ASSESSMENT OF COASTAL HAZARDS, VULNERABILITY AND RISKS FOR THE COAST OF OMAN

TSUNAMI VULNERABILITY AND RISK ASSESSMENT FOR THE DEVELOPMENT OF PLANNING TOOLS IN OMAN

Reducing Tsunami Risk in the Western Indian Ocean: a Regional Conference in Muscat, Oman
22 - 23 March 2015, Muscat, Oman

Mauricio González, Ignacio Aguirre-Ayerbe, Pino González-Riancho, Iñigo Aniel, Raúl Medina

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OUTLINE

1. TSUNAMI VULNERABILITY AND RISK ASSESSMENT

2. TSUNAMI RISK REDUCTION MEASURES
   2.1. CATALOGUE OF MITIGATION MEASURES
   2.2. METHODOLOGY FOR THE RECOMMENDATION OF MITIGATION MEASURES AT PARTICULAR LOCATIONS
   2.3 MITIGATION HANDBOOK FOR THE COAST OF OMAN
1. **Tsunami Vulnerability and Risk Assessment**
Risk Assessment
Conceptual framework
\[ R = H \times E \times V \]
Risk Assessment

Working Methodology

- Hazard
  - Human Vulnerability Index
  - Infrastructure Vulnerability Index
    - Human Risk
      - Risk: 0.6
    - Infrastructure Risk
      - Risk: 0.4
HAZARD ASSESSMENT

HAZARDS: TSUNAMI /STORM SURGE (CYCLONS)
WORST CREDIBLE SCENARIOS (AGGREGATED MAP)

**Max: H, h, (U,V)**
Risk Assessment

Working Methodology

- Hazard
- Human Vulnerability Index
- Infrastructure Vulnerability Index
  - Human Risk
  - Infrastructure Risk
    - Risk
      - 0.6
      - 0.4
# Vulnerability Assessment

## Variables

<table>
<thead>
<tr>
<th>Reduced Mobility, Slow Evacuation</th>
<th>Limitations to Understand a Warning Message</th>
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<tbody>
<tr>
<td>People in hazard area</td>
<td>People &lt; 10 and &gt;65 yr old</td>
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<tr>
<td></td>
<td>Disabled people</td>
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<td>Illiterate people</td>
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<td>Expatriates</td>
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## Indicators

<table>
<thead>
<tr>
<th>Exposed population</th>
<th>Sensitive age groups</th>
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<tr>
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<td>Illiteracy</td>
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<td>Foreign language</td>
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</table>

## Indices

<table>
<thead>
<tr>
<th>Exposed buildings and infrastructures</th>
<th>Critical buildings</th>
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<tr>
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<td>Emergency</td>
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<td>Supply</td>
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<td>Dangerous</td>
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## Indices Values

<table>
<thead>
<tr>
<th>Vulnerability Index Class</th>
<th>Class / Color assigned</th>
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<tbody>
<tr>
<td>1</td>
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<td>2</td>
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<tr>
<td>4</td>
<td>High</td>
</tr>
<tr>
<td>5</td>
<td>Very High</td>
</tr>
</tbody>
</table>
Risk Assessment

Working Methodology

- Human Vulnerability Index
- Infrastructure Vulnerability Index
- Hazard
- Human Risk
- Infrastructure Risk
- Risk

Values:
- Human Risk: 0.6
- Infrastructure Risk: 0.4
Risk Assessment

Hazard Assessment

Vulnerability Assessment

Aggregated Risk

Value ranges

Risk classes

Aggregated risk classification

Risk classes

Very low
Low
Medium
High
Very high

Value ranges

[1 – 1.5)
[1.5 – 4.5)
[4.5 – 9.5)
[9.5 – 18.5)
[18.5 – 25]
Hazard, Vulnerability and Risk Atlas
Hazard, Vulnerability and Risk Atlas

9 Study Areas at Local Scale
RISK ASSESSMENT. NATIONAL SCALE

Human Risk

Infrastructure Risk
EXAMPLE HUMAN RISK ASSESSMENT
LOCAL SCALE - MUSCAT

HUMAN VULNERABILITY INDEX CLASSES

HAZARD CLASSES (Drag level)

HUMAN RISK CLASSES

Built-up area

People at Risk
(Number and percentage of inhabitants)

Very high
High
Medium
Low
Very low

69297
75%
12345
13%
10074
11%
738
1%
20
0.02%

12345
13%
69297
75%
10074
11%
738
1%
20
0.02%

(Numbers and percentages of inhabitants)
2. Tsunami Risk Reduction Measures

2.1. Catalogue of Mitigation Measures

2.2. Methodology for the recommendation of mitigation measures at particular locations

2.3 Mitigation Handbook for the Coast of Oman
# Catalogue of Mitigation Measures

## Fact-sheet example

### Seawalls and Sea Dikes

**Goal**

Prevention or reduction of wave overtopping for protection of low-lying coastal areas from inundation by the sea under extreme marine climate conditions or tsunamis.

### Rationale

Seawalls and sea dikes are rigid structures built along the shore with diverse typologies (vertical, sloping, curved,...). They are usually conceived as coastal erosion protection structures that limit shoreline movement. The limitation of shoreline retreat prevents inland territory from further flooding in the future. Besides, they effectively prevent coastal flooding by means of an elevated freeboard. Design height of many seawalls is based on the highest known flood level (Van der Meer, 1998).

### Preliminary Requirements

- Local geology assessment.
- Seasonal and inter-annual erosion rates.
- Wave-structure interaction assessment.
- Proper design and construction supervision (UNFCCC, 1999).

### Supplementary Measures

- Movable barriers and closure dams; Land claim.
- Beach nourishment; Managed realignment.
- Flood Hazard/vulnerability/Risk mapping and assessment.
- Capacity building.

### Efficiency

High degree of protection against coastal flooding up to the seawall design height.

### Durability

Usual life design is 50 years, although they may need some repairs after extreme events.

### Cost

- Initial cost:

  Vertical seawalls: From 0.4 to 27.5 US$m$/Km (Linham et al. 2010). Costs variation due to design height, wave energy, typology, construction methods, availability of construction material,...

  Maintenance cost: Continued investment is highly recommended to ensure continued operation of the structure.

### Success Factors

- Diwan of Royal Court
- MEECA, MoTC, MoAF, MoT, MoI, MoH.
- SCP
- NPO, Coast Guards.
- Municipalities.
- Private contractors/developers.

### Examples

- Santander (Spain): Source: Hydraulics Institute.
- Al Qurum (Oman): Source: IH cantabria.

### Strengths

- Effectively protects against coastal flooding for rising water levels up to the seawall design free board.
- Long term solution in comparison to soft engineering solutions.
- Effectively deflects and/or dissipates wave energy.
- Little occupation of sea floor (specially the vertical wall).

### Weaknesses

- Very expensive to construct.
- Likely to develop scours at the base.
- Difficult cross-shore accessibility.

### Opportunities

- Efficient coastal erosion protection for shoreline stabilization.
- Can be used for recreation and sightseeing.
- Compatible with other flooding mitigation measures.

### Threats

- Affection to coastal dynamics: possibility of erosion down drift from the structure.
- Reflected waves magnify wave energy at seawall foot resulting in possible local erosion and scours.
- Aesthetic problems in natural touristic areas.
- Obstacle natural inshore-offshore processes: It can destroy habitats such as wetlands and intertidal beaches.
- Some revetments might reduce bottom friction and, therefore accelerate flow velocity.

### References


**Engineer-based Prevention Measures**

<table>
<thead>
<tr>
<th>Scheme</th>
<th>Examples of seawalls</th>
</tr>
</thead>
<tbody>
<tr>
<td>Irregular face</td>
<td>Santander (Spain)</td>
</tr>
<tr>
<td>Revetment</td>
<td>Al Qurum (Oman)</td>
</tr>
<tr>
<td>Vertical wall</td>
<td>Natori Green Belt before and after the 2011 Japan Tsunami (Japan)</td>
</tr>
</tbody>
</table>

**Efficiency**

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Methodology for the recommendation of mitigation measures at particular locations

1. Determination of management units

   National Scale
   Identification of Hot-Spots (HS) by the RAW-WG
   Assignments of:
   1. Risk class (Tsunami and Storm Surge National Risk Assessment)
   2. Geology/Land Cover type.

   Local Scale
   Delimitation of Management Units (MU) in base to homogeneous:
   1. Risk class (Tsunami and Storm Surge Local Risk Assessment)
   2. Geology/Land Cover type.

2. Selection of Mitigation Measures
   - Decision matrix

   National Scale
   According to:
   - HS type
   - Geology/Land Cover type.

   Local Scale
   According to:
   - Geology/Land Cover type

3. Prioritization of Mitigation Measures

RAW-WG

Risk assessment Workshop (part 1, Muscat, 1 - 5 June 2014).
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   - National Scale
   - Local Scale

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   According to:
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   - Geology/Land Cover type.

3. Prioritization of Mitigation Measures
   - National Scale
   - Local Scale

   According to:
   - Geology/Land Cover type.
Methodology for the recommendation of mitigation measures at particular locations.
Methodology for the recommendation of mitigation measures at particular locations

9 Local Study Areas
Example - Sohar
Methodology for the recommendation of mitigation measures at particular locations

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   - National Scale
     - Identification of Hot-Spots (HS) by the RAW-WG
     - Assignment of:
       1. Risk class (Tsunami and Storm Surge National Risk Assessment)
       2. Geology/Land Cover type.
   - Local Scale
     - Delimitation of Management Units (MU) based on homogeneity:
       - Risk class (Tsunami and Storm Surge Local Risk Assessment)
       - Geology/Land Cover type.

2. Selection of Mitigation Measures
   - Decision matrix
     - National Scale
       - According to:
         - HS type
         - Geology/Land Cover type
     - Local Scale
       - According to:
         - Geology/Land Cover type

3. Prioritization of Mitigation Measures
# Methodology for the recommendation of mitigation measures at particular locations

## Decision Matrix

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Approach</th>
<th>Mitigation measure</th>
<th>CODE</th>
<th>Geology</th>
<th>Land Cover</th>
<th>Hot spots</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td></td>
<td>Bare non consolidated</td>
<td>Bare consolidated</td>
<td>Built-up</td>
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<tr>
<td>Prevention</td>
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<td>EN. 1</td>
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<td></td>
<td></td>
<td>Breakwaters</td>
<td>EN. 2</td>
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<tr>
<td></td>
<td></td>
<td>Movable barriers and closure dams</td>
<td>EN. 3</td>
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<td></td>
<td>Land claim</td>
<td>EN. 4</td>
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<td></td>
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<td>Managed realignment</td>
<td>NA. 1</td>
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<td></td>
<td>Beach nourishment</td>
<td>NA. 2</td>
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<td>Artificial sand dunes, dune restoration</td>
<td>NA. 3</td>
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<td>Living shorelines</td>
<td>NA. 4</td>
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<td>Wetland restoration</td>
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<td></td>
<td>Coastal Planning and Architectural</td>
<td>Building standards</td>
<td>PL. 1</td>
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<td>Flood proofing</td>
<td>PL. 2</td>
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<td></td>
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<td>Coastal setbacks</td>
<td>PL. 1</td>
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<td></td>
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<td>Raising awareness</td>
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<td>Capacity building</td>
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</table>
Methodology for the recommendation of mitigation measures at particular locations

1. Determination of management units

   National Scale
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   - Delimitation of Management Units (MU) in base to homogenous:
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     - Geology/Land Cover type.

2. Selection of Mitigation Measures
   - Decision matrix
     - National Scale
       - According to:
         - HS type
         - Geology/Land Cover type
     - Local Scale
       - According to:
         - Geology/Land Cover type

3. Prioritization of Mitigation Measures
Methodology for the recommendation of mitigation measures at particular locations

Prioritization from workshop

Mitigation measures priority scores (RAW-WG)

Seawalls and sea dykes          .
Breakwaters          .
Movable barriers and closure dams          .
Land claim          .
Managed realignment          .
Beach nourishment          .
Artificial sand dunes and dune rehabilitation          .
Living shorelines          .
Wetland restoration          .
Building standards          .
Flood proofing          .
Coastal setbacks           .
Flood Hazard mapping and assessment          .
Flood Vulnerability mapping and assessment          .
Flood Risk mapping and assessment          .
Raising awareness           .
Capacity building          .
Education          .
Early Warning Systems          .
Evacuation planning          .

Risk assessment Workshop
(part 1, Muscat, 1 - 5 June 2014).

RAW-WG
Mitigation Handbook
### Mitigation Handbook

#### National Atlas– Example for a Hot spot

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Approach</th>
<th>Mitigation measure</th>
<th>Code</th>
<th>Geology</th>
<th>Land Cover</th>
<th>Hot spots</th>
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<td>Bare consolidated</td>
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<td>Built-up</td>
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<td>Lagoons, mangroves</td>
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<td>Turtle nesting areas</td>
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<td>Relevant infrastructures</td>
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<td>Coastal Planning</td>
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</table>

### Relevant mitigation measures by order of preference:

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>EN. 1</td>
<td>Beach nourishment</td>
</tr>
<tr>
<td>EN. 2</td>
<td>Breakwaters</td>
</tr>
<tr>
<td>EN. 3</td>
<td>Movable barriers and closure dams</td>
</tr>
<tr>
<td>EN. 4</td>
<td>Managed realignment</td>
</tr>
<tr>
<td>NA. 1</td>
<td>Artificial sand dunes, dune restoration</td>
</tr>
<tr>
<td>NA. 2</td>
<td>Living shorelines</td>
</tr>
<tr>
<td>EN. 5</td>
<td>Wetland restoration</td>
</tr>
<tr>
<td>PL. 1</td>
<td>Flood proofing</td>
</tr>
<tr>
<td>PL. 2</td>
<td>Coastal setbacks</td>
</tr>
<tr>
<td>PL. 3</td>
<td>Hazard vulnerability mapping and assessment</td>
</tr>
<tr>
<td>PR. 1</td>
<td>Awareness raising and capacity building</td>
</tr>
<tr>
<td>PR. 2</td>
<td>Risk management and assessment</td>
</tr>
<tr>
<td>PR. 3</td>
<td>Early Warning Systems</td>
</tr>
<tr>
<td>EM. 1</td>
<td>Risk planning and mitigation measures</td>
</tr>
<tr>
<td>EM. 2</td>
<td>Preparedness</td>
</tr>
</tbody>
</table>

### Map Example:

- **National Specific Map**
  - **Legend**
    - **Risk Class**
      - Very High
      - High
      - Medium
      - Low
      - Very Low
    - **Geology/Land Cover**
      - Bare non-consolidated
      - Covered by vegetation
  - **Type of HS: Transport related infrastructure**
  - **Risk Class**: Very High
  - **Geology**: Bare non-consolidated

- **Recommended**:
  - **HA. 1**: Hazard Mapping and Assessment
  - **PL. 1**: Floodproofing
  - **PL. 2**: Coastal set-backs
  - **PL. 3**: Hazard vulnerability mapping and assessment
  - **PR. 1**: Awareness raising and capacity building
  - **PR. 2**: Risk management and assessment
  - **PR. 3**: Early Warning Systems
  - **EM. 1**: Risk planning and mitigation measures
  - **EM. 2**: Preparedness
Mitigation Handbook

9 Local Atlantes at selected cities

Example - Sohar

[Image of maps and diagrams related to storm surge and tsunami risks, along with specific mitigation measures for Sohar.]
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