Delft3D model based investigation of the possible existence of large scale circulation patterns along the North coast of Sri Lanka (Phase 1 Report)

August 2016

Sri: Northern Province Sustainable Fisheries Development Project

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Project :
COMPREHENSIVE MODELLING OF LONGSHORE SEDIMENT TRANSPORT AT PESALAI, GURUNAGAR, POINT PEDRO AND MULLAITIVU, SRI LANKA

August 2016

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Executive Summary

In Nov. 2015 , under the Asian Development Bank (ADB) – UNESCO-IHE partnership, UNESCO-IHE was invited to to perform a detailed, state-of-the-art numerical modelling study to comprehensively assess the present-day longshore sediment transport regimes along the North coast of Sri Lanka to inform the planned construction of four fishery harbours along the North coast of Sri Lanka.

The overall study consists of two Phases. Phase 1 will develop a coarse hydrodynamic model to simulate the dominant large scale wave, wind and tide driven circulation patterns and use those results to design and implement a bathymetric survey of the 4 study areas (Pesalai, Gurunagar, Point Pedro and Mullaitivu) which will feed into Phase 2. Phase 2 will perform detailed coastal sediment transport modelling for the 4 sites, and assess the prevailing alongshore sediment transport regime in the 4 study areas.

This report is the deliverable of the first phase of this project and documents the application of coarse grid Delft3D model to determine large scale tidal and wave driven circulation patterns in the vicinity of the 4 study areas.

The globally available data for Bathymetry, Tide, Wind and Wave have been collected and a course (500 m x 500m) Delft3D model is setup for the north coast of Sri Lanka. This model is used to carry out a simulation for a complete one year simulation (2015). The results show that :

- The main driving forces for large scale currents around the north coast of Sri Lanka are wind and tide.
- Maximum current velocity is around 0.8 m/s which occurs over Adam's bridge during the south west monsoon.

Based on these observations, it is concluded that there are no significant and persistent large scale circulation patterns that might affect sediment transport in the vicinity of the proposed fishery harbours. Therefore, to setup the detailed Delf3D models in Phase 2 of the study, it was deemed sufficient to collect locally concentrated bathymetric data at the proposed harbour sites. These surveys were completed in mid-June. The raw data of surveyed bathymetries for 4 study sites are shown in Figure E1.

Furthermore, to capture the possible effects of far field wave refraction, it is recommended that sub-regional models using globally available data be setup to obtain boundary forcing for the detailed local Delft3D models for the study sites.

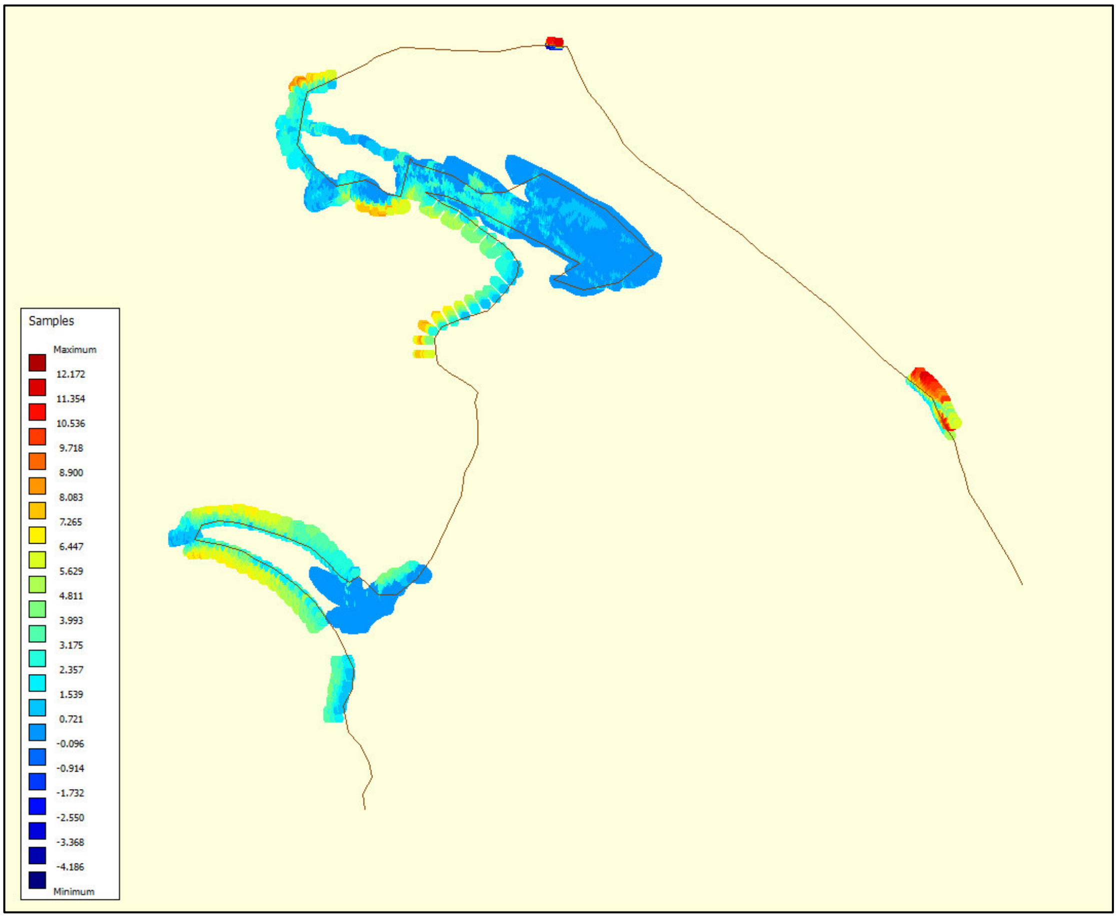


Figure E1. Raw data of surveyed bathymetries

1. Introduction

In November 2015 , under the Asian Development Bank (ADB) - UNESCO-IHE partnership agreement, UNESCO-IHE was invited to to perform a detailed, state-of-the-art numerical modelling study to comprehensively assess the present-day longshore sediment transport regimes along the North coast of Sri Lanka to inform the planned construction of four fishery harbours along the North coast of Sri Lanka. The Sri Lanka government has no in-house expertise to undertake the sophisticated numerical modelling required to obtain such longshore sediment transport estimates. Therefore the government has requested the ADB to facilitate the study via the ADB-UNESCO-IHE Knowledge Partnership.

The proposed construction of fishery harbours at Pesalai, Gurunagar, Point Pedro and Mullaitivu will inevitably involve the construction of jetties and/or breakwaters which will interrupt the natural wave driven sediment transport along the coastline. Both the functionality of the harbours and the adjacent coast may face severe negative impacts if the design of the harbour jetties/breakwaters does not take into account the natural prevailing alongshore sediment transport rates in their vicinity. The main potential negative impacts that may be felt are; (a) rapid shoaling of the harbour entrance and basin, and (2) severe wave driven erosion of the adjacent coastline. Oluvil and Kirinda harbours which were recently constructed without due consideration of the prevailing alongshore sediment transport regime in the area are good examples of the manifestation of such negative impacts. To ensure that the proposed harbours at Pesalai, Gurunagar, Point Pedro and Mullaitivu do not face the same fate, it is therefore essential to have reliable estimates of prevailing alongshore sediment transport rates in these areas. The proposed sediment transport study will provide these estimates using a state-of-the-art coastal numerical model.

The overall study consists of two Phases. Phase 1 will develop a coarse hydrodynamic model to simulate the dominant large scale wave, wind and tide driven circulation patterns and use those results to design and implement a bathymetric survey of the 4 study areas (Pesalai, Gurunagar, Point Pedro and Mullaitivu) which will feed into Phase 2. Phase 2 will perform detailed coastal sediment transport modelling for the 4 sites, and assess the prevailing alongshore sediment transport regime in the 4 study areas.

This report is the deliverable of the first phase of this project and documents the application of coarse grid Delft3D model to determine large scale tidal and wave driven circulation patterns in the vicinity of the 4 study areas (Pesalai, Gurunagar, Point Pedro and Mullaitivu) and determines the domains that need to be modelled in detail at each site. This report also presents the bathymetry surveys carried out to initialise the detailed models (in Phase 2) of the study areas.

2. Study Area

This report focusses on the modelling efforts to investigate the existence of large scale circulation patterns in the broad area of interest. The study area which is subjected to the numerical simulation in this part of study is the northern part of Sri Lanka. Figure 1 shows the extent of study area.

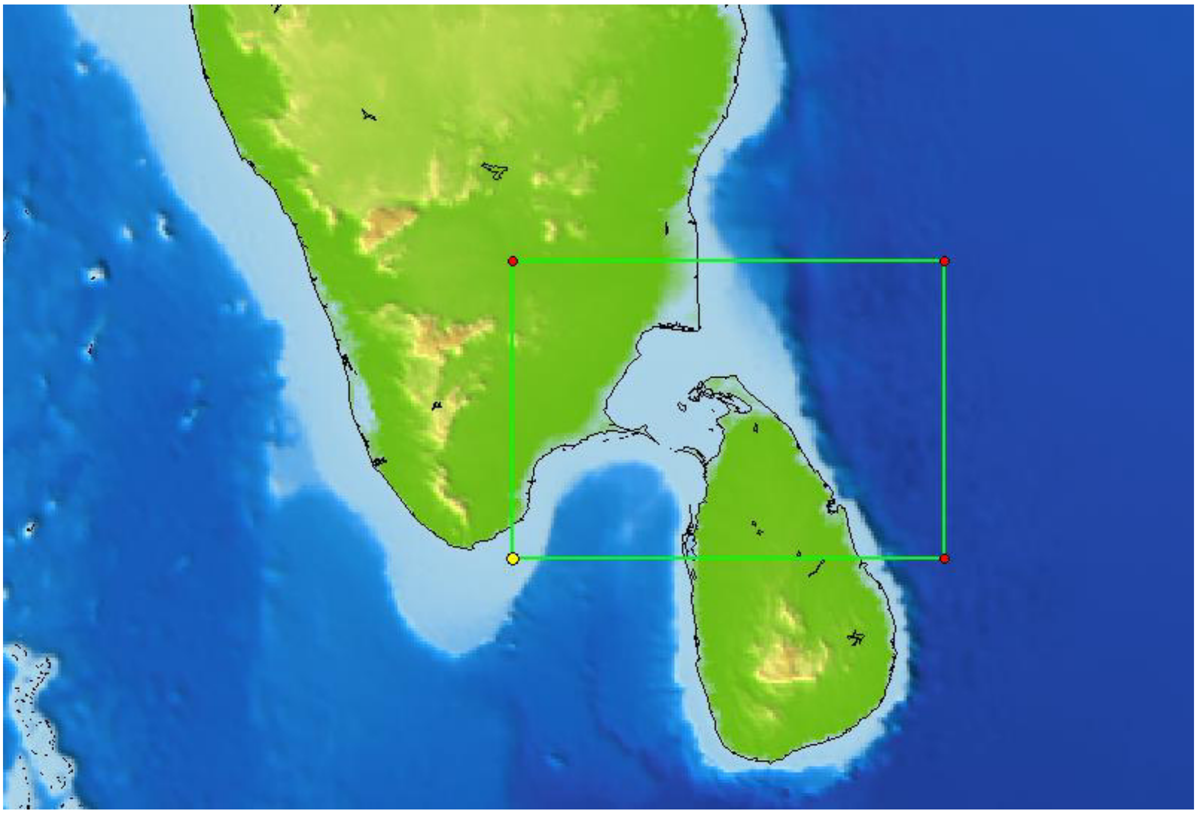


Figure 1. Northern coastal area of Sri Lanka and the domain of the large scale model (green rectangle).

3. Available data

In order to setup a large scale model for the study area different types of data are needed. Due to the scale of the model, in this project we have relied mostly on freely available global data which have been used before in modelling projects around Sri Lanka. These data are summarized below.

3.1. Bathymetry

For the bathymetry, data from General Bathymetric Chart of the Oceans (GEBCO-BODC, 2003), which is a publicly available bathymetry of the oceans, were used. GEBCO data can be projected on grids with different resolution. These data are not very accurate close to the coastline and on the continental shelf, but for the study presented in this report, it is sufficiently accurate for modelling the large scale wave, wind and tide driven circulations. (http://www.gebco.net – last visited 01.May.2016)

3.2. Tides

There are two different sources for tide data; local tidal stations and global tidal models. Figure 2 shows all the International hydrographic Organization (IHO) tidal stations around the study area and Figure 3 shows an example of tidal data for the Point Pedro station for one month.

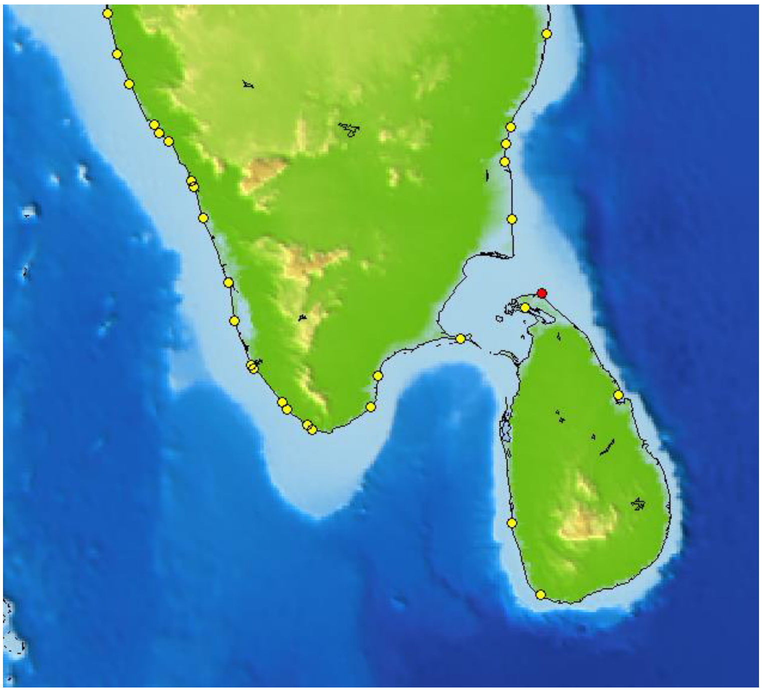
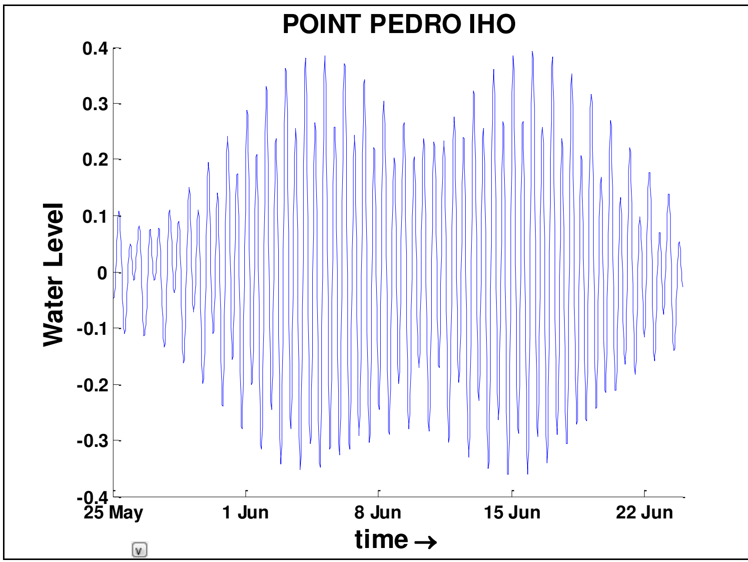


Figure 2. International hydrographic Organization (IHO) tidal stations around the study area



	Amp. (m)	Phase (deg)
M2	0.213	82.5874
S2	0.094	105
K2	0.024	104.5482
N2	0.079	75.5815
K1	0.052	245.2741
O1	0.009	286.3133
P1	0.018	245.7259

Figure 3. Example of tidal data (signal and component) for the Point Pedro station for one month.

From these data it is observed that, the main sea level variation in the study area is due to the semi diurnal tides with an amplitude of 0.10 – 0.25 m. M2 is the dominant tidal constituent. The spring tide range recorded in the Bay of Bengal is around 2.4 m while it is about 0.6 m along the western coast of Sri Lanka. This range appears to be smaller in the northern region. The tidal phases between east coast and west coasts of Sri Lanka show a significant phase difference with a rapid change of phase along the southern coast.

The other source for tidal data used in this study is the global models of Oregon state university (Egbert and Erofeeva, 2002), which is freely available at http://volkov.oce.orst.edu/tides/ (last visited on 1.May.2016). They provide two sets of models; the global tidal model TPXO providing simulated tidal data around the globe, and a collection of models for regional and local tides. Figure 4 shows the areas that the latter set of models cover. One of these regional models is setup for Bay of Bangal at a resolution of 1/30 deg (3.5 km)

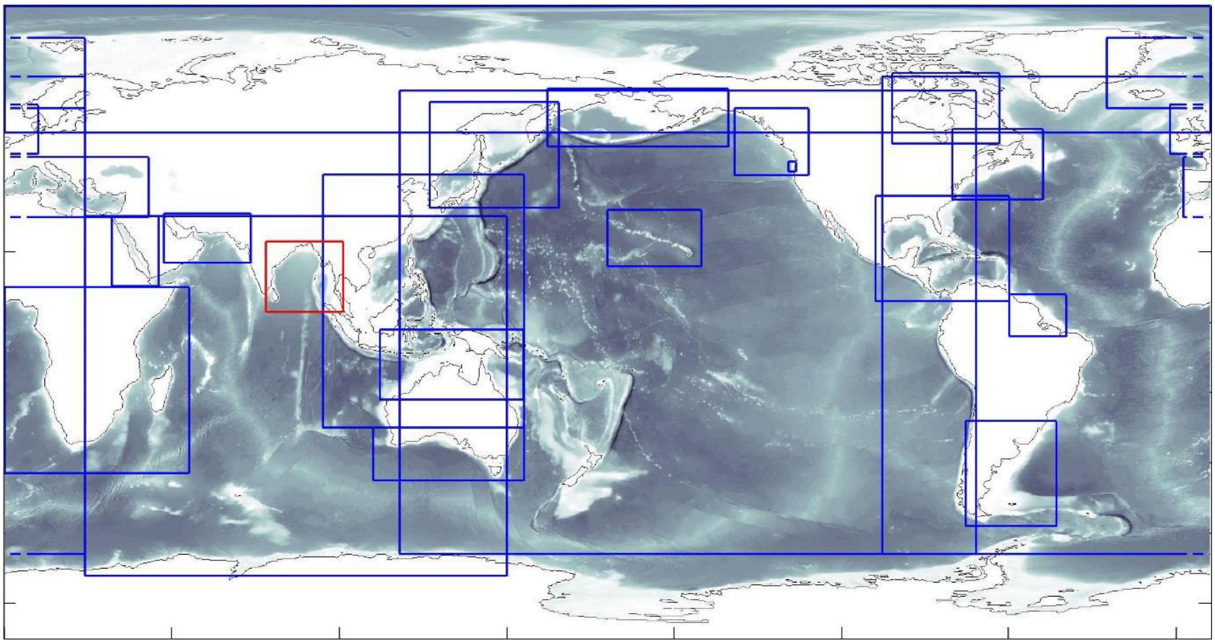


Figure 4. OSU Regional tidal models from http://volkov.oce.orst.edu/tides/region.html (last visited 1.May.2016)

In this study, IHO tidal stations, TPXO Ver. 7.2 and the regional tidal model of Bay of Bangal were used for tidal data.

3.3. Winds and Waves

For wind and wave data, ERA- Interim, which is a global atmospheric reanalysis from 1979 (Berrisford et al. 2011) on a grid of 0.75 x 0.75 deg over the study area was used. Figure 5 shows the grid of wind and wave climate superimposed on the study domain and Figure 6 shows the 2015 wind rose for the upper right corner of the wind grid. The same data were extracted for all the grid points shown in Figure 5.

Wind speed over the study area appears to vary between 1-12 m/s and there are two different incident wind directions; winds incident from 10-60° (i.e. north east direction) and from 240-280° (i.e. south west direction) with the winds from the latter direction occurring more frequently. These two wind directions are associated with the north-east and south-west monsoons respectively.

Figure 7 illustrates the wave rose for the wave data extracted at point * shown in Figure 5. Significant wave height, mean wave direction, and mean wave period were extracted from these data for model forcing (see below).

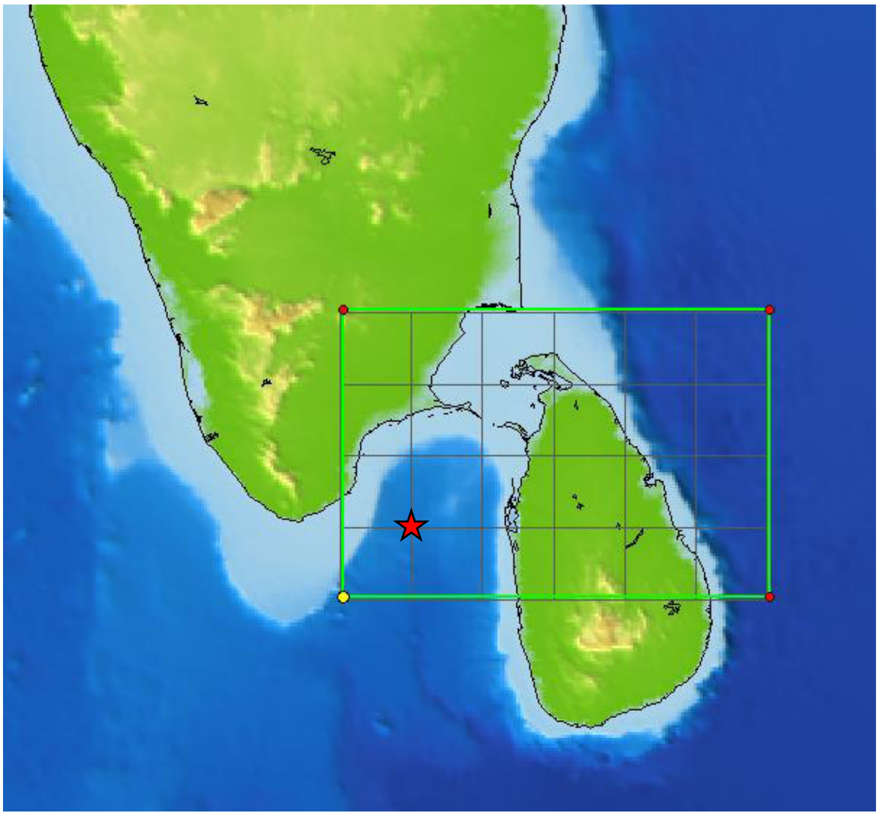


Figure 5. Grid of extracted wind and wave climate from ERA- Interim global models

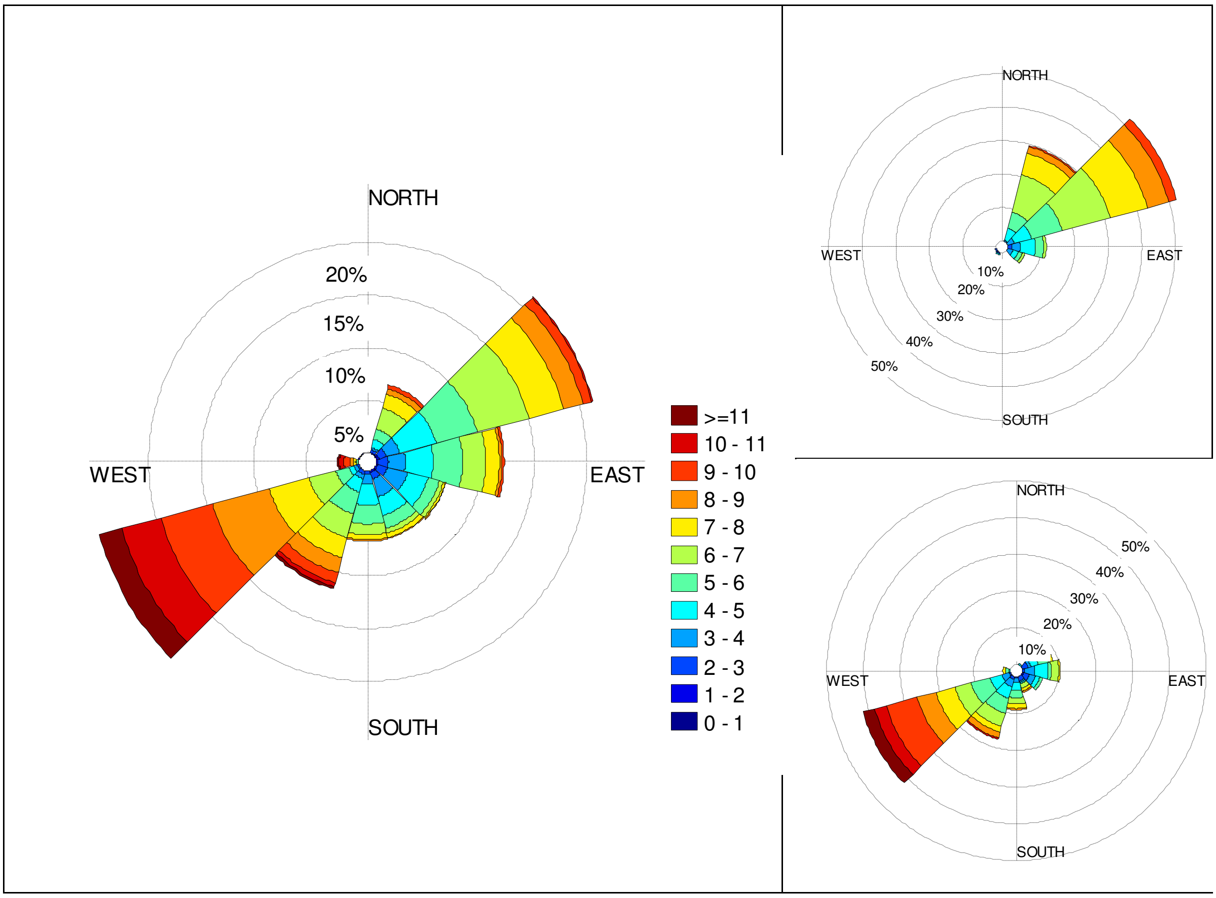


Figure 6. Year 2015 Wind rose for upper right corner of the grid shown in Figure 5– left : entire year, top right : January (NE monsoon) , bottom right : May (SW monsoon)

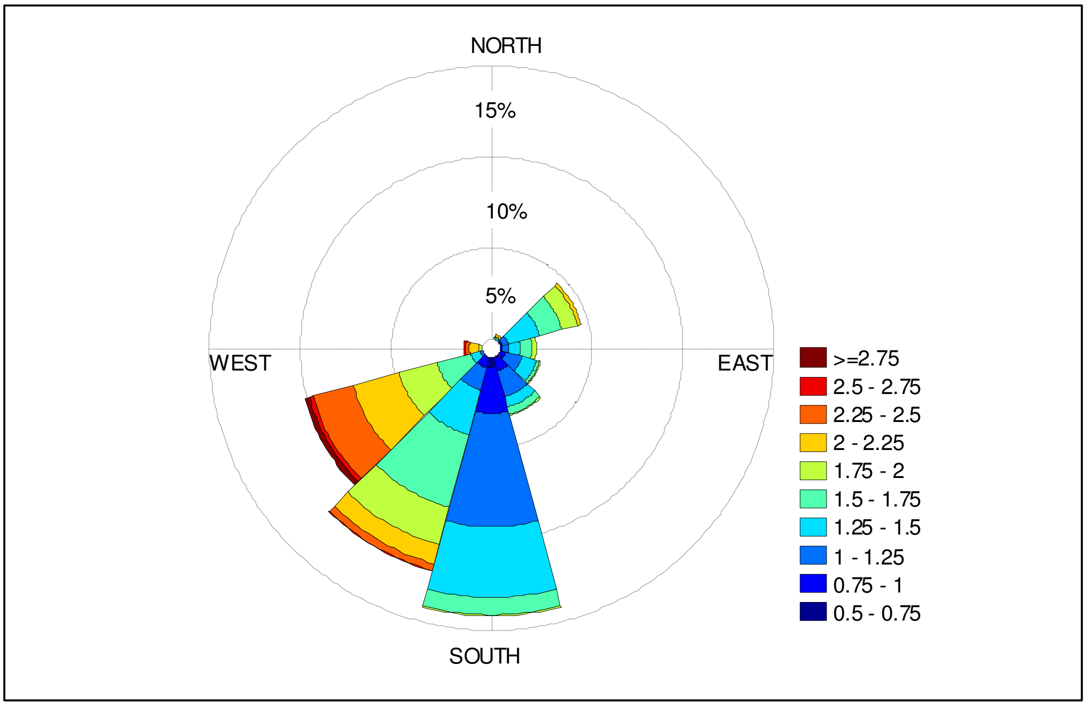


Figure 7. Wave rose of the waves extracted at point * in Figure 5.

4. Model setup

The model used in this study is a 2DH (depth-averaged) version of Delft3D (Lesser et al., 2004), in which there are two numerical modules interacting with each other : FLOW and WAVE. The FLOW module is a numerical solver which is based on finite differences and solves the unsteady shallow-water equations. The system of equations consists of the horizontal momentum equations including wave and wind generated forces, continuity equation, and a turbulence closure model. In order to add the wave forcing to the shallow water equations of the FLOW module, this module interacts with the WAVE module. The Delft3D WAVE module (third generation SWAN - Simulating WAves Nearshore - model (Booij et al., 1999)) is used to simulate the evolution of random short-crested waves in coastal zones. This module interacts with the FLOW module in an online manner meaning that initially, the WAVE module runs using the initial conditions and forcing boundary conditions. Then the resulting wave generated forces are communicated to the FLOW module. Then the FLOW module, including these wave generated forces, runs for a user specified number of time steps. After the FLOW computation is finished for these time steps, the updated, water levels, and flow field are fed back to the WAVE module.

4.1. Grid and bathymetry

To achieve a reasonable computational time and to be able to simulate the phenomena desired in this study, a 500 x 500 m rectangular grid was defined over the large scale study area shown in Fig. 8. The computational grid in this model covers the area of interest, i.e. the Northern part of Sri Lanka. Areas with elevations higher than 2m above mean sea level is considered land and was excluded from the computational grid. The same grid was used for both the FLOW and the WAVE models.

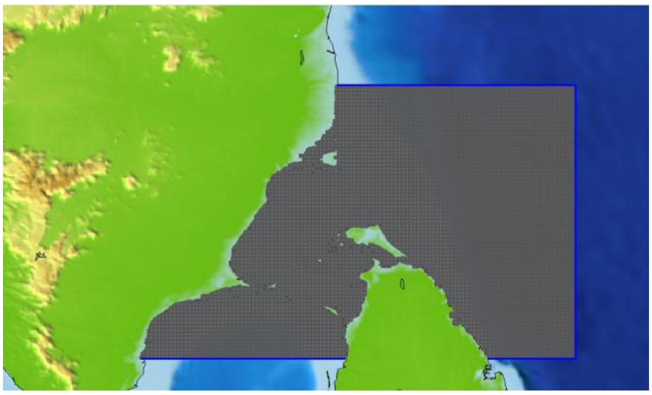


Figure 8. FLOW and WAVE Computational grid

Ocean bathymetry extracted from the GEBCO database (please see section 3.1) was projected on this rectangular grid. Figure 9 shows the bathymetry used in the simulations.

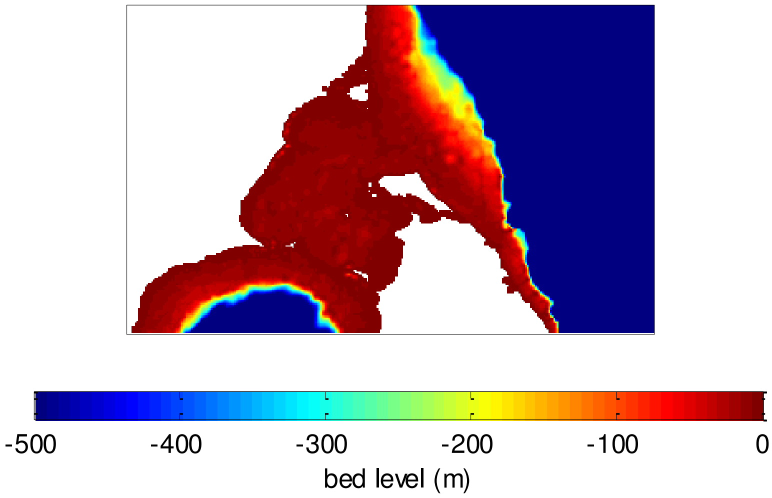


Figure 9. Bathymetry of the study area

4.2. Model Forcing (boundary conditions)

Three different forcing were applied to the simulations:

a. Water levels: At the open (wet) South, North and East boundaries of the model, a set of astronomical tidal components were applied at a 50 km resolution (i.e. 100 grid points) . These components were generated from regional model of Bay of Bengal provided by Oregon State University (please see Section 3.2).
b. Winds: The Wind file extracted from ERA-interim was applied as forcing condition. This wind field varies in time every 8 hours. At each 8 hour time step the *v* and *u* (north-south and east –west) components of wind speed were applied on a 0.75 x 0.75 degree (80 km) grid (see Section 3.3)
c. Waves: Wave forcing was applied at the open boundaries of the model based on data from ERA-interim as Significant wave height, Peak period and direction every 6 hours. (see Section 3.3)

4.3. Model Simulations

Since the goal of this part of the study is to determine whether any large scale tide/wave/wind driven circulations occur on an annual basis (rather than extreme or exceptional conditions), a complete one year simulation (2015) was carried out with the abovementioned forcing and the resulting flow field throughout the year was carefully analysed. This approach allows the consideration of both monsoons and the calm inter-monsoonal periods in the simulation and also enables the examination of the flow field during the transitional periods.

4.4. Results and Conclusions

The above described large scale Delft3D simulation shows that:

- The main driving forces for large scale currents around the north coast of Sri Lanka are wind and tide.
- Maximum current velocity is around 0.8 m/s which occurs over Adam's bridge during the south west monsoon.

Figures 10, 11 and 12 show snapshots of the variable wind field, water level and maximum current velocity. (During the south west monsoon 5th of May 2015)

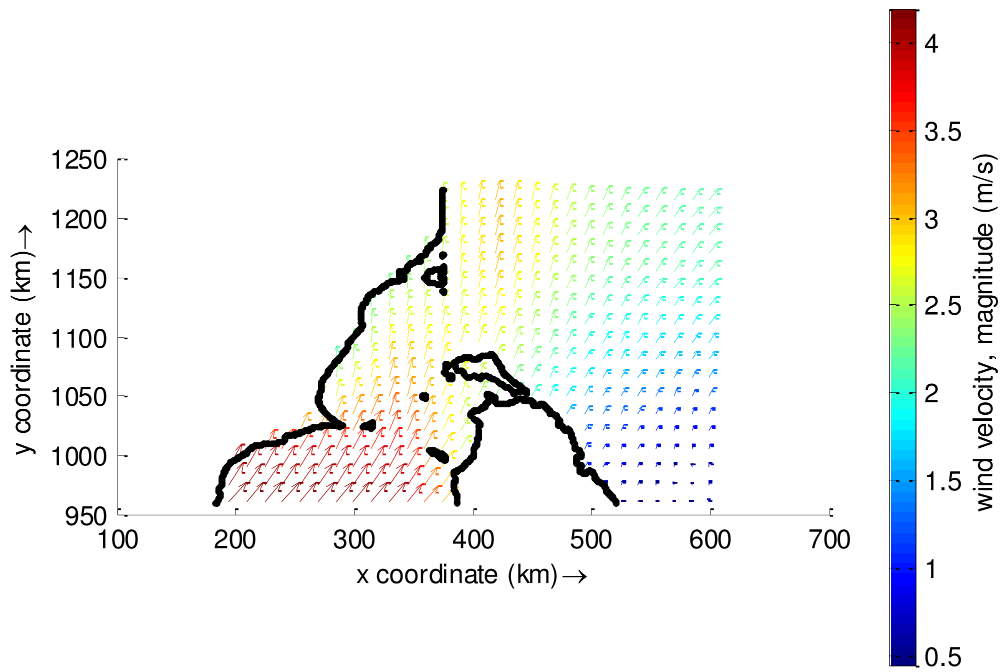


Figure 10. Snap shot of spatially variable wind field applied to the model

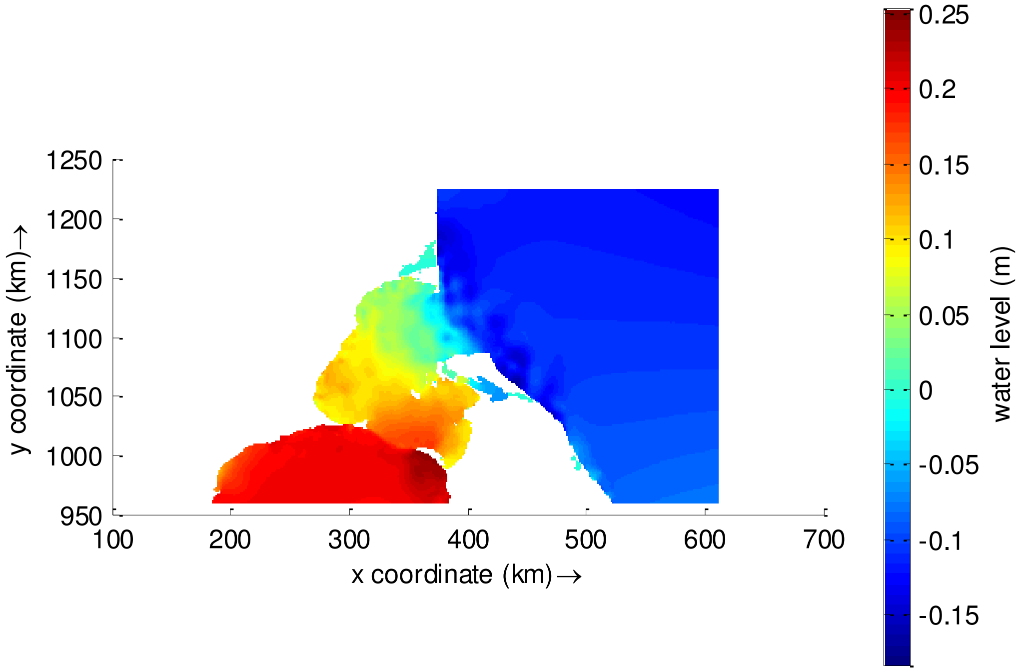


Figure 11. Snap shot of resulting water levels in the study area

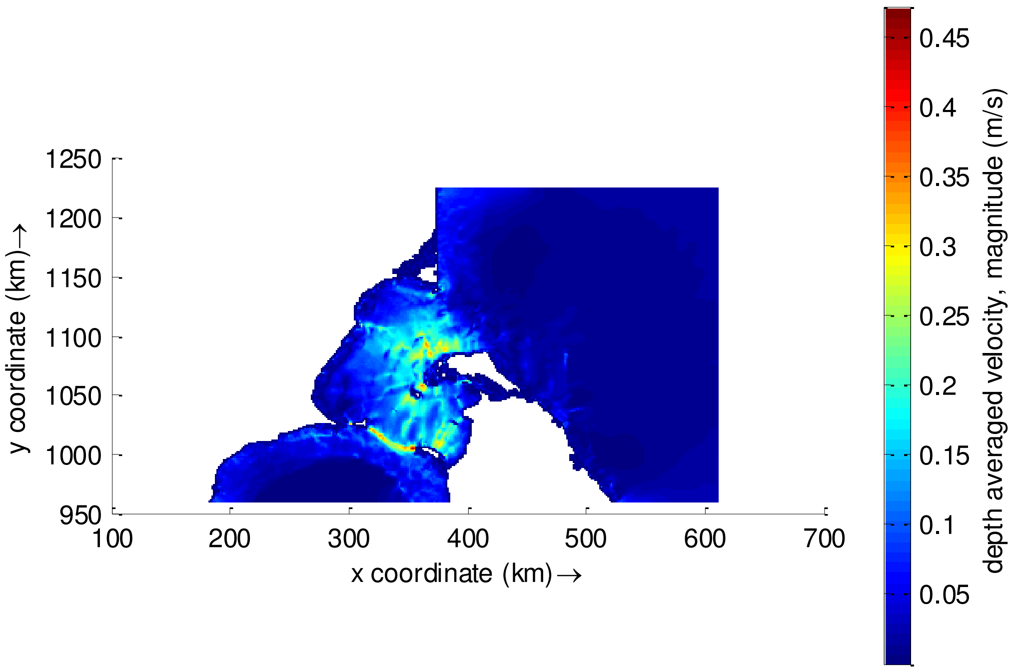


Figure 12. Snap shot of resulting current velocity in the study area

5. Modelling strategy and surveyed bathymetries

5.1. Modeling strategy

Based on the simulation results presented in this report, it is concluded that there are no significant and persistent large scale circulation patterns that might affect sediment transport in the vicinity of the proposed fishery harbours. Therefore, to setup the detailed Delf3D models in Phase 2 of the study, it was deemed sufficient to collect locally concentrated bathymetric data at the harbour sites as shown in Figures 13-16. However, to capture the possible effects of far field wave refraction it is recommended that sub-regional models using globally available data be setup to obtain boundary forcing for the detailed local Delft3D models for the study sites.

5.2. Measured bathymetries

For setting up detailed models around the proposed fishery harbours detailed surveyed bathymetries for all the locations are needed. These surveys were completed in mid-June based on the specifications shown in Figures 13-16.

Bathymetric surveys were undertaken via in-situ sonar. Tidal data were used to correct raw sonar depth readings. For tidal measurements, a temporary tide gauge was installed near the project sites, and an elevation benchmark was established. Sonar surveys were conducted using a commercial single beam fish finder following an optimized route design that included densified surveys in areas with local variations. Table 1 summarizes the equipment used in the surveys. For more details about the surveys please refer to Annex 1. Figures 17-20 also show the raw data of surveyed bathymetries at each site.

Table 1. Bathymetric survey equipment

Activity	Equipment
Tide gauge installation	Portable tide gauge
Tidal measurement	Portable tide gauge
	Tide staff
Sonar survey	Vessel (boat)
	Single beam sonar transducer
	Transducer mount
	Battery
	Battery charger
	Calibrated rope/bar
	Handheld GPS
	Laptop

5.2.1. Gurunagar

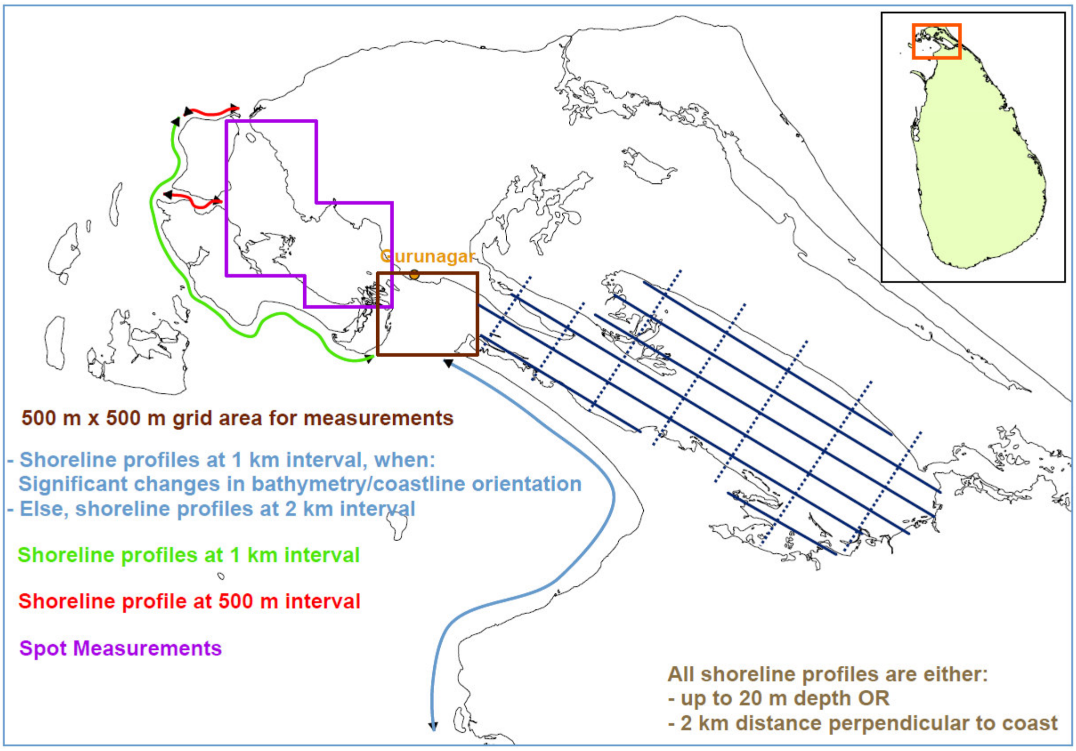


Figure 13. Locations and specifications of the bathymetric survey at Gurunugar

5.2.2. Pesalai

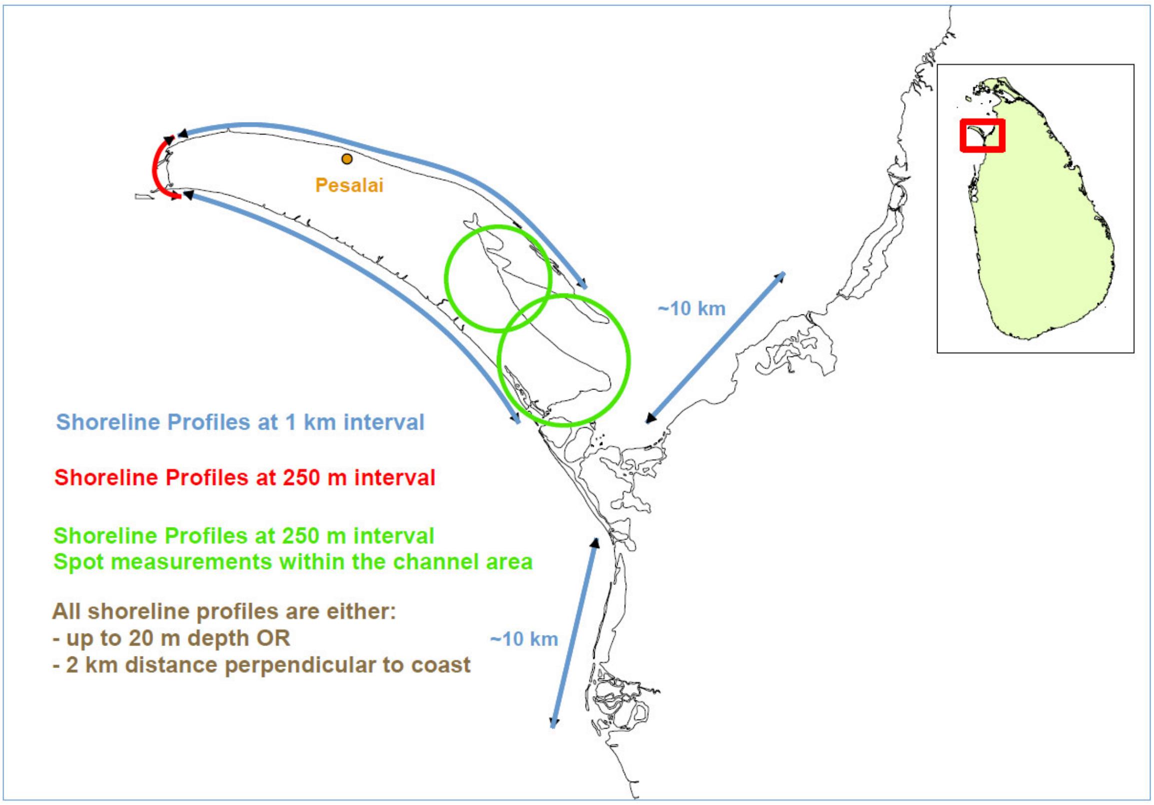


Figure 14. Locations and specifications of the bathymetric survey at Pesalai

5.2.3. Point Pedro

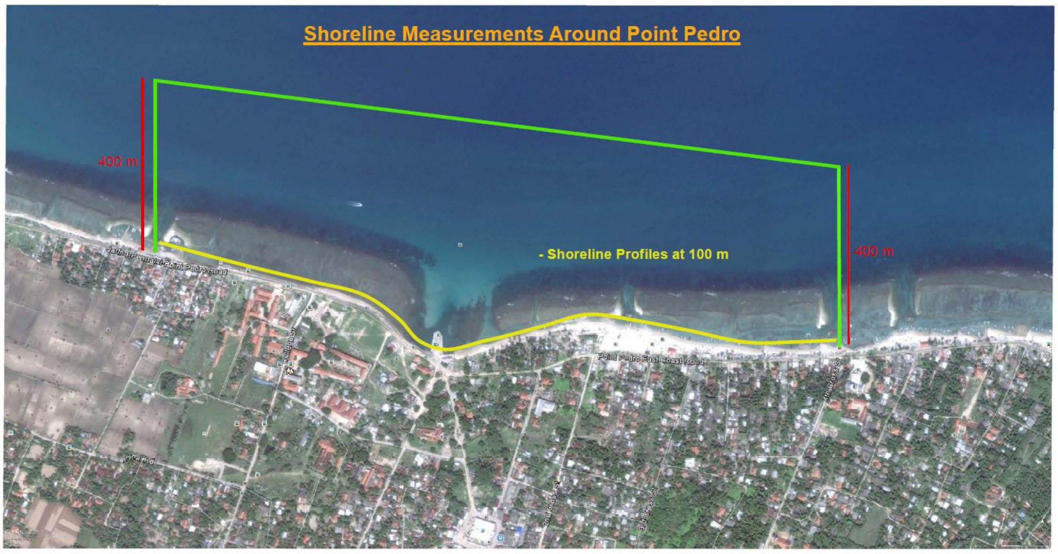


Figure 15. Locations and specifications of the bathymetric survey at Point Pedro

5.2.4. Mullaithivu

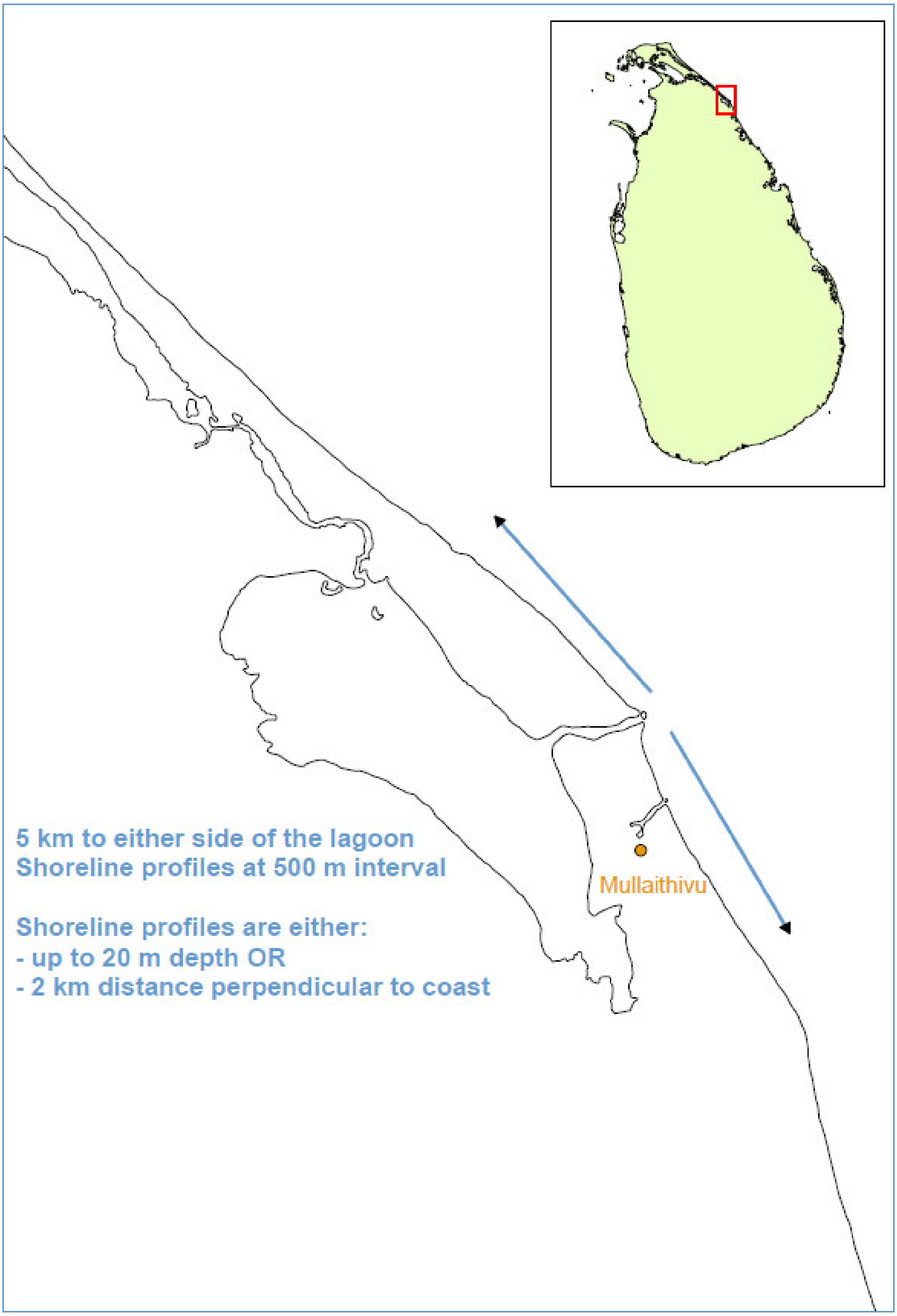


Figure 16. Locations and specifications of the bathymetric survey at Mullaithivu

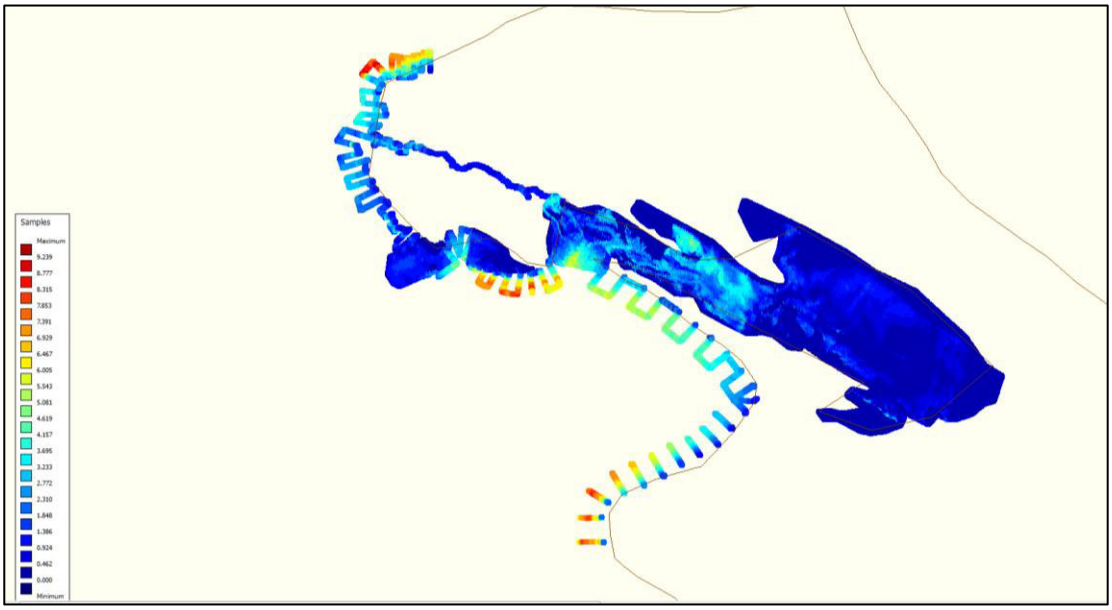


Figure 17. Raw data of surveyed bathymetry at Gurunugar

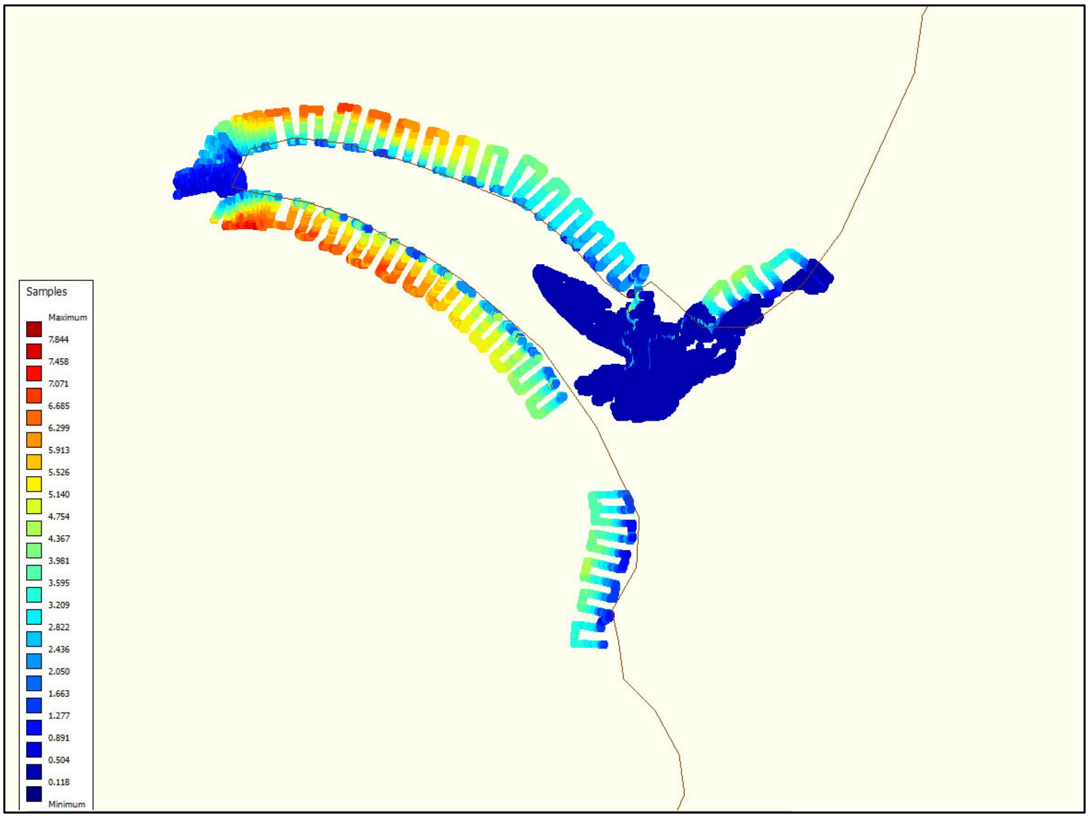


Figure 18. Raw data of surveyed bathymetry at Pesalai

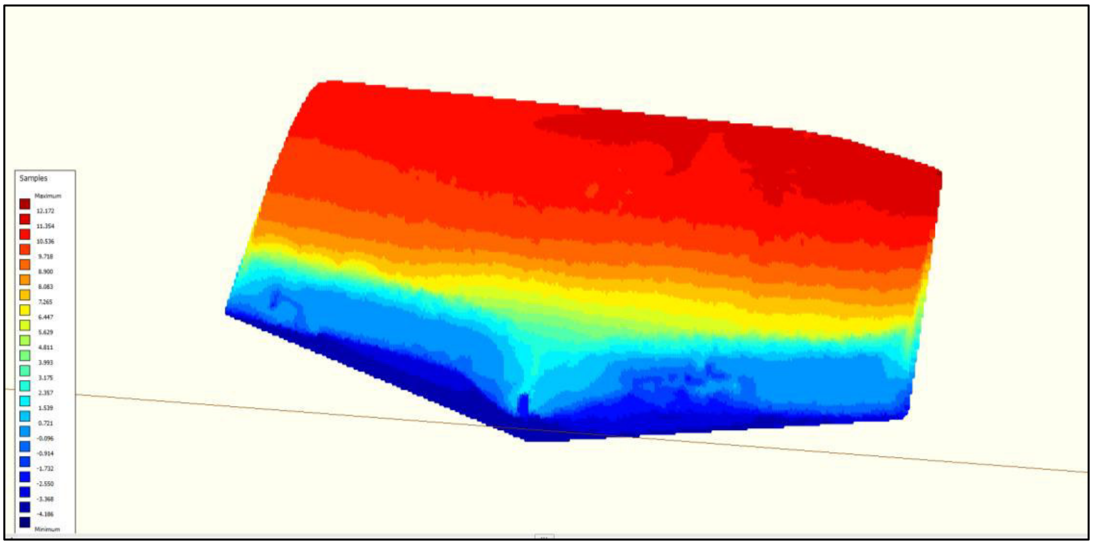


Figure 19. Raw data of surveyed bathymetry at Point Pedro

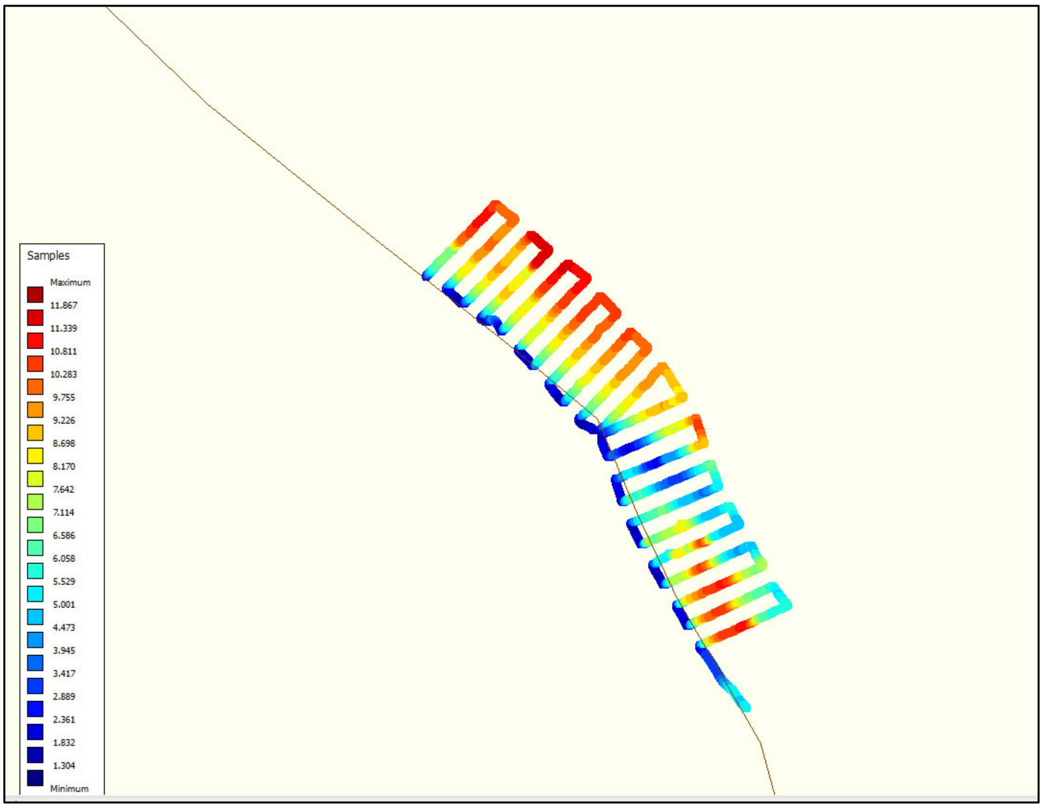


Figure 20. Raw data of surveyed bathymetry at Mullaithivu

6. REFRENCES

BODC, 2003. The GEBCO Digital Atlas published by the British Oceanographic Data Centre on behalf of IOC and IHO, 2003. http://www.gebco.net

Berrisford, P., Dee, D., Poli, P., Brugge, R., Fielding, K., Fuentes, M., Kallberg, P., Kobayashi, S., Uppala, S. and Simmons, A., 2011. The ERA-Interim archive Version 2.0, ERA Report Series 1, ECMWF, Shinfield Park.Reading, UK, 13177.

Egbert G.D. and Erofeeva, S.Y. 2002. Efficient Inverse Modeling of Barotropic Ocean Tides. J. Atmos. Oceanic Technol., 19, 183204.

Lesser, G.R., Roelvink, J.A., Van Kester, J.A.T.M., Stelling, G.S., 2004. Development and validation of a three-dimensional model. Coast. Eng. 51, 883–915.

Annex 1. Report of Bathymetric Survey around Pesalai

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Bathymetric Survey Plan for Sri Lanka

1. Project site

The project site is located in Mannar, Sri Lanka.

a. Survey coverage

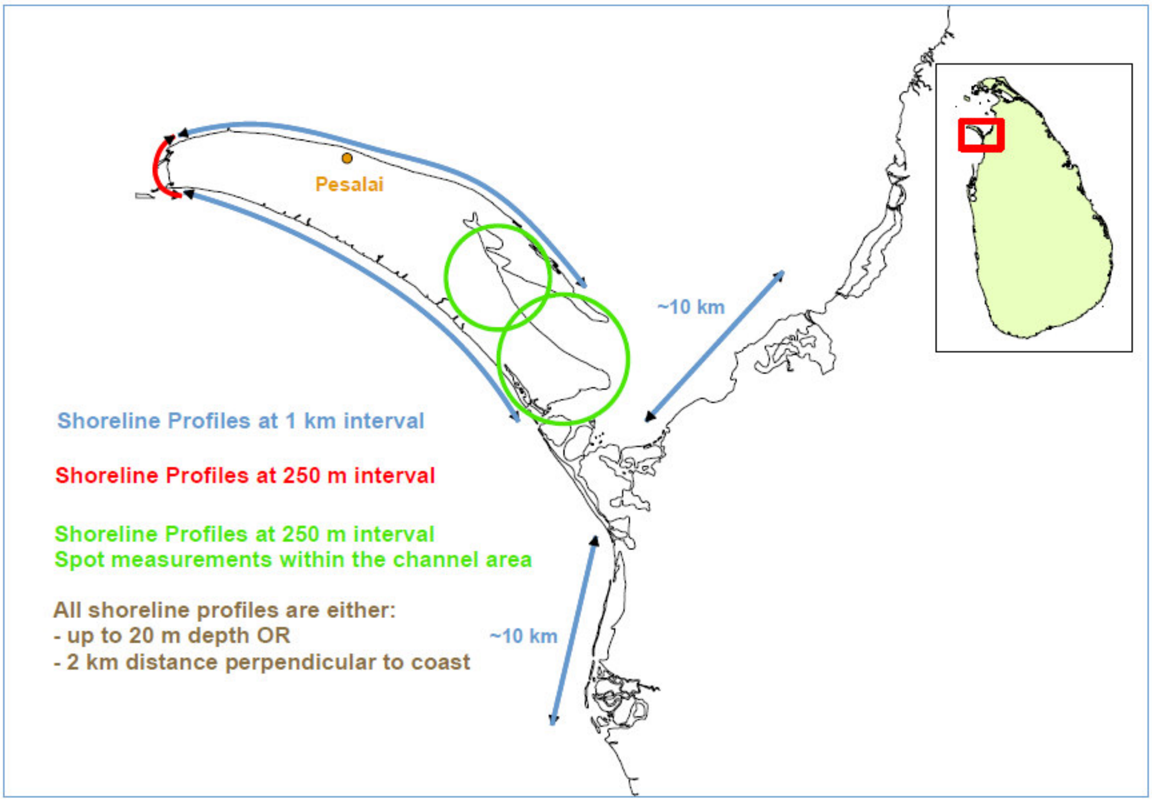

Figure 1. Project site

2. Bathymetric survey

Bathymetric data acquisition is composed of two parts (i) tidal and (ii) sonar. Tidal data will be used to correct raw sonar depth readings. For tidal measurement, a temporary tide gauge will be installed near the project site, as well as tidal benchmarks that will be established by leveling survey from a known point.

Sonar survey will be conducted using a commercial single beam fish finder following an optimized route design that includes densified surveys in areas with local variation.

A common datum such as the mean sea level (MSL) will be used to 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.

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2.1 Equipment, Personnel and Duration

Table 1. Bathymetric survey equipment, personnel and duration

Activity	Equipment	Personnel	Duration
Tide gauge installation	Portable tide gauge		1 day (prior to survey)
Tidal measurement	Portable tide gauge	Local security	15 days
	Tide staff		
Sonar survey	Vessel (boat)	Driver	15 days
	Single beam sonar transducer	Navigator	
	Transducer mount	Operator (sonar)	
	Battery	Technical support(2) Labor	
	Battery charger		
	Calibrated rope/bar		
	Handheld GPS		
	Laptop		

2.1.1 Instrument setup for sonar survey

To conduct daily sonar operations, the following list of equipment and accessories are needed:

a. Lowrance echo sounder
b. Maintenance-free car battery (12V 45Ah)
c. Croc wire plus adapter (connect sonar cable to car battery)
d. Waterproof case
e. Transducer
f. Transducer mount
g. Vessel
h. Garmin Handheld GPS
i. Battery charger

Figure 2 shows the recommended sonar setup on the boat. The power source, such as the maintenance-free car battery (12V 45Ah), should be encased in a waterproof container to protect it from water contamination. Image C in Figure 2 shows the adapter attached to the crocodile wire used to connect the sonar console to the power source.

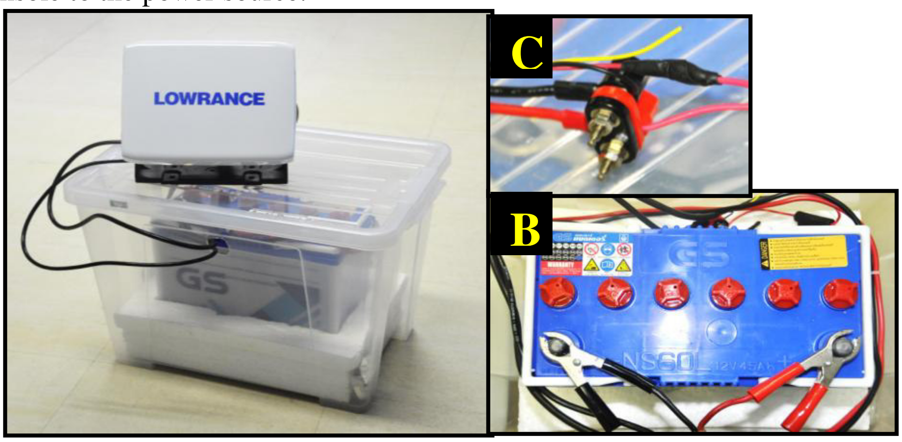

Figure 2. Sonar setup

Sonar charging (figure 3) is conducted overnight after every survey to ensure that the battery is fully charged before the start of the next survey.

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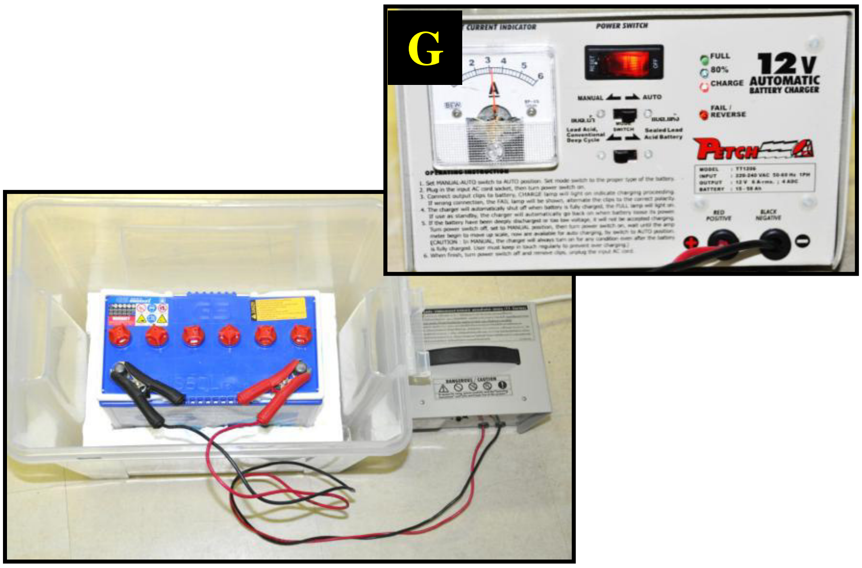

Figure 3. Sonar charging setup

Figure 4 shows the sonar setup on the boat using the Yamaha fishfinder and transducer mount in January 2010. The transducer was mounted over the side of the boat using a stainless steel pipe attached to a clamp. The survey was conducted in Phuket, Thailand as part of the research on low-cost bathymetric survey. However, the language used in the instrument is Japanese, hence the need to switch to a brand with the English language.

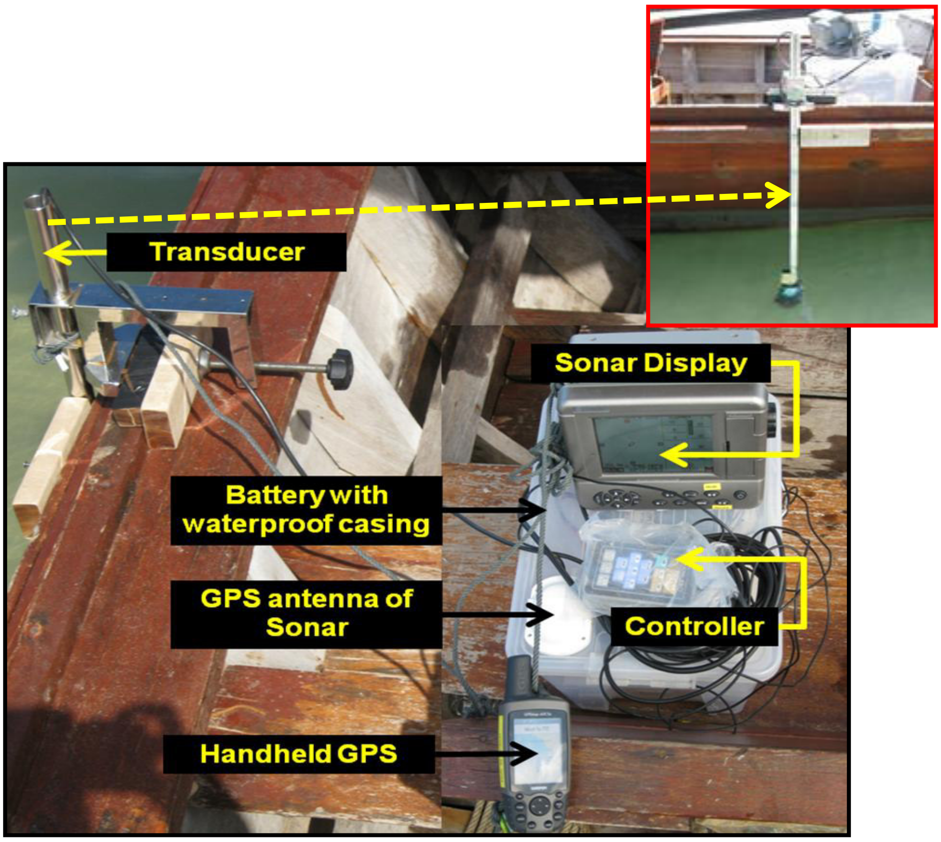

Figure 4. Yamaha transducer mounted over the side of the boat (2010)

Figure 5 shows the sonar setup on a survey skiff using the Lowrance fishfinder in January 2013. The transducer was mounted at the back of the boat, away from bubble influence generated by the propeller. The survey was conducted in Barrio Barretto, Olongapo City, Philippines for the project on *Enhancing Coastal Hazard Early Warning and Response: Tools and Institutional Strengthening.*

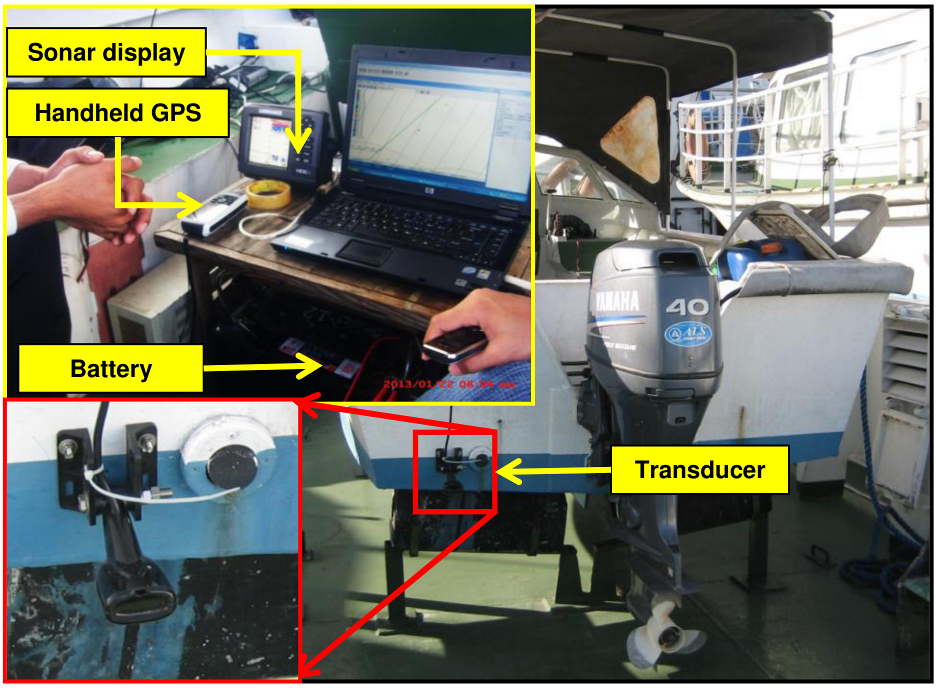

Figure 5. Transom mount of a Lowrance transducer on NAMRIA skiff (2013)

2.2 Tidal measurement

A portable pressure-sensor water level recorder will be established within the project area to collect tidal readings every 10-15 minutes. To ensure that the pressure sensor is submerged in the water for the whole duration of the survey, it should be installed below the lowest possible water for that area.

Table 2. 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

2.2.1Accuracy assessment

The portable tide gauge will be compared to a high grade tide gauge such as that in Keeri beach, Mannar (SL Navy jetty) for a few days prior to actual survey.

2.2.2 Site for tidal measurement

A possible site where the portable water level recorder (tide gauge) can be installed at Navy peer at Keeri beach, Mannar

Figure 6. NARA tide gauge in Keeri beach, Mannar

2.3 Sonar survey

An optimized survey route design will be followed during the sonar survey. Increase in survey detail for areas with significant variation in bathymetry can improve the accuracy of the final output. To ensure the accuracy of sonar readings, survey should be conducted only during calm seawater conditions.

2.3.1 Survey route design

<u>Location</u>

Bathymetric survey of shoreline profiles to be carried out either up to 20 m depth OR 2 km distance perpendicular to coast. The total survey consists of five sections as shown in figure 6

Line spacing

10 Km span to north of the point (8°57'0.06"N 79°56'44.55"E) and to south from (8°52'47.66"N 79°55'43.31"E) will be in 1Km line spacing. From the point (8°57'33.32"N 79°53'15.66"E) to (9° 4'6.05"N 79°44'48.83"E) and from (9° 0'50.84"N 79°55'29.81"E) to (9° 6'20.71"N 79°45'9.77"E) will be in 1Km line spacing. From the point (9° 4'6.05"N 79°44'48.83"E) to (9° 6'20.71"N 79°45'9.77"E) will be in 250 m line spacing.

possibility of survey boat reach up to there as much as possible close to the beach will be depend subjected to the weather and obstacles as rocks and reef at sea.

No of survey lines

Number of lines with 250m line spacing – 32

Number of lines with 1Km line spacing – 74

Total number of lines – 106

Distance to be surveyed – 212 Km

Spot measurements within the channel – 13 Km

Total distance to be surveyed – 225 Km

2.3.2 Sonar setup

Sonar survey will be collected using an ordinary fishing sonar, operating at 200kHz (12^{o} cone angle) at shallow depths and 50kHz (35^{o} cone angle) at deeper depths. The transducer will be mounted over the side of the boat to prevent noise interference from the bubbles. It has a built-in internal GPS that will provide the horizontal coordinates. An SD card will be used to store and transfer data to a laptop computer.

The sonar setup is composed of the display, transducer, transducer mount, power supply enclosed in a waterproof casing and a handheld GPS for navigation and tracking.

Table 3. 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

2.3.3 Accuracy assessment

A cross-check line survey will be conducted to check the accuracy of the sounding data. This can be done by setting up a route perpendicular or diagonal from the main survey line, in this case, the perpendicular to the shoreline.

2.4 Common datum

A common vertical datum is required to integrate both bathymetric and topographic data. Sometimes, bathymetric data may be referred to the MLLW or LAT, and topographic data may be referred to the MHHW or MSL. As long as both data are referred to one vertical datum, any datum can be used. For purposes of this project, the final output will be referred to the local MSL datum.

A leveling survey will be run from a known tidal benchmark to establish tidal benchmarks in the area. Good candidates for tidal benchmark will be near the temporary tide gauge and known GPS benchmarks so as to derive the relationship between datums. This survey activity can be conducted in parallel with the tidal measurement and sonar survey.

If there is an existing tidal station in the area, the portable tide gauge can be installed near the station's tide gauge. The elevation of the tidal benchmark will be used as reference for tidal readings measured from the portable tide gauge.

2.5 Data processing

Since the sonar equipment measures depth data from the transducer to the seafloor only, raw sounding data will be corrected for draft and tidal effects.

After filtering erroneous data along the survey line, local variation areas will be determined when standard deviation is 0.5m for every 1000m distance along the survey line. This will define the area where resurvey will be conducted in greater detail (500m interval spacing).