



# NEAR-SHORE FIELD SURVEY FOR TSUNAMI RISK ASSESSMENT

HAMBANTOTA TOWN  
SRI LANKA

APRIL 2013



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## CHAPTER 1 INTRODUCTION

For countries with inadequate resources for disaster preparedness, as is the case for most countries in the Indian Ocean and Southeast Asian region, identification of areas at high risk to tsunamis is crucial for prioritizing resource allocation. Tsunami risk assessment, which provides an estimate of potential losses in lives and cost of building damage, would reveal communities that would be highly vulnerable to the hazard and, hence, need to be prioritized for enhancing readiness. The assessment, however, entails detailed inundation modeling for a range of scenarios from most important source zones, and requires computational capability and good-quality near-shore bathymetric, topographic, and exposure datasets, which most countries in the region lack.

Investment of scarce resources also favors ventures that are effective, efficient, and have longer-lasting impact. In this regard, development of tsunami early warning systems has taken a multi-hazard approach, and early warning integration into broader disaster risk reduction and development and regional resource sharing are among the sustainability strategies.

The project entitled “*Enhancing coastal hazard early warning and response: tools and institutional strengthening*”, supported by the United Nations Economic and Social Commission for Asia and the Pacific (ESCAP) through the Trust Fund for Tsunami, Disaster and Climate Preparedness, aims to build tsunami risk assessment capacities in Myanmar, Philippines, Sri Lanka, and Thailand, building on UNESCO/IOC efforts in the Indian Ocean region and taking advantage of low-cost methodologies developed at RIMES; and develop a regional data sharing policy for RIMES Member States and collaborating countries, for improving data availability for warning purposes. RIMES shall build tsunami risk assessment capacity through training, demonstration of tool application, and transfer of equipment, software, systems, and training manuals to the countries to facilitate replication/upscaling. These tools are: a) low-cost near-shore bathymetric, topographic, and exposure survey methodologies, and data processing tool to generate high-resolution data required for tsunami risk assessment; and b) computer-based tsunami risk assessment (named INSPIRE) and evacuation mapping (named ESCAPE).

Target groups for this project are:

- a) Technical government agencies involved in the generation of near-shore bathymetric and topographic maps and exposure data in Myanmar: Myanmar National Hydrographic Center and Department of Land Survey; Philippines: National Mapping and Resource Information Authority (NAMRIA); and Sri Lanka: National Aquatic Resources Research and Development Agency (NARA) and the Survey Department
- b) Technical agencies involved in tsunami risk assessment in Myanmar: Department of Meteorology and Hydrology (DMH); Philippines: Philippine Institute for Volcanology and Seismology (PHIVOLCS); Sri Lanka: Coast Conservation Department; and Thailand: Department of Disaster Prevention and Mitigation (DDPM)
- c) Research institutions/ universities involved in risk assessment
- d) Users of risk assessment products in Myanmar: DMH, Relief and Resettlement Department, and General Administration Department; Philippines: PHIVOLCS and National Disaster Risk Reduction and Management Council (NDRRMC); Sri Lanka: Department of Meteorology (DoM) and Disaster Management Center (DMC); and Thailand: Department of Disaster Prevention and Mitigation (DDPM)
- e) Local authorities and other disaster management organizations at the pilot sites, such as the National Red Cross Society, NGOs, and CBOs
- f) Members of the RIMES Council, consisting of National Meteorological and Hydrological Services (NMHSs) and/or technical agencies mandated to generate and provide early warning

Table 1.1 details the project’s activities, and Table 1.2 the involvement of project partners in each of these activities.

Table 1.1 Updated project schedule

	2012				2013												2014						
	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	
1. Project initiation																							
1.1 Project initiation meeting	M	P	S																				
2. Capacity building in tsunami risk assessment																							
2.1 Training on near-shore field surveys					P	S										M							
2.2 Training on survey data processing, DEM generation										P	S						M						
2.3 Training on tsunami risk assessment, evacuation mapping												P	S				M						
3. Improvement of response capabilities																							
3.1 Evacuation map testing and exercise, manual adaptation													P	S				M					
4. Regional resource sharing policy and mechanism devt																							
4.1 Resource sharing policy and mechanism development																							

Note: M-Myanmar; P-Philippines; S-Sri Lanka

Table 1.2 Involvement by partners in project activities

Training	Location	Days	Local Staffs	Target	Additional participants*	Tool, equipment for transfer to targets
Near-shore bathymetric survey	On-site	11	6	NARA/ CCD/ DoM		Survey methodology Equipment: depth sonar, laptop computer, low-cost tide gauge
Near-shore topographic survey	On-site	10	5	Survey Department /CCD/ DoM		Survey methodology Equipment: handheld GPS, leveling scope
Exposure survey	On-site	10	4	Survey Department /CCD/ Local government/ DoM		Survey methodology
Survey data processing and DEM generation	RIMES	30	6	NARA/ Survey Department/ CCD		DEM generation methodology Imagery processing software Mapping software
Tsunami risk assessment using INSPIRE	National capital	5	20	CCD/DoM/NARA	Research institutions/ universities	INSPIRE prototype
INSPIRE product interpretation and application	National capital	2	20	CCD/DoM/DMC		
Evacuation mapping using ESCAPE	National capital	5	20	DMC		ESCAPE prototype
Evacuation map testing and exercise	On-site	1	30	DMC/DoM	Local authorities and other disaster management organizations at the sites	Tsunami exercise manual Risk maps Evacuation maps

This report, as part of the project, presents details of field data collection and demonstration of a low-cost methodology to generate geographic information needed for tsunami inundation modeling, tsunami risk assessment, and evacuation planning for the pilot site in Sri Lanka.

## 1.1 Pilot Site: Hambantota Town

The project inception meeting on 22 November 2012 agreed on Hambantota (Figure 1.1) as the project's pilot site, noting the suitability of its geographic size for survey. In addition, the city shall benefit from the project's activities on tsunami early warning and response capability improvement.



Figure 1.1 Pilot site location

## 1.2 Key Activities

Data collection and demonstration of the survey methodology involved the following key technical and disaster management agencies: National Aquatic Resources Research and Development Agency (NARA), Survey Department, Coast Conservation Department, Department of Meteorology, and Disaster Management Center in Hambantota. Activities undertaken from 1-11 April 2013 included:

- 1) Project launch meeting at the Government Office Complex in Hambantota for project introduction and implementation arrangement with local authorities
- 2) Bathymetric survey
- 3) Topographic survey
- 4) Exposure survey

Table 1.3 lists the data received for planning the survey activities, while Table 1.4 presents the survey schedule followed.



Table 1.5 Accuracy of data sources

Data type	Spatial resolution	Accuracy	Data source
Topographic DEM	30 m x 30 m	X,Y: 20m / Z: 30 m	ASTER G DEM
Bathymetric DEM	30 sec x 30 sec (900 m x 900 m)	N/S	GEBCO-08
Building location	1 m	X,Y: 5 m	Google Earth
Building properties	N/S	N/S	N/S

*N/S: Not Specified*

### 1.3.1 Bathymetric DEM

Bathymetry can be defined as the seafloor topography relative to a known vertical datum, such as the Mean Sea Level (MSL) for coastal area management, or the Mean Lower Low Water (MLLW) for navigation. Bathymetric maps represent the seafloor depth as a function of geographic coordinates, in the same way the topographic maps represent the elevation of the earth's surface at different geographic points. Usually, seafloor terrain is shown as depth contours (isobaths) and spot depths on bathymetric maps.

A digital elevation model (DEM) is a digital representation of the Earth's surface. Although it can be represented as triangulated irregular networks (TIN), it is more often represented as a raster or grid of squares for ease in model calculations. Land DEMs are typically acquired by remote sensing satellites, but bathymetric DEMs are mostly generated by interpolating ship-mounted depth soundings. Available data sources that can provide standard accuracy bathymetric DEM, without the need for field survey, include interpolated sounding data from bathymetric maps and DEMs that can be downloaded freely from the Internet, such as ETOPO and GEBCO DEMs.

Depending on the scale, accuracy of bathymetric maps or nautical charts varies from high accuracy large-scale maps (1:50,000) to low accuracy small-scale maps (1:200,000). Compared to ETOPO and GEBCO DEMs, most bathymetric maps can provide higher accuracy. However, unlike the two DEMs which can cover almost all areas in the world, bathymetric maps may be not be available, or may have limited extent for the areas of interest. Up until 2009, ETOPO1 DEM (Earth TOPOgraphy 1), developed by NOAA NGDC with 1 arcminute or approximately 2 km spatial resolution, was the most common source of bathymetric DEM. ETOPO1 is the latest version of the Global Relief Models developed by NOAA NGDC in August 2008. It was developed to upgrade the resolution and accuracy of the previous version ETOPO2v, a 2 arcminute global relief model designed to aid in tsunami forecasting, modeling and warning, as well as ocean modeling and earth visualization. It is a one minute grid, integrated from different topographic and bathymetric datasets, such as shoreline, bathymetry, topography, integrated bathymetry-topography, and bedrock all over the world, that are shifted to a common horizontal and vertical datum, the WGS84 and the sea level, respectively (Table 1.6).

Table 1.6 ETOPO1 DEM characteristics

Versions	Ice Surface, Bedrock
Coverage Area	Global: -180° to 180°; -90° to 90°
Posting interval (spatial resolution)	1 arcminute
Geographic coordinates	Geographic latitude and longitude( WGS84)
Vertical Datum	Sea Level
Vertical Units	Meters
Data Format	Multiple: netCDF, g98, binary float, tiff, xyz

*Source: Amante & Eakins, 2009*

In January 2009, the GEBCO-08 Grid (General Bathymetric Chart of the Oceans DEM), with a 30 arcsecond spatial resolution, was released by the British Oceanographic Data Center (BODC). This is generated by quality-controlled ship depth soundings, with interpolation between sounding points guided by satellite-derived gravity data. Although it is currently a development product, it undergoes periodic updates to reduce errors in the dataset. GEBCO's aim is to provide the most authoritative publicly

available bathymetry of the world's oceans. It operates under the joint auspices of IOC and the International Hydrographic Organization (IHO).

The GEBCO-08 was developed to improve the resolution and accuracy of the GEBCO One Minute Grid, released in 2003. As with ETOPO1 bathymetric DEM, the accuracy of the GEBCO-08 DEM is only as good as the quality of the sonar equipment and bathymetric surveys conducted in the respective countries. The bathymetric data are generated from the integration of sounding data, bathymetric contour maps, predicted depth data based on version V16.1 of the Sandwell and Smith gravity anomaly from Geosat and ERS1 satellite altimeter and the Smith and Sandwell global topographic grid, as well as SRTM, GTOPO30 and the Geoscience Laser Altimeter System (GLAS) instrument on the Ice, Cloud and land Elevation Satellite (ICESat) laser altimetry digital elevation model for topographic data. The GEBCO-08 comes with a source identifier (SID) grid that identifies which grid cells in the GEBCO-08 Grid are based on bathymetric soundings or predicted depths. The values in the GEBCO-08 SID Grid are as follows; Table 1.7 shows the characteristics of GEBCO-08 DEM.

- 0 data is interpolated with the help of satellite-derived gravity data
- 1 data has been constrained by bathymetric sounding data during the gridding process
- 2 value is taken from version 2.23 of the International Bathymetric Chart of the Arctic Ocean (IBCAO)
- 3 value for land, in positive value

Table 1.7 GEBCO-08 DEM characteristics

Coverage	Global
Posting interval (spatial resolution)	30 arcsecond (900 m x 900 m)
Geographic coordinates	Geographic latitude and longitude (WGS84)
Data format	netCDF (signed 16 bits), ASCII
Special DN values	Positive for land body, and negative for sea water body

The NOAA Center for Tsunami Research provides integrated bathymetric and topographic DEMs for United States coastal areas through the NOAA National Geophysical Data Center. For the Indian Ocean and Southeast Asian region, RIMES has started an initiative to generate updated and accurate local bathymetric and topographic DEMs for the region, following IOC standards for tsunami modeling.

In accordance with Yeh (IOC, 2001), the Scientific Committee on Oceanic Research of the IOC (SCOR-IOC) has set some scientific requirements on spatial resolution for tsunami modeling. In addition, it has emphasized the need to refer both the topographic and bathymetric DEMs to the same datum to ensure accurate elevation data along the coast. Table 1.8 shows the tsunami modeling requirements set by these three organizations, for comparison.

Table 1.8 IOC Scientific requirements for tsunami models

Area	IOC	NOAA	RIMES
<b>Horizontal Resolution (m)</b>		<1 to <100	5/3 arcsecond (approx. 50 m)
Continental Shelf < 2.5 m deep	50	N/S	N/S
Continental Shelf 2.5–10 m deep	100	N/S	N/S
Continental Shelf 10–250 m deep	100-500	N/S	N/S
Canyons and Ridges	500	N/S	N/S
Open Ocean	>2000	N/S	N/S
<b>Vertical Resolution (m)</b>	N/S	<1	1

Note: N/S for Not Specified

Sources: IOC (2001); NOAA NGDC (2009)

For this project, tsunami propagation and coastal inundation are modeled using INSPIRE. This tool requires four input DEMs, wherein region 1 covers a very large area (regional) while region 4 covers a small area (interest area only). In order to link the large to the small coverage areas, cell size of each region must be fixed according to the ratio defined in the code; for example, ratio of cell sizes for regions 1 to 4 is 1: 1/8: 1/24: 1/72, respectively with corresponding cell sizes of 120:15:5:5/3 arcseconds. The DEMs should be in the same coordinate system; hence, the geographic coordinate system is used.

To meet modeling requirements, this project covered only near-shore areas of up to 30-50 m depths to ensure that the incoming wave is still in constant wavelength and satisfy deep water wave condition. Output DEM should have a horizontal resolution of 5/3 arcseconds and a vertical resolution and accuracy of 1 m.

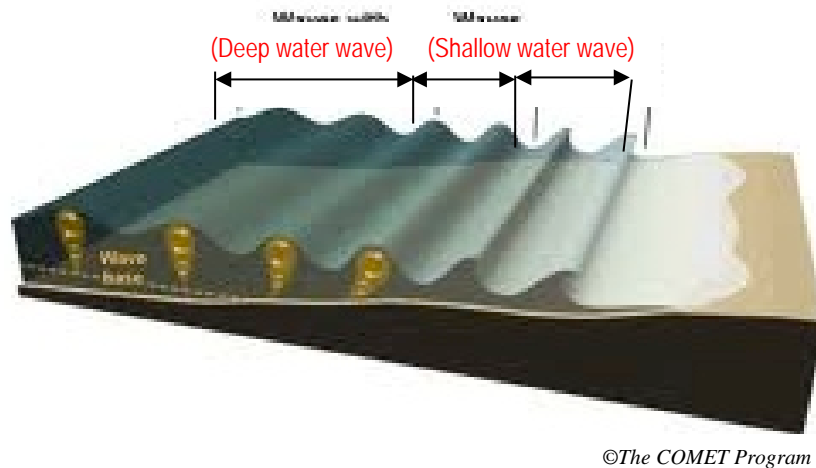


Figure 1.2 Wave shoaling

### 1.3.2 Topographic DEM

There are available data sources that can provide standard accuracy DEM, without the need for field survey, including topographic map (1:50000 scale or larger), ASTER GDEM, and SRTM DTED level 1. Estimated accuracy for these data is better than 20 meters.

Topographic maps are the data provided by local mapping agencies. These can sometimes be represented as high accuracy data, especially for larger scale (1:4000). Large-scale maps, however, are not available everywhere. Normally, these cannot cover the whole extent of the interest area, so that lower accuracy data, such as small-scale maps, ASTER GDEM, or SRTM DTED level 1, can be used to supplement the large-scale map, thus reducing the overall accuracy. Expected accuracies of topographic maps are shown in Table 1.9.

Table 1.9 Topographic map accuracy

Map scale	Data accuracy
1:4,000	1 m contour interval
1:10,000	5 m contour interval
1:50,000	20 m contour interval

The ASTER GDEM covers land surfaces between 83°N and 83°S, and is comprised of 22,600 1°-by-1° tiles. Tiles that contain at least 0.01% land area are included. The ASTER GDEM is in GeoTIFF format, with geographic lat/long coordinates and a 1 arcsecond (approximately 30 m in the Southeast Asian region) grid. It is referenced to the WGS84/EGM96 geoid. Table 1.10 summarizes the basic characteristics of the ASTER GDEM. Pre-production estimated (but not guaranteed) accuracies for this global product were 20 m at 95 % confidence for vertical data, and 30 m at 95 % confidence for horizontal data.

Table 1.10 ASTER GDEM characteristics

Coverage	North 83° to south 83°
Tile size (download unit)	3601pixel x 3601 pixel (1°-by-1°)
Posting interval (spatial resolution)	1 arcsecond (30 m x 30 m)
Geographic coordinates	Geographic latitude and longitude (WGS84/EGM96 geoid)
Data format	GeoTIFF, signed 16 bits, and 1m/DN
Special DN values	-9999 for void pixels, and 0 for sea water body

SRTM DTED level 1, the Shuttle Radar Topography Mission (SRTM), successfully collected Interferometric Synthetic Aperture Radar (IFSAR) data over 80 percent of the landmass of the Earth between 60 degrees North and 56 degrees South latitudes in February 2000. The mission was co-sponsored by the National Aeronautics and Space Administration (NASA) and National Geospatial-Intelligence Agency (NGA). NASA's Jet Propulsion Laboratory (JPL) performed preliminary processing of SRTM data, and forwarded partially finished data directly to NGA for finishing by NGA's contractors and subsequent monthly deliveries to the NGA Digital Products Data Warehouse (DPDW). All data products delivered by the contractors conform to the NGA SRTM products, and the NGA Digital Terrain Elevation Data (DTED) to the National Center for Earth Resources Observation & Science (EROS) of the U.S. Geological Survey (USGS). The DPDW ingests SRTM data products, checks them for formatting errors, loads the SRTM DTED into the NGA data distribution system, and ships the public domain SRTM DTED to EROS ([http://gcmd.nasa.gov/records/GCMD\\_DMA\\_DTED.html](http://gcmd.nasa.gov/records/GCMD_DMA_DTED.html)). Table 1.11 shows the characteristics of SRTM DTED level 1 data.

Table 1.11 SRTM DTED level 1 characteristics

Coverage	North 60° to south 56°
Tile size (download unit)	3601pixel x 3601 pixel(1°-by-1°)
Posting interval (spatial resolution)	3 arcsecond( 90 m x 90 m)
Geographic coordinates	Geographic latitude and longitude( WGS84/EGM96 geoid)
Data format	GeoTIFF, signed 16 bits, and 1m/DN
Special DN values	-9999 for void pixels, and 0 for sea water body

### 1.3.3 Building Footprints and Properties

Building footprints and properties, such as building location and characteristics, and population distribution maps are required to generate tsunami vulnerability maps. Remote sensing data, including aerial photographs, satellite images, and especially Google Earth, can be used as base data for generating building footprints. Quality of footprints, however, depends on the quality of images.

Image quality is divided into two parts namely, location accuracy and image clarity. Location accuracy requirement is 5 meters or better for standard accuracy data. Horizontal location accuracy for aerial photographs and geo-rectified level 2B satellite images is around half pixel; thus, the 1-meter IKONOS images or higher resolution images can be used for footprints extraction.

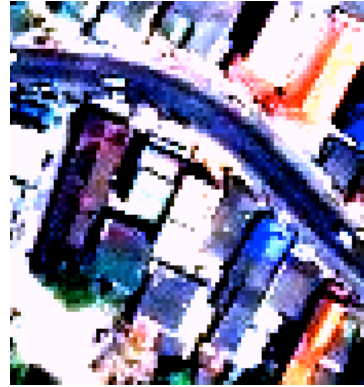
Image clarity refers to the quality of buildings that can be identified. Building footprints can be extracted from a high-resolution image as polygon feature. Low-resolution image allows only the extraction of building location as point feature. Initially, Landsat images were used as base image; later, these were replaced by higher resolution images, such as SPOT-5, IKONOS, QuickBird, or Geo-Eye, when available. Google Earth provides data to represent the global world for free. Accuracy of Google Earth images should be the same as the original source, but is not guaranteed.



a) 0.25 m DMC



b) 0.4 m Geo-Eye



c) 1 m IKONOS



d) Google Earth 1



e) Google Earth 2



f) Google Earth 3

Figure 1.3 Image clarity

## CHAPTER 2 BATHYMETRIC SURVEY

### 2.1 Methodology

Bathymetric data acquisition is composed of two parts: (i) sonar and (ii) tidal, both of which can be acquired in parallel. Sonar survey is conducted using a commercial fish finder, following an optimized route design that includes densified surveys in areas with local variation, while tidal data is used to correct raw sonar depth readings. For tidal measurement, a temporary tide gauge is installed near or within the pilot site, and data is recorded periodically by the tide gauge data logger.

A common datum, such as the mean sea level (MSL), will facilitate the merging of both bathymetric and topographic data. This will serve as the vertical reference for both bathymetric and topographic data in the final output. A leveling survey is conducted to transfer the elevation in MSL from a known tidal benchmark to the portable tide gauge, while (i) a GPS observation on a known MSL elevation benchmark, or (ii) a leveling survey on a known GPS benchmark, is conducted to determine the undulation value (geoid height), needed to transform all GPS data to MSL.

#### 2.1.1 Sonar Survey

##### *Survey Route Design*

An optimized survey route design was employed without compromising the accuracy requirement for tsunami modeling. The route consists of (i) basic 200m interval lines perpendicular to the shoreline, and (ii) detailed 100m interval in areas with local variation.

The recommended survey route design is composed of three parts:

1. Perpendicular to the shoreline with a 200m interval spacing
2. Parallel to the shoreline up to 1000m offshore:
  - a. 100m interval spacing until 600m offshore
  - b. 200m interval spacing until 1000m offshore
3. Densified survey at 100m interval spacing in areas with local variation

Figure 2.1 shows the extent of the project site in solid yellow line as well as a buffer of 1km in dashed yellow line. The sonar survey covers an approximate area of 25 sq. km. The total distances of the lines perpendicular to the shore (red line), parallel to the shoreline (blue) and local variation (black) are approximately 60km, 60km and 50km, respectively. If a conservative boat speed of 5kph is used, a 6-hour working time per day can generate a total distance of around 30km/day. Increasing the boat speed can generate a longer trip distance per day. The distance going from and back to the boat docking station is estimated at 7km. This is not included in the computed total trip distance per day.

In addition, sonar survey can be run along the centerline of rivers, zigzagging from bank to bank on the way back, or vice versa.

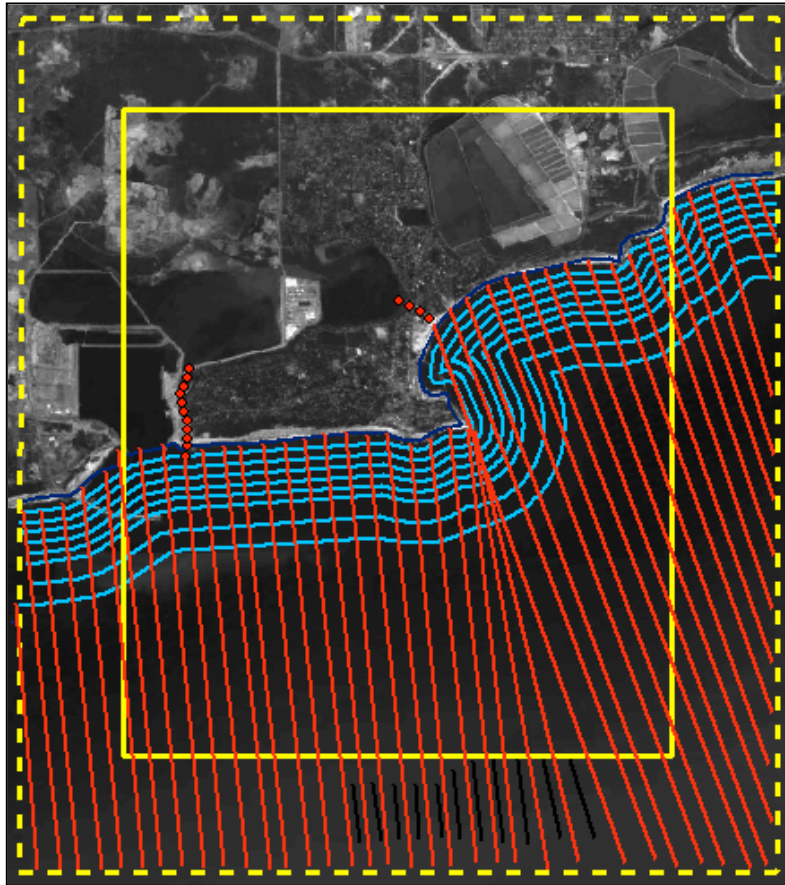


Figure 2.1 Survey route design

### *Sonar Survey*

A boat survey route plan was created to guide the boat operator during the actual survey. The survey was conducted using a Lowrance fishing sonar, mounted over the side of the boat. The sounding data from the fishing sonar was collected from a transducer operating at 200kHz (12° cone angle) at shallow depths and 50kHz (35° cone angle) at deeper depths. Strategic turning points were inputted to the handheld GPS using a freeware called *GPS TrackMaker* (Figure 2.2) to aid the boat operator in navigating the designed route. Skill is necessary to follow a straight line on the sea. Fortunately, the NARA boat operators were very skilled and experienced, so the survey lines were followed consistently and the trips were always safe, despite the rough seas.

Since raw sounding data has to be corrected for tide, which is varying over time, it is necessary to synchronize time for all equipment, such as sonar console, portable water level data logger, laptop, and handheld GPS.

To ensure that depth readings are intact, these were transferred to the laptop computer everyday. Draft offset, which will be used to correct raw sonar data, was made constant at 0.40m for the duration of the survey.

To ensure reliable depth readings and the safety of the surveyors, survey operations were conducted only during calmer seawater conditions. Rough seas occurred after 2-3 in the afternoon, so survey operations were conducted before this period.

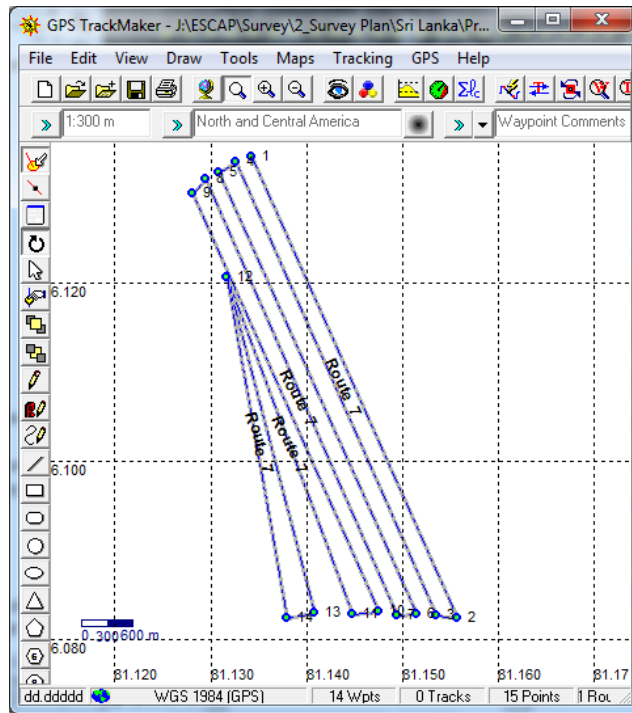


Figure 2.2 Route design in GPS TrackMaker

### *Local Variation*

Local variation is characterized by rugged terrain or abrupt changes in elevation in localized areas, such as those occurring along the shores, comprised of rocks and corals, and in the middle of the sea as mounts and depressions, as shown in Figure 2.3. If not well accounted for, these areas will introduce errors in the generated DEM. A local variation index (LVI) can be used to detect rough surfaces or areas where local variation exists (Figure 2.4). This index is defined as the standard deviation of sounding data, in this case 0.5m, over some distance, in this case 200m (Figure 2.5).

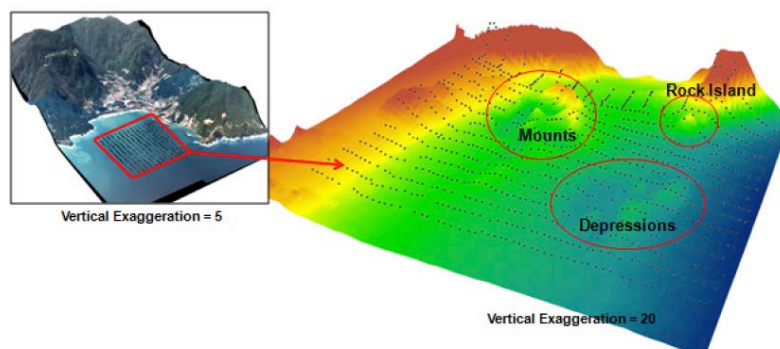


Figure 2.3 Area with local variation

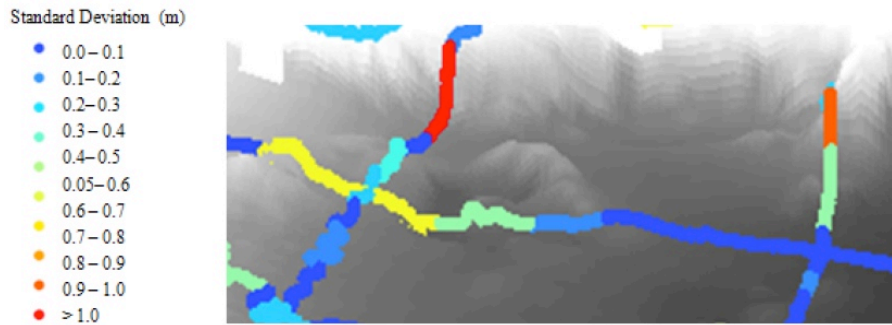


Figure 2.4 Local variation index

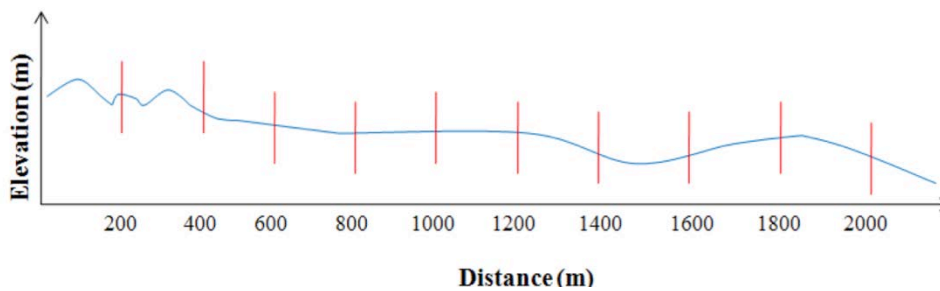
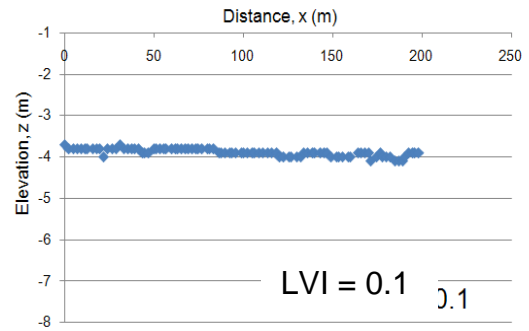
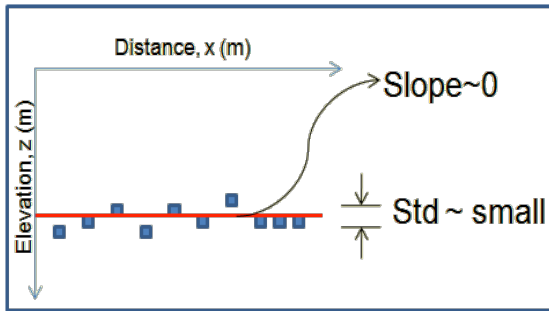


Figure 2.5 Standard deviation computed every 200m interval

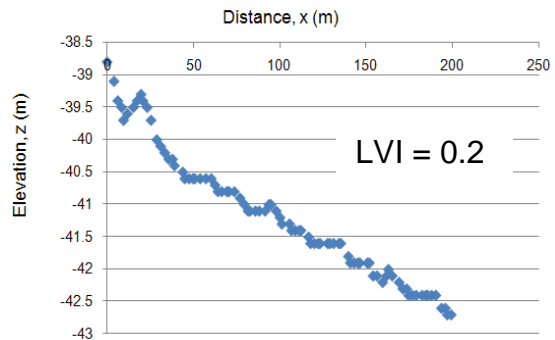
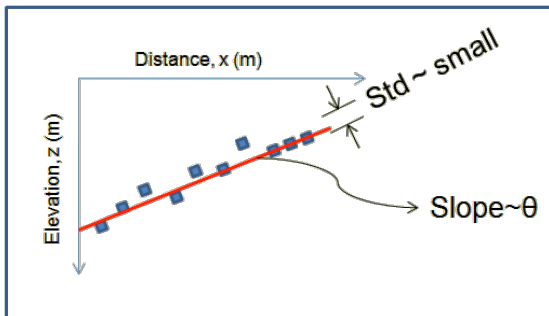
Local variation analysis is important to increase DEM accuracy by increasing survey detail in areas of local variation. Generally, near-shore bathymetry is characterized by smooth terrain. The idea behind the survey route is to create a design with the widest possible interval spacing (e.g. 200m interval) that can still effectively represent the general bathymetry of the sea according to the accuracy requirement for tsunami modeling, which is quite lower than typical hydrographic surveys (50m interval); and then, densifying survey in areas with variation to effectively represent these variations. As a result, time and cost to survey a large area is significantly reduced.

The following figures show the different bathymetric scenarios that can be detected. Mainly, these are categorized into smooth and rough bathymetry. The first two figures show smooth bathymetry in a flat terrain when the slope is approximately zero (Figure 2.6A), and sloping terrain where the slope is of some value  $\theta$  (Figure 2.6B). The LVI or standard deviation of the difference between the actual and modeled point is less than 0.5 m for both cases. The next two figures show local variation in a flat (Figure 2.6C) and sloping (Figure 2.6D) terrain. Also, it can be seen that the LVI for both scenarios are greater than 0.5 m.

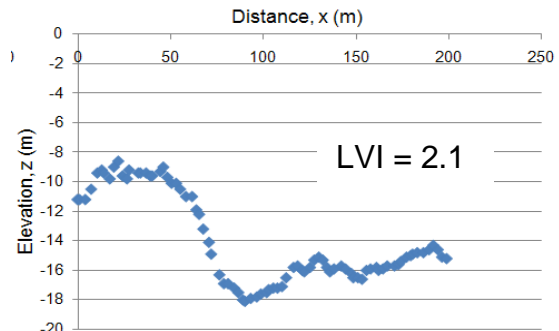
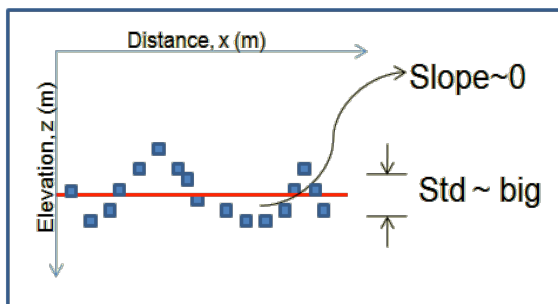
For this project, areas with local variation were initially estimated using the available nautical charts (blue area shown in Figure 2.7), since these were available. After the survey, the sounding data was analyzed for existence of local variation by inputting the raw data to the local variation analysis program, developed for this project. After detecting the hotspot areas, detailed survey was conducted in these localized areas, using the 100m interval spacing to compensate for errors that may be introduced by this condition.



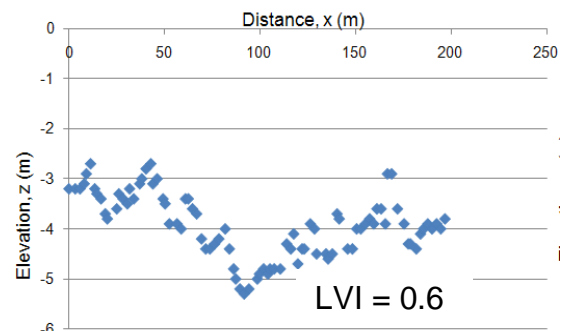
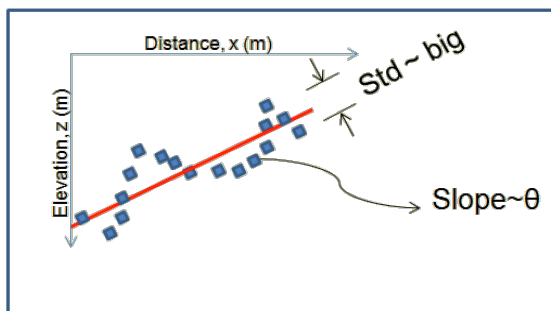
(A)



(B)



(C)



(D)

Figure 2.6 Bathymetric scenarios detected by local variation analysis: (A) Smooth and flat, (B) Smooth and sloping, (C) Rough and flat, (D) Rough and sloping

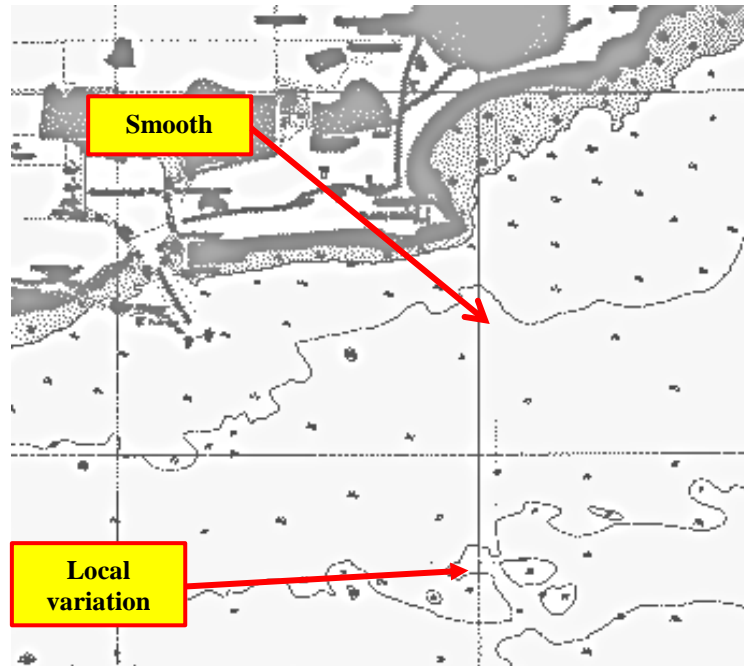


Figure 2.7 Local variation on nautical chart

### Accuracy Assessment

Accuracy assessment of the low-cost sonar was conducted during the Philippines survey, by comparing the corrected sonar data from two transducers: (i) low-cost transducer (Lowrance) and (ii) high-accuracy transducer (Odom). Results show that sonar data acquired by the low-cost transducer performed very well, satisfying the 1-m vertical accuracy requirement for tsunami modeling (Figure 2.8). Out of the 45 samples, taking account different bathymetric conditions (shallow, deep, smooth, rough), only one sample had a large difference between datasets (2.45m difference at around 15m depth).

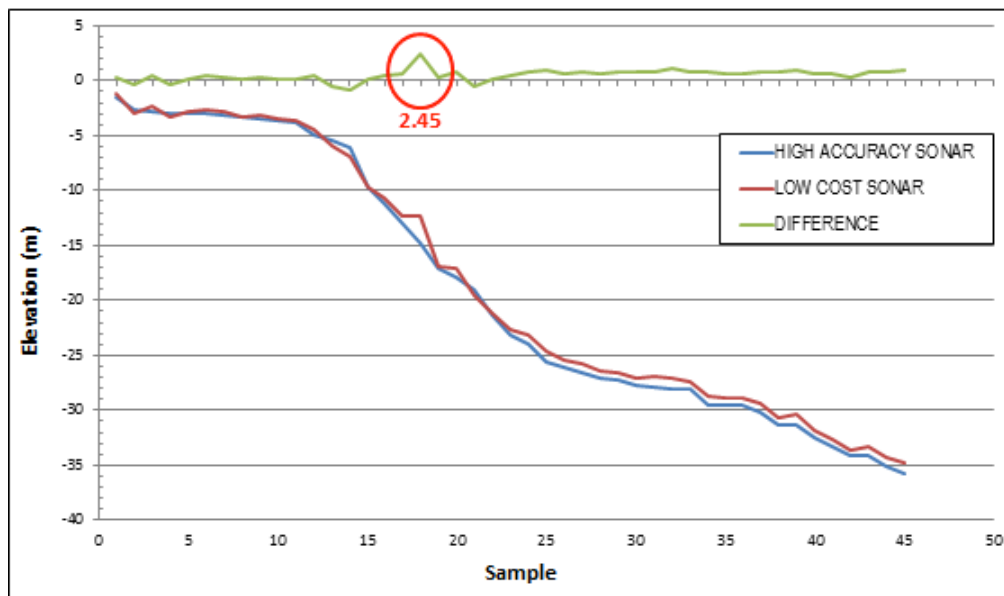


Figure 2.8 Comparison of high-accuracy sonar and low-cost sonar data

### *Methodology adjustments to adapt to local conditions*

In Sri Lanka, there were no existing sounding data in the pilot area to compare with. Since accuracy of the low-cost transducer has already been assessed in the Philippines survey, accuracy assessment in Hambantota was conducted only by manually measuring the depth of one point and comparing this with the depth recorded by the sonar. Assessment was conducted on the first day, using a calibrated wooden staff at random points, making sure that the staff was vertical during the readings to eliminate inaccuracies introduced by slant height.

## **2.1.2 Tidal Survey**

### *Tide Gauge Installation*

A portable tide gauge (pressure-type sensor with water level recorder) was established on the fishing harbor to collect tidal readings for the duration of the survey (Figures 2.9 until 2.11). To ensure that the sensor is submerged in the water for the whole duration of the survey, it was installed below the lowest possible water for that area. Prior to data logging, the instrument was first calibrated at some underwater depth for positive depth values and at atmospheric pressure for zero depth. Depths were then interpolated or extrapolated according to these settings.



Figure 2.9 Location of portable tide gauge

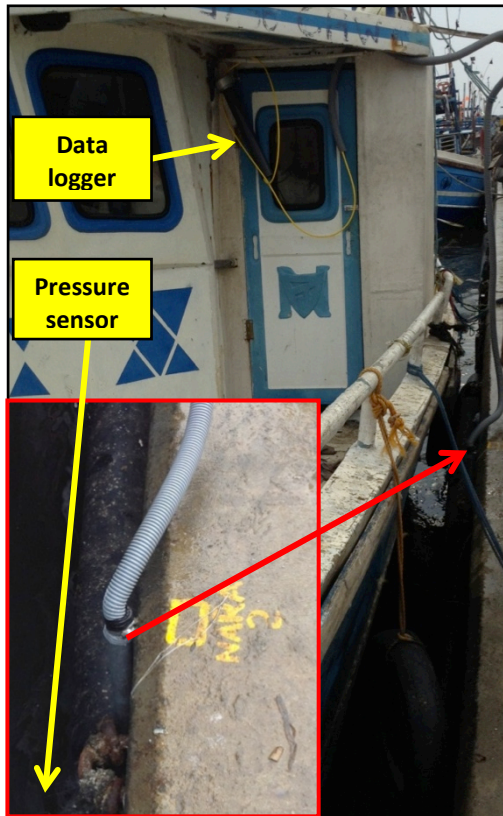


Figure 2.10 Tide gauge setup

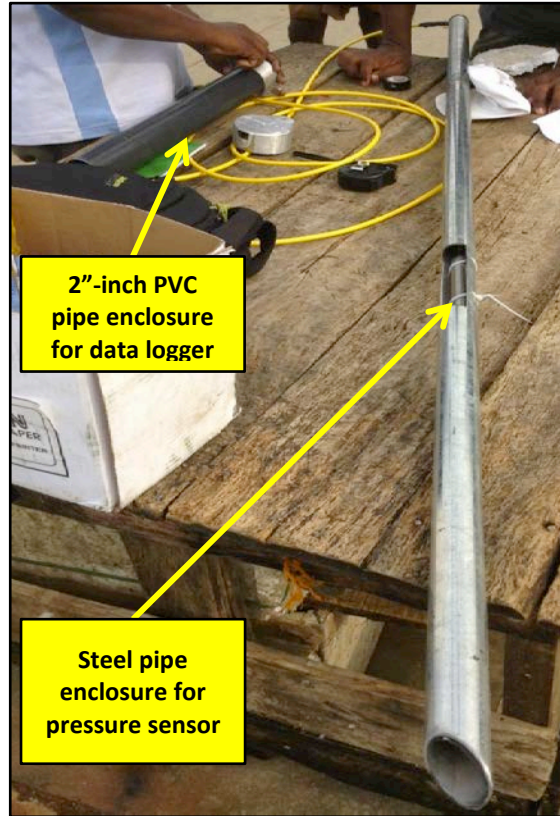


Figure 2.11 Installation of tide gauge

*Methodology adjustments to adapt to local condition*

Since the tide gauge was installed in the harbor, extra precaution was taken to protect the gauge from any untoward incidents. The gauge was enclosed in a steel pipe to stabilize the instrument.

***Tide Gauge Elevation***

A leveling survey was conducted to transfer the elevation in MSL from a known tidal benchmark to the low-cost tide gauge. Prior to leveling survey, a reconnaissance survey was conducted to check the actual location and condition of existing benchmarks, as well as to establish benchmarks that will be included in the survey.

***Tidal Measurement***

Tidal measurements every minute were logged in the portable tide gauge data logger. These data will be used to correct the raw sounding data. In addition, a local staff was requested to measure to keep the instrument safe for the whole duration of the survey.

***Accuracy Assessment***

A tide gauge from NARA was also installed near the low-cost tide gauge. Tidal measurements from both gauges were compared to assess the accuracy of the low-cost equipment. So, it is also important to synchronize the time from both tidal data sources.

## 2.2 Data and Equipment

The following table shows the list of data and equipment used and personnel employed for each activity in the bathymetric survey. The 3 major activities include (i) sonar survey data, (ii) tidal installation and measurement, and (iii) leveling survey. Since most of the equipment used are related to each other, time for all equipment (e.g. commercial fishing sonar, portable tide gauge data logger, handheld GPS, laptop, etc.) should be synchronized.

Table 2.1 List of data and resources used in bathymetric survey

Activity (Duration)	Data Used	Equipment Used	Personnel
1. Sonar survey: (2-9 April)	Nautical chart (1:15,000 & 1:30,000) Topographic map (1:10,000 & 1:50,000)	Survey vessel (skiff) Fishing sonar Battery (12V 45Ah) Battery charger Laptop SD card Calibrated rope	Boat driver Engine operator Navigator NAMRIA staff (2) RIMES staff
2. Tidal installation (RIMES- 1 April; NARA-March) and measurement (2-9 April)		Portable tide gauge	Local security
3. Leveling survey (April)	Tidal benchmark description	Vehicle Leveling scope Tripod Leveling rod	Driver Level operator Rod man (2) Recorder

### 2.2.1 Data

#### *Nautical Chart*

Two nautical charts were used for survey planning to estimate the survey route, extent of shoreline, and location of local variation. The first chart covers Hambantota harbor at a scale of 1:10,000 while the second chart covers approaches to Hambantota at a scale of 1:30,000. Both maps are referred to the Lowest Astronomical Tide (LAT) vertical datum and to the WGS84 horizontal datum. The MSL datum is 0.6m above the LAT.

#### *Vertical Benchmark*

Leveling survey was conducted to transfer the MSL elevation of the known tidal benchmark to the temporary tidal benchmark established near the low-cost tide gauge. This temporary tidal benchmark served as connection point between land and sea survey data.

#### *Sounding Data*

A 1:1,100-scale map containing sounding data within the harbor, surveyed in 2008, was acquired from the city engineer's office (Figure 2.12). All elevations are referred to the MSL. This will be used as part of the final DEM.

#### *Reference Data*

Reference tidal data was collected by a tide gauge established by NARA near the low-cost tide gauge.

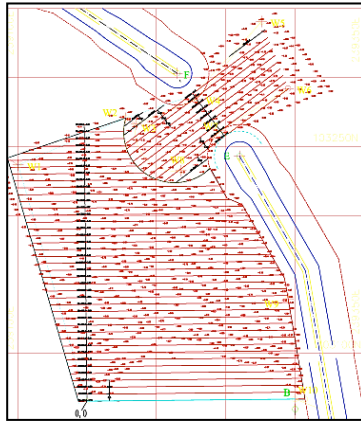


Figure 2.12 Sounding data of the Hambantota harbor basin

## 2.2.2 Equipment

### *Sonar Setup on the Skiff*

The sonar setup was composed of the display/console, transducer, power supply, handheld GPS for navigation and tracking, and laptop loaded on the skiff, which is owned by NARA, as shown in Figure 2.13.



Figure 2.13 Sonar setup on NARA skiff

## ***Fishing Sonar***

Bathymetric data were collected using ordinary fishing sonar (refer to Table 2.2 and Figure 2.15), operating at 200kHz (12° cone angle) at shallow depths and 50kHz (35° cone angle) at deeper depths. The transducer (Figure 2.14) was mounted at the transom of the skiff, far enough from the engine to prevent noise interference from the bubbles. It has a built-in internal GPS that can provide horizontal coordinates. An SD card was used to store and transfer data to a laptop computer.

Table 2.2 Fishing sonar characteristics

Brand/Model	Lowrance HDS5 Gen2
Frequency	200kHz/50kHz
Cone Angle	12/35 degrees
Input Power	10-17 VDC
Power Consumption	0.7A at 13 VDC with backlight on, 0.4A with backlight off
Depth Range	0-1524 m.
Display Dimension	480 mm. Width, 480mm. Height,
GPS	Internal, high sensitivity



Figure 2.14 Lowrance transducer on a side-mount



Figure 2.15 Lowrance HDS 5 console

## ***Power Source***

A 12V 45Ah battery (Figure 2.16) can be used as a power source to supply energy for a single survey day. To ensure safety of the battery, it is recommended to enclose it in a waterproof container during survey operations.



Figure 2.16 Power supply

### ***Battery Charger***

The battery has to be charged everyday to ensure smooth, uninterrupted survey everyday.

### ***Handheld GPS***

In order to keep the vessel on course, a handheld GPS (Figure 2.17) was used to navigate the waters. Strategic points along the survey lines, such as turning points, were inputted to the GPS, using a freeware called *GPS TrackMaker*, prior to the survey and then tracked during the actual survey.



Figure 2.17 Handheld GPS for tracking

### ***Laptop Computer***

A laptop computer onboard was used to transfer data from the sonar unit, ensuring that survey data is intact after every survey.

## **2.2.3 Tidal Installation and Measurement**

### ***Portable Tide Gauge***

A portable tide gauge/ water level logger (Table 2.3 and Figure 2.18) with a pressure-type sensor was established within the pilot site to record tidal readings every minute.

Table 2.3 Water level logger characteristics

Brand/Model	Global Water WL16U
Power supply	Logger:2 9VDC alkaline batteries Sensor: 10-36 VDC
Output	Sensor: 4-20mA
Operating temperature	Logger:Industrial, -40C to +85C Sensor: 0F to +185F
Sample Modes	Programmable 1sec to 1yr High speed: 10samples/sec Logarithmic sample rate
Storage capacity	81,759 recordings for 2 analog inputs
Communication port	USB Type B



Figure 2.18 Portable tide gauge

### *Leveling Survey Setup*

Leveling survey was conducted to transfer elevation from a known tidal benchmark to the portable tide gauge. The leveling survey setup included a leveling scope with tripod, leveling rods, temporary concrete monuments/benchmarks, and a vehicle to transport equipment and personnel.

## **2.3 Results and Discussion**

### **2.3.1 Sonar Survey**

Sonar survey, using the commercial fishing sonar, was conducted for 8 days, from 2-9 April. Figure 2.19 shows the accomplishment per day, where days 1-8 are represented by the colors red (28km), orange (32km), yellow (40km), green (48km), blue (38km), purple (7km), pink (51km), and white (36km), respectively.

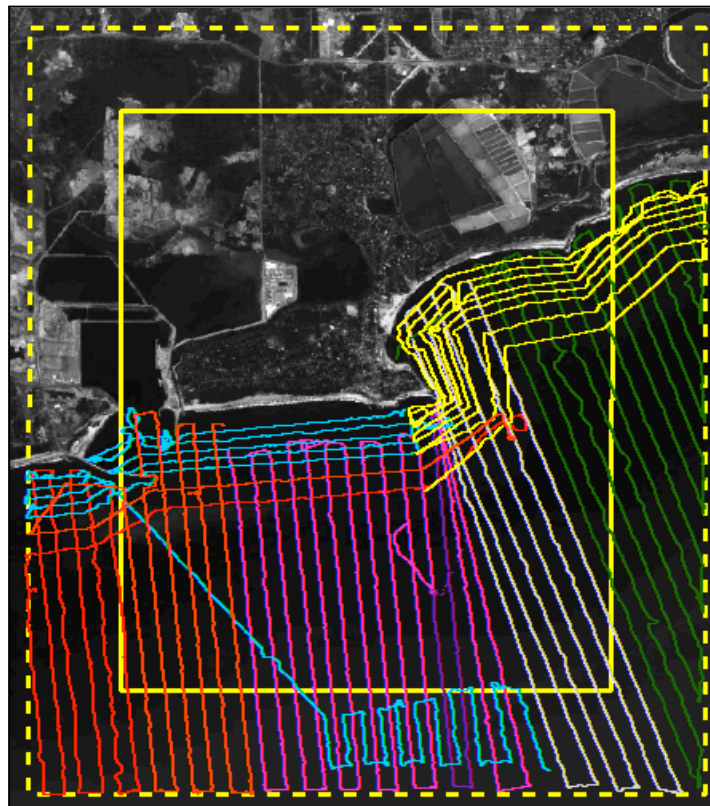


Figure 2.19 Results of sonar survey using commercial fishing sonar from 2-9 April 2013

The pilot site sits in the middle of the Indian Ocean, and is characterized generally by smooth bathymetry. However, since the area is located in the open sea, seawater condition is easily affected by sudden changes in weather. Although near, but not the yet the start of the monsoon period, occasional changes in wind patterns affected the seawater condition for survey. As a result, some areas have rough data caused by local wave action and long tidal period.

Prior to survey, sounding data from the commercial fishing sonar was first assessed using a calibrated staff at random points during calm seawater condition. The fishing sonar fared well with a depth difference within 30cm from the depth test (possible sources of error may be from slant height). The maximum speed of the skiff was around 8-14 kph. For the actual survey, since areas nearest to the shore are characterized by shallow depths, these were surveyed during the high tide to make sure that the skiff can navigate safely without damaging the transducer. However, it is very difficult to go very near the shore due to strong waves, especially during the latter part of a survey day.

## 2.3.2 Tidal Survey

### *Tide Gauge Installation*

The portable tide gauge was installed on April 1, enclosed in a steel pipe and attached to the pier in the fishing harbor. The distance from the pressure sensor to the floor of the pier (elevation in MSL measured by leveling survey) was determined to refer all tidal data to the MSL datum.

### *Tide Gauge Elevation*

Leveling survey was conducted to transfer the elevation in MSL of a known tidal benchmark to the low-cost tide gauge (Figure 2.20).



Figure 2.20 Elevation of temporary benchmarks from leveling survey

Results show that the elevation of the low-cost tide gauge is higher than the high-accuracy tide gauge by 1.333m. The elevations of the tide gauges, referred to the MSL datum, are as follows:

Table 2.4 Elevation of tide gauge referred to the MSL datum

Tide gauge	Elevation in m (MSL)
High-accuracy (NARA)	-1.556
Low-cost (RIMES)	-0.223

### *Tidal Measurement*

Tidal data was recorded every minute for 8 days, as shown in Figure 2.21. Results show that the pilot site is characterized by semi-diurnal tides with a tidal range of around 15cm (first half) and around 30cm (second half), where the start of a new period can be seen on April 4 (range is almost zero).

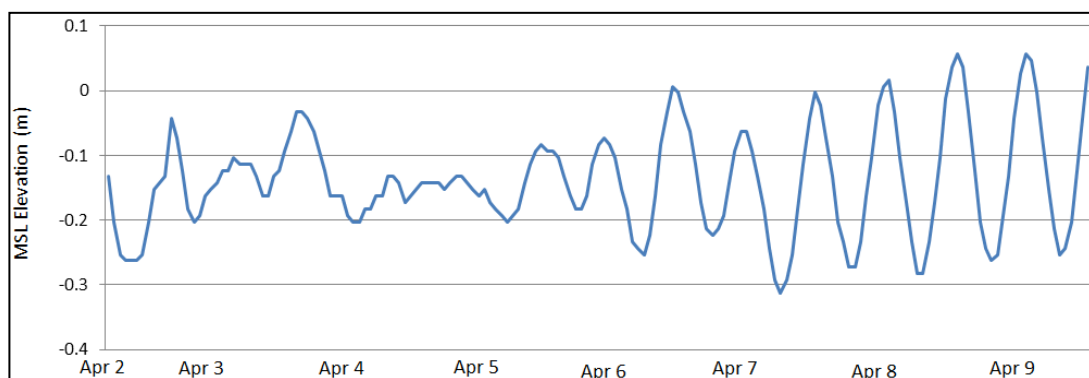


Figure 2.21 Result of tidal measurement carried out from 2-9 April 2013

### **2.3.3 Accuracy Assessment**

#### *Sonar Survey*

Since the accuracy of the low-cost transducer has already been assessed during the survey in the Philippines, sonar accuracy in Sri Lanka was assessed by comparing depth measurements from the calibrated staff and the transducer. Results show that the depths at each point vary by around 30cm. Difference in measured distance may be attributed to slant height when using the staff.

#### *Tidal Survey*

Tidal data from the low-cost tide gauge were compared with the tidal data from the NARA tide gauge. The following figure shows that the performance of the low-cost tide gauge is on par with the high-accuracy tide gauge.

Results show that the accuracy and precision of the low-cost tide gauge with respect to the high-accuracy tide gauge is very good. Figure 2.22 shows the tidal data referred to the MSL measured from both sensors. A systematic error of around 18cm can be seen, separating the two datasets. A number of factors may have contributed to this result, including changes in environment, observation error, etc.

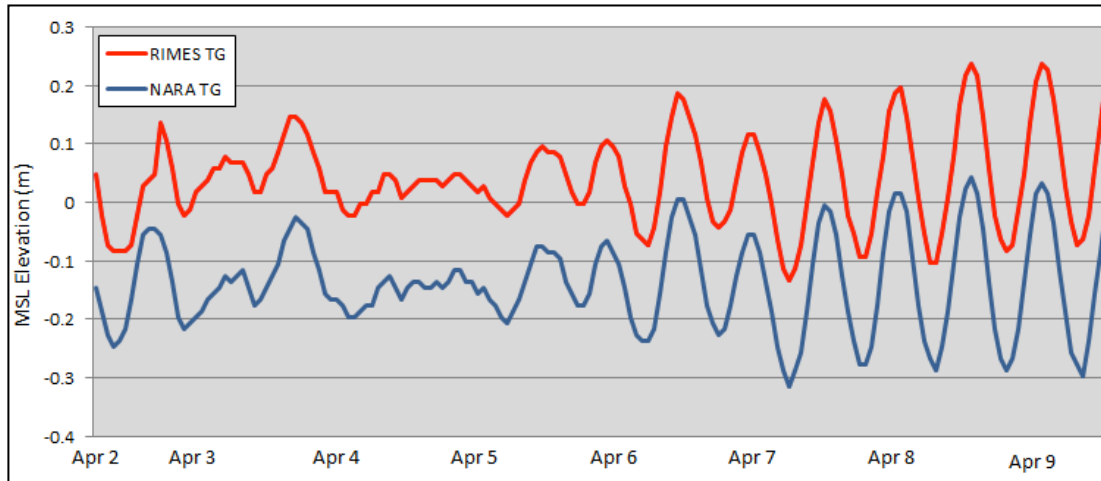


Figure 2.22 Comparison of tidal data referred to the MSL

However, when the systematic difference was removed, tidal data from both gauges fit very well as shown in the following figure.

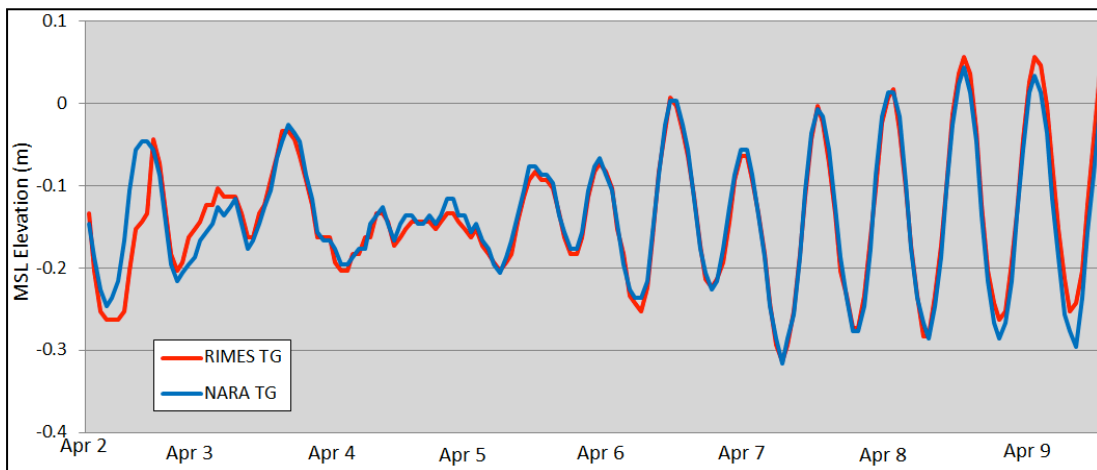


Figure 2.23 Comparison of tidal data from both tide gauges when systematic difference was removed

## 2.4 Problems Encountered and Recommendations

### 2.4.1 Sonar Survey

The major issue encountered is seawater condition. It is important to conduct sonar surveys during calm seas. However, there were days when there are strong winds which made the seawater condition quite rough, resulting in some data with rough outputs (due to local wave movement and long wave caused by the strong winds). Also, the waves are very strong near the shore so it was difficult to get close to the shoreline.

Other issues include the presence of obstruction, e.g. fishing line (Figure 2.24), structures (Figure 2.25), buoys, etc. which have to be avoided. In reality, these are always present in one form or another in varying conditions. Although issues of concern, these did not significantly hamper survey operations. However, it is best to always be prepared and know the possible limitations before the survey, so adjustments could be made.



Figure 2.24 Fishing line



Figure 2.25 Breakwater concrete structures

## CHAPTER 3 TOPOGRAPHIC SURVEY

### 3.1 Methodology

For the field survey in Hambantota, Sri Lanka, two types of GPS survey were conducted to collect topographic data. The first activity is fast static GPS observation to: (i) collect the position of ground control points (8 points), check points (4), and the local MSL benchmark (1) that will be used for photogrammetry; (ii) check accuracy of RTK GPS observation; and (iii) adjust offset with the tidal benchmark. The second is RTK GPS observation to collect elevation data along the road network, avoiding areas within 500m from the mountain to avoid large errors from multipath. In addition, WGS-84 was used as reference during the survey. GPS occupation on a level benchmark can determine the undulation value or the geoid height of an area that can be used to transfer topographic data, based on the ellipsoid to MSL.

#### 3.1.1 Base Station Preparation

Seven benchmarks, A024, A025, A027, A028, Payibokka FBM, 12-1A and TBM-1, were observed to setup and recheck the base station network shown in Figure 3.1. Five benchmarks, including Payibokka FBM, A-24, A25, A27 and A28, were used as base stations to control the GCP observation, while two GPS receivers were used as rovers to collect the GCPs.

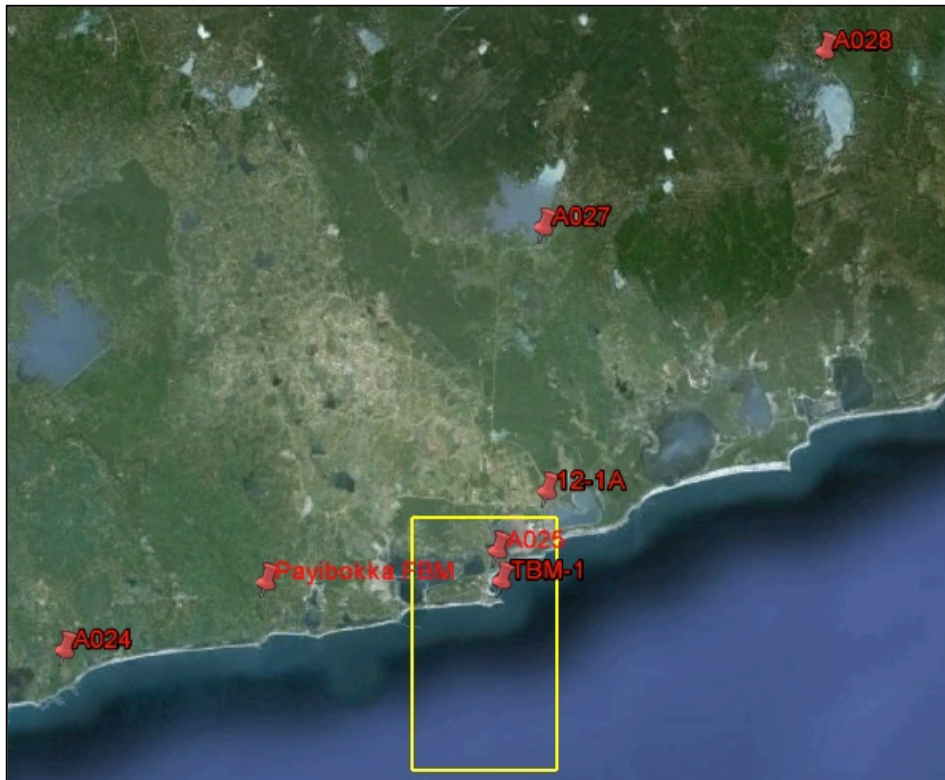


Figure 3.1 Location of base stations

### 3.1.2 Calculation of Undulation Value (Geoid Height)

In this project, the local MSL datum will be used as the vertical reference for all elevations. However, GPS coordinates are normally based on WGS-84 and, in some cases, heights will be transformed to MSL based on the global geoid models called "EGM96" or "EGM2008". Therefore, the undulation value or geoid height must be determined. The equation to calculate the undulation value between local MSL and WGS-84 ellipsoidal height is depicted in Figure 3.2.

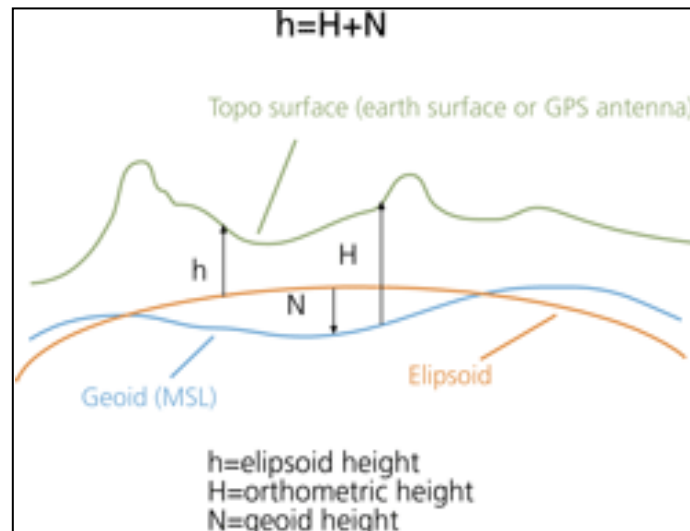


Figure 3.2 Relationship between ellipsoidal height, MSL and undulation value (geoid height)

During survey, some elevation benchmarks will be selected to determine the undulation value of an area. Each elevation in local MSL will be updated and checked, and then subtracted from the ellipsoidal height that will be derived from static GPS observation of the same point.

#### *Methodology adjustments to adapt to local condition*

In Sri Lanka, the GPS baseline processing method was used to reduce ellipsoidal heights to the MSL datum. For fast static GPS data, 5 benchmarks (A024, A025, A027, A028 and Payibokka FBM) were used to calculate the undulation value (geoid height) for GCPs and check point (NARA TBM). For kinematic GPS data, only one benchmark, A025, was used to determine the undulation value. This value will be used for all kinematic GPS data.

### 3.1.3 Ground Control Point using Fast Static GPS Observation

#### *Ground Control Point Survey Design*

GCPs are needed to rectify aerial photographs. As a requirement, GCPs should be located at each corner of a photogrammetry block, as well as one GCP within 3 images along a photo strip. Each point should be defined in as many images as possible and accessible in the actual field survey.

To rectify aerial photos in the pilot site, GCP 1-8 and CHK 1-4 were selected for ground control points and checkpoints, respectively, as shown in Figures 3.3, 3.4 and 3.5. The two survey teams, each using a van, were set to collect GCPs. The first team identified and marked GCP locations in the field, while the second team managed the drop and pick up of rover GPS receivers. All GCPs were observed using the fast static GPS method for at least 90 minutes. In addition, the NARA TBM was also observed by this method to determine the undulation value needed to adjust the topographic data to the same final datum as the bathymetric data, which is the local MSL.

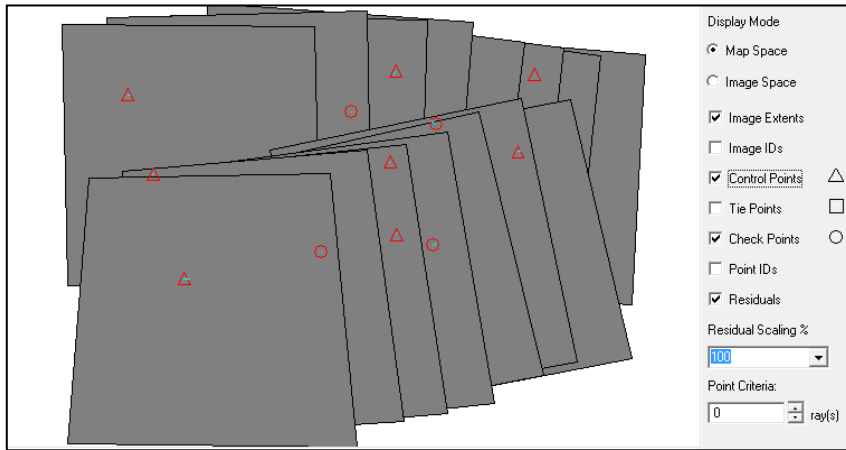


Figure 3.3 GCPs and check points overlaid on aerial photographs



Figure 3.4 GCPs for aerial photogrammetry



Figure 3.5 Checkpoints for aerial photogrammetry

### *Fast Static GPS Observation*

The following table shows the list of coordinates of the GCPs and checkpoints in the pilot site. Static GPS survey was conducted by multi-base station using Payibokka FBM, A-24, A25, A27 and A28 as base stations for all GCPs and checkpoints.

Table 3.1 Location of GCPs and checkpoints for aerial photogrammetry

Name	Longitude	Latitude
GCP1	81° 4'57.66"E	6° 7'1.86"N
GCP2	81° 4'37.52"E	6° 8'7.81"N
GCP3	81° 4'21.10"E	6° 8'59.10"N
GCP4	81° 7'11.35"E	6° 9'12.57"N
GCP5	81° 7'7.91"E	6° 8'15.36"N
GCP6	81° 7'11.99"E	6° 7'28.97"N
GCP7	81° 8'28.89"E	6° 8'21.69"N
GCP8	81° 8'39.22"E	6° 9'10.16"N
CHK1	81° 6'24.31"E	6° 7'18.12"N
CHK2	81° 7'34.61"E	6° 7'21.80"N
CHK3	81° 7'37.68"E	6° 8'39.15"N
CHK4	81° 6'43.45"E	6° 8'46.36"N

Figures 3.6 images a, b, c show the condition of base station of 12-1A benchmark when setting up the instruments. Images d, e, f show the conditions of the rover when measuring GCPs, marking position, measuring antenna height, and reference environments.



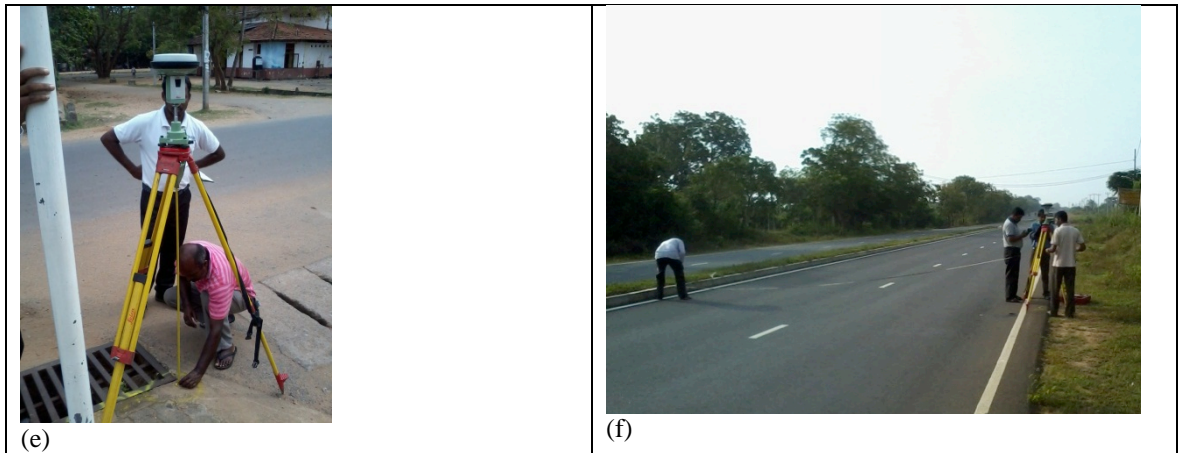


Figure 3.6 Static GPS survey condition above GCP1

The local MSL benchmark, NARA1-TBM, illustrated in Figure 3.7, which was not used for GPS adjustment, is used to compare the GPS observation with the local MSL system.



Figure 3.7 NARA1-TBM benchmark

### 3.1.4 Land Survey using Real-Time Kinematic Observation

#### *Kinematic Observation on Road Network by a Vehicle*

For this project, topographic elevation, gathered along the road network using RTK-GPS, should be finally referred to the local MSL. To survey the road network in the area, a technique called Real-Time Kinematic (RTK) was employed by setting up a base station at benchmark number A025 and broadcasting the correction data using radio to the rover, as shown in Figure 3.8. The correction data was used with raw observations to calculate the double difference, to gain better accuracy of positioning.

Using A025 as base station, RTK-GPS survey was conducted using a van, equipped with a rover GPS antenna, attached on the roof by a magnetic pole, as shown in Figure 3.9. The antenna height (1.910m) measured before survey was used to reduce the elevation data of the RTK-GPS survey from the antenna to the ground. Using 2 GPS receivers, RTK-GPS survey was conducted along the road network in Hambantota and vicinity, ensuring that PDOP is less than 6. Two days were used for this activity. The observed frequency was set as every 1 second (1Hz) for the first day. However, the GPS receiver's capacity is only 64K, so it can support only 3 hours of survey. Thus, on the second day, the observed frequency was changed to every 3 seconds (0.3Hz).



Figure 3.8 RTK GPS base station set up at benchmark number A025 and broadcasting correction data through radio



Figure 3.9 GPS receiver attached to the van, its height from antenna to the ground was measured using a measuring tape

### ***GPS Data Post-processing***

Solutions allowed for the RTK road network survey are *fixed* and *float* solutions, which can provide sub-meter height accuracy. After completing the road network survey, data were downloaded into the computer for data filtering.

Since vertical accuracy must be better than 1 meter, outliers greater than 1 meter were filtered out from the solution. The methodology to detect the outlier is described below:

**STEP 1:** Calculate the vertical difference and horizontal distance between the point  $P(N, E, h)_t$  and  $P(N, E, h)_{t-1}$ , where N and E are the horizontal components and V is the vertical component, as shown in equation (1) and (2) below.

$$Vdiff_t = \sqrt{(P(h)_t - P(h)_{t-1})^2} \quad (1)$$

$$Hdist_t = \sqrt{((P(N)_t - P(N)_{t-1})^2 + (P(E)_t - P(E)_{t-1})^2)} \quad (2)$$

**STEP 2:** Detect the Start Period of outlier by defining two constants called Hcon and Vcon, which will be used to qualify the RTK solution:

```

Begin
    if ((Vdifft > Vcon)&&(Hdistt > Hcon))
        return 1;
    else
        return 0;
    end;
End
where
    Hcon = 10 and Vcon = 0.5

```

the start period of outlier will begin at time "t"

**STEP 3:** Detect the End Period of outlier using the same constants, using a simpler methodology defined by:

```

Begin
    if ((Vdifft > Vcon))
        return 1;
    else
        return 0;
    end;
End
where
    Vcon = 0.5

```

the end period of outlier will be at time "t"

The proposed filtering method is used to separate data affected by biases. Further steps in DEM generation should be done carefully, especially when dealing with dataset and outliers.

### 3.1.5 Accuracy Assessment

RTK-GPS points were compared with the nearby static observations on GCPI-8 and CHK1-4.

## 3.2 Data and Equipment

Table 3.2 shows a list of data and equipment used, and personnel employed for the topographic survey. The 3 major activities include (i) pre-survey preparation and undulation value calculation; (ii) RTK GPS survey along the road network; and (iii) fast static GPS observation on GCPs and checkpoints.

Table 3.2. List of data and resources used in topographic survey

Activity (Duration)	Data Used	Equipment Used	Personnel
1. Instrument preparation and undulation value calculation (1 Apr)	GPS benchmark Level benchmark	Vehicle (van)  <b>Base Station:</b> Multi frequency GNSS receiver with internal memory GNSS Antenna Battery GNSS Controller Tripod	Local security Operator (instrument, data logging and navigation) Driver Survey Department staff (3) RIMES staff (1)
2. Fast static GPS survey on GCPs and checkpoints (1-2 Apr)	Location of GCPs and checkpoints derived from aerial photographs	Tribatch Measuring tape Mobile Phones  <b>Rover Station:</b>	
3. RTK GPS along road network (2-3 Apr)	Satellite image for navigation (Google Earth)	Multi frequency GNSS receiver with internal memory GNSS Antenna Battery GNSS Controller Single magnetic mount for GPS Mobile Phone Measuring tape	

### 3.3 Results and Discussion

#### 3.3.1 Undulation Value Calculation (Geoid Height)

From Section 3.1.2, 5 benchmarks, labeled “Control”, were used to determine the undulation value, as shown in Table 3.3. Adjustments were then made to all the GCPs and check point (NARA TBM), labeled “Adjusted”, observed by fast static GPS survey, as shown in Table 3.4.

On the other hand, for the kinematic GPS data, only one benchmark (A025) was used to determine the undulation value. Table 3.5 shows the corresponding ellipsoidal and local MSL elevation of the benchmark.

Table 3.3 Benchmarks used to determine the undulation value for fast static GPS data

Point ID	Point class	Latitude	Longitude	GPS data in ellipsoidal height (m)	Adjusted GPS data in MSL height (m)
Payibokka FBM	Control	6° 07' 21.18265" N	81° 03' 03.29281" E	-94.4050	3.4670
A028	Control	6° 17' 51.00328" N	81° 14' 17.05368" E	-70.5160	26.7140
A027	Control	6° 14' 22.63882" N	81° 08' 42.03944" E	-46.3390	51.0570
A025	Control	6° 07' 58.59627" N	81° 07' 39.98607" E	-88.0010	9.8040
A024	Control	6° 06' 01.95574" N	80° 59' 11.82973" E	-66.3780	31.2550

Table 3.4 Adjusted GCPs and check point

Point ID	Point class	Latitude	Longitude	GPS data in ellipsoidal height (m)	Adjusted GPS data in MSL height (m)
NARA TBM	Adjusted	6° 07' 25.30329" N	81° 07' 40.63065" E	-96.0218	1.92
GCP-9	Adjusted	6° 07' 17.86669" N	81° 06' 24.27380" E	-95.5135	2.358
GCP-8	Adjusted	6° 09' 10.15470" N	81° 08' 39.19460" E	-92.8997	4.823
GCP-7	Adjusted	6° 08' 21.55825" N	81° 08' 28.83574" E	-95.6783	2.148
GCP-6	Adjusted	6° 07' 28.99211" N	81° 07' 11.98714" E	-94.6484	3.235
GCP-5	Adjusted	6° 08' 15.37628" N	81° 07' 07.90472" E	-93.2894	4.51
GCP-4	Adjusted	6° 09' 12.26484" N	81° 07' 11.40206" E	-76.6771	21.044
GCP-3	Adjusted	6° 08' 58.95841" N	81° 04' 20.97737" E	-70.5995	27.076
GCP-2	Adjusted	6° 08' 07.79178" N	81° 04' 37.37055" E	-76.9486	20.811
GCP-12	Adjusted	6° 08' 46.33303" N	81° 06' 43.32867" E	-76.7797	20.968
GCP-11	Adjusted	6° 08' 39.16626" N	81° 07' 37.52525" E	-95.7401	2.036
GCP-10	Adjusted	6° 07' 22.10523" N	81° 07' 34.79631" E	-81.7781	16.153
GCP-1	Adjusted	6° 07' 01.51208" N	81° 04' 57.41785" E	-90.1091	7.752
12-1A	Adjusted	6° 09' 06.15073" N	81° 08' 37.69891" E	-95.4912	2.227

Table 3.5 Benchmark used to determine the undulation value for kinematic GPS data

Benchmark	Latitude	Longitude	Ellipsoidal height (m)	Local MSL (m)
A025	6° 07' 58.59627" N	81° 07' 39.98607" E	-88.0010	9.804

As mentioned in section 3.1.2, the undulation value or geoid height (N) can be computed as follows:

$$\begin{aligned}
 N &= \text{ellipsoid height} - \text{orthometric height (MSL)} \\
 &= -88.001 - 9.804 \\
 N &= \mathbf{-97.805}
 \end{aligned}$$

This undulation value is then applied to the ellipsoidal height (WGS84) to transform all elevations to the local MSL of the pilot site.

### 3.3.2 Ground Control Points using Static GPS Observation

Static GPS observation was conducted on 1-2 April 2013 to survey all GCPs and checkpoints needed for aerial photogrammetry. All data were post-processed using the "LEICA Geo Office 8.1". WGS-84 was the coordinate system used. Payibokka FBM, A-24, A25, A27 and A28 were used as fixed stations to process the rest by fast static observation points.

Observation standard deviations and position qualities are shown in Table 3.6. From the results, it can be concluded that the horizontal standard deviation and position quality is in the range of 0.2 to 0.6 cm and the vertical standard deviation and position quality is in between 0.7 to 1 cm, where both results agree with the accuracy requirement in this project.

The summary of coordinates for all GCPs and CHKs is shown in Table 3.7. The elevation difference using GPS observation and local MSL at NARA1-TBM benchmark is shown in Table 3.8. The result shows that GPS observation is higher than local MSL by 15.8 cm.

Table 3.6 GPS observation standard deviation (SD) and quality of position and height for all GCPs and CHKs

Point Name	SD Easting (m)	SD Northing (m)	SD height (m)	Position Quality (m)	Height Quality (m)	Position + Height Quality (m)
Payibokka FBM	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
A028	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
A027	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
A025	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
A024	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
12-1A	0.0022	0.0029	0.0069	0.0037	0.0069	0.0078
TBM-1	0.0028	0.0036	0.0079	0.0046	0.0079	0.0091
GCP-1	0.0026	0.0032	0.0069	0.0041	0.0069	0.0080
GCP-2	0.0027	0.0034	0.0073	0.0043	0.0073	0.0085
GCP-3	0.0026	0.0032	0.0068	0.0041	0.0068	0.0079
GCP-4	0.0031	0.0037	0.0077	0.0048	0.0077	0.0091
GCP-5	0.0027	0.0035	0.0084	0.0044	0.0084	0.0095
GCP-6	0.0025	0.0033	0.0085	0.0042	0.0085	0.0095
GCP-7	0.0030	0.0038	0.0081	0.0048	0.0081	0.0094
GCP-8	0.0030	0.0038	0.0084	0.0049	0.0084	0.0098
CHK-1	0.0021	0.0028	0.0068	0.0035	0.0068	0.0077
CHK-2	0.0024	0.0033	0.0081	0.0041	0.0081	0.0090
CHK-3	0.0026	0.0033	0.0072	0.0042	0.0072	0.0084
CHK4	0.0039	0.0045	0.0094	0.0060	0.0094	0.0111
NARA TBM	0.0038	0.0043	0.0096	0.0057	0.0096	0.0111

Table 3.7 Coordinates of all GCPs and CHKs

Point ID	Latitude	Longitude	MSL height (m)
GCP-1	6° 07' 01.51208" N	81° 04' 57.41785" E	7.752
GCP-2	6° 08' 07.79178" N	81° 04' 37.37055" E	20.811
GCP-3	6° 08' 58.95841" N	81° 04' 20.97737" E	27.076
GCP-4	6° 09' 12.26484" N	81° 07' 11.40206" E	21.044
GCP-5	6° 08' 15.37628" N	81° 07' 07.90472" E	4.510
GCP-6	6° 07' 28.99211" N	81° 07' 11.98714" E	3.235
GCP-7	6° 08' 21.55825" N	81° 08' 28.83574" E	2.148
GCP-8	6° 09' 10.15470" N	81° 08' 39.19460" E	4.823
CHK-1	6° 07' 17.86669" N	81° 06' 24.27380" E	2.358
CHK-2	6° 07' 22.10523" N	81° 07' 34.79631" E	16.153
CHK-3	6° 08' 39.16626" N	81° 07' 37.52525" E	2.036
CHK-4	6° 08' 46.33303" N	81° 06' 43.32867" E	20.968

Table 3.8 NARA-TBM elevation comparison

Benchmark	GPS observation	Local MSL
NARA1-TBM	1.920	1.762

### 3.3.3 Land Elevation using Real-Time Kinematic Observation

Post processing results of the kinematic GPS survey conducted from 2-4 April 2013 are shown in Figure 3.10 and Table 3.9.



Figure 3.10 Result of road network survey carried out on 24 January 2013

Table 3.9 Number of filtered data

Date	Total Number of Data
2/4/2013	7444
3/4/2013	3,955
4/4/2013	321
Total	11,720

From Figure 3.10, a lot of observed points in the dense urban area (red rectangle) were filtered out. Causes or error may be due to the narrow road condition and the overhead tree coverage that reduces the quality of GPS observation

The fast static GPS observed points from GCP survey were selected to check the elevation accuracy with nearby kinematic GPS observed points. However, the points which were compared are not exactly the same position. Most of the GCP points are located beside the road to avoid traffic during the observation, but the kinematic GPS points are almost in the middle of the road due to vehicle condition, in this case the GPS antenna was placed on the driver's side. Thus, the points in the middle of the road may be higher than the points on the side of the road by around 10-20 cm due to road slope. Table 3.10 shows that all checked points from the kinematic GPS survey are higher than the points from the fast static GPS survey by around 20-30 cm.

Table 3.10 Selected check points and ellipsoidal height difference

Sample No.	Point Name	h (m)	Difference (m)
1	GCP2	20.881	0.353
	Auto09686	21.234	
2	GCP4	21.044	0.286
	Auto03412	21.33	
	Auto03413	21.33	
3	GCP5	4.51	0.197
	Auto13441	4.707	
4	GCP7	2.148	0.266
	Auto0337	2.414	
5	GCP8	4.823	0.299
	Auto01969	5.122	
6	CHK1	2.358	0.019
	Auto08162	2.377	
7	CHK3	2.036	0.195
	Auto01129	2.231	
8	CHK4	20.968	0.102
	Auto04350	21.098	
	Auto04351	21.042	
Mean			0.237
STD			0.118
Max			0.353

### 3.4 Problems Encountered and Recommendations

#### *Outdated Imagery*

Available aerial photographs are outdated, as shown in Figures 3.11, 3.12, and 3.13. Large-scale developments, such as the construction of the deep harbor and related facilities that have drastically changed Hambantota's topography, are not captured in the aerial photographs. Features in the aerial photographs that have either changed or have been destroyed result in a more loose GCP geometry. During the survey, some GCPs had to be relocated in the field; there was no other option but to use GCP3 and GCP4, even though the location is quite unsure, due to the limitation of GCP geometry in the photogrammetry block.



Figure 3.11 Newly constructed harbor in Google Earth image (right), not shown in outdated aerial photo (left)

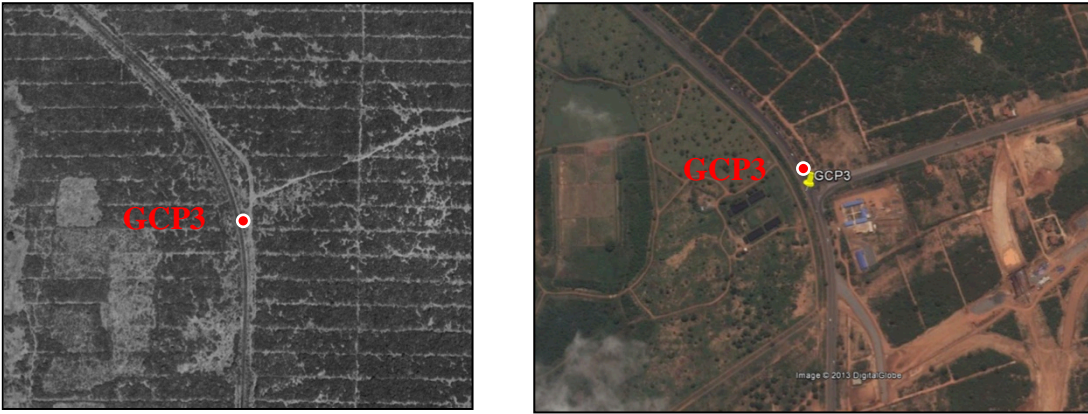


Figure 3.12 Current developments in Google Earth image (right), not shown in the outdated aerial photo (left)



Figure 3.13 GCPs relocated in the field

The above may cause the geometry of the photogrammetry block to be rougher. Furthermore, the observed points in the outdated aerial photographs will be just estimates.

### ***Traffic and Road Condition***

GCPs are usually located on the middle of the road, at the junction, because they are easy to identify in the image (especially in low resolution images). But several conditions, such as heavy traffic in narrow roads, or overhead obstructions, such as power lines, prevent the GCP from being observed in the best position. Thus, GCPs had to be relocated.

Likewise, accuracy of RTK GPS survey will also be affected by narrow roads with overhead coverage or tall wall/ obstruction beside the roads.

### Construction Activity

It is difficult to seek permission to access constructions sites, such as the recent deep harbor project (Figure 3.14) and other urban development projects because a number of agencies handle these projects. Moreover, the survey vehicle cannot get in some parts of the construction areas (Figure 3.15) due to the terrain condition. Recent and ongoing developments could further change the area's topography.



Figure 3.14 Construction area of the deep harbor



Figure 3.15 Construction sites in Hambantota

## CHAPTER 4

# SHORELINE DELINEATION

Shoreline or zero elevation line is delineated to define the connection between land and sea. For high slope or cliff areas, shoreline can be determined from existing maps or rectified aerial images. However, higher accuracy is required for low slope areas such as the beach.

### 4.1 Methodology

A walking GPS survey can be conducted to estimate shoreline in this area. This is done by carrying the GPS antenna on a pole, and walking along the water edge during the time when the predicted tide is at zero elevation.

Estimating zero elevation is critical, especially when the bathymetry of the area is very shallow: a slight difference in elevation may mean a big difference (e.g. greater than 50m) in horizontal position. Using the predicted tide to determine the time when the zero elevation occurs can help approximate the exact location of this line.

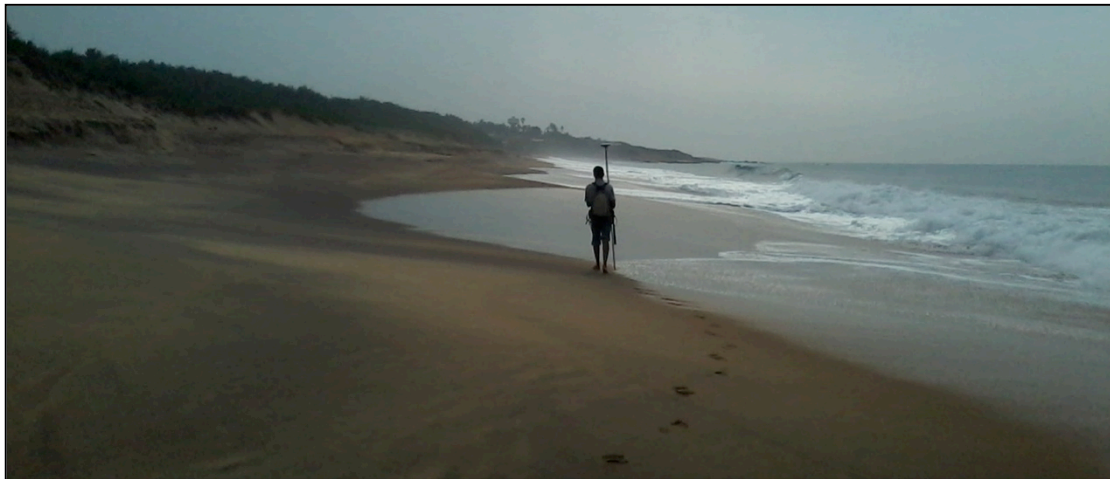


Figure 4.1 Surveyor walking along the beach to survey the shoreline

#### *Methodology adjustments to adapt to local condition*

Since the Kirinda tide station, the station nearest to the pilot site, was not functioning, the predicted tide for the area could not be assessed. Moreover, since the waves at the shore were very high and strong, RTK GPS survey along the water edge was quite difficult to undertake. So, survey was conducted at some safe distance (5m inland) away from the water edge.

RTK GPS survey was conducted using the antenna pole and a backpack set. The surveyors, equipped with the GPS, walked along the shoreline, as close as possible to the water edge. Elevation data were collected, not only along the beach, but also on barriers, such as breakwater structures and rocks.

## 4.2 Data and Equipment

The following table shows the list of data and equipment used, and personnel employed for the shoreline survey.

Table 4.1 List of data and resources used in shoreline survey

Activity (Duration)	Data Used	Equipment Used	Personnel
RTK-GPS survey (3 Apr)	GPS benchmark description	<b>Base Station:</b> Multi frequency GNSS receiver with internal memory GNSS Antenna Battery GNSS Controller Tripod Tribatch Measuring tape Mobile Phones  <b>Rover Station:</b> Multi frequency GNSS receiver with internal memory GNSS Antenna Battery GNSS Controller Mobile Phone Measuring tape	Staff to carry the 1.GPS antenna 2.GPS controller

## 4.3 Results and Discussion

The following figure shows the results of shoreline survey conducted on April 3. The survey covered the extent of the pilot site, including the beach (pink) and concrete structures (yellow) found along the shore (Figure 4.2). One breakwater structure within the lower left harbor, however, could not be surveyed due to ongoing construction.

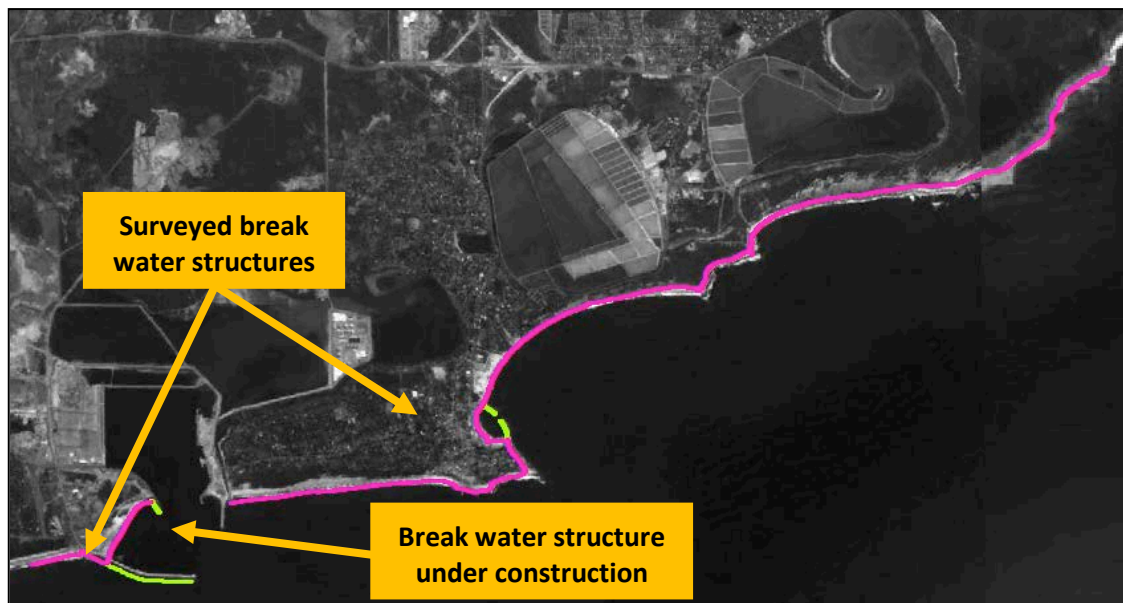


Figure 4.2 RTK GPS survey along the shoreline on 3 April 2013



Figure 4.3 Surveyor walking along the beach and going over the rocks



Figure 4.4 surveyor on the breakwater structure/barrier

#### 4.4 Problems Encountered and Recommendations

A major difficulty encountered in the shoreline survey in Hambantota were the big waves at the water edge due to the steep slope of the beach and its location in the open sea. Shoreline survey, which is usually observed along the water edge, had to be shifted inland, as shown in Figure 4.5 to secure the survey equipment from incoming waves.



Figure 4.5 Adjusted shoreline survey line

## CHAPTER 5

### RIVER SURVEY

River survey can be conducted differently, depending on the water level and terrain condition of the river. Three types of surveys can be conducted: sonar, pole, and walking RTK-GPS surveys. Measurements can be done along the banks and the centerline if the river is wide or sloping, or only along the centerline if the river is narrow or the terrain is flat.

#### 5.1 Methodology

##### 5.1.1 Sonar survey

When water level is high enough to safely use a motorboat, a sonar survey can be conducted along the centerline of the river, zigzagging along the banks.

##### 5.1.2 Pole survey

When water level is not high enough for sonar survey and not low enough for a walking RTK-GPS survey, a pole survey can be conducted. This is done by using a calibrated pole to measure instantaneous depth readings aboard a boat, small enough to travel during the low tide, as shown in Figure 5.1. Since it is not possible to estimate the actual terrain condition of the river below the water, the most conservative recommendation would be to take 3 measurements: (i) left bank, (ii) center, and (iii) right bank of each cross-section of the river, for every 100m interval distance. Prior to actual survey, a survey route, defining strategic points of measurements, is planned and inputted to the handheld GPS as waypoints using the *GPS TrackMaker* for convenient tracking during the actual survey. As in the case with sonar survey, depth readings from the pole survey will be corrected for tide. Hence, it is important to synchronize the time that the depth readings are taken with the time used by the portable tide gauge.



Figure 5.1 Pole survey along a river

Since water level condition for this case is critical, it is also important to consider the best time to survey, whether during the high or low tide period. Otherwise, neither pole survey nor RTK-GPS can be conducted until enough water comes in, or runs out. Without prior knowledge about the general terrain condition of the river, deciding the best time will depend mostly on local people's recommendation (e.g. fisherman, boat driver, etc.) and, if there is still uncertainty, on trial and error. A reconnaissance survey to check the terrain of the river should be done prior to actual survey to ensure smooth survey operations.

### 5.1.3 RTK GPS

When water level in the river is not high enough to conduct sonar or pole survey, a walking RTK-GPS can be conducted similar to the shoreline survey, as shown in Figure 5.2. If the river is flat, surveying along the centerline is enough. Otherwise, there may be a need to survey along the banks of the river if the river is sloping from bank to bank, or along the centerline and banks of the river if the river is sloping to the center.



Figure 5.2 RTK GPS survey along a dried up river

#### *Methodology adjustments to adapt to local conditions*

In Sri Lanka, sonar survey and pole survey cannot be conducted because the water level of the canal is not high enough for any boat to get in and existence of a sand barrier at the mouth. A walking RTK-GPS survey, therefore, was conducted, instead of on the river as well as on the sand barrier.

Along the canal, measurements were made every 100m interval. For each cross section, 3 depth readings were taken from bank to bank to account possible slope conditions below the water; since the canal is rather small, it is, then, most probably flat.

### 5.2 Data and Equipment

The following table shows the list of data and equipment used, and personnel employed for the walking RTK-GPS survey.

Table 5.1 List of data and resources used in river survey

Activity (Duration)	Data Used	Equipment Used	Personnel
RTK-GPS survey (4 Apr)	GPS benchmark description	<b>Base Station:</b> Multi frequency GNSS receiver with internal memory GNSS Antenna Battery GNSS Controller Tripod Tribatch Measuring tape Mobile Phones	Staff to carry the 1.GPS antenna 2.Controller

Activity (Duration)	Data Used	Equipment Used	Personnel
		<b>Rover Station:</b> Multi frequency GNSS receiver with internal memory GNSS Antenna Battery GNSS Controller Mobile Phone Measuring tape	

### 5.3 Results and Discussion

Figure 5.3 shows the result of the RTK GPS survey conducted on the canal and the sand barrier on April 4. The MSL elevations of the river and the sand barriers are around 0.1m and 2m, respectively.



Figure 5.3 RTK GPS survey along the canal on 4 April 2013

### 5.4 Problems Encountered and Recommendations

The initial survey plan included the survey of two rivers/canals in the pilot site. However, due to several constructions near the harbor, entrance to the river within the area was prohibited, hence it was possible to survey only the small canal near the salt pan.

A striking characteristic of the rivers and canals in the pilot area and their vicinity is the presence of sand barriers that prevent the river water from going out to the sea. This is also one of the reasons why it is difficult to access the canal by boat. Fortunately, the water level of the canal is not high enough so the surveyor can walk along the canal to take the measurements.

In case the water level is too high for walking or too low to bring in a motorboat with a transducer, a pole survey using a smaller boat can be conducted. However, since the canal water is blocked at the mouth by sand barriers (Figure 5.4), tidal data from the gauge cannot be used to correct the raw sonar data. Instead, an RTK GPS survey can be conducted first to measure the elevation of the water surface at several sections, especially if the river is long and big, from where all pole readings will be referred.



Figure 5.4 Sand barrier at the canal mouth

Extra precaution is necessary to avoid unexpected accidents during survey. To avoid contact with river water and stepping on dangerous debris (Figure 5.5), it is recommended to wear safety boots when conducting the survey.



Figure 5.5 Canal condition

## **CHAPTER 6**

### **EXPOSURE SURVEY**

Within this project, assessment of tsunami risk is presented in the context of (i) tsunami vulnerability and loss, and (ii) people's ability to evacuate. Tsunami exposure and lifeline information were, hence, collected to address the spatial and temporal component of the population and property at risk. Concept for the analysis, methodology for exposure data collection, and list of collected data are presented in the following sections.

#### **6.1 Tsunami Vulnerability and Loss Estimation**

In the coastal zone exposed to tsunami inundation, buildings and infrastructure are not uniformly at risk within the flood zone. The probability of damage is related to both vulnerability (structural capacity to resist) and wave energy. In other words, damage level to buildings depends on building type and on inundation depth. The vulnerability criteria used to classify buildings are defined as "intrinsic factors" that influence its vulnerability, such as type of construction material, height, and number of floors. For this project, vulnerability function concept is used to express probable loss or impact to the element at risk for a particular hazard level, ranked in order of severity.

An online tool named "INSPIRE" (Srivihok et al, 2012) has been developed at RIMES for tsunami inundation simulation and tsunami loss estimation. INSPIRE is composed of two main components: (i) tsunami hazard evaluation module, and (ii) tsunami loss estimation module. For tsunami hazard evaluation, the TUNAMI model (IUGG/IOC TIME Project, 1997) was customized and integrated into the system for tsunami propagation and inundation simulation. The user can arbitrarily specify earthquake parameters for generating initial sea-floor deformation, and input local near-shore topographic and bathymetric data, or use default data (GEBCO08\_30sec) for the simulation. Under the current project, near-shore topographic and bathymetric data, obtained from field survey, will be inputted for the analysis. Tsunami losses can be estimated by correlating the most critical tsunami parameter with the location and properties of exposed elements, through the vulnerability function. By this approach, building classification is considered to reflect more realistic building response capability to the tsunami impact and probability of building damage.

Loss and damage estimation will provide information to local authorities on buildings that need to be reinforced or even relocated because of their vulnerability to tsunami damage. This information, thus, is useful for formulating planning regulations, directing building programs, and issue of construction license. Social vulnerability, quantitatively evaluated in terms of probability of a population to survive based on spatial and temporal population distribution, could be of interest to disaster managers and emergency planners. The analysis could provide information on buildings that house large numbers of people who may likely be trapped, population density change over time, and buildings that do not offer opportunity for vertical evacuation.

##### **6.1.1 Selection of Tsunami Fragility Curves for Sri Lanka**

In general, tsunami fragility curves, also referred to as experience curves, are developed from recorded damages of past tsunami events. The curve expresses the ratio of damaged buildings to all buildings, at a particular level of tsunami hazard. Tsunami fragility curves for building are technically expressed by the cumulative probability of damage occurrence, as standardized normal distribution or log normal distribution functions of the hydrodynamic features of tsunami, e.g. inundation depth, current velocity, and hydrodynamic force:

$$P(x) = \Phi \left[ \frac{x - \mu}{\sigma} \right] \quad (6.1)$$

$$P'(x) = \Phi \left[ \frac{\ln x - \mu'}{\sigma'} \right] \quad (6.2)$$

where  $x$  is the hydrodynamic feature,  $\Phi$  is the standard normal distribution/ lognormal distribution function,  $\mu$  and  $\sigma$  are the mean and standard deviation of  $x$ , and  $\mu'$  and  $\sigma'$  are the mean and standard deviation of  $\ln x$ , respectively. Each fragility curve was developed using a specific method, dataset of the tsunami event and location, and structural type (material, low/high rise) and damage level. Fragility curves should be properly selected for estimating tsunami loss for different types of exposures.

In this project, the tsunami fragility curve for Hambantota is selected from literature. Muraio and Nakazato (2010) investigated building damage conditions as a result of the 2004 Indian Ocean Tsunami in Galle, Matara, and Hambantota. The total coastline length of the investigated areas was approximately 7 km, and the total number of buildings was 1,535. Most of the houses were one or two storeys in the districts; most of the one-storey houses were brick-brick, block-built, or wooden. On the other hand, two or more storey houses, including apartments in the residential area, and public, commercial, or office buildings with several storeys were mainly reinforced concrete or steel buildings. Hence, buildings in the areas were classified into two structural types: non-solid buildings and solid buildings (Figure 6.1).



Type	Non-solid buildings	Solid buildings
Structure (material)	Brick-built, block-built, or wooden	Reinforced concrete, steel
The number of floors	One or two	Two or more
Usage	Housing (commercial)	Public, commercial, or office
Image		

Figure 6.1 Building construction type classification for Hambantota

Building damage due to the tsunami was classified into four levels (complete damage, heavy damage, moderate damage, and no/slight damage), based on visual investigation of each building's damage condition on the ground and interviews of residents for confirmation (Figure 6.2).

The least square method on logarithmic normal probability was applied to develop fragility curves (Figure 6.3), based on damage statistics corresponding to the inundation depth. Parameters of tsunami vulnerability functions for building in Sri Lanka are shown in Table 6.1.





Damage Rank	Complete Damage	Heavy Damage	Moderate Damage	No/Slight Damage
Definition	Complete structural damage	Structural damage and unusable	No visible structural damage and reusable	No visible mentionable damage
Image				

Figure 6.2 Classification of potential damage from tsunami impact

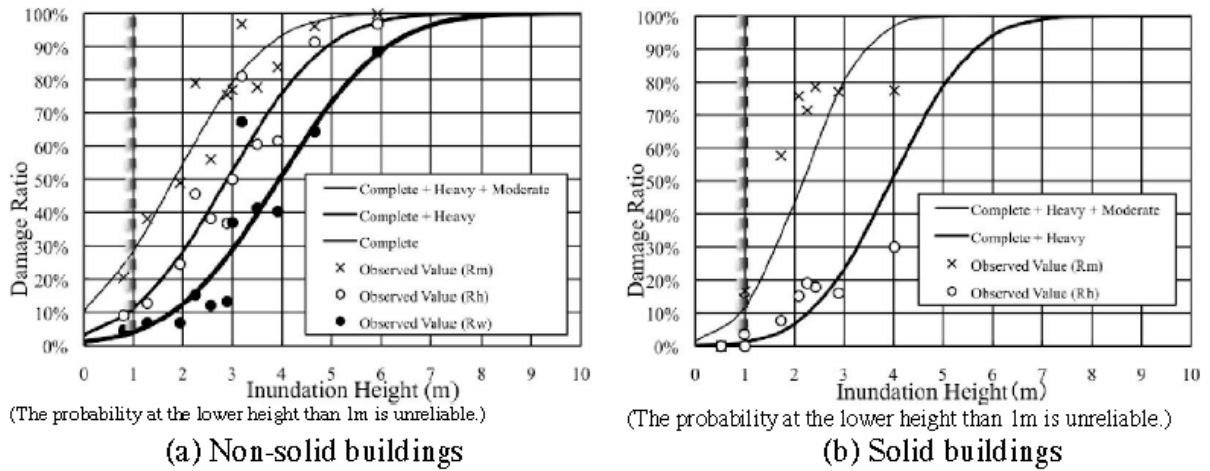


Figure 6.3 Tsunami fragility curves for Hambantota

Table 6.1 Parameters of tsunami vulnerability functions for building in Sri Lanka, proposed by Murao and Nakazato (2010)

	Damage Rank	$\mu'$	$\sigma'$	$R^2$
Non-solid Buildings	Complete ( $R_c$ )	3.94	1.69	0.846
	Complete + Heavy ( $R_h$ )	2.89	1.56	0.908
	Complete + Heavy + Moderate ( $R_m$ )	1.82	1.45	0.859
Solid Buildings	Complete ( $R_c$ )	-	-	-
	Complete + Heavy ( $R_h$ )	3.96	1.31	0.684
	Complete + Heavy + Moderate ( $R_m$ )	2.16	0.98	0.641
All Buildings	Complete ( $R_c$ )	4.25	1.74	0.931
	Complete + Heavy ( $R_h$ )	3.19	1.60	0.971
	Complete + Heavy + Moderate ( $R_m$ )	1.87	1.65	0.901

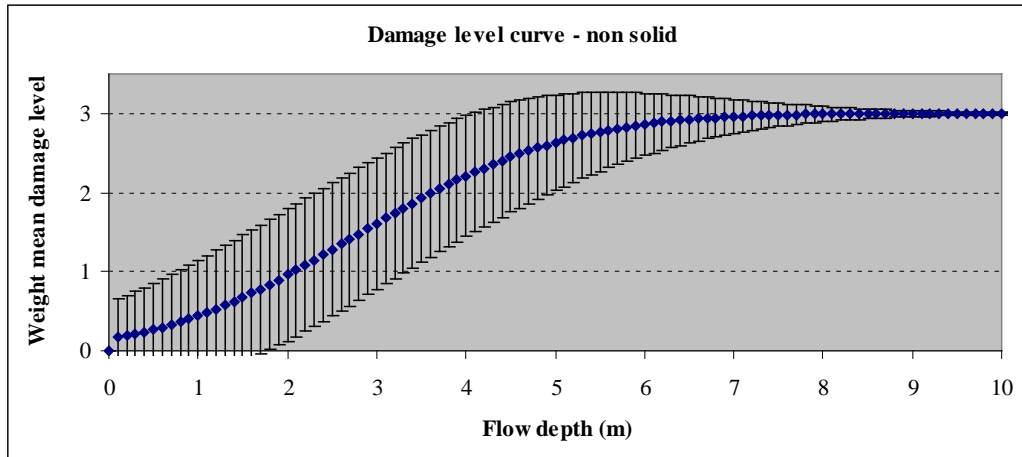
Since the fragility curve can present the ratio of damaged buildings to all buildings, a zoning map can be generated based on the application of the fragility curve, to present comparatively high/medium/low ratio of damaged building zone, e.g. percentage of building damage for each site. In addition, by modifying fragility curves, damage level can be estimated for an individual building, if the tsunami inundation depth is known at the building location. Concept of weight mean damage level, firstly proposed by Valencia et al (2011), is adopted for this project, as presented by the Equation (6.3):

$$\bar{D}_i = \frac{(1 \times nD1_i) + (2 \times nD2_i) + (3 \times nD3_i) + \dots + (k \times nDk_i)}{nD1_i + nD2_i + nD3_i + \dots + nDk_i} \quad (6.3)$$

where  $\bar{D}_i$  is the weight mean damage level,  $nD1_i$  is the total number of buildings with Damage level 1 for the flow depth with interval “i” and  $nD2_i$  the total number of buildings with Damage level 2 for the flow depth with interval “i”; and  $k$  is the maximum damage level, etc. Uncertainty can be expressed by the standard deviation ( $\sigma_{D_i}^2$ ) as presented in Equation (6.4):

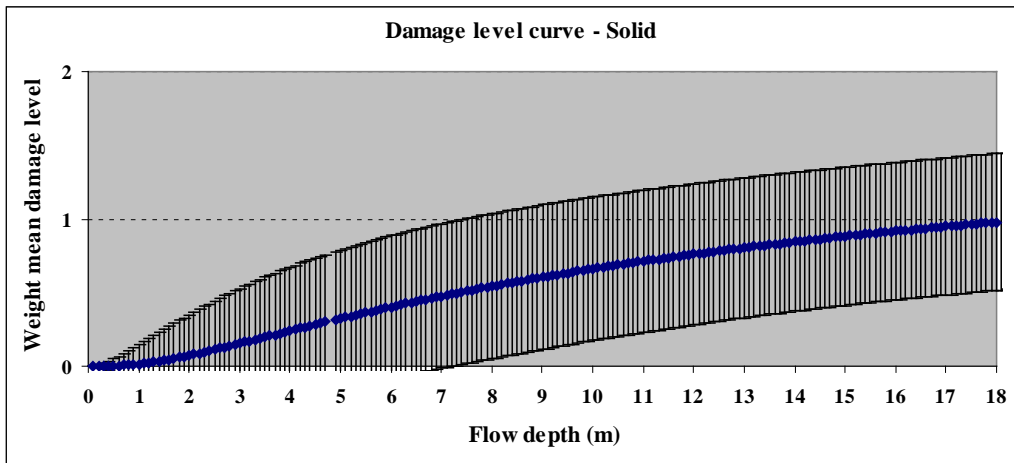
$$\sigma_{D_i}^2 = \frac{nD1_i \times (1 - \bar{D}_i)^2 + nD2_i \times (2 - \bar{D}_i)^2 + nD3_i \times (3 - \bar{D}_i)^2 + \dots + nDk_i \times (k - \bar{D}_i)^2}{nD1_i + nD2_i + nD3_i + \dots + nDk_i} \quad (6.4)$$

Weight mean damage level presents the average damage level for a particular building type when subjected to a particular range of tsunami inundation depth. However, uncertainty of damage range is also included. Damage level curves with uncertainty range developed for non-solid, solid, and all buildings are plotted in Figures 6.4, 6.5, and 6.6, respectively.



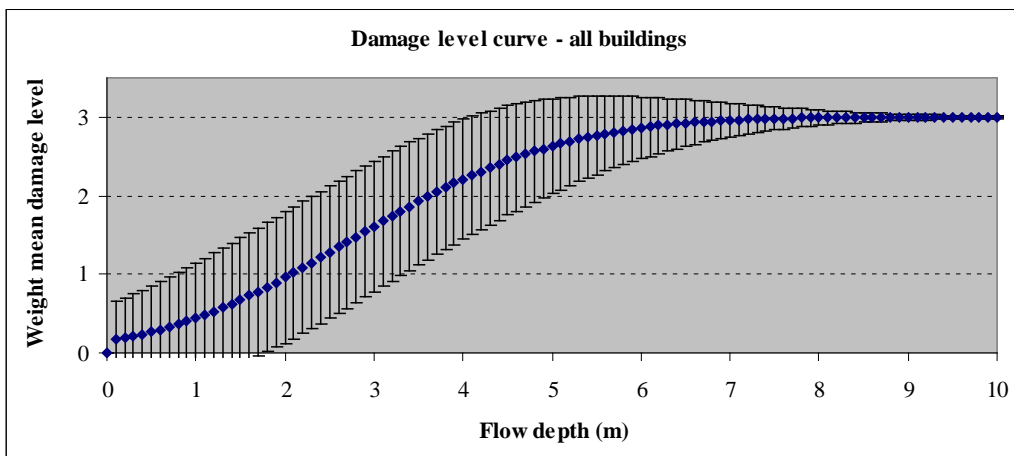
Flow depth (m)	Mean damage level
0	0 (No damage)
0.1 to 2.0	1 (Rm)
2.1 to 3.8	2 (Rh)
> 3.8 m	3 (Rc)

Figure 6.4 Damage curve for non-solid building



Flow depth (m)	Mean damage level
0	0 (No damage)
0.1 to 1.8	1 (Rm)
> 18	2 (Rh)

Figure 6.5 Damage curve for solid building



Flow depth (m)	Mean damage level
0	0 (No damage)
0.1 to 2.0	1 (Rm)
2.1 to 3.7	2 (Rh)
> 3.7 m	3 (Rc)

Figure 6.6 Damage curve for all buildings

## 6.1.2 Methodology

Vulnerability and loss estimation uses building inventory as main dataset. The inventory provides information about location and properties of each building, e.g. building construction type, building usage, and number of residents. Building footprint can be captured from high-resolution satellite images or aerial photographs, while building properties are mainly collected from field survey and combined with existing data from national and local government agencies.

Under the current project, location and properties of critical facilities and public buildings were gathered during the site visit. For ordinary buildings in the town, cameras with GPS receiver, mounted on the survey vehicle, were used to record building image along the survey route. While traveling through road network in the area, building images, with geographical coordinates, were captured. Building construction type and usage will be visually post-processed from the VDO images. Classification of building type in the area would be based on the selected fragility curves, as presented in Section 6.1.1.

Buildings located far from the road networks could not be captured by VDO camera. However, building construction type can be estimated from interpretation of roof shapes from satellite image, while building usage can be estimated from neighboring buildings and land use type, where the building under consideration is located. The estimation technique assists in completing the database gathered during field surveys, which are hardly satisfactory because of limitations in time, as well as in economic and human resources.

Population distribution data was collected from the local government office, e.g. statistics and census data. Number of resort and hotel rooms was also collected for tourist areas, for estimating the number of tourists, especially during the high season. Table 6.2 shows the list of data collected for the vulnerability and loss estimation for Hambantota.

Table 6.2 List of data collected for tsunami vulnerability and loss estimation

Data Type	Data Source	Analysis Details
1. Building footprint	<ul style="list-style-type: none"> <li>○ Building footprint layer from the Survey Department</li> <li>○ Digitized from Google Earth</li> </ul>	<ul style="list-style-type: none"> <li>○ Roof shape</li> <li>○ Building location</li> </ul>
2. Building construction type	<ul style="list-style-type: none"> <li>○ Field visit</li> <li>○ Analysis of video footage, linked to building footprint</li> <li>○ Roof shape interpretation</li> </ul>	<ul style="list-style-type: none"> <li>○ <i>Type A</i>: Non-solid buildings</li> <li>○ <i>Type B</i>: Solid buildings</li> </ul>
3. Building usage	<ul style="list-style-type: none"> <li>○ Field survey</li> <li>○ Analysis of video footage, linked to building footprint</li> <li>○ Land use map interpretation</li> <li>○ Estimate from neighboring buildings</li> </ul>	<ul style="list-style-type: none"> <li>○ Residential</li> <li>○ Commercial</li> <li>○ Industrial</li> <li>○ Agriculture</li> <li>○ Religion</li> <li>○ Government</li> <li>○ Education</li> <li>○ Tourist</li> <li>○ Supply</li> <li>○ NGOs</li> </ul>
4. Population distribution	<ul style="list-style-type: none"> <li>○ Census data from Statistics Department (to be linked to building footprint)</li> <li>○ Resident interview at critical buildings</li> </ul>	<ul style="list-style-type: none"> <li>○ Estimated population distribution in each household/function building</li> </ul>
5. Tourist distribution	<ul style="list-style-type: none"> <li>○ Interviews with hotel staffs</li> <li>○ Google Earth and Google map for hotel location and number of rooms, assumed to have 2 pax/room (if hotel website is available) (to be linked to building footprint)</li> </ul>	<ul style="list-style-type: none"> <li>○ Estimated tourist number distribution in each resort/ hotel building</li> </ul>

### 6.1.3 Data and Equipment

#### *Survey of Critical Facilities and Public Buildings*

Geographical location of and building properties for critical facilities and public buildings were collected during the site visit, using handheld GPS and interviews of residents (Figure 6.7 presents the building survey form used). Experiences of tsunami inundation depth and loss/damage from the Indian Ocean tsunami in 2004 were also collected and recorded as remarks in the survey form.

#### **Building survey form for tsunami risk assessment in Sri Lanka**

**Date:** \_\_\_\_\_ **Time:** \_\_\_\_\_ **Name of surveyor:** \_\_\_\_\_  
**Building ID:** \_\_\_\_\_ **Village Name:** \_\_\_\_\_

<b>Building Name:</b>		<b>GPS Coordinate:</b>	_____ N _____ E
<b>No. of floor:</b>		<b>No. of residents:</b>	Day time _____ Night time _____ Max. Capacity _____ (in case of potential shelter)
<b>Building Construction Type:</b>		<b>Type A</b> Non Solid building : brick/block-built or wooden, 1-2 floors	
		<b>Type B</b> Solid Building: RC or steel, >=2 floors	

<b>Building Usage (HAZUS Occupancy) :</b>	
<b>Residential</b>	
	RES 1: Single Family Dwelling
	RES 2: Mobile Home
	RES 3: Multi Family Dwelling
	RES 4: Temporary Lodging
	RES 5: Institutional Dormitory
	RES:6 Nursing Home
<b>Commercial</b>	
	COM 1: Retail Trade
	COM 2: Wholesale Trade
	COM 3: Personal and Repair Services
	COM 4: Professional/Technical/Business Services
	COM 5: Banks
	COM 6: Hospital
	COM 7: Medical Office/ Clinic
	COM 8: Entertainment and Recreation
	COM 9: Theaters
	COM 10: Parking
<b>Industrial</b>	
	IND 1: Heavy
	IND 2: Light
	IND 3: Food/Drugs/Chemicals
	IND 4: Metals/Minerals Processing
	IND 5: High Technology
	IND 6: Construction
<b>Agriculture</b>	
	AGR 1: Agriculture
<b>Religion</b>	
	REL 1: Church/Membership Organization
<b>Government</b>	
	GOV 1: General Services
	GOV 2: Emergency Response
<b>Education</b>	
	EDU 1: Schools/Libraries
	EDU 2: Colleges/Universities

**Building Usage (Additional):**

**Tourist**

TOU 1: Hotel, Resort, Bungalow

**Supply**

SUP 1: Public utilities

**Non-Government Organization**

NGO 1: Office of Non-Governmental Organization

Figure 6.7 Building survey form



Figure 6.8 Data collection on critical facilities and public buildings using building survey form

***Building Image Capture by VDO Camera***

*VDO camera with GPS receiver*

Two VDO cameras with GPS receiver were mounted on the survey vehicle for recording building image at the right and left sides of the road (Figure 6.9). Cameras should be properly mounted at an angle of about 20 degrees from horizontal, in order to capture all building storeys. Traveling speed through the road network in the area was limited to about 30 km/h.

*Handheld GPS and road network map*

Handheld GPS (Figure 6.10) was used to navigate and check locations, while the road network map was used to navigate the survey route and record the survey track in each survey day.

Table 6.3 summarizes the data and equipment used and personnel employed for the exposure survey.



Figure 6.9 VDO camera with GPS receiver mounted on the survey vehicle



Figure 6.10 Handheld GPS for navigation and travel route record on road network map

Table 6.3 Data, equipment, and personnel for the exposure survey

Activity (Duration)	Data Used	Equipment Used	Personnel
1. Survey of critical facilities and public buildings	Survey form	Handheld GPS Digital camera	Local guide Recorder
2. Building image capture by VDO camera	Road network map	Survey Vehicle VDO camera Handheld GPS	Driver Local guide Recorder

## 6.1.4 Results and Discussion

### *Administration Boundaries*

GIS layer of Grama Niladhari (GN) boundaries of Hambantota district was collected from the Survey Department office in Hambantota. Figure 6.11 shows the GN boundaries (blue lines) and project area in Hambantota town (red frame) located in Hambantota DS Division, which covers four (4) GN Divisions namely, Siribopura, Samodagama, Hambantota East and Hambantota West.

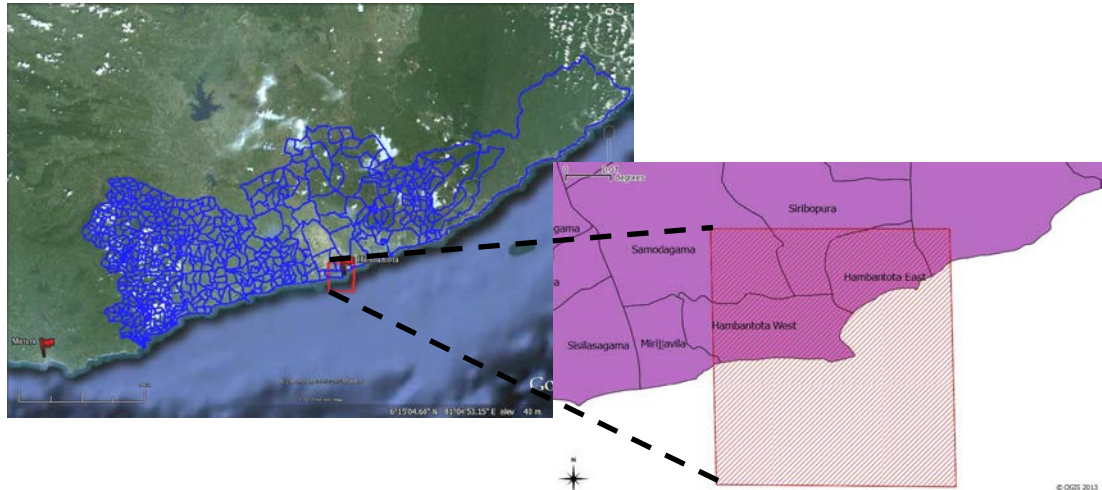


Figure 6.11 GN boundary in Hambantota District and survey area (in shaded rectangle)

### *Building Footprint*

Building footprint for Hambantota (Figure 6.12) was collected and extracted from Hambantota Town map scale 1:5,000 from the Survey Department of Sri Lanka. This building footprint will be validated and updated by comparing to high-resolution satellite images from Google Earth captured in July 2012.



Figure 6.12 Building footprint (location and roof shape) used Google earth as the base map

### ***Critical Facilities and Public Buildings***

Data of sectional damage and possible tsunami affected schools, hotels, and designated shelters were collected from Hambantota Disaster Management Center to guide the field visit. Locations of critical facilities and public buildings are plotted in Figure 6.13. Building properties classification according to construction type, building usage, and tsunami inundation records are presented in Figures 6.14, 6.15, and 6.16, respectively. Detailed building information is provided in Table 6.4.



Figure 6.13 Location of surveyed critical facilities and public buildings (Point IDs are linked to building ID in Table 6.4)



Figure 6.14 Critical facilities and public buildings classified by building construction type (A: non-solid building and B: solid building)



Figure 6.15 Critical facilities and public buildings classified by building usage

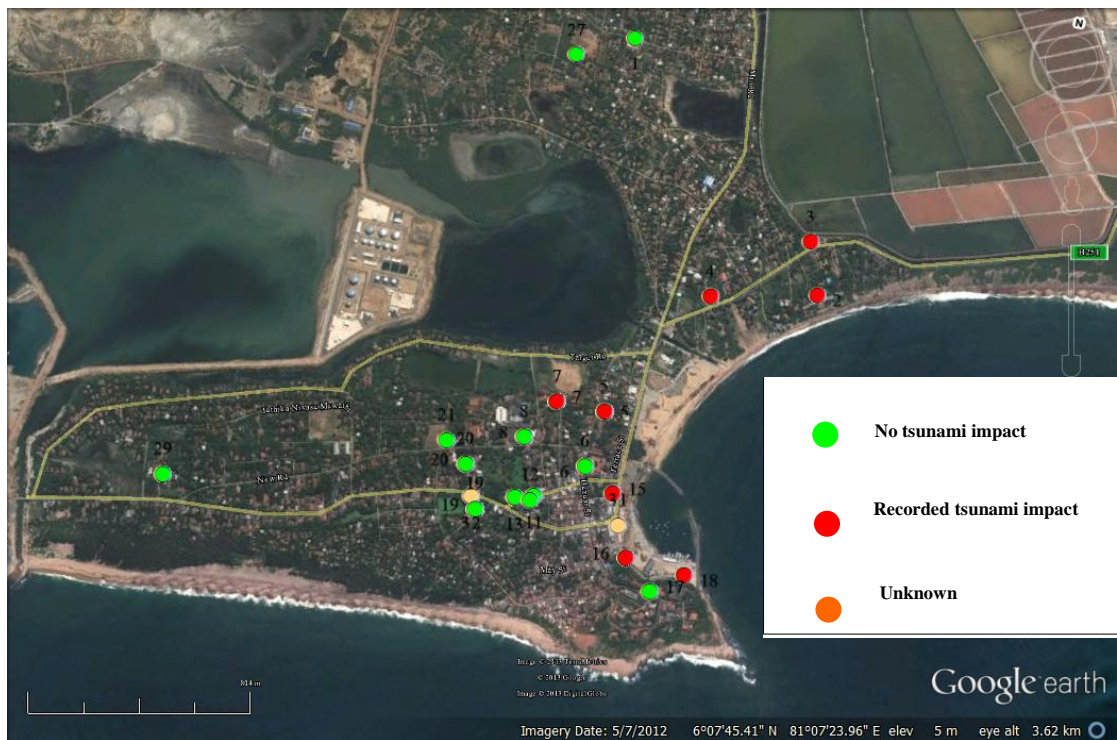


Figure 6.16 Inundation from Indian Ocean Tsunami event in 2004 at critical facilities and public buildings

Table 6.4 Survey information for critical facilities and public buildings

Place name	Long	Lat	No. of floors	No. of bldgs.	Residents (daytime)	Residents (nighttime)	Capacity	Bldg. type	Bldg. usage	GN Name	Bld. ID	Remarks
Al Masjidun Noor Jumma Mosque	81.1234	6.1415	2	1	650	-		B	REL.1	Siribopura	1	DMC Evacuation Centre, Under Construction, already finished 1 <sup>st</sup> Floor
Peacock Beach Hotel	81.1314	6.1338	4	1	248	248	298	B	TOU.1	Hambantota East	2	Tsunami affected. Inundation depth was about 17 Feet
Jadewin Restaurant	81.1308	6.1356	1	1	36	36	150	A	COM.8	Hambantota East	3	Tsunami affected. Inundation depth was about 10 Feet
Survey Department – District Survey Office	81.1278	6.1330	1	4	18	-	22	A	GOV.1	Hambantota East	4	Tsunami affected. Inundation depth was about 6 Feet
Iqra Primary School	81.1250	6.1283	2	2	574	-	574	B	EDU.1	Hambantota West	5	Completely Damaged. Inundation depth was about 10 feet. Capacity more than 1,000 people during emergency
			1	2				A				
Zahira College	81.1247	6.1264	3	4	626	-	626	B	EDU.1	Hambantota West	6	Not Effected by tsunami
			1	1				A				
St.Mery's College	81.1233	6.1283	3	1	1172	-	1172	B	EDU.1	Hambantota West	7	Tsunami affected. Inundation depth was about 10 Feet
			1	26				A				
District Hospital Hambantota	81.1225	6.1269	4	1	2200	891	2200	B	GOV.1	Hambantota West	8	Not affected by tsunami. Last Tsunami in 2004, this hospital provided medical services to 10,000 people
			3	1				B				
			2	1				B				
			1	8				A				
Water Tank	81.1232	6.1251	1	1	n/a	n/a	n/a	B	SUP.1	Hambantota West	11	Water supply & Drainage Board. 650m <sup>3</sup> /per day
Electricity Board- Sub Station	81.1231	6.1249	1	1	12	2	12	A	SUP.1	Hambantota West	12	Not affected by tsunami. There are 180 Transformers. One Transformer supplies 100 houses. No Generators. In case of emergency they can be requested by Ambilipitiya. Provide service 24 hours.
Hambantota Arabic College	81.1226	6.1249	2	1	100	n/a	1000	B	REL.1	Hambantota West	13	Mosque. Not affected by tsunami. Potential Evacuation Shelter
Police Station	81.1255	6.1257	2	1	100	60	100	B	GOV.1	Hambantota East	14	DMC Evacuation Centre with Early Warning Tower
			1	3								
Main Bus stand	81.1258	6.1257	2	1	800	200	1000	B	GOV.1	Hambantota East	15	Completely Damaged. Inundation depth was about 12 feet
Telecom Office- Hambantota	81.1267	6.1237	3	1	55	49	67	B	COM.4	Hambantota East	16	Tsunami affected .Inundation depth was about 10 feet
Maha Naga Mandiraya	81.1277	6.1228	1	1	n/a	n/a	1500	A	GOV.2	Hambantota East	17	Not affected by tsunami. DMC Evacuation Centre.
Ceylon Fishery Harbour	81.1287	6.1235	2	1	32	2	32	B	GOV1	Hambantota East	18	Tsunami affected. This building is re-constructed.
Fishery Community Center	81.1287	6.1235	1	2	100	n/a	100					
Chamee Guest House	81.1214	6.1242	2	1	6	6	6	B	TOU.1	Hambantota West	19	Not affected by tsunami
			1	2				A				

Place name	Long	Lat	No. of floors	No. of bldgs.	Residents (daytime)	Residents (nighttime)	Capacity	Bldg. type	Bldg. usage	GN Name	Bld. ID	Remarks
Nimba Aramaya(temple)	81.1208	6.1256	2	2	15	15	15	B	REL.1	Hambantota West	20	1-2stories (under construction), Evacuation center, not tsunami affected. Can accommodate1500 people with camping facilities
			1	6				A				
Recreation Ground	81.1200	6.1263	n/a	n/a	n/a	n/a	3000	n/a	GOV.1	Hambantota West	21	Safe location. Only for camp management
Seetharama Vihara (temple)	81.0712	6.1167	2	1	7	7	500	B	REL.1	Sisilasagama	22	Evacuation Centre with Tsunami Tower. 1,000 people capacity with camp management
			1	3				A				
Oasis Beach Resort	81.0708	6.1119	2	1	55	55	138	B	TOU.1	Sisilasagama	23	Tsunami affected
			1	10	20			A				
Pallemalala Primary School	81.1846	6.2686	2	1	258	-	258	B	EDU.1	Pallemalala	24	Tsunami affected.
			1	4				A				
Devi Rest	81.0806	6.1239	2	1	114	100	114	B	NGO.1	Mirijjawila	25	30 Rooms. Not affected by tsunami
			1	3				A				
Udamalla Maha Vidyalaya	81.1665	6.1685	1	6	335	-	335	A	EDU.1	Udamalla	26	Tsunami affected
Samodagama Primary School	81.1215	6.1405	1	5	298	-	298	A	EDU.1	Siribopura	27	Not affected by tsunami. There are Water Board Water Tank
Samren Restaurant	81.1271	6.1481	3	1	30	27	30	B	COM.8	Siribopura	28	Not affected by tsunami
			1	2				A				
School of Nursing	81.1109	6.1232	1	17	92	86	92	B	EDU.2	Hambantota West	29	Not Effected by tsunami
Gotapabbatha Raja Maha Vihara	81.5190	6.1101	2	1	2	2	130	B	REL.1	Ambantota	30	Not Affected. By tsunami. Evacuation Centre with Warning Tower
			1	3				A				
P.Weerasinghe Ceypetro (Gov. gas station)	81.1262	6.1247	1	1	-	-	-	A	SUP.1	Hambantota East	31	<b>Consumption of fuel per day:</b> Petrol: 2000 L, Diesel:2000 L, Kerosene: 3000L <b>Stock of fuel per day:</b> Petrol: 9000 L, Diesel:21000 L, Kerosene: 9000 L <b>Vending machine</b> Petrol: 1, Diesel: 2, Kerosene: 1
IOC Weldisi Pvt.Ltd (Private gas station)	81.1212	6.1246	1	1	-	-	-	A	SUP.1	Hambantota West	32	<b>Consumption of fuel per day:</b> Petrol: 1500 L, Diesel:3500 L <b>Stock of fuel per day:</b> Petrol: 9000 L, Diesel:21000 L <b>Vending machine</b> Petrol: 2, Diesel: 2
Ceypetro Sri Lanka Red-Cress Filling Station (Private gas station)	81.1433	6.1534	1	1	-	-	-	A	SUP.1	Hambantota East	33	<b>Consumption of fuel per day:</b>  <b>Stock of fuel per day:</b> Petrol: 1400 L, Diesel:4500 L <b>Vending machine</b> Petrol: 3, Diesel: 3

### *Building Images Captured by VDO Camera with GPS Receiver*

Capture of building images in Hambantota town was undertaken from 3-5 April 2013. Figure 6.17 presents the survey route in the area of interest. Example of building image captured by VDO camera is illustrated in Figure 6.18.



Figure 6.17 Survey route for building image capture  
 Orange line: trip on 3 Apr 2013, Green line: trip on 4 Apr 2013, and  
 Yellow line: trip on 5 Apr 2013

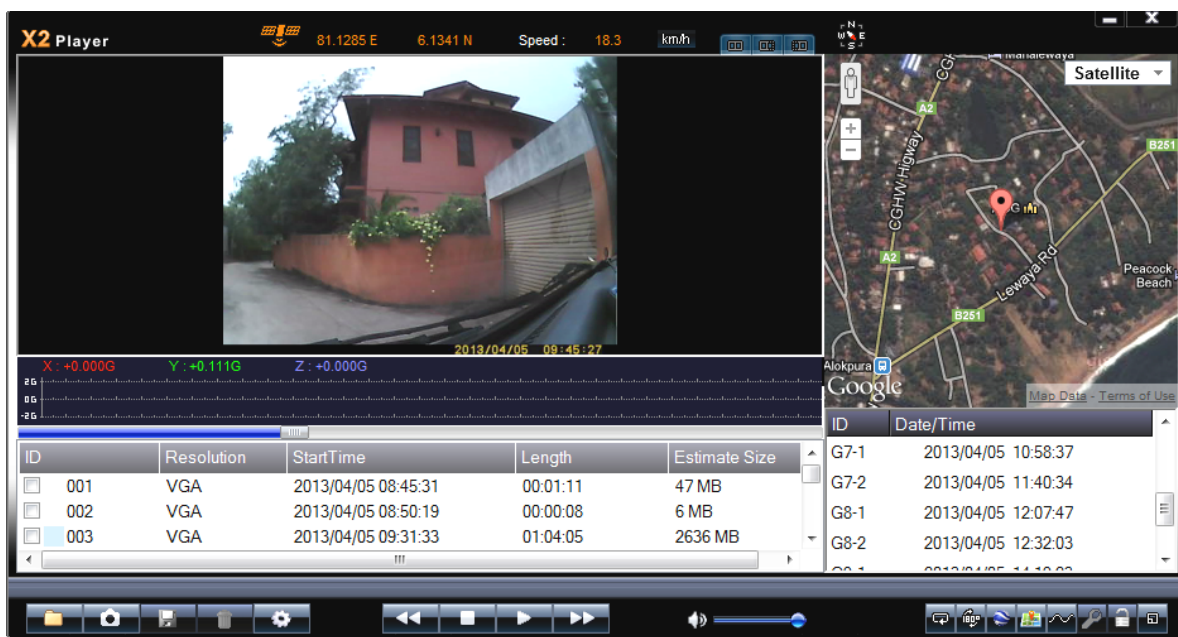


Figure 6.18 Example of building image and location capture along the survey route on 5 Apr 2013

## Population Distribution

Household location with number of residents is not available in Hambantota. Population per GN Division in 2012 from the Department of Census and Statistics of Sri Lanka was collected for further analysis and estimating household size. The information was extracted only for the area covered by the pilot site.

Table 6.5 Household and census data for the pilot area for each GN Division, Hambantota

GN Division	No. of households	Total Population	Gender		Age range		
			Male	Female	< 15 year	15-59 year	> 59 year
Hambantota East	221	978	572	451	272	624	82
Hambantota West	1757	7280	3548	3732	2016	4504	760
Sirobopura	1675	6487	3188	3299	2146	3877	464
Samodagama	432	1756	901	855	643	1006	107

Source: Department of Census and Statistics of Sri Lanka

## 6.1.5 Problems Encountered and Recommendations

### Building Footprint

Validation of the building footprint map at 1:5000 scale, collected from the Survey Department, against Google Earth satellite image taken in July 2012 showed mismatches in building location and deviation in building shapes in some areas. These are most probably due to temporal difference and the base image rectification method used for footprint map generation, as illustrated in Figure 6.19. The footprint map at 1:5000 scale shall be updated and missing buildings shall be filled-in using Google Earth as base image. Adjustment and digitization can be operated on Google Earth for consistency of image rectification.

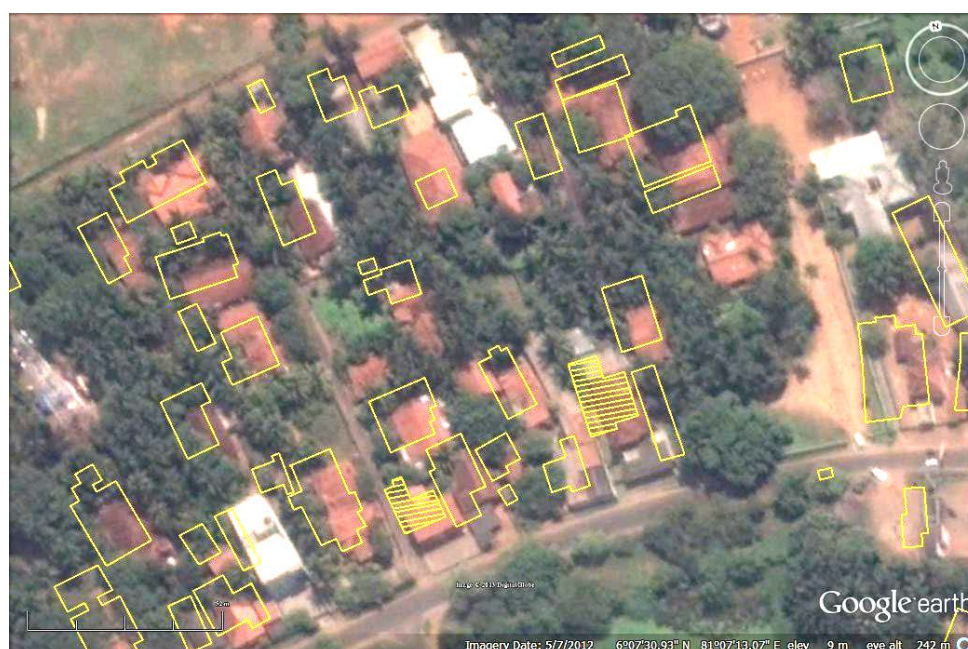


Figure 6.19 Building location mismatch with Google Earth image

### ***Linking Number of Residents to Building Footprint***

Since household location with number of residents is not available for Hambantota town, the average household size in each GN division was computed from the total population divided by the number of households. This average household size was equally distributed to all buildings in this area, except the critical facilities and public buildings where the number of residents is available from interview during field visit. Table 6.6 presents the household size estimates for the pilot area. It is observed that the average household size for all GN divisions is comparable at approximately 4 person/household.

Table 6.6 Average household size in each GN Division

GN Division	No. of households	Total Population	Average household size (persons/household)
Hambantota East	221	978	4.4
Hambantota West	1757	7280	4.1
Sirobopura	1675	6487	3.9
Samodagama	432	1756	4.1

### ***Identification of Building Construction Type and Usage with the use of Land Use Map***

Trees obstructed buildings during the video capture, making it difficult to interpret building construction type and usage, as illustrated in Figure 6.20. In this case, land use map may be employed to assist building type and usage identification. Detailed and large-scale land use map was collected from the Survey Department for facilitating building usage estimation.



Figure 6.20 Image showing buildings covered by trees

## 6.2 Assessment of People's Ability to Evacuate

Assessment of people's ability to evacuate is important for evacuation planning. An evacuation plan should be based on a hazard assessment by analyzing possible scenarios of hazards that could affect the target area, including procedures for safe transfer from the affected area into safe places. Hazard assessment requires knowledge of probable tsunami source, probability of occurrence, and tsunami characteristics at different places along the coast. In cases where past data are limited, numerical model of tsunami inundation can provide estimates of tsunami inundation profile and minimum time of tsunami arrival. This project shall apply INSPIRE's tsunami hazard assessment module for the assessment of tsunami hazard.

To assess people's ability to evacuate, the following questions have to be answered to support decision to evacuate in case of a tsunami event:

- a) *Where are the safe places for evacuation?*** In general, temporary gathering areas or shelters should be located outside tsunami affected areas at ground elevation higher than 15 m from the mean sea level. Public locations with adequate capacity can be selected as the gathering/assembly points. This evacuation process is called horizontal evacuation (horizontally evacuate away from inundated area). However, in areas that are too far from horizontal evacuation places, people may not have enough time to reach safe places before tsunami strikes. Vertical evacuation, which is the process of moving people to higher floor of buildings, may be considered instead. Public facilities, multi-storey buildings, available reserve space for temporary evacuation, and good quality construction buildings can be identified as vertical evacuation sites. Areas identified as shelters must be manageable, in terms of health, sanitation, and necessary facilities; adequate infrastructure should also be in place (DDPM, 2005).
- b) *Where are the potential evacuation routes?*** To define the best evacuation route from a given point, the safe and fastest path from that point to the safe places has to be searched. The fastest path is not always the shortest path, but the concept of accessibility is calculated on a "***cost surface***" of the area. The cost surface consists of a regular two-dimension grid, where each cell represents the time required to cross the cell. Physical condition of the area influences travel cost, e.g. a flat road allows faster travel speed (lower cost) than one with dense vegetation. For this reason, calculation of distance between two points considers not only the geometric distance, but also the cost to move along a particular path. Cost Weight Distance (CWD), therefore, replaces geometric distance. Once the cost of all cells is defined, CWD between two given points can be calculated for the best or fastest path. Instead of defining the CWD surface as the distance between starting point and each cell in the cost surface domain, it is possible to define it as the distance between each cell and the safe areas, which can be more than one. The path with the lowest accumulated cost from each cell to the safe place gives the fastest route to the closest evacuation point. The escape route from every point within the domain can then be computed (ADPC, 2007).
- c) *Are shelter capacities enough to accommodate evacuees?*** By CWD method, it is possible to define the area in each safe place. Disaster managers can understand if the safe place is big enough to accommodate evacuees from a subdivision and estimate the supplies needed during an event.
- d) *Are people in the risk area able to reach the safe place within the given time?*** Since the safe place can be designated to each subdivision and cost grid is known for the entire area, required evacuation time from any point in the area can be calculated. Disaster managers can assess whether people have enough time to reach the safe place before the tsunami strikes.

## 6.2.1 Methodology

ESCAPE (<http://escape.rimes.int>), a tool developed at RIMES, is used in this project to support evacuation planning. The system provides information on the fastest evacuation path and direction toward the shelters. Evacuation basins partition the threatened area into several zones, which can be accommodated by the designated safe places/shelters. Capacity of shelters can be evaluated if the number of people in the risk areas is identified. Evacuation speed and capability consider several factors, including topographic condition, land cover, location of critical facilities, and population density, age and gender.

A spatial information system shall be developed for Hambantota from the dataset collected from local government agencies and field survey (Table 6.7) to support planning and development of counter-measures to ensure effective and safe evacuation of people from threatened locations, before the tsunami strikes.

Table 6.7 List of data collected for tsunami evacuation planning

Data Type	Data Source	Analysis Details
1. Land use/ Land cover	Land use map from the Survey Department at 1:10,000 scale	<ul style="list-style-type: none"> <li>○ BLTPA: Built-up area</li> <li>○ BRRNA: Barren land</li> <li>○ CHENA: Chena</li> <li>○ HOMSA: Homesteads/ garden</li> <li>○ HYDRA: Water body</li> <li>○ MRSHA: Marsh</li> <li>○ OTHRA: Other cultivation</li> <li>○ PDDYA: Paddy</li> <li>○ QRRYA: Quarry</li> <li>○ SCRBA: Scrub land</li> <li>○ SPRSA: Sparsely used crop land</li> <li>○ SWMPA: Swamp</li> <li>○ UNCLA: Unclassified</li> </ul>
2. Topographic slope	<ul style="list-style-type: none"> <li>○ To be derived from field survey data by topographic survey team</li> </ul>	<ul style="list-style-type: none"> <li>○ 0%</li> <li>○ 0-5%</li> <li>○ 5-15%</li> <li>○ 15-30%</li> <li>○ 30-45%</li> <li>○ &gt;45%</li> </ul>
3. Road network	<ul style="list-style-type: none"> <li>○ Transportation network map from the Survey Department at 1:10,000 scale</li> <li>○ Field survey</li> </ul>	<ul style="list-style-type: none"> <li>○ Highway</li> <li>○ Local road</li> <li>○ Walkway to safe areas</li> </ul>
4. Potential safe areas for horizontal evacuation	<ul style="list-style-type: none"> <li>○ Field survey by exposure survey team</li> </ul>	<ul style="list-style-type: none"> <li>○ Coordinates</li> <li>○ Occupancy/ Capacity</li> </ul>
5. Potential safe areas for vertical evacuation	<ul style="list-style-type: none"> <li>○ Field survey by exposure survey team</li> </ul>	<ul style="list-style-type: none"> <li>○ Coordinates</li> <li>○ Capacity</li> </ul>
6. Critical facilities and supplies during emergency	<ul style="list-style-type: none"> <li>○ Field survey by exposure survey team</li> </ul>	<ul style="list-style-type: none"> <li>○ Coordinates</li> <li>○ Capacity</li> <li>○ Operational plan</li> </ul>
7. Population density, age and gender	<ul style="list-style-type: none"> <li>○ Interview of GN Division head</li> <li>○ Census data from the Department of Census and Statistics, Sri Lanka</li> </ul>	<ul style="list-style-type: none"> <li>○ Total population</li> <li>○ Age/gender ratio</li> </ul>
8. Administration boundary for planning and disaster management	<ul style="list-style-type: none"> <li>○ Hambantota city boundary map from the Survey Department at 1:1,000 scale</li> <li>○ GN Division map from Survey Department (district survey office)</li> </ul>	<ul style="list-style-type: none"> <li>○ GN division boundary</li> <li>○ Land parcels</li> </ul>

## 6.2.2 Data and Equipment

### *Handheld GPS and digital camera*

Handheld GPS and digital camera (Figure 6.21) were used to record geographical location and photos of potential safe places and critical facilities.



Figure 6.21 Handheld GPS and camera for recording location and photos of potential safe places and critical facilities

Table 6.8 Data, equipment and personnel for the field survey

Activity (Duration)	Data Used	Equipment Used	Personnel
Site visit to evacuation shelter, critical facilities, and supplies during emergency	Local map (captured from Google Earth) Building survey form	Survey Vehicle Digital camera Handheld GPS	Driver Local guide Recorder

## 6.2.3 Results and Discussion

### *Land Use Map and Transportation Network*

Land use map and transportation network layer (scale 1:10,000) were collected from the Survey Department for Hambantota town, as shown in Figure 6.22.

### *Evacuation Shelters, Critical Facilities and Supplies during Emergency*

Data on evacuation shelters, critical facilities, and supplies during emergency were collected during the field visit, as shown in Table 6.9 and Figure 6.23. The designated evacuation shelters are places that have already been officially identified as evacuation shelters. Under this project, potential evacuation shelters shall be identified, i.e. places that were not affected by the Indian Ocean tsunami in 2004, are easily accessible, and with available evacuation facilities.

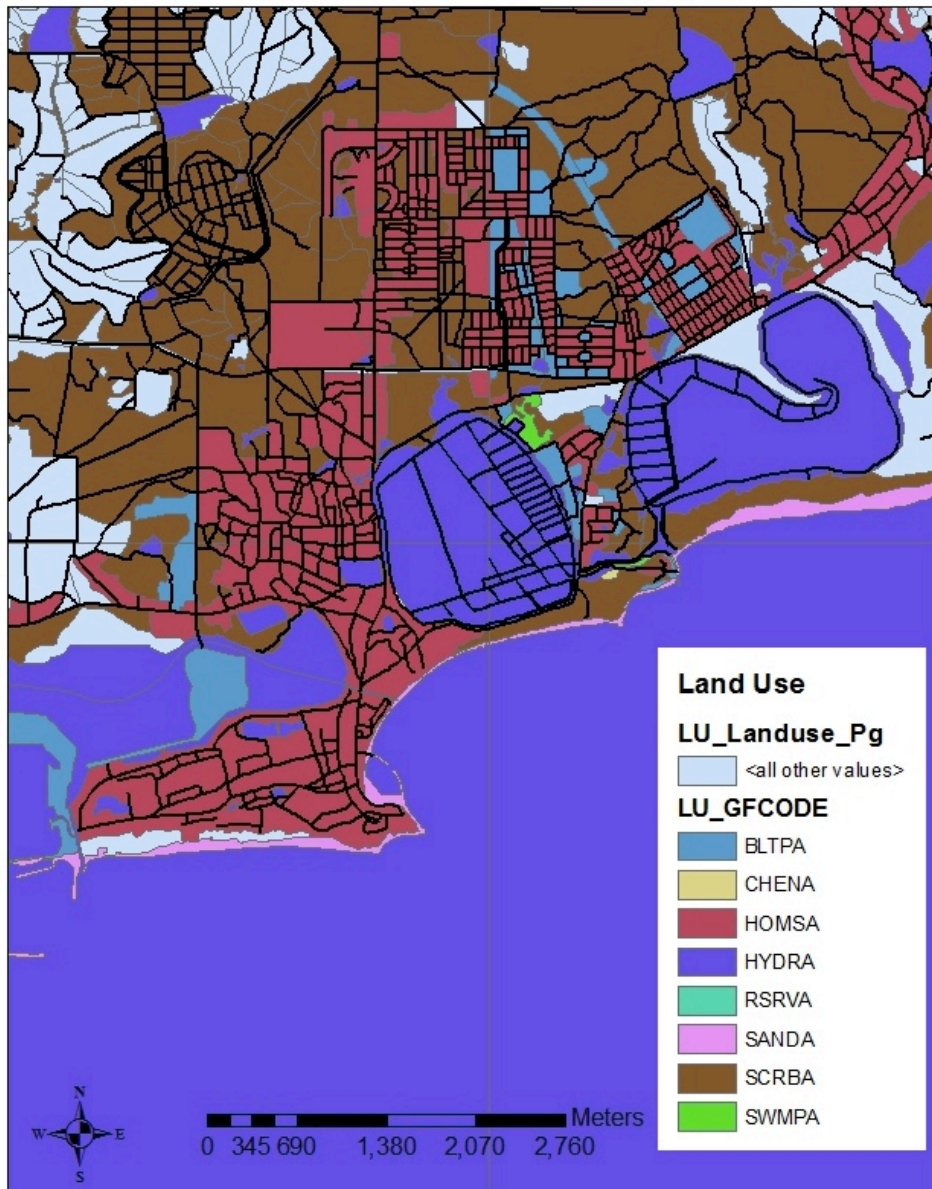






Figure 6.22 Land use map and transportation network

Table 6.9 Inventory of evacuation shelters, critical facilities and supplies during emergency

Long	Lat	Bldg. ID	Code	Place name	Photo
<b>Designated Evacuation Shelters by DMC</b>					
81.12339	6.14149	1	SHLT_1	Al Masjidun Noor Jumma Mosque	
81.12545	6.12572	14	SHLT_2	Police Station	
81.12767	6.12279	17	SHLT_3	Maha Naga Mandiraya	
81.12076	6.12565	20	SHLT_4	Nimba Aramaya(temple)	
81.11996	6.12629	21	SHLT_5	Recreation Ground	

Long	Lat	Bldg. ID	Code	Place name	Photo
<b>Potential Evacuation Shelters</b>					
81.12472	6.12639	6	PT_SHLT_01	Zahira College	
81.12261	6.12490	13	PT_SHLT_02	Hambantota Arabic College	
81.12147	6.14048	27	PT_SHLT_03	Samodagama Primary School	
<b>Critical Facilities and Supplies during emergency</b>					
81.12250	6.12694	8	HOSPITAL	District Hospital - Hambantota	

Long	Lat	Bldg. ID	Code	Place name	Photo
81.12322	6.12508	11	WATER_01	Water Tank- Hambantota-West	 A photograph of a tall, cylindrical water tank structure with a concrete frame and a large circular tank at the top. The structure is supported by several vertical pillars and has a utility pole with wires in the foreground.
81.12768	6.12210	-	WATER_02	Water Tank- Hambantota-East	
81.12313	6.12491	12	POWER	Electricity Board- Sub Station	 A photograph of a small, yellow building with a tiled roof, identified as an electricity substation. There are green plants and a sign in the foreground. A timestamp '2019-04-29' is visible in the bottom right corner of the photo.
81.12581	6.12569	15	BUS_ST	Main Bus stand	 A photograph of a bus stand area. A yellow and blue bus is visible, along with a person standing near a railing. The structure has a sign above the entrance.

Long	Lat	Bldg. ID	Code	Place name	Photo
81.12667	6.12370	16	TELECOM	Telecom Office- Hambantota	
81.12620	6.12469	31	PETRO_1	P. Weerasinghe Ceypetro (Gov. gas station)	
81.12117	6.12464	32	PETRO_2	IOC Weldisi Pvt.Ltd (Private gas station)	
<b>Early Warning Siren</b>					
81.12545	6.12572	14	SIREN_1	Police Station (1.5 km effective radius)	

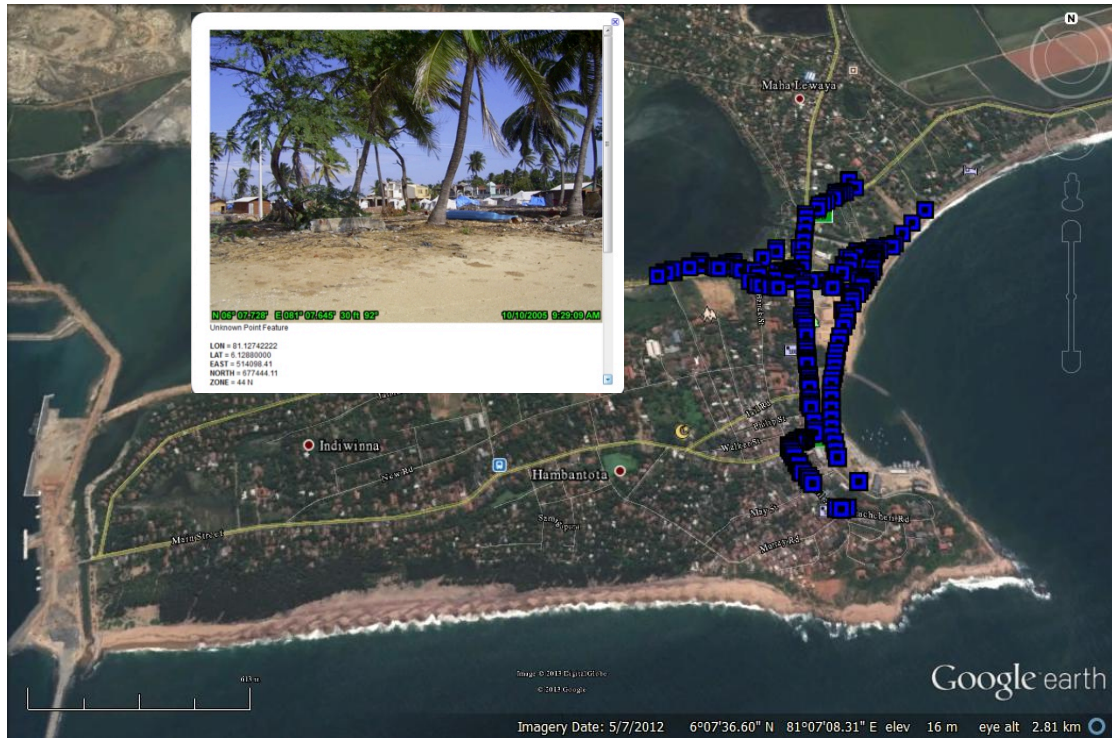
Long	Lat	Bldg. ID	Code	Place name	Photo
<b>Telecom Tower</b>					
81.11372	6.12530		TT_1	TelecomTower	
81.12754	6.13328		TT_2	TelecomTower	
81.12523	6.12990		TT_3	TelecomTower	
81.13889	6.12527		TT_4	TelecomTower	



Figure 6.23 Map of Evacuation shelters, critical facilities and supplies during emergency

***Building and Site Condition Images***

Building and site condition images, taken in October 2010 by the Survey Department and the Joint Research Center (JRC, European Commission) during the Tsunami Damage Assessment project using very high resolution images, were collected for use under the current project. Figure 6.24 presents the locations for which building and site condition images are available.



Source: Survey Department

Figure 6.24 Locations and example (inset) of images taken during the Tsunami Damage Assessment project

## 6.2.4 Problems Encountered and Recommendations

### *Potential Evacuation Route and Safe Place near the Southeastern Area*

It was observed during the field visit that the southeastern coast of Hambantota has a city bus terminal, fishing harbor, and a number of commercial and business entities. The closest designated tsunami shelters are the police station (SHLT\_2) and Maha Naga Mandiraya (SHLT\_3). While the police station (SHLT\_2) has no record of tsunami impact during the 2004 Indian Ocean tsunami, its location, however, is just behind the bus terminal, which suffered severe damages with recorded tsunami height of 12 feet. In view of this, this shelter could be re-examined, using detailed land elevation data. The station also hosts an early warning siren. Vertical evacuation is not recommended in Hambantota since lead time before tsunami arrival is long enough for horizontal evacuation.

The other designated shelter, Maha Naga Mandiraya (SHLT\_3), is located in a high land area and is able to accommodate a number of people. Access roads to this shelter are available, since it was the previous DS office complex. A small walking path provides a shortcut access to the area (Figures 6.25 and 6.26). However, if this route will be used, stair way should be expanded and maintained.



Figure 6.25 Stair way connected seaside area to the high ground near fishing harbor



Figure 6.26 Red line shown the location of stair way which is the shortcut to the high ground

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**INFORMATION COLLECTED FROM**  
**HAMBANTOTA DISASTER MANAGEMENT CENTER**

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**Contact person:** KKH Ravindra  
**Contact detail:** Tel: 0773957875  
Email: harsharavindra39@yahoo.com

**I. Disaster Management Policy and Initiative**

Referring to the current guidelines for disaster management provided by the government, the process information flow during disaster includes:

1. Information to the Government Agent
2. Information to DG-DMC
3. Information to Divisional Secretary
4. Information to Grama Niladhari
5. Information to Police Station
6. Taking action according to the early instruction given by Assistant Director (District) –DMC to Grama Niladhari.

Working groups are:

- a) Early warning and distribution
- b) Search and rescue
- c) Camp management & coordination
- d) Health & welfare
- e) Patrol & security

**II. Major hazards in the area**

Elephant attack, flood, drought, strong wind

**III. Specific fund for Disaster Management**

On request

**IV. Human Resource and Equipment for Rescue**

- Staffs involved in the Unit: 20 staffs
- Equipment that the municipality currently has for rescue operation after any disaster: On request
- Are equipment sufficient for rescue operation? Not sufficient

Sectional Damage Report - Hambantota Ds Division			
Sector	Relavant Institute	Damage Buildings	Estimated Damages (Rs. Million)
Telecommunication	Sri Lanka Telecom	Outside Plant	80
		Buildings	15
		Transmission Plant	20
		Power Plant	10
		Switching Plant	120
		Tower	15
		Vehicles	5
		<b>TOTAL</b>	<b>265</b>
Tourism	Hotels & Resturent	Peakok Beach Hotel	250
		Seaspray Hotel	
		Jade Grenn Restaurant	
		<b>TOTAL</b>	<b>250</b>
Roads & Bridges	Roads	Hambantota Kachcheriya Road	2.5
		Hambantota Hospital Road	0.8
		Mahalewaya Hambantota Road	230
		<b>TOTAL</b>	<b>233.3</b>
Irrigation Board	Irigation Department	Curcuit Bunglow	2.5
		Vehicles	1.5
		<b>TOTAL</b>	<b>4</b>
Commercial (According To UDA)		Houses	562
		Commercial Buildings	163
		Lands	53
		Hotels	3
		Private Office	2
		Government Office	17
		<b>TOTAL</b>	<b>800</b>
Education	St.Meris College	Buidings	0.075
		School Theator	0.675
		Toilets	0.145
		Wall	0.75
		<b>TOTAL</b>	<b>1.645</b>
	Sazira College	Main Hall	1.6
		Thee Stories Building	8.5
		Single Floor Building	1.8
		<b>TOTAL</b>	<b>15.19</b>
Water Board	Water Board - Hambantota	House Connection	3.6
		Distribution & Pumping	0.42
		Bridge Crossing	0.02
		Vehicles	0.03
		<b>TOTAL</b>	<b>4.07</b>
Agriculture	Agrarian Service	Paddy Land - Bandagiriya	3.5
		Other Crops	0.83
		<b>TOTAL</b>	<b>4.33</b>
Co-operative		Main Office of Society	8.2
		Paddy Miller & the Store	4.8
		Seminar Room with Equipment	6.5
		Vehicles	1.1
		Rural Devisional Bank Office	0.799
		Medical Centre	0.764
		Stors	1.03
		Filling Centre	1.14
		Rented Building Complex	1.5
		Unrecovered Payment	15.8
		<b>TOTAL</b>	<b>41.633</b>
Commercial	Private Premises	Whole Sale	46.7
		Construction	12.1
		Services	75

Population - 2010 (Nationality)					
Sinhala	Srilankan Tamil	Burger	Malle	Sri Lankan Yonaka	Total
45,786	746	112	6,923	3,816	<b>57,383</b>
Population - 2012 (Gender & Age)					
Gender		Below 15	Between 15-59	60 & Above 60	Total Population
Male	Female	16,061	35,528	5,464	<b>57,053</b>
28,668	28,385				

Tsunami Damage Houses 2004 event - DS Hambantota					
In Side		Out Side		Total	
Fully	Partially	Fully	Partially	Fully	Partially
232	77	278	130	<b>510</b>	<b>207</b>

Tsunami Effected Personals	
No. of effected Families	No. of effected Personals
3,500	13,208

Death and missing list from tsunami diaster in Hambantota district	
Type of Death Bodies	Number of death bodies
Male	847
Female	1215
Children	350
Foregone	42
Total	2454
Number of missing personnel	616
Total affected	3070

Tsunami Affected Personnels in DS division		
DS Division	Number of affect families	Number of affected persone
Tangalle	5591	21348
Ambalantota	2452	10036
Hambantota	3500	13208
Tissamanharamaya	1873	7236
Beliatta	266	1028
Weeraketiya	87	348
Walasmulla	25	89
Katuwana	62	224
Okewela	24	83
Augunakolapelessa	82	315
Sooriyawewa	112	457
Lunugamwehera	158	683
Total	14232	55055

Damaged Houses (Inside/Outside -Buffer zone)						
DS Division	Inside		Outside		Total	
	Fully	Partially	Fully	Partially	Fully	Partially
Tangalle	419	277	202	653	621	930
Ambalantota	58	7	78	223	136	230
Hambantota	232	77	278	130	510	207
Tissamaharamaya	43	12	94	20	137	32
	752	373	652	1026	1404	1399
						2803

**Tsunami Affected Hotel - Hambantota District**

SER No.	Hotel name and address	GS Division	Contact No.
50	Oenser beech hotel sisilasagame hambantota	Hambantota	472206507
51	Fun bech restturant layan rathnawera	Hambantota	777107168
52	Chamila gest vhouse rathna kumara	Hambantota	473489338
53	Pecok bech hotel hambantota	Hambantota	475671000
54	Jed greenrest hambantota	Hambantota	472220692
55	Kalana restaurant hambantota	Hambantota	712689924
56	Chamee rest hambantota	Hambantota	713647857

**Tsunami Affected School - Hambantota District**

SER No.	Name of school	GS Division	Contact No.
01	H/Bondala K.V.	Hambantota	776066500
02	H/Shantha Mery National School	Hambantota	0713120100/0472220880
03	H/Samodagama K.V.	Hambantota	718079946
04	H/Udamala K.V.	Hambantota	718020438
05	H/Pollemalala K.V.	Hambantota	718307078
06	H/Hungama Vijayaba N.V.	Hambantota	714496391
07	H/Theraputta Primary School	Hambantota	0772029019/0472226036
08	H/Magama M.V.	Hambantota	0718276535/0472225460
09	H/Andaragasyaya Primary School	Hambantota	0718096282/0477203310
10	H/Kirindagama Muslim M.V.	Hambantota	7144770256
11	H/Kirindagama	Hambantota	718577515
12	Primary School	Hambantota	485717494

Number of damaged housing and non housing building units due to tsunami 2004 - Hambantota District												
Affected DS Division	Housing Units				Non Housing Units				Total Building Units			
	Completely Damage	Partially Damage (Unusable)	Partially Damage (Usable)	Total	Completely Damage	Partially Damage (Unusable)	Partially Damage (Usable)	Total	Completely Damage	Partially Damage (Unusable)	Partially Damaged (Usable)	Total
Tissamaharamaya	132	26	52	210	105	4	9	118	237	30	61	328
Hambantota	549	55	178	782	225	23	92	340	774	78	270	1122
Ambalantota	104	21	65	190	12	0	2	14	116	21	67	204
Tangalle	433	202	724	1359	96	31	191	318	529	233	915	1677
<b>Total</b>	<b>1218</b>	<b>304</b>	<b>1019</b>	<b>2541</b>	<b>438</b>	<b>58</b>	<b>294</b>	<b>790</b>	<b>1656</b>	<b>362</b>	<b>1313</b>	<b>3331</b>



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