

## Chapter 20

# Monitoring Long-Term Disaster Recovery – Space and Ground Views

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**Abstract** Remote sensing plays a crucial role in post-disaster and emergency responses. For years, it has been a key player in providing invaluable multi-temporal synoptic data for landuse and landcover change detection. Surprisingly, it has not been fully exploited for monitoring long-term disaster recovery due to the involvement of various timeframes and scales in monitoring. This chapter reports our investigation of medium resolution satellite image use in association with ground direct observation, socio-economic field data collection and interviews for monitoring recovery of the tsunami-affected areas in Phanga, Thailand. Multi-temporal landuse/landcover maps of the study area were produced via conventional supervised classification. Socio-economic data was analyzed to obtain information related to the recovery process on the ground. To bridge the gap between the classified maps and the point-based socio-economic data for comparison, landuse/landcover clusters presenting the aggregated level of information were used against buffer regions around the village points. The two data sets presented a good agreement in detection of the recovery of tourism and expansion of agricultural activities. It was not possible to confirm whether a building was newly built but the rehabilitation of mangrove forest could be observed. Overall, ASTER images are sufficient to capture the large landuse/landcover changes induced by human activities. Our study area has been in smooth recovery and some minor decrease in population or slowdown of economic activities could not be observed from the ASTER images. To some extent, the integration of ASTER images and ground data proved useful in providing a clear picture of the recovery process in an area like Phang Nga, Thailand. It would be more effective to have administrative boundaries instead of village points and an enabled-location-awareness interview setting to better link the spatial distribution of socio-economic data with the monitoring context.

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## 20.1 Introduction

In recent decades, the world has experienced more frequently (every few years) large-scale disasters such as the 1995 Kobe-Japan earthquake, the 1999 Kocaeli-Turkey earthquake, the 2001 Gujarat-India earthquake, the 2003 Bourmedes-Algeria earthquake, the 2003 Bam-Iran earthquake, the 2004 Indian Ocean earthquake and tsunami, the 2005 Katrina hurricane, the 2008 Sichuan-China earthquake, the 2011 giant Tohoku earthquake and tsunami, and most recently the 2013 Haiyan typhoon. Numerous other events such as hurricanes, wildfires, drought, and volcanic eruptions are also occurring worldwide. The social and economic impacts of these events continue for years from local to global scales (Huppert and Sparks 2006). The recovery process needs to be carefully monitored, as it is a complex process and involves various stakeholders (Brown et al. 2010).

Much research on the uses of remote sensing and geospatial technologies has been carried out to see how they can really help in the disaster management cycle. It has indicated that satellite remotely sensed imagery is an important data source for disaster management at all stages including *post-disaster responses* (Adams et al. 2004; Eguchi et al. 2000; Vu et al. 2007; Vu and Ban 2010; Acqua and Gamba 2012), *recovery process* (Hill et al. 2006), and *preparedness and mitigation* (Taubenbock et al. 2008; Tralli et al. 2005; Romer et al. 2012). Their wide coverage, huge archives and reasonable-temporal-resolution are significantly valuable in disaster management. They are even the only data source of the hard-hit and difficult-to-access areas at the early stage. The dissemination of such early vital information is improving under the coordination of UN-SPIDER and the activation of the International Charter on Space and Major Disasters. The recent use of satellite images has mainly focused on the response phase, whereas little attention has been paid to its use for monitoring and accessing the recovery phase (Hill et al. 2006).

Following our recent disaster response related research for the tsunami-affected areas in Thailand (Kamthonkiat et al. 2011a, b, 2012; Vu et al. 2007; Vu 2008, 2011), we further investigate the use of medium spatial resolution ASTER imagery in monitoring the long-term recovery of the area. A few relevant studies are discussed in Sect. 20.2 to highlight the need for our study. Our methodology will be described in Sect. 20.3 prior to results and discussion in Sect. 20.4. Finally, concluding remarks and future work are presented in the Sect. 20.5.

## 20.2 Remote Sensing for Monitoring Disaster Recovery

A few attempts have been made to explore the usability of remote sensing images during recovery processes. Vu (2008) introduced a recovery monitoring system using remote sensing data on a grid-computing platform. It targeted long-term recovery involving a huge data set; hence, grid-based large-scale database and parallel computing were introduced as a suitable approach, which was also

extendable to a sharing platform for continual monitoring. Focusing on remote sensing processing and storage, it did not reveal many issues relevant to real recovery on the ground. Romer et al. (2011) used high-resolution satellite images to assess the recovery of different vegetation types in a tsunami-affected area. The main work was change detection analysis and in interpreting the results, the authors inferred some impact of human activities on vegetation recovery. Likewise, Kamthonkiat et al. (2011a) focused more on monitoring mangrove recovery with medium spatial resolution satellite ASTER images. This work focused more on the usability of satellite remote sensing in monitoring the recovery process. The same research group went a bit further to investigate overall landuse recovery of Phuket after the 2004 tsunami disaster using ASTER images (Kamthonkiat et al. 2011b). Damaged areas were located along the coastline and it was shown that less than 1 m resolution satellite imagery was more appropriate to detect the damage (Vu et al. 2007), which indicates that it is hard to establish a direct link to damage situations when using ASTER imagery in monitoring recovery. The problem of incompatible spatial resolution was mitigated with direct ground observation. In damage mapping and monitoring the recovery of housing areas, the suitability of high-resolution images was illustrated (Vicini et al. 2011). In this study, some attempts were made to develop a quantitative scale for measuring the recovery of a building. The aforementioned studies solved the problem from the remote sensing perspective. However, what should be measured during the recovery period remains unclear.

Brown et al. (2010) reported the outcomes of The Recovery Project, which aimed at identifying the indicators for measuring, monitoring and evaluating post-disaster recovery, both in the short-term and long-term. Remote sensing was proposed as one of the main tools together with ground observation and social audit techniques. Measuring recovery highly depends on timeframe and scale. The project emphasized using very high-resolution satellite images, from which detailed changes can be detected, and recommended investigation of medium resolution satellite imagery to achieve the measurement at a coarser scale. Similarly, the combination of field surveys, ground interviews and remote sensing was proposed in Bevington et al. (2011) to understand the ways of recovery in the aftermath of a disaster.

The recovery stage is the least investigated and still poorly understood (Rubin 1985; Comerio 2005; Bevington et al. 2011) due to the various timeframes and scales that need to be taken into account. Capturing information about the Earth's surface from space, remote sensing techniques would provide both synoptic and detailed (up to half-meter spatial resolution with current satellite platforms) land cover and land use over time. As noted above, remote sensing has been recommended and proved to be a significant source of information to fill the gaps across multiple spatio-temporal scales (Brown et al. 2010; Bevington et al. 2011). To some extent, it can reveal little information about real human activities in the area. For instance, a residential area fully occupied with new buildings (roofs) as can be seen from a satellite image does not imply that life there is getting back to

normal. Change detection applications of remote sensing, so far, are more to report the biophysical changes, which comprise just one aspect of the disaster recovery process.

Among the four periods of the recovery process, i.e. emergency relief, early recovery, reconstruction and on-going development (Brown et al. 2010), the last two seem less investigated due to their longer time-frames and hence have received less attention from international organisations, authorities and media. Looking into these periods, this study aims at further establishing the use of remote sensing in monitoring the recovery process. Using a case study of Phang Nga, Thailand, a tsunami-affected area, this study assessed the feasibility of using medium resolution satellite images for regional monitoring in long-term recovery focusing on human activities and environmental rehabilitation. It subsequently identified the gap between information captured from space and socio-economic data from the ground. Two important questions need to be addressed: “To what extent can medium multi-spectral resolution satellite images reveal the real recovery process on the ground?” “Is it possible to link the captured pixel-based information to ground-based social survey information in an integrated manner?” In attempts to respond to these questions, the study provides a few recommendations for expanding remote sensing uses in monitoring the recovery process.

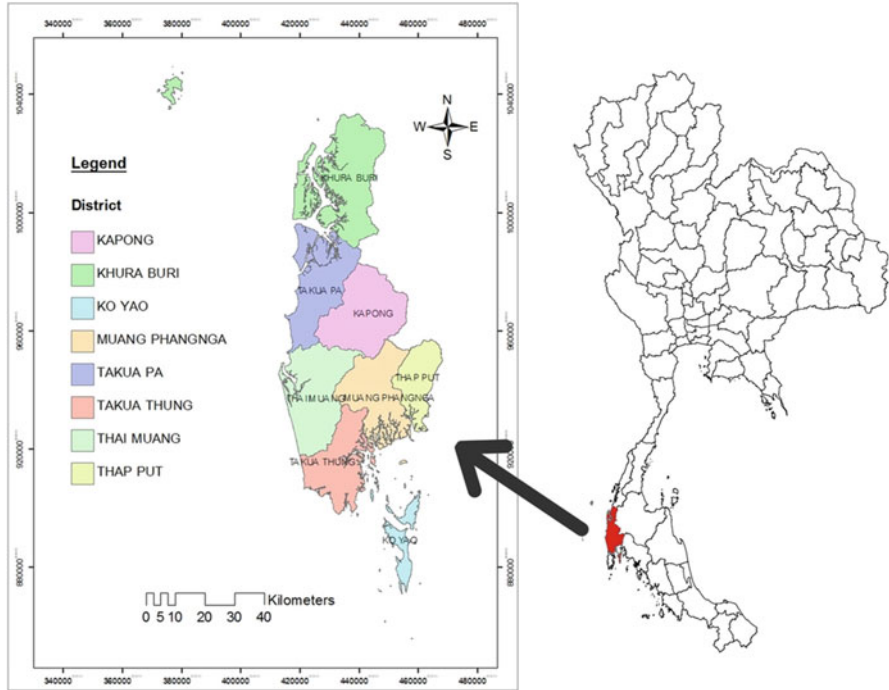
## **20.3 Methodology**

### **20.3.1 Study Area**

The tsunami impacted provinces in the South of Thailand are Phang Nga, Phuket, Satun, Krabi, Ranong, and Trang. Among these, Phang Nga was the most severely affected by the 2004 Indian Ocean tsunami (Fig. 20.1). Although the tsunami did not strike the area instantly after the Sumatra quake due to the distance, the area was not prepared for such a disaster and hence, the negative impact was intensified, especially on the tourist and fishing activities, which are main contributors to the local economy. Fishing villages are mainly located in the north of Phang Nga whereas tourist resorts are in the central region. It would be very interesting to observe how the area changed after such a devastating event in terms of the physical landscape and its relationship to human life and activities.

### **20.3.2 Landcover/Landuse (LULC) Change Detection**

Previous studies have indicated that high-resolution satellite images are suitable for damage detection and monitoring detailed recovery at the building level. To look into the recovery on a regional scale like the entire Phang Nga province, it would



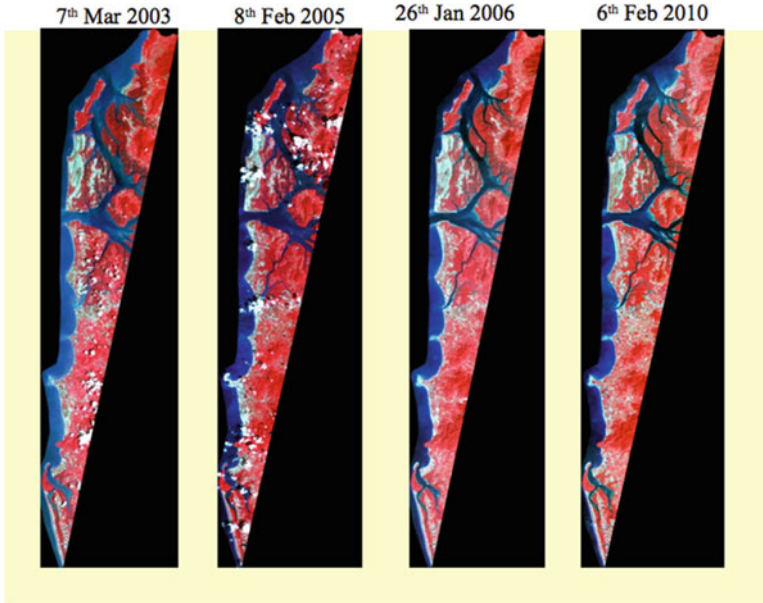
**Fig. 20.1** Phang Nga province, Southern Thailand

**Table 20.1** Descriptions of ASTER scenes used for mapping LULC changes

| Acquisition date | Wavelength and spatial resolution (m) | Remarks   |
|------------------|---------------------------------------|---|
| 07 March 2003    | VNIR, 15 m                            | About 2 years before the 2004 tsunami   |
| 31 December 2004 | VNIR, 15 m                            | 5 days after the 2004 tsunami. Cloudy image, only a fraction of mangrove area in Takua Pa was observed. |
| 08 February 2005 | VNIR, 15 m                            | 43 days after the 2004 tsunami  |
| 26 January 2006  | VNIR, 15 m                            | 1 year after the 2004 tsunami   |
| 6 February 2010  | VNIR, 15 m                            | 6 years after the 2004 tsunami  |

be unnecessarily costly to only use high-resolution satellite images. In observing the changes over a large area, medium resolution ASTER images were acquired at four different times including about 2 years before and three other times after the disaster event in December 2004. As the entire study area can be only fully covered with three scenes, in total 12 scenes were acquired as listed in Table 20.1.

The analysis of land cover and mangroves in this study was performed in the western part of Tai Muang, Takuapa and Kuraburi districts according to the limitation of scene area of the ASTER images presented in Fig. 20.2, which shows the mosaicked ASTER images used for this study. Other ancillary data include:



**Fig. 20.2** Multi-temporal remote sensing data used in this study

- Landuse Map 2000 (1:50,000) and 2007 (1:25,000) of Phang Nga from the Land Development Department (LDD), Ministry of Agriculture and cooperatives;
- Landuse (Base Map) 1999 of Phang Nga, 1:50,000 from the Pollution Control Department, Ministry of Natural Resources and Environment;
- Landuse and road maps 2006 of Phang Nga Province, 1:50,000 from The Royal Thai Survey Department;
- Mangrove Plantation Sites in Phang Nga, 1:50,000 from Mangrove Administrative Division 2, Krabi Province, Thailand;
- Socio-economic data – Village Profile Data (survey every 2 years) and Family Profile Data (annual survey) of Phang Nga, 2003, 2005, 2006, 2007, 2010 and 2011 from the Ministry of Interior, Thailand;
- Tsunami damage level in Phang Nga from the Department of Disaster Prevention and Mitigation (DDPM), the Ministry of Interior, Thailand.

As illustrated in Fig. 20.3, post-classification change detection was employed for monitoring and mapping LULC changes in the study area. The road network in vector format was used to assist with the precise alignment of ASTER images from different time periods. It is noted that the 2004 tsunami event also caused the displacement of the shoreline (Kamthonkiat et al. 2012). This was also taken into account in image-to-image registration. Intensive field surveying was conducted to guide the supervised classification with the maximum likelihood technique, and only greater than 75 % classification accuracy was accepted to mitigate the possible errors propagated in change detection.

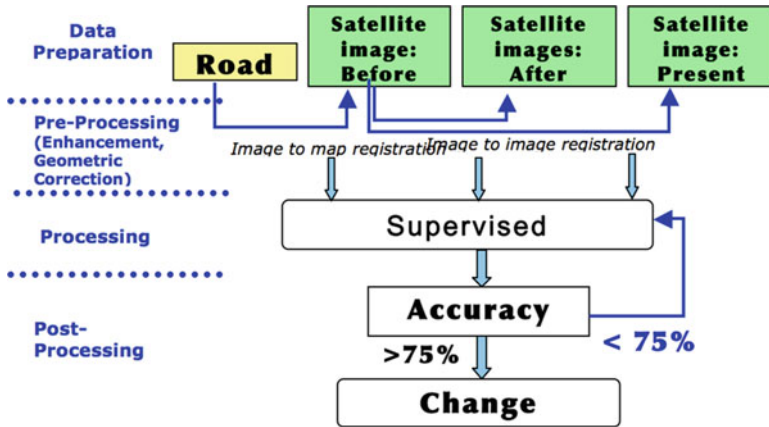


Fig. 20.3 Change detection analysis flowchart

### 20.3.3 Interpretation of Life Recovery and Environmental Rehabilitation

LULC information derived from satellite image classification provides a synoptic view of geo-biophysical changes over a large area. Remote sensing products have never been a sole data source in any application; careful ground truth and operators’ knowledge are required to obtain a reliable outcome. To what extent can medium resolution satellite imagery like ASTER contribute to monitoring the recovery process on the ground?

Based on the outcomes of the image classification, visual interpretation carefully assessed the LULC pattern changes over time with reference to the status before the disaster in March 2003. While the change detection in Sect. 20.3.2 provided overall quantitative information about LULC changes, the assessment here was a step forward. We carefully compared the classified results with ground truth data, including direct observation and interviewing, to reveal the real recovery of mangrove forest and to analyse changes at the village level by checking how the recovery of human activities has been taking place.

Villages in our study areas were categorised into three different groups: North (fishing village and agriculture), Central (tourist hotels, resorts) and South (mangrove forest). Environmental rehabilitation was investigated for villages in the South region whereas detailed assessment of human activities was carried out for heavily impacted villages in the North and Central regions.

Unfortunately, socio-economic data at the village level was provided in the form of attribute tables associated with village point shapefiles, i.e. from socio-economic village profile data. There was an obvious gap between the presenting point-based data and the relevant activities on the ground. Direct comparison of pixel-based LULC information with socio-economic point-based data would not lead to any logical findings.



**Table 20.2** Visual interpretation of recovery process

| Damage level                   | Pre-event main activities                     | Pattern changes from ASTER | Ground observation | Remarks                |
|--------------------------------|---|----------------------------|--------------------|------------------------|
| Very High, High, Moderate, Low | Fishing, Tourism, Forest, Agriculture, Others | e.g. LULC changes          | Real activities    | Interpreter's comments |

To fill the gap between two data sets for a possible comparison, we summarised (based on majority rule) the classified LULC using the clusters formed by mean-shift clustering (Comaniciu and Meer 2002). On the other hand, a buffer with a fixed radius of 500 m was created for an approximate estimation of LULC of a village. Subsequently, visual interpretation was performed on the classified satellite images using socio-economic village profile data in 2003, 2005 and 2007, ground survey photos and fact finding via interviews in local communities. The interpretation results were to fill in the observation table (Table 20.2) to assist the investigation.

## 20.4 Results and Discussion

An extensive field survey was conducted in the area. We collected ground truth data for training and validation of the LULC classification. In addition to that, interviews with local people provided another aspect of the real situation on the ground for assessing the extent which ASTER can cover. On the other hand, the team was also equipped with a Global Positioning System (GPS), topographic maps and time series satellite images (Fig. 20.4) to confirm the displacement of Phang Nga shorelines after the disaster and observe the environmental rehabilitation, especially of mangrove forest areas. This information was subsequently used to validate the classified ASTER images.

There was a steady rate of erosion in several locations in our study area after the disaster. The inland-shifted positions of the shoreline in 2005 were about 514 m at Pak Ko Village on Kho Khao Island, 85 m at Nam Khem Village, 652 m at Coral Reef Point, and 64 m at Bang Khaya Village. In 2004, the positions of the shoreline at Pak Ko Village had changed while the sand beach was swept. The series of tsunami waves had also re-allocated the sand dune under the sea; this affected the direction of current and thus stronger waves hit the beach as presented in the ASTER 2005 and 2010 (Fig. 20.5). Further details were reported in Kamthonkiat et al. 2012. The field survey also recorded the measures taken for shoreline protection as depicted in Fig. 20.6.

As mentioned in the methodology, the accepted overall accuracy of the classification was at least 75 %. Table 20.3 shows the referenced maps and field data used for accuracy assessment, and the percentages of overall accuracy of each classified image are also presented. The results of the supervised classification of ASTER in





Fig. 20.4 Field survey – beach and shorelines in Phang Nga

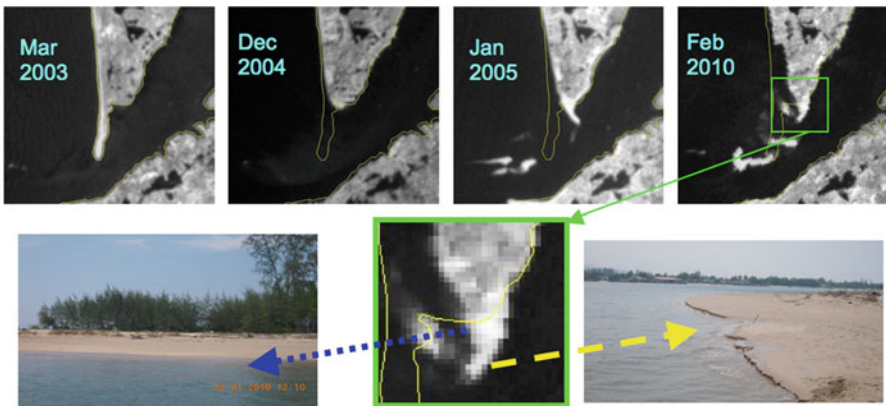


Fig. 20.5 Analysis of shorelines shifting using remote sensing – Pak Ko Village on Kho Khao Island

2003, 2005, 2006 and 2010 (concentrated on the western part of Tai Muang, Takuapa and Kuraburi districts) presented forest, mangrove, agricultural land, built-up, bare land, beach, water bodies and miscellaneous (Fig. 20.7).

Beach, built-up, and mangrove areas in 2003 had changed to bare soil, water bodies and miscellaneous in 2005. One year after the event, about 50 % of beach



**Fig. 20.6** Shoreline protection

**Table 20.3** Overall accuracy of image classification

| Classified image | Source of reference data                      | Overall accuracy (%) |
|------------------|---|----------------------|
| 07 March 2003    | Landuse 2000 (Land Development Department)    | 84.2                 |
| 08 February 2005 | Landuse 2006 (Land Development Department)    | 77.8                 |
| 26 January 2006  | Landuse 2007 (Land Development Department)    | 79.9                 |
| 6 February 2010  | Ground truth data (field survey in 2009–2010) | 81.6                 |

and built-up (resorts, hotels and shops) areas in Takua Pa, a famous tourist beach, recovered in early 2006 while mangrove had slightly decreased. In 2010, the inland built-up area had increased compared to the area in 2003–2006, mangrove areas presented almost the same extent as in 2003 while forest had been turned into agriculture and built-up.

After the 2004 Indian Ocean tsunami, a 6-year conservation and rehabilitation program for mangrove forests in the tsunami impacted areas was established by the Thai Government. However, information about mangrove restoration or reforestation is limited only to the field scale. The integrated use of remote sensing and field data enabled a regional study of the changes in mangrove areas pre- and post-tsunami and its recovery up until 2010. Classified images showed some degree of reforestation in 2005 but the process decreased in 2006. In some locations where the topography and soil structure had changed, only a small number of trees could

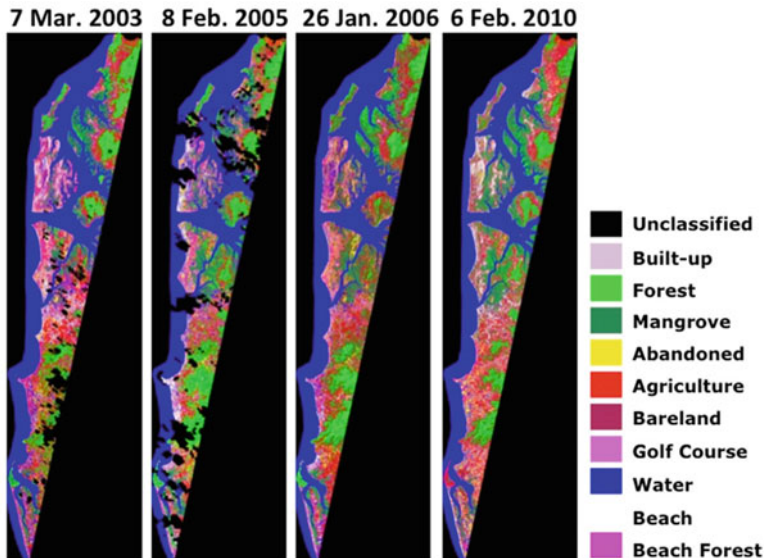


Fig. 20.7 Classified results

survive and hence these areas might be classified as other land cover types like water bodies and bare soil. In addition, the development of shrimp farms, urban recovery and development for tourist activities after the tsunami also disturbed regrowth of the mangroves in the study area, which is outside the tsunami-impacted zone.

Figure 20.8 presents the location of damaged and reforested mangrove near Nam Khem Village, Takua Pa District. The mangrove trees were swept away by the series of tsunami waves and became bare soil in 2004. As aforementioned, the reforestation in 2005 did not succeed in many places, and at this location this was due to degraded soil conditions after the waves carried up salted and sandy soil and deposited it on top. After a few years of mangrove reforestation, the area of mangrove has gradually increased and completely recovered in 2010 as shown in Fig. 20.8. Monitoring of mangrove conditions in the reforested areas is therefore crucial for understanding the progress of recovery (see Fig. 20.9).

The levels of damage were identified by field surveys and the height of wave or inundation level; Low impact ( $\leq 2$  m height of wave/inundation), Moderate ( $> 2$  and  $\leq 5$  m), High ( $> 5$  and  $\leq 10$  m) and Very High ( $> 10$  m). Sixty-four villages along the west coast of Phang Nga Province were listed at different damage levels: Low (23 villages), Moderate (14 villages), High (19 villages) and Very High (8 villages) (DDPM 2006). This information was presented in map format for better understanding the tsunami impact: location of villages and damage level as shown in Fig. 20.10. Most of the high and very highly impacted villages were located in Takua Pa District.

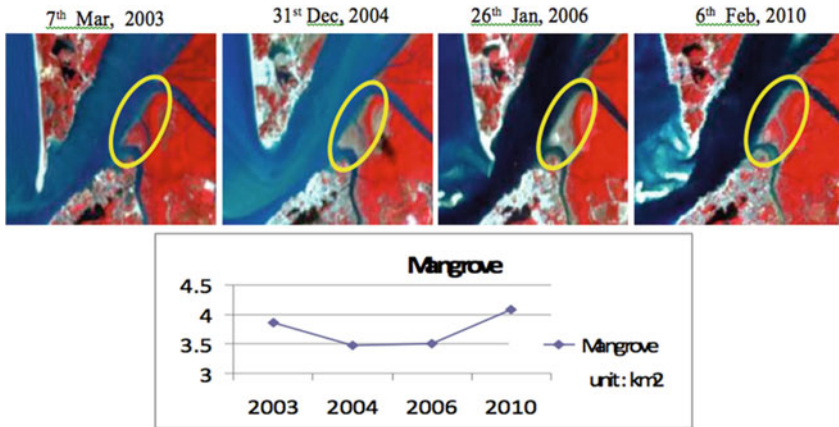


Fig. 20.8 An impacted mangrove area and its recovery



Fig. 20.9 Monitoring of mangrove conditions in the reforested areas in Takua Pa District

The statistical data of population and hired workers in the tsunami-impacted villages were compared using only 3 crucial periods: 2003 (pre-event), 2005 (post-event damage monitoring) and 2007 (post-event recovery monitoring). In addition, the 2010–2011 data was used to identify recovery and assess recent status. Overall, the population changes are depicted in connection with village location in Fig. 20.11. It shows that the population in 2005 of the Low and Moderately impacted villages had slightly decreased in comparison to that in 2003, but it had significantly decreased in the High and Very Highly impacted villages. Only Nam Khem Village has a higher population in 2005 because there were many charities and people who moved into the area for the recovery process. In 2006–2007, most of the impacted villages had recovered physically and in terms of population. In 2010–2011, populations in the Low and Moderately impacted villages were significantly increased (various from 10 to 300 %). The populations in the high and very highly impacted villages had rarely increased while decreased populations (10–50%) were reported for Pak Weep, Pak Jok, Nam Khem and Tab Yang villages in Takua Pa District.

The fluctuation of the amount of hired workers pre- and post-2004 tsunami presented the same trend as the fluctuation of population levels explained above. It



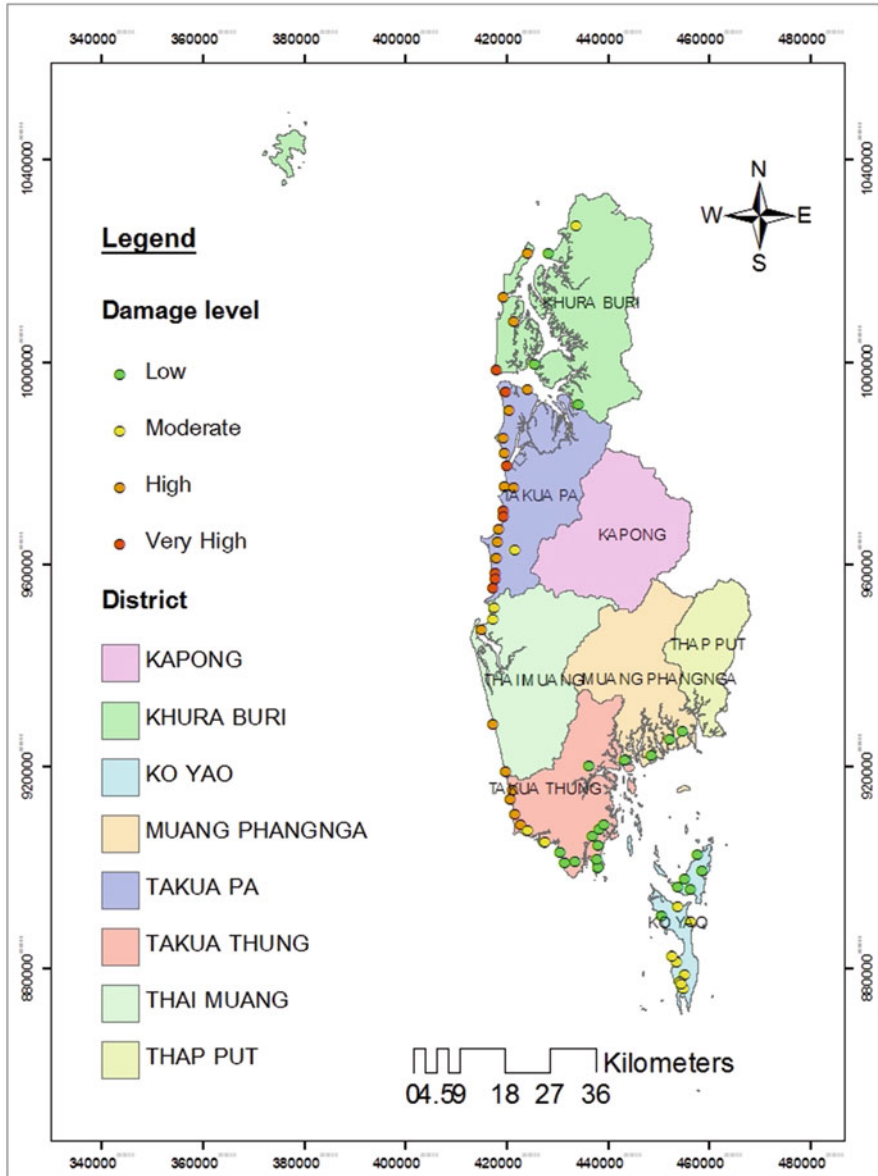


Fig. 20.10 Tsunami impact villages, classed by damage levels

was reported in 2005 that unemployment had increased especially among fishermen and tourist related workers. In 2007 and 2010, the number of hired workers recovered in the field of tourism and increased in the field of agriculture.

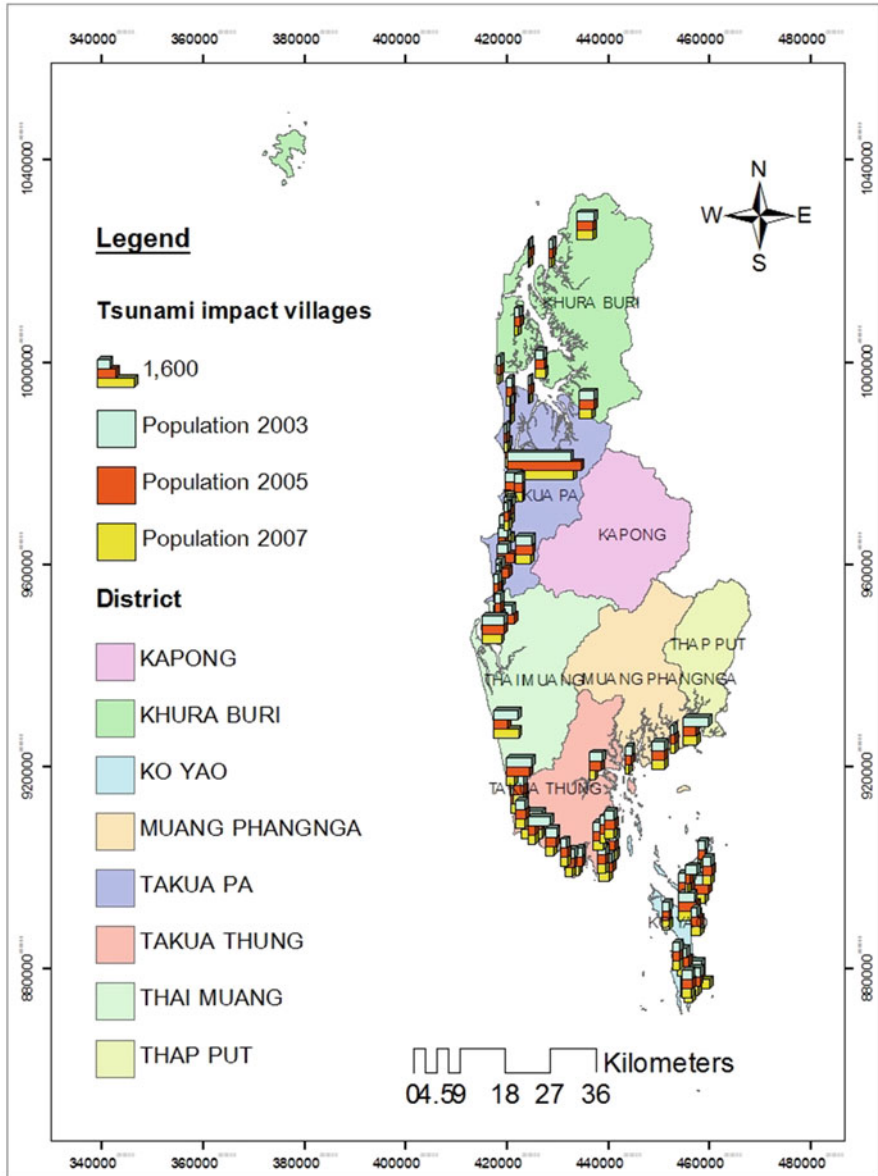


Fig. 20.11 Tsunami impacted villages: population changes in 2003, 2005 and 2007

During the recovery, the changes in population and employment as observed from socio-economic data and field interviews, led to some obvious LULC pattern changes. Recovery of tourism activities and population increase resulted in (and was also a result of) the recovery and expansion of built-up areas including beach resorts

and housing areas. Similarly, the expansion of agricultural land could indicate more people engaged in agricultural activities; we need further detailed analysis of socio-economic data to reveal the ratio between hired workers and residents in the rise of population. It was difficult to observe clearly any evidence related to fishing activities on ASTER images. On the downside, the small decrease of population in some villages could not be captured in classified ASTER images since it did not induce any clear change on a coarse resolution image like ASTER.

In the aftermath of the 2004 tsunami, many international and Thai charities provided for accommodation recovery by fixing or rebuilding new houses at the same location and set up the inland tsunami victim villages. Based on our field survey, accommodation recovery was observed and mapped as shown in Fig. 20.12. We could observe the recovery of built-up areas on ASTER images but were unable to confirm if they were newly built. This would be possible with higher resolution imagery.

The cluster-based classified ASTER images provided an aggregated form of LULC for comparison with socio-economic data. The point-based socio-economic data, in its usual form, provided no spatial distribution. While LULC can reveal the spatial distribution of consequences of human activities, there remains a big gap between the two data sets for monitoring recovery. In this study, we simply tried to improve the information presentation derived from the satellite image and used unrealistic buffer zones around the village points. To better integrate them in a more systematic manner, at least the administrative boundaries in polygon form would be required. The socio-economic and field survey data subsequently would be plotted against the two sets of polygons: clusters from classified ASTER images and administrative boundaries. Moreover, direct observation and field interviews were conducted to provide additional information about the real situation on the ground. To be more effective, the sampling strategy needs to be taken into account so that it enables location-awareness in the process of field data collection and subsequent data analysis. The socio-economic figures associated with each single village point would then be remapped together with field survey clues within the administrative boundary of that village.

Moreover, during the survey, the understanding of tsunamis and the response plan and reactions to unexpected tsunamis in the future were discussed with the villagers (see Fig. 20.13). Since the tragic and catastrophic tsunami in 2004, most of the tsunami victims and Thais had learnt about tsunamis: their source and cause, warning signs before their occurrence, their character and attack style of the series of waves, etc. Since 2005, a preparedness plan and tsunami facilities (barrier, observatory and broadcasting towers, maps and signs of safety zones and routes of evacuation, etc.) were set up and distributed in the tsunami impacted provinces, especially in Phang Nga and Phuket (Kamthonkiat et al. 2011b). Since then, evacuation activities have been conducted annually.



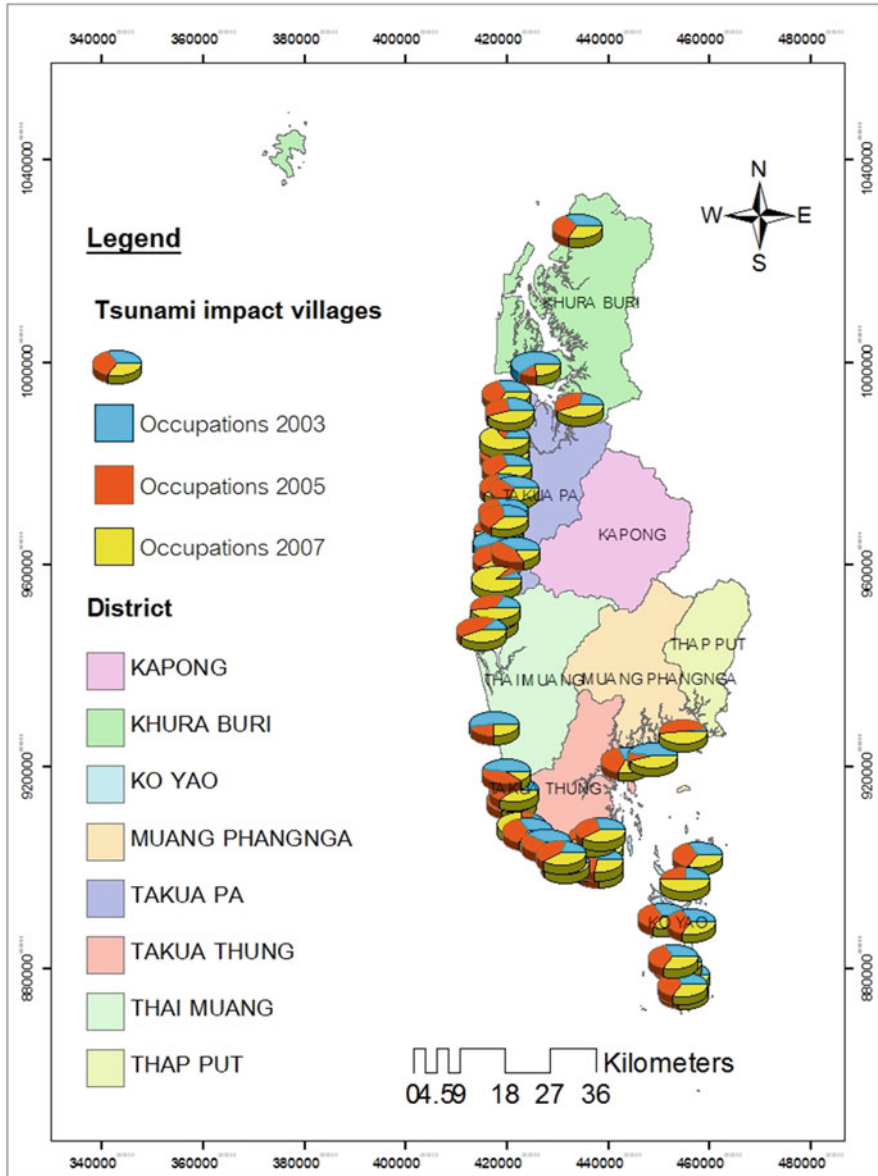


Fig. 20.12 Relocation of houses of tsunami-affected people/villagers based on field survey

*Survey – Rebuilt village, interview their tsunami's understanding, information of mangrove area and their activities...*



**Fig. 20.13** Field survey – rebuilt village and interview with tsunami victims

## 20.5 Conclusion

In the aftermath of the 2004 Indian Ocean Tsunami, remote sensing has played an important role in mapping impacted areas in Southern Thailand, namely: Phang Nga, Phuket, Krabi, Satun, Ranong and Trang provinces. In this study, monitoring the recovery of environmental rehabilitation and human activities was intensively focused on Phang Nga using ASTER time series data (medium resolution remote sensing) and annual field surveys.

It has been proven clearly that multi-temporal ASTER images or the like are the right data sources for such a regional study of shoreline displacement and mangrove rehabilitation. Interpreting the recovery of human activities faced a tougher challenge due to incompatible data formats. To some extent, information derived from satellite images could help to infer some big changes in human activities in the areas such as recovery of tourism and expansion of agricultural activities. Integration of satellite images, socio-economic data (population, and employment in different sectors) and social survey information are helpful in monitoring physical and living conditions(?) recovery in Phang Nga. In future research, we propose the consideration of a sampling strategy for social interviews and direct observation on the ground, which will help to enable a better connection between conventional socio-economic databases and spatially distributed information derived from satellite images.

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