and to provide maximum satisfaction to the community [9]. National recovery programs must therefore be flexible and incorporate local opinion [10]. It is also important that communities are provided with adequate guidance and technical support. After the Chi-Chi Earthquake, residents complained due to a lack of technical information by engineers, which led to construction that did not comply with local building codes [11].

C. *Measuring recovery*

Due to the recent conceptualisation of recovery as a dynamic, endless process: identifying outcomes and indicators poses a number of issues. The consensus is that the minimum goal is to replace lost housing stock and to return to pre-disaster economic function [6]. The US government will only provide funds that return buildings to their pre-disaster state to avoid people benefiting from the disaster, but Alesch noted that improvements are made to ensure there isn't a repeat of the destruction [2]. US, Japanese and EU governments also look for a return to normality over a regional scale when evaluating recovery [12].

Some recovery programs have successfully improved upon pre-disaster conditions by revitalizing urban areas, reducing vulnerability and preserving historic buildings [13]. In some cases, disasters have created reconstruction booms that allow community reconstruction and re-planning projects to commence that were urgently required before the disaster. Despite this, aid agencies and governments must be realistic about what they can achieve. A single disaster may only bring limited opportunities for promoting change and can not undo decades of underdevelopment [14].

Rubin suggests that both the *speed* and the *quality* of the recovery process must be monitored [15]. Speed is important to keep markets functioning and to prevent further losses. But speed is generally not accepted if it is at the expense of quality. A pre-disaster plan may ensure a fast, high quality recovery. Furthermore, it may be used to measure the success of the process [16]. The measurement of recovery is highly dependent on the scale and timeframe being analysed, as well as the perceptions of the researcher [1] [12]. These issues are discussed in more detail below:

1)Timeframe: Researchers should take care not to prematurely announce the success or failure of a recovery program as the trajectory of a recovery process may alter for a number of reasons. Firstly, the fate of the individual households or businesses may not be determined until several years after the disaster. For example, over half of the Earthquake recovery projects in San Francisco and Santa Cruz were still under construction 15 years after the Loma Prieta Earthquake [12]. Secondly, the economic output and level of employment may initially rise but then drop several years later in-line with the construction market. Thirdly, the trajectory may be complicated by random, unpredictable events. For example, a lack of rain in the year following the Chi-Chi earthquake caused a reduction in agricultural output [17]. Finally, many aspects of the recovery process are ultimately determined by the funding strategies and timeframes of donors and affected governments, which may in turn be defined by politics, bureaucratic rules or media pressure. The World Bank for example, may omit activities from their Emergency Recovery Loan if they can't be completed within three years [18].

2)Scale: Recovery can be analysed at a range of scales, including individual, household, business, community or neighborhood. The level of damage and the progress of recovery may be interpreted differently depending on which of these scales is used. For example, whilst business or household elements may fail, the return of the economic and labour markets may suggest a successful recovery at community level. Ideally, all of these scales should be analysed collectively: a study of individual households should include information about their context within the environment and a study of the community should involve an understanding of the actions and behaviours of individual elements.

3)Perceptions: The results of the analysis may also vary according to the perspective of the evaluator e.g. whether they are independent, local, a funding provider or a recipient. For example, whilst one local community may deem their recovery unsuccessful, the province or state departments may differ from that opinion. Quarantelli suggests that administrative levels have more realistic concepts about recovery, whilst individual household or businesses are more idealistic [1]. After the 5-year reconstruction plan that followed the Chi-Chi Earthquake, the level of accomplishment perceived by residents was 50% to 80% (average 65.1%), whilst public bureau workers perceived levels between 60% to 100% (69.9%). When asked at what point they considered recovery to be complete, 31.1% of residents said it was when construction was complete and 45.7% felt it was when their living standards had recovered, whereas public bureau staff answered 31.6% and 26.3% respectively [17].

II. The recovery project

The main objective of the Recovery project is to identify indicators of recovery that exploit satellite imagery, internet-based statistics and advanced field survey techniques. This work will be used to produce a set of guidelines on how to measure, monitor and evaluate recovery after a major disaster.

A number of guidelines and theoretical frameworks for relief and recovery already exist [2] [10] [19], but they commonly lack a systematic and standardized approach. In May 2006, a Shelter meeting of the aid community in Geneva identified an urgent need for basic and applied research into the long-term recovery process. In particular, they noted the lack of a standard, independent and replicable approach to measure, monitor and evaluate the relief and recovery processes.

To date, the recovery process has been monitored with the use of qualitative and subjective information, gained through interviews and focus groups. Recent technological advances present the opportunity to enhance this data using methods that are quantitative, systematic and objective. These advances include: the commercial availability of very high-resolution satellite imagery; internet-based statistics, records and reports, and advanced field survey techniques that allow the capture of detailed geocoded photographs, videos and observations.

The indicators to be developed in the Recovery project will be based on a user needs survey of aid agencies and will be validated against published data and field survey observations. This author believes such a method of measurement would benefit aid agencies in targeting resources effectively and evaluating the effectiveness of their expenditure.

The project began in March 2008 and will last for 24 months, consisting of three phases:

A. Phase 1: Project Definition (6 months)

1)User-needs Survey: A user needs survey of the international aid community (e.g. ECHO, UNOCHA, World Bank, Red Cross, DfiD, USAID), national government recovery agencies (ERRA, GISDTA) and local NGOs is currently being carried out to assess the perceived requirements for indicators of monitoring recovery. The survey was emailed to over 40 people working in a wide range of aid organisations. Most of these people were also contacted in person or by telephone.

The first part of the survey asked people about current practice, for example what information they use to assess needs and monitor recovery. In general terms, aid organisations and national governments tend to be more systematic in the way they assess needs in the aftermath of a disaster than they are in monitoring the process of recovery over a long period. This issue has been recognised by the aid community and efforts are being made to integrate relief and recovery [39]. This means that the information systems need to address both needs assessment and monitoring.

Currently, three-quarters of respondents (76%) say that their organisations already use satellite imagery to assess needs and nearly all the respondents (90%), as a minimum, say that their organisation uses field surveys and published statistics. People feel that currently there is a serious lack of good base line data, that damage assessment mapping is inadequate and that there is inadequate monitoring of recovery.

The second part of the survey asked people about what indicators they thought it would be useful to map. All but one of respondents would like a comprehensive approach to monitoring recovery, using multiple indicators, rather than a simple approach similar to the Sphere Guidelines. Consistent with this, most of the 24 indicators we offered respondents were given a high priority. These fall into the following four major categories:

- Livelihoods, including agriculture and fisheries
- Housing, including drinking water supply
- Environment, including vegetation and removal of floodwater sand and debris
- Infrastructure, including road access and reconstruction

In addition, a number of other indicators were suggested. These fall into two main categories: population movement and contamination and vulnerability.

2) Data and Case Study Selection (in progress): A conceptual model was designed to assist the selection of data and case study sites. A literature search was first conducted to find evidence of damage and recovery. The Areas of Interest (AIO) were further refined according to their accessibility and the availability of field data. Archive searches were then conducted for very high-resolution satellite data, including Ikonos and Quickbird. The footprints were imported into ArcGIS and viewed along with their quick look images and information on the acquisition date, image angle and cloud cover. This allowed an effective method of analysing the spatial and temporal availability of imagery. Where possible, images were ordered according to their availability to capture key moments in the recovery trajectory.

All images have been ordered with the following specifications: Bundle (Panchromatic and Multispectral Bands); Bit Depth: 16-Bit; File Format: GeoTIFF 1.0; DRA (Contrast Enhancement): DRA Off; Resampling Kernel: Cubic Convolution; Projection: UTM; Projection Datum: WGS84.

B. Phase 2: Data Acquisition and Analysis (12 months)

The second phase of the project will involve the acquisition and analysis of remote sensing imagery by the remote sensing team, as well as ground investigation work alongside local research teams. Visible recovery characteristics will be explored using a spatially tiered approach that comprises both per-building and community scales. Image processing techniques for rapid post-disaster damage assessment at a per-building scale [20] [21] will be modified, enhanced and extended to measure and monitor recovery characteristics at key intervals following the event. A combination of pixel- and object-based image processing techniques will be investigated to attempt to quantify changes in location, structural configuration and construction materials. At a community scale, theoretical frameworks associated with planning and network modeling will be explored and new techniques will be investigated for measuring changes in settlement distribution and density.

The remote sensing investigations will be supplemented by advanced field surveys using the VIEWS field reconnaissance system. VIEWS will be deployed in sample localities to capture a geocoded photographic and video record of recovery at a particular moment. Local field investigations will also be conducted on the ground to acquire an understanding of the physical, social and institutional achievements of recovery. The remote sensing indicators will then be compared with the in-field observations, statistics and interviews to establish to what extent the results from Phase 2 have the potential to serve as indicators.

C. *Phase 3: Synthesis and Production of Guidelines (6 months)*

Finally, the results from the first two phases will be reviewed and defined, before a set of measurable indicators will be selected by evaluating them against criteria of robustness, ease of measurability, replicability and value. A set of guidelines will then be produced and reviewed by the intended users. This document will define and introduce the proposed indicators and explain the measurement approaches available for each.

III. Case study and data selection

A. *Ban Nam Khem, Thailand*

After the 2004 South Asian tsunami, damage assessment conducted by the Pacific Disaster Centre highlighted four areas of interest: 1. Ban Nam Khem 2. Khao Lak 3. Phuket Island and 4 Phi Phi Island. Phi Phi island was immediately dismissed based on issues of accessibility and the unavailability of ground data. Phuket was not selected due to its heavy dependence on the tourism industry, which we felt might bias the speed and quality of the recovery process. Between 2000 and 2004, the tourism Gross Provincial Product (GPP) was on average 40 times greater in Phuket Province than it was in Phang Nga Province [22]. Furthermore, only 17 % of hotels in Phuket were affected. Most of the buildings on the island had mid-rise reinforced concrete frames and therefore only received damage to their ground floors [23]. In contrast, a report by the Asian Disaster Preparedness Centre stated that “the whole village of Ban Nam Khem was badly damaged with only a few buildings left standing” [24].

The Ban Nam Khem imagery was ordered with an area of 49 Km², which is the minimum area for Ikonos imagery. This Area of Interest (AIO) was chosen to ensure it included the following features:

a)The whole settlement of Ban Nam Khem, with different levels of damage.

b)Three known temporary camps: Bang Muang, Pruteow and Bor Him.

c)Agricultural land to the south that was both flooded and unaffected.

d)The main road leading from Khao Lak to Akua Pa, which is lined with buildings.

e)Aquaculture pools to the East of Ban Nam Khem.

The literature search provided evidence of reconstruction within six months of the tsunami, which prompted us to acquire imagery 4 and 7 months after the disaster. High quality Ikonos or Quickbird imagery was not frequently available on the Thai coast due in part, to the frequent cloud cover and haze. Despite this, images were acquired 1, 2 and 4 years after the tsunami. An image will also be tasked to coincide with our field deployment next year.

Table 1 Satellite imagery acquired for ban nam khem

Date	Timeline	Sensor
24 June 2002	- 30 months	Ikonos
2 January 2005	+ 2 days	Quickbird
1 April 2005 14 July 2005	+ 4 months + 7 months	Ikonos Quickbird
February 2006	+ 1 year	Quickbird
November 2006	+ 2 years	Ikonos
February 2008	+ 4 years	Ikonos

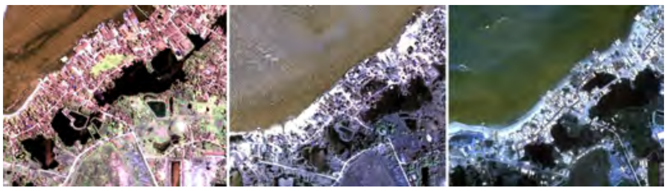

Figure 1. Three subset images of Ban Nam Khem: Ikonos – 24 June 2002 (left), Quickbird – 2 January 2005 (middle) and Quickbird - 14 July 2005 (right).

B. *Muzaffarabad, Pakistan*

A 7.6 magnitude earthquake occurred in northern Pakistan on the 8 October 2005, causing widespread destruction in Azad Jammu Kashmir and in the eastern districts of North West Frontier Province. A map produced by the European Commission’s Joint Research Centre (JRC) showed severe damage stretching south-west from Balakot in the north to Bagh in the south. As part of our site selection process, we looked at the location, access, damage, evidence of recovery and main industry for 12 villages, towns and cities in the affected area.

Of these sites, severe damage was observed in both Balakot and Muzaffarabad. The government’s decision to relocate the town of Balakot 25 Km south meant it would not be a suitable case study for recovery. EEFIT reported that Muzaffarabad also received some of the heaviest damage. Damage was identified using both remote sensing techniques and EEFIT field surveys. Heavy damage occurred in the center of the urban area and schools had also almost completely collapsed despite being built with reinforced concrete column and slab with masonry infill [24].

Favourable image availability allowed us to select images from either Ikonos or Quickbird. Quickbird was considered more desirable due to its higher spatial resolution and its smaller *Minimum Image Size* (25 Km² instead of 49 Km²), which reduced the cost of acquisition. A large subset was first produced by analysing the spatial overlap between available images. A smaller subset was then chosen that incorporated the city and the areas of severe damage. One pre-and-post disaster image was purchased, as well as a recovery image, which was acquired 8 months after the earthquake. The recovery image was attained in June 2006 (over 2 years ago), so we are currently working to task a new image as quickly as possible. The extent of the imagery incorporates the whole of Muzaffarabad city. It also includes several smaller villages and settlements, and Chela Bandi, the site of a landslide 3000 m high [23]. It will therefore allow us to compare different recovery trajectories within a relatively narrow geographic location.

TABLE 2 IMAGERY ACQUIRED FOR MUZAFFARABAD

Date	Timeline	Sensor
13 August 2004	**- 14 months**	**Quickbird**
22 October 2005	**+ 14 days**	**Quickbird**
13 June 2006	**+ 8 months**	**Quickbird**

Figure 2. Three Quickbird images of Muzaffarabad: 13 August 2004 (left), 22 October 2005 (middle) and 13 June 2006 (right).

Figure 3. Subset of pansharpened Quickbird Images of Muzaffarabad: 13 August 2004 (left), 22 October 2005 (middle) and 13 June 2006 (right).

IV. BAN NAM KHEM RECOVERY NARRATIVE

Miles & Chang recommended that researchers collect empirical data on recovery to help build our understanding of the process in different contexts [25]. The availability of online reports and statistics from the field provide researchers with an opportunity to collate detailed descriptions and statistics describing different aspects of recovery. A detailed narrative of recovery in Ban Nam Khem was produced to gain a more comprehensive understanding of a single recovery trajectory. This exercise was useful at highlighting important elements of the recovery process and therefore potential indicators for our work. It will also aid our interpretation of the physical changes that are observable within the satellite images and allow us to begin identifying potential relationships between the agents in a spatial context. The work also highlighted the overall complexity of the processes involved. The research was based on agency and governmental reports and websites, as well as surveys and work carried out by academic institutions.

Ban Nam Khem is a small fishing village located north of Khao Lak, on the Andaman coast. An account by the Thai Government described 4 waves striking Ban Nam Khem between 9:35 am and 10:03 am ranging from 2 to 10 m high. Ban Nam Khem's low elevation and its proximity to the mouth of the Pak Ko River contributed to the loss of over half of its population of 6,000 people and up to 80% of its infrastructure, including fishing fleet, harbour and fish processing facilities [26]. The tsunami also caused psychological trauma, damage to coral reefs and coastal reefs, as well as the degradation of water quality and agricultural land [27].

The state spent $2 billion on reconstruction and assistance in the first year in a response that involved the collaboration of the Royal Thai Government, the Thai Private Sector and Non-Governmental Organisations [27]. There was no national preparedness plan; instead the disaster was managed by the Prime Minister. Most of the immediate relief efforts were focussed at the Bang Muang refugee camp in Takua Pa District, which housed 3,500 people and acted as a central base for 57 relief groups. The camp successfully brought the survivors together and enabled them to influence their recovery through group meetings and decisions. The camp provided temporary accommodation, health, bathing and cooking facilities, as well as psychological support, education and a focal point for aid agencies. Temporary houses were built in long rows with rubber-tree pole frames, plywood or fiber-cement panelled walls, corrugated tin sheet and cost between $300 and $1,200.

As part of the government's compensation scheme, villagers who lost property to the tsunami were offered either a free house or a lump sum of money. The Thai Army used cement bricks and corrugated-iron roofs for the houses, which had a floor space between 4 m x 4 m and 6 m x 6 m (see Figure 4) [28]. The size of the government-provided housing was a lot smaller than aid agency housing and was consequently less accepted by the local population [29]. The exact material, size and design differed according to the agency's access to funds and expertise. Crucially, the government offered no consultation or input on building design or allotment procedures. Interviews and focus groups indicated that most villagers wanted to live near the shore because many of them were fishers and proximity to the sea enhanced their income.

Figure 4. *Left and middle:* Permanent housing in Ban Nam Khem. Source: [30]. *Right:* New constructions with different floor spaces can be located in Ban Nam Khem on Quickbird imagery: 4m x 10m (yellow); 6.5m x 8m (red) and 4m x 15m (green).

The tsunami brought about complex land right disputes, which slowed the overall recovery process. Many villagers settled in Ban Nam Khem before it became valuable due to tourism, but did not obtain title deeds or lease contracts. The Centre On Housing Rights and Evictions (COHRE) reported that by 2 and 3 May 2005 there were at least 200 evictions and displacement by the Far East Trading and Construction Company, which planed to build a resort and claimed the occupants were staying on its land illegally [31].

The livelihoods of the post-tsunami communities were found to be particularly vulnerable due to their reliance on so few forms of income, many of which were based on the region's fragile coastal resources. At least 22 shrimp hatcheries and 12,726 m² of cage cultures were lost [26]. A survey conducted by Paphavasit reported that one-third of respondents and one-quarter of dependants were unemployed after the tsunami and over half of the respondents had to change jobs. Many of the fishers became unskilled labourers and had to move from their homes, which dramatically changed their livelihoods. The people in Ban Nam Khem estimated that they would face economic strain for at least 4 years after the disaster [22].

V. Discussion

A. Qualitative Analysis of Imagery Timelines

The diagram at the end of this paper shows a number of potential indicators of recovery derived from the literature search and Ban Nam Khem narrative. The diagram is by no means comprehensive, but it does introduce some of the agents and processes involved in recovery and is intended as a working document to be discussed and amended. In the diagram, recovery has been divided into six categories: 1. Vulnerability 2. Services 3. Livelihoods 4. Housing 5. Infrastructure 6. Environment. Each of these categories have sub-categories attached to them. For example, the *services* category consists of four sub-categories: *administration, education, food* supply and health. Physical objects with the potential to be measured by remote sensing are contained in grey hexagon boxes whilst, potential outcomes are shaded in black. After locating and extracting these physical objects we may be able to infer further information from them by studying their individual attributes such as their size, location, spatial context, relative age etc.

The team are currently working on a comprehensive table of indicators that will suggest which physical attributes we might be able to analyse using remote sensing and which analytical techniques we might use to study them, as well as a ranking of the indicators' relative importance.

B. Object-based Classification

Object-based classification offers an effective method of data extraction [31]. This method of image classification allows an image to be segmented into objects at various scales. Multiple criteria are then used to classify each of the objects, including spectral and spatial data, object morphology, image texture and band ratios, as well as contextual information and elevation data.

Ishiguro used stereo matching techniques to generate elevation data for Ban Nam Khem following the tsunami [33]. Uniquely, the work used one Ikonos image and another Quickbird image to obtain height information. The availability of stereo pairs is typically rare, but disasters commonly present an opportunity when both Ikonos and Quickbird imagery are acquired at approximately the same time. The accuracy of Isiguro's DEM was compared to elevation data extracted from aerial photography and had a standard deviation of 1.42 m. One aim of this project could be to explore whether this sort of elevation data would be useful in aiding object-based classifications and data extraction methods following a disaster.

Throughout the study, object-based classification techniques will be refined and used to extract building footprints and land cover classifications. There are several pieces of software available on the market that incorporates object-based technology, such as Definiens Developer, Feature Analyst, Feature Extraction and Imagine Objective. An assessment will be made to determine which of these will be most suitable for our objectives.

C. Visualising Recovery

Another potential area of research is the development of a system capable of archiving, sharing and storing recovery data. Murao shows how three-dimensional models of reconstructed areas were developed and used to monitor the recovery process after the Chi-Chi earthquake [34]. Due to the complexity of the recovery process the creation of an effective and user-friendly database may be an important step towards understanding the process. It could also potentially allow scientists from around the world to view and share data on recovery.

Murao first used Ikonos imagery to derive building footmarks. Information was then attached to these polygons to allow the identification of key services, their building type and their damage state [34]. In addition, an image archive database was created, which consisted of 1,500 photographs of building facades and information on each of the buildings' height, roof form and storey number. This information was used to create a 3D textured representation of Chi-Chi using Google Sketch, a 3D modelling tool freely available on GoogleEarth [35].

Visualisation and storing data on urban change will be particularly important if we are to assess urban development and growth throughout the recovery process. The combination of high resolution satellite data and ground-based observations are now increasingly used to monitor urban environments [36]. The acquisition of multi-temporal imagery following two natural disasters provides us with a unique opportunity to monitor and assess post-disaster urban development using methods such as agent-based modelling [37].

D. Modelling Community Recovery

Miles & Chang created a model of community recovery to demonstrate how a complex set of relationships could be modelled and to evaluate the consequences of different decision variables [7] [25]. An Object Modelling Technique was employed due to a lack of numerical data but a rich knowledge base. They suggest that it is not a comprehensive model of disaster recovery but a tool to help us understand the process.

The work comprises 32 equations based on empirical data that describe the relationships between the agents, using Simulink modelling tools of Mathwork's MATLAB. A graphical interface allows the user to define attributes of the population, businesses, lifelines, building stock and disaster preparedness.

It is hoped that the results of the Recovery project will contribute towards our understanding of the recovery process. There is currently a lack of literature and research on recovery and reconstruction, especially long-term empirical studies [38]. It is the least investigated and understood component of post-disaster aid [12]. In particular, we need to understand more about how recovery proceeds over time, how it varies spatially and the relationship between sectors.

This paper introduced these complexities and the difficulties that may arise when trying to measure or evaluate recovery's progress. A list of potential indicators of recovery is provided as a starting point for further discussion. In Phase 2 of the project, the team will re-evaluate these indicators, finish the acquisition of data and then begin to explore how they may be monitored.

References

[1] E.L. Quarantelli, *"The disaster recovery process: what we know and do not know from research"*. Preliminary Paper #286. University of Delaware. Disaster Research Cemter. 1999.

[2] D.J. Alesch, *"Complex urban systems and extreme events: towards a theory of disaster recovery"*. 1st International Conference of Urban Disaster Reduction. Kobe, Japan. 19 January 2004.

[3] J.E. Haas, R.W. Kates, and M.J. Bowden, "*Reconstruction following disaster"*. Cambridge: MIT Press. 1977.

[4] M.C. Comerio, *"Disaster hits home: new policy for urban housing recovery"*. Berkeley: University of California Press. 1998.

[5] J.M. Nigg, *"Disaster recovery as a social process"*. In *"Wellington after the quake: The challenge of rebuilding"*. Wellington New Zealand: The Earthquake Commission. 1995.

[6] R. Olshansky, L. Johnson, and K. Topping, *"Post-disaster redevelopment: lessons from Kobe and Northridge"*. Final Report, NSF Award No. CMS-9730137, July 11 2003.

[7] S.B. Miles, and S.E. Chang, *"Urban disaster recovery: A framework and simulation model"*. MCEER-03-0005. 29 July 2003.

[8] I. Nakabayashi and T. Ichiko *"Comparative study of urban and housing reconstruction process during five years after earthquake among Japan, Taiwan and Turkey"*. 1st International Conference of Urban Disaster Reduction. Kobe, Japan. 19 January 2004.

[9] A. Fujieda, R.Y. Nakagawa, R. Shaw, H. Kobayashi, and M. Kobayashi, *"Roles of social capital and community organizations in the recovery process: Experience from Kobe and Gujurat Earthquakes"*. 1st International Conference of Urban Disaster Reduction. Kobe, Japan. 19 January 2004.

[10] P.R. Berke, J. Kartez, and D. Wenger *"Recovery after disaster: achieving sustainable development, mitigation and equity". Disasters: 17 (2), 93-109. 1993.*

[11] Yu, C-C. "*Could home be re-built? – Lesson learned from Taiwan 1999 Chi-Chi earthquake recovery"*. 1st International Conference of Urban Disaster Reduction. Kobe, Japan. 19 January 2004.

[12] M.C. Comerio, *"Key elements in a comprehensive theory of disaster recovery"* 1st International Conference of Urban Disaster Reduction. Kobe, Japan. 19 January 2004.

[13] M.B. Tyler, K. O'Prey, and K. Kristiansson, *"Redevelopment after earthquakes"*. Portola Valley, CA: Spangle Associates, 2002.

[14] Provention Consortium & Alnap, *"Responding to earthquakes. Learning from earthquake relief & recovery operations". 2008. http://www.proventionconsortium.org/themes/default/pdfs/ALNAP-ProVention_earthquake08.pdf Last Access: 31 July 2008.*

[15] C.B. Rubin, *"The community recovery process in the United States after a major natural disaster". International Journal of Mass Emergencies and Disasters, Vol., 3, 9-28. 1985.*

[16] J. Schwab, *"Planning for post-disaster recovery and reconstruction"*. Chicago: American Planning Association. 1998.

[17] P-C. Shao, E. arumi, and Y. Murosaki, *"Situation and evaluation of housing reconstruction for Taiwan Chi-Cho Earthquake"*. 1st International Conference of Urban Disaster Reduction. Kobe, Japan. 19 January 2004.

[18] World Bank, *"Hazards of nature, risks to development: an IED evaluation of World Bank assistance for natural disasters"*. Washington: World Bank. Independent Evaluation Group. 2008.

[19] Sphere.Project, *"Humanitarian charter and minimum standards in disaster response"*. Oxford, OXFAM Publishing. 2004

[20] B.J. Adams, *"Improved disaster management through post-earthquake building damage assessment using multitemporal satellite imagery."* Proceedings of the ISPRS XXth Congress Volume XXXV(Istanbul). 2004

[21] K. Saito, R. Spence, C. Going, and M. Markus, *"Using high-resolution satellite images for post-earthquake building damage assessment: A study following the 26 January 2001 Gujarat earthquake." Earthquake Spectra 20(1): 145 - 170. 2004.*

[22] N. Paphavasit, C. Chotiyaputta, and S. Siriboon, *"Pre-and post-tsunami coastal planning and land-use policies and issues in Thailand"*. In: *"Proceedings of the workshop on coastal area planning and management in Asian tsunami-affected countries"*. 27-29 Sptember 2006, Bangkok, Thailand. Food and Agriculture Organisation (FAO). http://www.fao.org/docrep/010/ag124e/AG124E00.HTM

[23] A. Pomonis, T. Rossetto, S. Wilkinson, D. Del Re, B. Happold, N. Peiris, N. Koo, R. Manakapig, and S. Gallocher, *"Preliminary Reconnaissance Report. The Indian Ocean Tsunami. 26th December*

2004". Earthquake Engineering Field Investigation Team (EEFIT), Web Report 2005, www.eefit.org.uk

[24] L.M.N. Peiris, T. Rossetto, P.W. Burton, and S. Mahmood, *"EEFIT Mission: October 8, 2005 Kashmir Earthquake".* Preliminary Reconnaissance Report, Earthquake Engineering Field Investigation Team (EEFIT), Web Report, February 2006, www.eefit.org.uk

[25] S.B. Miles, and S.E. Chang, *"Modelling community recovery from earthquakes".* Earthquake Spectra. Volume 22 (2). 439 – 458. 2006.

[26] UNDP, World Bank and FAO, "*Livelihood Recovery and Environmental Rehabilitation. Thailand. Joint Tsunami Disaster Assesment Mission".* 10 January 2005. http://www.undp.org/cpr/disred/documents/tsunami/thailand/jointassessment_190105.pdf

[27] United Nations Country Team, *"Tsunami Thailand — one year later: national response and contribution of international partners".* Joint publication by the Untied Nations Country Team with lead support from UNDP and the World Bank. 2006.

[28] S. Bhumiprabhas, *"A second wave hits Baan Nam Khem".* The Nation Newspaper: Tsunami. One Year On. 13 December, 2005. http://www.nationmultimedia.com/specials/tsunami/tsunami2.php

[29] M.D. Baumgartner, *"Under construction: A descriptive report on the post-tsunami reconstruction processes in Khao Lak, Thailand and Banda Aceh, Indonesia".* P. S. G. o. D. Research. 2006.

[30] Asian Coalition for Housing Rights (ACHR), *"Housing by People in Asia".* Newsletter of the Asian Coalition for Housing Rights. Number 16, August 2005. http://www.achr.net/000ACHRTsunami/Download%20TS/ACHR%2016%20with%20photos.pdf

[31] Centre on Housing Rights and Evictions (COHRE), *"Asian tsunami, evictions and land rights monitoring". 2005* http://www.cohre.org/store/attachments/COHRE_TsunamiMonitor_2005_05.pdf

[32] L. Gusella, B.J. Adams, G. Bitelli, C.K. Huyck, and A. Mognol, *"Object-oriented image understanding and post-earthquake damage assessment for the 2003 Bam, Iran Earthquake".* Earthquake Spectra. Volume 21 (S1). 225-238. 2005.

[33] S. Ishiguro, T. Sugimura, S. Sano, and Y. Suzu Ki, *"DSM accuracy generated by combining single-images from IKONOS and Quickbird: A case study of Nam Khem Plain, Thailand".* JSPS & Nagoya University: Asia and Africa Science Platform Program. Geomorphological Comparative Research on Natural Disaster Mitigation in the Coastal Regions of Tropical Asia. 2006.

[34] O. Murao, "Description of building reconstruction process of Chi-Chi area using image archives after the 1999 Chi-Chi earthquake, Taiwan". 1st International Conference of Urban Disaster Reduction. Kobe, Japan. 19 January 2004.

[35] O. Murao, T. Ichiko, and I. Nakabayashi, *"Evaluation of building reconstruction process in Chi-Chi area based on a GIS-database after the 1999 Chi-Chi Earthquake, Taiwan".* 13th World Conference on Earthquake Engineering. Vancouver, Canada. August 1-6 2004.

[36] D.J. Cowen, and J.R. Jensen, *"Extraction and modelling of urban attributes using remote sensing technology".* In: *"People and pixels. Linking Remote sensing and social science".* National Academy Press. Washington D.C. 1998

[37] M. Batty, *"Cities and complexity. Understanding cities with cellular automata, agent-based models, and fractals".* The MIT Press. London, England. 2007.

[38] R.B. Olshansky, "*Toward a theory of community recovery from disaster: a review of existing literature".* 1st International Conference of Urban Disaster Reduction. Kobe, Japan. 19 January 2004.

[39] Post Disaster Needs Assessment (PDNA), phase II: Practical Guide to a Recovery Results Framework. (2008) World Bank, UNDP, European Commission.