Tsunami hazard assessment for the petroleum facilities in the northeast coast of Oman: Oman Liquefied Natural Gas, Mina AlFahl and Sohar Port

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Outline

1. Background and objective
2. Study areas
3. Tectonics and geological setting
4. Dataset and methodology
5. Results and discussion
6. Conclusion

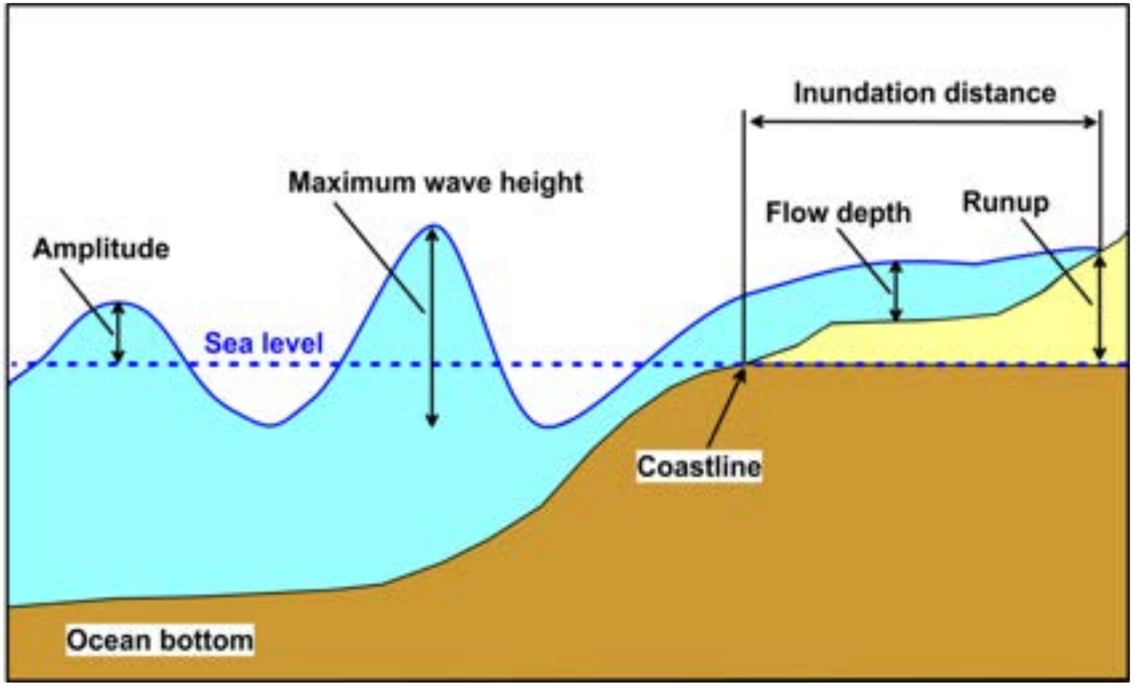
1. Background and objective

- Tsunamis and natural hazards
- Niigata earthquake and tsunamis (1964, 7.6 Mw): Oil refinery fires, Oil/gas spills
- Makran earthquake and tsunami (1945, 8.1Mw)
- Indian Ocean tsunami (2004, 9.2 Mw)
- Minor tsunami after Pakistan earthquake (2013, 7.7 Mw)
- Tsunami exposure and vulnerability of Oman
- Nearest tsunamigenic source: Makran Subduction Zone (MSZ)

1. Background and objective

The main objective of this study is develop deterministic and probabilistic tsunami hazard assessment for the main petroleum facilities located in northeast coast of Oman.

- Schematic illustration of physical quantities such as amplitude, wave height, flow depth, run up and inundation distance referenced to a given sea level



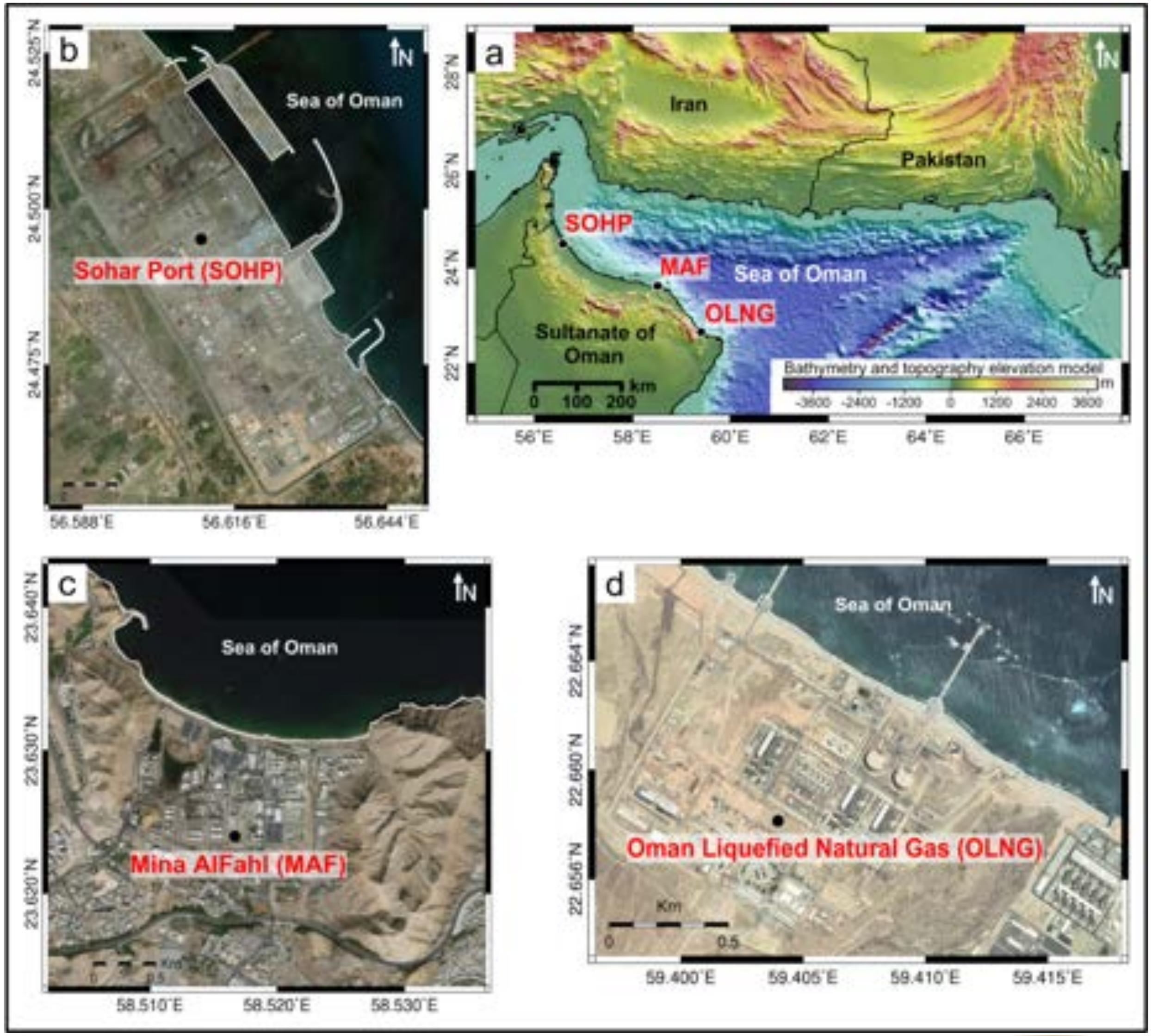
2. Study areas

a) The locations of the main petroleum facilities in northeast coast of Oman

b) Sohar Port (SOHP)

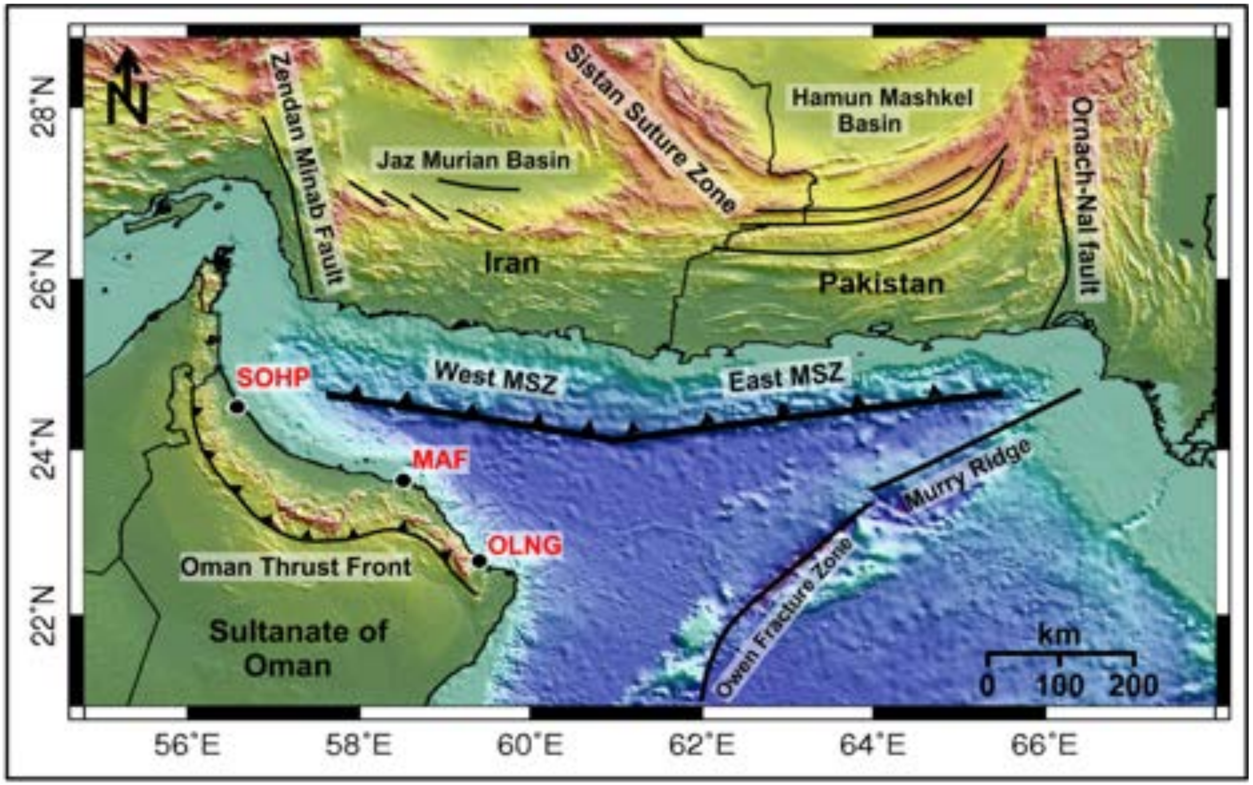
c) Mina AlFahl (MAF)

d) Oman Liquefied Natural Gas (OLNG)



3. Tectonics and geological setting

- The main tectonics in the region
- The Makran Subduction Zone (MSZ) segments (modified after Z. Al-Habsi et al., 2022)



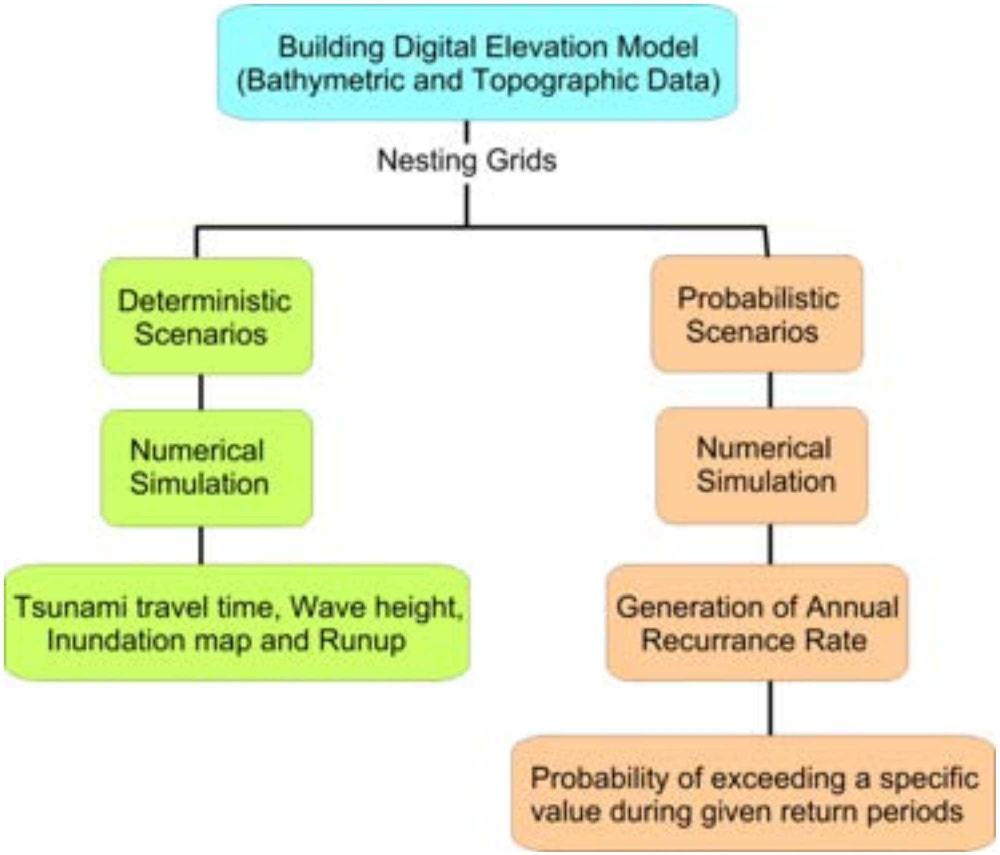
- Stratigraphy of the Makran coast and adjacent areas from Abbasi et al. 2016.

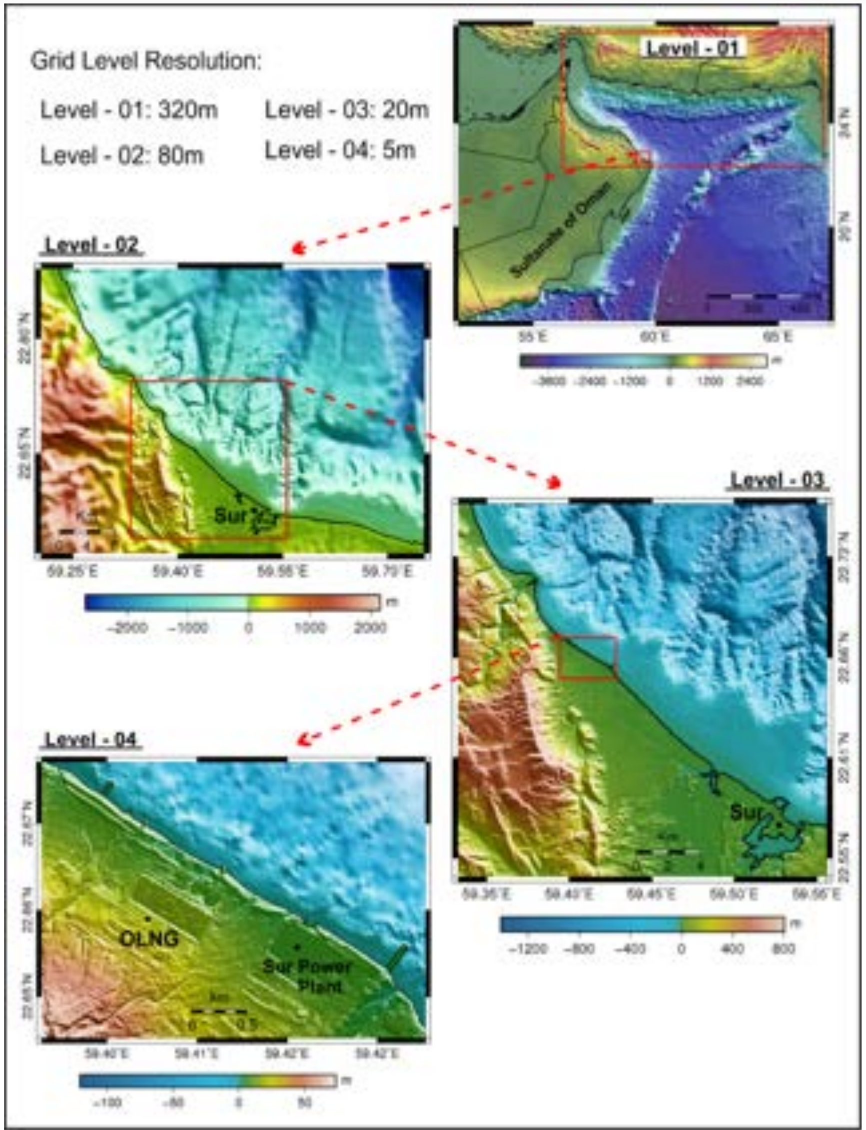
AGE		GROUP	FORMATION	LITHOLOGY
Quaternary	Holocene	MAKRAN GROUP	Jiwani Formation	Littoral deposits of shelly limestone, sandstone & conglomerate
Quaternary	Pleistocene	MAKRAN GROUP		Unconformity
Quaternary	Pleistocene	MAKRAN GROUP	Ormara Formation	Soft & poorly consolidated mudstone & minor sandstone
Quaternary	Pleistocene	MAKRAN GROUP		Unconformity
Quaternary	Pleistocene	MAKRAN GROUP	Chitti Formation	Greenish grey, poorly bedded mud-stone interbedded siltstone
Tertiary	Pliocene	MAKRAN GROUP		Unconformity
Tertiary	Pliocene	MAKRAN GROUP	Talar/Hinglaj Formation	Sandstone, conglomerate, shale, shelly limestone
Tertiary	Miocene	TURBAT GROUP	Parkini Formation	Greenish grey, poorly bedded mud-stone interbedded thin sandstone
Tertiary	Miocene	TURBAT GROUP	Panjgur Formation	Grey sandstone & quartz arenite (basinal turbidites)
Tertiary	Miocene	TURBAT GROUP	Hoshab Shale	Bluish grey shale with thin sand-stone intercalations
Tertiary	Oligo-cene	Bathyal muds underlain by oceanic crust		

4. Dataset and methodology

In order to achieve the main objective of this study:

Datasets: General Bathymetric Chart of the Oceans (GEPCO) elevation data (~462m), coastal topography (5m) and nearshore bathymetry (~30m to 150m).





4. Dataset and methodology

Deterministic Tsunami Hazard Assessment (DTHA)

1- Define the earthquake scenarios

- Fault size from Seismicity of East MSZ
- Maximum earthquake magnitude from empirical equations (Blaser et al., 2010)

2- Calculate initial sea surface deformation

- Okada (1985) half-space elastic theory

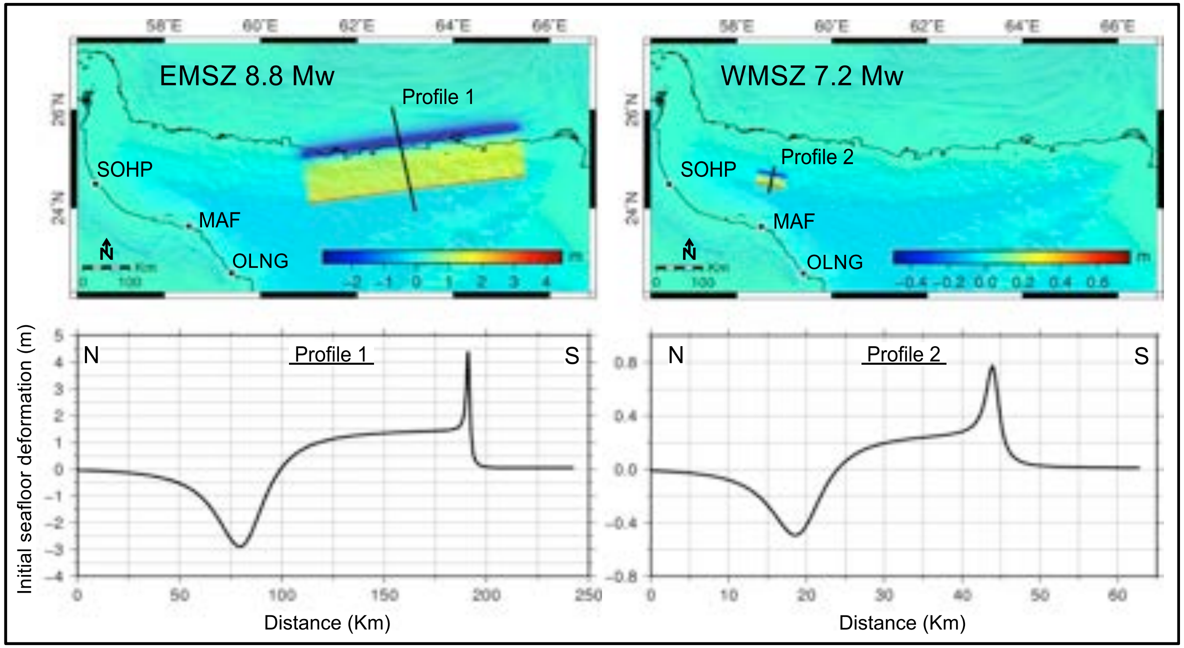
3- Numerical Simulation Code

- NSWING: non-linear shallow water equations (Miranda et al., 2014)

Table of faults parameters of the deterministic scenarios

Scenario	Mw	Length (km)	Width (km)	Slip (m)	Dip (^{0})	Rake (^{0})	Strike (^{0})
EMSZ[1]	8.8	461	110	11	7	90	263
WMSZ[2]	7.2	62	25	2	7	90	281
HMSZ[3]	8.1	150	70	6.6	7	90	261

1 East MSZ Scenario 2 West MSZ Scenario 3 Historical 1945 Earthquake Scenario



4. Dataset and methodology

Probabilistic Tsunami Hazard Assessment (PTHA)

1- Construct scenario database

- EMSZ: 6.6 to 8.8 Mw
- WMSZ: 6.6 to 7.2 Mw
- Total of 194 scenarios

2- Generate the recurrence rates N(Mo)

- Molnar (1979) and Deif & El-Hussain (2012) models

3- Use the logic-tree method (Omira et al., 2016) to derive probability **P** that a wave height/flow depth **η** exceeds a threshold **ηt** at a given exposure time **T**

$$P(\eta > \eta_t) = 1 - \Pi_{j=1}^{J}[1 - (1 - \exp(-v_j T)) \Sigma_{i,j,k}(W_{sz}(i) x W_{FL}(k)) P(\eta > \eta_t | Es_{ijk})]$$

$$P(\eta > \eta_t | Es_{ijk}) = \begin{cases} 1 & if \ \eta > \eta_t \\ 0 & if \ not \end{cases}$$

Table of the PTHA scenario database.

Mw	Mo (dyne/cm^2)	TF location	L (km)	W (km)	slip (m)	Scenario count	N(Mo)	T(Mo)	Scenario probability
6.6	1.00E+26	WMSZ	28	14	0.8	24	0.001485	673	0.021
6.8	2.00E+26	WMSZ	37	17	1.1	18	0.000866	1154	0.028
7.0	3.98E+26	WMSZ	48	20	1.4	14	0.000438	2285	0.036
7.2	7.94E+26	WMSZ	62	25	1.7	10	0.000139	7175	0.050
6.6	1.00E+26	EMSZ	28	14	0.8	32	0.041741	24	0.016
6.8	2.00E+26	EMSZ	37	17	1.1	24	0.028273	35	0.021
7.0	3.98E+26	EMSZ	48	20	1.4	19	0.019174	52	0.026
7.2	7.94E+26	EMSZ	62	25	1.7	14	0.012992	77	0.036
7.4	1.58E+27	EMSZ	81	30	2.2	11	0.009673	103	0.091
7.6	3.16E+27	EMSZ	105	36	2.8	8	0.006494	154	0.125
7.8	6.31E+27	EMSZ	137	43	3.5	6	0.004302	232	0.167
8.0	1.26E+28	EMSZ	178	52	4.5	5	0.002782	359	0.200
8.2	2.51E+28	EMSZ	231	63	5.7	3	0.001724	580	0.333
8.4	5.01E+28	EMSZ	301	77	7.3	3	0.000984	1016	0.333
8.6	1.00E+29	EMSZ	391	92	9.2	2	0.000463	2158	0.500
8.8	2.00E+29	EMSZ	461	110	11.1	1	0.000092	10868	1.000

5. Results and discussion

Tsunami hazard model results

a) Regional map

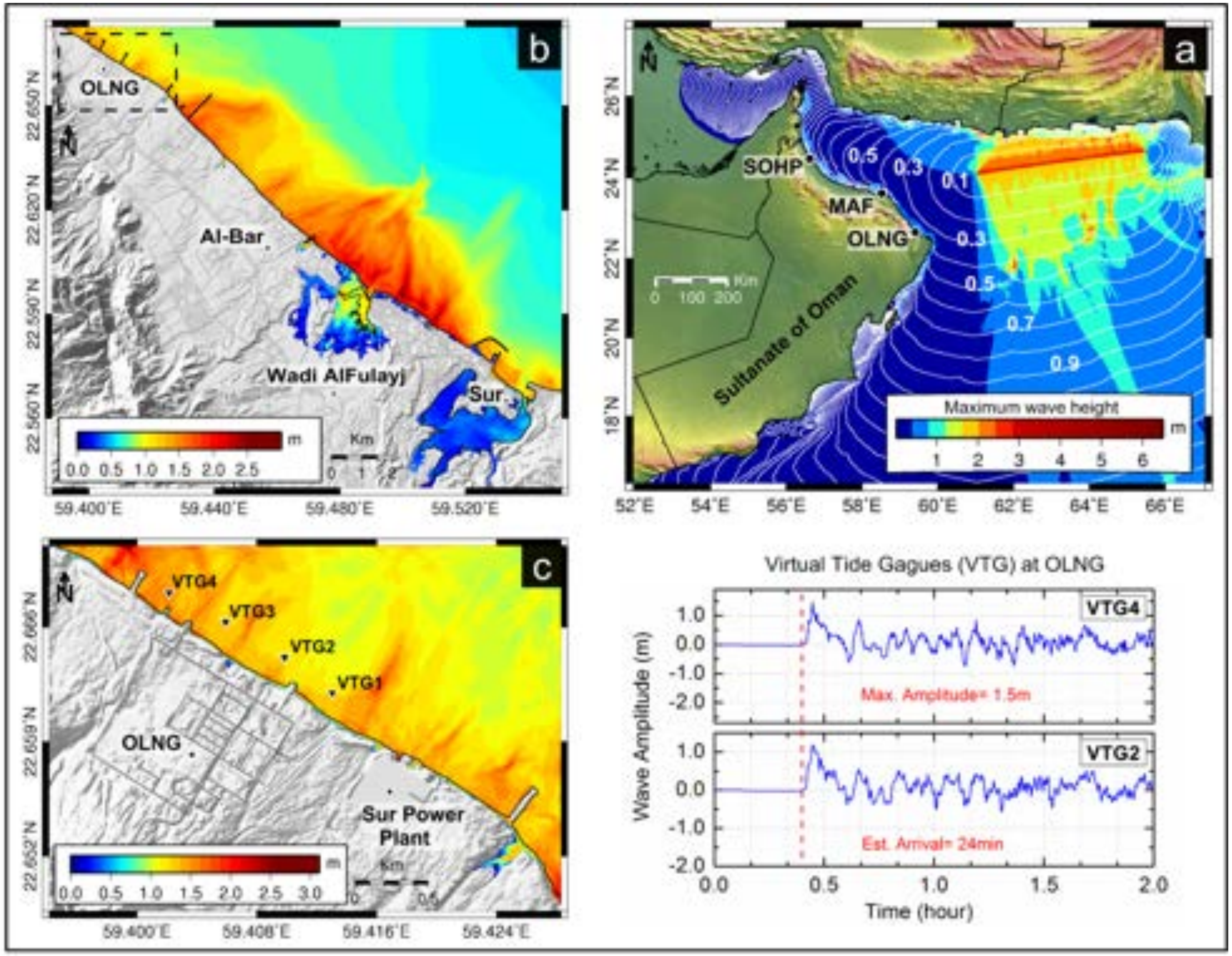
- Tsunami energy direction
- Tsunami Travel Time (hr.)

b) Local map

c) Site map

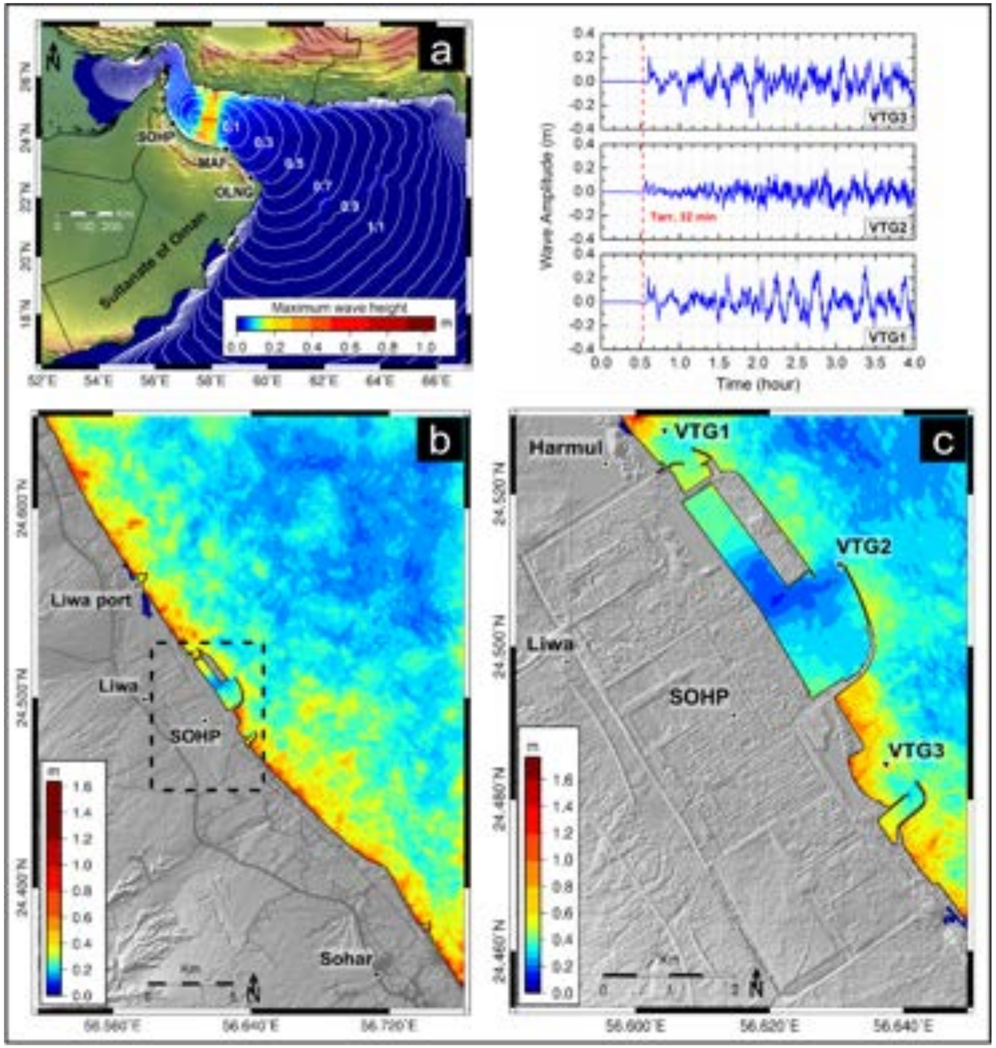
- Maximum wave height/flow depth
- Synthetic tsunami waveforms

- OLNG site, the East MSZ 8.8Mw scenario

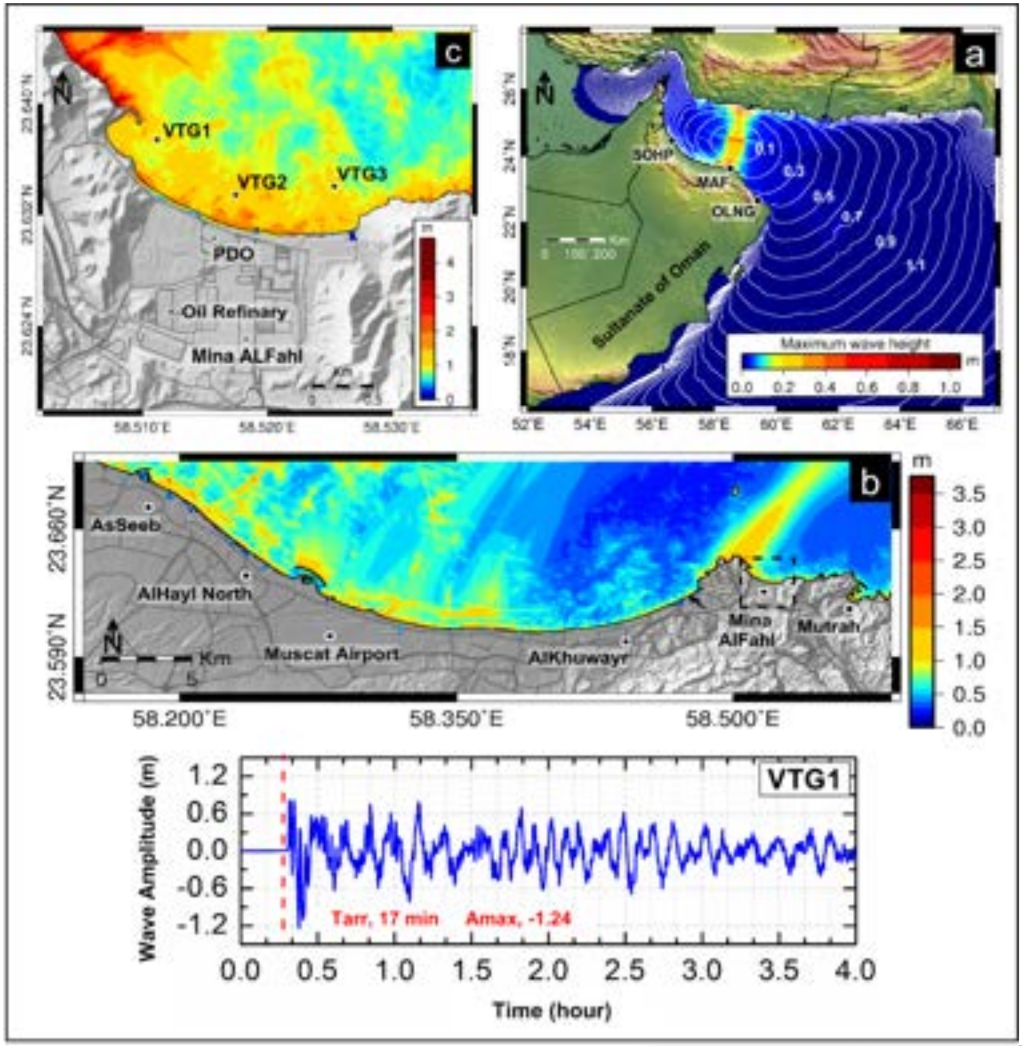


5. Results and discussion

- Sohar Port, the West MSZ 7.2Mw scenario



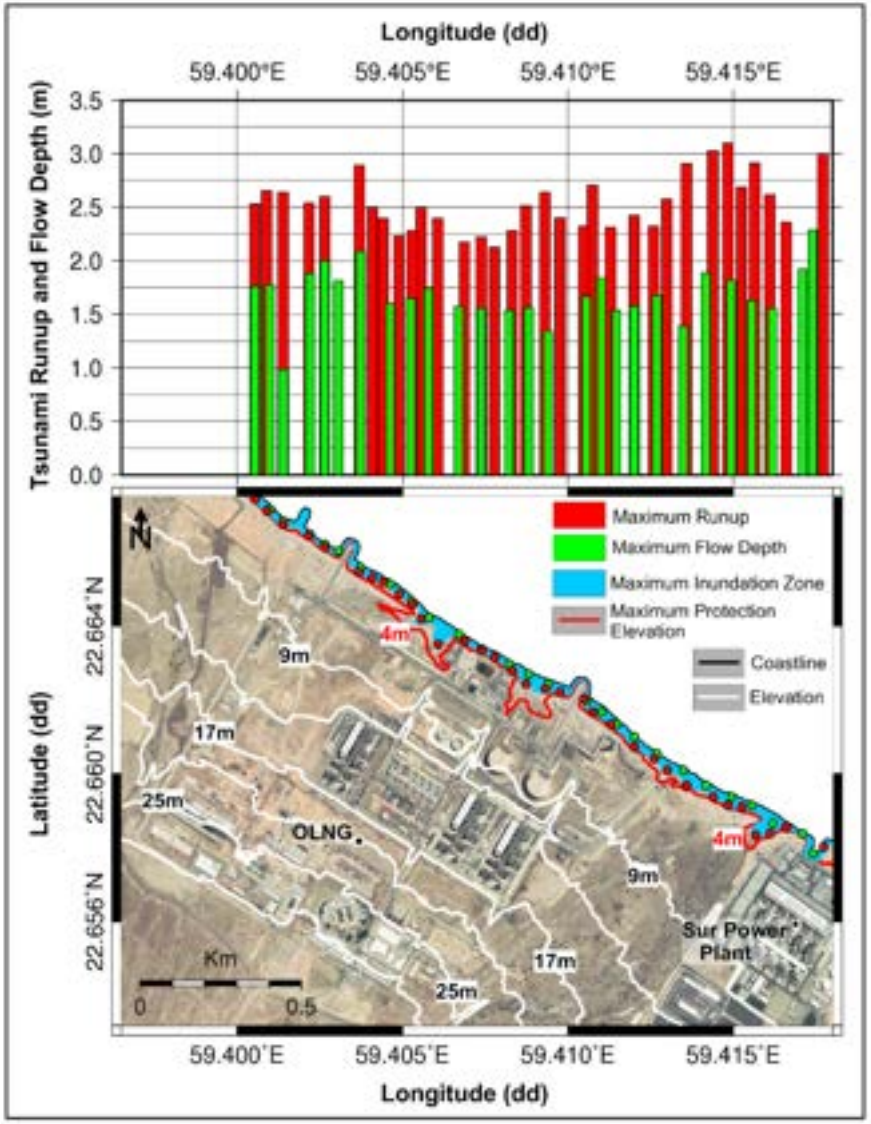
- Mina AlFahl, the West MSZ 7.2Mw scenario



5. Results and discussion

An aggregate tsunami hazard scenario — 7.2Mw WMSZ and 8.8Mw EMSZ — at OLNG site:

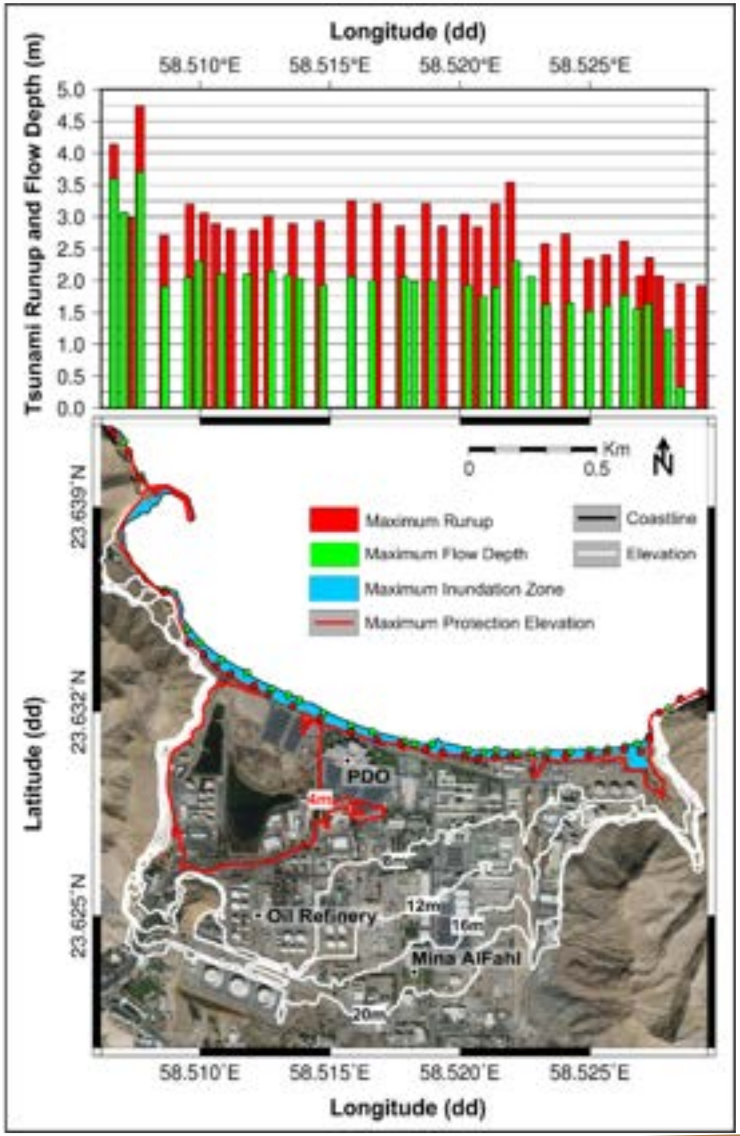
- Maximum inundation zone
- Maximum flow depth (2.3m)
- Maximum Runup (3.1m)
- Maximum protection elevation using 150% safety factor (Borrero et al. 2006)
- Safe zone (Above 4m elevation)



5. Results and discussion

An aggregate tsunami hazard scenario — 7.2Mw WMSZ and 8.8Mw EMSZ — at MAF site:

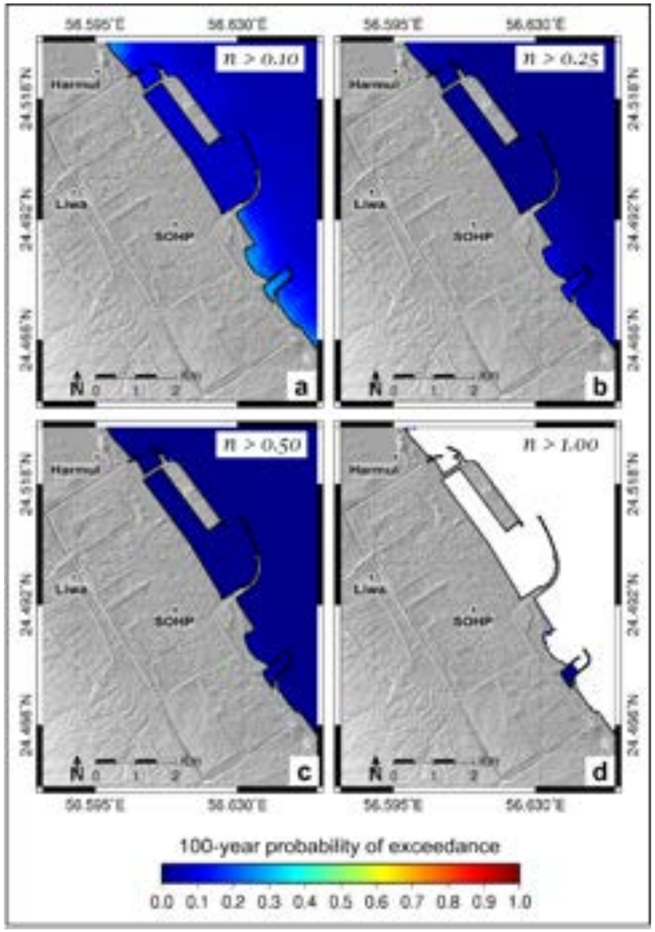
- Maximum inundation zone
- Maximum flow depth (3.7m)
- Maximum Runup (4.7m)
- Maximum protection elevation using 150% safety factor (Borrero et al. 2006)
- Hazard zone (below 4m elevation)



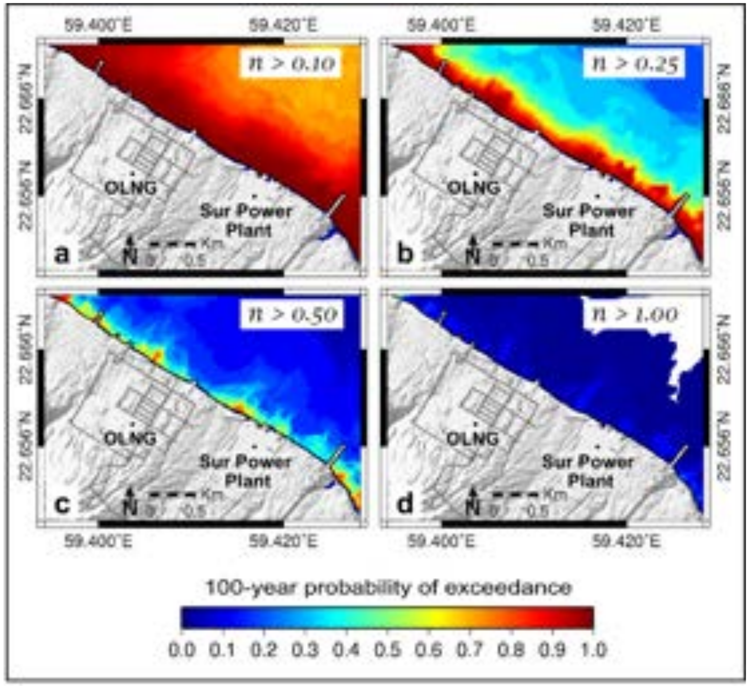
5. Results and discussion

Probability that a tsunami maximum wave height/flow depth: (a) exceeds 0.10 m, (b) exceeds 0.25 m, (c) exceeds 0.50 m, and (d) exceeds 1.00 m for an exposure time of 100-year.

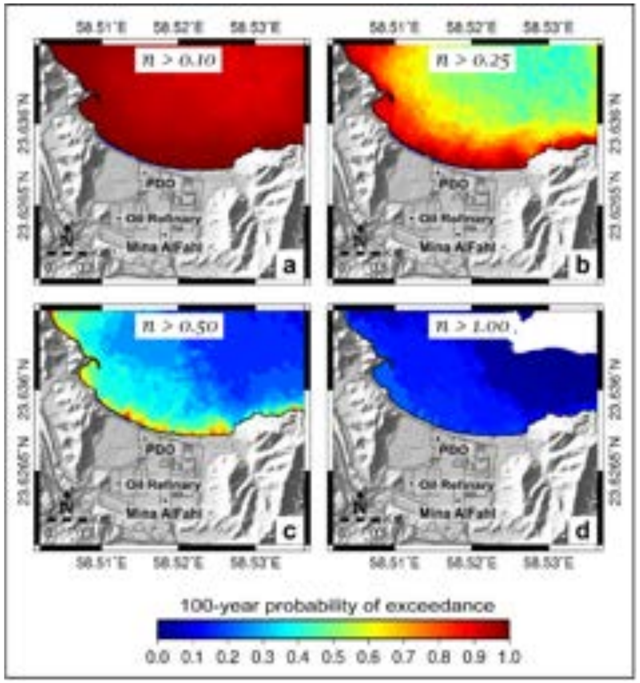
- SOHP (a 40%,b 20%, c 10%, d 0%)



- OLNG (a,b 100%, c 80%, d 20%)



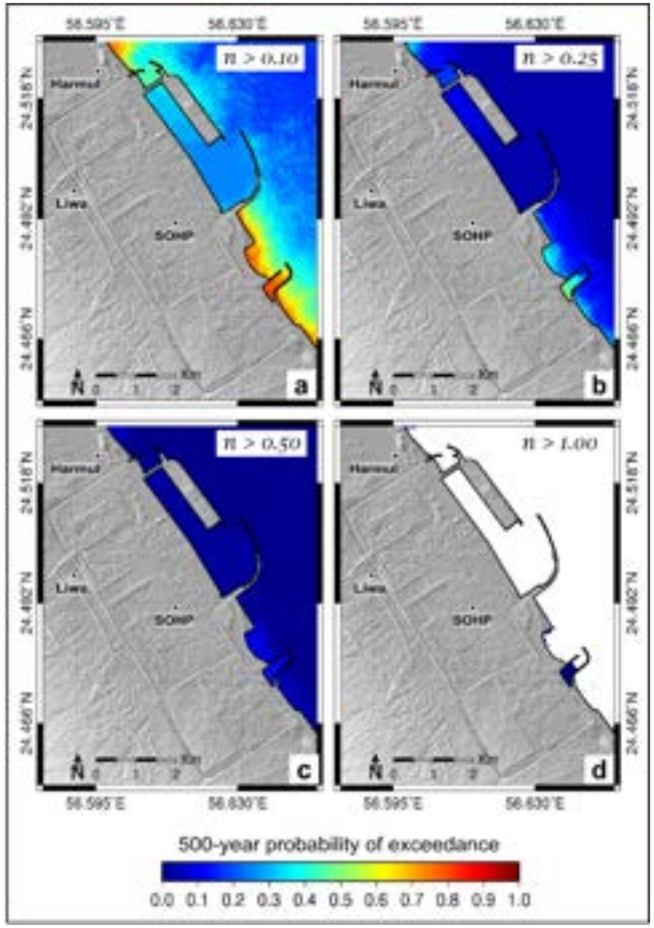
- MAF (a,b 100%, c 90%, d 30%)



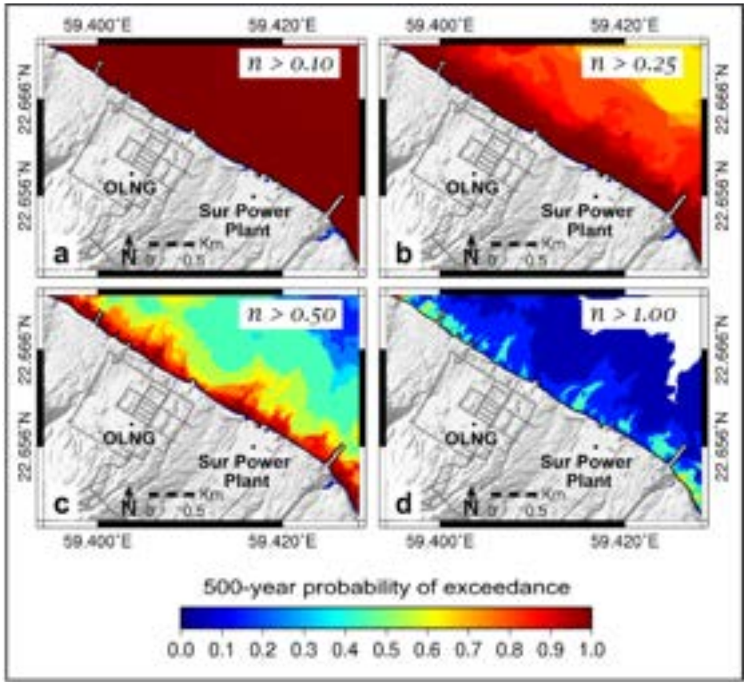
5. Results and discussion

Probability that a tsunami maximum wave height/flow depth: (a) exceeds 0.10 m, (b) exceeds 0.25 m, (c) exceeds 0.50 m, and (d) exceeds 1.00 m for an exposure time of 500-year.

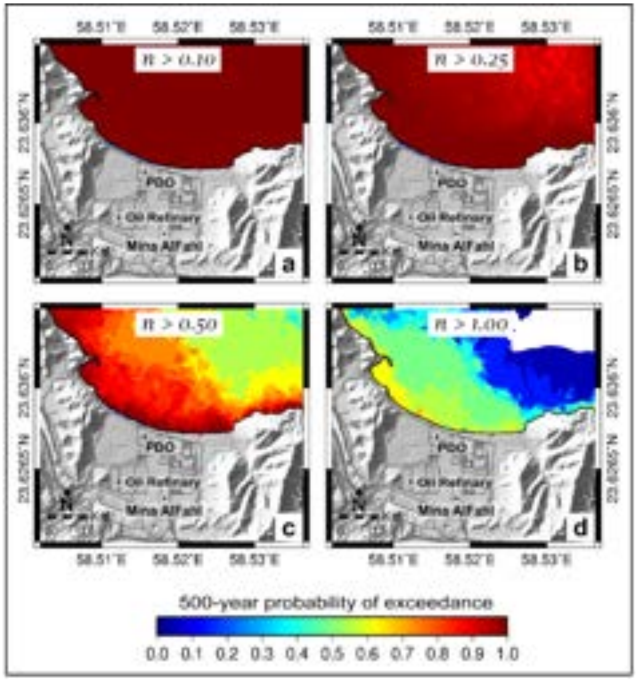
- SOHP (a 80%,b 45%, c 25%, d 0%)



- OLNG (a,b,c 100%, d 55%)



- MAF (a,b,c 100%, d 70%)



6. Conclusion

- This study aimed to assess the tsunami hazard for three critical petroleum facilities in northeast coast of Oman.
- Based on the tsunami hazard assessment models, we were able to shed lights of potential consequences of tsunami threats to OLNG, MAF and SOHP sites via:
  - Determining the maximum tsunami impact characteristics using both DTHA & PTHA
  - Mapping the inundation zone (aggregate scenario) and define the protection limits
- This study shows the importance of assessing the tsunami hazards to develop options to mitigate any future disasters for the economy, population and environment

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Thank you!

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