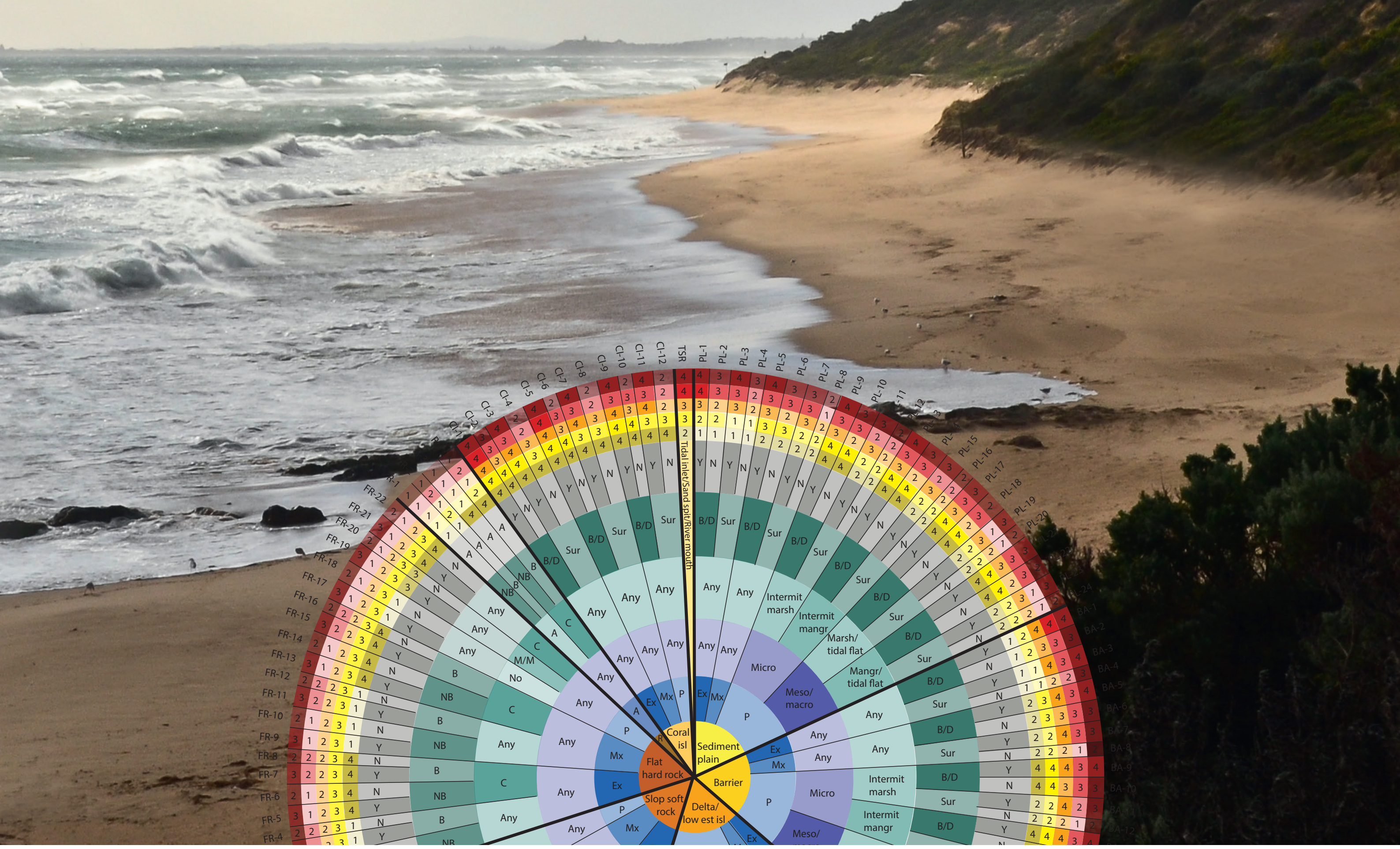
UNEP

MANAGING CLIMATE CHANGE HAZARDS IN COASTAL AREAS

THE COASTAL HAZARD WHEEL DECISION-SUPPORT SYSTEM

QUICK START GUIDE



25 YEARS 2016 UNEP DTU PARTNERSHIP

UNEP-DHI PARTNERSHIP
Centre on Water and Environment
UNEP DHI

Managing climate change hazards in coastal areas

The Coastal Hazard Wheel decision-support system

Quick start guide

Lead Authors
Lars Rosendahl Appelquist, Thomas Balstrøm,
Kirsten Halsnæs

Contributing Authors and Reviewers
Robert J. Nicholls, Matthew M. Linham, Jason Spensley, Joost Stronkhorst, Peter Koefoed Bjørnsen, Gareth James Lloyd, Gorm Jeppesen, Ole Vestergaard

Acknowledgements
We would like to thank the following for their valuable feedback and advice: Troels Aagaard, Ibrahim Al-Zu'bi, Daniel Tutu Benefor, Sanju Deenapanray, Ilaria Firmian, Ib Kidde-Hansen, Thanak De Lopez, Karsten Mangor, Jacopo Monzini, Anne Olhoff, Moussa Sall, Rami Abu Salman.

ISBN: 978-92-807-3593-2

UNEP Job No: DEP/2029/NA

Design and Layout: Paprika-Annecy

Cover photo credit: Bent Charles Bille Brahe Selby

TABLE OF CONTENTS

Skagen sand spit in northern Denmark (Photo: Arth63/Shutterstock).

1 INTRODUCTION

The Coastal Hazard Wheel (CHW) is an information and decision-support system for coastal stakeholders worldwide. It can be used for three main purposes:

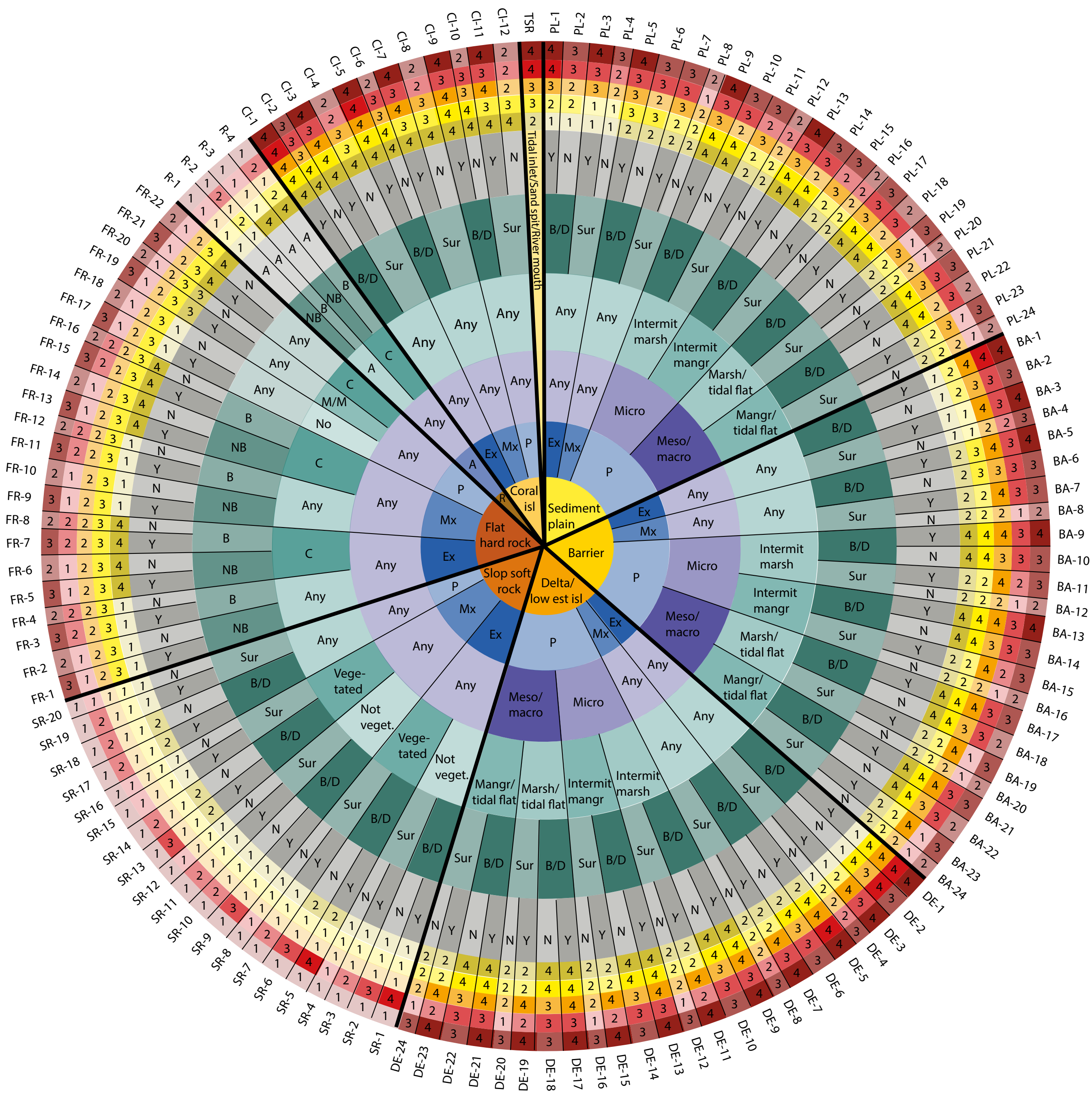
- Multi-hazard-assessments at local, regional and national level
- Identification of relevant management options for a specific coastal location
- As a standardized coastal language to communicate coastal information

The CHW is developed as a universal coastal classification system that can be used in areas with limited data availability and can therefore be used in both developed and developing countries. The CHW constitutes a key for classifying a particular coastal location, determining its hazard profile, identifying relevant management options and communicating coastal information. The system can be used to support coastal management at local to national level and covers all the main coastal hazards, hereunder the hazards of ecosystem disruption, gradual inundation, salt water intrusion, erosion and flooding. As the CHW incorporates climate change effects in the hazard evaluations, it is especially relevant for climate change adaptation. Furthermore, it is suited for Disaster Risk Reduction under the Sendai Framework.

This Quick start guide provides a brief introduction on how to use the CHW to support coastal decision-making and information exchange. It begins with a brief outline of the coastal classification procedure and subsequently describes how to use the CHW for the three purposes listed above. Further technical instructions can be found in the Main manual. Generally, the CHW is well-suited for facilitating communication and information exchange between different management levels, scientists and policy-makers, as the CHW codes can be easily communicated and interpreted. The CHW is displayed in Fig 1.

Gold Coast barrier in Queensland, Australia (Photo: Zstock/Shutterstock).

THE COASTAL HAZARD WHEEL 3.0



COASTAL CLASSIFICATION (start in wheel center)

Geological layout

Wave exposure — Ex Exposed; Mx Moderately exposed; P Protected

Tidal range

Flora/fauna

Sediment balance — B/D Balance/deficit; Sur Surplus; NB No Beach; B Beach

Storm climate — Y Yes to tropical cyclone activity; N No to tropical cyclone activity

Note: R= Sloping hard rock; C=Corals; M/M=Marsh/Mangrove; A=Any

INHERENT HAZARD LEVEL

	Low	Moderate	High	Very high
Ecosystem disruption	1	2	3	4
Gradual inundation	1	2	3	4
Salt water intrusion	1	2	3	4
Erosion	1	2	3	4
Flooding	1	2	3	4

Fig. 1. *The Coastal Hazard Wheel 3.0 consisting of six coastal classification circles, five hazard circles and the coastal classification codes. It is used by starting in the wheel centre moving outwards through the coastal classification (modified from Rosendahl Appelquist and Halsnæs 2015 and Rosendahl Appelquist 2013).*

2 THE COASTAL CLASSIFICATION PROCEDURE

The coastal classification system distinguishes between 131 generic coastal environments and is developed particularly for decision-support. The CHW is used by starting in the wheel centre, moving outwards through the coastal classification and ending with the hazard evaluations and coastal classification codes in the outermost circles. A single application of the CHW will always apply to a particular coastal stretch of 200-300 meter coastline, and larger regional and national assessments consist of e.g. hundreds of individual coastal sections classified with the CHW.

In many cases there is a gradual transition between the different coastal environments and hence it is up to the user to make the best possible judgement on the appropriate coastal classification. This can lead to some inaccuracies but is considered an unavoidable precondition for using the system. Also, the same coastal type may in some areas extend for many kilometres while in others it changes every few hundred meters. Human modifications of the coastal layout should only be included in the classification if it can be considered as permanent modifications of the coastal environment.

The following sections describe how to determine the different classification parameters and the data mentioned constitutes the core data requirement that can be supplemented with field verification and more detailed data (or be determined entirely in the field).

DETERMINING THE GEOLOGICAL LAYOUT

The geological layout constitutes the basis on which the dynamic processes act and has been created by various past dynamic processes including glacial, fluvial, marine, volcanic and tectonic. The definitions for the geological layout categories used in the CHW are the following:

- **Sedimentary plain:** Coasts with an average elevation of less than 6-8 meters 500 meter inland of the Mean Sea Level (MSL) that are composed of sedimentary deposits.
- **Barrier:** Coasts that consist of low-lying, shore parallel sedimentary bodies. The seaward side of a *barrier* often contains a wave dominated beach environment, while the landward side consists of protected environments.
- **Delta/low estuary island:** Coasts composed of fluvial transported sediment that is deposited in front of a river mouth (sloping estuary coasts are not included in this category).
- **Sloping soft rock coast:** Coasts composed of soft rock material with an average elevation of more than 6-8 meters 500 meter inland of the MSL. These coasts can be present in the form of coastal cliffs and gently sloping hills and to meet the definition of soft rock material it should be possible to push a knife some centimetres into the rock material without using excessive force.
- **Flat hard rock coast:** Coasts consisting of hard rocky material with an average elevation of less than 6-8 meters 500 meter inland of the MSL. Can be present in different forms such as rocky coastal plains, islands and archipelagos and the hard rock can sometimes be partly hidden by a layer of weathered rock/loose sediments.
- **Sloping hard rock coast:** Coasts consisting of hard rocky material with an average elevation of more than 6-8 meters 500 meter inland of the MSL. Can be present in different forms such as coastal mountain chains, hills, headlands, islands and archipelagos and the hard rock can sometimes be partly hidden by a layer of weathered rock/loose sediments.
- **Coral island:** Coasts of low-lying coral islands in the form of tropical atolls and coral cays. Tropical atolls are open ocean coral islands that rest on a subsiding volcanic foundation while coral cays are younger islands formed from accumulation of reef-derived sediment due to wave action.
- **Tidal inlet/sand spit/river mouth (displayed as a slice pointing northwards in the CHW):** Special category for highly dynamic coastal features. *Tidal inlets* are defined as the coastline of a tidal inlet itself and one kilometre parallel to the shore on each side of the inlet. *Sand spits* are defined as elongate sedimentary features formed from

sediment deposited by longshore currents. *River mouths* are defined as the coastline one kilometre on each side of a well-defined river mouth. The TSR category is assigned high priority in the CHW system, meaning that e.g. a *sedimentary plain* will fall into this category if it is located less than one kilometre on each side of a river mouth.

The geological layout can be determined with a basic geologic map of the area, Google Earth's satellite images and Google Earth's terrain elevation function (displayed next to the geographical coordinates). The geological map is used to determine whether the coastline is composed of soft or hard rock material (can also be determined in the field), Google Earth's satellite images are used to get an overview of the coastal outline and identify form-features such as barriers, deltas, tidal inlets, sand spits, etc. and Google Earth's terrain elevation function and ruler is used to determine whether the coastline has a flat or sloping character. One should note, however, that Google Earth's elevation numbers can be significantly affected by dense vegetation and buildings, leading to overestimated elevation numbers for some areas. Field verification, more detailed elevation data, local topographic maps or sound judgement based on landscape features may therefore be necessary.

DETERMINING THE WAVE EXPOSURE

The CHW applies a wave environment perspective and distinguishes between *exposed*, *moderately exposed* and *protected* coastlines. The simplified way of estimating the wave exposure makes use of basic information on the general wave climate, waterbody size (fetch length) and wind conditions and is done through the following process:

1) Determine the general wave climate of an area based on Fig 2. All coastlines falling into "West coast swell", "East coast swell" and "Trade/monsoon influences" are classified as swell wave climates while the remaining types are classified as non-swell wave climates.

2) Determine the specific exposure level for a coastal location based on Table 1.

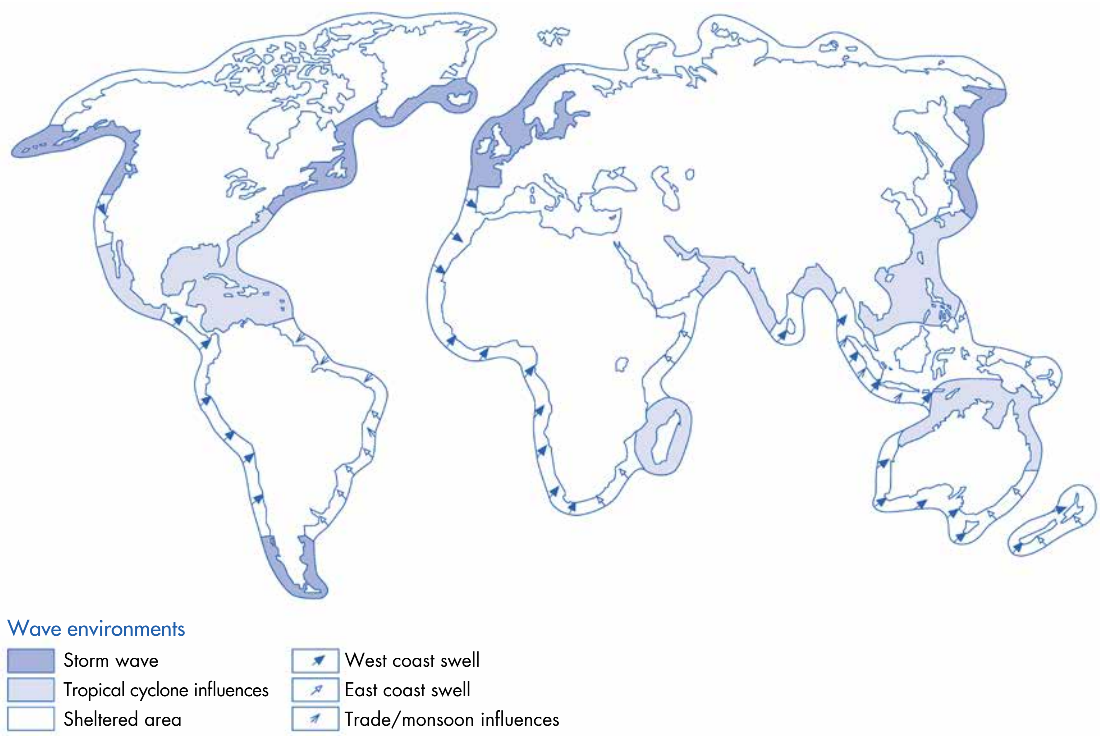


Fig. 2. *Global wave environments (Davies 1980, modified by Masselink and Hughes 2003 and Rosendahl Appelquist).*

General wave climate	Waterbody size (fetch length)	Specific coastal conditions	CHW classification
Swell wave climate (West coast swell, East coast swell, Trade/ monsoon influences)	Any	Extreme swell (West coast swell south of 30°S)	Exposed
		Swell	Moderately exposed
		Backbarrier, inner waters, inner estuary, fjord	Protected
Non-swell wave climate (Storm wave, Tropical cyclone influences, Sheltered area)	> 100 km	Stronger on-shore winds	Exposed
		Weak on-shore winds	Moderately exposed
	10 - 100 km	Stronger on-shore winds	Moderately exposed
		Weak on-shore winds	Protected
	< 10 km	Any	Protected

Table 1. *Wave exposure classification for the CHW system.*

Areas with extreme swell can be identified with the geographical coordinates displayed in Google Earth. The waterbody size (fetch length) can be determined using Google Earth's satellite images and ruler and should just be a rough estimation. Presence of weak on-shore winds can be determined with basic knowledge of the regional wind conditions and one should be particularly aware of possible weak on-shore winds in regions categorized as "Sheltered area" in Fig 2. Generally, the whole "Sheltered area" of Southeast Asia can be considered as having weak on-shore winds.

If detailed wave data is available for the coastal area in question, the wave exposure can be more properly determined based on the Hs 12h/yr as described in the Main manual. For islands not covered by Fig 2, one needs supplementary wave data to apply the CHW.

Waves braking against Tynemouth Pier, England (Photo: Gail Johnson/Shutterstock).

DETERMINING THE TIDAL RANGE

The CHW uses the relative tidal range principle that takes into account the relative importance of the wave exposure and tidal range. The classification system uses three different tidal categories, namely *micro*, *meso/macro* and *any* that are simply determined based on Fig 3 (note that the meso/macro conditions are considered together in the CHW). For islands not included in Fig 3, one has to obtain supplementary information on the local tidal conditions.

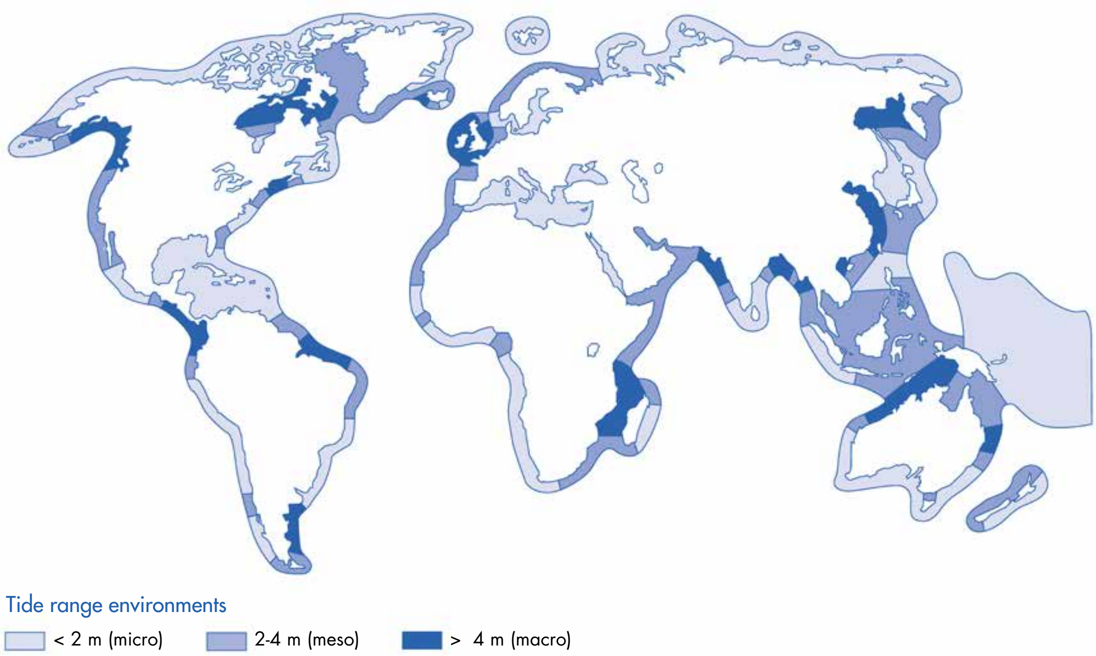


Fig. 3. *Global tidal range environments (Davies 1980, modified by Masselink and Hughes 2003).*

DETERMINING THE FLORA/FAUNA

For some coastal environments, the flora/fauna constitutes an important parameter for their character and hazard profile. In the CHW system, the flora/fauna has been included where it is considered to play an important role for the coastal characteristics and the flora/fauna categories can be determined based on the following information:

- The presence of marsh/mangrove vegetation can be determined based on Google Earth's satellite images, the latitude of the area and if possible local photos available in Google Earth.
- The presence of vegetation on S*loping soft rock coasts* can be approximately determined based on Google Earth's satellite images and if possible combined with field verification. If the initial coastal slope has a vegetation cover >25% the coast is considered vegetated.
- The presence of coral reefs can be determined based on UNEP-WCMC's coral reef database (*http://data.unep-wcmc.org/datasets/1*). One should note that the coral reef category can only be selected for hard rock coastlines as corals generally need a hard foundation to thrive on.

DETERMINING THE SEDIMENT BALANCE

The sediment balance is an essential dynamic parameter and particularly important for coastlines falling into the sedimentary/soft rock categories. The sediment balance determines whether there is a net balance, deficit or surplus of sediment at a particular coastline over time and is mainly depending on the sediment dynamics and relative sea level change. In the CHW, the sediment balance classification includes the two main categories *balance/deficit* and *surplus* that applies to the sedimentary/soft rock coastlines and the two special categories *no beach* and *beach* that applies to hard rock coastlines.

For the sedimentary/soft rock coastlines, the sediment balance can be determined based on changes in the coastal vegetation line. This is done using Google Earth's satellite images and historical imagery function in the following way:

1) Draw a line in Google Earth (using Add path in the top bar) at the approximate coastal vegetation line based on the most recent satellite image.
2) Turn on Google Earth's historical imagery function (displayed as a clock in the top bar).

3) Shift back and forth between current and historical satellite images, monitoring the vegetation line.

4) If the vegetation line is stable there is a *sediment balance*, if it retreats landwards there is a *sediment deficit* and if it advances seawards there is a *sediment surplus*.

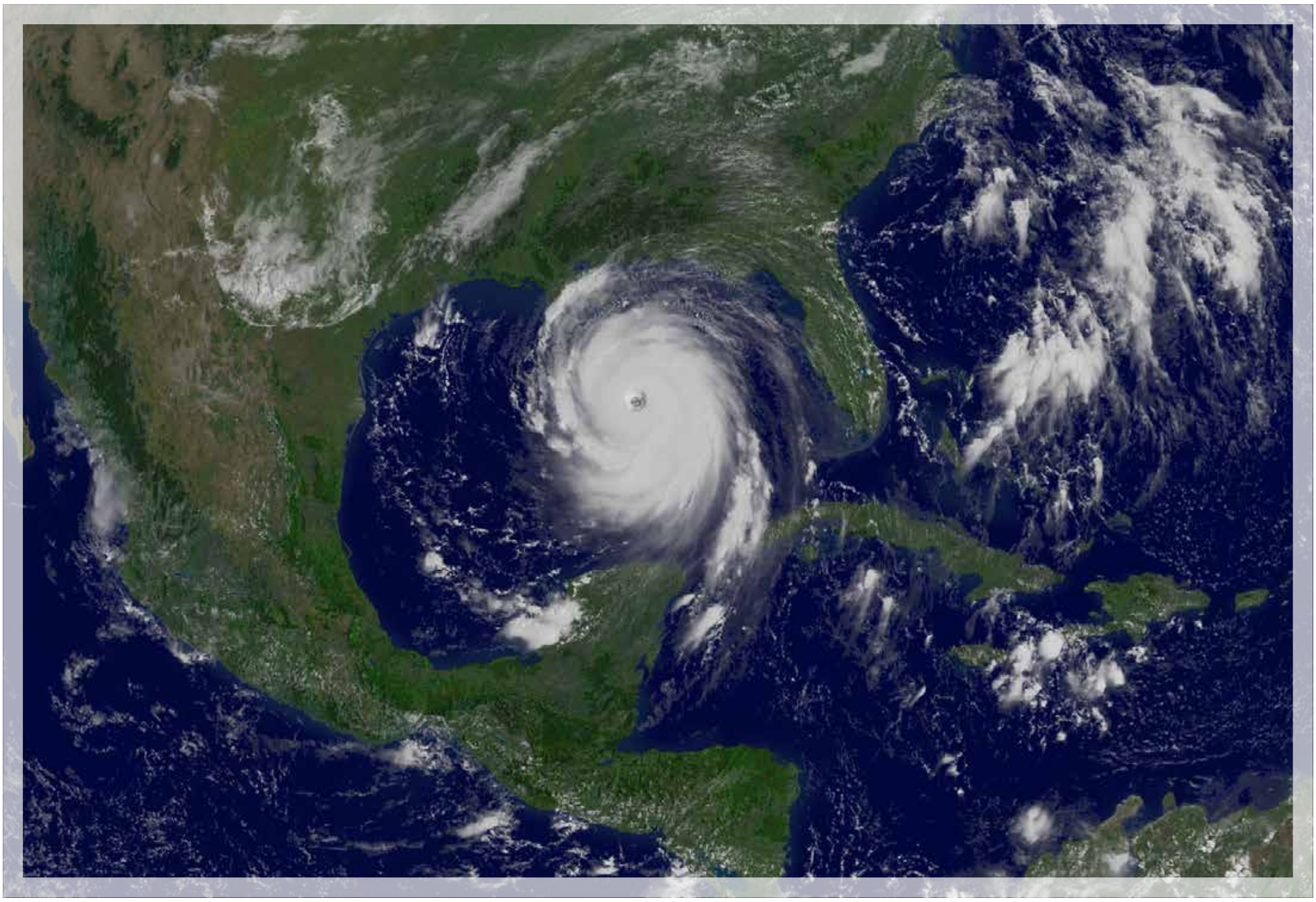
In some locations e.g. in desert coastlines, the vegetation line may not be visible and in that case it is necessary to draw an approximate vegetation line or rely on coastal evolution data (it is recommended not to use the land-water border between a few satellite images as this can fluctuate due to e.g. tidal variations). Since the evaluation of the sediment balance can be challenging, the CHW has the *balance/deficit* option as default category. This means that if there are any doubts about the sediment balance or possible human alterations, the user should assume a *balance/deficit*.

For all hard rock coastlines, one should simply determine whether some kind of beach environment is present based on Google Earth's satellite images.

DETERMINING THE STORM CLIMATE

The CHW distinguishes between locations with and without tropical cyclone activity and the system uses the map shown in Fig 2 to identify areas with tropical cyclones activity.

In areas indicated to be under "Tropical cyclone influence" the CHW applies a *yes* to tropical cyclone activity while it applies a *no* for locations outside these areas.



Tropical cyclone Katrina seen from space (Photo: NASA).

3 READING THE HAZARD VALUES

The hazard values are displayed in the outermost circles of the CHW. They are defined as the hazards being part of the bio-geophysical properties of a coastal environment when exposed to the predicted climate change over the coming decades (IPCC 2013; IPCC 2007a). The hazards included in the CHW describe the following:

- **Ecosystem disruption:** The possibility of a disruption of the current state of the coastal ecosystems under a changing climate.
- **Gradual inundation:** The possibility of a gradual submergence of a coastal environment under a changing climate.
- **Salt water intrusion:** The possibility of salty sea water penetrating into coastal surface waters and groundwater aquifers under a changing climate.
- **Erosion:** The possibility of erosion of a coastal environment under a changing climate.
- **Flooding:** The possibility of a sudden and abrupt inundation of a coastal environment caused by a short term increase in water level due to storm surge and extreme tides under a changing climate.

The CHW contains a total of 655 individual hazard evaluations that are divided into four different hazard levels describing the relative hazard level for each particular coastal type. The graduation is displayed as a combined number/colour code to give the best possible overview of the hazard profile of a specific coastal type. The hazard of tsunami has not been included as a separate hazard circle in the CHW due to the large local uncertainties, but tsunami management is included in section 5 and 6 and further addressed in the Main manual.

Coastal erosion in Holderness, England (Photo: Matthew J Thomas/Shutterstock).

4 APPLICATION FOR LOCAL, REGIONAL AND NATIONAL MULTI-HAZARD-ASSESSMENTS

The CHW can be applied for coastal multi-hazard-assessments at local, regional and national level. Depending on the data availability and accuracy requirements, the CHW can be applied at three different assessment steps and the core data requirements described in this Quick start guide represents step 1. It should be noted that the different assessment steps do not change the 200-300 meter "grid-size" but is a measure of data availability and accuracy for the assessment.

For use for local/spot-assessments, it may be appropriate simply to note down the results from the CHW, i.e. the coastal classification code and hazard values. For regional and national assessments, a manual assessment procedure for ArcGIS is outlined in this publication that allows for development of high-quality hazard maps and hazard layers for Google Earth. For the ArcGIS assessment procedure, the first thing to do is to create an up-to-date coastline for the assessment area by digitising the coastline at the approximate MSL, including backbarrier and estuary areas.

Secondly, the coastline is split into segments based on the CHW and the CHW classification code is entered for each segment. If the same coastal type extends for longer distances, a single classification segment can be extended for more than 200-300 meters to ease the classification. Following this, the CHW hazard values are added as a separate attribute table and joined to the coastline attribute table, and after that the hazard maps are created. The complete procedure for implementing multi-hazard-assessments in ArcGIS is described in the Main manual and information on ongoing data activities can be found at www.coastalhazardwheel.org.

Fig 4 and Fig 5 provide examples of hazard maps developed in ArcGIS. Generally, a standard multi-hazard-assessment will result in a series of hazard maps covering the five hazard types included in the CHW system.

> "It should be noted that the different assessment steps do not change the 200-300 meter "grid-size" but is a measure of data availability and accuracy for the assessment."

Shanghai is one of many cities located in high hazard coastal environments (Photo: Eugene Lu/Shutterstock).

Ecosystem Disruption Hazards, Djibouti

Fig. 4. *National hazard map for Djibouti showing the hazard of ecosystem disruption (Rosendahl Appelquist and Balstrøm 2014).*

Coastal hazard maps for northern Karnataka

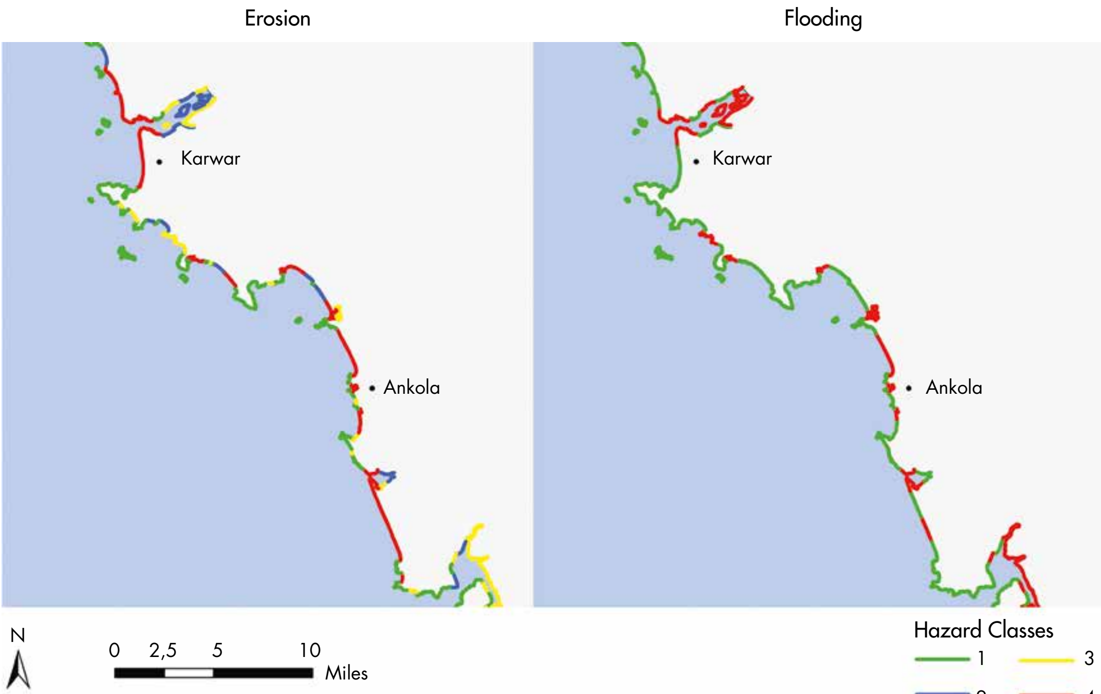


Fig. 5. *Sub-regional hazard maps for northern Karnataka, India showing the hazards of erosion and flooding (Rosendahl Appelquist and Balstrøm 2015).*

5 APPLICATION FOR IDENTIFICATION OF HAZARD MANAGEMENT OPTIONS

The CHW can be used for identifying relevant hazard management options for a specific coastal location. This is done using the matrix shown in Fig 6 that displays how the most commonly used management options apply to the different coastal environments and which hazard types they primarily address. The included management options can be used for mitigating one or more hazard types and can be used in isolation or as combined measures. In total the matrix includes 24 different management options, hereunder: *Beach nourishment, Breakwaters, Cliff stabilisation, Coastal setbacks, Coastal zoning, Dikes, Dune construction/ rehabilitation, Ecosystem based management, Floating agricultural systems, Flood mapping, Flood proofing, Flood shelters, Flood warning systems, Fluvial sediment management, Ground water management, Groynes, Jetties, Land claim, Managed realignment, Revetments, Sea wall, Storm surge barrier/closure dam, Tsunami warning system and Wetland restoration.*

Whereas some of the listed management options offer temporary and flexible hazard mitigation, others are more static and permanent measures. Common for all management options, however, is the need for continuous monitoring, iterative improvements and maintenance over time, as they are continuously affected by the natural dynamics. Choosing between management options should therefore include a thorough consideration of pros and cons of different short and long term hazard reduction effects, the flexibility of the strategy over time and the wider societal use of a coastal area.

The matrix shown in Fig 6 is used by entering with the CHW coastal classification code and then identifying the relevant management options for the coastal environment in question. Reference to the relevant sections in the Catalogue of hazard management options is provided in the second row from the top. The geological layout categories *Sedimentary plain*, *Barrier* and *Delta/low estuary island* are considered together for simplification reasons as the management options available for these layouts are relatively similar.

Beach nourishment with Trailing Suction Hopper Dredger (Photo: Rohde Nielsen).

Ecosystem disruption

Management options	Coastal zoning	Dune construction/rehabilitation	Ecosystem Based Management	Fluvial sediment management	Groundwater management	Wetland restoration
Catalogue section no	5	7	8	14	15	24
PL/BA/DE-1	x	x	x	x		
PL/BA/DE-2	x	x	x	x		
PL/BA/DE-3	x	x	x	x		
PL/BA/DE-4	x	x	x	x		
PL/BA/DE-5	x	x	x	x		
PL/BA/DE-6	x	x	x	x		
PL/BA/DE-7	x	x	x	x		
PL/BA/DE-8	x	x	x	x		
PL/BA/DE-9	x		x	x		x
PL/BA/DE-10	x		x	x		x
PL/BA/DE-11	x		x	x		x
PL/BA/DE-12	x		x	x		x
PL/BA/DE-13	x		x	x		x
PL/BA/DE-14	x		x	x		x
PL/BA/DE-15	x		x	x		x
PL/BA/DE-16	x		x	x		x
PL/BA/DE-17	x		x	x		x
PL/BA/DE-18	x		x	x		x
PL/BA/DE-19	x		x	x		x
PL/BA/DE-20	x		x	x		x
PL/BA/DE-21	x		x	x		x
PL/BA/DE-22	x		x	x		x
PL/BA/DE-23	x		x	x		x
PL/BA/DE-24	x		x	x		x
SR-1	x		x			
SR-2	x		x			
SR-3	x		x			
SR-4	x		x			
SR-5	x		x			
SR-6	x		x			
SR-7	x		x			
SR-8	x		x			
SR-9	x		x			
SR-10	x		x			
SR-11	x		x			
SR-12	x		x			
SR-13	x		x			
SR-14	x		x			
SR-15	x		x			
SR-16	x		x			
SR-17	x		x			
SR-18	x		x			
SR-19	x		x			
SR-20	x		x			
FR-1	x		x			
FR-2	x		x			
FR-3	x		x			
FR-4	x		x			
FR-5	x		x			
FR-6	x		x			
FR-7	x		x			
FR-8	x		x			
FR-9	x		x			
FR-10	x		x			
FR-11	x		x			
FR-12	x		x			
FR-13	x		x			
FR-14	x		x			
FR-15	x		x			
FR-16	x		x			
FR-17	x		x			
FR-18	x		x			
FR-19	x		x			x
FR-20	x		x			x
FR-21	x		x			
FR-22	x		x			
R-1	x		x			
R-2	x		x			
R-3	x		x			
R-4	x		x			
CI-1	x		x		x	
CI-2	x		x		x	
CI-3	x		x		x	
CI-4	x		x		x	
CI-5	x		x		x	
CI-6	x		x		x	
CI-7	x		x		x	
CI-8	x		x		x	
CI-9	x		x		x	x
CI-10	x		x		x	x
CI-11	x		x		x	x
CI-12	x		x		x	x
TSR	x		x	x		x

Gradual inundation

Management options	Beach nourishment	Coastal setbacks	Coastal zoning	Dikes	Floating agricultural system	Flood proofing	Fluvial sediment management	Groundwater management	Land claim	Managed realignment	Storm surge barriers & closure dams	Wetland restoration
Catalogue section no	1	4	5	6	9	11	14	15	18	19	22	24
PL/BA/DE-1	x	x	x	x		x	x	x	x	x		
PL/BA/DE-2	x	x	x	x		x	x	x	x	x		
PL/BA/DE-3	x	x	x	x		x	x	x	x	x		
PL/BA/DE-4	x	x	x	x		x	x	x	x	x		
PL/BA/DE-5	x	x	x	x		x	x	x	x	x		
PL/BA/DE-6	x	x	x	x		x	x	x	x	x		
PL/BA/DE-7	x	x	x	x		x	x	x	x	x		
PL/BA/DE-8	x	x	x	x		x	x	x	x	x		
PL/BA/DE-9		x	x	x	x	x	x	x	x	x		x
PL/BA/DE-10		x	x	x	x	x	x	x	x	x		x
PL/BA/DE-11		x	x	x	x	x	x	x	x	x		x
PL/BA/DE-12		x	x	x	x	x	x	x	x	x		x
PL/BA/DE-13		x	x	x	x	x	x	x	x	x		x
PL/BA/DE-14		x	x	x	x	x	x	x	x	x		x
PL/BA/DE-15		x	x	x	x	x	x	x	x	x		x
PL/BA/DE-16		x	x	x	x	x	x	x	x	x		x
PL/BA/DE-17		x	x	x	x	x	x	x	x	x		x
PL/BA/DE-18		x	x	x	x	x	x	x	x	x		x
PL/BA/DE-19		x	x	x	x	x	x	x	x	x		x
PL/BA/DE-20		x	x	x	x	x	x	x	x	x		x
PL/BA/DE-21		x	x	x	x	x	x	x	x	x		x
PL/BA/DE-22		x	x	x	x	x	x	x	x	x		x
PL/BA/DE-23		x	x	x	x	x	x	x	x	x		x
PL/BA/DE-24		x	x	x	x	x	x	x	x	x		x
SR-1	x		x									
SR-2	x		x									
SR-3	x		x									
SR-4	x		x									
SR-5	x		x									
SR-6	x		x									
SR-7	x		x									
SR-8	x		x									
SR-9	x		x									
SR-10	x		x									
SR-11	x		x									
SR-12	x		x									
SR-13	x		x									
SR-14	x		x									
SR-15	x		x									
SR-16	x		x									
SR-17			x									
SR-18			x									
SR-19			x									
SR-20			x									
FR-1		x	x	x		x				x		
FR-2		x	x	x		x				x		
FR-3	x	x	x	x		x				x		
FR-4	x	x	x	x		x				x		
FR-5		x	x	x		x				x		
FR-6		x	x	x		x				x		
FR-7	x	x	x	x		x				x		
FR-8	x	x	x	x		x				x		
FR-9		x	x	x		x				x		
FR-10		x	x	x		x				x		
FR-11	x	x	x	x		x				x		
FR-12	x	x	x	x		x				x		
FR-13		x	x	x		x				x		
FR-14		x	x	x		x				x		
FR-15	x	x	x	x		x				x		
FR-16	x	x	x	x		x				x		
FR-17		x	x	x		x				x		
FR-18		x	x	x		x				x		
FR-19		x	x	x		x				x		x
FR-20		x	x	x		x				x		x
FR-21		x	x	x		x				x		
FR-22		x	x	x		x				x		
R-1			x									
R-2	x		x									
R-3			x									
R-4	x		x									
CI-1	x	x	x	x		x				x		
CI-2	x	x	x	x		x				x		
CI-3	x	x	x	x		x				x		
CI-4	x	x	x	x		x				x		
CI-5	x	x	x	x		x				x		
CI-6	x	x	x	x		x				x		
CI-7	x	x	x	x		x				x		
CI-8	x	x	x	x		x				x		
CI-9		x	x	x		x				x		x
CI-10		x	x	x		x				x		x
CI-11		x	x	x		x				x		x
CI-12		x	x	x		x				x		x
TSR	x	x	x	x	x	x	x			x	x	x

Salt water intrusion

Management options	Coastal zoning	Dikes	Dune construction/rehabilitation	Floating agricultural system	Fluvial sediment management	Groundwater management	Storm surge barriers & closure dams	Wetland restoration
Catalogue section no	5	6	7	9	14	15	22	24
PL/BA/DE-1	x	x	x		x	x		
PL/BA/DE-2	x	x	x		x	x		
PL/BA/DE-3	x	x	x		x	x		
PL/BA/DE-4	x	x	x		x	x		
PL/BA/DE-5	x	x	x		x	x		
PL/BA/DE-6	x	x	x		x	x		
PL/BA/DE-7	x	x	x		x	x		
PL/BA/DE-8	x	x	x		x	x		
PL/BA/DE-9	x	x		x	x	x		x
PL/BA/DE-10	x	x		x	x	x		x
PL/BA/DE-11	x	x		x	x	x		x
PL/BA/DE-12	x	x		x	x	x		x
PL/BA/DE-13	x	x		x	x	x		x
PL/BA/DE-14	x	x		x	x	x		x
PL/BA/DE-15	x	x		x	x	x		x
PL/BA/DE-16	x	x		x	x	x		x
PL/BA/DE-17	x	x		x	x	x		x
PL/BA/DE-18	x	x		x	x	x		x
PL/BA/DE-19	x	x		x	x	x		x
PL/BA/DE-20	x	x		x	x	x		x
PL/BA/DE-21	x	x		x	x	x		x
PL/BA/DE-22	x	x		x	x	x		x
PL/BA/DE-23	x	x		x	x	x		x
PL/BA/DE-24	x	x		x	x	x		x
SR-1	x					x		
SR-2	x					x		
SR-3	x					x		
SR-4	x					x		
SR-5	x					x		
SR-6	x					x		
SR-7	x					x		
SR-8	x					x		
SR-9	x					x		
SR-10	x					x		
SR-11	x					x		
SR-12	x					x		
SR-13	x					x		
SR-14	x					x		
SR-15	x					x		
SR-16	x					x		
SR-17	x					x		
SR-18	x					x		
SR-19	x					x		
SR-20	x					x		
FR-1	x	x				x		
FR-2	x	x				x		
FR-3	x	x				x		
FR-4	x	x				x		
FR-5	x	x				x		
FR-6	x	x				x		
FR-7	x	x				x		
FR-8	x	x				x		
FR-9	x	x				x		
FR-10	x	x				x		
FR-11	x	x				x		
FR-12	x	x				x		
FR-13	x	x				x		
FR-14	x	x				x		
FR-15	x	x				x		
FR-16	x	x				x		
FR-17	x	x				x		
FR-18	x	x				x		
FR-19	x	x				x		x
FR-20	x	x				x		x
FR-21	x	x				x		
FR-22	x	x				x		
R-1	x					x		
R-2	x					x		
R-3	x					x		
R-4	x					x		
CI-1	x	x				x		
CI-2	x	x				x		
CI-3	x	x				x		
CI-4	x	x				x		
CI-5	x	x				x		
CI-6	x	x				x		
CI-7	x	x				x		
CI-8	x	x				x		
CI-9	x	x				x		x
CI-10	x	x				x		x
CI-11	x	x				x		x
CI-12	x	x				x		x
TSR	x	x		x		x	x	

Erosion

Management options	Beach nourishment	Breakwaters	Cliff stabilization	Coastal setbacks	Coastal zoning	Dune construction/rehabilitation	Fluvial sediment management	Groundwater management	Groynes	Jetties	Land claim	Managed realignment	Revetments	Sea Walls	Wetland restoration
Catalogue section no	1	2	3	4	5	7	14	15	16	17	18	19	20	21	24
PL/BA/DE-1	x	x		x	x	x	x		x		x	x	x	x	
PL/BA/DE-2	x	x		x	x	x	x		x		x	x	x	x	
PL/BA/DE-3	x	x		x	x	x	x		x		x	x	x	x	
PL/BA/DE-4	x	x		x	x	x	x		x		x	x	x	x	
PL/BA/DE-5	x	x		x	x	x	x		x		x	x	x	x	
PL/BA/DE-6	x	x		x	x	x	x		x		x	x	x	x	
PL/BA/DE-7	x	x		x	x	x	x		x		x	x	x	x	
PL/BA/DE-8	x	x		x	x	x	x		x		x	x	x	x	
PL/BA/DE-9				x	x		x				x	x			x
PL/BA/DE-10				x	x		x				x	x			x
PL/BA/DE-11				x	x		x				x	x			x
PL/BA/DE-12				x	x		x				x	x			x
PL/BA/DE-13				x	x		x				x	x			x
PL/BA/DE-14				x	x		x				x	x			x
PL/BA/DE-15				x	x		x				x	x			x
PL/BA/DE-16				x	x		x				x	x			x
PL/BA/DE-17				x	x		x				x	x			x
PL/BA/DE-18				x	x		x				x	x			x
PL/BA/DE-19				x	x		x				x	x			x
PL/BA/DE-20				x	x		x				x	x			x
PL/BA/DE-21				x	x		x				x	x			x
PL/BA/DE-22				x	x		x				x	x			x
PL/BA/DE-23				x	x		x				x	x			x
PL/BA/DE-24				x	x		x				x	x			x
SR-1	x	x	x	x	x		x	x	x			x	x	x	
SR-2	x	x	x	x	x		x	x	x			x	x	x	
SR-3	x	x	x	x	x		x	x	x			x	x	x	
SR-4	x	x	x	x	x		x	x	x			x	x	x	
SR-5	x	x	x	x	x		x	x	x			x	x	x	
SR-6	x	x	x	x	x		x	x	x			x	x	x	
SR-7	x	x	x	x	x		x	x	x			x	x	x	
SR-8	x	x	x	x	x		x	x	x			x	x	x	
SR-9	x	x	x	x	x		x	x	x			x	x	x	
SR-10	x	x	x	x	x		x	x	x			x	x	x	
SR-11	x	x	x	x	x		x	x	x			x	x	x	
SR-12	x	x	x	x	x		x	x	x			x	x	x	
SR-13	x	x	x	x	x		x	x	x			x	x	x	
SR-14	x	x	x	x	x		x	x	x			x	x	x	
SR-15	x	x	x	x	x		x	x	x			x	x	x	
SR-16	x	x	x	x	x		x	x	x			x	x	x	
SR-17			x	x	x		x	x				x			
SR-18			x	x	x		x	x				x			
SR-19			x	x	x		x	x				x			
SR-20			x	x	x		x	x				x			
FR-1					x										
FR-2					x										
FR-3	x	x			x		x		x						
FR-4	x	x			x		x		x						
FR-5					x										
FR-6					x										
FR-7	x	x			x		x		x						
FR-8	x	x			x		x		x						
FR-9					x										
FR-10					x										
FR-11	x	x			x		x		x						
FR-12	x	x			x		x		x						
FR-13					x										
FR-14					x										
FR-15	x	x			x		x		x						
FR-16	x	x			x		x		x						
FR-17					x										
FR-18					x										
FR-19					x		x								x
FR-20					x		x								x
FR-21					x										
FR-22					x										
R-1					x										
R-2	x	x			x		x		x						
R-3					x										
R-4	x	x			x		x		x						
CI-1	x	x		x	x				x			x	x	x	
CI-2	x	x		x	x				x			x	x	x	
CI-3	x	x		x	x				x			x	x	x	
CI-4	x	x		x	x				x			x	x	x	
CI-5	x	x		x	x				x			x	x	x	
CI-6	x	x		x	x				x			x	x	x	
CI-7	x	x		x	x				x			x	x	x	
CI-8	x	x		x	x				x			x	x	x	
CI-9				x	x							x	x	x	x
CI-10				x	x							x	x	x	x
CI-11				x	x							x	x	x	x
CI-12				x	x							x	x	x	x
TSR	x	x		x	x		x		x	x		x	x	x	x

Flooding

Management options	Coastal setbacks	Coastal zoning	Dikes	Dune construction/rehabilitation	Floating agricultural system	Flood mapping	Flood proofing	Flood shelter	Flood warning systems	Fluvial sediment management	Managed realignment	Storm surge barriers & closure dams	Tsunami warning system	Wetland restoration
Catalogue section no	4	5	6	7	9	10	11	12	13	14	19	22	23	24
PL/BA/DE-1	x	x	x	x		x	x	x	x	x	x		x	
PL/BA/DE-2	x	x	x	x		x	x		x	x	x		x	
PL/BA/DE-3	x	x	x	x		x	x	x	x	x	x		x	
PL/BA/DE-4	x	x	x	x		x	x		x	x	x		x	
PL/BA/DE-5	x	x	x	x		x	x	x	x	x	x		x	
PL/BA/DE-6	x	x	x	x		x	x		x	x	x		x	
PL/BA/DE-7	x	x	x	x		x	x	x	x	x	x		x	
PL/BA/DE-8	x	x	x	x		x	x		x	x	x		x	
PL/BA/DE-9	x	x	x		x	x	x	x	x	x	x		x	x
PL/BA/DE-10	x	x	x		x	x	x		x	x	x		x	x
PL/BA/DE-11	x	x	x		x	x	x	x	x	x	x		x	x
PL/BA/DE-12	x	x	x		x	x	x		x	x	x		x	x
PL/BA/DE-13	x	x	x		x	x	x	x	x	x	x		x	x
PL/BA/DE-14	x	x	x		x	x	x		x	x	x		x	x
PL/BA/DE-15	x	x	x		x	x	x	x	x	x	x		x	x
PL/BA/DE-16	x	x	x		x	x	x		x	x	x		x	x
PL/BA/DE-17	x	x	x		x	x	x	x	x	x	x		x	x
PL/BA/DE-18	x	x	x		x	x	x		x	x	x		x	x
PL/BA/DE-19	x	x	x		x	x	x	x	x	x	x		x	x
PL/BA/DE-20	x	x	x		x	x	x		x	x	x		x	x
PL/BA/DE-21	x	x	x		x	x	x	x	x	x	x		x	x
PL/BA/DE-22	x	x	x		x	x	x		x	x	x		x	x
PL/BA/DE-23	x	x	x		x	x	x	x	x	x	x		x	x
PL/BA/DE-24	x	x	x		x	x	x		x	x	x		x	x
SR-1		x											x	
SR-2		x											x	
SR-3		x											x	
SR-4		x											x	
SR-5		x											x	
SR-6		x											x	
SR-7		x											x	
SR-8		x											x	
SR-9		x											x	
SR-10		x											x	
SR-11		x											x	
SR-12		x											x	
SR-13		x											x	
SR-14		x											x	
SR-15		x											x	
SR-16		x											x	
SR-17		x											x	
SR-18		x											x	
SR-19		x											x	
SR-20		x											x	
FR-1	x	x	x			x	x	x	x		x		x	
FR-2	x	x	x			x	x		x		x		x	
FR-3	x	x	x			x	x	x	x		x		x	
FR-4	x	x	x			x	x		x		x		x	
FR-5	x	x	x			x	x	x	x		x		x	
FR-6	x	x	x			x	x		x		x		x	
FR-7	x	x	x			x	x	x	x		x		x	
FR-8	x	x	x			x	x		x		x		x	
FR-9	x	x	x			x	x	x	x		x		x	
FR-10	x	x	x			x	x		x		x		x	
FR-11	x	x	x			x	x	x	x		x		x	
FR-12	x	x	x			x	x		x		x		x	
FR-13	x	x	x			x	x	x	x		x		x	
FR-14	x	x	x			x	x		x		x		x	
FR-15	x	x	x			x	x	x	x		x		x	
FR-16	x	x	x			x	x		x		x		x	
FR-17	x	x	x			x	x	x	x		x		x	
FR-18	x	x	x			x	x		x		x		x	
FR-19	x	x	x			x	x	x	x		x		x	x
FR-20	x	x	x			x	x		x		x		x	x
FR-21	x	x	x			x	x	x	x		x		x	
FR-22	x	x	x			x	x		x		x		x	
R-1		x											x	
R-2		x											x	
R-3		x											x	
R-4		x											x	
CI-1	x	x	x			x	x	x	x		x		x	
CI-2	x	x	x			x	x		x		x		x	
CI-3	x	x	x			x	x	x	x		x		x	
CI-4	x	x	x			x	x		x		x		x	
CI-5	x	x	x			x	x	x	x		x		x	
CI-6	x	x	x			x	x		x		x		x	
CI-7	x	x	x			x	x	x	x		x		x	
CI-8	x	x	x			x	x		x		x		x	
CI-9	x	x	x			x	x	x	x		x		x	x
CI-10	x	x	x			x	x		x		x		x	x
CI-11	x	x	x			x	x	x	x		x		x	x
CI-12	x	x	x			x	x		x		x		x	x
TSR	x	x	x		x	x	x	x	x		x	x	x	x

Fig. 6. *Matrix of hazard management options for the different coastal environments. It is used by entering with the CHW coastal classification codes in the far left column and moving horizontally to identify relevant management options. Reference to the Catalogue of hazard management options is provided in the second row from the top (modified from Rosendahl Appelquist and Halsnæs 2015).*

6 APPLICATION AS A STANDARDIZED COASTAL LANGUAGE

The CHW can be used as a standardized coastal language to describe the conditions at a given coastal location. This is done by combining the CHW coastal classification codes with codes for land use and implemented hazard management measures.

The codes for land use are based on the EU LUCAS categories to facilitate compatibility with international statistics. The coding is displayed in Table 2 and can either be determined based on observations in the field/Google Earth or on more complete statistical information. If relevant, the complete detailed EU LUCAS coding can be used (Eurostat 2015).

Land use	Standardized code
Agriculture	U110
Forestry	U120
Aquaculture and fishing	U130
Mining and quarrying	U140
Energy production	U210
Industry and manufacturing	U220
Transport, communication networks, storage, protective works	U310
Water and waste treatment	U320
Construction	U330
Commerce, finance, business	U340
Community services	U350
Recreational, leisure, sport	U360
Residential	U370
Unused	U400

Table 2. *Standardized land use codes based on the EU LUCAS main categories.*

Residential and recreational land use at Cape Cod, USA (Photo: Holbox/Shutterstock).

The codes for implemented hazard management measures are displayed in Table 3. Since the quality of the hazard management measures is essential for their hazard mitigation function, the coding includes four quality levels that should be estimated by the user.

Hazard management measures	Standardized code
Beach nourishment	BE
Breakwater	BR
Cliff stabilisation	CL
Coastal setback	CS
Coastal zoning	CZ
Dike	DI
Dune construction/rehabilitation	DU
Ecosystem based management	EC
Floating agricultural system	FA
Flood mapping	FM
Flood proofing	FP
Flood shelter	FS
Flood warning system	FW
Fluvial sediment management	FU
Groundwater management	GM
Groyne	GR
Jetty	JE
Land claim	LA
Managed realignment	MA
Revetment	RE
Sea wall	SE
Storm surge barrier/closure dam	ST
Tsunami warning system	TS
Wetland restoration	WE
User defined	*Write full word*

Quality level of hazard management measures	
No information	0
Low	1
Moderate	2
International state of the art	3

Table 3. *Standardized codes for hazard management measures and quality level.*

The standardized language obeys the following format with the codes from Table 2 and 3:

CHW coastal classification code: Land use, Hazard management measure-Quality level

If several land use or hazard management measures are present at a coastal location, several codes can be added after each other using the same format and comma-separation. This is illustrated for the coastal locations Labutta town, Lagos CBD and Miami Beach below. Since some land use categories may be of minor importance for a particular coastal site, it is up to the user to determine the main activity(s) that should be listed.

- Labutta town, Myanmar: **DE-21: U130, U370, FW-1**
- Lagos CBD, Nigeria: **TSR: U310, U340, U370, FW-2, JE-3, LA-3**
- *Miami Beach, USA:* **BA-1: U310, U340, U360, U370, BE-3, FW-3, TS-3**

It should be noted that the hazard values displayed in the CHW do not take possible hazard management actions into account as their specific effect is surrounded by great uncertainty depending on design. However, if a recommended hazard management measure is implemented at “moderate” to “international state of the art” quality at a coastal location, one can assume that the hazards it is designed to address are reduced.

www.unep.org

United Nations Environment Programme
P.O. Box 30552 - 00100 Nairobi, Kenya
Tel.: +254 20 762 1234
e-mail: publications@unep.org
www.unep.org

Managing climate change hazards in coastal areas - The Coastal Hazard Wheel decision-support system

25 YEARS 2016 UNEP DTU PARTNERSHIP

UNEP-DHI PARTNERSHIP
Centre on Water and Environment