Disaster Recovery Indicators
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CURBE was established in 1997 to create a structure for interdisciplinary collaboration for disaster and risk research and application. Projects link the skills and expertise from distinct disciplines to understand and resolve disaster and risk issues, particularly related to reducing detrimental impacts of disasters. CURBE is based at the Martin Centre within the Department of Architecture at the University of Cambridge.

About the research
These guidelines are the output from a research project funded by the UK Engineering and Physical Sciences Research Council (EPSRC), entitled Indicators for Measuring, Monitoring and Evaluating Post-Disaster Recovery.

The aim of the Recovery Project is to develop indicators of recovery by exploiting the wealth of data now available, including that from satellite imagery, internet-based statistics and advanced field survey techniques. The work was carried out with a view to developing a standardised, independent and replicable approach to measure, monitor and evaluate the relief and recovery processes. Investigative case studies were carried out between March 2008 and March 2010 in areas affected by the 2004 Indian Ocean Tsunami and the 2005 Pakistan Earthquake, covering a diverse range of recovery characteristics.

Project team
The project team included Dr Torwong Chenvidyakarn, Dr Keiko Saito, Dr Emily So and Daniel Brown, CURBE, University of Cambridge Ltd; Professor Robin Spence and Dr Stephen Platt, Cambridge Architectural Research; Dr Beverley Adams and Dr John Bevington, ImageCat. Inc; Dr Ratana Chuenpagdee, University of Newfoundland who led the fieldwork team in Thailand; and Professor Amir Khan, University of Peshawar who led the fieldwork team in Pakistan.

The Steering Committee included Professor Arleen Hill, Department of Earth Sciences, University of Memphis, USA; Professor Peter Atkinson, School of Geography, University of Southampton, UK; Professor Ian Davis, Cranfield University, UK; Mr. Doekle Wielinga, World Bank.
Disaster Recovery Indicators:
guidelines for monitoring and evaluation

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1 Executive summary

Monitoring and evaluation of recovery and reconstruction after natural disasters can assist on-going aid effort, provide accountability and guide aid policy. These guidelines provide a systematic, independent and replicable approach to monitoring and evaluating the recovery process. The indicators proposed in the guidelines were tested in case study research of Ban Nam Khem, Thailand that was hit by the 2004 Indian Ocean tsunami, and Chella Bandi, Muzaffarabad, AJK Pakistan, that was struck by the 2005 Kashmir earthquake.

The research was conducted by a team from the University of Cambridge, Cambridge Architectural Research Ltd and ImageCAT Inc and was funded by the Engineering and Physical Sciences Research Council (EPSRC). The World Bank have helped steer this work through their role on the Project Steering Committee. Our tools and methods complement the advice and approaches covered by the World Bank's Handbook on Reconstruction.

The report is aimed at senior policy makers in NGOs and governmental relief agencies as well as people charged with monitoring recovery. It is intended to give the reader information about how the proposed indicator set was derived, detailed feedback on the application of these indicators in the two case studies and finally an assessment of how useful we found remote imagery to be in monitoring recovery.

The need

There is a pressing need for a systematic approach to monitoring and evaluating recovery and reconstruction following a disaster and a need for a framework that promotes transparency and warns if the reconstruction is not going to plan. Operationally, effective monitoring and evaluation is necessary to improve coordination, situational understanding and decision-making. It may also lead to a better understanding of both good and bad practice, so lessons can be learned. Strategically, it would provide accountability to ministers, boards of directors, and the public. A system is called for that, according to the World Bank, “allows all parties to track the progress of reconstruction – who is doing what and where - is essential to coordinating an effective response, and good for public morale”.

Indicators

The indicators adopted by the Recovery Project encompass a range of physical, environmental, social and economic factors that combine to give an accurate picture of the reconstruction process at specific intervals. Both the speed and quality of recovery can be monitored and evaluated by comparing key indicators to base-line statistics also acquired with satellite imagery.

Remote sensing-based performance indicators offer national governments and donor agencies a systematic and independent framework for accurately and comprehensively monitoring and evaluating recovery and reconstruction. From a time-series of satellite images a comprehensive set of indicators bring together pieces of the recovery jigsaw that would otherwise take considerable time and resources to assemble.
Figure 1.1 Monitoring and evaluation methodology

Figure 1.2 Typical output from monitoring using satellite imagery
Recommendations

Our recommendations on how remote sensing can be used to monitor post-disaster recovery are based on the experience of the project team and feedback from users and stakeholders. They revolve around five key questions.

What to measure?

Knowing which indicators to measure and when to acquire satellite imagery is dependent on the nature of the disaster, the needs of the users and the limitations of the satellite imagery available. The Recovery Project created a list of indicators after consulting with users via a user-needs survey. The results of this survey suggest there is a strong preference for a comprehensive approach to monitoring recovery encompassing multiple sectors. This is the approach we took. The proposed M&E methodology therefore covers a manageable number of indicators that encompass all sectors of recovery. Users can choose which indicators to monitor according to their own needs and resources.

When to measure?

Because of the dynamic nature of recovery, the timing and duration of different recovery processes is likely to differ and the importance of different indicators is likely to vary. The frequency that images are acquired also depends on whether the evaluation is ongoing or of completed projects. To monitor the on-going progress of recovery, data should ideally be acquired a few weeks after a disaster and every 6-12 months thereafter, while completed project evaluations can be carried out using just two images: a pre-project image (baseline) and a post-project image. Figure 1.3 shows some of the key processes and events visible in satellite imagery with estimations of when they are likely to appear, relative to each other. In some cases, the overall progress of recovery may be inferred by monitoring proxy indicators, such as the presence or absence of transitional shelters.

![Figure 1.3 Timing and duration of key recovery processes](image-url)
How to measure?

Measurement tools may be divided into two broad categories: Direct Observation (e.g. remote sensing and ground survey) and Social-Audit (e.g. focus group meetings, household surveys and key informant interviews). The tools may be used independently of each other, but are usually more effective if used in a complementary way.

Direct Observation: Satellite imagery now allows direct observation to be completed remotely. However, it needs to be supplemented by other data. 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.

Social-Audit: Various social-audit techniques are used, including semi-structured interviews, surveys and focus groups. They are used to collect data about many aspects of recovery, including people’s perceptions, satisfaction and to explore why things happened the way they did.

Mixed Methods: The tools can supplement each other. To create an efficient workflow the tools must be deployed at the right time and in an appropriate order. Although this will vary, a typical workflow is described below:

Pre field deployment

1. **Key informant interviews** allow a team to become acquainted with the status of the area and provide an overview of the timing of different aspects of recovery. These might be conducted remotely over the telephone.

2. **Initial imagery analysis** and mapping of key indicators, for example accessibility and temporary camps, can be conducted before a field deployment.

3. **Published information** including official statistics may be obtained from the Internet, recovery agencies and national and local government offices.

Field work

4. Once in the field, **focus group meetings** and further key informant interviews can explore and verify these initial results.

5. **Ground survey**, using GPS cameras, is used to survey buildings, probably choosing a random sample of building points. This data can be incorporated into the geodatabase (GIS) and used to inform subsequent imagery analysis.

6. **Household surveys** can also be conducted, perhaps in parallel to the ground survey by a different team. Information from talking to affected families then allows the analysts to infer what the mapping means in terms of people’s lives and their experience of recovery.

Detailed imagery analysis

7. **Detailed imagery analysis** is conducted back at base using insight and information from the information sources above. This is repeated at suitable intervals, perhaps every six months, during the period of recovery that may take as long as five years.

Is the method transferable?

This approach to monitoring and evaluation using satellite imagery was designed to be non-country or hazard specific. To test the transferability of the Indicators similar techniques were applied to two case studies: Ban Nam Khem in Thailand and Muzaffarabad in Pakistan. The case study sites differed markedly. Nevertheless, the case studies demonstrated that the same indicators and similar approach could be applied in widely differing situations. The replicable, quantitative nature of the results also allows recovery in different sites to be compared.
**How much will it cost?**

The cost of satellite images can be significant but can be used for multiple indicators. The average cost of imagery in 2009 was $20 per km². Typically imagery will be needed for before the disaster, immediately after and for each subsequent six months or yearly interval. So the cost of the imagery will vary in direct relation to the size of the area and the period of recovery to be monitored. If the area is very large, a sampling and/or case study strategy needs to be adopted. It is important to note that the technology is constantly changing. Since we did this case study Worldview-1, Worldview-2 and Geoeye-1 have been launched making it easier to acquire the necessary images. These new satellites have a higher resolution that will make interpretation significantly easier and more accurate and will create opportunities for automatic pattern recognition.

**Conclusion**

In summary, remote sensing and GIS analysis can be used to help plan, coordinate and monitor recovery. Its main strengths include its ability to monitor large areas, its non-intrusiveness and the fact that it minimises the need for access to the study site by the survey teams. Our main conclusion, therefore, is that remote sensing, when judiciously combined with fieldwork, provides an unparalleled degree of useful information. Different agencies have different information needs and might consider doing their own remote sensing. However, it might make sense for a single agency to take overall responsibility for monitoring recovery in a comprehensive way.
2 Introduction

Monitoring and evaluation of recovery and reconstruction after natural disasters can assist on-going aid effort, provide accountability and guide aid policy. These guidelines provide a systematic, independent and replicable approach to monitoring and evaluating the recovery process. The indicators proposed in the guidelines were tested in case study research of Ban Nam Khem, Thailand, that was hit by the 2004 Indian Ocean tsunami, and Chella Bandi, Muzaffarabad, AJK Pakistan, that was struck by the 2005 Kashmir earthquake.

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The need

Major natural disasters pose immense problems for the people, societies and economies affected and for agencies and national governments attempting to rectify the damage, disruption and injury. How long a society takes to recover depends on a complex interplay of factors including preparedness and economic wealth. Many experts distinguish immediate emergency relief from the longer-term process of recovery. Certainly people with different skills are involved in the two.

Between 1975 and 2008 the number of people affected by natural disasters quadrupled. In part this increase is due to better reporting. The number of reported disasters also quadrupled. But the increase is also due to increasing urbanisation and the vulnerability of urban areas to risk. 14 of the world’s 19 megacities are in coastal zones and over 70 of the 100 largest cities can expect a strong earthquake at least once every 50 years. In the same period the average estimated annual damage to property and economic activity caused by natural disasters increased tenfold from about US$8 to US$80bn whilst the number of people killed has more than halved. Both these trends are related to parts of the world getting richer. The richer the society, the greater the financial loss but the better the buildings are able to withstand disasters without killing people. The total amount of international aid for natural disasters from 2000 to 2009 was US$37bn. Part of this went in immediate relief and part in recovery, reconstruction and development.

Current monitoring and evaluating

Currently there is no agreed standard approach to evaluating the effectiveness of recovery aid, although international frameworks such as PDNA (Post-Disaster Needs Assessment, by United Nations Development Program, European Commission and World Bank) are currently being developed, and TRIAMS (Tsunami Recovery and Impact Assessment and Monitoring System) is being implemented to monitor recovery from the Indian Ocean Tsunami.

There have been various attempts to devise ways of analysing recovery. After the Kobe earthquake in 1995, Japanese researchers used published local government data covering many aspects of socioeconomic activity to compare trends before and after the event. The problem with applying this approach to other places is that it requires large amounts of pre-disaster data. After the Chi-Chi earthquake in Taiwan in 1999, researchers proposed a method of measuring physical recovery using a spatial reconstruction model based on the physical reconstruction of public buildings.
A number of frameworks for post-disaster monitoring and evaluation have also been developed. The Economic Commission for Latin America and the Caribbean (ECLAC) provides a comprehensive loss assessment toolkit that measures the impact a disaster can have on a community. Development indicators are also referred to in the United Nation’s Millennium Development Goals and the World Development Indicators. The Sphere Project contains guidelines and minimum standards on various aspects of the humanitarian response to a disaster although its focus is on emergency relief rather than long-term recovery.

Another approach to monitoring recovery has been to develop information management systems. The simplest system is known as a Logistics Support System (LSS) and was used in Guatemala after Hurricane Stan in 2005 to monitor the distribution of supplies and donations. The Development Assistance Database (DAD), a web-based aid management system, has been used to track the provision of aid and the progress of reconstruction projects in over 30 countries. The Disaster Recovery and Mitigation Information System (DREAMIS) launched in March 2009 by the World Bank is an online database that provides financial statistics to support reconstruction.

Whilst DAD and DREAMIS are designed to track financial data, the Relief and Information Systems for Earthquake Pakistan (RISEPAK) developed after the 2005 Pakistan Earthquake, and Aceh Info 2.0, devised after the Indian Ocean Tsunami, provide information on needs and response.

This review highlights the lack of a systematic method of monitoring recovery, a concern that was signalled by the Tsunami Recovery Impact Assessment and Monitoring System (TRIAMS).

**Aims and objectives**

Collecting information quickly and systematically can be particularly difficult in a post-disaster situation where there are no accurate maps or shared language, and where there are a large number of agencies working independently of each other in different sectors of recovery. The objective of these guidelines is to provide a set of indicators that can be measured systematically across a large geographical area using high-resolution satellite imagery.

The objective was, first, to develop a set of indicators to systematically and comprehensively monitor and evaluate recovery and, second, to examine the role of remote sensing imagery in measuring change in these indicators.

The guidelines aim at helping answer the kinds of questions that people involved in post-disaster recovery are likely to ask, for example:

1. How much recovery has been achieved?
2. Where do we need to focus new interventions to encourage recovery and development?
3. Have our efforts been worthwhile and what can we learn from recovery in this situation that can be applied in responding to future disasters?

**Case studies**

The 2004 Indian Ocean tsunami and 2005 Pakistan earthquake were chosen for study because they were particularly large recent events that resulted in huge loss of life and damage to property. The 2004 tsunami has been described as one of the worst disasters in recent history. Pakistan and Thailand had also been the subjects of recent field trips by members of the research team and so we had local academic contacts in both places.
Case Study 1: Ban Nam Khem, Thailand

On the morning of 26 December 2004 an undersea earthquake of magnitude 9.0 on the Richter scale triggered devastating waves that hit many countries bordering the Indian Ocean. This was one of the biggest undersea disturbances ever recorded with an epicentre just off the coast of Sumatra, Indonesia. Many countries were affected by the waves but the hardest hit were Indonesia, Sri Lanka, India and Thailand. The earthquake occurred at 7:58am on Boxing Day, which is a national holiday for many countries and meant that there were large numbers of tourists in the area. The total number of fatalities is reported to be over 225,000 with an estimated 1.2 million having been displaced.16

Damage assessment by the Pacific Disaster Centre after the 2004 Asian tsunami highlighted four potential case study sites: 1. Ban Nam Khem, 2. Khao Lak, 3. Phuket Island and 4. Phi Phi Island. Phi Phi Island was excluded because of problems of accessibility and lack of ground data. Phuket was excluded because its dependence on tourism may have affected the recovery process and because most buildings were reinforced concrete frames and only ground floors were damaged.17 In contrast the whole village of Ban Nam Khem was badly damaged with only a few buildings left standing.18 Consequently Ban Nam Khem was chosen. Recovery was monitored 3-4 years after the disaster.

Case Study 2: Chella Bandi, Muzaffarabad, AJK Pakistan

At 8:50am on Saturday 8 October 2005 an earthquake of magnitude 7.6 struck northern Pakistan causing widespread destruction in Azad Jammu Kashmir and the eastern districts of North West Frontier Province as well as India and Afghanistan.19 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.20 The epicentre was 12 miles northeast of Muzaffarabad, Azad Jammu Kashmir and 65 miles from Islamabad.21 The disaster caused widespread devastation, leaving millions of people homeless and thousands of buildings destroyed. It resulted in 74,500 people losing their lives22, over 100,000 were seriously injured23 and more than 3 million people were left without shelter or adequate
food. It destroyed more than 200,000 housing units and affected another 190,000; 5000 educational buildings and 500 health facilities were destroyed in addition to 37% of the country’s roads.

We knew from our field study visits in November 2005 and June 2006 that Balakot and Muzaffarabad were severely damaged. The Government’s decision to relocate Balakot 25km to the south excluded it as a suitable case study site. Heavy damage occurred in the centre of the urban area of Muzaffarabad, and schools had almost completely collapsed despite being built with reinforced concrete column and slab construction with masonry infill. Chella Bandi, a suburb of Muzaffarabad, was chosen as the case study area largely because we had conducted a household casualty survey there in 2006. Recovery was monitored 3-4 years after the disaster.

Structure of report

There are four main parts to the report. Chapter 3 presents the proposed recovery indicators and describes how they were devised. Chapter 4 analyses the various methods used to monitor these indicators, including imagery analysis and Chapter 5 describes how these indicators and methods were applied in the two case studies. Finally, Chapter 6 summarises the benefits of using each method.
3 Indicators of recovery

The start of our research coincided with a conference on Post Disaster Needs Assessment (PDNA) in Brussels in May 2008 attended by forty people working in the relief and recovery sectors. The aim of the initiative, led by the UNDP, the World Bank and the European Union, is to develop a way of coordinating agencies involved in post disaster needs analysis (PDNA) in order to bridge the gap between relief aid and development funding, to restore the foundations for development as early as possible and to identify opportunities for positive change that will increase resilience to future disaster. The approach is to build on current post conflict needs analysis, in particular the World Bank method of calculating damage and loss called ECLAC and the assessment of livelihoods and social issues by aid agencies like WFP and ILO.

The delegates at this conference formed the contacts for our user needs survey. The aim was to find out what information relief and development agencies currently use to monitor recovery and what information they lack. This survey was emailed to 50 people. 26 people responded. The survey was also used at round table meetings and individual interviews with recovery stakeholders in Thailand and Pakistan.

The survey found that two-thirds of respondents (69%) say that their organisations already use satellite imagery to assess needs. In addition people also mention using mapping and GIS data, local knowledge, interviews with key informants, focus groups, surveys and reports, networking and contacts with agencies in the field, damage and loss calculations, press articles and websites.

The user survey also contributed to the compilation of the indicators of recovery. Respondents were asked to prioritise our proposed set of 24 indicators. They each tended to prioritise indicators relevant to their own agency’s needs but collectively we found that all 24 were given a medium to high priority. In response to their comments this list of indicators was reduced to 13 Recovery Categories.

The top five indicators selected by the user needs survey are shown in Table 1.

<table>
<thead>
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<th>Indicator</th>
<th>Rank</th>
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<tr>
<td>Livelihoods</td>
<td>1</td>
</tr>
<tr>
<td>Crops / livestock / fisheries</td>
<td>2=</td>
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<tr>
<td>Water quality</td>
<td>2=</td>
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<tr>
<td>Housing reconstruction</td>
<td>2=</td>
</tr>
<tr>
<td>Drinking water</td>
<td>5</td>
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<tr>
<td>Road reconstruction</td>
<td>6=</td>
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*Table 1 Top five indicators selected in user needs survey.*
4 Methods of monitoring

This chapter discusses monitoring tools and their capabilities. Five methods were used in the case studies as follows: key informant interviews, household surveys, ground surveys using GPS video, official publications and finally, the subject of this study, remote sensing using satellite imagery. The methods complement each other and can and should be used in combination. Ground surveys aid imagery analysis and interviews, household surveys and official publications help validate interpretation. In Thailand and Pakistan key informant interviews were done first followed by household surveys and ground surveys. Finally, we analysed the remote sensing and official publications back at base.

Insights from applying the various methods in two case studies allows us to discuss how they can best be combined to monitor recovery effectively. But we also wanted to compare the methods in terms of their cost-benefit and make recommendations about their relative efficiency for different kinds of information needs.

The primary objective is to measure the speed and quality of recovery in each indicator.

In each case study we were assisted by a local team of researchers. In Thailand Dr Ratana Chuenpagdee of the Coastal Development Centre and Dr. Kungwan from Kasetsart University, Bangkok, led a team of researchers, and in Pakistan Professor Amir Khan led a team from the University of Peshawar. These local researchers conducted meetings with representatives of national governmental agencies and NGOs, and organised the key informant and household surveys. In Thailand the Cambridge team conducted a comprehensive ground survey using the GPS video while in Pakistan Professor Khan’s team did a more limited ground survey of the 50 sample homes with a GPS still camera.

![Figure 4.1 Leaders of the surveys teams in Thailand and Pakistan](image)

Key informant interviews

The aim of the key informant survey was to contact 10–15 local informants to provide an overview of the impact of the disaster and the recovery process. The contacts were chosen on the basis of local knowledge and the survey, in the form of a face-to-face interview, was conducted in people’s homes or place of work. The interviewer used a standard set of questions and recorded the answers in the form of hand-written notes that were typed up later. Eleven people were interviewed in Ban Nam Khem and five in Muzaffarabad.

These interviews provide a quick overview of the process of recovery. For example, in Ban Nam Khem informants told us that access was difficult to most of the village for the first 2–3
days and that within a week most areas were cleared except for the market. In Muzaffarabad access was difficult everywhere and roads were blocked and transport disrupted for 1–2 months.

Interviewing local informants provides answers to questions that affect the whole community and allows you to drop these questions from the household surveys. It is also helpful to make contact with community leaders before beginning the household surveys. The kind of broad overview this survey provides is shown in Figure 4.2. Interestingly this shows, that in the opinion of key informants in Muzaffarabad the rate of recovery in the first 3 years after the disaster was similar for all indicator categories, apart from the step change in schooling when the temporary school was replaced. Each indicator category was, however, affected differently by the disaster and so the environment, which in the opinion of key informants was the most severely affected category, still has the lowest percentage recovery after 3 years. This kind of analysis is obviously crude. It doesn’t map where recovery has occurred and if there are differences in different areas. Nevertheless, it does provide a benchmark against which imagery analysis may be verified.

![Figure 4.2 Results of key informant survey in Pakistan](image)

**Household survey**

The aim of the household survey was to gain more information about the recovery experience of the affected households and to create a qualitative narrative for each indicator to aid and validate the image analysis; in particular we wanted to obtain dates in the recovery when particular services were reinstated. We also wanted to establish how household structure was affected by the disaster and to analyse how socio-economic status might have affected household recovery.

A two-page household survey was designed, piloted and implemented in the two case study areas (Appendix A3). The survey opened with questions about the socio-economic and demographic characteristics of the household, to establish the losses they experienced and to derive a recovery narrative, including key dates. The main part of the survey has sections corresponding to each of the indicator categories. For each of these sections the survey aims to determine what problems were faced, how the household overcame these issues, if their situation is better, worse or the same as before the disaster, when key events occurred.
and how the recovery process could have been improved. Due to the complex nature of recovery the majority of the questions were designed as open-ended prompts to invoke discussion about their experiences. The survey ends with a series of questions designed to identify the household’s perception of community recovery. It also aims to establish which aspects of recovery are most important to the householder and to obtain recommendations on how the recovery process as a whole may have been improved.

The survey was piloted in Ban Nam Khem by Dr Ratana Chuenpagdee and her team with members of the Cambridge team observing. Problems were highlighted and, where necessary, amendments were made. The pilot ensured that the interviewers were comfortable with the questions and to judge how long each interview would take. The households to be interviewed were identified on maps provided to the interviewers. The teams were asked to visit each highlighted building and to interview the household present. If the building was unoccupied, the teams were asked to go to the nearest building until an interviewee was found. The sample households were selected using ArcGIS (Figure 4.4). A Shapefile was created with each point representing a building in the satellite imagery. Several different methods of sampling were tested. Using the quadrant sampling method, an equal proportion of points were selected within each 500m grid square. The problem with this approach was that in grids with less than 20 buildings, no points were selected, which skewed the sample. Random distribution was chosen as the preferred approach as it provided an even geographic distribution over the whole case study site. Fifty households were sampled in each of the two case study sites.

Figure 4.3 The surveys teams in Thailand and Pakistan
The interviews collected two different kinds of information – descriptive and factual. In many ways the descriptive accounts provide the better record of people’s experience, but this information is difficult to analyse. There are also some limitations to this dataset as a representative sample. For example, the team could only interview families who were living in the case study areas at the time. For obvious reasons families with no survivors or those that had migrated could not be interviewed. Questions about jobs and income were designed to give an indication of the pace of economic recovery but with only 50 interviews it is difficult to assess whether the reported changes would have occurred anyway without the tsunami. Finally, in any kind of survey work, there is a potential of subjective interpretation of questions by interviewers and interviewees. Although every effort was made to brief the local surveying team, a few questions were changed or omitted by the interviewers or misinterpreted by the respondents and there is very little one can do once the team has left the area to capture missing information. The households surveyed in Ban Nam Khem and Muzaffarabad had been interviewed numerous times by other NGOs and university students so there is an obvious danger of survey fatigue.

Ground survey

The objective of the ground survey is to capture physical information about the case study sites, including buildings, roads, power lines, water tanks, schools, sources of livelihood and the natural environment. The ground data is then used to validate the satellite image observations. The field survey also records detailed information on ground conditions that are not amenable to remote sensing, such as building use and details about alterations and minor repairs. For example, home-made and agency-provided extensions to homes were visible in the imagery as square, bright objects and the ground survey photographs were able to confirm these modifications. The field survey in Ban Nam Khem was conducted across the whole extent of the satellite image and included areas that were directly and indirectly affected by the tsunami, including a community of prefabricated houses that were built several kilometres away.

Two methods were used to capture geo-coded imagery in Ban Nam Khem – still photographs taken by a GPS camera and video linked to the VIEWS™ system. The VIEWS™ (Visualizing Earthquakes with Satellites), developed by ImageCat Inc, integrates remotely-sensed imagery with high definition video through a map overlay that draws a track.
of the recording linked to the video playing in a window next to the satellite image. VIEWS™ collects continuous imagery from a site from two high definition video cameras in a slow-moving vehicle: one camera pointing sideways to record building facades and the other pointing forward to capture building heights and additional information such as road type and power-lines. The VIEWS system and a GPS camera were used in Ban Nam Khem to capture, store and visualise 10 hours of video data and 1,500 geo-referenced photographs.

Figure 4.5 Members of the team conducting a ground survey from a moving vehicle using VIEWS™

These ground techniques can gather information on processes that are not visible in satellite imagery and can supplement remote sensing by providing details about the progress and quality of the construction work. For example, the progress of repairs can be monitored and arrangement of windows and doors can indicate the quality of day lighting and ventilation. Ground surveys are also used to validate remote sensing, such as verifying the number of units, building use and roof type. Figure 4.6 shows an army-built structure in the centre of Ban Nam Khem and compares them to a structure outside of Ban Nam Khem. The buildings both have pitched roofs but are seen to differ in their size, colour and number of storeys.

Figure 4.6 Houses constructed by the Rotary club (left) and the Army (right).

Information about the structure-type and building materials may also be acquired from the ground. A detailed survey may adopt a system such as that developed by the Applied Technology Council to identify buildings that might pose serious risk of loss of life or injury. ATC-21 involves the identification of the primary load-resisting system and its building material. A basic structural hazard score is then assigned that highlights buildings that
should be analysed in more detail by a professional engineer. In addition GPS photography and video footage may also be used to describe the building’s architectural aesthetic.

Finally, the occupation of a building may be more confidently established. Vacant buildings and the overall prosperity and attractiveness of an area may be identified in the photographs by observing a general lack of up-keep of the structures and the surrounding area. Visible signs of degeneration might include boarded windows, the presence of trash, graffiti or overgrown vegetation. This ground study may be extended beyond residential structures to identify the functionality of other places of social capital such as local shops, hospitals and religious buildings, which are important aspects of a community’s recovery. It could also note the location of small features such as water towers, power lines and tsunami-warning towers, as well as recreational and commemorative features such as monuments and parks. Figure 4.7 shows some of the additional signs of recovery progress in Ban Nam Khem acquired using geo-coded ground survey work.

![Sources of Livelihood, Water Storage Facilities, Tsunami Warning Tower](image)

**Figure 4.7 Additional signs of recovery captured using GPS photography in Ban Nam Khem**

The main benefit of the system is that it provides the remote image analysts with a store of side view images that can be easily accessed to resolve a query about the overhead satellite imagery, for example uncertainty about building use or degree of damage. By clicking on the GPS track on the screen the video freezes on still photographs of the adjacent scene. In addition to the cost of the satellite imagery the VIEWS™ system involves a one-off cost of about $5,000 for the system, plus the cost of the field deployment. To survey the whole of Ban Nam Khem and collect 10 hours of data it took the 3-person team about 30 hours. The cost of using the still camera, both in terms of equipment and labour, was much less. A GPS Camera (Ricoh Caplio 500SE) was used over 2 days to conduct a per-building analysis of the affected part of Ban Nam Khem, consisting of over 1,500 geocoded images of buildings and other signs of recovery. In Muzaffarabad a still GPS camera was used to record the 50 dwellings included in the household survey.

**Official reports, publications and statistics**

We obviously wanted to make as much use as possible of reports, statistical data and any other documents produced by government departments and international agencies. We needed base line data on population, housing and economic activities. We would also have liked data about the recovery process, for example about population movements, temporary housing and many other variables. In the event it proved to be extremely difficult to get any useful information at all. Despite being offered large volumes of data and despite finding many reports and official documents about both disasters, very little was useful and relevant to our needs. The principal issue is that most published information is not available at the scale we needed.

Requesting official statistics was time-consuming and often unsuccessful. A second problem with official statistics stemmed from not knowing the methods that were used to collect the
data, in particular, which areas had been surveyed. In some cases, multiple sources of data were available: each showing different results. Therefore, the accuracy and reliability of the data is often difficult to determine.

Remote sensing

The remote sensing analysis used in this study was simple. It involved scrutinising high-resolution satellite images from before the disaster and detecting changes in images taken at different times after the disaster. The main strength of remote sensing is the potential accuracy and reliability of the quantitative data that can be measured. The downside is that some important aspects of recovery are difficult or impossible to see in static remote images. This weakness can be mediated to a considerable extent by combining imagery analysis with key informant, household and ground surveys. Analysis is also significantly improved if the interpreter has local knowledge, preferably from visiting the disaster site. The key advantage of using remote sensing to monitor recovery is that it provides a standard replicable way of accurately measuring indicators. It is, however, a relatively expensive process. Images have to be obtained and many person-hours devoted to interpretation. These costs are obviously proportional to the area affected by the disaster and will be analysed in detail in relation to the case studies in the following chapter.

The choice of images is an all-important first step. In part it depends on what imagery is available and what can be afforded. High-resolution optical satellite images were acquired for the two case study sites. Table 2 shows that more comprehensive imagery was available for Ban Nam Khem than for Muzaffarabad, and for this reason more effort was put into the Thai case study. As can be seen we were reliant on two satellites: Ikonos and Quickbird. The spatial resolution of Ikonos images is 80cm per pixel and of Quickbird images is 60cm. The satellites all have sun-synchronous orbits which means they cross a given point on the earth’s surface at the same local time; approximately 1am for both our case study sites. In time more and more imagery will become available and it will become increasingly crucial to choose the optimum set of imagery that minimises effort yet captures the temporal nature of the recovery. Information from the key informant survey about the timing of change, for example when roads were cleared, when families moved from temporary shelter to permanent homes and when schools reopened can inform this selection. The frequency that a particular indicator needs to be monitored, and therefore whether all the images need analysing, depends on the impact of the disaster and other factors that affect the rate and timing of physical reconstruction, such as the availability of funds/materials and how quickly new urban plans can be approved.

<table>
<thead>
<tr>
<th>Ban Nam Khem</th>
<th>Muzaffarabad</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ikonos Geoeye 24 June 2002</td>
<td>Quickbird Digital Globe 13 August 2004</td>
</tr>
<tr>
<td>Ikonos PDC 01 January 2005</td>
<td>Quickbird Digital Globe 22 October 2005</td>
</tr>
<tr>
<td>Quickbird Digital Globe 28 February 2006</td>
<td>Quickbird Digital Globe 6 July 2009</td>
</tr>
<tr>
<td>Ikonos CRISP 21 November 2006</td>
<td>Quickbird Digital Globe 6 July 2009</td>
</tr>
<tr>
<td>Ikonos CRISP 08 February 2008</td>
<td>Quickbird Digital Globe 6 July 2009</td>
</tr>
<tr>
<td>Quickbird Digital Globe 05 February 2009</td>
<td>Quickbird Digital Globe 6 July 2009</td>
</tr>
</tbody>
</table>

Table 2 Imagery obtained for case studies

Satellite images are supplied in the form of a high-resolution black and white image plus lower resolution red, green, blue and infrared data. Before analysis they were pre-processed. Pan-sharpening involves combining low-resolution multi-spectral data with the
black and white image to produce a high resolution colour image. Four different pan-
sharpening algorithms were assessed. The Pansharpen PCI Geomatica algorithm delivered
the greatest contrast and most clearly defined building edges. The images also had to be
registered to each other so they could be overlain accurately. In Ban Nam Khem pre-
processing each image took approximately 5 hours.

Figure 4.8 Still camera imagery and satellite image being viewed in ArcGIS

After the images were processed, they were visually analysed to identify signs of post-
disaster recovery. In particular, any changes, particularly signs of physical recovery detected
between one image and the next, were described and recorded. This log gives an indication
of those aspects of recovery that can be observed using satellite imagery alone. It was clear
that it would be possible in Ban Nam Khem to monitor accessibility, buildings, environment
and even livelihoods using satellite imagery. How the imagery was used to monitor each
indicator will be described in the following chapter. The accuracy and reliability of each
measurement will also be assessed. Image interpretation, although a straightforward
process, requires a degree of expertise and experience. It doesn’t involve a great deal of
special equipment, however, other than a computer, a high quality monitor and a copy of
geographic information system software. We used ArcGIS. Figure 4.8 shows how still
camera photographs and satellite imagery can be viewed in ArcGIS.
5 Monitoring each indicator

This chapter describes each of the indicators in detail, describing how they are measured and what information they provide. It analyses their strengths and weaknesses and indicates their cost in terms of time and equipment. It also provides examples of how the indicators were applied in our two case study sites.

The aim is to explore the practicality of using satellite imagery to monitor recovery for each of the indicators. Other methods are used to provide additional information and to corroborate the findings of the remote sensing. The chapter provides examples from the case studies and discusses the benefits and limitations of using remote sensing. Of the original set of 24 indicators some were combined and some were not amenable to analysis using remote sensing. The final set of indicators used in the case studies is tabled below.

<table>
<thead>
<tr>
<th>Indicator</th>
<th>1. Road condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accessibility</td>
<td>2. Accessibility analysis</td>
</tr>
<tr>
<td></td>
<td>3. Bridges and public transport facilities</td>
</tr>
<tr>
<td></td>
<td>4. Presence of vehicles</td>
</tr>
<tr>
<td>Buildings</td>
<td>5. Removal and construction of buildings</td>
</tr>
<tr>
<td></td>
<td>6. Change in urban land use and building morphology</td>
</tr>
<tr>
<td></td>
<td>7. Quality of dwelling reconstruction</td>
</tr>
<tr>
<td>Population</td>
<td>8. Temporary accommodation</td>
</tr>
<tr>
<td></td>
<td>9. Population</td>
</tr>
<tr>
<td>Services and Utilities</td>
<td>10. Administration, Education, Healthcare and Religious facilities</td>
</tr>
<tr>
<td></td>
<td>11. Utilities: Power, Water and Sanitation</td>
</tr>
<tr>
<td>Environment</td>
<td>12. Land-cover and urban green space</td>
</tr>
<tr>
<td>Livelihoods</td>
<td>13. Recovery of livelihoods</td>
</tr>
</tbody>
</table>

Table 3 Indicators used in the case studies
Accessibility

Indicator 1: Road condition

Justification

Accessibility is a crucial issue that can determine the success of many other different aspects of relief and recovery. Aid agencies and national governments need access to deliver immediate relief and longer-term recovery depends on access to service facilities and sources of livelihood. Inaccessibility may also affect people’s health, the overall speed of reconstruction and the maintenance of reliable market prices. Key transport routes must be cleared and restored to allow relief vehicles and personnel access to severely affected areas and throughout recovery, consistent access routes are required to ensure the reliable import and export of food and other resources. The main dataset generated for this indicator is a GIS file showing the multi-temporal changes in both the location and length of the transport networks.

Method

Indicators 1–3 involve manually delineating the transport network in a GIS and identifying damaged or broken sections of the network immediately after the disaster and cleared or reconstructed sections at intervals through the recovery process. Each image is analysed and, using the Sketch tool, a series of points are drawn down the centre of each road or

![Image of ArcGIS software interface](image_url)

*Figure 5.1 Delineating and classifying attributes of the road network in Ban Nam Khem using ArcGIS software.*
track. The user requires both remote sensing image interpretation skills along with good GIS technical ability to complete this.

Having delineated the complete network, roads are classified as a path, dirt track non-asphalt road or asphalt road. Damage to the roads is classified as: flooded, vegetation, debris, heavy debris, washed away, structures in road, cleared but not resurfaced, and covered by landslide.

**Road classes**

<table>
<thead>
<tr>
<th>Path</th>
<th>Dirt Track</th>
<th>Non-Asphalt Road</th>
<th>Asphalt Road</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Path" /></td>
<td><img src="image2" alt="Dirt Track" /></td>
<td><img src="image3" alt="Non-Asphalt Road" /></td>
<td><img src="image4" alt="Asphalt Road" /></td>
</tr>
</tbody>
</table>

**Damage classes**

<table>
<thead>
<tr>
<th>Flooded</th>
<th>Vegetation</th>
<th>Debris</th>
<th>Heavy Debris</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image5" alt="Flooded" /></td>
<td><img src="image6" alt="Vegetation" /></td>
<td><img src="image7" alt="Debris" /></td>
<td><img src="image8" alt="Heavy Debris" /></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Washed Away</th>
<th>Structures in road</th>
<th>Cleared, but not resurfaced</th>
<th>Covered by landslide</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image9" alt="Washed Away" /></td>
<td><img src="image10" alt="Structures in road" /></td>
<td><img src="image11" alt="Cleared, but not resurfaced" /></td>
<td><img src="image12" alt="Covered by landslide" /></td>
</tr>
</tbody>
</table>

*Figure 5.2 Classification of the road network and damage categories used in Ban Nam Khem and Chella Bandi, Muzaffarabad*

Once the network has been delineated, tools in the GIS can be used to calculate statistics such as length of road of each category. Swapping between images can help check difficult to identify roads and obscured roads can be attributed if the features appear unchanged between the time periods before and after the obscured image date.

The initial damage and destruction to the transport network is typically followed by a period of clearance, rapid repair and reconstruction. The changes to the transport network observed in the satellite imagery, such as repaired roads or bridges are and removed roadblocks, are incorporated into the network database by editing the shapefiles.
Road network analysis – Ban Nam Khem, Thailand

Before the tsunami in Ban Nam Khem, the total length of roads was 46 km. The tsunami destroyed or made impassable 29.8 km of road. Remote sensing analysis shows that most of the permanent repair and reconstruction work was completed in one year and that the total length of road in February 2009 was 8.01 km longer than it was before the disaster.

Chella Bandi, Muzaffarabad, Pakistan

Figure 5.3 Damage to road network in Ban Nam Khem

Figure 5.4 Damage to road network in Chella Bandi
Before the earthquake in Chella Bandi, the total length of the roads was 28 km. The earthquake destroyed 4 km of road or subsequently made impassable. The highest proportion of new roads was constructed before June 2006 (2 km) and the total length of road in Chella Bandi in July 2009 was 0.6 km longer than it was pre-disaster.

**Discussion**

Accessibility is a fast-evolving phenomenon in post-disaster situations. The extent of damage in Thailand was huge, with roads literally being removed by the tsunami. This resulted in a longer time period for the recovery of transport networks than was seen in Chella Bandi. The post-earthquake imagery in Ban Nam Khem was collected 7 days after the disaster, rather than 14 days in Chella Bandi. So it is important to note that there is the possibility that significant clear up operations could have occurred in the interim time period to allow the access and regress of traffic responding to the earthquake.

Despite the fact there were few changes in accessibility evident in the Chella Bandi imagery, it is still important to understand the evolution of the road network during the recovery phase to infer access restrictions or impediments across the study area, especially those routes leading to IDP camps, key services and residential areas.

The road classes used (Figure 5.2) were widely applicable to Ban Nam Khem and Chella Bandi and have also been applied after the 2008 Wenchuan, China earthquake to good effect. However, not all of the classes of damage were seen in each case study (e.g. no flooding in Chella Bandi, no landslides in Ban Nam Khem), and future disasters may create scenarios not accounted for in these classes, in which case, the set of damage classes can be extended. Images from other earthquake events show the validity of monitoring accessibility from satellite imagery. The Wenchuan earthquake resulted in widespread disruption to the road network due to landslide inundation and building collapse. There was also evidence of these effects following the Haiti earthquake of January 2010.

**Indicator 2: Accessibility analysis**

**Justification**

This indicator monitors changes in the accessibility of the transport network in terms of travel time and distance brought about either by damage to the network or relocation of homes and services. It also identifies households and businesses with inadequate access to key facilities and services.

**Method**

These measures involve manually delineating the transport network within a GIS and then identifying *damaged* sections of the network immediately after the disaster and *cleared or reconstructed* sections at intervals through the recovery process. Having allocated attributes to the digitised network to describe its condition, road length by type and condition can be calculated. This might have been completed for Indicator 1. Once the transport network has been digitised accessibility may be assessed using network analysis tools which are available as part of most GIS packages.

**Case study:**

**Application in Ban Nam Khem**

Affected households were re-located to various housing developments around Bang Muang sub-district throughout the recovery process. *Best Route* analysis was used to show how this affected people’s access to services and facilities. Figure 5.6 shows the shortest travelling routes from six housing developments to Ban Nam Khem School. The routes were produced using Network Analyst in ArcGIS and exported as shapefiles for further analysis.
Figure 5.5 Location of new housing in Ban Nam Khem

Figure 5.6 Best route from new housing to Ban Nam Khem school showing shortest distance

Based on Thai speed limits and studies of pedestrian walking speeds, shortest route distances can be converted to travel times by assuming average speeds of 32 km an hour for vehicles and 4.5km an hour for people walking. Before the tsunami the average walking time to school for most children was about 15 minutes. For the 191 households relocated to Pruteow the walking time along a busy main road increased to over 2.5 hours. The household survey suggests that children in Pruteow transferred to the school in Takua Pa. A similar best route analysis was conducted from the new housing to the fishing piers. Prior to the disaster most homes were within a 10 minute walk of the piers. After relocation households in Bang Muang, ITV Housing and Pruteow had a significantly longer distance to
travel, which is likely to have led to significant changes in their lifestyle and source of livelihood.

Service Area analysis identified households and businesses with insufficient access to key facilities and services. To analyse the impact of a new school at Pruteow on the Service Area, a hypothetical new school was added to the Network Dataset. Figure 5.7 shades the Service Area after the construction of a new school. Service area analysis could also be used to ensure that sources of livelihood and emergency services are all sufficiently accessible. The shaded area encompasses all places within a given travelling distance of the two main schools. Red dots indicate buildings outside of this service area. The majority are located at Pruteow, 9 km east of Ban Nam Khem.

![Figure 5.7 School service area analysis showing that housing in Pruteow is currently poorly served on the left hand map and the impact of building a new school on the right hand map](image)

**Discussion**

With a skilled image analyst, these indicators provide a high level of accuracy. The amount of time required for interpretation will depend on the size and complexity of the transport infrastructure being analysed. In Ban Nam Khem, an area of approximately 6 km² with 50 km of roads took roughly 4 hours to delineate the network and identify points of interest like schools, homes and places of work for each image scene.

The frequency of monitoring depends on the impact of the disaster and other factors that affect the rate and timing of physical reconstruction, such as the availability of funds and materials and the speed at which new urban plans may be approved. Due to the rate at which the clearing and reconstruction of roads commonly occurs, the indicator will have to be monitored every few days or weeks during the relief phase and every 6-12 months during reconstruction. Local information may be used to determine when reconstruction is due to begin and how often images may need to be acquired.

High-resolution satellite imagery such as Quickbird and IKONOS for example (between 60cm – 1m spatial resolution) can reliably distinguish asphalt from non-asphalt road surfaces. The width of the roads can also be accurately measured to classify tracks, roads and highways. Fifty GPS photographs containing road surfaces were selected at random to check the satellite interpretation results, with a 96% accuracy rate. There was confusion in densely built areas where road surfaces were obscured by building facades and shadows, but otherwise the results were highly accurate.

Due to the spatial resolution of imagery, it can sometimes be difficult to identify minor damage or debris on the road surface or localised subsidence, so the technique and it may be more
useful for identifying tsunami or landslide damage rather than earthquake damage. Vegetation blocking roads can be difficult to interpret and classify since it is often natural for roadside vegetation to appear to cover road surfaces when viewed from remotely sensed imagery. The imagery is also incapable of identifying the quality of the construction work. Accurate geo-referenced imagery is important when classifying and delineating roads, especially if there is a dense network. Points of reference (landmarks) should be used whenever possible, to help monitor changes in the road layout.

Accurate, detailed and highly reliable observations and statistics may be produced that describe the length of the transport network that has been cleared and reconstructed. The method would be time-consuming and expensive to conduct over a wide area. Minor damage, road blocks or the quality of construction cannot be derived from remote sensing, however it has been shown the surface material can be determined from high resolution imagery.

**Indicator 3: Bridges and public transport facilities**

**Justification**

This indicator monitors the reconstruction of bridges and public transport facilities. These often provide essential links within an area damaged by a disaster, and facilitate mobility of the population. The number of bridges reconstructed is a TRIAMS indicator that is used by the DDPM in Thailand. The aim is to identify damage to bridges and date when they were repaired, constructed or reconstructed. Key public transport infrastructure is also identified from the imagery, and its functionality and damage level determined.

**Method**

Image interpretation involves manually identifying and digitising bridge structures from the satellite imagery. Experience with satellite imagery is preferred to perform the visual interpretation work accurately, but is not essential, as bridge features are often clearly identifiable (Figure 5.8).

Figure 5.8 Easily identifiable bridge: The main road bridge over the Jhelum River connecting Muzaffarabad city centre and Chella Bandi to the north

This indicator also monitors the reconstruction and use of public transport facilities. The aim is to date when public transport facilities were constructed or reconstructed and when public transport facilities began functioning. Large public transport facilities such as bus stations, train stations, airports and ferry ports are manually located in the imagery. These facilities are sometimes more difficult to detect solely from the imagery, however they can be identified through the congregation of buses, ferries or trains in a small area.
Case studies

In Ban Nam Khem and Chella Bandi, it took under an hour to identify and delineate bridges in each image. In Chella Bandi, there were no centralised public transport facilities that could be identified in the imagery. In Ban Nam Khem, the ferry facilities took under an hour to identify and delineate for each image.

In Ban Nam Khem, due to their form and location, the ferry port facilities and the ferry itself were all easily identifiable in the satellite imagery. It can be seen in Figure 5.9 the tsunami directly hit the pier and ferry facilities, demolishing all of the buildings in the area. Immediately after the tsunami the pier is still standing but the surrounding area is covered in heavy debris. The road surfaces and buildings were all reconstructed between April 2005 and February 2006. The ferry is present in all of the images from February 2006, so it is presumed to be functioning from that date.

![Figure 5.9 Analysis of ferry service in Ban Nam Khem](image)

Discussion

It was found that bridges can be analysed at a per-feature scale using high resolution imagery. Delineating bridges is a quick process and requires very little technical ability once the images have been prepared and pre-processed. However, to identify all bridge locations in the affected region confidently additional information from a ground survey or a pre-disaster satellite image may be required. Minor damage to bridge structures cannot be identified using satellite remote sensing alone; only complete collapses and new constructions may be confidently identified and recorded. Nor can remote sensing alone determine the quality of the construction work and key-informant or ground surveys are likely to be better at obtaining information on the quality of reconstruction.

A range of different public transport facilities, such as bus stations, airports, ferry ports and train stations, can be analysed at a per-building scale using high resolution imagery.
Delineating public transport facilities is a quick process and requires very little technical ability once the satellite images have been prepared. However, only large facilities such as railway stations, bus stations, ferry ports and airports can be confidently identified with satellite imagery alone, yet often less developed nations rely on informal modes of public transport such as mopeds or minivans, which can function without the need for centralised infrastructure (such as a station). At present these would therefore be impossible to quantify from satellite imagery alone.

It is apparent that ground information or reference maps can be used to assist this process. It is also not always easy to determine in satellite imagery if the facilities are occupied. Key-informant surveys or ground surveys may be more appropriate methods of discovering when facilities come back into use and about the quality of the reconstruction and of the frequency and reliability of the service.

**Indicator 4: Presence of vehicles**

**Justification**

Traffic activity may be used to estimate the extent to which different transport routes are being utilised. The presence of vehicles in a disaster-hit area may be a sign of recovery, both in terms of indicating accessibility and as a sign of human activity, which could be useful during the relief phase. In particular, the presence of vehicles may determine if roads are being used and if facilities and services, such as schools or recreational sites, are in use by noting the presence of vehicles in the immediate vicinity.

**Method**

This is an image-based analysis, and involves manually identifying and quantifying the number of vehicles present in the image, and their location on the transport network. Experience with satellite imagery is needed to perform the visual interpretation accurately but this can be learnt relatively easily. It was not possible to verify the accuracy of the analysis because suitable ground information was unavailable at the same time and date of the imagery.

![Figure 5.10 Images from Ban Nam Khem and Chella Bandi showing clarity of vehicles](image-url)
Case Study: Application in Ban Nam Khem

In Ban Nam Khem, this analysis took approximately 1–2 hours, with less time taken for Chella Bandi. Figure 5.11 shows the results of the January 2005 image analysis, acquired 7 days after the tsunami hit Ban Nam Khem. Vehicles are symbolised by green dots and areas of interest have been magnified.

a) Cars near to the shore, indicating human activity in the worse affected area and the possible presence of emergency relief workers.
b) Cars at Ban Nam Khem school, located just outside the worse-affected area and the site where Ban Nam Khem camp was later constructed.
c) Lorries, tents and relief supplies in the grounds of Bang Muang School, indicating the arrival of relief material into the area.
d) Significant amount of traffic on the main road from Khao Lak to Takua Pa compared to later images indicating an exodus of people across the Province.
e) Cars using the newly constructed roads in the inundated areas from July 2005.

Discussion

Data on traffic activity has many different potential applications. High-resolution satellite imagery can differentiate between vehicle-types, for example between cars and trucks, to monitor return to homes and business recovery in commercial districts.

The ease with which vehicles can be identified depends on the size and colour of the vehicle and the colour and texture of the surface on which the vehicle is sitting. It also depends on the spatial resolution of the imagery being used. (Figure 5.11) A typical full-length car measures approximately 5 metres, which is the equivalent of 7 pixels in a Quickbird image or 4–5 pixels in an IKONOS image. Vehicles are therefore significantly easier to identify in clear, cloud-free Quickbird imagery, or using aerial imagery or new satellite sensors such as WorldView-2 or GeoEye-1.

Field-based cameras or weigh-in motion sensors are also used to monitor traffic flow but these are rarely available in less developed countries. Remotely sensed imagery is now
increasingly used to provide a more synoptic view of traffic. One advantage of this imagery is that it gives a snapshot of a large geographic area, whilst a camera on the ground can only show vehicle-use on a single road. Vehicle counts may be conducted using manual image interpretation techniques, but this is impractical and relatively expensive when there is a large amount of imagery to analyse.

Monitoring manually is time-consuming and automated techniques are not yet available. But various approaches are being explored to automatically detect vehicles using IKONOS and Quickbird Imagery, and there is likely to be significant progress in this area. Vehicles are not always easy to identify, especially those not on smooth asphalt road surfaces and buildings, vegetation and shadows may obscure vehicles. Vehicles may also be mistaken for other features, such as boats or tents. Care must be taken in interpreting traffic activity from a single image, since travel volumes vary with time of day and day of the week. Furthermore, analysts must be aware that some vehicles may be empty and stranded.

Clearly monitoring the presence of vehicles gives snap-shots of one aspect of recovery rather than monitoring traffic activity. Nevertheless, it does allow monitoring of a large area and may be the only data available in less developed countries. Remote sensing can give a quick overview to monitor traffic activity, but lacks the adequate revisit rate to make observations significant. Traffic activity ideally needs to be monitored every few minutes or at least several times a day. It was useful though to identify human activity in particular areas of interest, especially in the initial relief phase of recovery when access was limited. The presence of vehicles in the imagery may be used as a sign of human activity and used to assist other accessibility indicators.
Buildings

The Recovery Project offers three indicators and a range of techniques that can be used to monitor the built environment. The tools are applied at various scales: town/city, neighbourhood and per-building, which differ in the amount of detail they can provide. At a town/city scale, Indicator 5 Removal and Construction of Buildings and Indicator 6 Change in Urban Land Use and Morphology may be used to review the overall reconstruction process through the creation and analysis of a building points database. Change detection analysis highlights building construction and building removal, while spatial analysis of the points highlights changes to the density and morphology of the built-up area. Observing buildings at this scale may be used to monitor the progress of reconstruction, to identify spatial disparity and to ensure adequate resource availability and distribution. Additional spatial metrics may then be applied to mapped building footprints at a neighbourhood scale to analyse how building form (density, size and shape) has changed, which can be used as a proxy for living conditions. The availability of VHR Satellite Imagery also allows individual buildings to be analysed in detail (Indicator 7 Quality of Dwelling Reconstruction). A suite of techniques has been designed to monitor buildings’ structural attributes, stage of development, location and building context. Features associated with the building may also be monitored such as the presence of a garden, driveway or extension.

Indicator 5. Removal and construction of buildings

Justification

This indicator tracks the construction and removal of buildings by monitoring their presence and absence throughout the recovery process. Shelter is a fundamental aspect of post-disaster response and recovery as it provides warmth, security and safety to its inhabitants. The Sphere Guidelines Project summarises the importance of shelter in the following way:

“Beyond survival, shelter is necessary to provide security and personal safety, protection from the climate and enhanced resistance to ill health and disease. It is also important for human dignity and to sustain family and community life as far as possible in difficult circumstances.”

Method

The first step of the analysis is to delineate the extent of the built environment in each satellite image. Change detection analysis is then applied to the urban maps to identify the expansion and contraction of urban areas between two states in time.

Two different approaches for mapping the built environment are provided in this chapter: a manual method and a semi-automatic method. The first involves systematically identifying each building as a single point and the second involves using a supervised classification algorithm to classify impervious surfaces. The most appropriate technique will depend on the resources available to the user and the amount of detail and accuracy that is required.

Method 1: Manual location of building points

Individual building footprints were first identified in the satellite images using visual analysis. A point vector layer was then produced using a GIS and a single point was placed in the centre of each visible building. Visual analysis was then repeated on subsequent images to identify the removal of existing buildings and the construction of new buildings. Within the vector layer’s attribute table, a new column was created for each of the satellite images and a unique code was applied to every point to signify the building’s presence or absence in each image. The following scheme was used: 0 – absent; 1 – present; 99 – Unknown (due to
presence of cloud, occlusions, or discrepancies in the images’ extents). The results of the analysis were stored in a multi-temporal building database with a single record representing each building location.

Method 2: Supervised classification of urban areas

The Maximum Likelihood algorithm was used to semi-automatically classify impervious surfaces and to produce classification images and statistics that describe the extent of the built environment. The Maximum Likelihood algorithm applies a statistical decision rule that examines the probability function of a pixel for each of the classes, and assigns the pixel to the class with the highest probability. The probability values are based on training statistics provided by the analyst in the form of sample pixels, which represent the classes that are to be classified. Training areas were selected across the image by delineating pixels, ensuring that each training sample encompassed the different land cover types that occur within a single class.

Change Detection

Once the extent of the built environment was mapped using either Method 1 or 2, change detection analysis was performed on the urban maps. Change detection may be defined as the process of identifying differences in the stage of an object or phenomenon by observing it at different times. This technique produced change detection maps and statistics that described the rate that the buildings were constructed and removed and identified where these processes took place. Change detection techniques may be broadly divided into pre-classification methods (spectral change detection) and post-classification methods. Post-classification techniques were used in this work as they allow information to be extracted about the type of land cover change that has occurred.

Case Studies: Ban Nam Khem & Chella Bandi

Method 1: Manual delineation of building points

Change detection analysis was applied to a building point database of Ban Nam Khem to identify removed and constructed buildings between each of the seven satellite images analysed between June 2002 and February 2009. The pattern of change can be plotted on a graph to show the change in the number of buildings over time and the overall rate of reconstruction. The locations of the buildings that were constructed and removed were also mapped by allocating symbols to each of the classes: in the maps below (Figure 5.12) the reconstructed buildings are mapped in green while the removed buildings are mapped in red. From these maps, spatial-temporal patterns of construction and building removal were analysed and a series of Areas of Change were identified and later analysed in more detail. These observations were then used to describe how and why the total number of structures varied between each image acquisition.

A total of 621 buildings were washed away by the tsunami or otherwise removed between June 2002 and 02 January 2005 (7 days after the tsunami). A further 52 buildings were demolished between 02 January 2005 and 02 May 2005. It is assumed that these buildings were demolished because they were deemed unsafe or because they were an obstruction to construction work. Most of the reconstruction work was complete by February 2006, but construction was still on-going in February 2009: 592 buildings were built between January 2005 and May 2005 and another 474 were constructed between May 2005 and February 2006. A further 330 buildings were added between February 2006 and February 2009. The following maps and graphs show the process in detail, while Table 4 summarises the reconstruction process by describing clusters of building removal and building construction observed in each image.
Figure 5.12 Building removal and construction in Ban Nam Khem (black = pre-existing; red = destroyed or removed; green = reconstructed)

<table>
<thead>
<tr>
<th>Timing</th>
<th>Summary of building removal and construction</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 week</td>
<td>Almost all of the buildings facing the ocean were washed away by the tsunami. Small clusters of buildings were also lost inland, but some larger concrete buildings near to the coast remained standing in the North East.</td>
</tr>
<tr>
<td>7 days – 5 months</td>
<td>There were three clusters of construction: either side of the main coastal road, a small residential area 400 m inland and a planned camp in the grounds of Ban Nam Khem school.</td>
</tr>
<tr>
<td>5 – 14 months</td>
<td>Houses were constructed opposite the temple. Phase 1 housing under construction and a few transitional shelters built in the grounds of the temple. At BNK school some tents were removed.</td>
</tr>
<tr>
<td>14 – 23 months</td>
<td>There were no significant clusters of construction during these dates, but reconstruction work was still on-going and scattered throughout the village of Ban Nam Khem.</td>
</tr>
<tr>
<td>47 – 50 months</td>
<td>The Phase 2 housing complex was completed by the Rotary Club, whilst the final transitional shelters at the school and the temple were removed.</td>
</tr>
</tbody>
</table>

Table 4 Timing of removal and construction of buildings in Ban Nam Khem

A similar per-building analysis was completed for the Chella Bandi, Muzaffarabad. (Figure 5.13 and Table 5) The number of intact buildings in the area from before to immediately after the earthquake (22 October 2005), with a steady increase in the total number of structures throughout the recovery process; the overall number was still increasing in 2009. By this stage, there had been an 80% rise in total numbers of buildings from the pre-event state to 2009. This phenomenon was due in large part to the long-term presence of temporary structures such as tents. Subsequent disaggregation of these data showed that in June 2006, over 40% of buildings within the study area were identified as temporary structures. Figure 5.14 shows how this trend varied over time in the building stock.
Figure 5.13  Number of buildings in Chella Bandi study area throughout recovery time period

<table>
<thead>
<tr>
<th>Time Period</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Post-earthquake (+14 days)</td>
<td>Approximately 30% of all pre-existing buildings were completely destroyed by the earthquake. These buildings were evenly distributed across the studied area. The post-earthquake image showed nearly 700 temporary buildings that had been erected following the earthquake – mostly in communal areas and public ground.</td>
</tr>
<tr>
<td>14 days – 8 months</td>
<td>Significant numbers of structures were built during this time period (a 37% increase on the number of post-event buildings). The university area saw the most new builds, with temporary structures erected on cricket pitches in the area.</td>
</tr>
<tr>
<td>8 – 35 months</td>
<td>This time period witnessed the most construction, with new-builds accounting for 38% of the total numbers of buildings in the study area. Large numbers of temporary buildings were removed from the university area during this time period.</td>
</tr>
<tr>
<td>35 – 44 months</td>
<td>The number of newly constructed buildings was vastly reduced during this time, with most construction focussing on the northern parts of the study area. There was only a 6% net increase in total structures during this period.</td>
</tr>
</tbody>
</table>

Table 5  Timing of removal and construction of buildings in Chella Bandi
Figure 5.14 Proportion of temporary and permanent structures in Chella Bandi

Disaggregation of data: analysis of neighbourhoods

The building point data can be disaggregated so that the speed of reconstruction may be monitored by geographic location, construction agency or building type. In Figure 5.15 a 250m grid has been placed over the building points and is used to disaggregate the data across Ban Nam Khem. Building reconstruction is then plotted for 8 of the grid cells. Each grid shows a different pattern and rate of recovery. The size and shape of the curve may be used to characterise the type of recovery occurring in a different place.

The map shows that most areas in the centre of Ban Nam Khem were reconstructed to pre-tsunami levels within 1 year of the tsunami, except for those areas on the coast where a 30m non-construction zone was in place. The numbers of buildings in these central areas are similar to the number of buildings present before the tsunami. Outside of Ban Nam Khem there is evidence of new developments and of planned encampments.
Distinguishing new builds from rebuilds

By applying rule-based change detection to the building point database it was possible to distinguish new build constructions (on previously unoccupied land) from rebuilds (on existing sites) (Figure 5.16). Of the 2,691 buildings in the scene, 544 were unaffected or repaired, 455 were rebuilt and 1,128 were new builds. The remaining buildings were destroyed, dismantled or were only present temporarily. Most of the 1,128 new builds are in clusters outside of Ban Nam Khem, which has led to a significant extension of the town. The total number of buildings present in Ban Nam Khem increased by 48% from 1,170 to 1,727.
Presence or Absence

<table>
<thead>
<tr>
<th></th>
<th>June 2002</th>
<th>Jan 2005</th>
<th>Feb 2009</th>
<th>Category</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>still standing or unaffected</td>
<td>544</td>
<td></td>
</tr>
<tr>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>destroyed by tsunami and not built back</td>
<td>183</td>
<td></td>
</tr>
<tr>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>demolished (present before)</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>Y</td>
<td>N</td>
<td>demolished (not present before tsunami)</td>
<td>22</td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>N</td>
<td>N</td>
<td>temporary Jan 2005 and Feb 2009</td>
<td>201</td>
<td></td>
</tr>
<tr>
<td>Y</td>
<td>N</td>
<td>Y</td>
<td>rebuild</td>
<td>458</td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>new build (immediately after tsunami)</td>
<td>125</td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>N</td>
<td>Y</td>
<td>new build (later)</td>
<td>1,128</td>
<td></td>
</tr>
</tbody>
</table>

- Destroyed and Not Built Back
- Demolished after the tsunami
- New-Build
- Re-Build
- Temporary Building
- Still-Standing/Unaffected

Figure 5.16 Disaggregating re-build from new-build in Ban Nam Khem

With adequate ground knowledge, new housing can even be disaggregated by the agency responsible for the build. For example, World Vision built 160 extensions across Thailand. These extensions are small 1-storey rectangular buildings that are attached to the side or the back of government-built housing to provide residents with more living space. They are easily seen on satellite imagery because of their uniform shape (rectangular) and spatial context (in residential areas, attached to government-built housing). The roof’s flatness and metallic composition also meant they have a consistent reflective response in the imagery. The buildings were analysed using the satellite imagery and validated using the GPS photo and VIEWS data alongside other ground notes. In total, 110 World Vision extensions were distributed across the whole of Ban Nam Khem.

In Chella Bandi, 1,541 buildings were unaffected or repaired, 161 were rebuilt and 1,363 were new builds. Many of the new builds were pre-fabricated housing provided by public assistance relief organisations such as Saudi Public Assistance for Pakistan Earthquake Victims (SPAPEV) and Pakistan/Turkish Red Crescent aid housing. SPAPEV housing can be clearly seen from remotely sensed imagery by their distinctive blue roof tops and regular square shape. (Figure 5.17)
Needs maps show the progress of an indicator relative to an expected outcome. For the building indicator they were produced by normalising the number of buildings present against the number of buildings expected to be reconstructed. A needs map of Ban Nam Khem was produced by placing a 100 m grid over the building point database and normalising the number of buildings present against the number of buildings before the disaster (Figure 5.18). Grids containing fewer buildings than the pre-disaster state are shaded in blue and grids containing more buildings are in orange or red. The left-hand map, 4 months after the tsunami, shows that more buildings are ‘needed’ along the coast. It also shows the transitional shelters at BNK School. The 2009 map shows how the town has grown and that some buildings on the coastline have not been rebuilt.

Figure 5.18 Rebuilding (Blue represent losses and yellow and orange gains)
Method 2: Supervised classification of urban areas

Maximum Likelihood Classification was used to classify impervious surfaces. Change detection analysis was then applied to the classification images to produce change detection maps that identified areas of construction. Figure 5.19 shows subsets of the change detection maps. Areas converted to impervious surfaces between the two dates are displayed in grey. The results show how semi-automatic classification algorithms can be used to identify the construction of new roads, permanent buildings and transitional shelters.


The change detection images were aggregated to create maps that show the speed of reconstruction and changes in the extent of the urban area. As an example, the map in Figure 5.20 shows how fast the urban area was reconstructed in the centre of Ban Nam Khem. Urban polygons were derived from the Maximum Likelihood Classification for 4 dates and later stacked on top of one another, with the earliest date first. From the map it is possible to determine that most of the building work in this subset was conducted by April 2005 and that the road re-surfacing work was conducted between April 2005 and February 2006.
Discussion

Method 1: Manual delineation of building points

Very accurate, detailed statistics were produced to describe the number of buildings that were constructed and removed throughout the recovery process. The technique was based on the delineation of individual buildings and therefore produced very detailed outputs at a per-building scale. To test the accuracy of manual building detection, 50 GPS photographs acquired during field deployment in Ban Nam Khem were selected at random and the number of buildings in the photographs was compared with the satellite imagery. There were nine errors: 4 commission errors and five omission errors, resulting in 82% accuracy. Similarly, in Chella Bandi, a total accuracy of 90% was achieved with 3 omission errors. Commission errors occurred when garages, gated areas or outbuildings were counted as dwellings and when roof extensions were interpreted as separate buildings. Figure 5.21 shows an example of an omission and commission error in Ban Nam Khem. Typically, omission errors occurred when more than one building was located under a single roof. These errors can be significantly reduced where ground data is available. Access to the Chella Bandi area was restricted to all but a small team, who collected a total only 88 field photographs across the studied area.
Building removal, building construction and major levels of damage (e.g. major structural damage and at least partial collapse: EMS Damage States D4 and D5) were identified in the satellite imagery, but it was not possible to identify non-structural damage or repairs due to satellite imagery’s vertical angle and its limited spatial resolution (Quickbird-02 imagery was used with a spatial resolution of 60cm – to date the finest available resolution from satellite sensors is 50cm).

Another issue that affected the accuracy of the remote sensing analysis is the assumption that all standing buildings are occupied and in-use. It is likely, however, that some of the buildings will be vacant, either because they have slight damage or for other reasons. The method also assumes that most buildings that were removed between the acquisition of the pre-disaster image and the post-disaster image were demolished by the disaster event, but it is possible that some of the buildings may have been demolished before the first post-disaster image was acquired. To conduct an accurate damage assessment it is therefore important to do so as soon after the disaster as possible, and also to use pre-event imagery as close to the disaster date as possible.

The amount of time required for this analysis will depend on the extent of the damage, the number of buildings present, and the density and morphology of the built environment. In Ban Nam Khem, a 2 x 3 km area with 1,700 buildings, took approximately 4–6 hours to delineate for each image. In Chella Bandi, it took 30 hours because work was also required to distinguish transitional shelters from permanent buildings. The remote sensing analysis can be expensive to conduct over a wide area, but costs would be dramatically reduced if a suitable GIS infrastructure was already available, and if an existing building inventory dataset already existed. This work therefore highlights the importance of generating and maintaining up-to-date GIS databases before a disaster has occurred.

In summary, the manual delineation method provides a relatively accurate and reliable method of creating a building database and extracting detailed statistics on the number of buildings constructed or removed. Ground surveys may be conducted in addition to satellite analysis or as an alternative. They are likely to be more time-consuming, but could be used to obtain more accurate data. They can also be used to obtain information on the quality of the building construction and repair work, and the use of the buildings – information that is difficult to acquire with remote sensing alone.

**Method 2: Supervised classification of urban areas**

The maximum likelihood algorithm was used to test a semi-automatic method of classifying surfaces to produce maps and statistics of the extent of the built environment. The technique provides a relatively quick method of identifying areas of construction and estimating the rate of construction, but it cannot be used to analyse reconstruction at a per-feature level.

Despite this, accurate and reliable maps and statistics were produced to describe changes in the extent of impervious surfaces in the affected area.
Comparing the results of the classification to 1,742 building points led to an accuracy of 83%. Impervious surfaces were particularly conspicuous immediately after they were constructed and therefore easier to classify. However, with time roofs weathered and became less spectrally prominent by blending with the surrounding bare ground. Users must be aware of potential commission and omission errors that might arise due to the spectral similarity of impervious surfaces to other land cover classes, such as bare ground, forest shadow, sparse vegetation and water glint.

The semi-automatic method was a lot less time-consuming than manually delineating individual building points and can be applied quickly across a large geographical extent. Selecting suitable training areas in the image and applying the classification algorithm took approximately 1–2 hours per image. The results have been shown to be accurate but are less detailed than the manual delineation technique. Supervised classification does not directly extract building numbers, but semi-automatically extracts urban area from other land cover types. The technique is still fairly expensive though and requires staff with sufficient remote sensing expertise to select suitable training areas and to apply the classification algorithm.

The user may choose the most appropriate method based on resources available to them and their data requirements. Alternatively, the two methods may be used to complement each other in the same workflow. For example, the Supervised Classification method may first be used to identify ‘areas of interest’ (e.g. areas of significant building removal or building construction), which may then be analysed in more detail at a per-building scale using the manual delineation of satellite images and/or ground survey techniques.

Comparison of the two methods

The project proposes two different ways of using remote sensing to measure building construction and building removal. The first method involves the manual delineation of individual buildings that produces detailed results; the second method involves the semi-automatic classification of impervious surfaces, which delineates ‘urban area’ from other land cover types. Figure 5.22 compares the outputs from the two methods both normalised to the pre-disaster state. There was a positive relationship (0.874) between the two outputs. The results show how the semi-automatic classification of impervious surfaces may be used to plot the trend in reconstruction following an event, such as a tsunami.

Figure 5.22  Building construction in Ban Nam Khem. A comparison of the outputs from two urban delineation methods: Number of Structures derived from Method 1. Manual delineation of building points and Urban Area derived from Method 2. Supervised classification of urban area.
Alternative Tools

Ground Surveys

Ground surveys can be conducted to collect data about buildings present. This will be more expensive and time-consuming than remote sensing but would provide more accurate data. In addition, ground surveys can be used to obtain information on occupancy, use and the quality of construction, information that is difficult to obtain with remote sensing alone. A major advantage of using ground survey over remote sensing is therefore this ability to collect qualitative data. The sample must accurately represent all the reconstructed building types and all of the executing agencies involved in the recovery process. Typically a 10% sample might prove sufficient in most instances. Field surveys can add this contextual level of detail to a building dataset; however it is limited in its ability to identify changes in the use of a building at different time periods throughout the recovery process.

Household Surveys

A household survey can provide information about who provided the housing, to what extent households were involved in the process and how satisfied residents are with their new homes. In Ban Nam Khem, for example, most of the rebuilding was done by NGOs and most of the interviewed households were happy with the speed and quality of the recovery of their community, though those who were unhappy mentioned the small sizes of the reconstructed houses and expressed concern that there was an uneven distribution of aid and reconstruction.

Although unable to provide data on the number of buildings reconstructed the household survey can be used to estimate how long reconstruction took. Households were asked when they moved into tents, shelters and permanent homes. In Ban Nam Khem, on average, households surveyed took 10 months to move into shelters and 22 months to move into permanent housing. Remote sensing and official statistics showed that most temporary shelters were constructed within 5 months and most housing construction had been completed within 24 months of the tsunami.

There is close agreement between the findings from the household survey and remote sensing for when families moved into permanent housing. There is a bigger discrepancy between the household survey and remote sensing in timing of the move to temporary shelters. This might have occurred for a variety of reasons. The question may have been misinterpreted by some respondents or respondents may have rounded their answers to the nearest year. Because of this discrepancy the results of the household survey need to be interpreted carefully. Nevertheless, household surveys give a general indication of the speed of recovery and reconstruction at a town/city scale. Surveys can also be implemented in tandem with the collection of other field information such as ground surveys.

Official Statistics

Table 6 contains building number statistics obtained from agency reports, surveys and other publications, and compares them to the results obtained with remote sensing. The table has been split into three rows, representing 1) the number of buildings present before the disaster, 2) the number of buildings destroyed by the tsunami and 3) the number of buildings constructed after the tsunami. A level of accuracy has been derived for each row by directly comparing the remote sensing estimate to figures derived from official statistics.
<table>
<thead>
<tr>
<th>Number of Houses</th>
<th>Remote Sensing</th>
<th>Official Statistics</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-disaster</td>
<td>1,215</td>
<td>1,556</td>
<td>-22%</td>
</tr>
<tr>
<td>Destroyed</td>
<td>641</td>
<td>1,270</td>
<td>-50%</td>
</tr>
<tr>
<td>Constructed</td>
<td>845</td>
<td>722</td>
<td>+17%</td>
</tr>
</tbody>
</table>

Table 6  Comparison of remote sensing and official statistic data

Compared to official statistics remote sensing underestimated the number of buildings present before the disaster because it is not possible to identify individual dwellings using satellite imagery. It also underestimated the number of buildings destroyed because only serious damage levels could be identified. The estimated number of buildings constructed was significantly more accurate because the new buildings are relatively conspicuous. The official data was obtained from the local district office who told us the data matched the extent of our case study. The actual extent and methods used to determine these statistics could not be determined though. This is a common problem with official statistics and a reason why they must be interpreted cautiously.

Comparison of recovery in the two case studies

![Figure 5.23 Building stock recovery in Ban Nam Khem and Chella Bandi, Muzaffarabad](Figure 5.23 Building stock recovery in Ban Nam Khem and Chella Bandi, Muzaffarabad)

Recovery of the building stock in Ban Nam Khem and Chella Bandi varies dramatically (Figure 5.23). The graph shows a significant difference in the timing and duration of construction in the two places. In Ban Nam Khem there was an intense period of construction in the first year, while in Muzaffarabad construction occurred over a prolonged period and still appears to be in progress 3.5 years after the earthquake.

The nature of the hazards meant they had very different impacts. 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 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 can be monitored. For example, in Ban Nam Khem, planned camps were used to house displaced persons. These transitional shelters were removed and people re-housed within three years of the tsunami – a relatively short amount of time. In contrast, in Muzaffarabad there was an observed increase in the number of temporary shelters, such as tents and pre-fabricated structures, across the affected region. This is partly because residents in some urban parts of Pakistan were prohibited from starting reconstruction until blue prints for the cities had been finalised. This delay meant that the compensation tended to get used for general living expenses until there was none left for rebuilding their homes.40

Indicator 6. Change in urban land use and building morphology

Justification

Features of urban form such as building density are an important issue in urban planning. Densely built areas may be difficult to redevelop and are commonly associated with smaller dwellings and a lack of green space. Urban design also affects a building’s light, noise and comfort levels, and the layout and morphology of the built environment can affect an area’s overall attractiveness and vibrancy, so these measures may be used as proxies for monitoring living conditions.41 Results from the household survey suggest that building size was a particularly important factor in determining the satisfaction rate among households.

Method

Method 1: Building density and nearest neighbour

Several methods are presented that can be used to measure urban layout and morphology. The first two indices, building density and nearest neighbour, are derived from the building point database produced for Indicator 5. Building density maps are produced by applying kernel analysis to the building point database. A kernel is passed across the scene and the number of building points within the kernel is counted. The pixel at the centre of the kernel is then assigned a building density. Building density identifies changes to urban morphology and produces change detection maps at the town scale. Nearest neighbour is another Spatial Analyst tool available in most GIS software and can be used to measure the distance between each building, producing a range of outputs. The most complex is a N×N distance Matrix showing the distance between every point in the database, but for this purpose, a summary of the distance statistics was sufficient (e.g. for each point the minimum, maximum, mean and standard deviation was calculated).

Method 2: Landscape Metrics

Landscape Metrics are a set of spatial statistics that allow maps to be quantitatively described and compared. They are produced by analysing a series of ‘patches’. A patch corresponds to a polygon or an individual unit on a map. The method was initially developed for ecological applications to quantify landscape patterns, in support of habitat modelling, biodiversity conservation and forest management, but the method has been adopted and applied to building footprints and urban maps. This metric may therefore be used to quantify changes to the total built-up area and to monitor average building density, shape and size.

The input to the analysis is a binary vector map containing two categories: 1. Buildings and 2. Non-Buildings. The reliability of the Landscape Metrics is dependent upon the accuracy of this vector dataset, so the buildings were manually digitised to ensure the highest possible
accuracy. The Landscape Metrics were then applied to 250 x 250 m subsets; the size of the subset was selected so that it covered several blocks of buildings and therefore provided an effective overview of an urban subset. The subset is big enough to contain enough buildings to acquire an accurate statistical representation of a localised area. Several subsets may therefore be used to show disparity in urban form across the reconstructed area.

In total, 20 Landscape Metrics were produced, but it soon became apparent that much of the data produced was redundant as many of the plots showed similar patterns to each other. Similarly, a multivariate factor analysis by Ritters found that 26 metrics used to measure land use and land cover had six common and orthogonal factors or dimensions that explained 87% of the variation. For the purpose of this study, 8 indices were selected and grouped into four categories that described different aspects of the built environment’s form and morphology (see Table 7). Redundant metrics were removed from the analysis.

<table>
<thead>
<tr>
<th>Category</th>
<th>Landscape Metric</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Building Extent</td>
<td>Class Area (CA)</td>
<td>The total building area.</td>
</tr>
<tr>
<td></td>
<td>Number of Patches (NUMP)</td>
<td>The total number of buildings.</td>
</tr>
<tr>
<td>Building Shape</td>
<td>Mean Shape Index (MSI)</td>
<td>The sum of building perimeter divided by the square root of building area, adjusted against a standard square, divided by the number of patches (NP) (measures the complexity of average patch shape in the landscape compared to a standard shape).</td>
</tr>
<tr>
<td></td>
<td>Mean Perimeter-Area Ratio (MPAR)</td>
<td>Sum of each patch perimeter/area ratio divided by the number of patches (measures ‘shape complexity’ – amount of edge per area).</td>
</tr>
<tr>
<td>Building Size</td>
<td>Mean Patch Size (MPS)</td>
<td>The average building size.</td>
</tr>
<tr>
<td></td>
<td>Mean Patch Edge (MPE)</td>
<td>The average building perimeter.</td>
</tr>
<tr>
<td>Building Density</td>
<td>Mean Nearest Neighbour (MNN)</td>
<td>The average distance to the neighbouring building.</td>
</tr>
<tr>
<td></td>
<td>Patch Density (PD)</td>
<td>Building Density.</td>
</tr>
</tbody>
</table>

Table 7  Landscape Metrics used to describe building size, density, shape and number

Case study

Method 1: Building density/nearest neighbour

Building density maps were generated for structures in every satellite image available. The points dataset that was generated by the building point analysis (Indicator 5) was used as input to density and nearest neighbour algorithms in ArcGIS. The nearest neighbour statistics for June 2002 and February 2009 in Ban Nam Khem are presented below. The average distance between buildings fell by 1.62 m, suggesting that a lot of the buildings in Ban Nam Khem had been built back closer together than they were before the tsunami. The minimum nearest neighbour statistic also dropped by 3.01 m from 3.57 m to 0.56 m, indicating a significant change to some parts of the built environment. The density statistics are supplied for Chella Bandi; they show there was a greater density of buildings in post-disaster Chella Bandi than was seen before the earthquake. There was a 2.2% increase in density over the whole of the study area.
<table>
<thead>
<tr>
<th>Chella Bandi</th>
<th>Ban Nam Khem</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building density (b/ha)</td>
<td>Nearest neighbour (m)</td>
</tr>
<tr>
<td>August 2004</td>
<td>July 2009</td>
</tr>
<tr>
<td>5.81</td>
<td>12.63</td>
</tr>
<tr>
<td>Maximum</td>
<td>246</td>
</tr>
<tr>
<td>Average</td>
<td>14</td>
</tr>
</tbody>
</table>

Table 8  Building density statistics for Chella Bandi (buildings per hectare) and nearest neighbour statistics for Ban Nam Khem

The density maps for Chella Bandi and Ban Nam Khem are presented in Figure 5.24. The Ban Nam Khem maps show that the extent of the built-up area had expanded, especially in areas away from the coast developed by aid agencies. There was also an increase in building density in most of the government-built housing developments, but many of the areas near to the coast decreased in building density.

![Building Density maps for Chella Bandi (left) and Ban Nam Khem (right). Generated using remote sensing-derived building points combined with GIS analysis.](image)

A change detection map was created for both case study sites by comparing the pre-event image with the latest post-event image. These maps and statistics showed the overall change in building proximity, as well as ‘hot-spot’ areas where intensive building construction and deconstruction occurred. Figure 5.25 shows the hot-spot analysis and nearest neighbour change in Chella Bandi. There was a significant change in the building density and nearest neighbour to the north of Chella Bandi. These areas witnessed new settlements following the earthquake, mainly prefabricated housing units sited on land that was vacant before the earthquake. Most of these new buildings have remained in Chella Bandi, and have become permanent features. The hot-spot analysis was used to identify those areas with significant changes, targeted for in-depth analysis.
Figure 5.25 Building density (hot-spot analysis) and nearest neighbour change in Chella Bandi between 2004 and 2009. Red areas in the left map show an increase in buildings, with the right-hand map showing that this increase has reduced the distance of neighbouring buildings in these areas.

Method 2: Landscape Metrics

The Landscape Metrics were applied to a 250 m subset in the centre of Ban Nam Khem. The results show that the total number of buildings increased far beyond the pre-disaster number, but the building area returned to a similar level. The Perimeter-Area Ratio also increased, suggesting more complex building shape (possibly due to increased fragmentation – more buildings of smaller size), but Mean Shape Index (MSI) decreased slightly, suggesting less diversity in shape across the subset. Average building area and building perimeter decreased significantly by 2009 although immediately after the tsunami average building area increased, suggesting that small buildings were more vulnerable to being washed away than larger buildings.
To summarise, in this subset there are more buildings in February 2009 than there were before the tsunami, but the buildings occupy the same area: across the subset, the buildings are now smaller and more densely built. Building complexity across the subset increased, but the diversity of shapes slightly decreased due to standard building designs being used. Figure 26 shows various views of the subset in Ban Nam Khem studied with Landscape Metrics.

Figure 5.26  Landscape metrics applied to buildings in Ban Nam Khem throughout the reconstruction

Figure 5.27  A 3-D model of the centre of Ban Nam Khem was created to explore changes in the lighting and shading caused by the new building layout.
Discussion

This indicator is used to monitor changes to the urban layout and morphology of a disaster-affected region. Building density maps and nearest neighbour statistics are derived at a town-scale to describe the distance between buildings and landscape metrics are used to quantify changes to the total built-up area and to monitor the average density, size and shape of the buildings.

The creation of building density maps and nearest neighbour statistics both require the building points database created (Indicator 5: The Removal and Construction of Buildings). The points database was created by manually delineating individual buildings and so took several hours to create. If the building points are already available though, the building density maps and nearest neighbour statistics may be produced in 30 minutes and applied quickly across the whole affected region. The maps and statistics produced from this method give a synoptic view of the changes to the built environment throughout the recovery process. This method may also be used to identify new building developments and areas that have not been re-built.

The Landscape Metrics method creates detailed statistics on the total built-up area, and the average density, size and shape of the reconstructed buildings. Building design is likely to have a significant effect on the occupant’s life and their overall perception of recovery. Results from the household survey suggest that building size was a particularly important factor in determining whether the respondents believed their house was better or worse than before a disaster. The Landscape Metrics method may therefore be used to collect important data on the dimensions of the reconstructed buildings, which may also be used as proxies for monitoring living conditions and can be used to systematically monitor planned or invested developments.

Accuracy

The reliability of each technique is dependent upon the accuracy of the input data, e.g. the building points database used to create the density maps and nearest neighbour statistics, and the building footprints used to create the Landscape Metrics. The accuracy of the building point database was tested by comparing 50 GPS photographs to the number of buildings counted in the satellite imagery; an accuracy of 82% was obtained in Ban Nam Khem and 90% in Chella Bandi. For the building footprints used in the Landscape Metric analysis, the satellite imagery was able to extract building dimensions within a few metres-squared. Turkstra et al. similarly found that delineation underestimated building size by approximately 7 m² (N=91).

Time/staff costs

Building density and nearest neighbour analyses are quick to conduct if the building point database is already available from Indicator 5 and takes an hour. Calculating landscape metrics takes longer because the analysis is at a building scale, building footprints have to be delineated and the polygons entered into a GIS spatial analysis program, such as Fragstats or Patch Analyst. Significant experience of ArcGIS is needed to conduct these analyses.

Alternative tools

The household survey and focus group meetings were important sources of information about attitudes to the new homes. The households were asked if their homes were better or worse than before the disaster. The respondents answered “better” (15%), "same" (2%) or "worse" (56%). The major factor affecting peoples’ answers seems to be the size of the house. Most of the families living in government-built homes felt that they were worse off than before the tsunami. Size was not the only factor affecting people's level of contentment with their homes though. Other households thought that their property was not strong enough to resist another tsunami.
The focus group meetings in Ban Nam Khem also raised other reasons why people were unhappy with the new houses. Many were much farther away from their sources of livelihood. The new concrete homes were also hotter and lacked ventilation compared to the original wooden houses on stilts. Villagers also complained about less light, space and kitchen facilities. Some households had built stoves and makeshift kitchens outside of their government-built buildings. These observations show the importance of incorporating social audit techniques into a holistic monitoring process. Remote sensing can be used to quantify and triangulate these impressions and opinions.

Indicator 7. Quality of dwelling reconstruction

Justification

This indicator monitors changes to the size, shape, arrangement, location and context of a random sample of buildings, in this case 50 dwellings. In addition to their structural attributes, changes to the natural and built environment surrounding them are also examined. The aim is to describe the timing and quality of the building construction process and to infer occupant satisfaction. The use of suitable samples also allows the methodologies to be applied across large geographic extents.

Method

Fifty buildings were selected across the affected region using a random geographic sampling method. The sample included all possible building types, locations and different levels of damage and loss, and was non-stratified to avoid introducing bias.

A time-series of Very High Resolution satellite images was analysed to monitor the state of the buildings and associated features such as gardens, driveways and extensions. The building footprints were first delineated and changes in the size, shape and colour of the buildings were monitored using both manual and semi-automatic techniques. The date that reconstruction was completed was also recorded, as was the presence of nearby features such as gardens and driveways. The building and vegetation density within 50 m buffers of the buildings was also measured, as was the accessibility to important features such as schools, parks and commercial districts.

VHR satellite images contain a large amount of information about the buildings and the landscape surrounding them. Image analysts may utilise tone, colour, texture, shape, size, orientation, pattern, shadow silhouette, site and situation of objects. In a recovery context, this information may be used to determine the rate and pattern of reconstruction and to describe changes in the building design and urban form. This assessment of buildings and reconstruction will focus on four elements: structural attributes, stage of development, location and spatial context:

Structural attributes: Information about the structures themselves may be obtained by delineating the building’s footprint and monitoring changes within the boundary of the building. The size, shape and orientation of the buildings may be established, as well as the roof colour and roof material. In addition, any modifications or extensions to the building may also be identified. A post-reconstruction environment is often quite sterile due to the standard building designs used and the loss of historic designs: it is therefore very common for households to modify their properties. All of these attributes may then be integrated within a geospatial database and used to determine the speed of reconstruction and to infer information about the type of buildings that have been constructed.

Stage of Development: The progress of the construction process may be determined by monitoring the construction process and by identifying the clearance of land and the construction of foundations. A 6-stage development cycle was created, which can be analysed using VHR satellite imagery with a minimum resolution of 1.0 m. The development
cycle includes a stage where buildings have been seriously damaged and five stages of construction in chronological order from cleared land to buildings with modifications.

<table>
<thead>
<tr>
<th>1. Building demolished/collapsed</th>
<th>2. Empty site/Rubble Cleared</th>
<th>3. Foundations being laid</th>
</tr>
</thead>
<tbody>
<tr>
<td>4. Walls being constructed</td>
<td>5. Building completed</td>
<td>6. Further modifications and extensions</td>
</tr>
</tbody>
</table>

*Figure 5.28 Stages of building development at different sites in Ban Nam Khem*

**Location:** each building has a unique geographic location which may be mapped using its latitude and longitude. The location of the building is important for various reasons. It affects the environment in which the building is present (e.g. rural, suburban or urban), which ultimately determines its proximity to services, facilities and livelihoods. It also affects its proximity to nuisances and hazards such as busy roads, flood plains etc. Relocation can also divide once strong communities, breaking social bonds and contributing to long-term psycho-social issues. It is therefore important to monitor the relocation of households following a disaster. This may be achieved by monitoring the location of new developments, rebuilds and the location of vacant sites. The position of the building relative to the surrounding facilities and services may be analysed by assessing travelling times. The origin–destination (OD) cost matrix function in ArcGIS software can measure travel distances from the houses to multiple locations of interest, such as schools, health facilities, parks and major sources of income. The results are joined to the building database as building attributes and saved as a shapefile.

**Building context:** the state of the built and natural environment immediately surrounding a residential property may also have a large part to play in the household’s quality of life. In particular, the analyst should note the dominant land cover and the morphology of the urban form in which the building is located. In this study this is achieved by semi-automatically extracting the building density, nearest neighbour and vegetation density within a 50 m buffer of each structure. The quality and type of road structure within each buffer is also
extracted using a similar semi-automated technique. In addition, the analyst should note the layout of the surrounding built environment to determine if there is sufficient access to key facilities such as schools and enough space between each building. Information about the affluence of a neighbourhood may also be inferred by observing the presence or absence of key features such as: driveways, car parks, lawns, trees, crops, external buildings and swimming pools.

**Case study 1: Agency-built structure vs. army-built structure**

**Remote Sensing Analysis**

The following section presents a detailed comparison of two buildings constructed in post-tsunami Ban Nam Khem. One building was built by the army and the other was built by the Rotary Club. A detailed description of both buildings is provided using the remote sensing and household survey results. Table 9 lists the attributes for each building using remote sensing. A discussion follows describing how the buildings differ in terms of their size, shape, arrangement, location and context.

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Government-built House</th>
<th>Agency-built House</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location</td>
<td>98.276123, 8.863943 In the centre of BNK town.</td>
<td>98.271341, 8.857685 In a new development several hundred metres south of BNK.</td>
</tr>
<tr>
<td>Number of Units</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Garden</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Porch</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Driveway</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Garage</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Outbuildings</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Fence</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Extensions or Modifications</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Dimensions (m)</td>
<td>11 x 5</td>
<td>13 x 6.5</td>
</tr>
<tr>
<td>Building Size (m²)</td>
<td>55</td>
<td>51 (102 over 2 storeys)</td>
</tr>
<tr>
<td>Porch Size (m²)</td>
<td>---</td>
<td>35</td>
</tr>
<tr>
<td>Number of Storeys</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Shape</td>
<td>Rectangle</td>
<td>Rectangle</td>
</tr>
<tr>
<td>Roof Colour</td>
<td>Grey</td>
<td>Grey</td>
</tr>
<tr>
<td>Roof Type</td>
<td>Pitched</td>
<td>Pitched</td>
</tr>
<tr>
<td>Building Direction</td>
<td>North-east</td>
<td>East</td>
</tr>
<tr>
<td>Attached/Detached</td>
<td>Attached</td>
<td>Detached</td>
</tr>
<tr>
<td>Construction Type</td>
<td>Brick Masonry</td>
<td>Brick Masonry</td>
</tr>
<tr>
<td>Damage Type</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Reconstruction Type</td>
<td>New Build</td>
<td>New Build</td>
</tr>
<tr>
<td>Previous Land Use</td>
<td>Water and Grassland</td>
<td>Grassland</td>
</tr>
<tr>
<td>Distance to Park (m)</td>
<td>1433.9</td>
<td>1147.0</td>
</tr>
<tr>
<td>Distance to Fishing Pier (m)</td>
<td>543.9</td>
<td>1007.3</td>
</tr>
<tr>
<td>Distance to Commercial Area (m)</td>
<td>33.2</td>
<td>1110.2</td>
</tr>
<tr>
<td>Distance to BNK School (m)</td>
<td>691.5</td>
<td>665.1</td>
</tr>
<tr>
<td>Distance to Nuisances or Hazards (distance to shoreline) (m)</td>
<td>263.0</td>
<td>483.5</td>
</tr>
<tr>
<td>Building Density (Number of buildings within 50 m buffer)</td>
<td>Pre: 17 Post: 16 Feb 2009: 23</td>
<td>Pre: 0 Post: 0 Feb 2009: 24</td>
</tr>
<tr>
<td>Nearest Neighbour (m)</td>
<td>5.7 m</td>
<td>12.4 m</td>
</tr>
<tr>
<td>Vegetation Density (m² within 50 m buffer)</td>
<td>Pre: 1043.9 Post: 234.1 Feb 2009: 1171.7</td>
<td>Pre: 6935.1 Post: 83.2 Feb 2009: 113.4</td>
</tr>
<tr>
<td>Nearest Road Type</td>
<td>Asphalt</td>
<td>Asphalt</td>
</tr>
<tr>
<td>Road Length (within 50 m buffer) (m)</td>
<td>June 2002 (Asphalt): 139.4 June 2002 (Non Asphalt): 40.9</td>
<td>June 2002 (Asphalt): 0.0 June 2002 (Non Asphalt): 0.0</td>
</tr>
<tr>
<td></td>
<td>June 2009 (Asphalt): 139.4 Feb 2009 (Non Asphalt): 51.5</td>
<td>Feb 2009 (Asphalt): 0.0 Feb 2009 (Non Asphalt): 0.0</td>
</tr>
<tr>
<td>Vulnerability Score</td>
<td>Very High (4.3)</td>
<td>Moderate (2.3)</td>
</tr>
</tbody>
</table>

53
Table 9 Comparison of households living in army-built and agency-built structures

**Structural attributes:** The dimensions of the agency-built structure (including the porch area) are 31 m² (56%) bigger than the army-built structure. It also has 2-storeys compared to the army-built structure’s 1-storey. Ground survey work established that the army-built structures only consisted of 1 room with a separate space for a toilet. Many residents complained to the survey team about these building designs and had resorted to adding their own building extensions to these structures. In some cases, households also decided to vacate their houses altogether. The army structures are designed to hold no more than four people, subsequently providing less than 15 m² per person. Both structures are rectangular, with grey-pitched roofs which are important for drainage during the rainy season.

*Three-dimensional model of agency-built home in Google Sketch-up using building dimensions from VHR satellite imagery and texture from ground photographs.*  
*Inside an abandoned army-built structure in Ban Nam Khem.*

**Figure 5.29 Detailed case study using remote sensing and ground survey**

**Speed of reconstruction:** Both buildings were newly built on greenfield sites (grassland) that were previously unoccupied. The army-structure was built between April 2005 and July 2005 (only 7 months after the tsunami), while the agency building was finished sometime between February 2008 and February 2009 (3 to 4 years after the tsunami). The agency building therefore took approximately 30 months longer to organise and construct.

**Associated features:** The army building has no features associated with it other than a small space directly between its facade and the street, which contains a small table for reading and dining. In contrast, the agency structure has a garden, a porch (12.5 m²) and a driveway. There is also a lot more space surrounding the agency-built house. Neither of the structures have any other buildings or modifications associated with them.

**Location:** The army buildings were built in the centre of Ban Nam Khem, while the agency structures were built on the outskirts of the village. As a consequence, the agency structures are located farther away from the fishing piers and commercial area, but are still connected via a series of small roads. They are also farther away from the coastline and the harbour that has significantly reduced their vulnerability to tsunamis and storm surge. In contrast, the Government structure is more vulnerable, as it is located close to the shoreline and is thus a potential target for boats and other objects.

**Spatial context:** The army structure is facing a main road in a predominantly commercial area. The buildings in this area are mainly attached and the streets are relatively narrow (4.5 m) with no pavements, while the agency structure is in a residential neighbourhood comprised only of other detached 2-storey buildings. The structures immediately surrounding
the army building are more diverse in terms of their size and type, and its location means it has easier access to the commercial areas in Ban Nam Khem.

<table>
<thead>
<tr>
<th>Executing Agency</th>
<th>Agency House</th>
<th>Government House</th>
</tr>
</thead>
<tbody>
<tr>
<td>Losses</td>
<td>All assets lost</td>
<td>House totally destroyed</td>
</tr>
<tr>
<td>Move in date</td>
<td>December 2008 (4 years)</td>
<td>July 2006 (18 months)</td>
</tr>
<tr>
<td>Number of Members</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>Employment</td>
<td>Fishing industry. Remained fishing throughout recovery process</td>
<td>Fishing industry. Unemployed for one year</td>
</tr>
<tr>
<td>Income before</td>
<td>5,500 baht</td>
<td>5,500 baht</td>
</tr>
<tr>
<td>Income now</td>
<td>5,500 baht</td>
<td>5,500 baht</td>
</tr>
<tr>
<td>Compensation</td>
<td>None mentioned</td>
<td>60,000 baht (foundation)</td>
</tr>
<tr>
<td>Difficulty affording basic amenities</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>House better or worse than before tsunami</td>
<td>Better (because they now own a house; they previously rented)</td>
<td>Worse (the house is smaller than the one they used to own)</td>
</tr>
<tr>
<td>Land ownership before the tsunami</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Involvement in construction process</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Food Aid</td>
<td>One year</td>
<td>Six months</td>
</tr>
<tr>
<td>Power supply Restored</td>
<td>December 2008</td>
<td>October 2006</td>
</tr>
<tr>
<td>Water supply Restored</td>
<td>December 2008</td>
<td>December 2006</td>
</tr>
<tr>
<td>Problems</td>
<td>Decline in fish stock</td>
<td>Decline in fish stock, Rusty water supply, Low electricity current</td>
</tr>
<tr>
<td>Desire to move from Ban Nam Khem?</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Content with speed and quality of recovery?</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Table 10 Comparison of army-built and agency-built homes using household survey data

In the following section, recovery narratives for the households living in the same agency-built structure and army-built structure are presented based on their responses to the household survey. Table 10 presents a summary of the household survey results from the two properties. The results were used to validate the remote sensing analysis and to compare remote sensing and household surveys as data collection tools.

The results highlight how a household survey may be used to create a recovery narrative. The time taken to construct the buildings differed significantly: the agency building took over twice as long to plan and construct. The household survey was used to obtain information on the livelihoods of the households. Both households depend on fishing and earn 5,500 baht a month. They were both fishing again at the time of the survey earning the same amount they were earning before the tsunami. The household in the army-built structure were unemployed for one year after the tsunami but received 60,000 baht compensation from various foundations. The agency household continued to work in the year after the tsunami but did not receive compensation and therefore had difficulty affording basic amenities. The agency household thought their property was better than before because they now own a property instead of renting. The household living in the government property believed their property was worse because it was smaller. They also complained of a rusty water supply and low electricity current.

In summary, the agency housing took longer to construct but the final building was larger with no problems with water and power supply. It seems that the army could have prioritised speed over quality with regard to their approach to construction. This has led to dissatisfaction with the army-built structures. In contrast, the Rotary Club involved the households in the construction of their own homes and this has contributed to an overall sense of satisfaction despite the long construction and planning time. Many households in Ban Nam Khem complained about the unfair allocation of resources. This case study
highlights how one household that was previously renting is now in an arguably better situation than they were before the tsunami (in a bigger house with better water and power supply). It seems that this has led to discontent amongst many residents.

Case Study 2: Remote sensing analysis of the 50-building sample

Further remote sensing analysis was applied to fifty buildings selected across Ban Nam Khem using a random geographic sampling method. The sample encompassed all possible building types, locations, socio-economic statuses and different levels of damage and loss. Figure 5.30 shows a map of the fifty buildings and a thumbnail of each building derived from the satellite imagery.

![Figure 5.30 Fifty households were analysed across Ban Nam Khem](image)

**Structural attributes:** Of the fifty buildings analysed, 24 were present before the tsunami and 26 are new. Of the 24 buildings that were present before the tsunami 15 were rebuilt and 9 were repaired. The average size footprint of the building sample before the tsunami was 98m². After reconstruction, in February 2009, average size had increased by 18m² to 116m². This difference, however, is not statistically significant. Of the 15 buildings that were rebuilt, nine were bigger than they were before the tsunami, four the same size; only two were smaller. However, these findings are sensitive to the sample selected. An analysis of a 250m square grid in the centre of Ban Nam Khem suggested that the average size of residential and non-residential buildings had decreased by 52 m².

The proportion of buildings with driveways, gardens and extensions increased after the tsunami, but these features were almost exclusively associated with non-government built structures. Many of the agency structures were also built with 2-storeys compared to the single-storey government structures. These differences led to disparity across Ban Nam Khem with some groups benefiting more than others and has led to discontent amongst some residents. The proportion of detached buildings increased from 58% to 72% because the building designs used by the government were predominantly detached. It is unclear why the Government adopted detached building designs, but this might contribute to greater privacy despite the overall increase in building density. Finally, the proportion of red and blue roof tiled buildings also increased as a result of the reconstruction. Before the tsunami, 92% of the sampled buildings had grey roof tiles, and afterwards 84%. Buildings with red tiles appear to correspond to more affluent housing and to buildings with mixed uses.

<table>
<thead>
<tr>
<th>Pre-disaster %</th>
<th>Post-disaster %</th>
</tr>
</thead>
<tbody>
<tr>
<td>58</td>
<td>72</td>
</tr>
<tr>
<td>92</td>
<td>84</td>
</tr>
</tbody>
</table>
Table 11  Changes in building structure in Ban Nam Khem

Of the 50 sampled houses, half of them had modified or extended their property in some way. Seventeen households had built the extensions themselves, thirteen of which were in the form of a corrugated iron overhang to the side of the building built to provide additional cover from the rain and the sun and four were solid. Eight other extensions were built by Worldvision between November 2006 and February 2008. The average area of the buildings that had extensions was 105.1 m², which is smaller than the average size of the buildings that didn’t receive extensions (118.4 m²). It is still true that some of the buildings that didn’t receive extensions were smaller than those that did receive extensions.

<table>
<thead>
<tr>
<th></th>
<th>Pre-tsunami %</th>
<th>Post-tsunami %</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Driveway</td>
<td>92</td>
<td>66</td>
</tr>
<tr>
<td>Garden</td>
<td>100</td>
<td>84</td>
</tr>
</tbody>
</table>

Table 12  Associated features in Ban Nam Khem

Figure 5.31  Building extensions were common features in the post-construction landscape.

Stage of development: Most housing (78%) was constructed within 1 year of the tsunami. This is due to the army’s quick deployment and construction approach. The ITV housing, outside of Ban Nam Khem, was also constructed quickly with many structures completed by April 2005. The agency-built developments, however, took longer with some developments such as the Phase 2 housing not commencing until 2 years after the disaster, presumably because it took time to find and purchase appropriate land for construction and to raise the required capital. Army built homes were constructed within 7 months of the tsunami while agency-built homes were built 3 to 4 years after the tsunami.

Location: The government housing was rebuilt on their original location, and therefore maintained close proximity to the services and facilities in the centre of Ban Nam Khem, while the agency structures were built predominantly outside of Ban Nam Khem, leading to
significant changes to the lifestyle of a household. However, vulnerability to future tsunami has been significantly reduced by moving homes farther from the coast.

The position of the building relative to surrounding facilities and services may be analysed using GIS software to measure travel distances from homes to schools, health facilities, parks and work places. Between June 2002 and February 2009 the mean distance from homes to the market in the centre of Ban Nam Khem increased from 830 m to 2.1 km, with the Pruteow housing as far as 10 km. Such significant changes to residential location affected access to temples and schools. It also divided the pre-tsunami population into discrete populations located across Phang Nga Province.

Spatial context: The built and natural environment surrounding the property affects quality of life. Building and vegetation density within a 50 m buffer of each structure was semi-automatically measured. Information about the affluence of a neighbourhood may be inferred from plot size, building size, car parking, vegetation and other associated features.

![Figure 5.32 Building density and road layout in Ban Nam Khem](image)

Rebuilds in the Centre of Ban Nam Khem | New Builds on the Outskirts of Ban Nam Khem

Reconstruction between June 2002 and February 2009 led to an increase in housing density of 39% and a reduction in vegetation of 28%. The construction of new homes in particular led to significant vegetation reduction as they were predominantly built on greenfield sites.

Case study: Chella Bandi

The same forensic remote sensing analysis was applied to Chella Bandi, with a random sample of 50 buildings chosen from the building points database (Figure 5.33). Of the buildings analysed, 15 were present before the earthquake and 35 were new buildings. Of the 15 pre-earthquake buildings, only one was destroyed then later rebuilt. One new build had been completed between 2004 and 2005, with the remaining 34 new-builds constructed between 2006 and 2008, of which 5 were temporary buildings not present in 2004 and removed by 2009. 14% of all new-builds were identified as tent structures normally associated with temporary settlements, all but one of which were still present in the 2009 imagery.

38% of the buildings sampled were detached. The majority of buildings only had access to an unpaved road, and only 14% adjoining a sealed, asphalt road. This is representative of the whole of Chella Bandi, as described in the Accessibility indicator. The high proportion of dirt tracks and paths made counting driveways unfeasible. Most vehicles were parked near to buildings, but it would be inconclusive to infer affluence based on number of vehicles relating to the building in Chella Bandi and similar communities.
Discussion

The analysis demonstrated that the detailed information available in satellite imagery throughout the recovery process may be used to quantitatively monitor reconstruction so that the work of the executing agencies may be evaluated. The attributes measured by this indicator can be used to describe the building and its location, the speed of construction and the state of the surrounding natural and built environment. Although more work is required to determine how these elements contribute to levels of household contentment, the findings from the household survey suggests that the size of the building, access to facilities and services, the distance to potential hazards and the time taken to reconstruct the building are highly significant.

The remote sensing analysis was applied to residential buildings but the technique might also be applied to service buildings such as schools and places of worship. Using appropriate sampling methods, this indicator could be measured relatively quickly. The indicator also re-uses several data layers created for other indicators which speeds up the processing time. For example, road condition (Indicator 1), building points (Indicator 5) and vegetation maps (Indicator 12) were all originally produced at town/city scale and are reused for this indicator. Most of the semi-automatic processes can also be applied to all of the buildings at once by batch processing, which further reduces the processing time.

The level of technical ability required to perform these analyses is different for each attribute. Some attributes, such as roof colour and shape, simply require the analyst to visually interpret the building features and compare them to the pre-disaster state. Basic GIS experience is still required though in order to store and analyse the building database. The semi-automatic extraction of vegetation and building density and accessibility statistics requires good expertise of software such as ArcGIS, as the technique involves the spatial analysis of point and line vector datasets and the zonal analysis of raster datasets. Experience of remote sensing software such as ERDAS Imagine or ENVI is also necessary to run the NDVI algorithm and to produce maps of vegetation.

Comparison of tools

The case studies in this report highlight how a vast amount of information may be obtained about a household throughout recovery using both remote sensing and household surveys. Remote sensing was used to monitor changes to the size, shape, arrangement, location and
context of buildings. The household survey obtained information about changes to the socio-economic and demographic make-up of the households. Key information about their registration status and land entitlement was also established. In addition, it was used to produce a recovery narrative describing when key events happened and to infer their perception of recovery by identifying any problems residents faced and how the process of recovery could have been improved. Important information was also obtained about the households’ source of livelihood and any support they received, and it highlighted problems with the provision of utilities that were unobservable with remote sensing. In hindsight, there were several important aspects of recovery that were missed from our survey; these include the security of the households, their experience of crime throughout the recovery process and their participation in the community.

The household survey results show that both the size and the location of the buildings, for example their proximity to the coast and fishing facilities, were important factors in the households’ perception of recovery. Both of these attributes were objectively measured in satellite imagery in a quantitative manner. In fact, remote sensing was able to quantify changes to the proximity and connectivity of households in both Ban Nam Khem and Chella Bandi and households that were relocated elsewhere. Households that had been relocated outside of Ban Nam Khem have generally found it difficult to continue making a living in the fishing industry and felt disconnected from the village. The small size of the building was also a major factor contributing to the households’ discontent with the army-constructed buildings. Remote sensing was able to objectively show that an agency structure had a floor space 68% larger than the army-built structure. Both remote sensing and a household survey were used to estimate when the occupants moved into their houses. The agency household told us that they moved into their home in December 2008, which matched remote sensing’s estimate of a move in date between February 2008 and February 2009. The government household told us that they moved in July 2006 while remote sensing estimated a move in date between April 2005 and July 2005. This shows that the occupancy of a building cannot always be confidently determined with satellite imagery alone. It is known that with more images captured at <1 year intervals, the remote sensing estimates of these dates would improve further.

Ground survey work, such as the utilisation of geo-referenced photo and video equipment, may be used to collect detailed street view data. This data may be used to validate some remote sensing attributes such as the occupancy and the number of storeys. It may also be used to conduct a basic structural assessment of the structure by identifying the building’s material and structural type. Finally, detailed observations of the building facade and the area surrounding the building may be used to identify signs of general prosperity or degeneration. Visible signs of degeneration might include broken windows, vacant buildings and overgrown vegetation.

In summary, the household survey was able to capture unique information that was not possible in Remote Sensing, such as income, source of livelihood, the date water and power supplies were restored, and overall contentment levels with the recovery process. Assumptions could be made about a household’s overall contentment with their house and overall perception of recovery based on key measurements made with remote sensing such as the building size, the presence of a garden and its location and connectivity. For example, households living in bigger structures with a porch, garden and driveway were often the most content. Participation of the household in the construction of the house also appears to have been an important factor in ensuring overall contentment. The results from the remote sensing may be used to map the unequal allocation of building size and types across Ban Nam Khem. Recommendations may be made to improve future recovery work based on these results. It is important to recognise that good building design does not automatically equate to a good recovery. A full evaluation should also take into account issues such as affordability, environmental performance and the availability of a mix of building typologies.
Temporary accommodation and internally displaced persons

Introduction

This chapter introduces an extensive suite of indicators designed to 1. Identify temporary forms of accommodation, 2. Measure their longevity, infrastructure placement and environmental impact and 3. Estimate the population residing within them.

Indicator 8. Temporary accommodation

Justification

The arrival of emergency shelters immediately after a disaster and the transition into temporary and then permanent housing are obviously hugely significant for the affected population. A successful recovery will ensure that people are not staying in makeshift camps or temporary accommodation for longer than is necessary. The UNHCR, the UN agency responsible for refugees, has increasingly recognised the potential of remote sensing and GIS to locate suitable campsites and to plan and monitor camp layout, infrastructure placement and environmental impact. The following section shows how remote sensing may be used to monitor and evaluate planned camps after a disaster.

Method

This indicator maps the extent and the distribution of tents, makeshift shelters and transitional camps in a disaster-affected area. Building footprints are manually delineated as for Indicator 7 Quality of Dwelling Reconstruction and landscape metrics used to quantify the physical morphology of the camps. A narrative is then produced to describe the presence and absence of temporary buildings and encampments throughout the recovery process. The overall progress and speed of the recovery process may be inferred by measuring the camps’ longevity, spatial layout and building composition.

Remote sensing analysis can also be used to produce up-to-date maps of the camps and shelters, displaying the location of buildings, roads and other major topographic features and land cover. For a more detailed analysis, smaller features such as food and water distribution points may also be mapped by ground workers and integrated into the database. Spatial analysis of these features can be used to ensure that shelters, water taps, latrines, health facilities, waste bins and lighting structures are in the required locations. Furthermore, proximity analysis can ensure access to key utilities meets agreed standards, for example the recommendations of the Sphere Guidelines and the UNHCR’s Handbook for Emergencies. The minimum covered living space per person and the minimum surface area per person can also be monitored with satellite imagery. These standards are important to control the spread of disease and to prevent overcrowding.

<table>
<thead>
<tr>
<th></th>
<th>Dwellings to Water (Max) metres</th>
<th>Water to Latrine (Min) metres</th>
<th>Shelter to Latrine (Min/Max) metres</th>
<th>Living Space m² per person (Min) metres</th>
<th>Surface Area m² per person (Min) metres</th>
</tr>
</thead>
<tbody>
<tr>
<td>UNHCR</td>
<td>100</td>
<td>30</td>
<td>30/100</td>
<td>3.5</td>
<td>30</td>
</tr>
<tr>
<td>NRC</td>
<td>150</td>
<td>30</td>
<td>30/100</td>
<td>3.5</td>
<td>30</td>
</tr>
<tr>
<td>Sphere</td>
<td>500</td>
<td>30</td>
<td>30/50</td>
<td>4.5</td>
<td>45</td>
</tr>
</tbody>
</table>

Table 13 Recommended camp standards: UNHCR, Sphere Project and Norwegian Refugee Council

The environmental impact of the site may also be monitored with up-to-date maps showing changes to major topographic features and land cover classes. In particular, Normalised Difference Vegetation Index (NDVI) maps and change detection techniques may be applied...
to monitor signs of erosion, the build up of waste, the return of vegetation and the removal of materials and structures. The gathering of wood and the concentration of livestock around some camps has been a major cause of environmental degradation in the past. In addition to its role as a monitoring tool, GIS and remote sensing can be used to assist site selection and planning. The potential for monitoring temporary buildings and internally displaced populations (IDPs) with remote sensing is summarised in the following table:

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Description</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1  Coordinates</td>
<td>The camp’s geographic position (latitude, longitude).</td>
<td>Required to map the distribution of Internally Displaced People (IDP).</td>
</tr>
<tr>
<td>2  Location</td>
<td>A description of the camp’s location and the previous function of the buildings and land it is occupying (e.g. school grounds).</td>
<td>To ensure that the camps aren’t occupying important public land, such as school grounds, for longer than is necessary.</td>
</tr>
<tr>
<td>3  Size of camp</td>
<td>The length and width of the camp in metres.</td>
<td>Allows the capacity of the camp to be estimated.</td>
</tr>
<tr>
<td>4  Accessibility</td>
<td>The level of accessibility to the camp e.g. available transport links and the distance of the camp from the affected region.</td>
<td>Accessibility is crucial for the import of resources. In many cases, people want to be kept close to their home to assist with its maintenance and reconstruction.</td>
</tr>
<tr>
<td>5  Number of structures</td>
<td>The total number of buildings within each camp, and the date that they were constructed and dismantled.</td>
<td>The progress of the recovery process may be inferred from the presence and absence of emergency and transitional shelters.</td>
</tr>
<tr>
<td>6  Building Description</td>
<td>Building categorisation according to shape, size, spatial context and roof colour e.g. tent, tarpaulin, transitional shelter etc. If possible, gauge building use from these physical attributes.</td>
<td>Building use indicates which facilities and services may be available within the camps (this information may be supplemented and validated by ground workers).</td>
</tr>
<tr>
<td>7  Building Morphology</td>
<td>The average building size and building density may be extracted using the tools described in Indicator 6 Change in Urban Land use and Morphology.</td>
<td>Living standards may be inferred from building size, camp layout and building density statistics.</td>
</tr>
<tr>
<td>8  Proximity Analysis</td>
<td>The distance between structures and features within the camp may be monitored using proximity analysis.</td>
<td>With the integration of ground data the spatial distribution of shelters, water taps, latrines, health facilities, waste bins and lighting structures may also be analysed.</td>
</tr>
<tr>
<td>9  Population</td>
<td>The number of people residing in Emergency Shelters and Transitional Buildings (see Indicator 9. Location of the Population).</td>
<td>A successful recovery will ensure that people are not living in temporary buildings for longer than is necessary, and will ensure that people do not become dependent upon the services provided by the camps.</td>
</tr>
<tr>
<td>10 Contents of the camp</td>
<td>Description of other visible features and services within the camp e.g. boat yard, water tower.</td>
<td>Location of services may be acquired with ground surveys and integrated with remote sensing-derived maps.</td>
</tr>
<tr>
<td>11 Green Spaces</td>
<td>The presence of vegetation (gardens, parks, crop patches) within the camp.</td>
<td>Trees provide shade and pleasant surroundings and crops provide food and an income for inhabitants.</td>
</tr>
<tr>
<td>12 Environmental Impact Assessment</td>
<td>The condition of the site before and after the camp has been dismantled mapped with Normalised Difference Vegetation Index (NDVI) and Near-Infrared (NIR) false colour composite images.</td>
<td>Monitor signs of erosion, the build up of waste, the return of vegetation and the removal of materials and structures.</td>
</tr>
</tbody>
</table>

Table 14 Attributes of transitional camps that can be monitored using remote sensing
Case studies

The techniques used to identify temporary buildings in each of the case study sites varied according to the housing allocation approach adopted by the different administrations. The Shelter Project identified six settlement choices available to displaced people, which were divided into two categories: dispersed settlement and grouped settlement. In Ban Nam Khem, a grouped settlement approach was adopted, with large temporary buildings located within planned camps which were identifiable using visual analysis due to the buildings’ unique shape and morphology. In Chella Bandi, a dispersed strategy was used with detached temporary buildings distributed throughout the village. Areas with significant numbers of temporary structures were identified by applying change detection analysis to the building point database.

Several areas of interest were delineated and mapped in both case studies, using physical features such as roads and vegetation to demarcate the boundaries of individual areas. Each building footprint was subsequently digitised using a GIS, creating a map for each image date. The process was repeated for every time period, allowing the generation of multi-temporal descriptive statistics. The techniques identified four transitional camps in-and-around Ban Nam Khem and thirteen areas of interest in Chella Bandi. Figure 5.34 shows the changes in the composition of four of these in Chella Bandi.

![Image of maps showing changes in building morphology]

*Figure 5.34  Changes in building morphology in Chella Bandi*

The number of buildings present in each area may be represented in absolute or proportional terms. As an example, Figure 5.35 shows the proportion of temporary and permanent buildings in Chella Bandi’s University AIO and the absolute number of buildings at the School Camp in Ban Nam Khem.

Ban Nam Khem School Camp contained 92 temporary structures, 85 (92%) of which were built between January 2005 and April 2005 and 71 (77%) were removed by November 2006 (less than 2 years after the tsunami). In February 2006, the large transitional shelters were in the process of being dismantled suggesting that a great proportion of the camp’s inhabitants had begun to move to permanent housing by this time.
The university area in Chella Bandi experienced significant change during the studied period. A pre-event total of 44 structures rose sharply to 374 in the weeks following the earthquake. Of these, 88% were seen to be temporary structures. The numbers decreased gradually between 2005 and 2006, with a sharper decline from 2006 to 2009. Approximately 60 structures remained on the site in 2009 (four years after the earthquake).

![Building numbers for the University in Chella Bandi and School Site in Ban Nam Khem](image)

**Figure 5.35 Building numbers for the University in Chella Bandi and School Site in Ban Nam Khem**

**Detailed case study: Ban Nam Khem School Camp**

A detailed analysis was produced for each of the camps, which included information on their location, longevity, use and environmental impact. By way of example, a summary of the Ban Nam Khem School Camp analysis follows. The camp was located on the playing fields of Ban Nam Khem School between April 2005 and November 2006. The accessibility to the camp was good due to its central location, less than 1 km from the inundated part of the village. New roads were also constructed within the camp to provide suitable access. Maps of the camp and the surrounding area are shown in Figure 5.36.
Building use: Ban Nam Khem school camp was a relatively large, sophisticated camp with facilities for housing, cooking and sanitation, and services to support livelihood and physiological recovery. Figure 5.37 shows building use based on the physical attributes of buildings, their location and context.
Space standards: The camp measured approximately 50,000 m² (250 m x 200 m). The number and size of the transitional shelters was used to estimate a population of 720. This corresponded to a surface area of 69 m² per person, which is over 50% higher than the Sphere Guidelines recommend. The covered living space was estimated to be 4.6 m² per person, which is equal to the Sphere Guideline recommendations.

Environmental assessment: Vegetation and lines of trees can be seen within the camp, which would have helped to provide a more pleasant, natural environment and could have provided natural shelter from the elements for inhabitants. By February 2008, the site was restored to its former function as a playing field for Ban Nam Khem School. All materials and structures were removed and the vegetation remained intact in the surrounding area. Vegetation also began returning where structures once stood. Figure 5.38 shows False Colour Composite maps of the camp in 2005 and 2008, with vegetation displayed in red.

![Figure 5.38 BNK School Camp showing removal of temporary homes and restoration of playing field](image)

Change detection analysis was applied to NDVI maps of the camp to identify areas of land degradation. Figure 5.39 shows the change in thick vegetation cover between June 2002 (before the tsunami) and February 2009 (after the camp was dismantled). There was a significant amount of degradation in-and-around the newly constructed school buildings, but most of the campsite itself has returned to its pre-tsunami state.

![Figure 5.39 BNK School Camp. Green = vegetation; Brown = degraded](image)
Potential problems: The layout of the camp appears to provide very little space between the structures. The distance between some of the smaller structures is approximately 1.5 m, which may not be enough to ensure privacy for the residents or as an access route for emergency vehicles.

Positive aspects of camp: Despite being near to the site of a large school, the camp does not appear to have directly impeded the running or construction of the school, other than the temporary loss of its playing fields. The camp is compact, minimising walking distances and appears to be contained within a barrier to reduce potential security risks. All kitchen and sanitation facilities are assumed to be within the main part of the camp, so are no more than 60 m from the residential quarters; other facilities, such as the boat yard are no more than 200 m away. The overall arrangement of the camp and the clear-up afterwards appears to have been good. The map below shows several of the UNHCR and Sphere camp design recommendations being spatially validated using a hypothetical camp layout.

Figure 5.40  UNHCR and Sphere Guidelines applied to BNK School Camp

Discussion

Remote sensing was used to identify and map the physical attributes of the camps, such as the number of buildings and their spatial dimensions, and a description of the camp was derived by measuring attributes such as building density, surface area per person and the availability of green space. These data can act as important proxies for living standards, information that is not always easily available from agencies. Remote sensing can therefore provide an independent assessment of the camp size and its contents. However, it cannot always distinguish the extent to which the camp is in use.

The amount of time required to complete the analysis depends on the size and complexity of the camps and the amount of information and detail required by the user. In Ban Nam Khem, a 250 m x 250 m camp containing 92 structures took approximately 2 hours to analyse for each image. This is substantially less than a ground survey would take. In Chella Bandi, buildings distributed across 4 km² took 30 hours to delineate. Experience with satellite imagery is preferred to perform the visual interpretation work accurately and is necessary to create the Normalised Difference Vegetation Index (NDVI) and Near-Infrared (NIR) False Colour Composite images.

Table 15 presents a summary of the results obtained for the Bang Muang Sub-District Office Camp by remote sensing and compares them to official statistics published by various
sources. Remote sensing provides a highly reliable source of data for the description of structural and environmental changes within a camp. The existence of the Bang Muang camp was identified within a day of its official opening date. Remote sensing also identified the same number of tents at the camp as reported in the official statistics and underestimated the number of temporary shelters by only 6%. Similar levels of accuracy were obtained for the number of living units in the other camps in Ban Nam Khem. Remote sensing correctly estimated the number of dwellings at the temple and school camps and overestimated the number of dwellings at Pruteow by a mere 4%.

<table>
<thead>
<tr>
<th></th>
<th>Official Statistics</th>
<th>Remote Sensing</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Camp Size</strong></td>
<td>112,000 m² (CODI Survey)</td>
<td>135,000 m² (300 m x 450 m)</td>
<td>+ 20.5 %</td>
</tr>
<tr>
<td><strong>Date Opened</strong></td>
<td>1 January 2005 (300 people registered on the first day) (CODI Survey)</td>
<td>On 2 January 2005, there was plenty of evidence to suggest the presence of a camp: 3 large tents and 6 lorries were present and 150 small tents had been erected.</td>
<td>+ 1 day</td>
</tr>
<tr>
<td><strong>Tents</strong></td>
<td>500 tents (BNK book)</td>
<td>500 tents</td>
<td>0 %</td>
</tr>
<tr>
<td><strong>Small Shelters</strong></td>
<td>80⁵⁴</td>
<td>75</td>
<td>- 6.3 %</td>
</tr>
<tr>
<td><strong>Shelter Dimension</strong></td>
<td>3.5 x 5m⁵⁵</td>
<td>3.5 x 5 m</td>
<td>0 %</td>
</tr>
<tr>
<td><strong>Shelter Material</strong></td>
<td>Temporary houses were built in long rows with rubber tree pole frames, plywood or fibre-cement panelled walls, corrugated tin sheet roofs and windows of hinged plywood panels.</td>
<td>Buildings in long rows with corrugated roofs.</td>
<td>Building morphology and roof material correctly identified, but a detailed description of building type and quality must be obtained from ground survey work.</td>
</tr>
</tbody>
</table>

Table 15 Accuracy of remote sensing compared to official statistics for Bang Muang Camp

Although the number and type of buildings can be identified with some confidence using remote sensing, establishing building use with remote sensing alone is more error prone. For example in Ban Nam Khem School Camp, a large blue structure was correctly identified as a boat yard but what seemed like a communications tower and satellite dish were actually a tsunami warning tower and a water tower. Figure 5.41 compares a hand drawn map of Bang Muang Camp with a map produced with remote sensing. They show that the remote sensing image more accurately maps the camp’s layout but that the hand drawn map contains information about building use that cannot be inferred from the remote sensing map, suggesting that satellite image-derived maps must ideally be populated with data from the ground.
The registration process also offers a good opportunity to collect useful data. A significant amount of information about temporary camps in Phang Nga province was published by the agencies that worked in them. For example, a survey coordinated by the Community Organisations Development Institute (CODI), a Thai Government agency, captured detailed data on the demographics of the camp occupants on 01 January 2005 as the households were registered. The survey covered a wide range of topics including: employment status, house/land ownership, damage and losses, and health and education requirements – data that is unattainable with remote sensing.

Ban Nam Khem and Chella Bandi

The strategy used to provide temporary accommodation in Chella Bandi and Ban Nam Khem was very different. In Thailand, temporary dwellings were provided within the confines of planned camps, while temporary shelters were dispersed throughout the city of Muzaffarabad. This created different challenges in terms of monitoring the evolution from temporary accommodation to more permanent solutions. The different strategies appear to have also had a significant effect on the success of housing allocation. Figure 5.42 shows the number of temporary buildings in Ban Nam Khem and Chella Bandi. The graph shows a huge number of temporary shelters were created in Chella Bandi, compared to the pre-event state, peaking at 8 months from the disaster, with a steady decrease in numbers beyond this point. In the latest (2009) image, significant numbers of buildings were identified as temporary structures that had become permanent. Similar trends were seen for Ban Nam...
Khem, with a sharp increase in temporary shelters in the months following the tsunami. The overall numbers were lower than in Chella Bandi, possibly due to population differences between the two areas. However, the number of temporary encampments was reduced to almost zero 3-5 years after the event. From the remote sensing perspective, IDP camps appeared to be more centrally coordinated in Thailand than in Pakistan, resulting in the effective redistribution of the population into permanent homes. The reasons why this does not appear to have happened in Chella Bandi are less clear, due to a lack of ground validation data in this area.

Figure 5.42  Comparative recovery trends in temporary structures: Ban Nam Khem and Chella Bandi

The creation of transitional camps in Phang Nga province, Thailand was praised because of the way it drew everyone together and allowed people to take control of their own recovery. Logistically, it also allowed the provision of supplies to be made a lot easier. Some people preferred to stay close to their homes to protect and reconstruct them. In Pakistan, compensation was paid to occupants but they were prevented from building permanent homes. The compensation was subsequently spent, and in many cases, the temporary homes became permanent.

The observations were validated to some extent with field data. But less field data was available for Chella Bandi, leading to lower confidence levels. For example, it was not possible to attribute the use or occupancy of each temporary structure in the university AOI, as field information was lacking in the immediate aftermath of this disaster. Also, the field visits carried out in 2009 provided only a single photograph of this area. Identifying temporary buildings also became problematic in Chella Bandi when it became apparent that some of the temporary builds were becoming permanent. Recent disasters such as the 2010 Haiti and Chile earthquakes have seen crowd-sourcing methods emerge to map amorphous phenomena such as IDP camps, with the location, layout, administration and functionality all mapped through initiatives such as OpenStreetMap.

Indicator 9. Population

Justification

A key factor of post-disaster impact assessment is to identify the number of people affected in the immediate aftermath. This information is particularly important to inform the allocation of resources and the decision-making process so appropriate resources may be sourced and provided throughout the recovery process. The population living in temporary accommodation must also be monitored frequently to ensure people are re-housed in sufficient time and not living in temporary shelter for longer than is necessary.
Method

This indicator estimates the number of people in temporary and permanent accommodation throughout the recovery process focusing particularly on the number of Internally Displaced Persons (IDPs) housed in emergency or temporary shelters. The population is estimated by multiplying the number of dwellings by the number of people thought to be occupying each dwelling. The number of dwellings is derived from the building point database created as part of Indicator 7 (Quality of dwelling reconstruction). To distinguish residential and non-residential buildings a land use map is integrated into the analysis. Each land use category is assumed to contain a different proportion of residential buildings. The population affected by a disaster is then estimated by overlaying hazard information, such as earthquake intensity or water inundation zones.

The number of people in temporary accommodation is again estimated by multiplying the number of residential dwellings by the number of people assumed to be occupying each dwelling. Residential buildings are distinguished from other buildings by their shape and morphology. In Thailand, there were two common temporary housing designs: a) elongated, rectangular buildings containing multiple dwellings and b) single square units. The number of dwellings in an elongated unit was derived from field survey data that showed dwellings of this type had a width of 4m giving a total area per household of 14-18 m$^2$.

Case study: Ban Nam Khem

Population in permanent accommodation

According to the Bang Muang Sub-District Office, before the tsunami Ban Nam Khem had a registered population of 4,600 people and an estimated non-registered population of approximately 1,500, i.e. a total population of 6,100. In June 2002, the remote sensing analysis identified 1,215 buildings in Ban Nam Khem. The average household size in 2000 for Phang Nga province from the Population and Housing Census was 3.7. However, this province-wide average may underestimate average family size in Ban Nam Khem, especially if the non-registered population of mainly migrant Burmese fishermen was not included. Average family size at the time of the tsunami from household survey estimates was 5. But this survey was of a small sample of only 50 households (the statistical error is 13.8%, with 95% confidence levels).

Using figures from the household survey and assuming each building contained a single household, the estimated population would be 6,075 ($1,215 \times 5$). This is very close to the official estimate of 6,100. However, not all the buildings are residential. By incorporating the land use map into the analysis, the method estimated that 65% of the buildings are dwellings, which corresponds to a population estimate of 4,066 ($1,251 \times 0.65 \times 5$). This underestimates the pre-tsunami population by a third. Either the official estimate of the number of non-registered migrant workers is wrong or a large proportion of families were living in non-residential buildings, for example in shop or work premises. Using the same methodology, the population in February 2009 was estimated by remote sensing to be 6,131, but there are no data available to verify this estimate.

Affected population

Not everyone in Ban Nam Khem suffered directly from the tsunami and it is important for those agencies involved in recovery to estimate the number of people who were affected by the disaster. It was possible to map the extent of the tsunami and to incorporate a map of the inundated area with the pre-disaster building point data and the land use map to calculate the population affected. The inundated area was defined by tracing around the land scarred by the tsunami. This method estimated there were 602 residential buildings within the inundated zone. Multiplying this by a household size of 5 equates to about half the population or about 3,000 people. According to DDPM, 2,969 people were living in transitional accommodation in Phang Nga province, an error of 1%. By subtracting the
number of people estimated to be affected by the tsunami from the total estimated population we may assume that approximately 1,000 people were able to continue living in their permanent homes after the tsunami. Figure 5.43 shows a land use map of Ban Nam Khem which was created by manually delineating blocks of buildings based on their morphology and ground knowledge. The building point database and the tsunami inundation zone are also overlaid on top of the map.

<table>
<thead>
<tr>
<th>Zone Name</th>
<th>Residential %</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential</td>
<td>100</td>
<td>Blocks of residential new builds e.g. phase 1 and 2</td>
</tr>
<tr>
<td>Residential-Commercial</td>
<td>85</td>
<td>Predominantly residential interspersed with shops and services</td>
</tr>
<tr>
<td>Commercial-Residential</td>
<td>65</td>
<td>Predominantly commercial but attached residential dwellings</td>
</tr>
<tr>
<td>Industrial</td>
<td>50</td>
<td>Factories and fish processing areas</td>
</tr>
<tr>
<td>Rural</td>
<td>85</td>
<td>Predominantly residential interspersed shops and services</td>
</tr>
<tr>
<td>Services (e.g. school)</td>
<td>0</td>
<td>No Residential</td>
</tr>
<tr>
<td>Non-urban</td>
<td>0</td>
<td>No Buildings</td>
</tr>
</tbody>
</table>

Figure 5.43 Map of inundated area over buildings and land use used to calculate affected population

Population in temporary housing

According to the results of this analysis, approximately 3,000 people were displaced in Phang Nga province as a result of the tsunami. IDPs were temporarily accommodated in four planned camps located within, or close to, Ban Nam Khem. The estimated number of IDPs in each of the camps varied from 320 at BNK Temple camp to 1,456 at the Bang Muang Sub-District Office site. The map in Figure 5.44 shows the distribution of IDPs across Phang Nga province throughout the recovery process inferred from the presence of transitional shelters.
The results of the analysis show that the BNK School Camp and the Temple Camp were cleared or in the process of being dismantled by November 2006, only 1.5 years after the tsunami. The Bang Muang Sub-District Office site was the only camp still hosting people in February 2009; up to 192 people were estimated to be at the camp four years after the tsunami. The field deployment in February 2009 confirmed that these buildings were still occupied. It is unknown, however, if the occupants were victims of the tsunami or families from elsewhere. Ground surveys might be used to establish more information about these households. Figure 5.45 displays the population estimated to be residing at each camp in Phang Nga province throughout the recovery process.

**Discussion**

These techniques offer a rapid method of estimating the population affected by the disaster and living in permanent and temporary accommodation throughout the recovery process without the need for an extensive ground survey. However, the estimates are highly
sensitive to the number used for household size and, unless verified with ground knowledge, must be treated with caution.

**Population residing in permanent accommodation**

There were differences between the population estimates produced by remote sensing and the official statistics of the registered population in Ban Nam Khem. There are a number of possible reasons for these discrepancies. The population statistics provided by the sub-district office might be inaccurate or cover an area larger than the extent we surveyed. More than 3.7 people might be living in each dwelling. The number of dwellings might be underestimated, because more than one building was located under a single roof and the assignment of land use categories may be inaccurate, for example some families may be living in a buildings classified as non-residential.

**Population residing in temporary accommodation**

The population estimated to be residing at each of the planned camps was accumulated and compared to statistics for Phang Nga province supplied by the Department of Disaster Prevention and Mitigation (DDPM). The results correlate very well with a correlation coefficient of +0.99. Remote sensing overestimated the initial camp population by 8% and underestimated the February 2008 estimate 3 years after the tsunami by 9%. The results of the validation work are presented in Figure 5.46.

![Figure 5.46 Population living in transitional accommodation](image)

A number of assumptions were made during the analysis. For example, it was assumed that all the buildings identified as shelters were residential, and were occupied and in use. It was also assumed, based on aid agency guidelines, that each temporary dwelling housed 4 people. Some of the shelters are long multi unit buildings and, in calculating the number of dwellings under a terraced roof, it was assumed that each unit was 4 metres wide. Information on common shelter designs from around the world would fine-tune these assumptions and help achieve more accurate occupancy estimates. Figure 5.47 and Table 16 show the start of a temporary shelter database. The images and data were captured using Quickbird-2, Geoeye-1 and aerial Imagery.
<table>
<thead>
<tr>
<th>Type</th>
<th>Location</th>
<th>When</th>
<th>Source</th>
<th>Size m</th>
<th>Dwellings</th>
<th>Capacity (Sphere Guidelines)</th>
<th>Roof Colour</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Makeshift</td>
<td>Port-au-Prince Haiti</td>
<td>17 Jan 2010 (+5 days)</td>
<td>Self-help</td>
<td>2 x 3</td>
<td>1</td>
<td>1 or 2 people</td>
<td>Mix (blue, red and white)</td>
<td>Cramped, unsanitary conditions.</td>
</tr>
<tr>
<td>Tents</td>
<td>Yingxiu, Sichuan province, China</td>
<td>03 June 2008 (+22 days)</td>
<td>Chinese Government</td>
<td>4 x 4.5</td>
<td>1</td>
<td>4 people</td>
<td>Blue (appeared purple)</td>
<td>Orderly arrangement.</td>
</tr>
<tr>
<td>Tents</td>
<td>L’Aquila, Italy</td>
<td>08 April 2009 (+2 days)</td>
<td>Italian Government</td>
<td>8 x 6</td>
<td>1</td>
<td>10 people</td>
<td>Blue</td>
<td>Orderly arrangement on sports grounds and other open spaces.</td>
</tr>
<tr>
<td>Tents</td>
<td>Bang Munag, Thailand</td>
<td>02 January 2005 (+7 days)</td>
<td>NGOs</td>
<td>1.5 x 1.5</td>
<td>1</td>
<td>0 people</td>
<td>Mix</td>
<td>Cramped, but orderly arrangement of small tents.</td>
</tr>
<tr>
<td>Transitional Shelter</td>
<td>Yingxiu, Sichuan province, China</td>
<td>03 June 2008 (+22 days)</td>
<td>Chinese Government</td>
<td>40 x 7</td>
<td>10</td>
<td>6 people</td>
<td>Blue Roof</td>
<td>Colour coated steel sandwich panel with thermal insulation.</td>
</tr>
<tr>
<td>Transitional Shelter (Caravan)</td>
<td>New Orleans, USA</td>
<td>31 March 2006 (+7 months)</td>
<td>FEMA</td>
<td>7.5 x 4.5</td>
<td>1</td>
<td>7 people</td>
<td>White</td>
<td>Large caravans in an orderly arrangement.</td>
</tr>
</tbody>
</table>

*Table 16 Temporary shelter database*

*Figure 5.47 Temporary Building Database. Examples of aerial and satellite images showing transitional shelters in China, Haiti, Italy, Pakistan, Sri Lanka, Thailand and USA*
Recommendations

The process requires technical expertise in remote sensing and some ground knowledge of the areas being analysed. In particular, field data is needed to accurately determine land use, and to validate measurements made from the remotely sensed imagery. The method is unable to disaggregate the population by age or sex, and is unable to identify the number of vulnerable people, which is required to monitor many important cross-cutting issues. It is also unable to account for migration to and from the affected region.

Whilst remote sensing was used to provide a rapid estimate of the temporary and permanent populations in the affected region, household surveys were used to quantify changes to the region’s demographics at a household scale. The household survey found that before the tsunami the average household size was 5. This is considerably higher than census figure of 3.7 for the province. As mentioned earlier average household size before the tsunami may have been higher than the provincial average because Ban Nam Khem was home to a high proportion of informal settlers – Burmese migrants working in the fishing industry. This highlights how a small household survey may be used to derive an average household size at town scale, which might be used along with remote sensing to produce a rapid estimation of the affected population.

The household survey also found that the average household size in February 2009 was four. This gives an interesting insight into how demographics in the village might have changed. Households with more than four adult members were given more than one house by the government, which would have had a dramatic effect on reducing average household size. Loss of life and emigration may also have had an effect. On average, each household in our survey lost one family member to the tsunami, with one household losing up to seven family members. Migration trends were high in the aftermath of the tsunami: 26% of households had members that emigrated and 28% of households had members that immigrated, suggesting that the net impact on the population due to the movement of people is likely to have been negligible. The survey also identified that household members moved away from Ban Nam Khem to marry, study and find work whilst people were attracted by the availability of new permanent homes and to help their relatives recover after the tsunami.

More accurate population estimates might be obtained through ground survey work, in particular, camp registration offers a good opportunity to count the number of Internally Displaced Persons (IDPs), which can be disaggregated by gender and/or age. Vulnerable groups, such as children, the elderly or the injured may also be identified to ensure that cross-cutting needs are considered during the recovery process. Remote sensing offers a useful tool to map and visualise the displaced population across the affected region. This information is important to prevent overcrowding at camps and to assist resource allocation.
Services and Utilities

This chapter introduces a range of techniques that can be used to monitor the return of services and facilities to an area. The results are presented as maps, site layouts and timelines. The provision of key utilities such as water and power are also observed by monitoring features required for their supply; and power is additionally inferred by measuring night-time light radiance.

Administration, services and utilities

Indicator 10. Administration, education, healthcare and religious facilities

Justification

Services and facilities have been defined to include all aspects of the built-up environment that contribute to the functioning of a successful, cohesive community. These establishments often provide vital services and social capital to the community and are a central part of successful post-disaster recovery. They include, amongst others: administrative services, schools, health facilities, prisons, libraries, the emergency services and places of worship (e.g. churches, mosques or temples). It is important to monitor these services throughout the recovery process to ensure that they are reconstructed and functioning properly. Information about their abundance, speed of recovery and location, in particular their proximity and accessibility to households, can be analysed using remote sensing. After large emergencies, a central geodatabase of services and facilities enables information regarding their coverage, operating status and supply situation to be aggregated, which can be used to significantly assist decision-making and to identify priority areas. Ward et al.\textsuperscript{52} presented a similar approach to understanding recovery in New Orleans after the 2005 Hurricane Katrina.

Method

The first step is to create a geodatabase of services and facilities by mapping the location of the services across the affected region. The use of large, distinctive buildings such as schools and temples may often be established using satellite imagery, by analysing the buildings’ structural attributes and clues in the immediate environment. Table 18 lists some of the physical building attributes visible in clear, high-resolution satellite imagery that can be used to indicate a building’s use.

Many buildings lack these unique features and signatures, so the use of buildings is often indecipherable in satellite imagery without the integration of ground data. The creation of a comprehensive GIS map of services and facilities therefore requires the integration of other data sets, such as geo-referenced notes and images and/or the location of features incorporated from existing paper or electronic maps. After the 2010 Haiti Earthquake, volunteers used many different inventive ways of logging the location of 150 hospitals and health facilities across the affected area, including public internet searches, ground surveys on mopeds and aerial imagery analysis using OpenStreetMap.\textsuperscript{53, 54}

Once a building’s use and location has been established, the speed of reconstruction and changes to the building’s spatial context may be monitored. The same techniques used to monitor residential buildings (Indicator 7. Quality of dwelling reconstruction) can also be used to monitor the size, shape and location of service and facility buildings, as well as their accessibility and connectivity to other features. In some cases, effective data standards have been produced by leading agencies that can be used to determine their data requirements, such as the PAHO’s data model for health facilities.\textsuperscript{55}
<table>
<thead>
<tr>
<th>Building Type</th>
<th>Building Attributes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commercial</td>
<td>Air vents&lt;br&gt;Variable building sizes&lt;br&gt;Car park&lt;br&gt;Densely-packed buildings&lt;br&gt;Main high street (often straight)&lt;br&gt;Pedestrianised streets</td>
</tr>
<tr>
<td>Education Facilities</td>
<td>Playground&lt;br&gt;Playing Field&lt;br&gt;Fencing&lt;br&gt;Parking Area</td>
</tr>
<tr>
<td>Factories</td>
<td>Chimneys&lt;br&gt;Lorries / heavy vehicles&lt;br&gt;Warehouse&lt;br&gt;Other handling equipment (e.g. plant equipment, bulldozers, cranes)&lt;br&gt;Transportation to move raw materials around the site (e.g. conveyors, pipelines, railroads)</td>
</tr>
<tr>
<td>Health Facilities</td>
<td>Large Building&lt;br&gt;Red cross&lt;br&gt;Helipad&lt;br&gt;Ambulances</td>
</tr>
<tr>
<td>Homes</td>
<td>Regular building size and shape&lt;br&gt;Driveway&lt;br&gt;Garden&lt;br&gt;Garage</td>
</tr>
<tr>
<td>Hotels</td>
<td>Swimming pool&lt;br&gt;Tennis Court</td>
</tr>
</tbody>
</table>

Table 17  Physical attributes used to indicate building use

Case study: Ban Nam Khem

A detailed analysis of the services and facilities in Ban Nam Khem is presented. The first step was to create a geodatabase by locating services and facilities in the area. Some buildings had a distinctive physical signature and their use was therefore identifiable in the satellite imagery, for example temples had large pitched red roofs and school buildings were located near to playing fields. The use of non-descript buildings though, such as the police station, health centre and other services, was identified by ground surveys and by officials during the key informant interviews. The resulting service database contained 30 structures representing 18 different services, including a temple, church, school, water office, library and police station (Figure 5.48).
A diverse range of facilities are now available in the village with good access for most households. The number and distribution of services before the tsunami are not available for comparison, but the pre-disaster image was used to establish that several new services had appeared as a result of the recovery process, including the Community Development Centre, the Conference Centre and several Christian churches. The presence of these religious buildings as a result of the NGO-led recovery process was highly controversial, with a number of people complaining about their dominant presence in a predominantly Buddhist country.

The service map in Figure 5.48 shows the location of the services throughout Ban Nam Khem. A new temple and school building were constructed on their original sites, while health facilities were transferred to a new location. Many of the key services present, such as the community centre and the school, are clustered in the centre of the village - 1.0km from the coastline in an area that is slightly elevated and considered to be relatively less vulnerable.

The speed of reconstruction and other detailed attributes were measured for 5 of the main services in Ban Nam Khem using remote sensing, including the temple, school, community centre, police station and museum. The results of the detailed analysis were then verified using ground photography. Figure 5.49 shows the site of the temple and the main school in Ban Nam Khem in February 2009 with field photographs collected at the same time highlighting particular features of interest.
All of the service buildings were reconstructed between April 2005 and February 2006 (14 months after the tsunami), except for the temple which was not completed until 4 years after the tsunami. The construction of the school was particularly rapid, with all of the walls and part of the roof already constructed by April 2005 (only 4 months after the tsunami). Figure 5.50 shows a time-line of key events at Ban Nam Khem School collected with satellite imagery.
Validation: Education

To validate the service analysis, the remote sensing results were compared to official statistics and the results from the household survey. Bang Muang Sub-District Office informed us that the school in Ban Nam Khem was reopened within two weeks. Other reports claimed that Ban Nam Khem School reopened after one month and that Thai and foreign volunteers helped temporarily with the teaching in the school-yard. The later report more closely matched the remote sensing analysis, which showed that temporary structures were present on the school grounds for at least several months. Figure 5.51 shows the results of the detailed analysis of the school buildings in Ban Nam Khem.

![Building Status](image)

*Figure 5.51 Detailed analysis of Ban Nam Khem School site throughout the recovery process shows the construction of permanent and temporary structures.*

The 50 households in our household survey sent their children to various schools across the region, some were damaged and some were not. The families of children at Ban Nam Khem School identified damaged buildings and the school closure as problems after the tsunami. Most of the students at Ban Nam Khem School returned by April - May 2005, which coincided with the construction of small temporary structures visible in the imagery. The children at the unaffected schools all returned to classes within one or two months of the tsunami. Most children therefore appear to have been kept out of education for a minimal amount of time. Some households decided to move their children to other schools, but they returned within a year.

**Discussion**

This work shows how remote sensing may be used to create a geospatial database and framework that can host service and facility information across an affected region. Such a system is vital when determining the status of key services and can be used to assist decision-making on the ground and to identify priority areas.

Once a facility or service was identified, remote sensing was used to monitor changes to the service buildings, its accessibility and the speed of reconstruction. These results are presented in the form of time-lines, tables and thematic maps. During the data acquisition stage of the work, satellite imagery could be used independently to monitor and identify large, conspicuous features, but was a much more effective tool when integrated with auxiliary datasets acquired with ground-based observation tools such as ground surveys, and social-audit techniques such as household surveys and key informant interviews. New methods of data collection also proved to be very effective following the 2010 Haiti
earthquake and need to be developed and utilised, including crowd-sourcing techniques and public internet searches. More detailed aspects of education may be monitored accurately with a mix of methods, including household surveys and published statistics. The household survey proved to be a significant source of valuable information on the services available in Ban Nam Khem. In particular, information regarding the quality of the services was inferred by asking the households when the services resumed and if they experienced any problems. This study has shown how remote sensing may be used as part of the triangulation process to validate the results obtained from data sources such as surveys and interviews.

Indicator 11. Utilities – Power

Justification

Power is required by households and businesses for heat, light, cooking and communicating. The availability of power in a region may therefore affect issues of security and health, as well as the restoration of most sources of livelihood.

Method

As with most image analysis, the spatial resolution strongly determines what features may be identified and delineated. Satellite imagery with a resolution of at least 1.0 m is capable of displaying power facilities, such as power stations, transformers and substations. Imagery with a resolution of 50 cm is capable of showing the presence of local power supply, such as solar panels and wind turbines, while smaller features, such as utility poles and cables, require a spatial resolution of at least 25 cm to be visible. It might be assumed that collapsed power lines or pylons signify the temporary loss of power in a region while re-erected poles signify the restoration of power. Figure 5.52 shows the presence of shadows and cables in 15 cm aerial imagery of Haiti that indicate the presence of utility poles and power lines.

Figure 5.52  Power supply in Port-au-Prince after the 2010 Haiti earthquake

Night-time light datasets may also be used to monitor the removal and reinstallation of power by measuring radiance intensity and duration. Night-time lights have previously been used on a national scale to monitor a number of processes, including economic activity and CO₂ emissions and provision of electricity. At the present time though, the only civilian night-time light data is available at a resolution of 0.5-2.7km. The data is acquired by the Operational Linescan System (OLS) on-board a series of satellites belonging to the US Air Force Defense Meteorological Satellite Program (DMSP).
Case studies

In the Thailand and Pakistan studies, a time-series of DMSP-OLS annual night-light composite images from 2000 to 2009 were acquired from NOAA’s National Geophysical Data Center. To create these composite products, cloud-free single orbits were collected for each calendar year, then rectified and aggregated to generate stable light mosaics. The images therefore contain average night-time light values on a relative scale for each year. The results in Ban Nam Khem for the years 2002, 2004, 2006 and 2008 are presented in Figure 5.53.

![Image of night-time light data over Ban Nam Khem before and after the 2004 tsunami. Image and data processing by NOAA’s National Geophysical Data Center. DMSP data collected by US Air Force Weather Agency.](image)

The average night-light values in Ban Nam Khem increased after the tsunami peaking during the reconstruction process in 2006. They then dropped slightly but remained higher than they were before the disaster. Meanwhile, data from Chella Bandi show less variability in night-time light values after the 2005 earthquake. It is possible that this is due to pixel saturation caused by the bright lights from the city of Muzaffarabad. The increased radiance intensity in Ban Nam Khem after the tsunami is likely to be due to increased human activity due to reconstruction and the presence of temporary camps during this period. The results show the potential for using night-time light data to monitor the return of power after a disaster. The DMSP-OLS satellites acquire global coverage every 24 hours, so changes in night-time lights over a much shorter period of time may also be monitored. Figure 5.54 shows a comparison of average night-time light values in Ban Nam Khem and Chella Bandi between 2004 and 2009.
According to the key informants there were no significant problems associated with the reinstallation of power after the tsunami. Electricity supply was restored to some areas within 3-4 days although other areas had no electricity for a week. Power was also supplied to residents of temporary housing at no cost for the first year. The average installation date for the households in our survey was 16 months. The key informants also reported that the mains power was restored after 12 months on average. These observations match the date when a lot of the households had moved into government-supplied properties and also coincides with the peak in radiance observed in the night-time light composites. These structures all had electricity and transformers. Apparently temporary measures were adopted by some households that didn't already have access to electricity, by extending electrical cables from the army-built houses. However, according to the household survey, the supply of power in Ban Nam Khem was not consistent for all households, with 16% complaining of power cuts and others complaining that the current was low and unstable.

Discussion

In Ban Nam Khem, optical imagery could not confidently be used to monitor the return of power to the village, unless it was assumed that power was supplied with transitional shelters and all new constructions. Annual night-time light composites appear to show an increase in human activity during the reconstruction process. Individual night-time light images therefore have the potential to show changes in the provision of power. Ground survey work was used independently to identify features that indicate the use of electricity such as TV aerials, and to identify issues related to the amount of lighting in a home.

The household survey and the key informant interviews also obtained a significant amount of useful information on the provision of power, including: the date when mains power was restored to households and businesses, quality and reliability of supply, how a lack of power...
may have affected households and/or their livelihoods and about price changes. Figure 5.55 shows power supply features in Ban Nam Khem and the amount of light in a typical army-built house. It was not possible to carry out a similar comprehensive analysis for Chella Bandi, due to the lack of access for field teams in the area.

**Water**

**Justification**

Water is a critical resource throughout the recovery process and beyond. A clean, reliable source of water is immediately required for drinking and is an important aspect of personal hygiene, that can reduce the likelihood of disease or infection. Water is also a critical element for the recovery of many sectors of the economy.

**Method**

Remote sensing may be used to identify and locate features associated with the temporary and permanent supply of water. These features include local water storage facilities, such as tanks and towers, and larger facilities such as dams, reservoirs and other water bodies. Where aerial imagery is available, remote sensing and spatial analysis may also be used to monitor the distribution and connectivity of water points in transitional camps. The Sphere guidelines recommend that, during the relief period, the nearest water point is no more than 500m away from residential dwellings. A map can be produced from the image analysis that highlights households farther away from water points than the recommended distance.

Remote sensing may also be able to identify major contamination of water sources that might arise as a result of mudslides, inundation or some types of flooding, mines or industrial accidents. This may be achieved by conducting a spectral or visual analysis of ground water and by looking for evidence of debris, mud or salt. Remote sensing may also identify areas where coping strategies might be likely to occur, for example, where households are using unprotected sources of water. This is likely to happen where settlements are located near to rivers, lakes or unprotected wells and don’t have access to reliable water points or water storage.

**Case study: Ban Nam Khem**

In Ban Nam Khem, three features related to the supply of water were apparent in the satellite imagery: water towers, water tanks and roofed-towers containing tanks of water. Water towers have a linear shape and a bulb top that creates a unique shadow against a flat surface. There are at least 6 water towers observable in Ban Nam Khem, which implies the use of over-ground sources of water throughout the village. This was later confirmed with the analysis of the household survey results and the GPS and VIEWS field photos and video. In addition, water tanks are being used to collect rainwater from residential buildings. They are visible in the imagery, but because of their small size they are not realistically identifiable without ground data, or finer resolution aerial imagery. Water towers built on scaffolding frames with corrugated iron roofs were used in residential areas to store several tanks of water, but were difficult to distinguish from other residential structures.

The analysis of the key informant interviews and household surveys provided detailed information about the supply of water in Ban Nam Khem. According to the surveys, there were severe shortages of water during the first 2–3 days of the relief process and people had to buy drinking water, which was expensive. As a consequence, some households resorted to using potentially dangerous ground water and pond water. Bottled water was provided in temporary shelters, but during the first month there were still insufficient amounts of drinking water. The surveys suggest that permanent water supply was reinstated to
homes on average 15–22 months after the tsunami. In general, this timing coincided with the return of households to their new/repaired homes.

![Image of houses and satellite images]

**Figure 5.56 Features related to the supply of water in Ban Nam Khem**

**Discussion**

Remote sensing can be used to monitor features related to the supply of water. In Ban Nam Khem, satellite image analysis identified several features associated with the over-ground supply of water. This over-ground supply of water was of concern to many residents in the village, with many calling for a permanent underground system. Aerial imagery can also be used to monitor the reconstruction of larger facilities. For example, aerial imagery was used to monitor the Right Bank Drinking Water Treatment Plant in Iraq after increased insurgent activity prevented the possibility of site visits by the Office of the Special Inspector General for Iraq Reconstruction. Where possible though, field visits are necessary to inspect the quality of these facilities and social-audit methods are important to assess the quality of the services provided. Household surveys, key informant surveys and focus group meetings were useful mechanisms for identifying issues with water supply in our two case studies. When evaluating the provision of water after a disaster it is important to distinguish between the initial emergency supply of drinking water and the long-term provision of mains water.

**Sanitation**

The household surveys and focus group meetings were the most useful sources of information on the levels of sanitation in Ban Nam Khem. According to the results, sanitation appears to have been dealt with adequately, with sufficient toilets and bathroom facilities provided along with advice about hygiene. Toilets were also installed in transitional shelters after approximately 1 month and in permanent homes after approximately 1 year. There were regular collections of refuse at the temporary shelters, which also became an additional income for some workers. It took one year for the regular waste collection service to resume with temporary black bag measures adopted in the meantime. Despite this, some households complained that there were not enough toilets and that they were dirty. One
household also complained that there were no refuse collections near to their house that led to bad smells and slippery surfaces after localised flooding.

Natural Environment

Indicator 12. Land-cover and urban green space

A series of semi-automated methods were applied to both case study sites to provide a systematic overview of land cover change. Two detailed analyses were also applied to specially-selected subsets to monitor the distribution of mangrove forests and urban open spaces.

Justification

The natural environment contributes substantially towards the overall quality of life of people living in the affected area. Recovery of agricultural land and other natural resources is also essential for long-term food security and livelihoods that are reliant upon them. Public spaces and urban green areas provide habitats for biodiversity and they help to regulate temperature and provide clean air and water. Green spaces are also important for the mental and physical well-being of inhabitants and have been shown to have an effect on house prices and the overall attractiveness of an area. In countries such as Thailand, mangrove forests have an added value as they are known to mitigate the impacts of tsunamis and storm surge. They also trap sediment that prevents coastal erosion and provides important habitats. Table 18 summarises the type of environmental change that may be observed in satellite imagery and a list of processes that might be causing it.

<table>
<thead>
<tr>
<th>Land cover indicators</th>
<th>Observation</th>
<th>Possible Causes</th>
</tr>
</thead>
</table>
| Erosion and land degradation | Replacement of vegetation by bare ground or sparse vegetation | - Direct loss of vegetation by landslides and/or flooding  
- Overuse of access routes  
- Overexploitation of arable land (possible coping strategy) |
| Deforestation | Removal of forest land-cover | - Removal for arable land  
- Removal for construction |
| Construction | Replacement of non-urban land cover with urban land cover | - Construction of temporary structures  
- Construction of permanent buildings, roads or other urban structures |

Table 18  Examples of land cover change typically present in a recovery landscape

Changes to the natural environment may be brought about by the direct and indirect effects of both natural and anthropogenic disasters – the environment can be destroyed through landslides or flooding, or it can be affected by human activity following a disaster. Intense construction work might lead to long-term damage to natural habitats and ecosystems. The environment is an important cross-cutting issue that must be addressed throughout the recovery process and beyond. Monitoring environmental recovery or environmental degradation can be achieved by analysing non-urban land cover classes, including vegetation-based habitats and water bodies. Remote sensing images provide an unparalleled data source for the monitoring of the environment over time, and software analysis techniques are well established.
Method

A number of techniques have been developed to semi-automatically classify vegetation from satellite imagery. Vegetation can be classified by comparing the red and near-infrared bands of a multi-spectral satellite image. Difference in reflectance creates a phenomenon known as the red edge. Dense, healthy vegetation has a large red edge, while sparse, unhealthy vegetation has a more subtle red edge. For this study, two semi-automatic methods were used to extract data on vegetative land cover: Normalised Difference Vegetation Index (NDVI) and Maximum Likelihood Supervised Classification (MLSC). NDVI is a normalised index that quantifies the spectral reflectance of vegetated areas as a ratio of the red and near-infrared bands, while MLSC is a classification algorithm that classifies images according to class rules provided by the analyst. As MLSC is a supervised classification algorithm, the analyst provides training areas in the form of small segmented samples. The analyst must decide what classes to use. For both Ban Nam Khem and Chella Bandi, MLSC was used to classify the following five land cover classes:

1. Bare Ground (e.g. soil and sand)
2. Sparse Vegetation (e.g. grassland and lawns)
3. Thick Vegetation (e.g. tree canopies and ground vegetation, including mangrove)
4. Urban (e.g. impervious surfaces including roads, buildings and other bare ground)
5. Water (e.g. the ocean and inland water bodies, including shrimp pools)

Once the extent of the vegetation was mapped, change detection analysis monitored changes in land cover and identified areas of erosion, land degradation, deforestation and the removal of vegetation. It also identified flooding and urban development.

Case studies: Ban Nam Khem and Chella Bandi

NDVI and MLSC were calculated for the whole of Chella Bandi and Ban Nam Khem using the ENVI software suite. The maps and statistics produced allowed a systematic analysis of the changing land-cover. Results of the two techniques are shown in Figure 5.57. NDVI maps of Chella Bandi are on the left and MLSC maps of Ban Nam Khem are on the right.

Figure 5.57  Two semi-automatic methods of classifying land cover were used in this study. Results of the NDVI analysis applied to Chella Bandi are shown to the left, and land cover classifications of Ban Nam Khem produced using MLSC are shown on the right.
In Chella Bandi, the MLSC showed that the amount of classified urban areas in Chella Bandi increased by 8.6% from 2004-2005 and remained between 23 and 27% of the total classified land cover in the remaining image dates. The results also show a 9.8% increase in the proportion of sparse vegetation between 2004 and 2009, with an inverse trend evident for the dense vegetation class. Ground knowledge acquired by field teams suggests that the change in vegetation is likely to be due to seasonal differences. Close inspection of the imagery highlights areas of vegetation loss due to the construction of shelters and temporary access routes. There are also variations in the amount of classified water due to the seasonal differences in river volume in Chella Bandi.

The results from Ban Nam Khem similarly show that vegetation had not yet recovered to the pre-disaster state. Approximately 4.2km² of vegetation was removed by the tsunami and a further 0.7km² was removed during the first 4 months of recovery, presumably due to clearance and construction. Sparse vegetation was particularly affected but recovered significantly between April 2005 and February 2006, especially if adjacent to areas of thick vegetation. Figure 5.58 shows the proportion of each land cover class in Ban Nam Khem, classified using MLSC.

![Figure 5.58 Land cover in Ban Nam Khem, extracted from MLSC thematic maps](image)

A series of change detection images were then generated from the thematic maps to highlight areas of vegetation gain and loss. In Ban Nam Khem, most of the vegetation within 1 km of the coastline was removed by the tsunami, including mangrove forest and grasslands. During the immediate relief-effort, vegetation was also lost around transitional shelters and new school buildings. After four months, vegetation loss was seen in areas of construction throughout the village, including new roads, the construction site of the museum, community centre, new residential areas and new aquaculture pools to the east of Ban Nam Khem. Areas of vegetation gain were also seen around Ban Nam Khem, due to crop growth. Figure 5.59 shows a change detection map of Ban Nam Khem generated from
the MLSC thematic maps. The image displays areas of vegetation loss as a result of the recovery process and areas of new development between January 2005 and February 2009. Areas shaded grey have been transformed from vegetation to impervious surfaces and areas shaded brown represent change from vegetation to bare ground. Area A corresponds to the new Phase 2 housing development, Area B shows the main school site that has expanded during the recovery process and Area C contains new residential buildings that were built by the military within a year of the disaster.

![Image of MLSC thematic maps](image)

**Figure 5.59** Change detection map of Ban Nam Khem identifies at least three areas of new development: A. Phase 2 Housing B. Ban Nam Khem School and C. New military-built housing.

**Ban Nam Khem: mangrove analysis**

In total, 386 hectares of mangrove forest was impacted in Thailand by the tsunami. The level of damage ranged from the complete removal of trees to indirect damage caused by debris and salt deposits. Roemer et al. categorised forest damage into four damage classes: 1. no/low damage 2. direct forest damage 3. indirect forest damage and 4. degradation of understory, vegetation and soils. Many species of mangrove surround Ban Nam Khem, but *Rhizophora apiculata* and *Avicennia alba* are particularly widely distributed. (Figure 5.60)
Figure 5.60 Mangrove forests located to the east of Ban Nam Khem.

The extent of the mangrove forest was semi-automatically delineated in each image using NDVI. By overlaying the NDVI classification images, change detection analyses identified areas where trees had been completely removed either by the force of the waves or indirectly as a result of salt, debris or toxic deposits. In Figure 5.59 the dark green areas show the extent of the mangrove in January 2005, immediately after the tsunami when 16 hectares or 21% of mangroves were destroyed. The different shades of lighter green show the progress of mangrove forest recovery. 95% of the forest area that existed before the tsunami recovered in 1 year. The trees on the inside of the forest were the first to recover while the trees on the edge of the forest, that took the full velocity of the waves, took 3 to 4 years to recover. The total area of mangrove forest in February 2009 was 87 Hectares, 10% more than existed before the tsunami. The change detection map on the right of the figure shows where mangroves have extended (green) and been loss (red) between June 2002 and February 2009. The maps show that the mangroves appear to have fully recovered.
Green space area

To monitor the rehabilitation of green space in Ban Nam Khem a series of Landscape Metrics were applied to the vegetation maps created using NDVI. The Metrics were selected to show changes in the size, distribution and fragmentation of the green spaces. Fragmented green spaces are important in built-up areas for quality of life and as habitats for biodiversity. Adequately sized spaces are also required for parks and for recreational activities. Table 19 summarises the Landscape Metrics applied to the urban green space database.

<table>
<thead>
<tr>
<th>Metric</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large Patch Index (LPI)</td>
<td>The size of the largest green space.</td>
</tr>
<tr>
<td>Mean Nearest Neighbour (MNN)</td>
<td>The average distance between the green spaces.</td>
</tr>
<tr>
<td>Patch Density (PD)</td>
<td>The density of green patches.</td>
</tr>
<tr>
<td>Total Edge (TE)</td>
<td>The length of green edge exposed to the built environment. A measure often used in Quality of Life studies.</td>
</tr>
</tbody>
</table>

Table 19 Landscape metrics applied to urban green spaces database

In summary, 11.1ha of Urban Green Space in Ban Nam Khem were removed as a result of the tsunami. The green spaces that remained were highly fragmented, characterised by a low Large Patch Index (LPI) and a high Mean Nearest Neighbour (MNN). A further 1.7ha of Green Space were removed between January 2005 and April 2005, during the clearance work, leaving only 2.6ha. Between April 2005 and November 2006 vegetation began to
recover, with the green space area reaching 15.4ha in November 2006 (100% of the pre- 
tsunami area). During this time, fragmentation was seen to drop as LPI and Total Edge (TE) 
both increased to pre-tsunami status. There was a dip in the green space area in February 
2008.

Figure 5.62 Urban Green Space in Ban Nam Khem using NDVI Threshold and Landscape Metrics

Discussion

A variety of automated and semi-automated methods were used to provide a spatio-
temporal description of land cover change in Ban Nam Khem and Chella Bandi. Remote 
sensing images provide an unparalleled data source for the monitoring of vegetation change 
over time, and software analysis techniques are well established, as seen in the described 
methods. All classification work was completed using the ENVI software suite and the 
change detection analysis was completed using ArcGIS. A working knowledge of specialist 
image processing and GIS software is therefore required to perform this analysis. It is 
important to note that this analysis can only be performed on imagery with multiple spectral 
bands (including a near infra-red band). NDVI analysis cannot be performed on 1-band black 
and white (panchromatic) imagery, such as that acquired by the Worldview-1 satellite 
sensor.
The NDVI analysis took approximately 1 minute to apply to each image, while the MLSC took approximately 1 hour to process. MLSC is a supervised classification approach and therefore requires the operator to manually identify land cover classes and assign suitable segmented samples for each. Subsequently, there is a trade-off between the processing time and the amount of detail obtainable with each of the techniques: while the NDVI approach is used to delineate vegetative land cover, MLSC is much more flexible and can accurately classify other land cover classes including bare ground, urban and water.

MLSC achieved an overall accuracy of 82% when compared to ground knowledge information for 50 random points. Only the immediate post-disaster image of January 2005 achieved an accuracy of less than 80% when the average accuracy for the five classes was 68%. Disturbance to land cover caused by the tsunami appears to have led to a reduction in the accuracy of the classification. In this image there was frequent confusion between water-logged soil and urban land cover, leading to an overestimation of urban area; the presence of debris containing vegetation also led to an over estimation of sparse vegetation. Analysts must be aware of such commission and omission errors when attempting this form of analysis. Other factors may also be taken into consideration, including seasonality, tides and crop growing stages.

The change in land cover was much more significant in Ban Nam Khem than in Chella Bandi, due to the different nature of the hazards involved. In Ban Nam Khem, the tsunami washed away all vegetation within 1 km of the coastline. While changes in vegetation were also observed in Chella Bandi, it is not thought that the earthquake was a major contributor to this difference; rather it is more likely a function of vegetation seasonality and disparate stages of agriculture and crop growing processes. It is true though that the construction of buildings and temporary access routes also led to significant vegetation loss after the earthquake.

Figure 5.63 shows the comparative trends for each land cover in Ban Nam Khem and Chella Bandi. Several trends are apparent from the data: There was a large increase in the amount of bare ground following the tsunami, with vegetation removal the main cause. Conversely, there was a slight trend in Chella Bandi of change in bare ground to urban. These fluctuated slightly in Pakistan, while the total amount of bare ground in Ban Nam Khem consistently accounted for >15% total area than before the tsunami. Also apparent is the similar decline in overall vegetation in both areas over a 50 month period due to an increase in the amount of urban area needed for development.
Figure 5.63 Comparative trends in recovery in land use for Ban Nam Khem and Chella Bandi
Livelihoods

Indicator 13. Recovery of livelihoods

Justification
Livelihood refers to a household’s means of financial support and includes employment as well as other sources of income. It is important to ensure that livelihoods are restored as quickly as possible after a disaster and that households do not become reliant on aid. Shops and services should also be opened as quickly as possible to assist the recovery of the local economy and to provide key services and products. Types of livelihood can differ between before and after an extreme event, with typically an increase in the construction sector, especially in the early recovery time period.

Method
This assessment uses multiple tools to monitor the main economic sectors in disaster-affected areas as well as the overall macroeconomics of the wider region. A review of services and employment opportunities available in the area was carried out using proxies from remote sensing and ground survey techniques. Detailed analyses were conducted on the more conspicuous forms of livelihood using satellite imagery and the recovery of the wider region was assessed using official statistics and reports. In Ban Nam Khem, for example, the fishing industry was assessed by monitoring pier length and the presence of boats, shrimp hatcheries and shrimp ponds; tourism was monitored by the recovery of resorts and near-by beaches; and finally, agriculture was monitored by analysing arable land.

The first step of the analysis was to identify the different economic sectors operating in the region. A significant amount of information can be acquired using a combination of government statistics, data from international organisations and surveys of local media and press. More detailed information may also be obtained from focus group meetings with key informants and by surveying local households (the results of which are summarised at the beginning of the case study below).

Key informant interviews, the household survey and official reports were used to obtain an overview of livelihoods in Ban Nam Khem. Ground survey and satellite imagery analysis was used to identify physical features that indicate the presence or absence of particular livelihood types. By integrating GPS-tagged photographs from the field with very high-resolution satellite imagery, a livelihood map was produced. In total 1,583 GPS photographs were analysed for signs of livelihood. A map of livelihood features was produced by assigning colours to livelihood types. Quantitative statistics were then calculated to describe the number and size of features using the Select by Attributes tool and the Statistics tool. The date of construction was also estimated from the photographs.

Case study: Ban Nam Khem
The main sources of work in Ban Nam Khem were reported as fish processing, shrimp farming and fishing, retail and construction. The number of people employed in all these sectors increased consistently from 6 months after the tsunami to the present.

The tsunami had an enormous effect on the livelihoods of people in the whole of Phang Nga Province through the loss of income, loss of productive assets and loss of marine and coastal natural resources. Gross Domestic Product (GDP) dropped between 2004 (the year before the tsunami) and 2005 (the year after the tsunami) for three sectors: fishing (-1%), transport, storage and communication (-18%), and hotels and restaurants (-40%). The economic output from both fishing and tourism was affected by the tsunami, with boats, shrimp hatcheries and tourist resorts all taking the main brunt of the damage.
In recent years the population of Ban Nam Khem has risen by immigrants looking for work. Many of these workers were employed in tin-mining and fishing, industries that were heavily reliant on the region’s fragile coastal and natural resources. The dependence of the community on a narrow range of sources of income made post-tsunami immigrant communities particularly vulnerable. When the tsunami destroyed Ban Nam Khem’s fishing fleet and Khao Lak’s tourist resorts, it instantly removed many people’s main sources of income. A survey conducted by Paphavasit et al.\(^67\) reported that one-third of respondents and one-quarter of other household members were unemployed after the tsunami. Over half of the respondents had to change jobs. Many of the fishermen became unskilled labourers and had to move from their homes. Their income fell by 35% and the community leaders in Ban Nam Khem estimated that they would face economic strain for at least 4 years after the disaster.

People working on or near the water were the most affected as a result of the tsunami and the number of people working in the fishing industry is now 10% less than before the disaster. Retail work increased dramatically during the first two years of recovery, and the number of people working in this sector is now around the same as the pre-disaster level. In contrast, there are fewer construction workers than before the tsunami.

Other forms of livelihood, such as taxi driving, massage, trade and restaurateur all recovered to pre-disaster levels within 6 months. Some new forms of livelihood have appeared including hotel work, rubber plantation, travel agency, mining, security and mushroom culture. The unemployment rate in Ban Nam Khem fell from 50% to 14% of the survey sample six months after the disaster. DDPM statistics report that the number of people employed was 100% in 2006, at the same time 14% of the households interviewed by the Recovery Project were unemployed.

The ground survey identified at least 22 forms of livelihood encompassing a wide range of sectors, including agriculture, fishing and manufacturing. Remote sensing was used to monitor some of the more conspicuous forms of livelihood such as shrimp hatcheries, grow out ponds, piers, resorts and agriculture. In summary, it showed that shrimp hatcheries were destroyed by the waves and not built back, while grow out ponds were protected by mangrove forests; the presence of pumps in the ponds throughout the recovery process suggest that the productivity remained constant. Piers were also totally destroyed by the waves but were built back within one year and were being used by long-tail boats, trawlers and a car ferry. Tourist resorts in the area were also reconstructed within a year of the disaster.
Figure 5.64 Livelihood map of Ban Nam Khem, February 2009, using both satellite imagery and ground survey techniques

Figure 5.65 Presence of livelihood features in Ban Nam Khem
Shops and fish processing facilities are significant livelihood providers in Ban Nam Khem. The majority of the 64 shops in the village sell food, drinks and basic household items. A small number sell clothes, while stores near to the coast cater primarily for tourists. 32 fish processing facilities were identified covering a total area of over 10,000m². Other forms of livelihood include 12 restaurants, 12 swallow nest factories, 12 bars and cafes, 12 mechanics and 11 small factories.

Remote sensing was used to identify large, conspicuous forms of livelihood without the use of ground knowledge. Both fish processing facilities and other factories were instantly identifiable from their size and location. Fish processing facilities were located along the shore-line and factories were located in a small manufacturing zone to the east of Ban Nam Khem. Other conspicuous forms of livelihood, such as the mining platform construction around the canal, were visible in the satellite imagery but required ground knowledge to verify their use, as did smaller services, such as banks, hair parlours and restaurants. Geo-referenced ground photography was used to capture their location and status in February 2009.

Fishing Sector

Before the tsunami, most livelihoods were based on fishing or aquaculture. The infrastructure for much of this activity was completely destroyed by the tsunami and families suffered from the loss of income. Some switched jobs and others borrowed money. To worsen the situation further fish stocks fell, perhaps by as much as 20%.

Remote sensing was used to monitor a number of fishing sector indicators:

- Shrimp hatcheries
- Shrimp ponds
- Piers
- Boats
- Tourism

Shrimp hatcheries

Thailand is a major exporter of shrimps, producing over half a million tonnes a year. The cultivation of marine shrimps and prawns for human consumption comprises two phases: shrimp hatcheries and grow-out ponds. Both facilities can be identified in satellite imagery and monitored throughout the recovery process. The hatcheries consist of a series of concrete tanks while the grow-out ponds are large-aerated pools where the juveniles are left to grow to marketable size. At least 14 hatcheries were identified from their large size and proximity to the ocean.
Figure 5.66 Shrimp hatcheries Ban Nam Khem. All hatcheries were destroyed by the tsunami. One was later removed and the others were left to become derelict.

Before the tsunami, the hatcheries were more difficult to identify without ground knowledge because the tanks were covered with roofing to provide a protected environment for the larvae. The tsunami destroyed the walls and roofs of the hatcheries leaving only the concrete tanks behind, which were clearly identifiable in the imagery. Figure 5.67 shows a medium-scale hatchery in Ban Nam Khem before and after the tsunami.
Remote sensing can be used to count the number of hatcheries affected by the tsunami and to estimate the production capacity destroyed by calculating the area and number of tanks affected. The hatchery shown above contains approximately 40 tanks. All 14 hatcheries in Ban Nam Khem were sited by the coast and were totally destroyed by the tsunami. The remote sensing analysis shows none of these hatcheries was reconstructed and no new hatcheries were built. This was validated with ground data collected in February 2009 and confirmed by UNDP, World Bank and FAO reports.69 One of the hatcheries was demolished and the other 13 hatcheries were left derelict. These shrimp hatcheries ceased to operate in Ban Nam Khem because of high investment costs, low shrimp prices and low levels of compensation.70

**Shrimp ponds**

Unlike the hatcheries, the growing-ponds on the outskirts of the village were unaffected by the tsunami as the pools were protected from the waves by a stretch of mangrove forest.
Figure 5.68  Shrimp ponds located behind mangrove forest to the east of Ban Nam Khem

Figure 5.69  A subset of the shrimp pond database created from satellite imagery
The ponds were delineated and classified according to whether they were full of water or not. The area of shrimp ponds full of water is slightly lower immediately after the tsunami but quickly returned to a level higher than the pre-disaster state 4 months after the tsunami. The total area of shrimp ponds increased by 22% from January 2005 to February 2009. This suggests that productivity was unaffected by the tsunami and that the region is still attractive to new shrimp pond businesses despite the disaster and the loss of local hatcheries. There appears to be a trend to grow-out pond businesses having their own hatcheries and importing shrimp larvae.

Figure 5.70  Area of shrimp grow-out ponds, calculated from remote sensing

Figure 5.71  Shrimp ponds constructed between February 2006 and February 2008
Piers

The northern part of Ban Nam Khem faces the Andaman Sea and almost half of the seafront contains piers for mooring trawlers and long-boats. Large yards are located near to the piers for fish storage and other materials, such as timber. The number of harbours and jetties was an indicator adopted by TRIAMS as part of their infrastructure monitoring. For this study length of piers was deemed to be a better measure as it gives an indication of mooring capacity. The number and length of piers was measured in the satellite imagery and the functionality and use of each pier was also gauged from the presence of boats and the condition of the piers.

Before the tsunami, there were 25 piers measuring 539m in length. These were all totally destroyed by the tsunami, with only 1 pier (12m) remaining. Pier reconstruction was rapid. The satellite imagery showed that by July 2005 many of the piers had been restored and were being used by 67 boats, but not to the same extent as they were before the tsunami. By February 2009, there were 27 piers.

According to Bang Muang Sub-District Office, the fishing piers in Ban Nam Khem were rebuilt in about 6–7 months and the fishmongers started trading in June 2005. DDPM statistics also report that 100% of harbours and jetties in Phang Nga Province were constructed by 2006. These reports validate our observations and vice-versa.

Figure 5.72 One pier in June 2002 and February 2009
Information on pier use was gathered from ancillary field data, allowing different livelihood groups to be monitored. The piers had very different uses, ranging from ferries, mangrove fishers and ship repair. Figure 5.74 shows a map of pier use in Ban Nam Khem.
Boats

Two types of boat are used in Phang Nga Province: long-tail boats and fishing trawlers. Figure 5.75 shows boats in ground survey photography and satellite imagery. The long-tail boats are approximately 10m long. Trawlers are wider and measure between 15 to 20m. Both boat types are used predominantly for fishing, but the long-boats are also used as ferries. Individual boats were identified in satellite imagery and statistics on the number of boats, their location and proximity to harbour and pier facilities were extracted.

Figure 5.75  Long-tail boats and trawlers in ground photography and satellite imagery

The number of boats is used as a proxy for livelihood recovery. The imagery analysis shows that after the tsunami boats disappeared across the whole of Ban Nam Khem and returned between January 2005 and February 2006. The density maps in Figure 5.76 show the location of boats throughout the recovery process.
However, care must be taken when interpreting these results. The Department of Fisheries warned against interpreting boat numbers as an indicator of livelihood and a focus group meeting in Ban Nam Khem suggested that although there are more boats than before the tsunami, there are people who used to have boats that now don’t. The time of the day when images were acquired (11am in both case studies) is also significant because most fishermen are out at sea at this time.

Figure 5.76 Boat density in Ban Nam Khem throughout the recovery process

Figure 5.77 Site a. long-tail boats, b. large trawlers and c. mangrove fishers and boat repair yard
Most of the long-tail boats were provided by NGOs but government compensation was insufficient to repair or replace many boats and gear. Unregistered boats were not eligible for state compensation and fuel prices have risen by 40% preventing many people from continuing to earn a living by fishing.

Figure 5.78 Number of boats in Ban Nam Khem

A large number of long-tail boats were moored on the beaches at site (a) before the tsunami and throughout the recovery process. Immediately after the tsunami there are no boats and it is assumed that they were destroyed. They reappear between May 2005 and February 2006, with numbers returning to approximately 70-80% of those seen in June 2002.

At site (b), trawlers were located near to the large fish processing facilities. Despite the large size of the vessels all of the trawlers disappeared or were destroyed due to the tsunami. Some were washed far inland, and have been made into a permanent memorial of the tsunami. The number of usable trawlers gradually recovers, reaching 80% of the pre-disaster state by February 2009. This gradual recovery reflects the high cost of replacing trawlers.

In contrast, at site (c), there was an increase in the density of long-tail boats until February 2006 after which numbers dropped, but still remained higher than before the tsunami. The rise and fall of boat numbers is likely to be due to the temporary presence of new boats outside a boat yard. In February 2009, the number of boats in Ban Nam Khem still exceeded pre-disaster numbers by 122%. Many NGOs and other agencies built long-tail boats during the first year of recovery and several media reports suggested that more had been constructed than were required.

Boat Yard

A boat yard was set up at Bang Muang camp so that villagers could repair their boats and acquire new skills, rather than wait for official assistance. The group started with 10 fishermen and a grant of 100,000 Baht ($2,500) from CODI. The scheme was successful and attracted donations from Toyota, Cement Thai and others. As part of the scheme, the fishermen repaid half the cost of the boats once they had started fishing again. In total, the group planned to make 300 boats. The boat yard is visible in the satellite imagery near to Ban Nam Khem camp. It appeared between July 2005 and February 2006 and was removed by November 2006. At least 11 long-tail boats can be seen outside the temporary building (Figure 5.79).
Tourism

Interviewing key informants in the village and people working for various agencies identified a number of tourism initiatives in Ban Nam Khem. Post tsunami, the International Labour Organisation (ILO) and United Nations Development Programme (UNDP) formed partnerships with provincial tourism associations to support tourism by teaching English and handicraft skills. Responsible Ecological Social Tours developed tour programmes and the Ministry of Labour provided emergency response training in resorts as a method of attracting tourists back to the region.

In the short-term, however, many tourists were discouraged from visiting the region; after the immediate recovery process the number of international visitors dropped dramatically in 2006. The most conspicuous evidence of tourism visible in the satellite imagery are tourist resorts. Two large tourist resorts were located near to Ban Nam Khem. We visited the Andaman Princess Resort on the island of Koh Kho Khao. The resort contains 62 rooms, four suites and 16 individual villas set in tropical gardens. Satellite imagery was used to monitor the changes to the resort over time.

The building was due to open when the tsunami struck. All of the buildings are still standing after the tsunami but the area had been heavily scarred. According to the owner of the resort, the wave passed straight through the central building causing substantial damage to the whole complex, gutting many buildings. Within 4 months the site had been cleared and resurfaced with sand. In July 2005, several large diggers are visible and new construction work is apparent. A significant amount of reconstruction took place between July 2005 and February 2006: at least 6 large buildings were built, roads were laid with asphalt, lakes and swimming pools were filled with clean water and a tennis court was constructed. The construction appears complete in February 2006, only 13 months after the tsunami, and there are no other visible changes to the resort after this date. These changes were verified by the hotel owner.
Case study: Chella Bandi

Agriculture

One of the key sources of livelihood in Chella Bandi was subsistence farming, with maize and wheat grown for personal consumption and to be sold at market. There are many hillside terraces created for arable use, clearly identifiable in the imagery. The aim was to analyse the changes in available arable space before and after the earthquake. A manual method was used to delineate all fields in the imagery. Change detection maps and statistics were generated between each image date. For Chella Bandi, an area of 299 ha, with approximately 200 fields, it took close to 40 minutes to analyse each image.
Figure 5.81 Manual delineation of arable land from remotely-sensed imagery of Chella Bandi

Figure 5.82 shows the results of the cropland analysis. At first sight there appears to have been a reduction in the amount of arable land in Chella Bandi after the earthquake. But interviews with local landowners suggest that these results are actually due to the timing of crop cycles; crops were sown in June and harvested in September. The pre-earthquake image was acquired in August when the crops were fully-grown, while the post-earthquake images were acquired after the harvest when the fields were empty. The lesson for future environmental modelling is that a prior knowledge of crops cycles is necessary before ordering imagery.

The analysis provided rudimentary information on the amount of available cropland throughout the recovery time period, which could be used as a proxy for the health of the economy and security of sustainable agricultural activities. In particular, the analysis allows commentary on the reduction of green space in a settlement. Figure 5.83 shows how fields in the central area of Chela Bandi were used to accommodate tents and transitional shelters throughout the recovery process at the expense of arrable land.
Figure 5.83  Changes over time for a single arable field in Chella Bandi (left to right: 2004, 2005, 2006, 2008). It is clear that the creation of temporary structures reduced the amount of arable land in 2005 and 2006, with cultivated land returning to its pre-event state in the 2008 image.

Discussion

Remote sensing provides a tool for detailed analysis of key economic sectors. However, it is difficult to translate these observations into employment figures. At best, remote sensing provides information on the timing and extent of recovery of various conspicuous sectors. The household survey, in contrast, was able to estimate the proportion of households working in particular sectors at various points in time. It also identified various issues being faced by workers in different sectors and identified jobs not observed using remote sensing or ground survey, including pig farming, mushroom culture and clothes washing. The focus group meetings and key informant surveys were useful for identifying other issues; for example, despite the large number of boats, there were still many households without access to one.

Where possible, official statistics were collected from executing agencies, and local and national government departments. The only data available in Thailand was for the whole province of Phang Nga. The best method of collecting detailed data might be through the survey of local businesses and/or key informants.

Neither ground survey nor remote sensing could identify the unfair allocation of resources after the tsunami. This was only discovered by interviewing local people and asking about their livelihoods. However, despite the problems, satellite imagery was able to provide a significant amount of reliable information which corresponded with data from the household survey. The household survey suggests that approximately 60% of fishermen were working within one year of the tsunami. The satellite imagery analysis showed that 67% of boats had returned to Site (a). Figure 5.84 shows the proportion of fishermen working and the length of pier both normalised to the pre-disaster state. The results match reasonably well, which suggests that pier length might be used to infer the recovery fishing.
Figure 5.84 The number of fishers and the length of pier after the 2004 tsunami (normalised to the pre-disaster state)
6 Conclusions

This report introduces a list of remote sensing indicators, encompassing key sectors and areas of activity that can be used to monitor and evaluate the process of disaster recovery. The results demonstrate that 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.

It can 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.

The data requires VHR satellite imagery with a minimum resolution of 1.0 m. This kind of satellite imagery is readily available. The time and budget requirements for the analysis are also well-known and can be calculated at the outset. Once the initial mapping and database have been created, the resources needed to update the data are significantly less. This highlights the importance of constructing a pre-disaster database of high-risk urban areas of the world that is updated regularly. Maps produced for damage assessment work may also be used to monitor recovery. In contrast, fieldwork is relatively expensive and time-consuming. This is not to say remote sensing can entirely replace fieldwork, but the combination of methods can be much more cost effective.

Recommendations

Our recommendations on how remote sensing can be used to monitor and evaluate post-disaster recovery are based on the experience of the project team and feedback from users and stakeholders. They revolve around five key questions.

What to measure?

Knowing which indicators to measure and when to acquire satellite imagery is dependent on the nature of the disaster, the needs of the users and the limitations of the satellite imagery available. An understanding of these issues is crucial to acquiring suitable data and avoiding costly mistakes. It is therefore imperative that evaluators determine the needs of the information users at the beginning of each project. Some agencies, for example the World Bank, support a range of recovery work spanning multiple sectors and themes. Others, for example WHO, have specific information needs.

The Recovery Project created a list of indicators after consulting with users via a user-needs survey. The results of this survey suggest there is a strong preference for a comprehensive approach to monitoring recovery encompassing multiple sectors. This is the approach we took. The proposed M&E methodology therefore covers a manageable number of indicators that encompass all sectors of recovery. Users can choose which indicators to monitor according to their own needs and resources.

When to measure?

It is important for analysts to know how frequently to acquire satellite imagery to avoid costly mistakes. However, because of the dynamic nature of recovery, the timing and duration of different recovery processes is likely to differ. The importance of different indicators is also likely to vary. Evaluations should obviously be conducted when impacts are likely to be visible and measurable; this will depend on the progress of recovery on the ground. Monitoring therefore requires some understanding of the timing of recovery in the particular case.
The frequency that images are acquired also depends on whether the evaluation is on-going or of completed projects. To facilitate monitoring on-going progress data should ideally be collected every 6-12 months, while project evaluations can be carried out using just two images: a pre-project image (baseline) and a post-project image.

The need for M&E is also determined 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. Yet we know that recovery usually takes longer than this. Figure 6.1 shows some of the key processes and events visible in satellite imagery with estimations of when they are likely to appear, relative to each other. 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.

Figure 6.1  Key processes and events visible in satellite imagery

**How to measure?**

Agencies already collect monitoring data. The tools they use may be divided into two broad categories:

1) Direct Observation (e.g. remote sensing and ground survey)

2) Social-Audit (e.g. focus group meetings, household surveys and key informant interviews).

The tools each have strengths and weaknesses and can be used to collect different forms of data (subjective/objective, quantitative/qualitative, cross-sectional/longitudinal, primary/secondary). All of the tools may be used independently of each other, but are usually more effective if used in a complementary way. To understand the qualities of each method a cost-effectiveness analysis was conducted based on 5 criteria: expense, time, technical requirement, detail obtainable and accuracy. These results are used to make recommendations.

**Direct Observation**

Satellite imagery now allows some forms of direct observation to be completed remotely. However, the limited spatial resolution of satellite imagery and its non-oblique look angle means that it needs to be supplemented by other data. Handheld GPS devices, integrated with still or video cameras, means that data may be input directly into a GIS system whilst in the field. Per-building survey is best conducted using a GPS camera and a holistic overview
is best conducted using geocoded video deployed from a moving vehicle. 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.

**Social-Audit**

Various social-audit techniques were used, including semi-structured interviews, surveys and focus groups. They were used to collect data about many aspects of recovery, including people’s perceptions, satisfaction and to explore why things happened the way they did.

Key informant interviews were used to gain a holistic view of recovery. A sample of people representing various sectors of recovery were asked questions about the progress of recovery. The technique was quick and efficient and provided a brief synoptic review of recovery. The results were used to determine where and when imagery and other detailed survey data was required. But a significant amount of time and skill is required to design semi-structured interviews and translate, code and analyse the results.

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. The household survey 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.

**Mixed Methods**

Each data collection method has strengths and weaknesses that involve a trade-off between time/cost/technical ability on the one hand and the detail/accuracy of the data collected. The tools can supplement each other, for example, to provide an overview so that the analysis can focus on the most appropriate imagery or to provide richer detail and a more in-depth understanding of the issues. To create an efficient workflow, the tools must be deployed at the right time and in an appropriate order. Although this will vary with the situation and resources available, a typical workflow is described below.

**Pre-field deployment**

1. **Key informant interviews** allow a team to become acquainted with the status of the area and provide an overview of the timing of different aspects of recovery. These might be conducted remotely over the telephone.

2. **Initial imagery analysis** and mapping of key indicators, for example accessibility and temporary camps, can be conducted before a field deployment.

3. **Published information** including official statistics may be obtained from the Internet, recovery agencies and national and local government offices.

**Field work**

4. Once in the field, **focus group meetings** and further key informant interviews can explore and verify these initial results.

5. **Ground survey**, using GPS cameras, is used to survey buildings, probably choosing a random sample of building points. This data can be incorporated into the geodatabase (GIS) and used to inform subsequent imagery analysis.

6. **Household surveys** can also be conducted, perhaps in parallel to the ground survey by a different team. Information from talking to affected families then allows the analysts to infer what the mapping means in terms of people’s lives and their experience of recovery.
Detailed imagery analysis

7. Detailed imagery analysis is conducted back at base using insight and information from the information sources above.

Is the method reliable?

The virtue of remote sensing, when combined with ground survey, is that is provides an objective measurement of recovery. However, morale and community vitality are also significant in the process of socio-economic recovery. A close correlation between our independent measurements and resident perceptions' would indicate that our indicators are reliable.

To test the relationship between remote sensing indicators and residents’ perceived level of recovery we asked key informants what percentage of recovery had been achieved after 6, 12, 24 and 36 months in terms of: access, environment, housing, safety, local administration, schooling, healthcare, power, water and sanitation, food and livelihoods.

Accessibility

Buildings

Figure 6.2 Perception of key informants plotted against measured recovery

There is a moderate relationship (correlation coefficient: 0.76) between remote sensing and people’s perceptions for accessibility and a strong relationship in terms of rebuilding (correlation coefficient: 0.96). Although the roads were cleared rapidly within the first twelve months key informants and householders told us that they were unhappy with the quality of the roads. So road length alone is an insufficient measure of recovery whilst the number of permanent structures can be seen as a very good indicator of housing recovery.

The relevance of rebuilding to other aspects of recovery can be tested by plotting key informants perceptions of all aspects of recovery against the number of permanent buildings.
Figure 6.3 Perceived level of recovery against number of permanent structures

Figure 6.3 shows that the perceived level of recovery in most sectors correlated closely with the number of permanent buildings. Nevertheless, it should be noted that key informants think safety and water and sanitation have only recovered by 50-60% three years after the earthquake, compared to administration and livelihoods that are perceived to have recovered by 90%.

**Is the method transferable?**

This approach to M&E using satellite imagery was designed to be non-country or hazard specific. To test the transferability of the indicators similar techniques were applied to two case studies: Ban Nam Khem and Muzaffarabad. The case study sites differed markedly in terms of their cultures and economies, the recovery frameworks and approaches that were adopted and the type of hazard. Government policy and the approach to recovery also affected the pattern of recovery and how M&E methodology could be applied. Nevertheless, the case studies demonstrated that the same indicators and similar approach can be applied in widely differing situations. The replicable, quantitative nature of the results also allows recovery in different sites to be compared.

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 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 form the basis of a geospatial database capable of storing datasets collected using other methods. It therefore has the potential to provide a framework for tracking and analysing post-disaster recovery. It may also be used as a platform on which data may be shared between stakeholders working in numerous sectors and geographic locations.

Our main conclusion, therefore, is that remote sensing, when judiciously combined with fieldwork, provides an unparalleled degree of useful information. Different agencies have different information needs and might consider doing their own remote sensing. However, it might make sense for a single agency to take overall responsibility for monitoring recovery in a comprehensive way.
How much will it cost?

The cost of satellite images can be significant but can be used for multiple indicators. The average cost of imagery in 2009 was $20 per km$^2$. Typically imagery will be needed for before the disaster, immediately after and for each subsequent six months or yearly interval. So the cost of the imagery will vary in direct relation to the size of the area and the period of recovery to be monitored. If the area is very large, a sampling and/or case study strategy needs to be adopted. It is important to note that the technology is constantly changing. Since we did this case study Worldview-1, Worldview-2 and Geoeye-1 have been launched making it easier to acquire the necessary images. These new satellites have a higher resolution that will make interpretation significantly easier and more accurate and will create opportunities for automatic pattern recognition.

Conclusion

In summary, remote sensing and GIS analysis can be used to help plan, coordinate and monitor recovery. Its main strengths include its ability to monitor large areas, its non-intrusiveness and the fact that it minimises the need for access to the study site by the survey teams. Our main conclusion, therefore, is that remote sensing, when judiciously combined with fieldwork, provides an unparalleled degree of useful information. Different agencies have different information needs and might consider doing their own remote sensing. However, it might make sense for a single agency to take overall responsibility for monitoring recovery in a comprehensive way.
## Appendices

### A1 Indicator list

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Road condition</td>
<td>Monitors the transport network, identifying damaged or broken sections immediately after the disaster and cleared or reconstructed sections at intervals through the recovery process.</td>
</tr>
<tr>
<td>2. Accessibility</td>
<td>Monitors changes in the accessibility of the transport network in terms of travel time and distance brought about by damage to the network or relocation of homes and services. It also identifies households and businesses with inadequate access to key facilities and services.</td>
</tr>
<tr>
<td>3. Bridge and public transport</td>
<td>Monitors the reconstruction of bridges and public transport facilities.</td>
</tr>
<tr>
<td>4. Presence of vehicles</td>
<td>Monitors the presence of vehicles and traffic activity to determine if roads and facilities are in use.</td>
</tr>
<tr>
<td>5. Removal and construction of buildings</td>
<td>Tracks the construction and removal of buildings by monitoring their presence and absence throughout the recovery process.</td>
</tr>
<tr>
<td>6. Change in urban land use and morphology</td>
<td>Monitors changes to the urban form and morphology of a region. Quantifies changes to the total built-up area and monitors the average size and shape of the buildings.</td>
</tr>
<tr>
<td>7. Quality of dwelling reconstruction</td>
<td>Monitors changes to the size, shape, arrangement, location and context of buildings and to the natural and built environment surrounding them. Describes the timing and quality of the building construction process and to infer occupant satisfaction.</td>
</tr>
<tr>
<td>8. Temporary accommodation</td>
<td>A suite of indicators designed to identify temporary accommodation and to measure its longevity, infrastructure placement and environmental impact.</td>
</tr>
<tr>
<td>9. Population</td>
<td>An estimate of the population living in temporary accommodation based on the number of tents, makeshift shelters and transitional shelters, and an estimation of the population living in permanent accommodation based on the number of residential buildings.</td>
</tr>
<tr>
<td>10. Services and facilities</td>
<td>Describes the location and status of services and facility buildings across the affected region.</td>
</tr>
<tr>
<td>11. Utilities - power, water and sanitation</td>
<td>Maps features associated with the supply of key utilities including power, water and sanitation.</td>
</tr>
<tr>
<td>12. Land cover and urban green space</td>
<td>Identifies areas of vegetation gain and loss, including, for example, mangrove forest and open public space.</td>
</tr>
<tr>
<td>13. Recovery of livelihoods</td>
<td>Monitors changes in the main economic sectors in the disaster-affected areas, for example agriculture, fisheries and tourism.</td>
</tr>
</tbody>
</table>
A2 Key informant interview schedule

UNIVERSITY OF CAMBRIDGE and KASETART UNIVERSITY
Indicators for Recovery 2004 SE Asian Tsunami
Key Informant Survey

ID

1. Socio-economic and demographic characteristics of household
1.1 Gender
1.2 Position
1.3 Organisation_Haas
1.4 Where at time of disaster?

2. Accessibility and transport
2.1 What locations difficult to access?
When was reliable access restored to:
2.2 Shops / markets
2.3 Health facilities
2.4 Schools
2.5 Other access problems?
2.6 How could access been improved?

3. Health
3.1 Where were people treated?
3.1 Problems getting treated?

4. Education
4.1 What problems?
4.2 What temporary schooling?
4.3 Who provided temp schooling?
4.4 Timing of provision?
4.5 How education been improved?

5. Food
5.1 What problems getting food?
5.2 How food been improved?

6. Water
6.1 Problems getting clean water?
6.2 How long were suppliers rationed?
6.3 When were the following reinstated? Temporary supply Permanent supply
6.4 How water be improved?
7. Sanitation
7.1 What sanitation problems?
Access restored when?
7.2 Toilet
7.3 Rubble/debris removed
7.4 Regular waste collection

8. Power
8.1 What power problems?
8.2 Mains restored

9. Concluding remarks
9.1 Temporary accommodation
9.2 Clearing roads
9.3 Education services
9.4 Health services
9.5 Permanent homes
9.6 Sources of income

10. Priority 1 to 3
10.1 Accessibility
10.2 Environment
10.3 Housing
10.4 Safety
10.5 Admin
10.6 Food security
10.7 Livelihood
10.8 Water
10.9 Education
10.10 Healthcare
10.11 Power

11.1 How happy with speed and quality of recovery?
11.2 How recovery be improved?
11.3 Any other comments?
A3 Household survey

UNIVERSITY OF CAMBRIDGE UNIVERSITY OF PESHAWAR
Indicators for Recovery post Kashmir and N Pakistan 2005 Earthquake
Household Survey

ID 1 Interviewer
Interviewed before O Y O N
How many times
By whom

1. Socio-economic and demographic characteristics of household
1.1 How many people are in your household now?

<table>
<thead>
<tr>
<th>Relationship to Head</th>
<th>Gender</th>
<th>Age</th>
<th>Marital status</th>
<th>Age married</th>
<th>Education</th>
<th>Occupation</th>
<th>Income</th>
</tr>
</thead>
</table>

1.2 How many people in your household before the disaster? _____ 1.3 Number of lives lost? _____ and injured _____

1.4 After the disaster, did any move away? O Y O N 1.5 Where and why did they move?

1.6 After the disaster, did any members of your family join you? O Y O N

1.7 If so, where did they come from and why did they move?

1.8 When did you move into? Tent _______ Temporary Shelter _______ Permanent House _______

2. Housing
2.1 What damage did the disaster cause to your home?

2.2 What happened to your house after the disaster?

2.3 What financial help did you get for your housing?

2.4 What technical help did you get?

2.5 Did you have a say in the design?

2.6 In what ways is the new home better or worse than before?

2.7 Did you own the house and/or land prior to the disaster? O Y O N

2.8 Problems suffered with land ownership after the disaster:

3. Location
3.1 Are you local? O Y O N 3.2 If you migrated, district of origin

3.3 Were the members of your household registered at the time of the disaster? O Y O N

3.4 Did you want to move from your town before the disaster? O Y O N Why?

3.5 Do you want to move from your town now? O Y O N Why?

4. Accessibility and transport
4.1 What problems did you have after the disaster?

4.2 What difficulties do you have now?

4.3 How did you overcome these problems?

4.4 Is your accessibility better or worse now than it was before the disaster? O better O worse O same

4.5 How could the recovery of accessibility be improved?

5. Health
5.1 Health problems suffered as a result of the disaster

5.3 Did you have any other problems getting treatment?

6. Education
6.1 What schools did your children attend?

6.2 What are main problems? (Was the school damaged etc.?)

6.3 How did you overcome them? What assistance provided?

6.4 When did your children return to school permanently?

6.5 How could the recovery of education be improved?
7. Food
7.1 What problems have you been facing to get food after the disaster?

7.2 How long were you provided with food aid?

7.3 Has your diet changed since the disaster?

7.4 How could food aid food distribution be improved?

8. Water
8.1 What problems do you have getting clean water?

8.2 How did you overcome these problems?

8.3 When were the following reinstated? Temporary supply

8.4 How could the recovery of water be improved?

9. Sanitation
9.1 What problems do you suffer from unsewered conditions?

10. Power
10.1 What problems did you suffer with the electricity supply?

10.2 When was mains power restored?

10.3 How could recovery of power be improved?

11. Environment
11.1 How has the surrounding natural environment changed?

11.2 How has this impacted on your life?

12. Lifestyle
12.1 In what ways has your lifestyle changed?

12.2 What new appliances have you got?

13. Livelihood
13.1 What were your household's main sources of income?

| Occupation
| Income |
|-------|-------|
| Before | After | 1 year after | 2 years after | Now |

13.2 If you were unemployed, please explain why;

13.3 Was there a time when you could not afford the basics?

13.4 How did you overcome these problems?

13.5 How long did you receive compensation? O Y O N

13.6 Did you receive any advice, retraining or equipment?

13.7 Are you trying to find a new job now? O Y O N

14. Community Recovery
14.1 If the disaster happened again, what aspects should have priority? 1 for immediate, 2 for later.

<table>
<thead>
<tr>
<th>Accessibility</th>
<th>Environment</th>
<th>Housing</th>
<th>Vulnerability/Safety</th>
<th>Administration and services</th>
<th>Education</th>
<th>Healthcare</th>
<th>Livelihood</th>
<th>Power</th>
<th>Water</th>
</tr>
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<tbody>
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<td>O O 2</td>
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</tbody>
</table>

14.2 Are you happy with the speed and quality of recovery as it concerns you? O Y O N

14.3 How could recovery have been made more successful?

14.4 Any other comments or observations?
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