Monitoring and Evaluating Post-Disaster Recovery Using High-Resolution Satellite Imagery – Towards Standardised Indicators for Post-Disaster Recovery

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Monitoring and Evaluating Post-Disaster Recovery Using High-Resolution Satellite Imagery – Towards Standardised Indicators for Post-Disaster Recovery

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1. Abstract

The main objective of the *Recovery Project (2008-2011)* was to produce a universally-applicable suite of indicators and techniques that allow donors and executing agencies to Monitor and Evaluate (M&E) post-disaster recovery and reconstruction. The framework allows users to monitor recovery in a manner that is rapid, independent and reliable. Such a system is required to promote transparency and accountability and to contribute towards a more systematic understanding of the process of recovery. The indicators are based on the use of Very High Resolution Optical Satellite Imagery and have been developed to fit existing humanitarian approaches, such as the Post-Disaster Needs Assessment (PDNA) and the Humanitarian Cluster Framework, and according to the needs of the users, affected communities and appropriate stakeholders. The indicators encompass a range of physical, environmental, social and economic factors, which can be independently analysed or combined to provide a holistic representation of the reconstruction process. The paper begins by addressing the need for a monitoring and evaluation framework and by reviewing current guidelines and systems. The techniques developed by the project were applied to two case studies: Ban Nam Khem, Thailand (2004 Indian Ocean tsunami) and Muzaffarabad, Pakistan (2005 Kashmir earthquake). A summary of the remote sensing analysis of Ban Nam Khem, Thailand is presented. Recommendations are then made on how remote sensing may be used to M&E post-disaster recovery based on the experience of the project team and feedback from users and stakeholders. The recommendations revolve around three key questions: 1. Which indicators should be monitored? 2. When should they be applied and how often? 3. How can they be monitored? In addition, a cost-effectiveness analysis was used to identify the strengths and weaknesses of remote sensing in a recovery context and to compare it to other available tools, such as social-audit techniques (focus group meetings, household surveys and key informant interviews) and ground-based observational surveys. The paper concludes with a discussion on how remote sensing may be incorporated into current M&E frameworks and how these tools may be integrated and used collectively at different stages of the disaster management process.

2. Introduction

2.1. The Recovery Process

Recovery may be thought of as an attempt to bring a post-disaster situation to a level of acceptability (Quarantelli, 1999) through the rectification of damage and disruption that has been inflicted upon an urban system's built environment, people and institutions (Alesch, 2004). The process of recovery is often long, costly and complex, with roles and responsibilities distributed among numerous sectors and stakeholders. Recovery has been shown to vary over time and space due to socio-economic and political factors and because of a multitude of decisions made before, during and after a disaster (Olshansky et al. 2003). There are subsequently similarities between recovery and social vulnerability theories, which suggest that vulnerable groups may be more susceptible to losses and have more difficulty recovering (Miles and Chang, 2003).

Post-disaster recovery is often conceptualised as a complex, multi-dimensional process (Nigg, 1995); despite this, executing agencies, such as the United Nations, often find it useful to refer to four temporal phases of the Disaster Cycle. The main objective of these categories is often to differentiate emergency relief work from long-term recovery and mitigation. While the relief phase is characterised by life-saving tasks, such as finding survivors and providing food, water and sanitation; recovery is likely to include the reconstruction of the built environment (roads, bridges and buildings) and the restoration of amenities (water and power) and services (schools and health facilities). Local and national government structures must also be restored, as well as security and sources of sustainable livelihoods. In addition, a number of cross-cutting issues must be addressed, such as supporting vulnerable groups, risk reduction, community participation and environmental protection.

2.2. The need for Monitoring and Evaluating (M&E) Post-Disaster Recovery

Monitoring and evaluation is necessary to improve future aid policy, to provide accountability and to assist on-going work on the ground. Although many organisations and institutions are involved in the recovery process with different functions and data requirements they may be divided into two broad groups: 1. Executing agencies and 2. Donors. *Executing agencies* conduct development and logistical work and require data for operational reasons, to inform decision-making and situational understanding, and to identify issues as they arise. The *donors* fund the work conducted by the executing agencies. They require data to provide accountability and transparency to their stakeholders and to ensure their objectives are being met on time and to budget.

Billions of dollars are often pledged to assist reconstruction after large natural disasters. The amount pledged to support the relief and recovery after the 2004 Indian Ocean tsunami eventually reached US$14 billion. More recently, US$9.9 billion was pledged to provide immediate and long-term aid to Haiti after the 2010 earthquake.

The governments of affected countries also tend to invest heavily in the recovery process. For example, after the 2004 tsunami - the Government of India set aside approximately $1.4 billion in tsunami-related funds and the Government of Indonesia set-aside $2.0

billion. International financial institutions, such as the International Monetary Fund (IMF), the Inter-American Development Bank and the World Bank, have also become regular donors to long-term recovery. The World Bank is one of the largest funding agencies of disaster recovery and reconstruction in developing countries. Since 1984, the Bank has financed US$ 26 billion in disaster activities in over 600 disaster responses. It provided $710 million after the 2008 Wenchuan earthquake to reconstruct infrastructure, $448 million after the 2005 Pakistan Earthquake to support livelihoods and reconstruction, and $650 million to Indonesia after the 2004 tsunami (World Bank, 2010a).

Despite the large sum of money aiding recovery efforts and the complexity of the work being conducted there are currently no standard frameworks or methodologies that can be adopted to monitor and evaluate the process. 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 (Shelter, 2006). In particular, they noted the lack of a standard, independent and replicable approach to measure, monitor and evaluate the relief and recovery processes. More recently, the Active Learning Network for Accountability and Performance in Humanitarian Action (ALNAP) called for "further research on the mix of impact-assessment methods most appropriate in the different emergency phases of relief, recovery and reconstruction" (Proudlock et al. 2009).

2.3. Current Frameworks and Guidelines

Very few humanitarian organizations thought to measure the consequence of their actions until the 1990s, as it was largely assumed that their interventions were beneficial to the recipients (Barnett (2005). In the past 10 years though, a number of systems and projects have arisen that address the need for post-disaster monitoring and evaluation. The Sphere Project, for example, has provided minimum standards and guidance to humanitarian relief workers since it was devised in 1997 (Sphere Project, 2004). Information management systems capable of collating, storing and displaying recovery statistics, were also developed to provide accountability and to assist on-going recovery activities. *Data against Natural Disasters* reviewed six such information systems (Amin and Goldstein, 2008). The simplest, known as a Logistics Support System (LSS), was used in Guatemala after Hurricane Stan in 2005 to organise the distribution of supplies and donations and focused predominantly on tracking humanitarian supplies during the response phase of recovery. The Development Assistance Database (DAD) was used to track the provision of aid *and* the progress of reconstruction (Aid Effectiveness Portal, 2009) but the data has often been incomplete and unreliable.

While DADs were designed predominantly to track financial data, other systems have focused on monitoring the outcomes of recovery. The Relief and Information Systems for Earthquake Pakistan (RISEPAK) was developed after the 2005 Kashmir earthquake to provide information on needs and response at village scale for gap analysis from data collected by individuals in the field. The Tsunami Recovery Impact Assessment and Monitoring System (TRIAMS) created one of the most comprehensive attempts to monitor post-disaster recovery to date (TRIAMS, 2007). The framework endorsed by the Global Consortium for Tsunami-Affected Countries (India, Indonesia, the Maldives, Sri Lanka and Thailand) to define, promote and support the tracking of post-disaster recovery after the 2004 Indian Ocean tsunami. TRIAMS real innovation though was in the creation of output and outcome indicators categorised into four areas: vital needs, basic social services, infrastructure and livelihoods.

Alongside these systems, most international NGOs and fund providers have their own internal M&E policies and methods to ensure they are independently monitored. A review of the evaluation procedures of 24 bilateral donors and 7 multilateral institutions (OECD, 2010) estimated US$148 Million was spent on development evaluation in 2009 by those agencies alone. The World Bank Group spent the most on evaluation by providing a budget of US$31 million, while the UK's Department for International Development (DFID) had a budget of US$9 million.

2.4. Current Tools

A range of measurement approaches are now available to evaluators and analysts, including scientific and theory-based methods (World Bank, 2002). Most evaluating departments though have adopted a programme logic framework, based on a clear theory of change – also known as a results chain - and a set of clearly-defined activities, inputs, outputs and outcomes. At the World Bank, for example, an *Implementation Completion Report* is compiled for all of its development projects, using a results framework where objectives of the project are clearly stated and the progress towards the expected results is systematically monitored. A substantial amount of guidance material has been produced to support this evaluation work and is available publicly (Mosse and Sontheimer, 1996; Dabelstein, 2006; Daniba, 2006; World Bank, 2006, UNDP, 2009), much of which is based on the Development Assistance Committee evaluation criteria (OECD-DAC, 1999). The *DAC criteria* provide guidance to encourage evaluators to consider each programme's *relevance, effectiveness, efficiency, impact and sustainability*. The criteria are now considered an essential reference for those wishing to evaluate developmental-based programmes and projects.

The stakeholders use an assortment of tools and data collection techniques to collect data, including formal surveys, interviews, group discussions and direct observations (USAID, 1996a; Proudlock, 2009). This is in agreement with the DAC Evaluation Criteria, which recommends analysts use a mixture of field interviews, surveys and literature reviews. These methods are often time-consuming to apply across large geographic regions, subjective and prone to inconsistencies in data quality. In extreme cases - when access is denied, security a critical issue, or donors not welcome - M&E has been all but absent (e.g. when the World Bank was unable to send operatives to Burma after the 2004 tsunami and the 2008 cyclone Nargis). ALNAP recently analysed how agencies evaluate humanitarian action using a quality pro forma tool based on the DAC criteria (ALNAP, 2005). An assessment of 30 reports published in 2004 found that just over 27% used international standards - such as the Sphere minimum standards - in a satisfactory manner, and that only 59% used appropriate evaluation methods (Wiles, 2005). The TRIAMS project further highlighted weaknesses in the current data collection frameworks, concluding that recovery data is often lacking and not timely (TRIAMS, 2007).

Recent technological advances present the opportunity to enhance and support existing field-based tools and overcome many of the issues associated with passive frameworks and techniques. Remote sensing, in particular, the analysis of satellite imagery, is a proven data source for assisting disaster prevention efforts, mitigation, and relief, as well as damage and needs assessments. The post-disaster scenario can be confusing and dangerous, and collecting data is often challenging with numerous agencies working across large, disaster-stricken areas. Remote Sensing offers a systematic method of collecting independent and quantitative datasets rapidly and non-intrusively across large, dynamic geographic regions. The World Bank recently recognised the potential of remote sensing as a tool to monitor long-term recovery, but there are currently no proven methodologies in which to analyse the data (World Bank, 2010b).

3. The Recovery Project

3.1. Concept and Methodology

The main objective of the Recovery Project was to develop a standard approach to monitoring post-disaster recovery that is rapid, reliable and independent. This is achieved through the use of high resolution satellite image datasets and spatial analysis within a Geographical Information System (GIS). The Recovery Project was conducted from March 2008 to March 2011 and has been carried out in three phases. In the first year (Phase 1), appropriate case study sites were selected and datasets were acquired and integrated into a single database. A standardized monitoring framework was then developed after consulting affected communities and relevant stakeholders. In the second year (Phase 2), appropriate indicators and techniques were developed and applied to the case study sites. The results of the analysis were then verified using data collected with advanced ground survey techniques and social-audit methods. A detailed cost-effectiveness analysis was then conducted to identify the strengths and weaknesses of each tool and to provide recommendations on when they may be most appropriately deployed and how they may be integrated. A set of Guidelines have been produced to introduce this approach and to demonstrate remote sensing as an appropriate monitoring tool (CURBE, 2010). The following sections describe the methodology in more detail:

3.2. Phase 1: Project Definition

In Phase 1 the team reviewed current humanitarian frameworks, conducted a user needs assessment and held roundtable discussions with affected communities, NGOs and Government Departments involved in the recovery process. The work resulted in a list of indicators that encompassed relief, recovery and long-term development. The indicators were designed in partnership with users and affected communities to be SMART (Specific, Measurable, Attainable, Relevant and Time-Bound). Significant sources of reference when creating the indicator list, included the Sphere Guidelines (Sphere Project, 2004), ECLAC Handbook (ECLAC, 2003), Post-Disaster Needs Assessment (PDNA, 2008) and existing development indicators such as the Millennium Development Goals (MDG, 2008) and the World Development Indicators (WDI, 2008). Respondents to the user-survey included members of the international aid community (e.g. ECHO, UNOCHA, World Bank, Red Cross, DfiD, USAID), national government recovery agencies (ERRA, GISDTA) and local NGOs. Results demonstrated that all indicators received medium-to-high levels of prioritization suggesting there is a strong preference towards a *comprehensive* approach to monitoring recovery, but that the indicators of interest differed according to the nature of the organization. International financial organizations and affected governments are generally involved in numerous aspects of recovery. The World Bank, for example, has financed over 60 kinds of activity in disaster-related projects, from rubble clearance to the provision of emergency shelter, residential structures and transport infrastructure. Of the 528 disaster-related projects funded by the World Bank, 13% involved transport, 10% the environment and 9% urban (IEG, 2006). Other agencies specialise in particular areas of activity due to the nature of the work, such as the UNEP who asked for crop and forest loss to be mapped and the UNHCR who wanted population movement to be mapped rapidly after disasters. Selected comments from the survey respondents helped to highlight these specialised areas of interest:

Josef Leitmann - World Bank – Indonesia, Disaster Management Coordinator “We lack good information about damage to housing and infrastructure; impact on access; land cover change. It would be very useful to have these indicators of recovery mapped as overlays onto satellite imagery”
Anne-Cécile Vialle – UNEP, Associate Programme Officer “We need maps of agricultural damage, crop loss, forest loss, industrial and environmental sites, the location of displaced people and the sites where rubble/waste is being transported”.
Dan Ayliffe - DIFD, Response Officer “It would be useful to map population movements; rehabilitation of homes; rehabilitation of infrastructure, including roads, camps and medical centres; uptake of agricultural activities and other livelihoods”.

Two case study sites were also selected during this phase of the project and very high resolution (VHR) optical satellite images acquired from Digital Globe and Geoeye, based on evidence of recovery and the images’ availability. The two case study sites were selected to represent very different hazard types and different economic and cultural environments. The first case study, Ban Nam Khem, a fishing village on the West Coast of Phang Nga Province, Thailand, was severely hit by the Indian Ocean tsunami in December 2004. The second site, Muzaffarabad, Pakistan, was struck by the Kashmir earthquake in October 2005. Further descriptions of the user-needs survey results and case study sites can be found in Brown et al. (2008) and Brown (2009).

3.3. Phase 2: Data Analysis

The VHR satellite imagery was analysed and techniques developed throughout Phase 2. A range of techniques were developed for each indicator that use both manual and semi-automatic procedures. The techniques differ in the time and expertise required to conduct them and the amount of detail they are able to extract, so will appeal to users with different needs and resources. The methods were first applied to Ban Nam Khem and then applied to Muzaffarabad by a different team of analysts to test the transferability of the methodology. To summarise, the methodology is comprised of four components: 1. Pre-processing 2. Mapping / Database Creation 3. Data Analysis and 4. Product Creation. Recovery was monitored using a time-series of VHR satellite images acquired before the disaster, immediately afterwards and in the months-and-years thereafter. Buildings, roads and bridges and other key features were manually delineated, while Maximum Likelihood Supervised Classification was used to create land cover maps marking out the extent of the built and natural environment. More advanced extraction techniques, such as Object Based Image Analysis, were used to extract homogenous objects, including transitional shelters and shrimp ponds. These features were then integrated into a multi-temporal Recovery Geodatabase as point, line and polygon vector files. A new temporal layer of the database was derived from each satellite image, representing a different *state* in the process of recovery. Each temporal layer was further divided into 12 thematic sub-layers, each representing one of the main performance indicators (See Table 1).

Sector	Performance Indicator
Transport	1. Length of Road (Km)
	2. Accessibility
	3. Reconstruction of bridges and transport facilities
	4. Presence of vehicles
Buildings / Shelters	5. Removal and construction of buildings
	6. Change in urban land use and morphology
	7. Quality of dwelling reconstruction
Transitional Shelters and IDPs	8. Temporary dwellings and shelters
	9. Location of population
Services	10. Administration, education, healthcare and religious facilities
	11. Power, water and sanitation (WATSAN) facilities
Environment	12. Change in land cover and open public space
Livelihoods	13. Recovery of livelihoods

Table 1: Recovery Indicators applied to Ban Nam Khem and Muzaffarabad using VHR satellite imagery.

Once the features in the imagery were mapped and stored in a GIS database the speed of recovery was determined by applying change detection analysis to the geodatabase. This technique calculated the rate that various processes were conducted, including debris removal, building construction, road rehabilitation and vegetation recovery. The method also identified when key features, such as schools and sources of livelihood, appeared and when transitional shelters and planned camps were removed and dismantled. The overall progress of recovery was then inferred by noting the presence or absence of key features at different points in time. For more detailed analysis, the datasets were disaggregated by geographic boundaries and executing agency, allowing disparity in the speed of recovery to be assessed. The progress of recovery was further evaluated by normalising the numbers of features (number of buildings, length of roads) in each region to base-line statistics, which were constructed using the pre-disaster image and the objectives of each recovery project. This analysis was successful at identifying slow projects and gaps in the supply of resources. It was also used to substantiate claims that a region had been 'built back better'.

Where appropriate, additional information was extracted from the mapped features, including the number of Internally Displaced Persons (IDPs), which was calculated based on the number and size of structures located in planned camps. Information about the quality of recovery was also inferred by looking at changes to the size and shape of the features and by analysing their spatial and contextual properties. This was achieved using common spatial analyst tools in ArcGIS. More advanced analysis techniques were also employed, such as landscape metrics, which were used to quantify changes to building size, shape and density; and network analysis, which analysed changes to connectivity and travelling times brought about by the relocation of households and facilities. Spatial analysis and proximity analysis were also applied to planned camps to ensure occupants had sufficient living and covered space, and to measure infrastructure placement. These measurements were compared to minimum standards contained in the Sphere Guidelines and other humanitarian frameworks to ensure that latrines and other features were properly located and that there was adequate accessibility. In addition, proxy indicators were developed to allow certain social and economic aspects of recovery to be inferred from physical recovery processes. By observing features associated with major sources of livelihood for example, assumptions were made about the speed of livelihood recovery in various sectors.

At an intermediate stage in the imagery analysis, field work was carried out to obtain feedback on the recovery indicators and to acquire ground knowledge from official statistics, key informant interviews, household surveys and direct ground observations. The results from these tools were integrated into the recovery database as part of the verification process. The household survey for example, was used to derive a narrative of the recovery process, to infer household's levels of satisfaction and to provide information on key dates. Ground observations were collected as GPS-registered photographs and video footage by deploying a GPS Camera (Ricoh Caplio 500SE) and Imagecat's VIEWS system™ (Imagecat, 2010). Approximately 2,000 photographs and 10 hours of video footage were processed and used to record ground observations that were later used to infer progress and to verify the satellite analysis. Meetings, round-table discussions and one-to-one interviews were also held with those coordinating the disaster response, including Government Ministries and International Nongovernmental Agencies, and those directly involved in recovery, including Sub-District Officials and local NGOs. The aim of the meetings was again, to obtain feedback on the Recovery Indicators and to further verify the remote sensing analysis.

4. Results

4.1. Application of the Indicators

Each of the indicators provided a rich source of information that could be interpreted independently or integrated to provide a holistic understanding of the progress of recovery. Physical indicators allowed accessibility and travelling times to be analysed, building construction to be monitored, internally displaced persons (IDPs) to be mapped and transitional shelters to be assessed. The indicators were monitored using remote sensing and were found to closely match narratives from key informant interviews, focus group meetings and household surveys. The results were also found to be accurate when they were compared to detailed ground data collected using VIEWS™ and a GPS camera.

Some small commission and omission errors occurred that resulted in an overestimation or underestimation of the feature being analysed. This occurred due to both human and computational error. The analysis also relied on a number of assumptions that weren't always accurate, for example that all roads were in use and that all buildings were occupied at the time the satellite images were acquired. These errors and assumptions were minimised by collecting sampled ground knowledge before the image analysis has begun and by identifying likely forms of miss-interpretation. In addition to the physical indicator analysis, social indicators were successfully used to infer information about the recovery of livelihoods and local services. A detailed analysis of these sectors - including services, utilities and livelihoods - was not possible with remote sensing alone, but the information from satellite imagery was used to complement results acquired with ground surveys and social audit techniques. In particular, ground surveys were used to confirm building use and occupancy, and to inspect the quality of construction and the supply of utilities. Social-audit techniques were used to determine level of satisfaction, land ownership and to explain why many of the patterns observed in the imagery had occurred, for example the dereliction of hatcheries due to low levels of compensation. Issues such as land ownership also helped to explain differences in the speed of construction, with those households lacking land rights awaiting housing far longer than those with rights and appropriate documentation.

In section 5.4 the pros and cons of each tool are described in more detail and a workflow is proposed that shows how the various tools may be used in a complementary manner. A GIS was found to be a suitable system in which to store and analyse the various datasets, including satellite imagery, ground-based observations and survey results. The GIS also allowed multiple layers of the database to be analysed simultaneously, thus providing a greater contextual understanding of the progress on the ground. As an example of the results gained using this approach, a summary of the recovery process at Ban Nam Khem after the 2004 Indian Ocean tsunami is presented in Section 4.2. Table 2 shows a selection of the indicator results four months and four years after the tsunami, while figures 1 - 4 show a summary of the indicator results in the form of maps and graphs.

4.2. Case study: Ban Nam Khem

Indicator	Pre-disaster	Post-disaster	Apr-05	Feb-09
Displaced Population	N/A	N/A	3,200	192
Total Number of Buildings	1,170	678	1,212	1,723
Length of Functioning Road (km)	45.7	18.9	28.3	53.7
Number of School Buildings	10	10	11	27
Number of Health Facilities	1	0	0	2
Number of Temples	1	1	1	2
Functioning Shrimp Ponds (Area, Km²)	609.2	577.5	635.9	708.7
Pier Length (m)	539.0	12.5	296.1	452.1
Mangrove (Area, Km²)	787.3	625.3	689.8	866.2

Table 2: A selection of recovery indicator results from Ban Nam Khem, Thailand acquired using VHR satellite imagery two weeks, four months and four years after the 2004 Indian Ocean tsunami

In Ban Nam Khem, the 2004 Indian Ocean tsunami had a devastating effect on infrastructure and people's lives. Table 2 shows that over 40% of buildings were washed away and nearly 60% of roads were destroyed or made impassable. Figures 1–4 show how quickly recovery took place in Ban Nam Khem; just over one year after the disaster the road network had been reinstated and the school rebuilt. It took longer – three years – to move people from transitional shelters to permanent homes.

Natural resources were also affected by the tsunami, with severe damage to mangrove forest and urban green spaces. Livelihoods were disrupted by destruction of the fishing fleet, piers, ferries, shrimp hatcheries and shrimp ponds. All these activities were capable of being monitored with remote sensing. For example, imagery analysis showed an increase in the area of functioning shrimp ponds, but complete destruction of the shrimp hatcheries in the town. This was validated with ground surveys in February 2009 and confirmed by UNDP, World Bank and FAO reports (2005). Shrimp hatcheries were not reconstructed because of high investment costs, low shrimp prices and low levels of compensation (Arunmas, 2005).

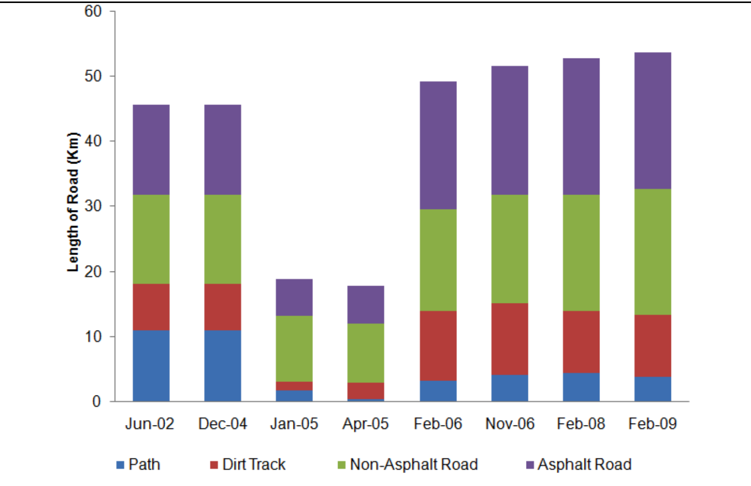

Figure 1: Total length of functioning road in Ban Nam Khem, by road type.

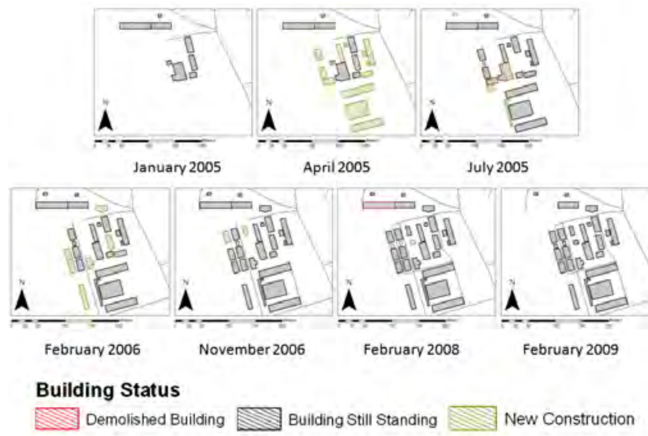

Figure 2: Ban Nam Khem School building construction and removal throughout the recovery process.

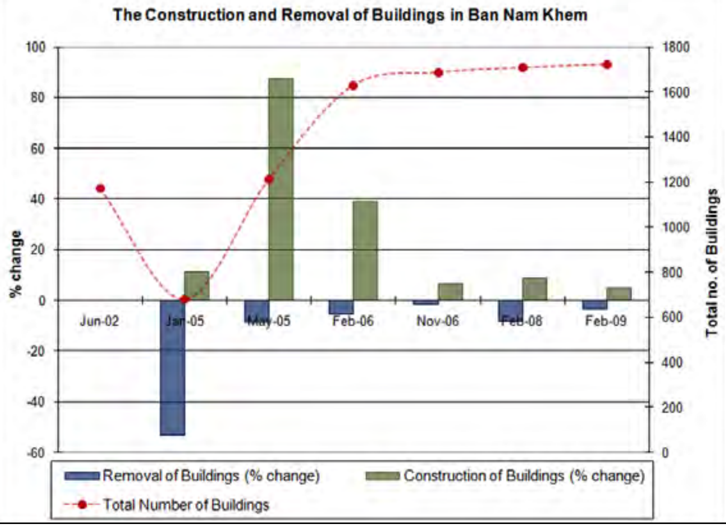

Figure 3: The construction and removal of buildings in Ban Nam Khem.

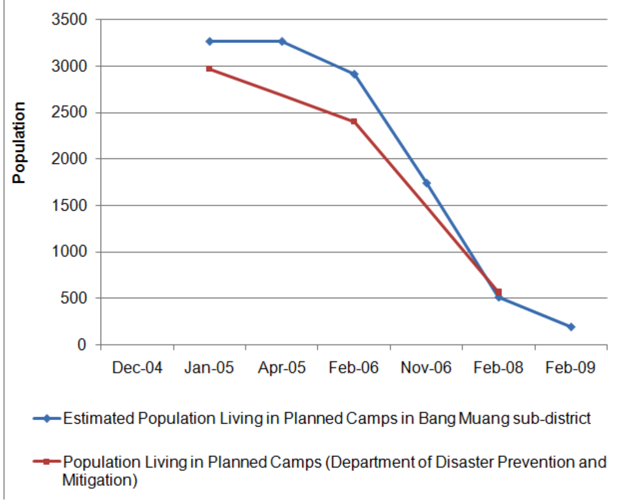

Figure 4: Estimated population living in transitional accomodation versus statistics supplied by the Thai Government.

5. Discussion

This paper presents a suite of remote sensing indicators that allow post-disaster recovery and reconstruction to be monitored and evaluated in a systematic and quantitative manner. The following section discusses how the methodology can be applied to other disasters and concludes by describing the transferability of the method across our two case study sites.

5.1. When to measure and how frequently

To avoid costly mistakes it is important for analysts to know when to monitor each indicator and how frequently to acquire satellite imagery. Evaluations must ultimately be conducted when impacts are likely to be visible and measurable. The frequency that images are acquired therefore depends on the progress of recovery, the evaluation questions that need to be answered and the indicators that will be used. It also depends on whether the data is intended to be used to monitor on-going recovery projects or to evaluate completed projects. To facilitate *detailed monitoring* of a project, data might need to be collected every few days or weeks throughout the response phase to keep track of the constantly changing situation, while imagery may only be required every 6-12 months in the long-term recovery phase to track construction and development projects. *Project evaluations* may be carried out using just two images: a pre-project image (baseline) and a post-project image to identify changes that have occurred as a result of the intervention.

Due to the dynamic nature of recovery, the timing and duration of events and processes on the ground is likely to vary after each disaster. There is also likely to be considerable spatial disparity in the speed of recovery activities after each single event due to various physical and social factors. This makes it difficult to know exactly when and where to collect data. Furthermore, the relevance and importance of different indicators is likely to vary throughout the recovery process. While some indicators are more emergency-based, such as the demolition of vulnerable buildings, others are not deemed so important in the immediate aftermath of a disaster, such as environmental rehabilitation. On-going monitoring therefore requires in-depth and up-to-date ground knowledge and understanding of when tasks are likely to happen and the amount of time they are expected to take.

Despite these caveats, certain assumptions can be made about the timing of events and processes. The different phases of recovery are often characterised by particular types of activity. Furthermore, the speed of recovery is often determined significantly by the funding strategies and timeframes of donors and affected governments. Activities funded by the World Bank's Emergency Recovery Loan (ERL) for example, are designed to meet urgent needs following a disaster and must be completed within 3 years (World Bank, 2008). A study by the Independent Evaluation Group (IEG) found that disaster-related projects, funded by the World Bank, varied significantly in their implementation time, from two to seven years, with an average implementation time of 6.6 years (IEG, 2006). ERL projects took on average 3.9 years. All of the crucial disaster response activities required more than three years, with infrastructure activities taking 6.5-7 years on average. Certain inter-dependencies exist between some processes that allow assumptions to be made about the progress of recovery. For example, debris clearance and building demolition are often necessary before intense periods of building construction may begin. In some cases, the overall progress of recovery may be inferred by monitoring proxy indicators, such as the number of permanent structures and the presence and absence of transitional shelters.

5.2. Spatial, spectral and temporal limitations of satellite imagery

The features and processes that can be monitored with remote sensing are ultimately limited by the spatial, spectral and temporal resolution of current satellite sensors. The most important issue in urban remote sensing is often thought to be spatial resolution (Welch, 1992). A Ground Sample Distance (GSD) of 0.5 – 1.0 m is required for the methods described in this paper so that major features may be delineated (Fraser et al. 2002). A resolution of 0.6 m was found to provide significantly more information than 1.0 m when conducting detailed building analysis and is recommended for these types of application. A resolution of 0.5 – 1.0 m is necessary to update a transport network and to identify major road types, while a resolution of at least 0.15 – 0.25 m is required to evaluate road conditions (Stoeckleler, 1979) and to view power lines and poles. This level of resolution is currently only available with aerial imagery though, which can be expensive and time-consuming to acquire. Geoeye-2, which is due to be launched in 2011, will have a 0.25 m resolution sensor, but US Government restrictions mean the data will only be publicly available at 0.5 m. Other optical satellites with a spatial resolution of at least 1.0 m, include Ikonos, Quickbird, Worldview-1, Worldview-2, and Geoeye-1.

The spectral resolution of satellite imagery is less important for manual delineation work, but better spectral resolution is likely to increase the accuracy of semi-automatic classification techniques. Building attributes may be manually extracted from black and white panchromatic imagery (0.5 – 0.7 μm) or colour imagery (0.4 – 0.7 μm), but the semi-automatic identification of vegetation – which is important for the analysis of green space and crops - requires the presence of a NIR band. Worldview-2, launched in 2009, has four new spectral bands in addition to the standard four bands (red, green, blue and near infrared) designed to assist the automatic extraction of urban and natural environments.

Satellite images may be acquired from archives held by satellite image providers, such as DigitalGlobe and Geoeye. If an image is required at a known time, to coincide with a particular event, such as ground survey work, the images may be *tasked*. The reliability of tasking depends on the atmospheric conditions, current demands on the satellite and the satellite's re-visit time. The re-visit time is used to describe how often a satellite can acquire imagery of a single location of earth. The revisit time is dependent upon the latitude of the target and the off-nadir look angle at the time of the acquisition. A greater off-nadir look angle will lead to a decrease in the average revisit time, but at the expense of spatial resolution. The satellite sensors listed above all have average revisit times under 3 days. For example, Worldview 1 and 2 have a revisit time of 1.7 and 1.1 days respectively at 1.0m GSD.

5.3. Transferability

The approach described in this report has been designed to be replicable and to be non-country or hazard specific. To test the transferability of the indicators they were applied to two case studies: Ban Nam Khem and Muzaffarabad. The case study sites differed dramatically in terms of their dominant cultures and economies, the type of hazard they were affected by and the recovery frameworks and approaches that were adopted afterwards. Recovery curves were constructed for the two case study sites by normalising the number of buildings present, using the pre-disaster building number at each site as the denominator. Figure 5 shows the difference in the speed of construction at both sites. The proportion of buildings relative to the pre-disaster state may also be identified: scores below 1.0 represent a decrease in building numbers and scores above 1.0 represent an increase.

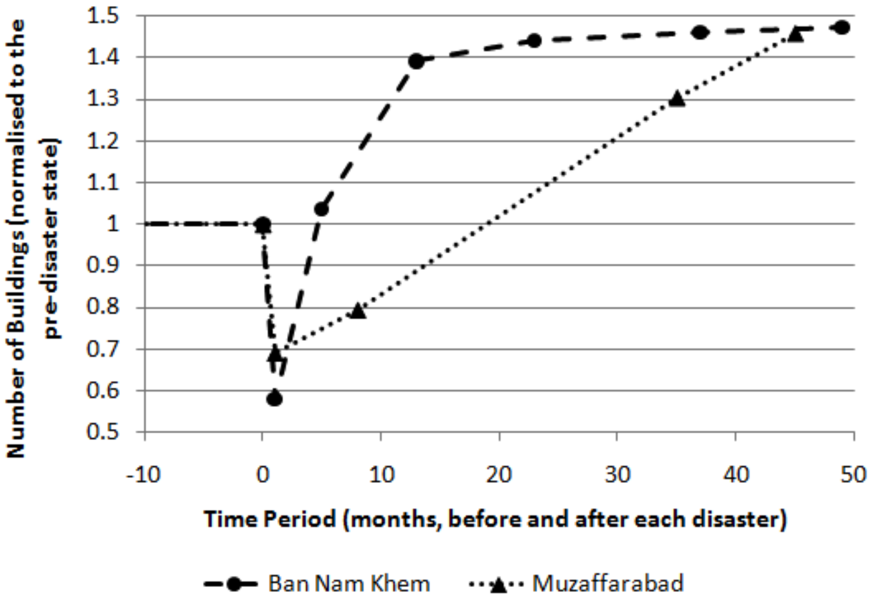

Figure 5: Comparison of building trends in Ban Nam Khem and Muzaffarabad

The results show a significant difference in the timing and duration of construction at the two sites. Ban Nam Khem saw an intense period of construction in the first year that began within several months of the event (as described in section 4.2), while Muzaffarabad saw lower rates of construction over a prolonged period of time. Muzaffarabad's recovery curve still appears to be increasing 3.5 years after the earthquake. Both sites have seen an increase in building numbers of over 40% within 4 years. In Muzaffarabad this is partly to do with the expansion of army barracks, while in Ban Nam Khem this was partly due to the construction of new housing developments outside of the village.

The nature of the hazards meant they had very difficult impacts on the case study sites. In Ban Nam Khem, the tsunami removed most of the coastal building stock, transport network and natural environment within a kilometre of the shoreline. The impact of the tsunami was enormous but it remained relatively localised. In contrast, Pakistan experienced widespread damage and changes across the country, which affected the government and its ability to respond.

The localised nature of the tsunami is therefore likely to have contributed to the faster recovery in Thailand than in Pakistan. The Thai Government's relative wealth and its approach to recovery also affected the pattern of recovery and how it may be monitored. For example, in Ban Nam Khem, planned camps were used to host displaced persons. They were removed and people re-housed within three years of the tsunami – a relatively short amount of time. In contrast, Muzaffarabad witnessed a rise in the total numbers of temporary structures, such as tents and pre-fabricated structures, scattered across the affected region. This is partly because residents in some urban parts of Pakistan were prohibited from starting their own construction until master-plans for the cities had been finalised.

When conducting cross-disaster comparisons there are often many cultural and economic differences to be aware of. For example, much of the economy in Ban Nam Khem is based on the fishing industry, while households in Muzaffarabad are more reliant upon farming and the public sector. The main religious structures in each country also differed, with Thai communities based around the Temple and Pakistani communities around the local mosque. It is imperative that image analysts are aware of such cultural matters before embarking on image analysis.

5.4. Comparison of Tools

A number of tools are already used by agencies to collect monitoring data. The tools may be divided into two broad categories: 1) direct observation / non-participatory methods (e.g. remote sensing and ground survey) and 2) social-audit techniques / participatory methods (e.g. focus group meetings, household surveys and key informant interviews). The tools each have their own strengths and weaknesses and can be used to collect very different forms of data (subjective/objective, quantitative/qualitative, cross-sectional/longitudinal, primary/secondary etc.). The methods are therefore likely to be more appropriate at different phases in the recovery process. To better understand the quality's of each method a cost-effectiveness analysis was conducted based on 5 criteria: a) Expense b) Time c) Technical Requirement d) Detail obtainable and e) Accuracy. The strengths and weaknesses of each tool were then examined and the results used to make recommendations on when each tool may be most appropriately applied. Guidance is also provided on how and when the methods may be integrated. All of the tools may be used independently of each other, but are usually more effective when used in a complementary manner.

5.4.1. Direct Observations

Direct observations of a project site can provide a rich, first-hand understanding of the subject (USAID, 1996b). The technique has traditionally been conducted on foot, often with the use of a structured form or survey to complete. For example, the ATC-21 survey developed by the Applied Technology Council of California (ATC, 2004) is used to identify seismic hazards and to ensure suitable mitigation measures have been adopted. The arrival of VHR satellite imagery now allows some forms of direct observation to be completed remotely. For example, remote sensing can be used to monitor changes to the size, shape, arrangement, location and context of buildings and other large features. Due to the limited spatial resolution of satellite imagery though and the non-oblique look angle of most satellite sensors, ground surveys will always be required to derive detailed observations throughout the recovery process. The recent integration of GPS into many systems now means ground survey analysts can collect detailed, geocoded street view data. There are two sources of data collection currently available that vary according to the amount of detail they can obtain: 1. Per-building analysis (best conducted using a GPS camera) and 2. Holistic overview (best conducted with geocoded video footage deployed in a vehicle). The availability of handheld GPS devices now means data may be input directly into a GIS system whilst in the field. The data acquired with these methods has the ability to be quantitative and objective and may be used to verify remote sensing attributes, such as building occupancy, use and the number of storeys. Detailed observations of the building facade and the area surrounding the building may also be used to identify signs of repair and signs of general prosperity and degeneration. Visible signs of deterioration might include broken windows, vacant buildings and overgrown vegetation. These techniques can be applied across the whole affected area and to places of social capital, such as shops, hospitals and churches. USAID (1996b) suggest that direct observations may be useful when performance monitoring data indicates results are not being accomplished, when an activity's process needs to be assessed and to obtain an inventory of physical facilities. The data from ground surveys is often more detailed and accurate than remote sensing, but can be very time-consuming and expensive to conduct – especially across large, often insecure geographic regions.

5.4.2. Social-Audit Techniques

There are various social-audit techniques available to the analyst, including semi-structured interviews, surveys and focus groups. The methods can be used to collect information about many aspects of recovery. For example, they may be used to assess the impact of a program on individuals, households and institutions. They can also be used to collect perceptions of recovery, to assess levels of satisfaction and to explore causes. Local and national actors are often crucial to assessing impact, as they are best placed to assess how lives have changed as a result of aid. A significant amount of time and skill is required to design semi-structured interviews and to translate, code and analyse the results. The Recovery Project's household survey for example, acquired detailed information about the socio-economic and demographic make-up of the households. It was also used to produce a recovery narrative describing when key events happened and to infer perceptions of recovery. Similarly, focus group meetings were used to measure perceptions, levels of satisfaction and to identify when and where key events occurred. Satellite maps were used during the meetings and surveys as memory prompts. Attendees were asked to identify features on the maps and to estimate when key events occurred. Focus groups are very prone to bias though, so it is important that they are carefully planned and moderated to ensure a balanced and non-threatening environment is created. Finally, key informant interviews were used to gain a holistic view of recovery. A sample of strategically-selected individuals, representing all sectors of recovery, was asked questions about the progress of recovery. The technique was found to be quick, efficient and capable of obtaining a brief but synoptic review of recovery. The results of which can be used to determine where and when imagery and other detailed survey data might be required. Participatory methods are increasingly being used to encourage the involvement of beneficiaries in the monitoring process and as a form of empowerment. Government Ministries commonly conduct household surveys, but the data is difficult to acquire by NGOs and academics and is often aggregated. There are also problems with inconsistency in data collection methods across the team. Censuses are infrequent and rarely contain recovery-related questions, but are commonly the only source of data. Better mechanisms are necessary to standardise the data acquired with these methods in a post-disaster context and to ensure data is shared between stakeholders. Households in Ban Nam Khem had been interviewed up to 30 times by academics, NGOs and Government Officials, leading to survey fatigue amongst respondents.

5.4.3. Mixed Methods

Mixed-method approaches to monitoring and evaluation are increasingly used, encompassing both participatory and non-participatory methods; for example, 90% of respondents to a recent ALNAP survey used a mixed-method approach. The most common reason for utilising mixed-methods was to allow results to be verified and cross-checked (Proudlock et al. 2009). Each data collection tool has its own strengths and weaknesses - often revolving around issues of cost, accuracy and technical requirement - which determine when and how frequently it may be deployed. The classic trade-off between time/cost requirements and the amount of detail/accuracy achievable often applies. The nature of the data produced by each method also determines when each tool may be most appropriately used. In general, quantitative approaches permit the estimation of magnitude and distribution by establishing 'what' and 'where' things happened, while qualitative approaches permit in-depth analysis and description of patterns (Prowse, 2007; Bamberger et al. 2009). When deployed in an effective work-flow, the tools can supplement each other to provide richer detail and a more in-depth understanding of the issues from numerous perspectives. To create such a work-flow, the tools must be deployed at the right time and in an appropriate order. For example, direct observations might initially be deployed to determine individual, household or community welfare, which can later be verified and explored in more detail using focus group meetings. Similarly, direct observations may identify unexplainable patterns that can be explored in more detail later during interviews and/or meetings. When time is limited, well-designed key informant interviews may acquire data that will allow a team to become acquainted with the status of an area relatively quickly and efficiently. Due to the large time and skill requirements for most participatory methods though these are likely to be deployed less frequently than other techniques. Figure 6 illustrates how the various forms of data may be integrated and used in a manner that is complementary. In summary, maps and images from satellite image analysis may be used to invoke discussion, inform survey design and to direct teams to appropriate study sites. Similarly, observations made using ground surveys and participatory methods may be geo-coded, integrated into a geodatabase and used to verify remote sensing and to identify gaps in the analysis. Mixed methods are particularly valuable as they allow different sources of information to be cross-checked or 'triangulated'. Triangulation is the process of using two or more methods of data collection or sources of data in order to check on the validity of the data that is being gathered.

6. Conclusion

This paper introduces a list of remote sensing indicators, encompassing different sectors and areas of activity that can be used to monitor and evaluate the process of recovery. The results suggest remote sensing is particularly well-suited to assist the analysis of

Accessibility, Buildings, Internally Displaced Persons and the Natural Environment. It can also be used to assist other important sectors including Livelihoods and Services. The data requires VHR satellite imagery with a minimum resolution of 1.0 m. It may be used to provide a holistic or selective view of recovery according to the needs and interest of the user. The data is rapid, independent and reliable; attributes which are particularly valuable in a dynamic post-disaster situation, where security is often an issue and data is hard to obtain. Satellite imagery is available to all and has been shown to be cost-effective. The time and budget requirements for the analysis are also well-known and can be provided at the outset of a project. In particular, once the initial mapping has been finalised and the database constructed, the time and resources necessary to update and query the data are significantly reduced. This work therefore highlights the importance of maintaining a pre-disaster database that is ideally updated every 1-5 years. Maps produced for damage assessment work may also be stored and used during recovery monitoring. In contrast, passive systems have been shown to be unreliable and field work is relatively expensive and time-consuming (Amin and Goldstein, 2008). This is not to say remote sensing can replace these existing tools, but should be considered as a complementary method capable of acquiring detailed data throughout a project's duration.

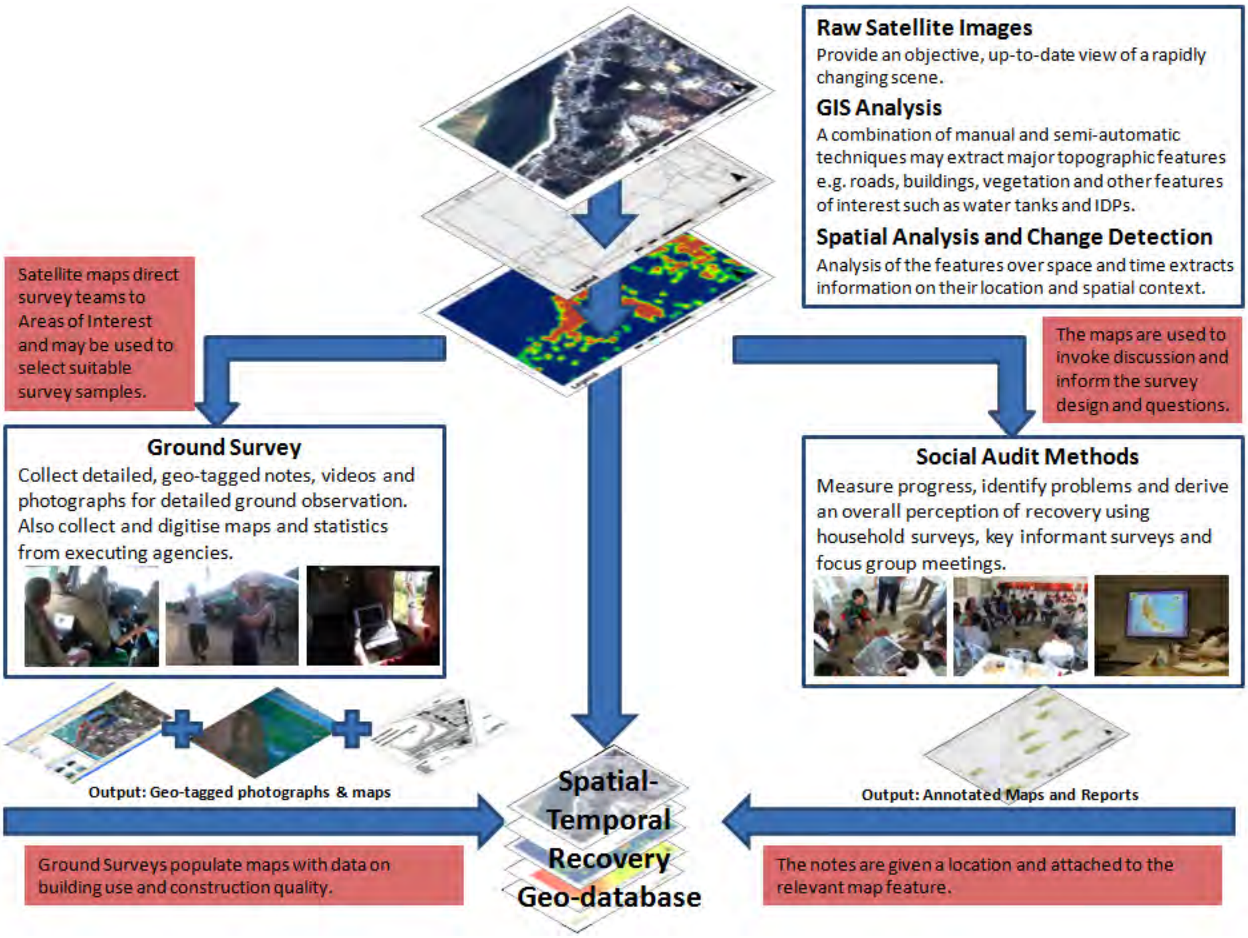

Figure 6: Participatory and non-participatory datasets may be integrated and used to supplement each other throughout the recovery process

In summary, remote sensing and GIS analysis can be used to help plan, coordinate and monitor recovery. It can visualise spatial disparity thus providing accountability to stakeholders and providing situational understanding to those on the ground, ultimately helping decision-making, preventing waste and identifying examples of good and bad practice. It can be used to supplement other tools by highlighting areas that need further investigation and by providing suitable samples and data to ground workers, preferably on handheld devices. It may also be used to cross-check other data sources and to identify data gaps as part of a process of triangulation. The data may form the basis of a geospatial database capable of storing datasets collected using both participatory and non-participatory methods. It therefore has the potential to provide a useful spatial framework for tracking and analysing post-disaster recovery data, which can ultimately be used to assist data management and analysis of a complex, dynamic process. It may also be used as a platform on which data may be shared between stakeholders working in numerous sectors and geographic locations.

Future work will continue to explore how these techniques may be applied across larger geographic areas through the use of more advanced automated systems and random sampling techniques. We will also explore the use of medium resolution satellite data and landscape metrics to extrapolate the results from VHR imagery across larger regions.

7. References

Alesch, D.J. (2004). *Complex Urban Systems and Extreme Events: towards a theory of disaster recovery*. 1st International Conference of Urban Disaster Reduction. Kobe, Japan. 19 January 2004.

ALNAP (2005). *Assessing the Quality of Humaniatarian Evaluations. The ALNAP Quality Proforma 2005* (v. 02/03/05).

http://www.alnap.org/pool/files/QualityProforma05.pdf

Amin, S. And Goldstein, M. (eds.) (2008). Data against natural disasters. Establishing effective systems for relief, recovery and reconstruction. The World Bank, Washington, DC.

Arunmas, P. (2005). No Relief in Sight. Bangkok Post. 03 July 2005.

ATC (2004). Rapid visual screening of buildings for potential seismic hazards training manual. 2nd edition. Applied Technology Council. California, USA.

Agustina, C.D. (2008). *Tracking the money: international experience with financial systems and databases for reconstruction*. DRR10607. Global Facility for Disaster Reduction and Recovery (GFDRR). The World Bank.

Bamberger, M., Rao, V. and Woolcock, M. (2009). *Using Mixed Methods in Monitoring and Evaluation: Experiences from International Development.* BWPI Working Paper 107. Brooks World Poverty Institute.

Barnett, M. (2005). *Humanitarism Transformed.* University of Minnesota.

Boag, F. (2010). *In Post-Katrina New Orleans. Assessment of Historic Sites.* Geoinformatics. Magazine for Surveying, Mapping and GIS Professionals. July/Aug 2010, Volume 3.

Brown, D., Saito, K., Spence, R., Chenvidyakarn, T., Adams, B., Mcmillan, A. and Platt, S. (2008). *Indicators for Measuring, Monitoring and Evaluating Post-Disaster Recovery.* 6th International Workshop on Remote Sensing for Disaster Application. Pavia, Italy. 11-12 September 2008. http://tlc.unipv.it/6_RSDMA/Finals/4.3%20-%20Brown.pdf

Brown, D. (2009). *PhD First Year Report*, submitted to the Department of Architecture, University of Cambridge, UK.

Comerio, M.C. (1998). *Disaster hits home: new policy for urban housing recovery.* Berkeley: University of California Press. 1998.

CURBE (2010). Disaster recovery monitoring and evaluation. CURBE, Centre for Risk in the Built Environment. Cambridge University.

Dabelstein, N. (2006). *Evaluating humanitarian action using the OECD-DAC criteria. An ALNAP guide for humanitarian agencies*. ALNAP.

DAC (2010). *Quality Standards for Development Evaluation.* DAC Guidelines and Reference Series. DAC Evaluation Network. Organisation for Economic Co-operation and Development (OECD).

Daniba (2006). *Evaluation Policy.* Danish International Development Agency. Evaluation Department Report.

ECLAC (2003). *Handbook for estimating the socio-economic and Environmental.* Effects of Disasters. Economic Commission for Latin America and the Caribbean (ECLAC).

Fraser, C.S., Baltsavias, E. and Gruen, A. (2002). *Processing of IKONOS Imagery for Submeter 3D Positioning and Building Extraction.* Remote Sensing of the Environment: 56. 177-194.

Government of the Republic of Haiti (2010). *Action Plan for National Recovery and Development of Haiti.* Immediate Key Initiatives for the Future. March 2010.

Haas, J.E., Kates, R.W. and Bowden, M.J. (1977). *Reconstruction following disaster*. Cambridge: MIT Press. 1977.

IEG (2006). *Hazards of Nature, Risks to Development. An IEG Evaluation of World Bank Assistance for Natural Disasters*. World Bank Independent Evaluation Group. Washington, D.C.

Imagecat, (2010). VIEWS™. http://www.imagecatinc.com/services/proprietary-solutions/views/

Kidd, R.A., McCallum, I., Ishadamy, M.Y. (2010). *The benefit of high resolution aerial imagery for topographic mapping and disaster recovery: lessons learnt from the 2004 Indonesian Tsunami*. In: *Geoinformation for Disaster and Risk Management. Examples and Best Practice* (Eds. Altan, O., Backhaus, R., Boccardo, P. and Zlatanova, S.) (2010). Joint Board of Geospatial Information Societies. United Nations Office for Outer Space Affairs.

Linnerooth-Bayer, Joanne, and A. Amendola (2000). *Global Change, Natural Disasters and Loss-Sharing: Issues of Efficiency and Equity.*" The Geneva Papers on Risk and Insurance— Issues and Practice, 25(2).

MDG (2008). *The Millennium Development Goals Report 2008*. United Nations. New York.

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

Mosse, R. and Sontheimer, L.E. (1996). *Performance Monitoring Indicators Handbook.* World Bank Technical Paper No. 334.

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

OECD-DAC (1999). *Guidance for Evaluating Humanitarian Assistance in Complex Emergencies*. Paris: OECD.

OECD (2010). *Development Evaluation Resources and Systems – A Study of Network Members*. Development Co-operation Directorate. Development Assistance Committee. The DAC Network on Development Evaluation.

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

Oxfam (****). *Oxfam GB Programme Monitoring Reviews*. Mandatory Requirements and Support Materials.

PDNA (2008a). Post *Disaster Needs Assessment (PDNA)*, phase II. Practical Guide to a Recovery Results Framework. Draft Concept Note.

Proudlock, K., Ramalingam, B. and Sandison, P. (2009). *Improving humanitarian impact assessment: bridging theory and practice*. In: ALNAP's 8th Review of Humanitarian Action. July 2009.

Prowse, M. (2007). *Aid Effectiveness: The role of qualitative research in Impact Evaluation.* ODI Background Note, London: ODI.

Quarantelli, E.L. (1999). *The disaster recovery process: what we know and do not know from research*. Preliminary Paper #286. University of Delaware. Disaster Research Center. 1999.

Shelter (2006). *Shelter Training Workshop. Co-hosted by UN-Habitat and CARE International.* 15-17 November 2006, Geneva.

Sphere Project (2004). *Humanitarian Charter and Minimum Standards in Disaster Response.* The Sphere Project. Oxford, OXFAM Publishing.

Stoeckleler, E.G. (1979). Use of aerial color photography for pavement evaluation studies. Highway research Record, 319:40-57.

TRIAMS (2007). *Tsunami Recovery Impact Assessment and Monitoring System (TRIAMS).* Second regional TRIAMS workshop. Bangkok, 21-23 March 2007.

UNDP (2009). *Handbook on Planning, Monitoring and Evaluating for Development Results*. United Nations Development Programme.

UNDP, World Bank and FAO (2005). 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

UNFPA (2010). *Guidelines on Data Issues in Humanitarian Situations. Guidelines for UNFPA Field Operations*. UNFPA.

USAID (1996a). *Performance Monitoring and Evaluation Tips. Conducting a Participatory Evaluation.* USAID Centre for Development Information and Evaluation. 1996, Number 1.

USAID (1996b). *Performance Monitoring and Evaluation Tips. Using Direct Observation Techniques*. USAID Centre for Development Information and Evaluation. 1996, Number 4.

Welch, R. (1982). *Spatial resolution requirements for urban studies*. Int. J. of Remote Sensing. 3. 139-146.

WDI (2008). The World Bank. Washington, *World Development Indicators 2008.* D.C.

Wiles, P. (2005). *Meta-Evaluation.* http://www.alnap.org/pool/files/rha04-c4meta.pdf

World Bank (2002). *Monitoring and Evaluation: Some tools, methods and approaches*. The World Bank. Washington D.C.

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.

World Bank (2010a). *Mobilizing Post-Disaster Help.* In: Haiti, Bank Team Prepares for Damage Assessment, Recovery Plan. Washington DC, January 15, 2010.

World Bank (2010b). *Safer Homes, Stronger Communities, Resources for Reconstructing Housing and Communities after Natural Disasters.* Global Facility for Disaster Risk Reduction (GFDRR).