Map of the spatial distribution of the critical zones most prone to combined flood, meteo-tsunami and seismic risk in a timely manner to give priority to intervention to authorities and involved parties

---

Final Version of 30/06/2022

Deliverable Number D.5.2.5

Project Acronym	PMO-GATE
Project ID Number	10046122
Project Title	Preventing, Managing and Overcoming natural-hazards risk to mitiGATE economic and social impact
Priority Axis	2: Safety and Resilience
Specific objective	2.2: Increase the safety of the Programme area from natural and man-made disaster
Work Package Number	5
Work Package Title	Measures for risk mitigations
Activity Number	2
Activity Title	Improved early warning systems for multi-hazard risks
Partner in Charge	UNIVERSITY OF FERRARA, DEPARTMENT OF ENGINEERING
Partners involved	UNIVERSITY OF SPLIT, FACULTY OF CIVIL ENGINEERING, ARCHITECTURE AND GEODESY
Status	Final
Distribution	Public

Summary

Abstract

This Deliverable presents maps of the spatial distribution of the critical zone most prone to combined flood, extreme sea waves and seismic risk for the HR pilot site Kaštel Kambelovac, Croatian settlement located along the Adriatic coast. The map for multi-hazard risks have been derived from single risk maps for flood, extreme sea waves and seismic action, by using the methodology for provision assessment indexes based on Spatial Multi-Criteria Decision Making and Web map for combined risks exposure for HR pilot site. The map for combined risks, as well as maps for single risks, have been integrated into a Geographical Information System (GIS) tool. The maps identify the risk for the buildings and areas to the flood due to sea level rise and extreme sea waves combined to seismic risks. The developed map for combined risks is a basis for improving safety and resilience to natural hazards at the pilot site.

1. Introduction

One of the purpose of PMO-GATE 5.2 Activity “Improved early warning systems for multi-hazard risk” is creation of a map of the spatial distribution of the critical zones most prone to combined flood, meteo-tsunami and seismic risk in a timely manner to give priority to intervention to authorities and involved parties.

Due to the low-laying topography, HR test site Kaštel Kambelovac, is exposed to sea level oscillations resulting from tidal effect, atmospheric pressure variations and climate change effect on sea level rise. The test area is further threatened by extreme sea waves whose impact has been based on analysis of critical wind directions and velocities for extreme wave development, resulting with different wave heights and inundation areas on the coastline. Furthermore, the seismic hazard in the area of the City of Kaštela of moderate intensity, combined with the high vulnerability of the buildings, and especially the historic centre, significantly contributes to the endangerment of the area in the event of simultaneous occurrence of these events.

This Deliverable presents maps of the spatial distribution of the critical zones most prone to combined flood, extreme sea waves and seismic risks. The maps have been derived from single risk maps for flood, extreme sea waves and seismic action by the methodology for provision assessment indexes based on Spatial Multi-Criteria Decision Making. The level of risk to the community depends on a number of other parameters whose activation in a particular hazard reduces the "resistance" to extraordinary events. Therefore, additional criteria have been included in combined risk analysis together with hazards and vulnerabilities.

The combined risks exposure for HR pilot site are presented in the Web map, which have been integrated into a Geographical Information System (GIS) tool.

The map is available at the site https://pmo-gate.maps.arcgis.com/.

2. Input maps and data for combined risk analysis

Three natural-hazards – seismic, flood, and extreme waves – are combined and evaluated together to assess the multi-hazard risk, and the analysis is made on the level of homogenous zones (Figure 1(.

Figure 1. Test site divided in homogenous zones

The two combined risk analysis are made: combination of two risks for seismic and flood hazard; and combination of three risks for seismic, flood and extreme waves hazard. Each analysis is made on three levels. First level of analysis is based on hazard and vulnerability data aggregated for each homogenous zone. Second and third level of analysis are using additional criteria for each homogenous zone (Table 1).

Table 1. Combined risks analysis and criteria for each level of analysis

Scenario / **Level**	***Combined seismic-flood risk: Scenario S-F***	***Combined seismic-flood-extreme waves risk: Scenario S-F-EW***
Level 1 criteria	Seismic hazard (1.1) Seismic vulnerability (1.2) Flood hazard (1.3) Flood vulnerability (1.4)	Seismic hazard (1.1) Seismic vulnerability (1.2) Flood hazard (1.3) Flood vulnerability (1.4) Extreme waves hazard (1.5) Extreme waves vulnerability (1.6)

Level 2 criteria	Seismic hazard (1.1) Seismic vulnerability (1.2) Flood hazard (1.3) Flood vulnerability (1.4) Construction density (2.1) Inhabitation density (2.2) Importance factor (2.3) Historical buildings (2.4)	Seismic hazard (1.1) Seismic vulnerability (1.2) Flood hazard (1.3) Flood vulnerability (1.4) Extreme waves hazard (1.5) Extreme waves vulnerability (1.6) Construction density (2.1) Inhabitation density (2.2) Importance factor (2.3) Historical buildings (2.4)
Level 3 criteria	Seismic hazard (1.1) Seismic vulnerability (1.2) Flood hazard (1.3) Flood vulnerability (1.4) Construction density (2.1) Inhabitation density (2.2) Importance factor (2.3) Historical buildings (2.4) Electrical infrastructure (3.1) Water supply infrastructure (3.2) Road network (3.3)	Seismic hazard (1.1) Seismic vulnerability (1.2) Flood hazard (1.3) Flood vulnerability (1.4) Extreme waves hazard (1.5) Extreme waves vulnerability (1.6) Construction density (2.1) Inhabitation density (2.2) Importance factor (2.3) Historical buildings (2.4) Electrical infrastructure (3.1) Water supply infrastructure (3.2) Road network (3.3)

Therefore 6 multicriteria analysis will be made: analysis on 3 different levels for each of 2 scenarios. These multi-criteria analysis will classify homogenous zones in accordance with multi-hazard risk.

3. Combined risk analysis for seismic and flood hazard

First analysis is combined seismic-flood risk (Scenario S-F) on 3 different level. Each level represents different criteria sets. Criteria are grouped in two groups: main criteria – related to hazard, additional criteria – related to some important spatial data. Each criteria group has its own weight. In this case, an equal weight is given to each group: 50%. Other criteria weights are presented in Table 2.

The input data for analysis is presented as a matrix with alternatives, in this case 14 homogenous zones (HZ) and up to 11 criteria depending on the level of analysis (Figure 2).

Table 2. Criteria weights for combined seismic-flood risk (Scenario S-F)

Criteria group	Group weight	Criteria	Criteria weight
Main criteria	***50 %***	*Seismic hazard (1.1)*	*21.7 %*
		Seismic vulnerability (1.2)	*21.7 %*
		Flood hazard (1.3)	*3.3 %*
		Flood vulnerability (1.4)	*3.3%*
Additional criteria *(n – number of additional criteria)*	***50 %***	*Construction density (2.1)*	*50/n %*
		Inhabitation density (2.2)	*50/n %*
		Importance factor (2.3)	*50/n %*
		. . .	. . .

Short Name	1.1 Seismic vuln.	1.2 Seismic haz.	1.3 Flood vuln.	1.4 Flood haz.	2.1 Constr. dens.	2.2 Inhab. dens.	2.3 Import. fact.	2.4 Histor. build.	3.1 Comm. infr. el.	3.2 Comm. infr. wtr.	3.3 Road net.
HZ 1	13.3	0.22	0	0	0	252	0	0	11	8	-216
HZ 2	17.4	0.22	0	0	0	130	0	0	13	7	80
HZ 3	11.6	0.22	0	0	0	243	0	0	11	8	492
HZ 4	12	0.22	0	0	0	112	0	0	9	11	-80
HZ 5	13.2	0.22	0	0	0	171	0	0	8	9	-121
HZ 6	19.4	0.22	0	0	0	18	0	0	2	2	60
HZ 7	43.5	0.22	0	0	0	90	0	0	5	4	39
HZ 8	16.2	0.22	0	0	0	86	0	0	7	9	-137
HZ 9	13.6	0.22	0	0	0	171	0	0	9	7	633
HZ 10	17.1	0.22	4	1.36	0	63	5	0	7	12	463
HZ 11	15.6	0.22	0	0	0	158	2	0	10	13	283
HZ 12	44.8	0.22	18.6	1.36	2	76	0	4	9	15	325
HZ 13	49.3	0.22	15.04	1.36	9	319	7	15	15	18	211
HZ 14	18.7	0.22	1.52	1.36	0	216	3	0	9	12	317

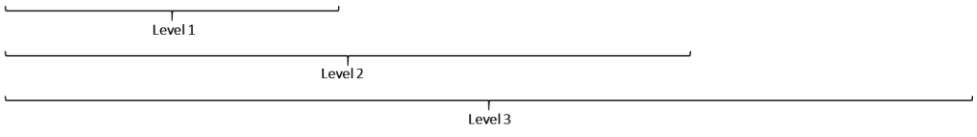
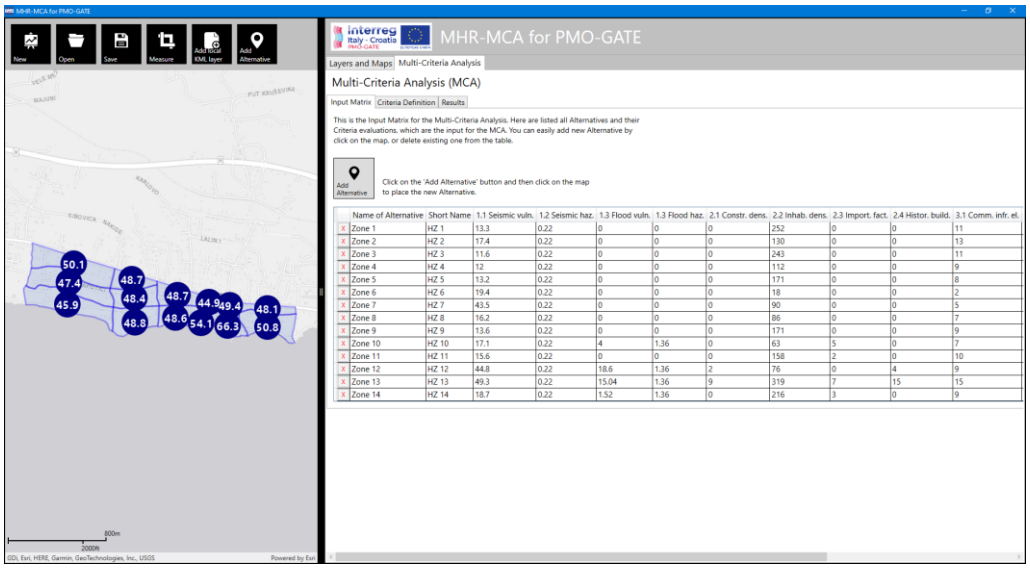


Figure 2. Input table for combined seismic-flood risk (Scenario S-F) multi-criteria analysis with criteria evaluation for all three levels

The input data (Figure 2) and criteria weights (Table 2) are imported in multi-criteria analysis application based on PROMETHEE method and results have been calculated for all three levels of analysis (Figure 3).



Name of Alternative	Short Name	1.1 Seismic vuln.	1.2 Seismic haz.	1.3 Flood vuln.	1.3 Flood haz.	2.1 Constr. dens.	2.2 Inhab. dens.	2.3 Import. fact.	2.4 Histor. build.	3.1 Comm. infr. el.
Zone 1	HZ 1	13.3	0.22	0	0	0	252	0	0	11
Zone 2	HZ 2	17.4	0.22	0	0	0	130	0	0	13
Zone 3	HZ 3	11.6	0.22	0	0	0	243	0	0	11
Zone 4	HZ 4	12	0.22	0	0	0	112	0	0	9
Zone 5	HZ 5	13.2	0.22	0	0	0	171	0	0	8
Zone 6	HZ 6	19.4	0.22	0	0	0	18	0	0	2
Zone 7	HZ 7	43.5	0.22	0	0	0	90	0	0	5
Zone 8	HZ 8	16.2	0.22	0	0	0	86	0	0	7
Zone 9	HZ 9	13.6	0.22	0	0	0	171	0	0	9
Zone 10	HZ 10	17.1	0.22	4	1.36	0	63	5	0	7
Zone 11	HZ 11	15.6	0.22	0	0	0	158	2	0	10
Zone 12	HZ 12	44.8	0.22	18.6	1.36	2	76	0	4	9
Zone 13	HZ 13	49.3	0.22	15.04	1.36	9	319	7	15	15
Zone 14	HZ 14	18.7	0.22	1.52	1.36	0	216	3	0	9

Figure 3. Data imported into application for multi-criteria analysis

The results of analysis for Level 1 are presented in Figure 4, the results of analysis for Level 2 are presented in Figure 5, and the results of analysis for Level 3 are presented in Figure 6. There are no significant variations in results except zone HZ 13, which becomes more exposed when additional criteria are used (Level 1 and 2). At the end, the results are exported into GIS, to be published as a Web map (Figure 7).

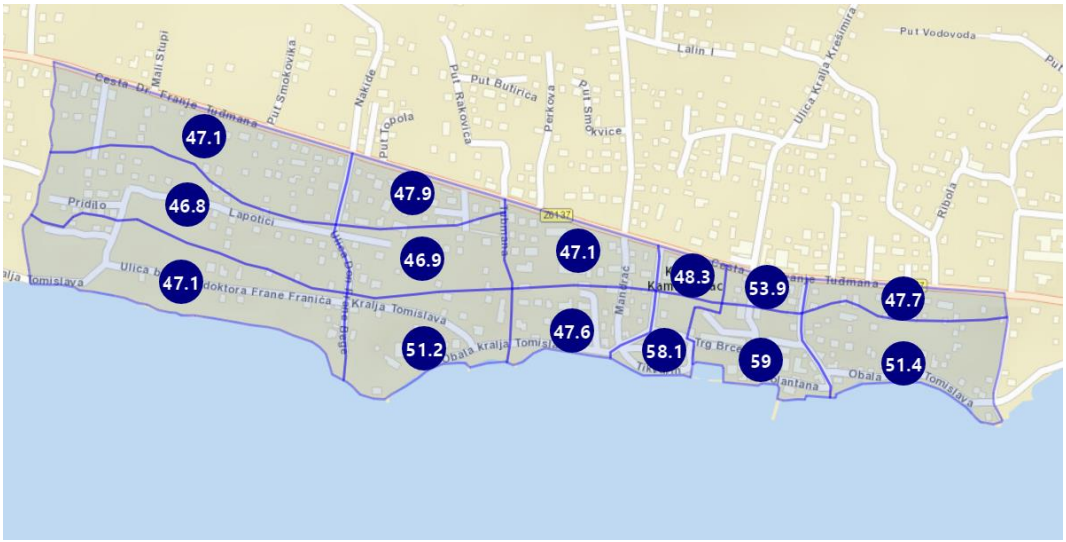


Figure 4. Results of combined risk analysis for seismic and flood hazard for Level 1 (Scenario S-F L1)

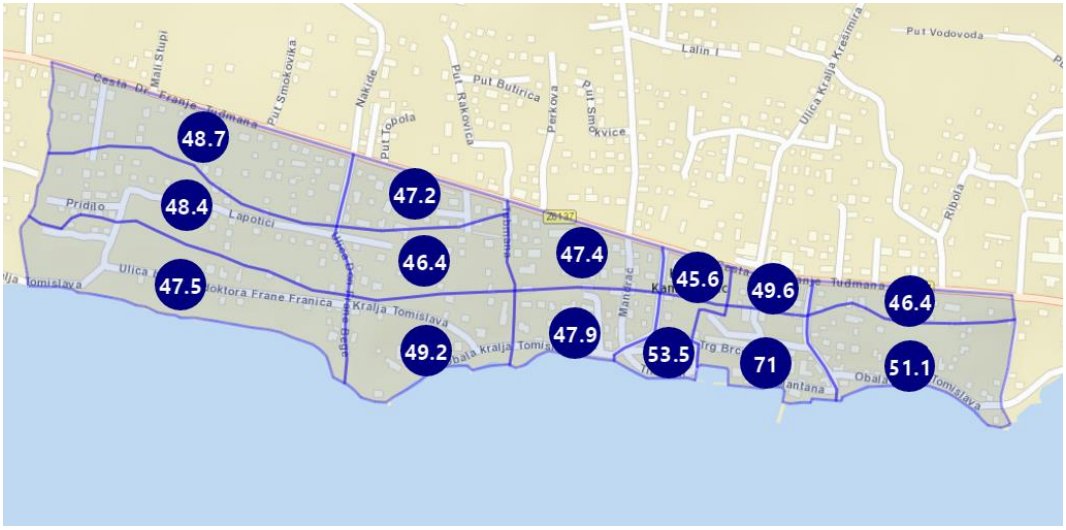


Figure 5. Results of combined risk analysis for seismic and flood hazard for Level 2 (Scenario S-F L2)

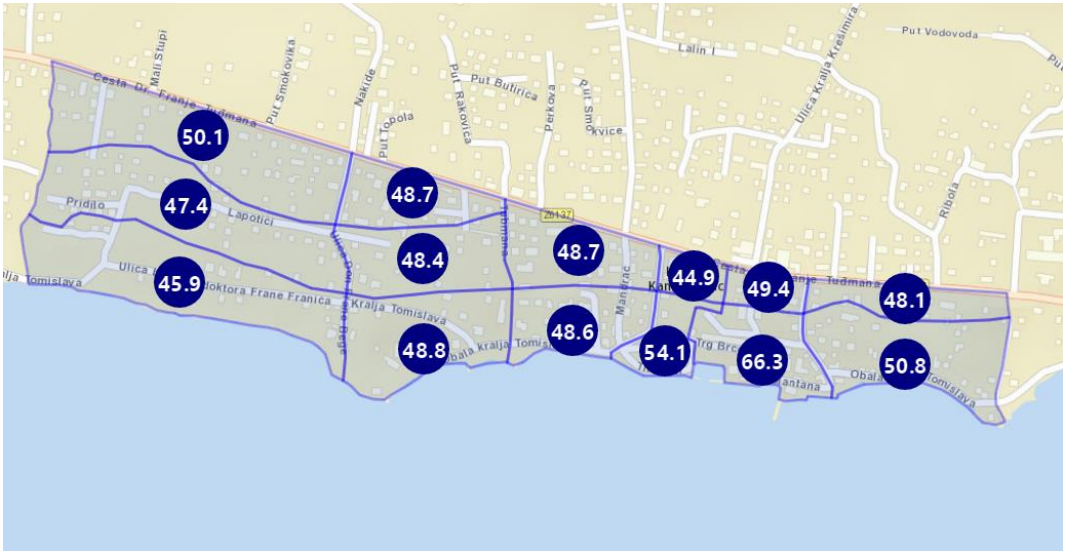


Figure 6. Results of combined risk analysis for seismic and flood hazard for Level 3 (Scenario S-F L3)

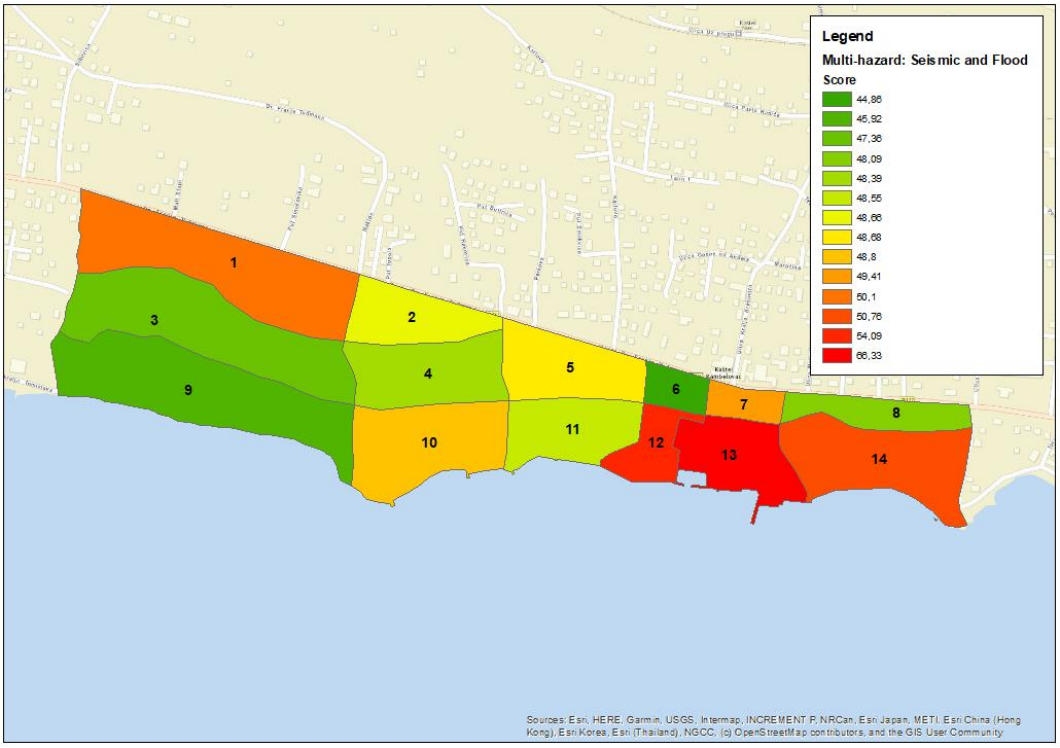


Figure 7. Results of combined risk analysis (Scenario S-F) exported to GIS for the Web map

4. Combined risk analysis for seismic, flood and extreme waves hazard

Second analysis is combined seismic-flood-extreme waves risk (Scenario S-F-EW) on 3 different level. Again, each level represents different criteria sets, and criteria are grouped in two groups: main criteria – related to hazard, additional criteria – related to some important spatial data. Each criteria group has its own weight. In this case, an equal weight is given to each group: 50%. Other criteria weights are presented in Table 3.

The input data for analysis is presented as a matrix with alternatives, in this case 14 homogenous zones (HZ) and up to 13 criteria depending on the level of analysis (Figure 8).

Table 3. Criteria weights for combined seismic-flood-extreme waves risk (Scenario S-F-EW)

Criteria group	Group weight	Criteria	Criteria weight
Main criteria	***50 %***	*Seismic hazard (1.1)*	*19.5 %*
		Seismic vulnerability (1.2)	*19.5 %*
		Flood hazard (1.3)	*2.5 %*
		Flood vulnerability (1.4)	*2.5%*
		Extreme waves hazard (1.5)	*3.0 %*
		Extreme waves vulnerability (1.6)	*3.0 %*
Additional criteria *(n – number of additional criteria)*	***50 %***	*Construction density (2.1)*	*50/n %*
		Inhabitation density (2.2)	*50/n %*
		Importance factor (2.3)	*50/n %*
		. . .	. . .

Short Name	1.1 Seismic vuln.	1.2 Seismic haz.	1.3 Flood vuln.	1.4 Flood haz.	1.5 Extr. wav. vuln.	1.6 Extr. wav. haz.	2.1 Constr. dens.	2.2 Inhab. dens.	2.3 Import. fact.	2.4 Histor. build.	3.1 Comm. infr. el.	3.2 Comm. infr. wtr.	3.3 Road net.
HZ 1	13.3	0.22	0	0	0	0	0	252	0	0	11	8	-216
HZ 2	17.4	0.22	0	0	0	0	0	130	0	0	13	7	80
HZ 3	11.6	0.22	0	0	0	0	0	243	0	0	11	8	492
HZ 4	12	0.22	0	0	0	0	0	112	0	0	9	11	-80
HZ 5	13.2	0.22	0	0	0	0	0	171	0	0	8	9	-121
HZ 6	19.4	0.22	0	0	0	0	0	18	0	0	2	2	60
HZ 7	43.5	0.22	0	0	0	0	0	90	0	0	5	4	39
HZ 8	16.2	0.22	0	0	0	0	0	86	0	0	7	9	-137
HZ 9	13.6	0.22	0	0	0	0	0	171	0	0	9	7	633
HZ 10	17.1	0.22	4	1.36	0	0	0	63	5	0	7	12	463
HZ 11	15.6	0.22	0	0	0	0	0	158	2	0	10	13	283
HZ 12	44.8	0.22	18.6	1.36	5.14	1.639	2	76	0	4	9	15	325
HZ 13	49.3	0.22	15.04	1.36	14.82	1.539	9	319	7	15	15	18	211
HZ 14	18.7	0.22	1.52	1.36	1.52	1.359	0	216	3	0	9	12	317

Level 1

Level 2

Level 3

Figure 8. Input table for combined seismic-flood-extreme waves risk (Scenario S-F-EW) multi-criteria analysis with criteria evaluation for all three levels

The input data (Figure 8) and criteria weights (Table 3) are imported in multi-criteria analysis application based on PROMETHEE method and results have been calculated for all three levels of analysis (Figure 9).

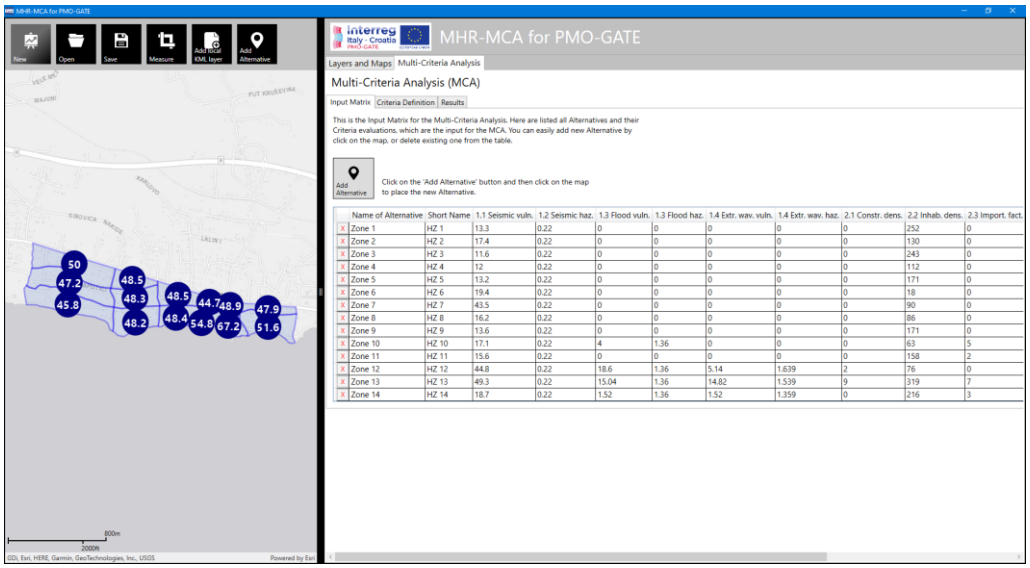


Figure 9. Data imported into application for multi-criteria analysis

The results of analysis for Level 1 are presented in Figure 10, the results of analysis for Level 2 are presented in Figure 11, and the results of analysis for Level 3 are presented in Figure 12. Again, there are no significant variations in results except zone HZ 13, which becomes more exposed when additional criteria are used (Level 1 and 2). At the end, the results are exported into GIS, to be published as a Web map (Figure 13).

Figure 10. Results of combined risk analysis for seismic and flood hazard for Level 1 (Scenario S-F-EW L1)

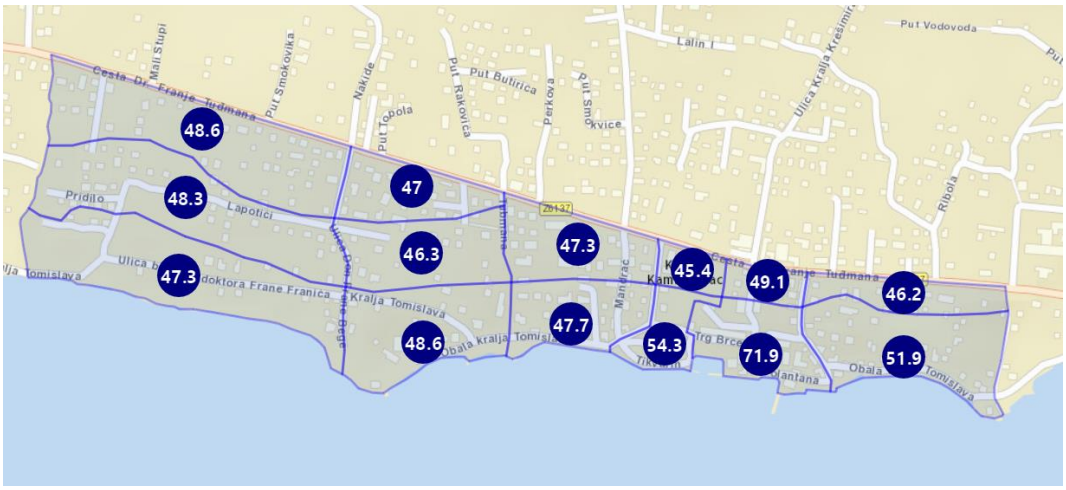


Figure 11. Results of combined risk analysis for seismic and flood hazard for Level 2 (Scenario S-F-EW L2)

Figure 12. Results of combined risk analysis for seismic and flood hazard for Level 3 (Scenario S-F-EW L3)

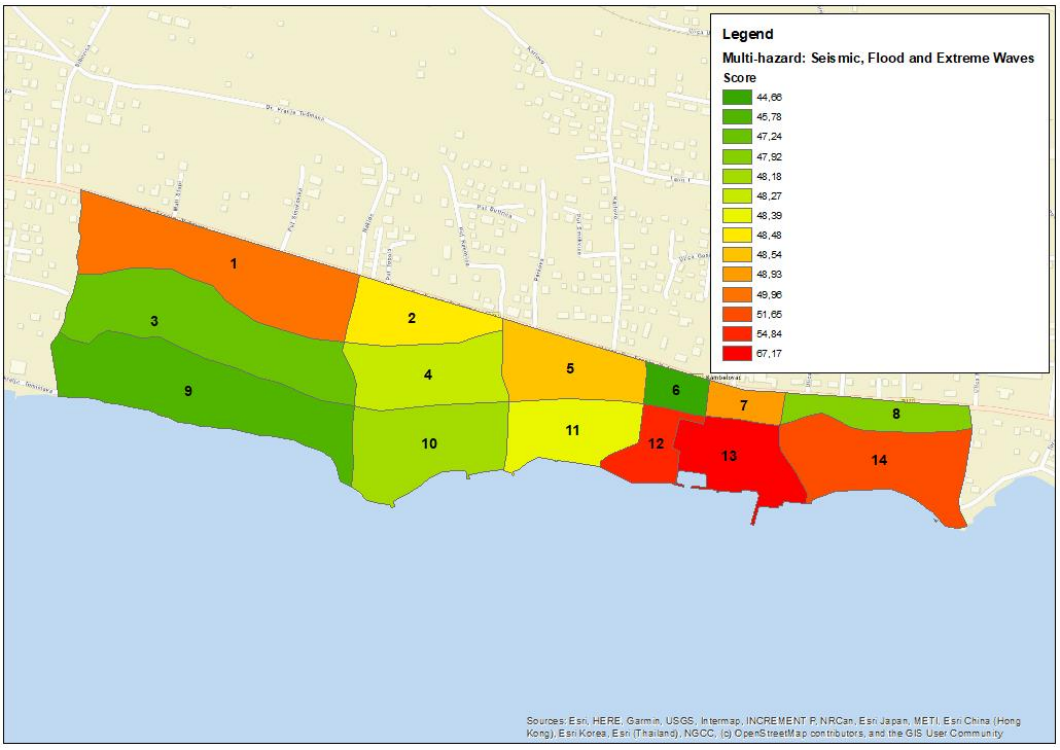


Figure 13. Results of combined risk analysis (Scenario S-F-EW) exported to GIS for the Web map

References

[1] Deliverable 4.1.1. Methodology for provision assessment indexes based on Spatial Multi-Criteria Decision Making, PMO-GATE project, 2022.

[2] Deliverable 4.2.1. Methodology for provision assessment indexes based on Spatial Multi-Criteria Decision Making for seismic-flood-meteo-tsunamis, PMO-GATE project, 2022.

[3] Deliverable 4.1.2. Web map with combined risks exposure for HR pilot site, PMO-GATE project, 2022.

[4] Deliverable 4.2.2. Web map with combined risks exposure for HR pilot site with seismic-flood-meteo-tsunamis, PMO-GATE project, 2022.