INUNDATION MAPS FOR TEP STUDY CASE (PAKISTAN)

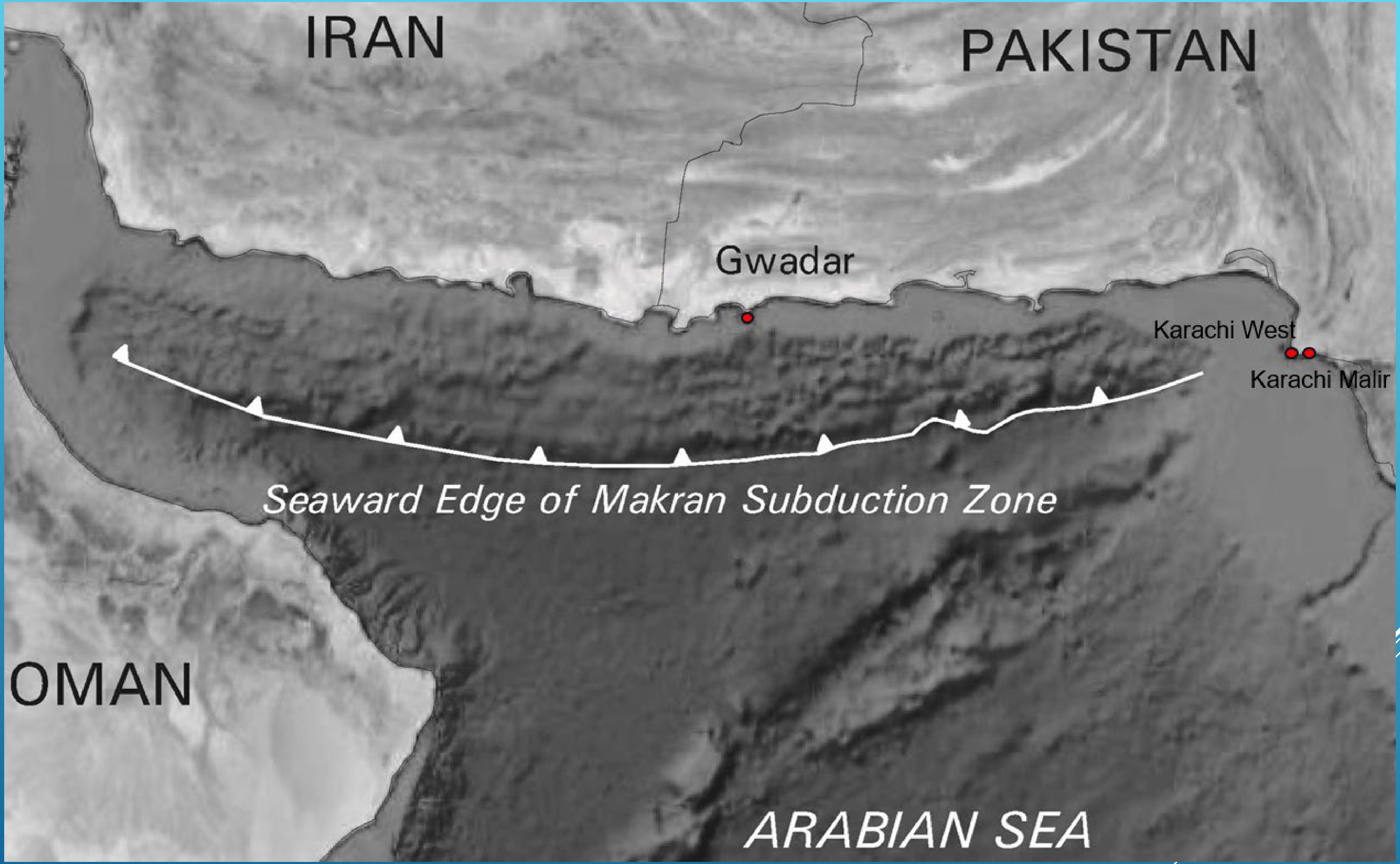
Hira Lodhi

unesco
Intergovernmental Oceanographic Commission

Indian Ocean Tsunami Information Centre

UNITED NATIONS ESCAP
Economic and Social Commission for Asia and the Pacific

CAA
هيئة الطيران المدني
CIVIL AVIATION AUTHORITY


IRAN
PAKISTAN
Gwadar
Karachi West
Karachi Malir
Seaward Edge of Makran Subduction Zone
OMAN
ARABIAN SEA

PILOT AREAS

- There are no inundation maps that are available to the emergency managers for any of the pilot areas.
- Though there have been maps for the city of Gwadar that were officially shared with the authorities in 2015 but these were not formally acknowledged or officially adopted.

OVERVIEW AND AVAILABILITY OF INUNDATION MAPS FOR PILOT AREAS

Developed at
Department of Civil Engineering
NED University of Engineering & Technology
Pakistan

Supported By
Oxfam GB
Pakistan Office

Maximum flow depths in Gwadar computed for a hypothetical tsunami from extreme rupture along the Makran Subduction Zone

Why this map?
The map is intended to save lives when the next tsunami comes ashore in Pakistan. It can be made into a map that shows areas of danger and safety, and which identifies evacuation routes. It is intended for use by disaster management agencies, local governments, and NGOs. It is not intended for use in land-use planning.

What does the map show?
The map identifies parts of Gwadar that would likely be flooded during an unusually large tsunami in the Arabian Sea. In the mapped scenario, the tsunami is generated by a sudden shift of the ocean floor during a hypothetical Makran earthquake of magnitude 9.

Why assume such a large tsunami?
The largest Arabian Sea tsunami in written history was generated during the 1945 Makran earthquake of magnitude 8.1. But written history is usually too short or incomplete to set reliable limits on tsunami size. It was said of the December 2004 tsunami from Aceh that nothing like this had ever happened before. Similarly in northeast Japan, the March 2011 tsunami surpassed any since July 1869. With these recent surprises in mind, it is important to avert surprises from an unusually large tsunami in Pakistan.

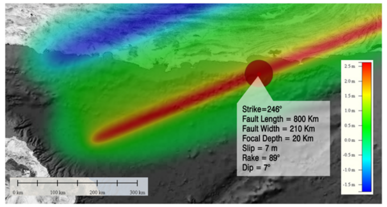


Fig. 1 Initial deformation of the worst case scenario and the corresponding earthquake parameters. Warmer shades represent uplift and cooler area represents subsidence.

What happened in 1945?
Hundreds of lives were lost to the 1945 tsunami between Gwadar and the Indus River delta. A recent booklet, presents the recent recollections of 9 eyewitnesses from Gwadar and 12 in Pasni [Kakar et al., 2015].

What are the steps for generating results?

The map shows the results of a computer simulation that has 5 main steps:

1. The simulation begins with deformation of the ocean floor (Fig 1) during a scenario earthquake of magnitude 9. This scenario is consistent with recent estimates of the area on the fault plane that potentially could break during a single earthquake [Smith et al., 2013]. For simplicity the simulation neglects additional ocean-floor deformation by submarine landslides that an earthquake may produce.
2. The ocean-floor deformation changes the level of the sea surface above. This change in water level defines the initial shape of the tsunami. This rise is depicted in wave gauge plot at time zero [Fig. 2].
3. The tsunami advances toward shore. Its speed and height change in response to water depth. For water depth the simulation uses bathymetric charts that were digitized [Fig. 3]. The computations themselves were made with Geoclaw, an open source code based on finite volume method [LeVeque et al., 2011].
4. The tsunami runs across the shore onto land. For topographic data we used satellite data Shuttle Radar Topographic Mission-30(SRTM-30). SRTM-30 has low coverage over the area of Gwadar, so local corrections are made. The population area of Gwadar city is low lying and the elevations throughout the neck are reported by locals as to be not higher than 3m. Topographic elevation equal to or below 3m was left unaltered along the populated neck. The rest were set be equal to 3m.
5. Simulations are run for 10 hours and maximum of maximum for flow depths on land are plotted to develop inundation map.

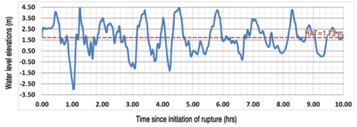
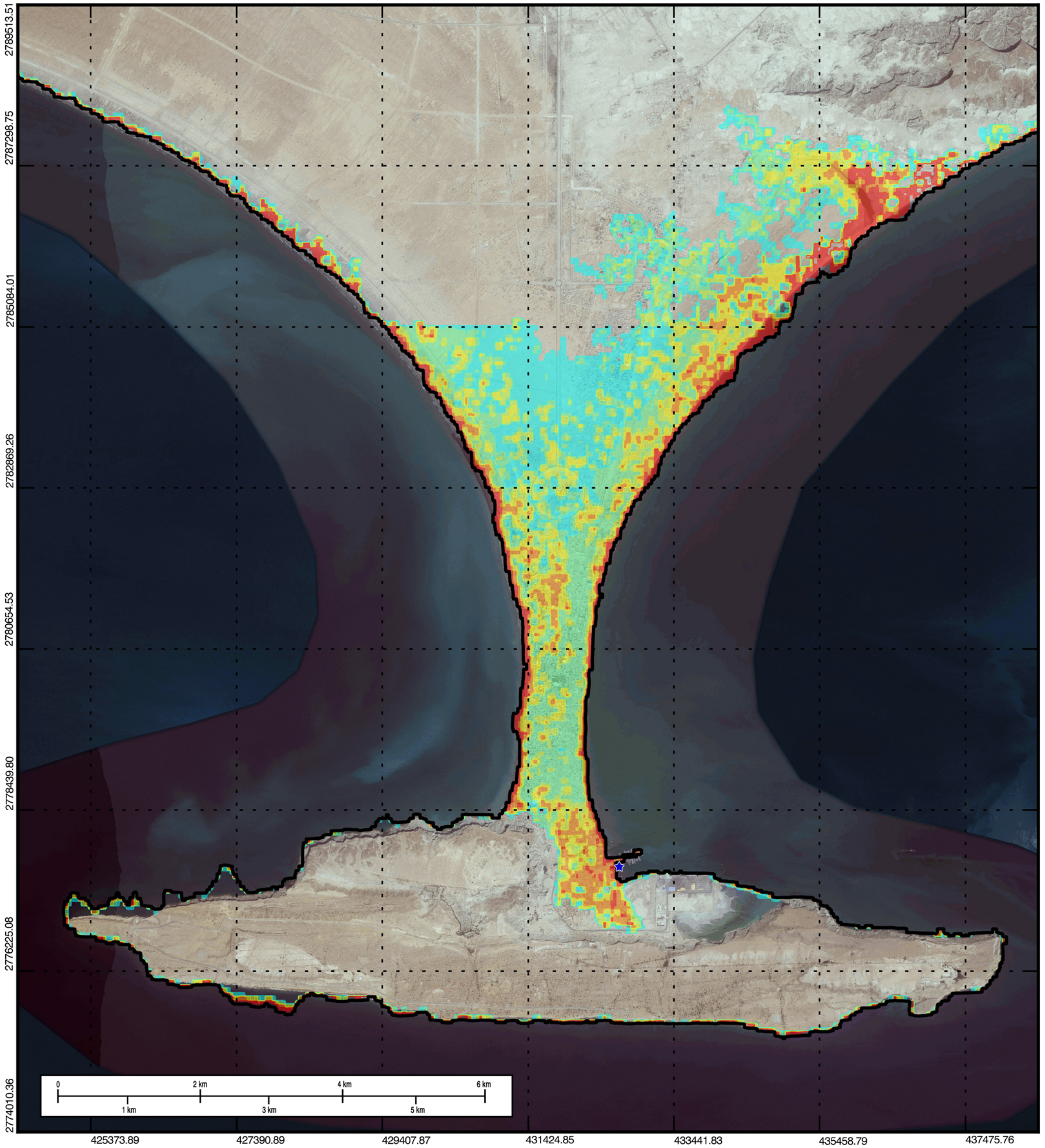
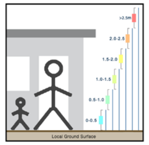


Fig. 2 Hypothetical tide gauge(marked by ★ in the inundation map) near Gwadar port showing time series of wave heights. HAT refers to highest astronomical tide that can be reached which has been taken as the sea level at Gwadar.



Flow Depth

Highest Level Reaached by Tsunami with respect to the ground surface in meters.
Figure show prominent elements to corresponding heights.



What are the main limitations?
Tsunami source is considered to be purely tectonic although there are possibilities of local landslides as suggested by two recorded events, with the most recent tsunami occurring on September 24, 2013 attributed to the Awaran earthquake with magnitude 7.7 [Baptista et al., 2014]. There were no tsunami related deaths and damages. However, the most destructive of the tsunami to have hit the coastal area of Pakistan was related to the Makran 1945 earthquake of magnitude 8.1 just offshore of Pasni [Pendse, 1946].
For the nearshore bathymetric data, bathymetric charts were digitized which gives variable resolutions throughout the domain. Moreover, SRTM-30 was utilized to depict topogarphy, but the region of study is a low coverage area and thus has vertical elevation errors.

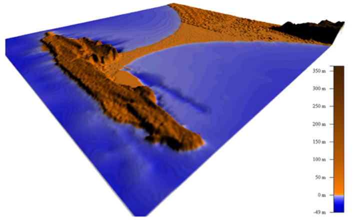


Fig. 3 3D representation of the Digital Elevation Model (DEM) for Gwadar city.

Who supported the mapping?
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Acknowledgements
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Pojection Information
Universal Transverse Mercator (UTM)
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Date: August 2015

Developed at
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Risk to critical facility & infrastructure in Gwadar for a hypothetical tsunami from extreme rupture along the Makran Subduction Zone

Why this map?

The map shows regions of Gwadar which are vulnerable to the hazard of Tsunami. The map can be used to identify safer areas and evacuation sites to ultimately save lives. It is intended for use by disaster management agencies, local governments, and NGOs. It is not intended for use in land-use planning.

What does the map show?

The map shows the exposure level of critical infrastructure and facilities to a hypothetical event of unusually large tsunami in the Arabian Sea due to an earthquake. In the mapped scenario, the tsunami is generated by a sudden shift of the ocean floor during a hypothetical Makran earthquake of magnitude 9.

Why assume such a large tsunami?

The largest Arabian Sea tsunami in written history was generated during the 1945 Makran earthquake of magnitude 8.1. But written history is usually too short or incomplete to set reliable limits on tsunami size. It was said of the December 2004 tsunami from Aceh that nothing like this had ever happened before. Similarly in northeast Japan, the March 2011 tsunami surpassed any since July 869. With these recent surprises in mind, it is important to avert surprises from an unusually large tsunami in Pakistan.

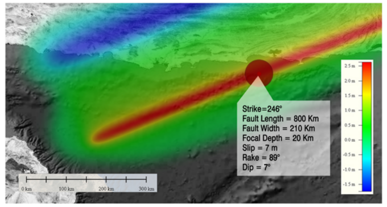


Fig. 1 Initial deformation of the worst case scenario and the corresponding earthquake parameters. Warmer shades represent uplift and cooler area represents subsidence.

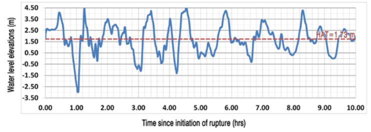
What happened in 1945?

Hundreds of lives were lost to the 1945 tsunami between Gwadar and the Indus River delta. A recent booklet, presents the recent recollections of 9 eyewitnesses from Gwadar and 12 in Pasni [Kakar et al., 2015].

What are the steps for generating results?

The map indicates the risk to critical facilities and infrastructure based on computer simulations. Generation of maps was based on five main steps.

1. The simulation begins with deformation of the ocean floor during a scenario earthquake of magnitude 9. This scenario is consistent with recent estimates of the area on the fault plane that potentially could break during a single earthquake [Smith et al., 2013]. For simplicity the simulation neglects additional ocean-floor deformation by submarine landslides that an earthquake may produce.
2. The ocean-floor deformation changes the level of the sea surface above. This change in water level defines the initial shape of the tsunami. This rise is depicted in wave gauge plot at time zero [Fig. 2].
3. The tsunami advances toward shore. Its speed and height change in response to water depth. For water depth the simulation uses bathymetric charts that were digitized [Fig. 3]. The computations themselves were made with Geoclaw, an open source code based on finite volume method [LeVeque et al., 2011].
4. The tsunami runs across the shore onto land. For topographic data we used satellite data Shuttle Radar Topographic Mission-30(SRTM-30). SRTM-30 has low coverage over the area of Gwadar, so local corrections are made. The population area of Gwadar city is low lying and the elevations throughout the neck are reported by locals as to be not higher than 3m. Topographic elevation equal to or below 3m was left unaltered along the populated neck. The rest were set be equal to 3m.
5. Simulation results were plotted and made into 3 severity zones depending upon flow depths.



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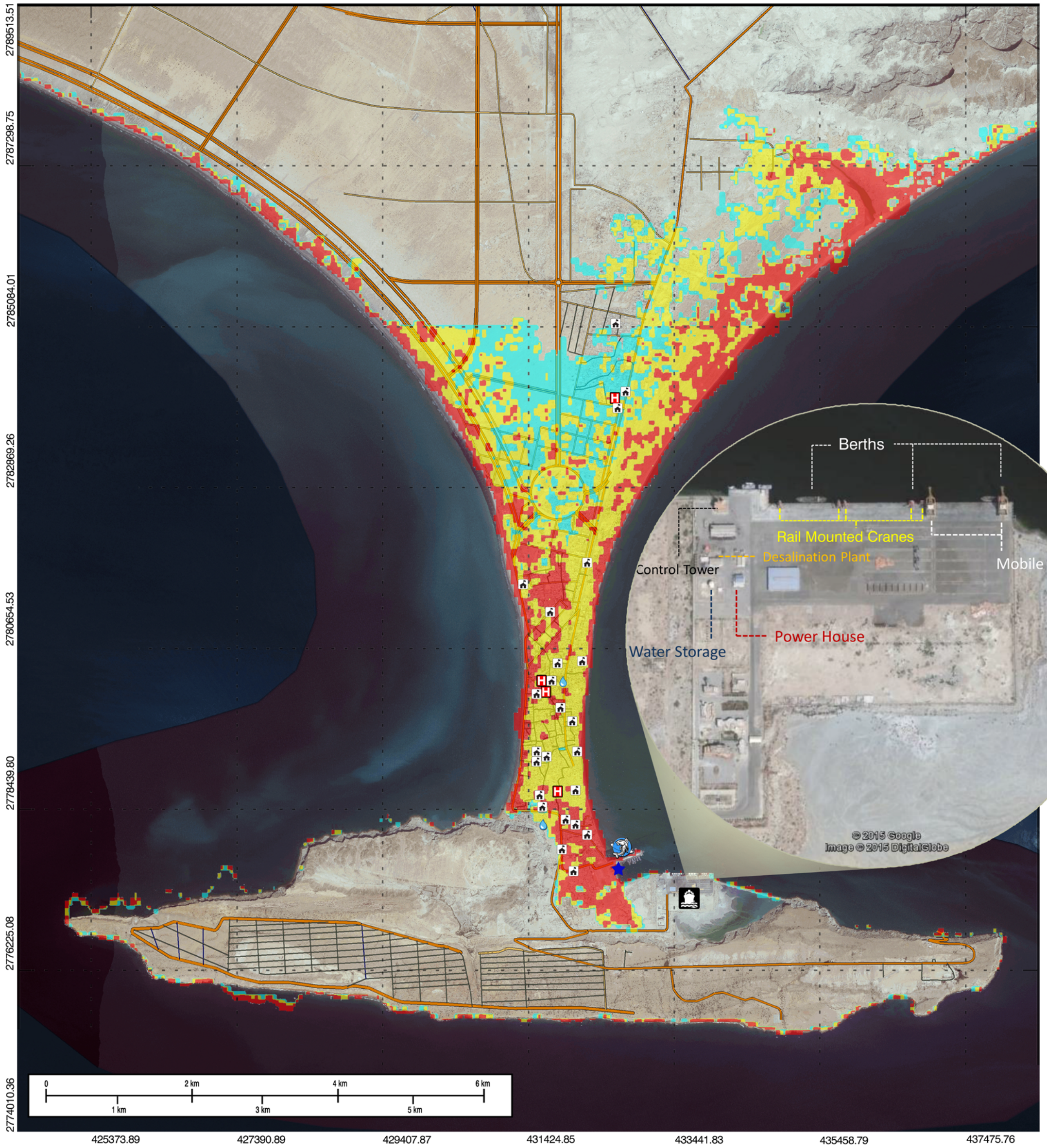

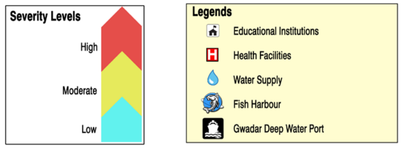

What are the main limitations?

Tsunami source is considered to be purely tectonic although there are possibilities of local landslides as suggested by two recorded events, with the most recent tsunami occurring on September 24, 2013 attributed to the Awaran earthquake with magnitude 7.7 [Baptista et al., 2014] though there were no tsunami related deaths and damages. However, the most destructive of the tsunami to have hit the coastal area of Pakistan was related to the Makran 1945 earthquake of magnitude 8.1 just offshore of Pasni [Pendse, 1946].

For the nearshore bathymetric data, bathymetric charts were digitized which gives variable resolutions throughout the domain. Moreover, SRTM-30 was utilized to depict topogarphy, but the region of study is a low coverage area and thus has vertical elevation errors.

Additionally no recent census report is available so the study had to rely on census report from 1998.

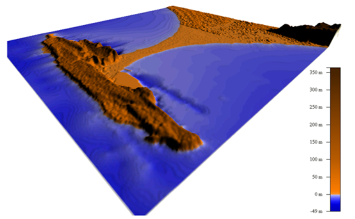

Fig. 3 3D representation of the Digital Elevation Model (DEM) for Gwadar city.

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Evacuation map of Gwadar for a hypothetical tsunami from extreme rupture along the Makran Subduction Zone

Why this map?

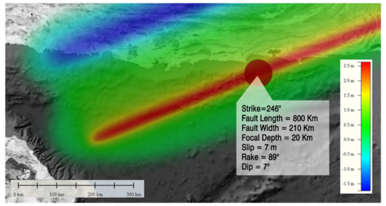
The map is intended to save lives when the next tsunami comes ashore in Pakistan. It can be used to guide people to safety and to educate people toward a tsunami resilient community. It is intended for use by disaster management agencies, local governments, and NGOs. It is not intended for use in land-use planning.

What does the map show?

The map identifies safe zones and possible routes that can be used by the locals to evacuate in case of a tsunami event. In the mapped scenario, the tsunami is generated by a sudden shift of the ocean floor during a hypothetical Makran earthquake of magnitude 9.

Why assume such a large tsunami?

The largest Arabian Sea tsunami in written history was generated during the 1945 Makran earthquake of magnitude 8.1. But written history is usually too short or incomplete to set reliable limits on tsunami size. It was said of the December 2004 tsunami from Aceh that nothing like this had ever happened before. Similarly in northeast Japan, the March 2011 tsunami surpassed any since July 869. With these recent surprises in mind, it is important to avert surprises from an unusually large tsunami in Pakistan.



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What are the steps for generating results?

The map indicates evacuation routes which are based on severity levels as generated by computer simulations that has 6 main steps:

1. The simulation begins with deformation of the ocean floor during a scenario earthquake of magnitude 9. This scenario is consistent with recent estimates of the area on the fault plane that potentially could break during a single earthquake [Smith et al., 2013]. For simplicity the simulation neglects additional ocean-floor deformation by submarine landslides that an earthquake may produce.
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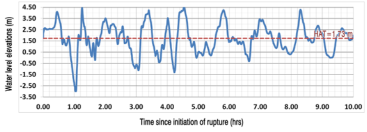
5. Simulation results were plotted and made into 3 severity zones depending upon flow depths.to develop inundation map.
6. Depending upon the severity zone, number of people exposed to risk and time required for evacuation to the nearest safe zone routes are selected. Gwadar city is divided into 2 halves so that a number of roads are used only to go northwards only and rest are used to move southwards in order to avert traffic jam.



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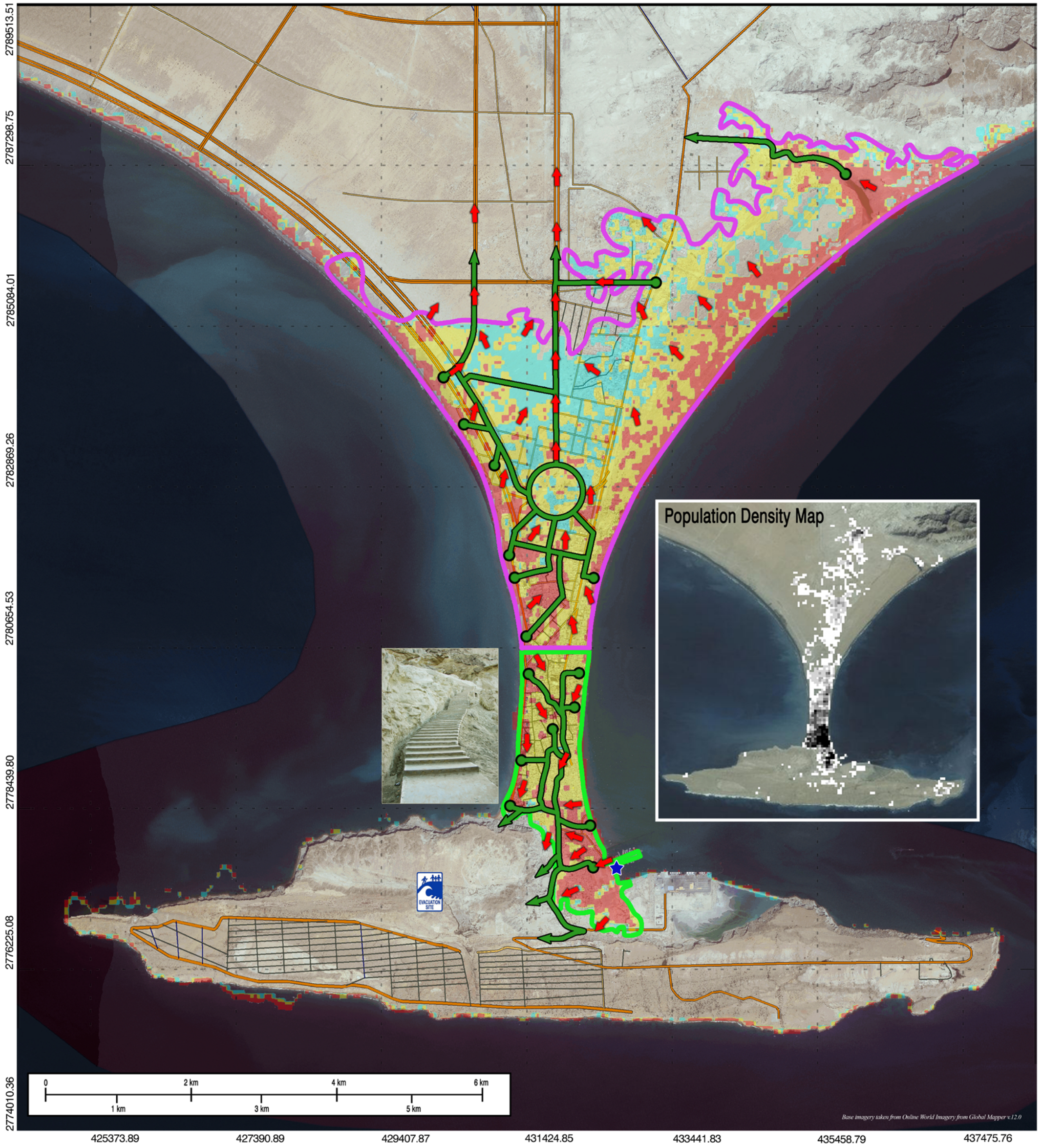

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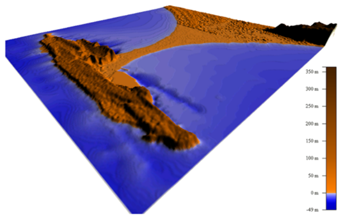
For the nearshore bathymetric data, bathymetric charts were digitized which gives variable resolutions throughout the domain. Moreover, SRTM-30 was utilized to depict topogarphy, but the region of study is a low coverage area and thus has vertical elevation errors.

Additionally no recent census report is available so the study had to rely on census report from 1998. Gwadar is an informal, unplanned city with not much finely constructed roads. Moreover the roads are narrow and not more than of two lanes.



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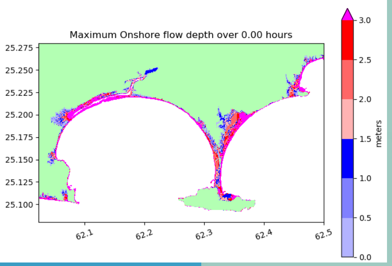
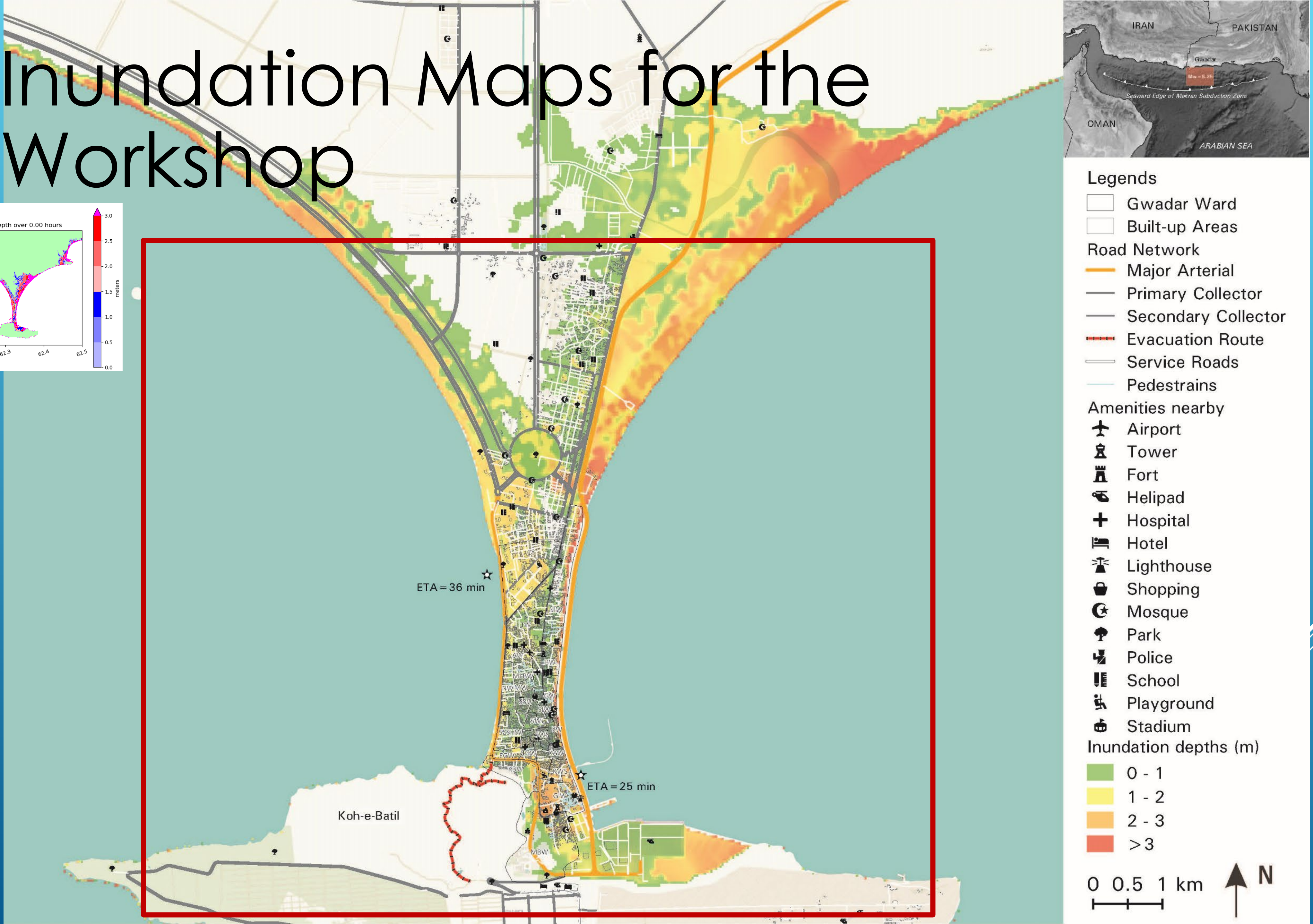
Inundation Maps for the Workshop





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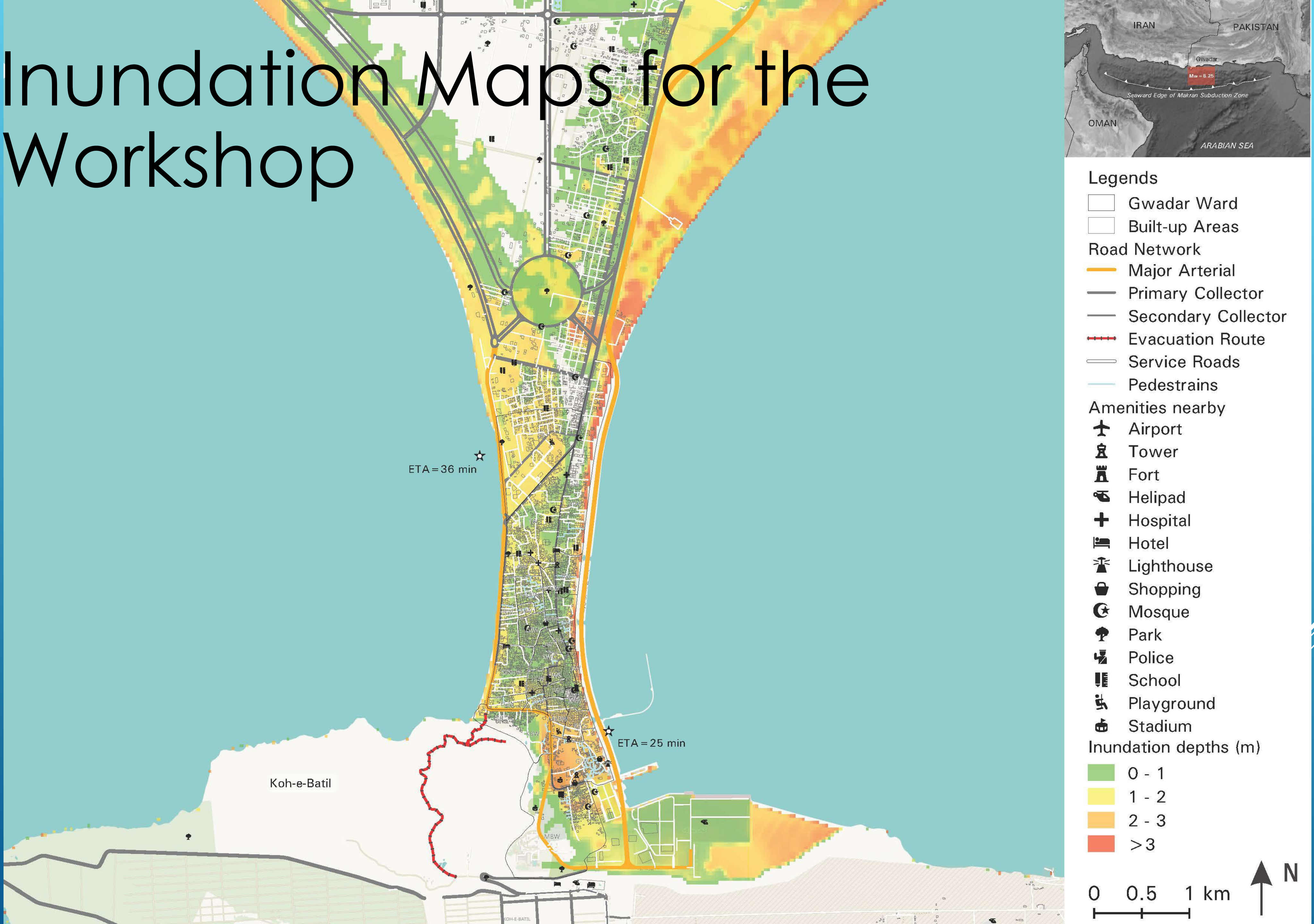

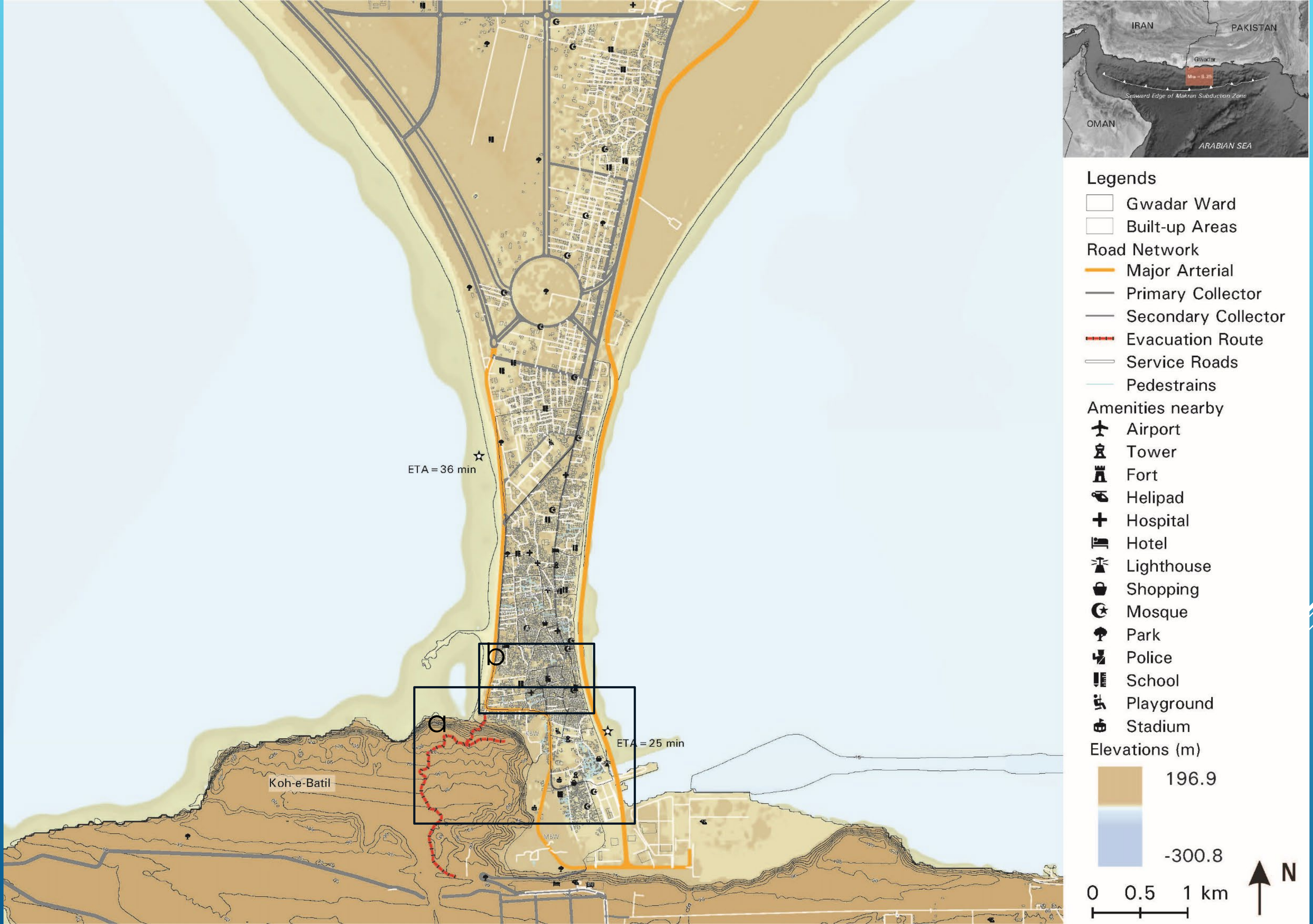

IRAN
PAKISTAN
Gwadar
Seaward Edge of Makran Subduction Zone
OMAN
ARABIAN SEA
ETA = 36 min
ETA = 25 min
b
a
Koh-e-Batil
Legends
Gwadar Ward
Built-up Areas
Road Network
Major Arterial
Primary Collector
Secondary Collector
Evacuation Route
Service Roads
Pedestrains
Amenities nearby
Airport
Tower
Fort
Helipad
Hospital
Hotel
Lighthouse
Shopping
Mosque
Park
Police
School
Playground
Stadium
Elevations (m)
196.9
-300.8
N
0 0.5 1 km


EGW
TGW
KAW
MKBW
KWS
KBW
GIW
ETA = 25
35
120
90
75
30
90
45


TGW
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MKBW
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KBW
GIW
ETA = 25


KW
SZSHW
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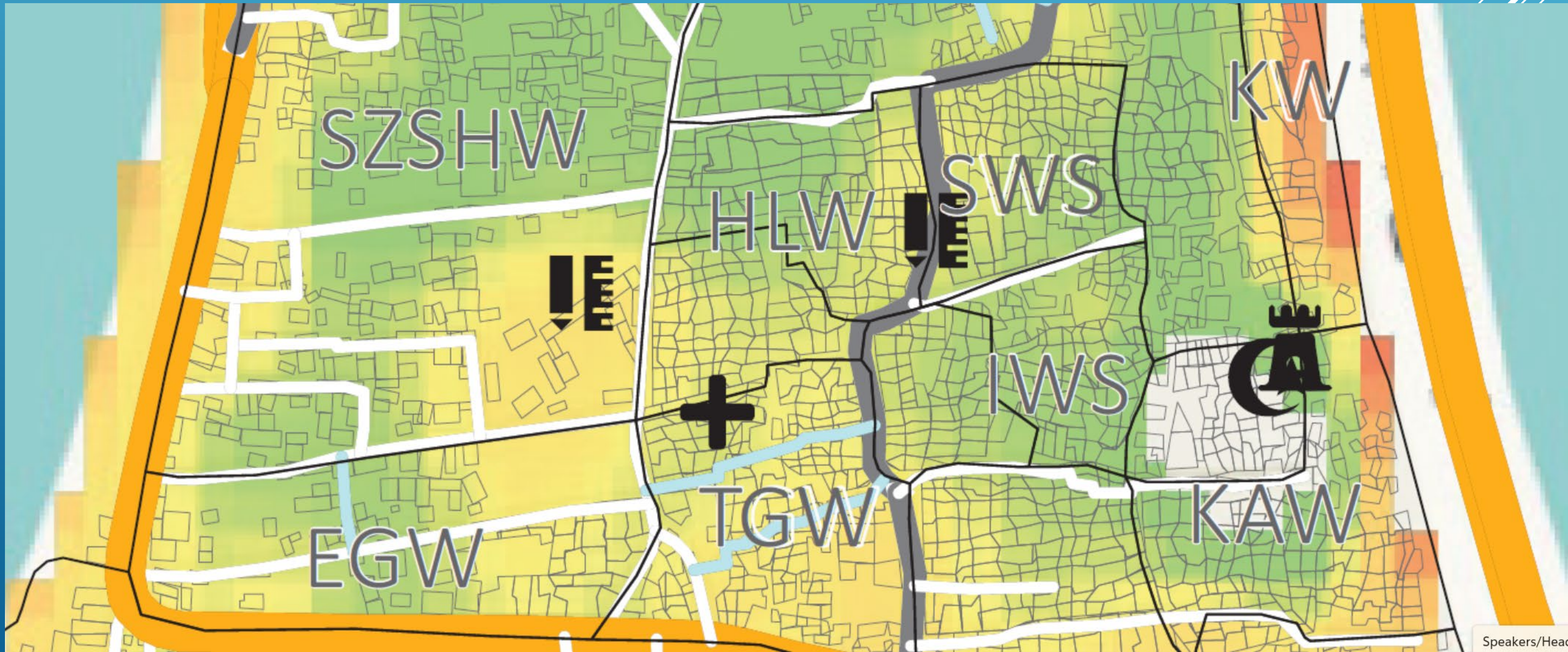
TGW
KAW
EGW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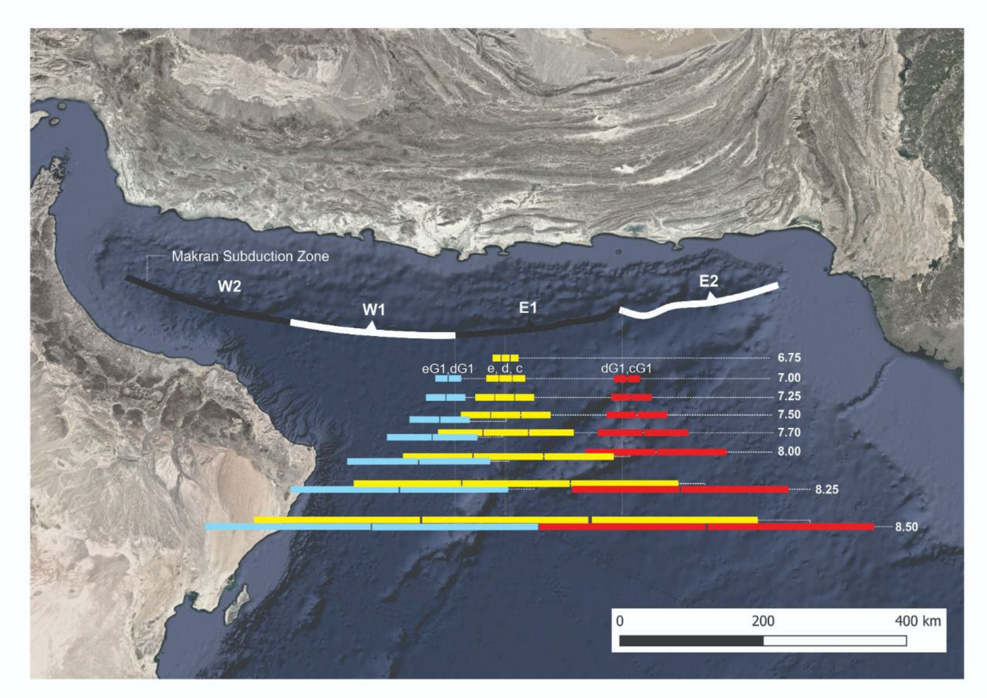
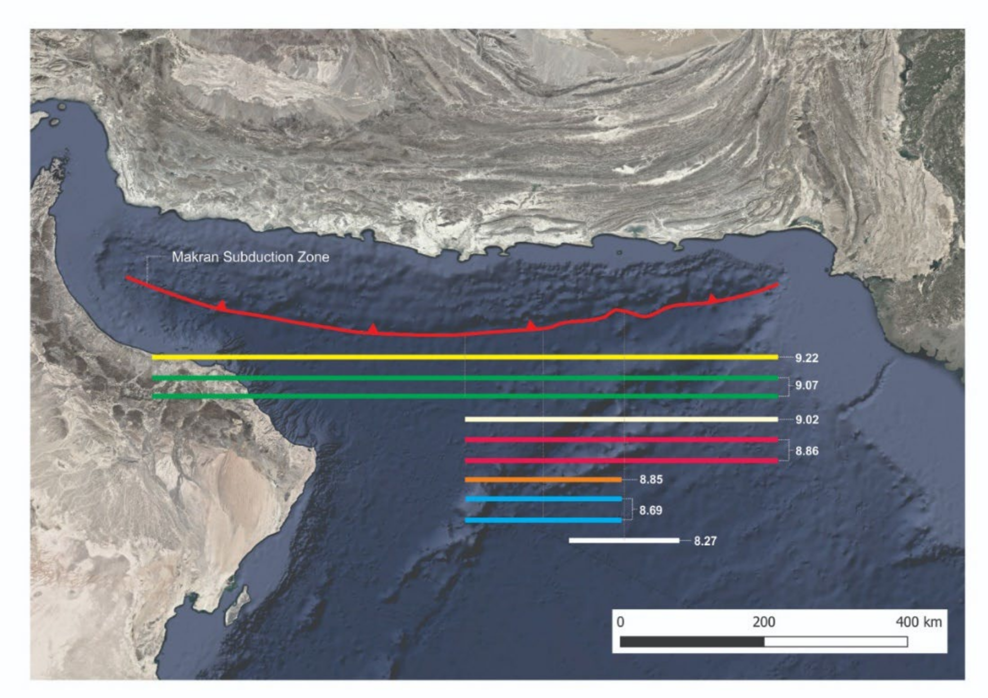
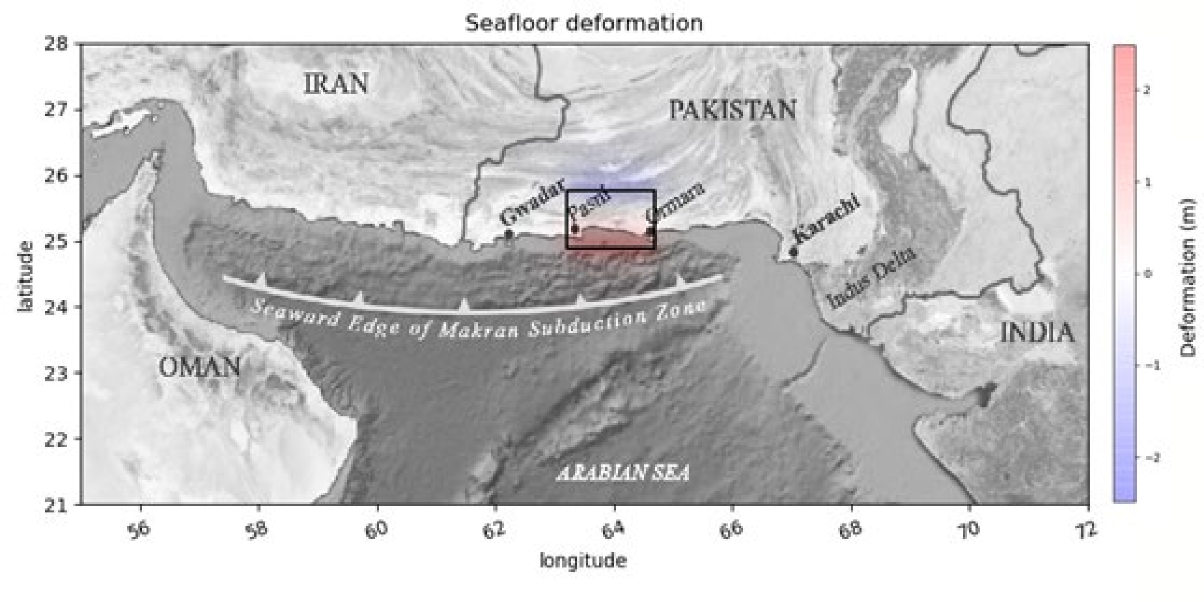
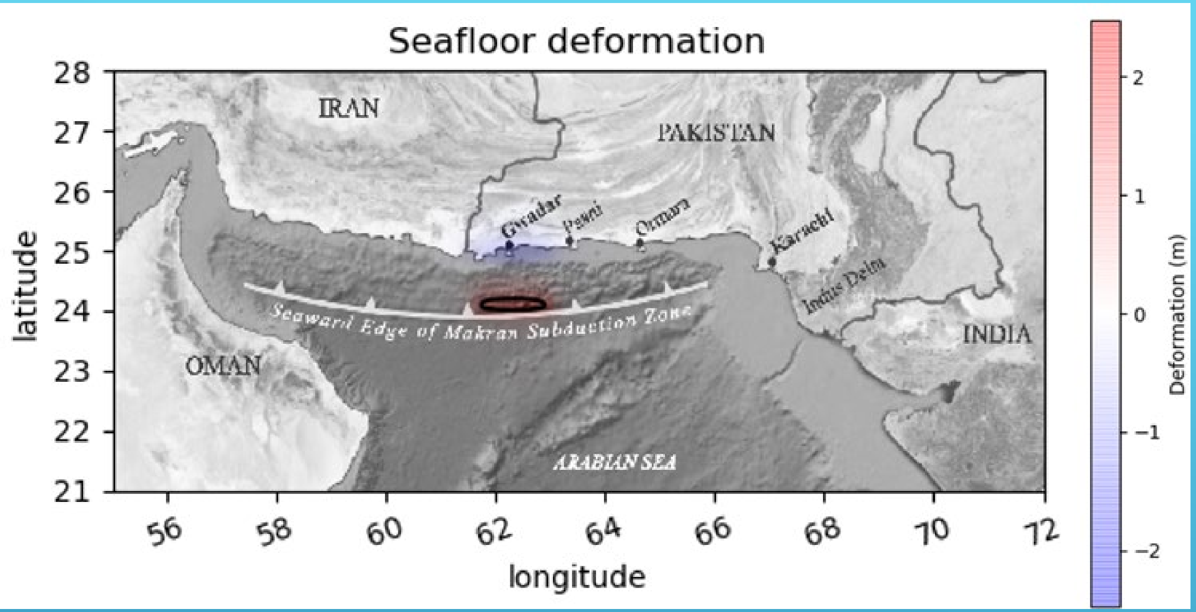
Scenarios Modelled



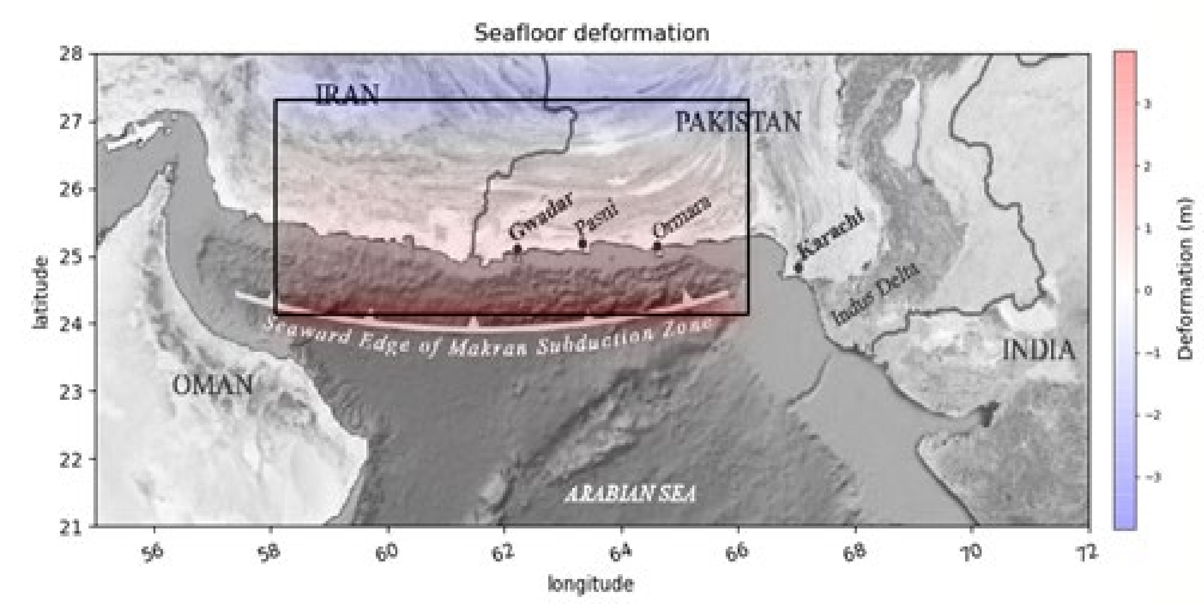




Sea-floor deformation for the 1945 event



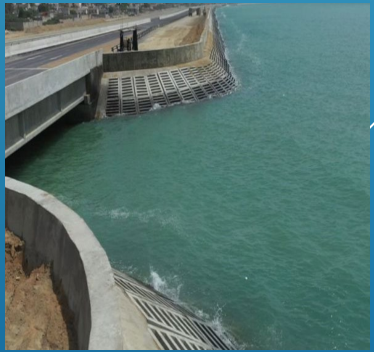
Sea-floor deformation for the 8.25 Mw event

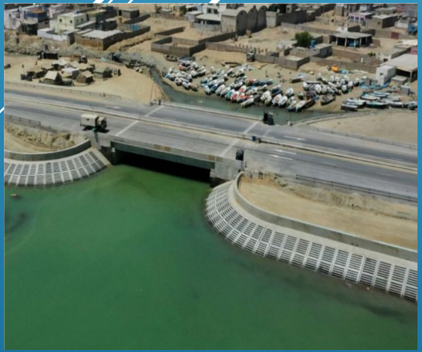


Sea-floor deformation for the worst case seismic event

LIMITATIONS

- The model considers only uniform slip.
- The data of the infrastructure is incomplete.
- The DEM used for study does not include the newly developed motorway on reclaimed land towards the east side of the neck that might change the inundation pattern significantly.





THANK YOU