

Table of Contents

| | |
|---|-------------|
| Abstract | ii |
| Acknowledgements | iv |
| List of Figures | viii |
| List of Tables | xii |
| Abbreviations | xiv |
| 1. Introduction | 1 |
| 1.1. Background | 1 |
| 1.2. Significance of the Research Study | 2 |
| 1.3. Problem Definition | 3 |
| 1.4. Objectives of the Research | 5 |
| 1.5. Research Questions | 5 |
| 1.6. Approach | 5 |
| 2. Literature Review | 7 |
| 2.1. Coastal Management in Sri Lanka | 7 |
| 2.2. The Problem of Coastal Erosion in Sri Lanka | 8 |
| 2.3. Available Knowledge on Sediment Transport and Budget | 11 |
| 2.4. Mitigation measures | 12 |
| 3. Research Methodology | 15 |
| 3.1. Sediment Budget Equation | 15 |
| 3.2. Data availability in data poor environments | 16 |
| 3.3. Research Approach | 19 |
| 3.4. Classification of Coastline in Coastal Cells | 23 |
| 4. Input Data for Assessing Sediment Budget | 25 |
| 4.1. Tide | 25 |
| 4.2. Wind Climate | 25 |
| 4.3. Wave Climate | 27 |
| 4.4. Depth of Closure (DoC) | 30 |
| 4.5. Sediment Characteristics | 31 |
| 4.6. Cross shore Profile (Dean) | 32 |
| 4.7. Coastline | 33 |
| 4.8. Coastal interventions | 33 |
| 4.8.1. River sand input | 33 |
| 4.8.2. Sand Mining | 34 |
| 4.8.3. Beach Nourishment | 36 |
| 4.8.4. Structures | 36 |
| 5. Model setup | 39 |
| 5.1. Wave Modelling (Delft3D) | 39 |
| 5.1.1. Model approach | 39 |

| | | |
|-----------|---|-----------|
| 5.1.2. | Model area, domain and bathymetry | 39 |
| 5.1.3. | Boundary conditions | 42 |
| 5.1.4. | Model settings | 44 |
| 5.1.5. | Model results and verification | 45 |
| 5.2. | Sediment Transport model (Unibest LT) | 47 |
| 5.2.1. | Model approach | 47 |
| 5.2.2. | Input data for an LT-model | 48 |
| 5.2.3. | The output of a LT-run | 48 |
| 5.2.4. | Model results and verification | 50 |
| 6. | Assessment of Sediment Budget | 53 |
| 6.1. | Assessment of Coastline Changes | 53 |
| 6.1.1. | Uncertainty of Coastline | 55 |
| 6.1.2. | Assessment of Sediment Volume Changes | 55 |
| 6.2. | Sensitivity Analysis | 56 |
| 6.3. | Coastal recession Relative Sea Level Rise | 58 |
| 6.4. | Definition of Sources and Sinks | 59 |
| 6.5. | Conceptual Sediment Budget | 60 |
| 6.6. | Limitations | 63 |
| 7. | Conclusions and Recommendations | 65 |
| 7.1. | Conclusions | 65 |
| 7.2. | Recommendations | 68 |
| | References | 70 |
| | Appendices | 72 |
| A. | Wave Data Validation | 72 |
| B. | Wave model results | 77 |
| C. | Sediment Budget Computation | 84 |

List of Figures

| | |
|--|----|
| Figure 1.1 Definition of Sri Lanka Coastal Zone (CCA of 1981)..... | 1 |
| Figure 1.2 Coastal erosion in Unawatuna and Payagala in the southern coast of Sri Lanka during south west monsoon. (Daily News, August 2013)..... | 3 |
| Figure 1.3 350 Km study area extended from Matara to Puttalam (Gebco data)..... | 4 |
| Figure 2.1 Picture shows the sand mining with heavy machinery at the dried up Daduru Oya River and the numbers of Lorries waiting for their turn of transporting mined sand (Daily news June 2012)..... | 9 |
| Figure 2.2 Map of Sri Lanka, erosion rates are based on the CZMP 2004 | 10 |
| Figure 3.1 Definition of sources and sinks as in Equation (1) | 15 |
| Figure 3.2 Comparison of significant wave height rose among ERA 40, ERA Interim and World Wave datae over the period of 1998-2009 at offshore location 6.0N 79.5E..... | 17 |
| Figure 3.3 Track line survey data from the IHO DCDB (http://www.iho.int/) | 17 |
| Figure 3.4 Flow chart for wave modelling | 19 |
| Figure 3.5 Flow chart for sediment transport modelling..... | 20 |
| Figure 3.6 Left: Areal photograph Right: LANDSAT image for the same coastal stretch (Cell 14)..... | 20 |
| Figure 3.7 The overview of the research methodology used in the study | 22 |
| Figure 3.8 Definition of Coastal cells (rights) and corresponding boundaries and lengths (left)..... | 23 |
| Figure 4.1 Offshore wind roses for the months of January (NE), April (1st intermonsoon), June (SW) and November (2nd intermonsoon) for the period of 1979-2012..... | 26 |
| Figure 4.2 Left panel: Offshore Wind roses for the period of 1979-2012 Right top panel: normalized wind speed of location 6.75N, 79.25E Right bottom panel: normalized wind direction of location 6.75N, 79.25E..... | 27 |
| Figure 4.3 Offshore wave roses for the months of January (NE), April (1st intermonsoon), June (SW) and November (2nd intermonsoon) for the period of 1979-2012..... | 28 |
| Figure 4.4 Left panel: Offshore Wave roses for the period of 1979-2012 Right top panel: normalized significant wave height of location 6.75N 79.25E Right middle panel: normalized Wave direction of location Right bottom panel: normalized Wave period of location 6.75N 79.25E..... | 29 |
| Figure 4.5 (a) Offshore wave rose (6.705 79.25) (b) Colombo near-shore wave rose (19 m depth) as seen in the map | 30 |
| Figure 4.6 Definition sketch showing limits d_i and d_l where d_i is the maximum water depth of near shore erosion by extreme (12 hour per year) wave condition..... | 30 |
| Figure 4.7 The relationship between the significant wave height and the percentage of time exceeded of Colombo 19 m depth wave data. | 31 |
| Figure 4.8 Particle size distribution curves in cell 17-18 | 31 |
| Figure 4.9 Sediment characteristics (D50) for defined coastal cell from Matara to Puttalam..... | 32 |
| Figure 4.10 Cross shore profile for D50 values of 0.20, 0.45 and 0.80 mm | 32 |
| Figure 4.11 Orientation of coastline from Matara to Puttalam top panel: 1956 bottom panel: 2014..... | 33 |
| Figure 4.12 Estimated extraction of sand in Sri Lanka (in Million cubic meter)..... | 35 |
| Figure 4.13 Coastal structures that influenced to change the orientation top panel: kalutara- Beruwala Middle panal: Colombo port- Dikkowita Bottom panal: Negombo- Chilow section..... | 37 |
| Figure 4.14 (a) Colombo harbour (b) Beruwala fishery harbour (c) Panadura river mouth jetty (d) Dehiwala and Wallawatta jetties | 38 |
| Figure 5.1 Curvilinear structured gird..... | 40 |
| Figure 5.3 Left: Wave Roses, Right: Wind Roses using ERA interim (1979-2012)..... | 41 |
| Figure 5.2 Detail bathymetry of the study area | 41 |
| Figure 5.4 Definition of the multidimensional classes as in the matlab code (ORCA)..... | 42 |
| Figure 5.5 Scenario no 107: Mean values (wave parameters) represent in red, wind parameters represent in blue and the reference location represents n green..... | 43 |

| | |
|--|----|
| Figure 5.6 First scenario in the md-vvac file. (SWAN0001.wnd file gives the wind speed and direction for the study area corresponding to scenario)..... | 44 |
| Figure 5.7 Comparison of Wave roses of significant wave height (non calibrated) at Colombo 19m depth Left: buoy measurements Right: Delft3D wave transformed (205 scenarios)..... | 45 |
| Figure 5.8 Comparison of Wave roses of significant wave height (non calibrated) at Galle 70m depth Left: buoy measurements Right: Delft3D wave transformed (205 scenarios)..... | 45 |
| Figure 5.9 Scenario no 151 Top Left: significant wave height (m) Top Right: mean wave direction Bottom Left: mean wave period (s) Bottom Right: wind velocity (m/s)..... | 46 |
| Figure 5.11 Overview of information inside a ray-file..... | 49 |
| Figure 5.10 Examples of computed distributions of longshore transport, wave height and longshore current along the profile (Deltares) | 49 |
| Figure 5.12 Sediment transport rate (million m ³ /year) using Bijker (1967, 1971) Red: Northward transport Blue: Southward transport..... | 50 |
| Figure 5.13 Sediment transport rate (million m ³ /year) using Kamphuis (2000) Red: Northward transport Blue: Southward transport..... | 50 |
| Figure 6.1 Comparison of coastline change along the northern part of the coastal stretch (S15) over the period of 1956 to 2014 (Red line 1956, Blue line 2005 and Black line 2005) | 54 |
| Figure 6.2 Net yearly average accretion/erosion rate (m/year) for the period of 1956-2005 | 54 |
| Figure 6.3 Net yearly average accretion/erosion rate (m/year) for the period of 2005-2014 | 54 |
| Figure 6.4 Comparison of net yearly average long term (1956-2005) and short term (2005-2014) erosion volume (1000 m ³ /year)..... | 56 |
| Figure 6.5 Comparison of net yearly average long term (1956-2005) and short term (2005-2014) accretion volume (1000 m ³ /year)..... | 56 |
| Figure 6.6 Sediment transport rate (million m ³ /year) using Bijker (1967, 1971) Blue line: 0.3mm, Green line: D50: 0.6 mm | 57 |
| Figure 6.7 Example of S-phi curve in a coastal section between Mutwal and Negambo (S13)..... | 57 |
| Figure 6.8 Comparison of sensitivity on the coastal orientation Blue line: add 5 degree to current coastline angle Green line: reduce 5 degree to current coastline angle | 58 |
| Figure 6.9 The Bruun Rule of shoreline retreat (After Cooper and Pilkey 2004) | 58 |
| Figure 6.10 Yearly average long-term (1956-2005) and short-term (2005-2014) erosion volumes based on shoreline retreat data..... | 59 |
| Figure 6.11 Comparison between transport gradient and accretion/erosion differences during 1956-2005 (uncertainties are represented by vertical bars) | 61 |
| Figure 6.12 Comparison between transport gradient and accretion/erosion differences during 2005-2014 (uncertainties are represented by vertical bars) | 61 |
| Figure 6.13 Yearly average sediment budget computations for the coastal cells S14 and S15 Top: 1956-2005 Bottom: 2005-2014..... | 62 |
| Figure 6.14 Yearly average sediment budget computations for the coastal cells S16, S17 and S18 Top: 1956-2005 Bottom: 2005-2014 | 62 |
| Figure 7.1 Comparison of net yearly erosion along the coastal cells between 1956-2005 and 2005-2014...65 | 65 |
| Figure 7.2 Flow diagram for Data QA module in ORCA. | 72 |
| Figure 7.3 Visual check for the ERA Interim data set of offshore location (79.5 7) Top: significant wave height Middle : peak wave period and Bottom: mean wave direction | 73 |
| Figure 7.4 Output of Check 4 for the ERA Interim data set at offshore location 79.5 7.0 for the period 1979-2012 Red: unadjusted time series of the black: time series without both deviation from the mean and variation outliers. | 73 |
| Figure 7.5 Output of check 7.shows the representation of consistent annual wind climate for the offshore data set (79.5 7). Top panel: selected data set bottom panel: entire dataset for 32 years..... | 74 |
| Figure 7.6 check 7: Joint occurrence tables of wind speed vs. wind direction for the offshore dataset (79.5 7) Top panel: selected data set bottom panel: entire dataset | 75 |

| | |
|---|----|
| Figure 7.7 Comparisons between WW11 and original ERA Interim data Left panel: Density scatter (red line: linear fit; dashed red line: linear fit with no intercept) Right panel: Percentile–percentile (blue line: linear fit)..... | 76 |
| Figure 7.8 Comparison between WW11 and corrected ERA interim data set (Percentile–percentile)..... | 76 |
| Figure 7.9 Left panel: locations of extracted near shore wave climate (72 locations) at 15 m depth Right panel: selected near shore wave climates in the defined coastal cells (S1-S18)..... | 77 |
| Figure 7.10 Comparison of Joint occurrence table at Galle 70 m depth Bottom: buoy measurements Top: Delft3D wave transformed (non calibrated)..... | 80 |
| Figure 7.11 Comparison of Joint occurrence table at Colombo 19 m depth Bottom: buoy measurements Top: Delft3D wave transformed (non calibrated)..... | 81 |
| Figure 7.12 Net yearly erosion rate (m/year) along the south-west coastline between 1956 and 2005 | 82 |
| Figure 7.13 Net yearly erosion rate (m/year) along the south-west coastline between 2005 and 2014 | 83 |
| Figure 7.14 Annual Regional sediment budget (yearly average data based on 1956 to 2005)..... | 85 |
| Figure 7.15 Annual Regional sediment budget (yearly average data based on 2005 to 2014)..... | 86 |

List of Tables

| | |
|--|----|
| Table 2.1 Overview of yearly erosion rates in the areas along the west and southwest coasts of Sri Lanka where critical erosion recorded (CCD 2004)..... | 8 |
| Table 2.2 Sand mining, sediment supply and deficit for the year 2001 and the period 1976 -2001 for the rivers Maha Oya, Kelani Ganga and Kalu Ganga (million m3) | 9 |
| Table 2.3 Overview of existing coast protection structures by coastal sector..... | 12 |
| Table 3.1 Data availability in the study area | 18 |
| Table 3.2 Overview of downloaded ERA Interim data | 19 |
| Table 4.1 Tidal constants from different stations in the study area NARA measurements..... | 25 |
| Table 4.2 Mean annual rainfall, erodibility and erosivity for selected locations in Sri Lanka (Joshua 1977)..... | 34 |
| Table 4.3 Discharge volume, catchment area and Average rain-fall (Water Statistics Handbook, Irrigation Department 2003)..... | 34 |
| Table 4.4 Comparison volume of estimated beach sand mining from Puttalam to Matara (Source CCD 2004)..... | 35 |
| Table 4.5 Reported beach sand nourishment in various coastal stretches (Source CCD 2004, Wickramaarachchi 2010, Fernando 2009)..... | 36 |
| Table 5.1 Delft3d-WAVE parameters | 44 |
| Table 6.1 Definition of sediment sources and sinks considered in the sediment budget study and the assessment procedure | 59 |

Abbreviations

| | |
|----------|--|
| GEBCO | : General Bathymetric Chart of the Oceans |
| SWAN | : Simulating Waves Near shore |
| ORCA | : met Ocean data tRansformation, Classification and Analysis |
| UNIBEST | : Uniform Beach Sediment Transport |
| NCEP FNL | : National Centre for Atmospheric Research Final |
| ECMWF | : European Centre for Medium-Range Weather Forecasts |
| MSL | : Mean Sea Level |
| CCD | : coastal conservation Department |
| CCA | : Coast Conservation Act |
| CERC | : Coastal Engineering Research Center |
| CRMP | : Coastal Recourse Management Plan |
| CZMP | : Coastal Zone Management Plan |
| LHI | : Lanka Hydraulic Institute |
| NARA | : National Aquatic Recourses research Development Agency |
| MoFARD | : Ministry of Fisheries and Aquatic Resources Development |
| IOC | : Intergovernmental Oceanographic Commission |