HarmoNIA

Harmonization and Networking for contaminant assessment in the Ionian and Adriatic Seas

Deliverable T3.2.3 Methodological proposal for assessing risk index of contaminant dispersion and results in case study areas

Work Package T3

Case Study of Contaminant Dispersion

Coordinators: D. Canu –OGS, D. Ivankovic, I. Vucic - IOF
Contributors: M. Lipizer, M.E. Molina Jack– OGS, G. Giorgi - ISPRA

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1. Introduction

The overall increase in maritime transport, coastal urbanization and the foreseen increase in offshore oil and gas extraction pose serious risks of pollution from hazardous substances for several coastal states in the whole Mediterranean, and in particular in the Adriatic - Ionian region [1]. Countries sharing a marine region or sub-region should adopt a common approach to environmental monitoring, good environmental status definition and assessment.

In order to support sharing of information and knowledge to promote a harmonized and coordinated approach in case of contaminant dispersion from sea-based sources, the project HarmoNIA encouraged cooperation at Adriatic - Ionian scale among research and environmental management authorities and of several complementary scientific to proposed a common approach to assess contaminant dispersion risk along the coast.

Based on the information collected at ADRION scale, a methodological proposal to assess the risk of oil spill dispersion is proposed, which will contribute to the Adriatic – Ionian regional strategy for a shared and harmonized evaluation of the risk due to contaminant dispersion from different sources of pollution. The results can be useful to authorities in charge of civil and environmental protection to improve their capacity and coordination in the prevention and preparedness to pollution events. As a final outcome from the analysis, maps of risk index of oil dispersion on coastal areas have been produced for the whole ADRION region as well as for three selected areas in the North and Middle Adriatic and in the Ionian Seas.

The term “risk” covers a range of meanings and multiple dimensions relating to the Safety, Economic, Environmental and Social issues. A commonly adopted paradigm for risk assessment component model is Source-Pathway-Receptor-Consequence (S-P-R-C) [2]. This is, essentially, a simple conceptual model for representing systems and processes that eventually lead to a particular consequence. Components of the model are the “source” or initiator event (e.g. oil spill), the “pathway” between the source and the receptor (e.g. surface currents) and the “receptor” or exposed element (e.g. protected area, sea surface, coastal area).

The risk is associated to the presence of a hazard, which is defined as the inherent property of an agent or situation having the potential to cause adverse effects when an organism, system, or (sub)population is exposed to that agent [3].

It is important to note that a hazard does not automatically imply a harmful outcome, but identification of a hazard does mean that the occurrence of harm is a possibility, with the actual harm depending upon the exposure to the hazard and the characteristics of the receptor (i.e. the exposed element).

Environmental risk assessments are procedures aiming at identifying and analyzing potential events that may negatively impact the environment, and its natural and human targets. The events taken into account by the risk assessment framework are not easily predicted and described using deterministic methods. Risk assessment methods have been developed to deal with both harmful natural events (e.g., earthquakes) and anthropogenic events (e.g., oil spills). A critical step within a risk assessment framework is the hazard quantification (or hazard mapping): the probabilistic estimation of the frequency of occurrence and magnitude, of the hazard event. The well-established seismic hazard framework suggests that an appropriate statistical description of the variable of interest is of fundamental importance to classify hazard and then risk [4].

Here we adopt a risk assessment framework for marine oil spill based on coastal and marine vulnerability, using two different approaches: a buffer zone approach, based on spreading contamination and a modelling approach, based on numerical models simulating the oil spill. Coastal vulnerability can be evaluated considering different environmental and socioeconomic targets, such as coastal geomorphology [5] [6], or considering the presence of Sites of Community Importance (SCI) and Special Protection Areas (SPA) [7]. Similar methodology is used also in some other projects regarding sea [8] or land environment [9].

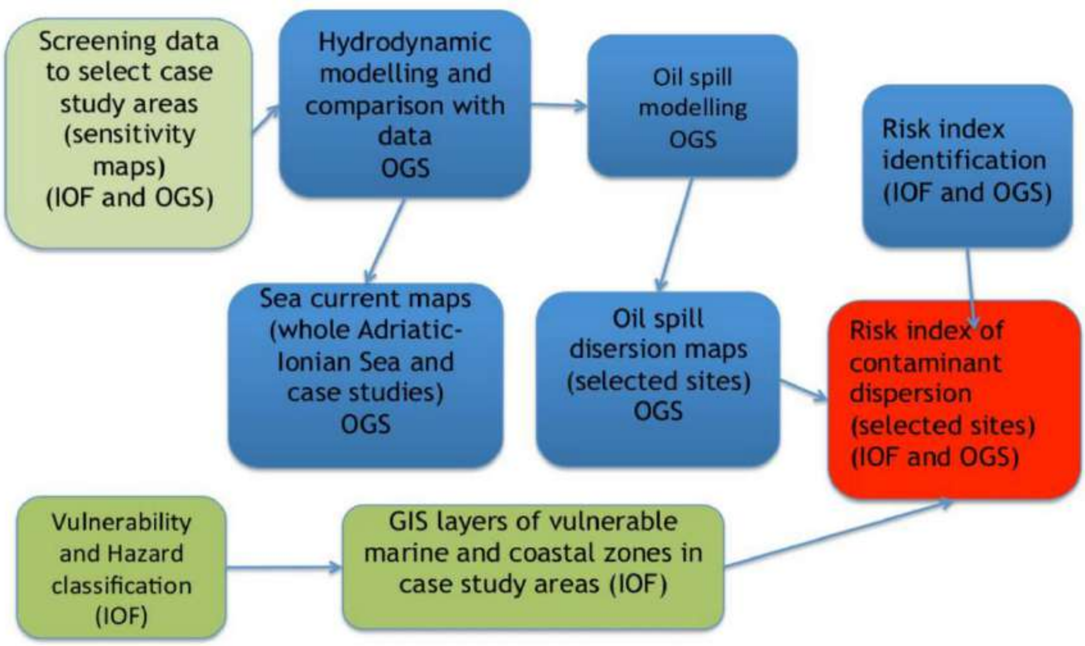


Figure 1 Conceptual diagram of the methodology used in the oil spill risk assessment and of the partners involvement in the process

The workflow followed within HarmoNIA to produce maps of risk of contaminant dispersion is shown in **Figure 1**. The approach was adopted for the whole ADRION area to provide an overall information on hazards, vulnerable areas and risk areas (at 1/64°spatial resolution) and focused on three case study sites at a finer resolution (1/320° in the Adriatic and 1/128° in the Ionian Sea). Based on occurrence of intense marine traffic, in particular from oil tanks, presence of exploration/production sites in the area, presence of potentially vulnerable environments, and, finally, on higher data and information availability, the selected case study sites are: the Gulf of Trieste in the North Adriatic, the Bay of Split in the Middle Adriatic and the Gulf of Patras in the Ionian Sea. The identification of the three sites was shared with stakeholders involved at the beginning of the activity, and took into account the potential occurrence of an oil spill related to marine traffic in particularly congested areas such as the Gulf of Trieste and the Bay of Split, and the oil exploration and extraction activities foreseen in the Gulf of Patras. In the Gulf of Trieste, the transnational aspect related to the proximity of Italian, Slovenian and Croatian national waters requires, in particular, a shared, harmonized and coordinated approach, in case of accidents.

2. Methodology

A quite extensive scientific literature dealing with Risk Index calculation methodology already exists and several projects on environmental management have been carried on using such approaches [5] [7] [8]. The risk is defined as the "probability of a loss", involving the concepts of hazard, vulnerability and exposure [11].

As the risk is assessed on the basis of hazard and vulnerability, it is important to underline that risk is not an objective quantity and can greatly change from application to application, and, most of all, it depends on the vulnerability data taken into account.

Risk index is considered relevant for purposes of spatial planning on land and, up to now, in a much smaller number of cases, on sea. HarmoNIA approach is based on the [8], [9], [13] and also [10] presented also in English in Annex I.

Several types of geospatial data were collected within HarmoNIA partnership, and subsequently harmonized in order to provide a common information framework on: the status of protection of coastal and marine environment, on the presence of habitats of high environmental concern, on socio-economic activities in the area relying on Good Ecosystem Status (GES) and on potential pollution threats. All data sets were categorized as:

a) potentially vulnerable to pollution

or

b) potential source of contamination

The first group of data sets (a) was used to define "vulnerability thematic GIS layers" such as marine protected areas layer, bathing waters locations, aquaculture sites, etc. which were used to calculate "Vulnerability Index". The second group of data sets includes "hazard thematic GIS layers" or the layers that indicate areas or locations that could represent potential source of contamination (e.g. ferry and shipping lanes, locations of ports and harbors, offshore platforms locations), and were used to calculate the "Hazard Index". All data sets were stored inside a spatial database and presented through HarmoNIA project GeoPortal (http://jadran.izor.hr/harmonia/#).

Spatial extension of vulnerable and hazard areas was calculated for the whole Adriatic-Ionian area using a "buffer approach". Since surface pollution, carried by surface currents, spreads during time, pollution can reach different distances during different periods. On the other side, after an incident, a certain amount of time is needed to take actions to limit pollution dispersion. A buffer is the spatial representation of an area within increased risk: e.g. if for setting oil spill barriers around mariculture site, six hours are needed, and pollution can reach 3500 meters in six hours, a buffer of 3500 meters represents the area of increased risk, because in case of incident inside this area, that mariculture site will be inevitably polluted. For three selected case study sites, beside the buffer approach, oil spill modelling approach was used to simulate oil spill dispersion from an offshore source in typical weather conditions. The oil spill simulations have been carried out to give the indication of the probability of the hazard of oil pollution related to an oil spilled from selected points, considering average meteo-marine conditions of each area, during 10 consecutive days after the spill. By using oil spill dispersion simulation, buffer size was defined for each of the hazard thematic data sets.

Combining information of hazard and vulnerability layers will allow to evaluate the risk of oil spill contamination.

2.1. Buffering

Based on the assumption that a generic hazard extends its threat to a surrounding area, but with a decreasing intensity, spatial properties should be defined in order to propose a set of hazard classes needed to compute hazard index. Buffering is one of the basic spatial operation which calculates a new polygon starting from a source object (point, line or polygon) with the property that its boundary is at a defined distance from the source object. In order to identify hazard classes, buffering has been used to produce polygons at different distance from the source object and whose classes are assigned taking into account the distance and the class of the source object.

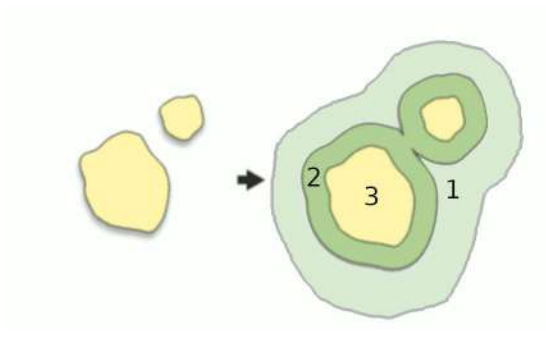


Figure 2 Example of classes produced with buffering: Source polygon class 3 (yellow), first buffer class 2 (green), second buffer class 1 (light green)

Buffering is easy applicable to a single layer, or few merged layers, producing as result polygons. When we have larger numbers of layers as input, with complex geometry and different features, calculating buffers is complex, and results can be unpredictable. Because of these constraints, in areas of complex geometry such as the Croatian coast, hazard and vulnerability indexes are calculated on a grid of points.

2.2. Grid of spatial points

By using a grid of spatial points, we can calculate, for each individual point, vulnerability index, hazard index and risk index. Grids are defined according to the grid used for hydrodynamic modelling, and we use four groups of grid resolutions:

- Adriatic/Ionian at 1/32 degree resolution (first version)
- Double Adriatic/Ionian at 1/64 degree resolution (current version)
- Case study area grid 1/320 degree resolution (Trieste and Split region) and 1/128 degree resolution (Patras region)

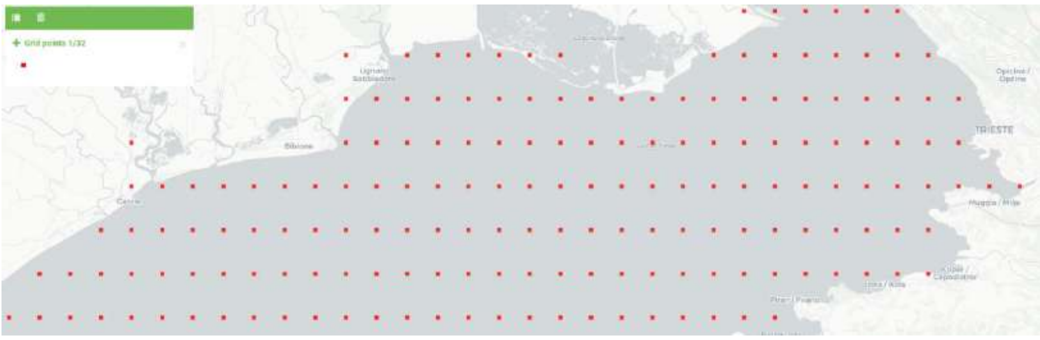


Figure 3 Grid 1/32 degree resolution

Figure 4 Grid 1/64 degree resolution

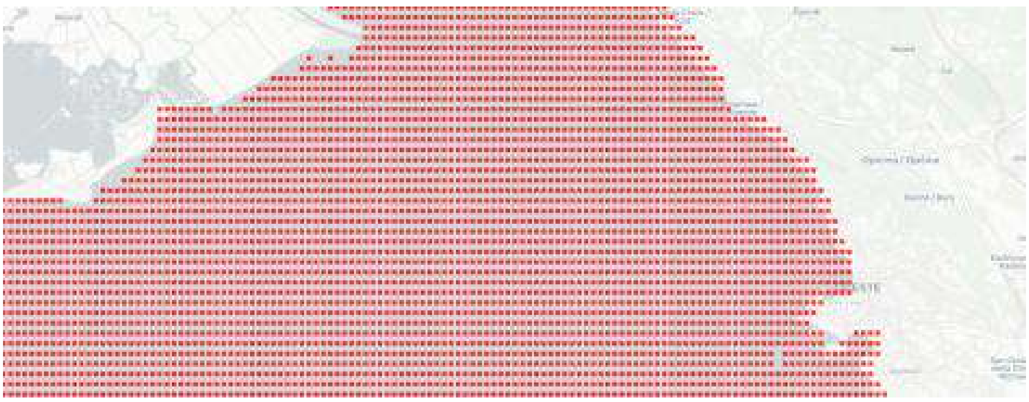


Figure 5 Grid 1/320 degree resolution (Trieste region)

2.3. Buffer size

Results from hydrodynamic and oil spill models were used to define the buffer size. Taking into consideration that six hours is the common maximum time expected for intervention operations, the distance and size of surface dispersion of oil coverage after approximately, two, three and six hours was used to obtain the buffer distances of 2000, 3500 and 5000 meters. These values will be used for calculation of hazard, vulnerability and risk **Figure 6**.

Figure 6 Oil spill model results for Trieste region after 2, 3 and 6 hours from incident

Using a grid with a better resolution (1/128 or 1/320 degree) for the whole Adrion region can improve results, and this is one of the future improvements for this methodology. From high resolution grid points various contoures can be calculated, and that can also lead to future improvement.

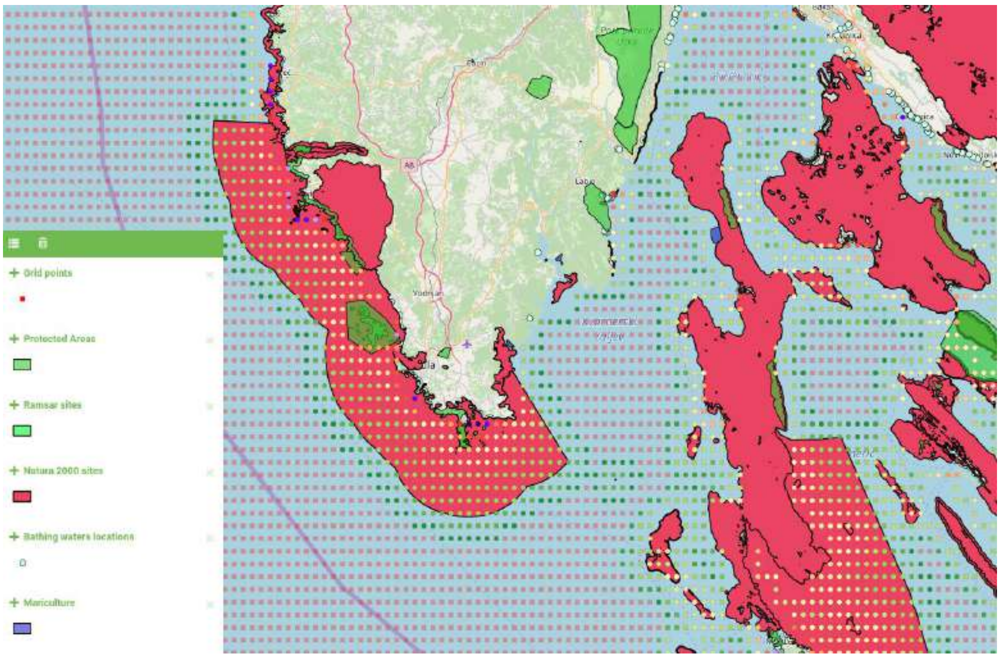


Figure 7 Example of vulnerability index calculation

3. Risk assessment components: Hazard

Oil spill modelling

Probability density maps of oil distribution from spills occurring from selected releasing points have been obtained from the oil spill model simulations, as presented in Deliverable T3.1.3. Releasing points were chosen in coordination with stakeholders and partners, and they represent, for each case study area, points with higher probability of oil spill accident **Figure 8**.

Figure 8 Locations of releasing points in Trieste, Split and Patras case study areas

Each map represents the 10-days evolution of an oil spill for the Surface oil and for the Beached oil indicating which are the most probable trajectories and targets of a possible oil spill occurring during a typical year.

According to [7], we assumed an equal probability of occurrence of an oil spill event for each day of the year and for each of the release areas. To obtain oil drift statistics representative of different weather conditions, we performed an ensemble of 365 simulations for each release point, each driven by a slightly different (1 day shifted) circulation field extracted from the 1-year period, and each tracking oil spill trajectory and transformation for 10 days.

Statistics were then extracted for each site and presented as the average of the 10-days oil spill hazard, i.e. the percentage of oil spilled at the release point that reaches coastal site "i" within the time interval "T" (of 1-to 10 days).

$$HI_{T,i} = \frac{\sum_0^T x_{i,t}}{max_{x_i} \sum_0^T x_{i,t}}$$

where HI is the hazard index for the site "i", for a spill that lasted for a period "T", and is calculated as the sum of particles reaching the site i in the time T divided by the maximum number of particles that reached one of the sites of the area in the time T. (With site, we consider the smaller unit in which our domain was divided.)

Gulf of Trieste oil spill simulation

Simulation of release of 1000 particles, representing the release of 3000 m^3 of crude oil. Resolution is 1/320 degree.

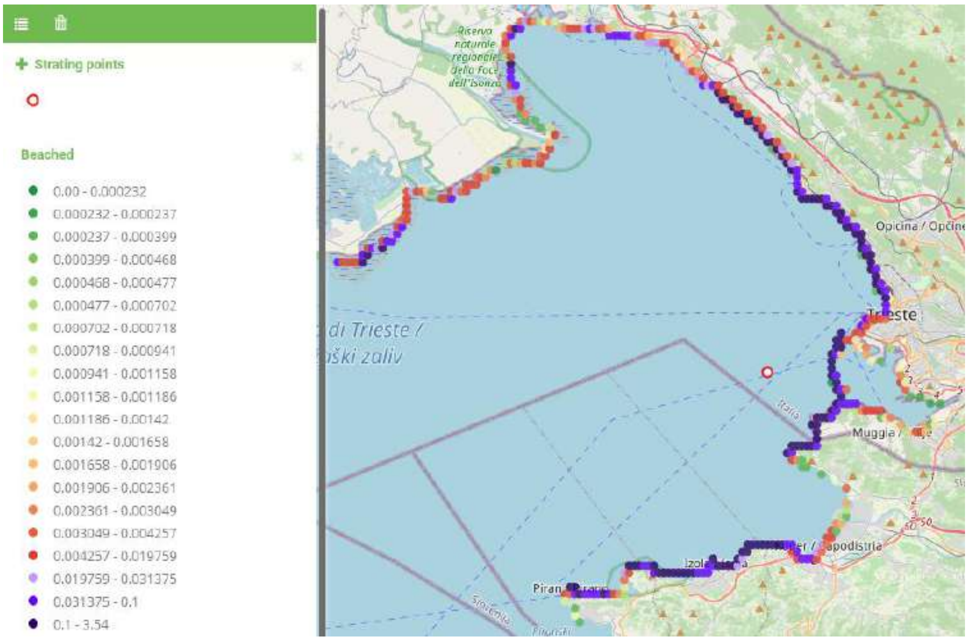


Figure 9 Gulf of Trieste: Oil spill hazard map at coast based on probability of oil spilled reaching the coast after 20 hours from simulated discharge in white point, using average meteorological conditions

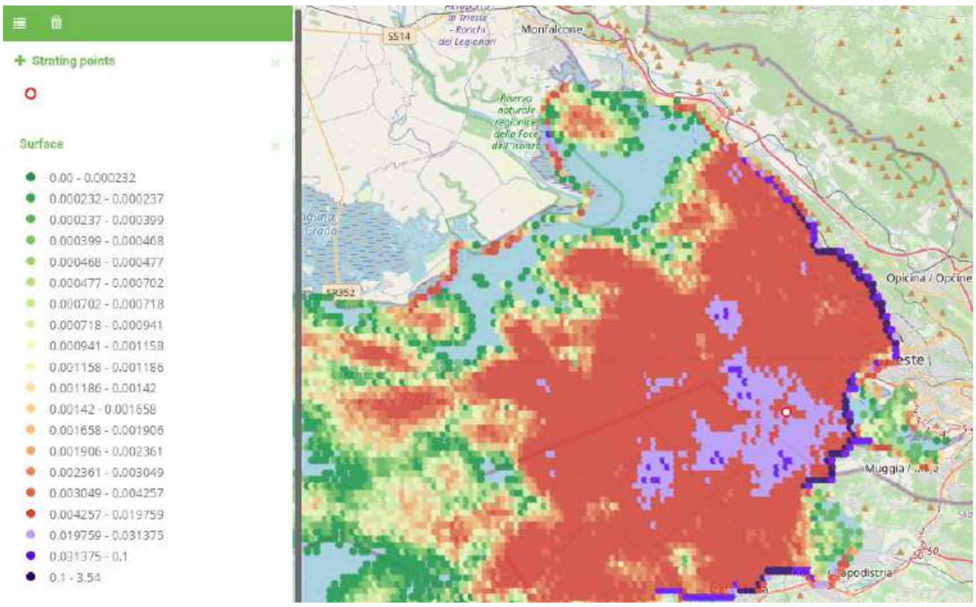


Figure 10 Gulf of Trieste: Oil spill hazard map at surface based on probability of oil spilled reaching the coast after 20 hours from simulated discharge in white point, using average meteorological conditions

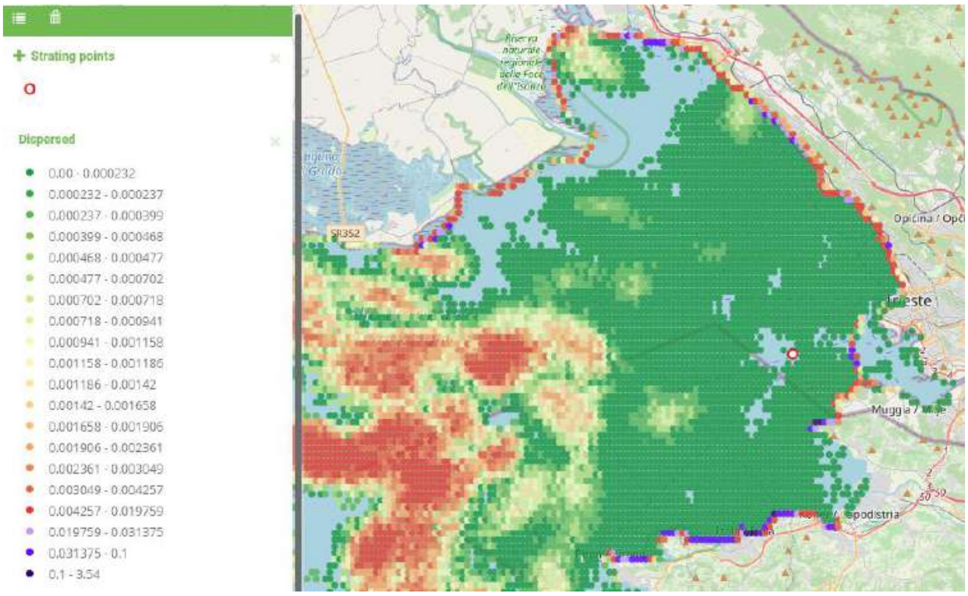


Figure 11 Gulf of Trieste: Dispersed oil spill hazard map based on probability of oil spilled reaching the coast after 20 hours from simulated discharge in white point, using average meteorological conditions

Bay of Split oil spill simulation

Simulation of release of 1000 particles, representing the release of 3000 m^3 of crude oil. Resolution is 1/320 degree.

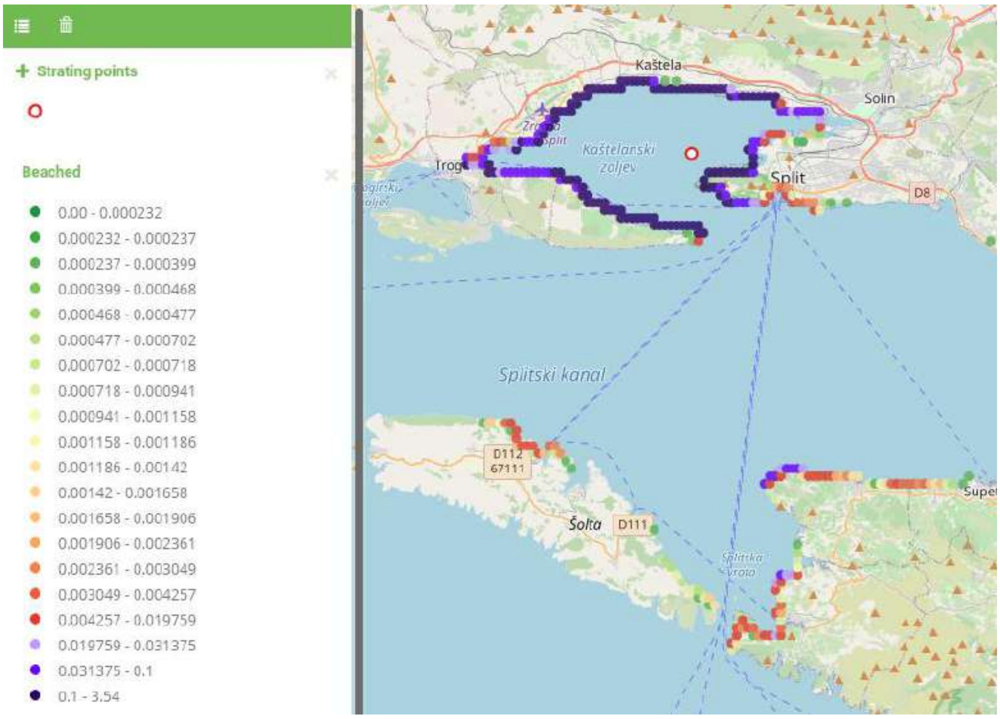


Figure 12 Bay of Split: Oil spill hazard map at coast based on probability of oil spilled reaching the coast after 20 hours from simulated discharge in white point, using average meteorological conditions

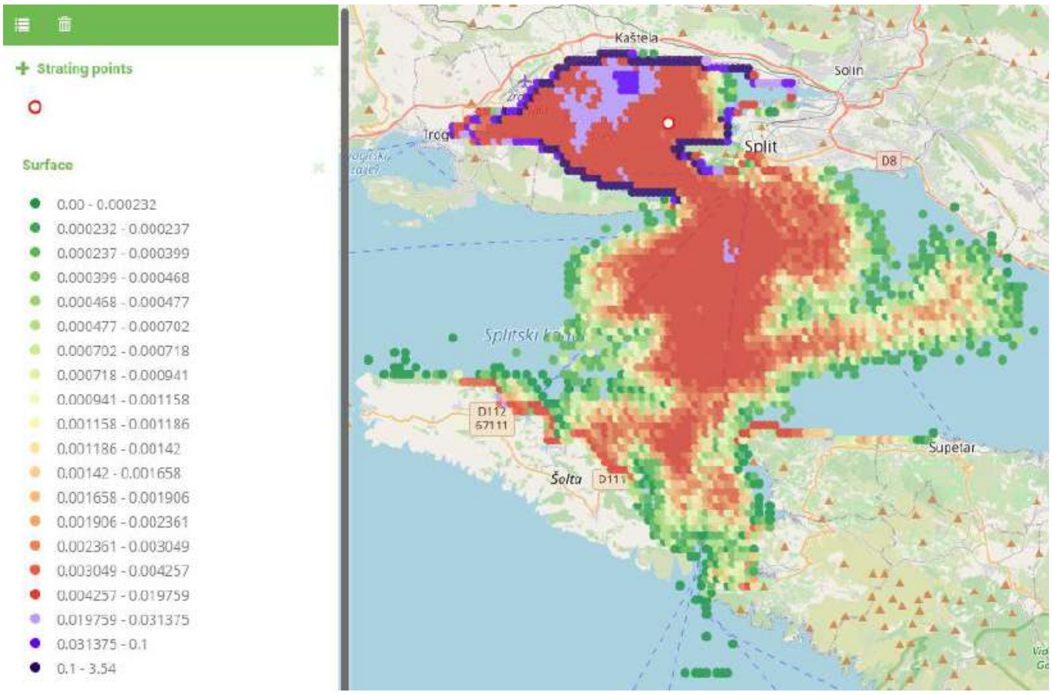


Figure 13 Bay of Split: Oil spill hazard map at surface based on probability of oil spilled reaching the coast after 20 hours from simulated discharge in white point, using average meteorological conditions

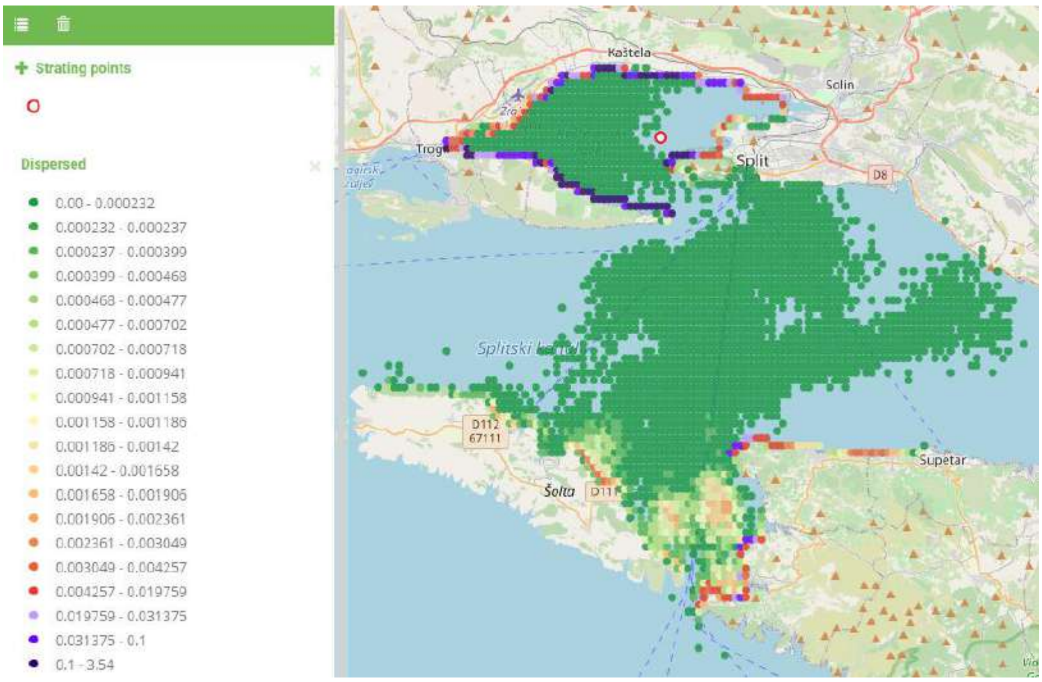


Figure 14 Bay of Split: Dispersed oil spill hazard map based on probability of oil spilled reaching the coast after 20 hours from simulated discharge in white point, using average meteorological conditions

Gulf of Patras oil spill simulation

Simulation of release of 1000 particles, representing the release of 3000 m^3 of crude oil. Resolution is 1/128 degree.

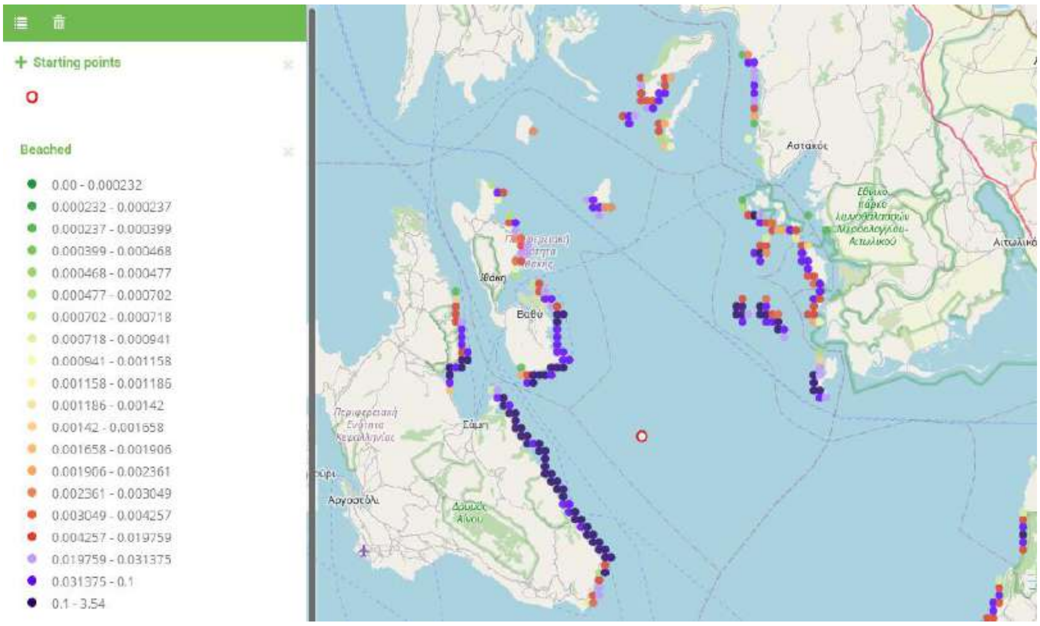


Figure 15 Gulf of Patras: Oil spill hazard map at coast based on probability of oil spilled reaching the coast after 20 hours from simulated discharge in white point, using average meteorological conditions

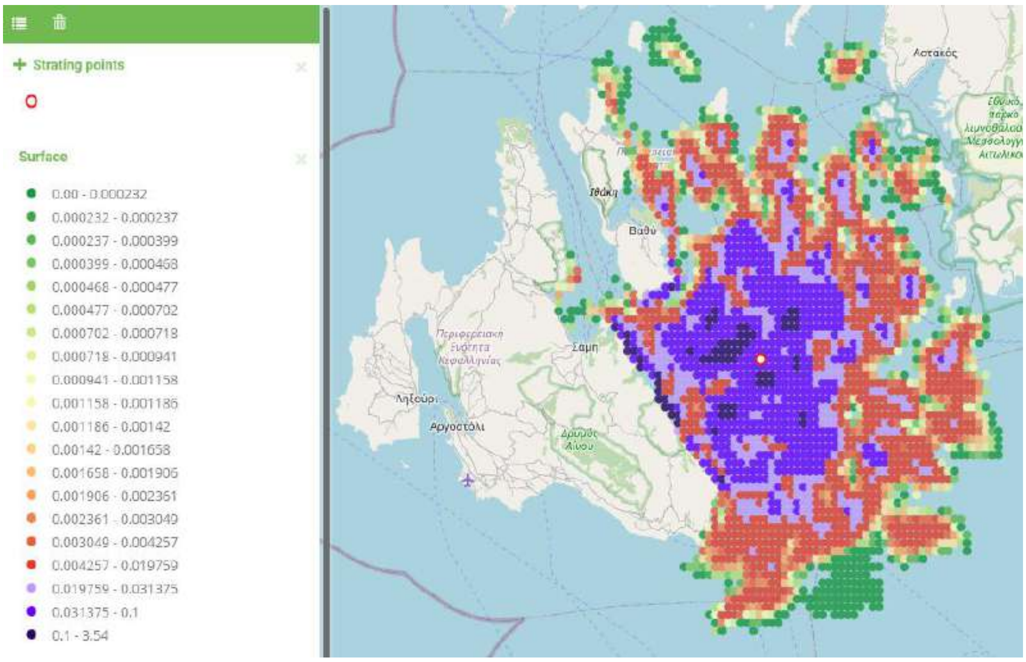


Figure 16 Gulf of Patras: Oil spill hazard map at surface based on probability of oil spilled reaching the coast after 20 hours from simulated discharge in white point, using average meteorological conditions

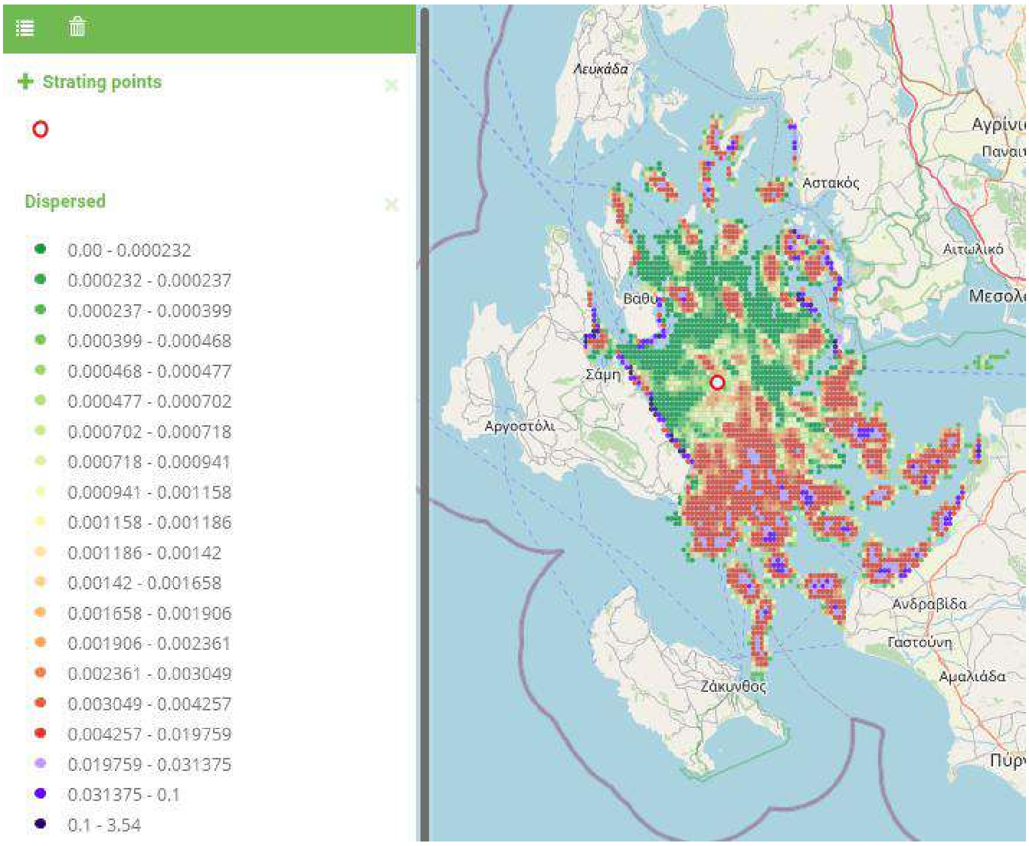


Figure 17 Gulf of Patras: Dispersed oil spill hazard map based on probability of oil spilled reaching the coast after 20 hours from simulated discharge in white point, using average meteorological conditions

Oil spill simulations on HarmoNIA GeoPortal

On the HarmoNIA GeoPortal (http://jadran.izor.hr/harmonia/) animations of oil spill are available. Animations are made using the layers representing the three types of hazard layers (surface oil, dispersed oil and beached oil) produced with the oil spill model. A total of 239 outputs per layer and per simulation are available, representing the evolution of the spill for 10 days. Animations can be used as classic layer and can be overlayed with any other layer. Points of discharge are available as separate layer (Starting points).

Simulation of oil spill along main shipping lines

Additionally, a simulation of oil spill along the main shipping routes is modeled, setting a spill probability moduled by the traffic density. The results will therefore depend on the combined contribute of the oil spill occurrence, of its probability, and by the oil behaviour in the sea, which is determined by the marine circulation and by the oil transformations. The results give hourly layers of surface, dispersed and beached oil, for ten days after the oil release. The results represent therefore, for each point of the Adriatic Sea basin, probability (hazard) of oil spill from the main traffic routes. **Figure 18**. shows the 24 hours layer.

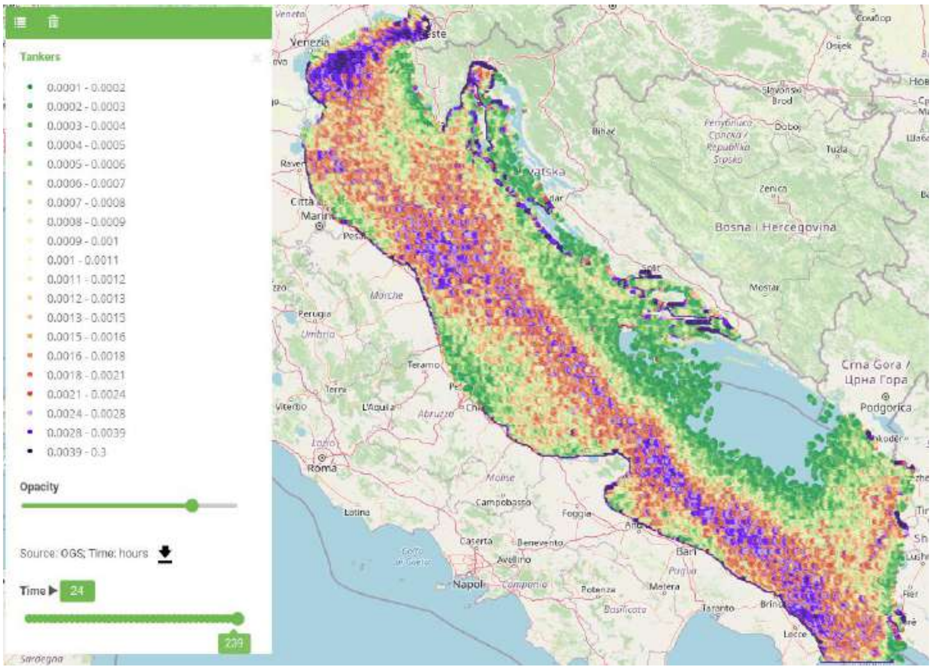


Figure 18 Results from oil spill modelling with source of pollution along main shipping lines (surface oil 24 hours after the spill)

3.1. GIS layers of oil spill hazard

As previously mentioned, the second group of layers consists in GIS layers that depict areas or locations that could present potential source of oil spill contamination, and are thus defined as: “hazard oil spill layers”.

This group currently includes:

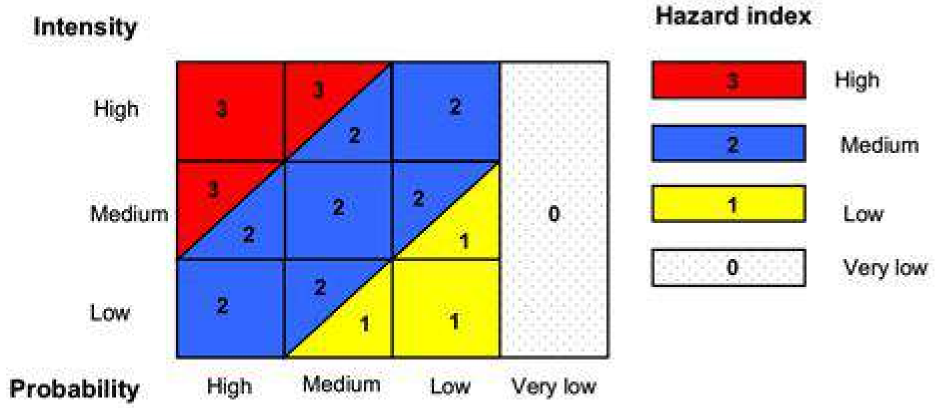
- Shipping routes[1]
- Ferry routes
- Ports and harbours
- Offshore oil and gas platforms
- Simulation of oil spill along main shipping lines[2]

[1] A more accurate approach will need information on shipping density, in particular of oil tanker shipping density

[2] Layer will be added to hazard risk during August 2020

Data belonging to the same theme provided by different project partners were merged into a single thematic layer to provide a harmonized information. For each layer, a hazard class is assigned taking into account the probability and the intensity of possible pollution dispersion of the different sources and values ranging between 1 - 3 (low, medium, high) were assigned according to **Table 1**:

Table 1 Probability and the intensity of possible pollution dispersion



Based on criteria illustrated in **Table 1**, the classification of hazard levels is here proposed (**Table 2**). The “component” in **Table 2** represents the weight factor regarding buffer distance corresponding with hazard level. The component is calculated from presence in buffer hi (that can be 0 - not present, or 1 - present) and weight factor for buffer/risk.

Table 2 Classification of the hazard levels

Class	Hazard Index	Component
High	3	h_1x3
Moderate	2	h_2x2
Low	1	h_3x1
Very low	0	1

For each point from grid, a total hazard index (Hi_i) is calculated with the following procedure.

Initially, each point has hazard component of 1 (very low). If a point is inside the biggest buffer with low class, value 1 is added. If it is in moderate class, value 2 is added, and finally for high class value 3 is added.

Total spatial hazard index h_i was calculated: $h_i = h_1*3+h_2*2+h_3+1$

For example if point is in high risk buffer value is: hi=1*3+1*2+1*1+1=7. h_2 and h_3 are also 1 because this point is also included in the wider buffers.

Once total hazard index regarding distance for each layer has been calculated, an overall total hazard index is derived assigning different weight factors for each layer according to the possibility and possible intensity of pollution from different sources.

$$Hi_i = \sum_{i=0}^{n} Wl * \sum_{i=1}^{n} \quad h_i$$

Formula for calculation of hazard index (Hi_i).
Wl is weight factor of layer and h_i is spatial component of point

Distances for the buffer zones are set according distance that pollution can reach after one, three and six hours.

Proposed distances for buffering layers with assigned hazard class weight factor:

- Shipping lanes (weight factor 4)
  - 2000m buffer Index 3 (h1)
  - 3500m buffer Index 2 (h2)
  - 5000m buffer Index 1 (h3)
- Ferry route (weight factor 1)
  - 2000m buffer Index 3 (h1)
  - 3500m buffer Index 2 (h2)
  - 5000m buffer Index 1 (h3)
- Ports and harbors (weight factor 1)
  - 2000m buffer Index 3 (h1)
  - 3500m buffer Index 2 (h2)
  - 5000m buffer Index 1 (h3)
- Off shore platforms (weight factor 7)
  - 2000m buffer Index 3 (h1)
  - 3500m buffer Index 2 (h2)
  - 5000m buffer Index 1 (h3)

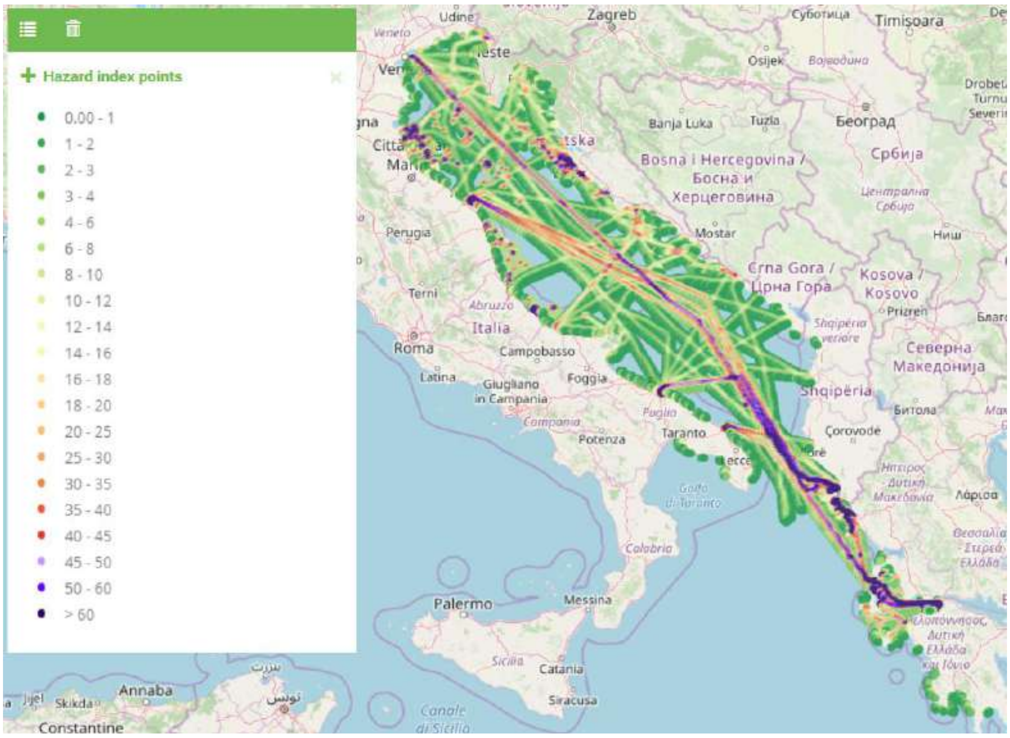


Figure 19 Hazard index calculated for the Adrian region using the described approach (1/64 degree resolution)

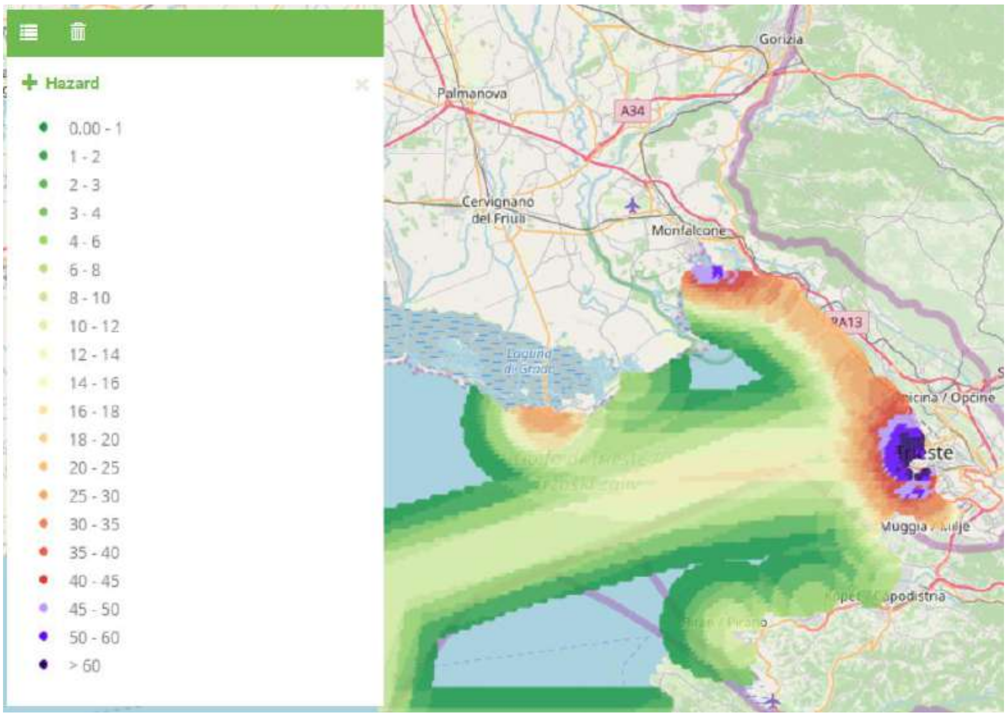


Figure 20 Hazard index for the Trieste region (1/320 degree resolution)

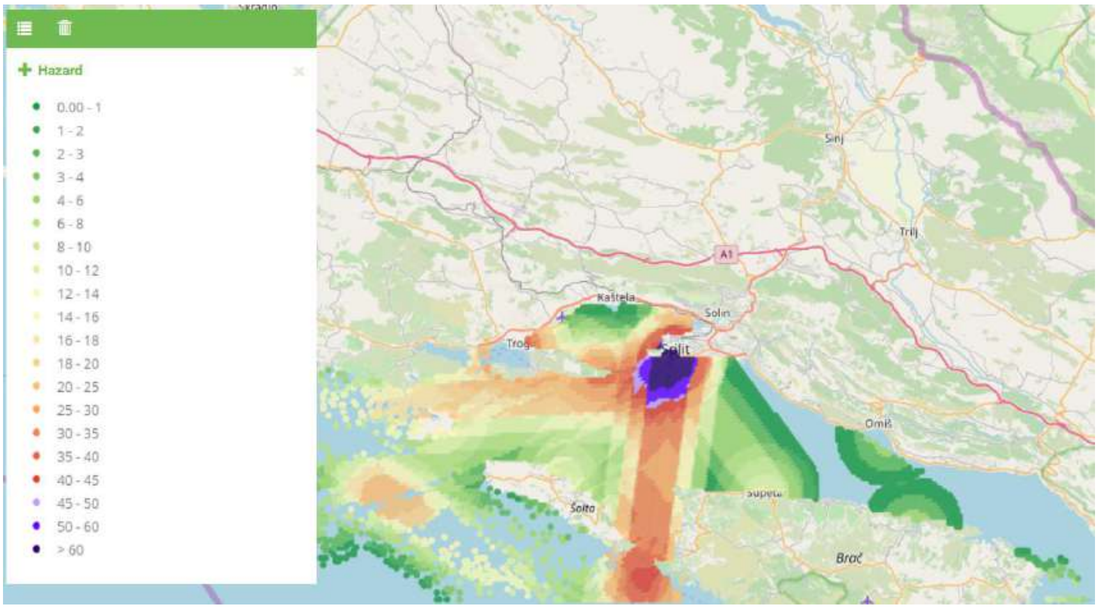


Figure 21 Hazard index for the Split region (1/320 degree resolution)

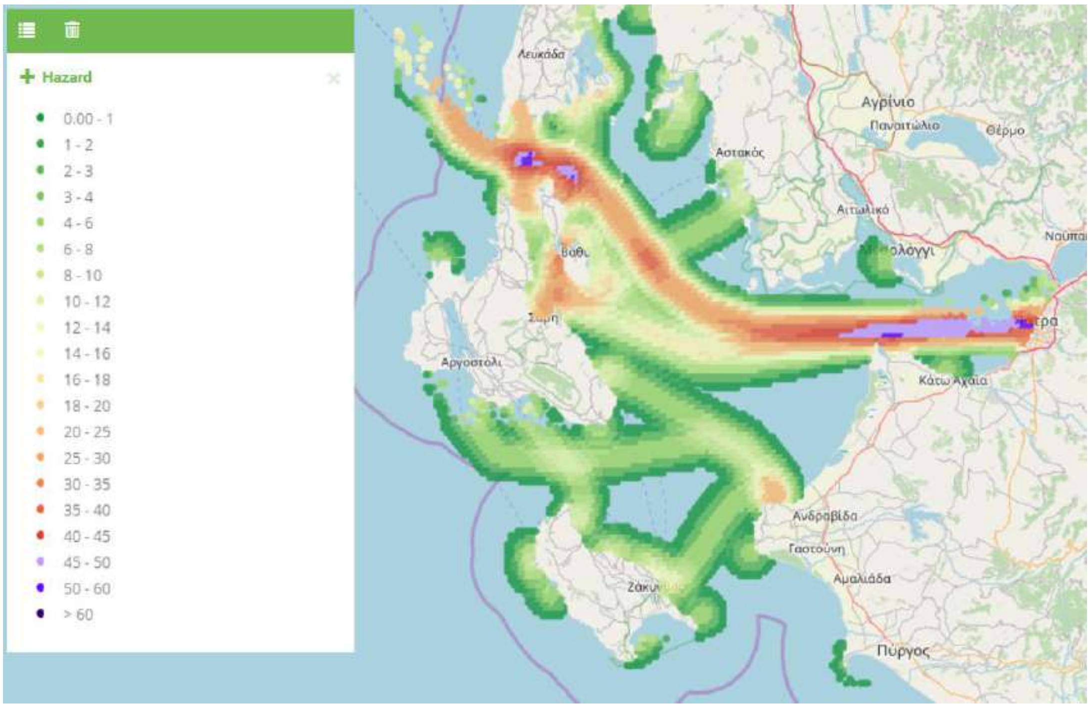


Figure 22 Hazard index for the Patras region (1/128 degree resolution)

4. Risk assessment components: Vulnerability

Vulnerability of coastal areas is determined according to two major groups of area properties: natural resources and protection, and human activities (socio-economic value). For this methodological proposal, weight factors were assigned according to previous studies [12]: for example areas with human activities have higher weight factor then natural protected areas. However, the choice of the weight factor is a crucial component of the analysis and needs to be discussed and agreed among several stakeholders. This is outside HarmoNIA scope, which aims rather to propose a methodological and technological approach.

Distance from the vulnerable site is also a very important factor to be taken into consideration when assessing vulnerability areas. For example, usually 300 meters from bathing areas is considered a limit for maritime traffic In the Croatian legislation [14], within distance of 300 meters from mariculture site, all other activities at the sea are prohibited, and this area around mariculture site has highest vulnerability level, as well as 300 meters from bathing location. The time required to respond to pollution event is also important. Some actions can be taken in short time of three to six hours [12]. Converting these times (three - six hours) to distance that, in average meteo-oceanographic conditions, pollution can reach, these correspond to 3500 and 5000 meters, respectively. More than 5000 meters from the vulnerable site, the vulnerability is considered low.

The approach to vulnerability calculation is similar to the one proposed by HAZADR project [12]. HAZADR proposed vulnerability of the coast line only, and that provides information on how vulnerable the coast is. Our approach deals also with open water areas, and that can assist when planning spatial management of marine activities.

4.1. GIS layers of vulnerable marine and coastal zones in case study areas

In order to assess the vulnerability of marine and coastal zones in case study areas, the following layers have been prepared:

- Land cover
- Protected areas
- Areas of socio-economic value

Data collected from project partners were merged together for each theme separately (eg. all ports locations from all partner countries in one layer).

The 'protected areas' layer was constructed using Ramsar sites data, Natura 2000 data and the national data about natural protected areas provided by project partners. Data used for 'land cover' layer have a good coverage for the whole Adrion region, but the improvement of data quality for this and all other layers is still an on-going activity. Two sets of data were used to present the 'areas of socio-economic value': locations of aquaculture sites from all countries involved in HarmoNIA and locations of beaches in Adriatic and Western Ionian area that are included in the monitoring under Bathing Water Directive. As with the previous layers, data about locations of beaches collected from all project partners were merged into a single GIS layer.

A vulnerability class is assigned to each layer according to the following table:

Table 3 Classification of the vulnerability levels

Class	Vulnerability Index	Component
High	3	v1x3
Moderate	2	v2x2
Low	1	v3x1
Very low	0	1

Component from **Table 3** is weight factor regarding buffer distance corresponding with vulnerability level.

Total vulnerability index V_i was calculated: $v_i = v1*3+v2*2+v3+1$

Once total vulnerability regarding distance for each layer has been calculated, an overall total vulnerability index is derived assigning different weight factors according to the importance of the area that constitute the layer.

$$VI_i = \sum_{i=0}^{n} Wl * v_i$$

Formula for calculation of vulnerability index (Vi_i).
Wl is weight factor of layer and v_i is spatial component of point

Proposed distances for buffering layers with assigned vulnerability classes and weight factors:

- All Natural protected areas (weight factor 1)
  - 100m buffer Index 3 (v1)
  - 3500m buffer Index 2 (v2)
  - 5000m buffer Index 1 (v3)
- Beaches (weight factor 3)
  - 300m buffer Index 3 (v1)
  - 3500m buffer Index 2 (v2)
  - 5000km buffer Index 1 (v3)
- Mariculture sites (weight factor 2)
  - 300m buffer Index 3 (v1)
  - 3500m buffer Index 2 (v2)
  - 5000m buffer Index 1 (v3)

Figure 23 Layers describing vulnerable areas available on HarmoNIA Geoportal

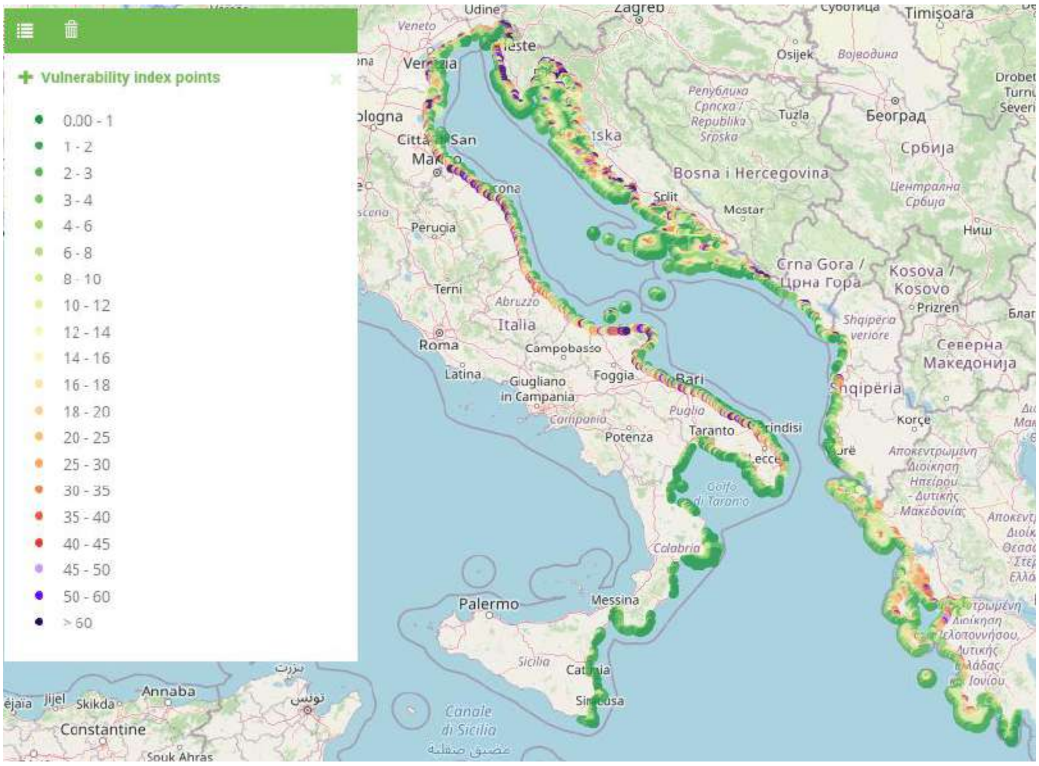


Figure 24 Vulnerability index for the whole Adrian region (1/64 degree resolution)

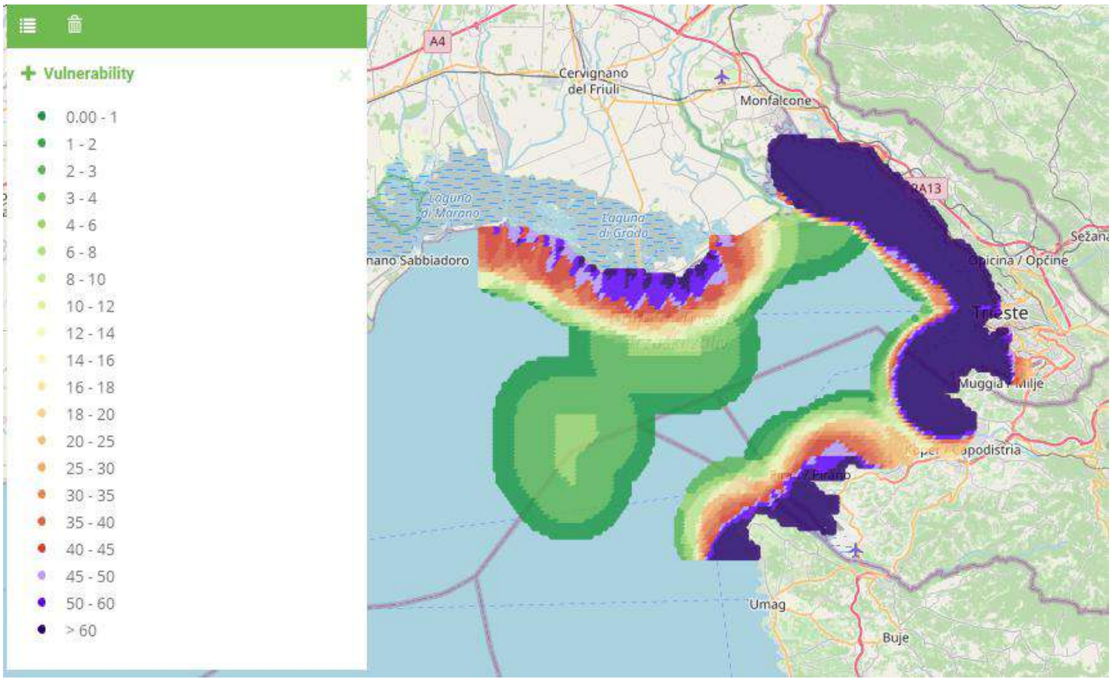


Figure 25 Vulnerability index for the Gulf of Trieste region (1/320 degree resolution)

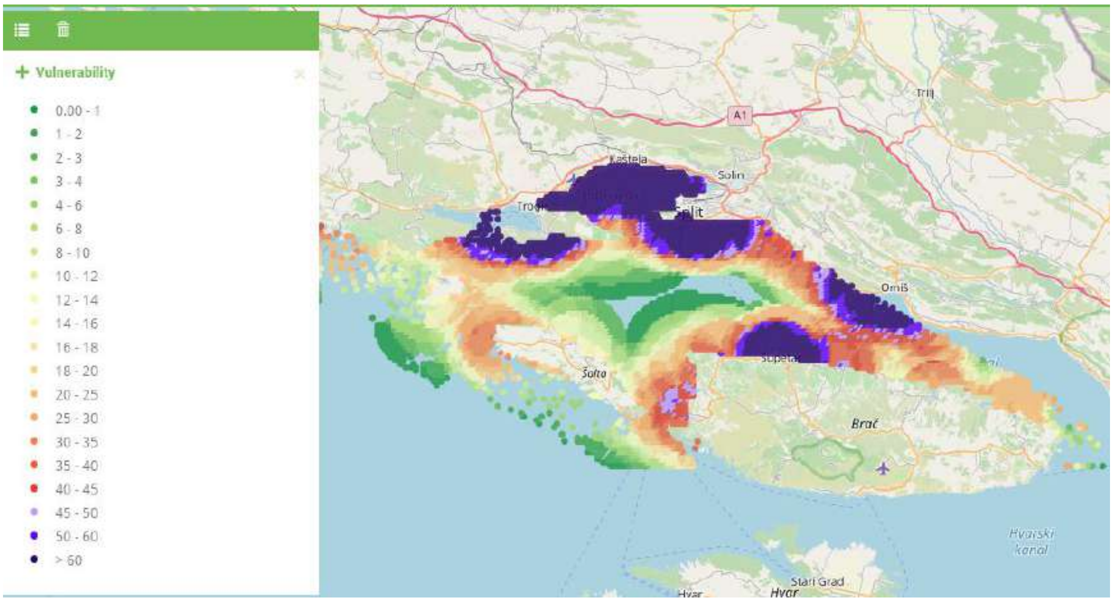


Figure 26 Vulnerability index for the Split region (1/320 degree resolution)

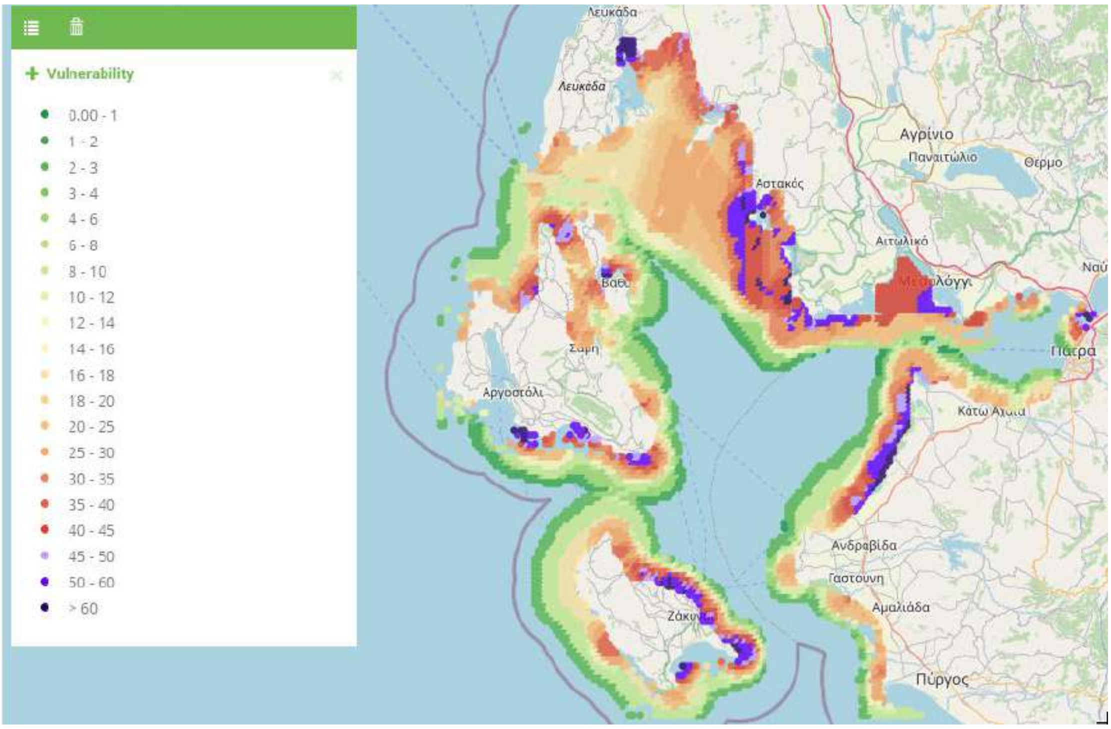


Figure 27 Vulnerability index for the Patras region (1/128 degree resolution)

5. Risk Index

The spatial extension of the Risk Index was calculated using vulnerability layers and oil spill hazard layers, already presented in previous project deliverables (Deliverable T3.1.3 and Deliverable T3.2.1 respectively). Adopting the usual definition, the risk index is derived as:

Hazard Index x **Vulnerability Index** = **Risk Index**

Risk index, thus, depends both on area vulnerability and hazard of pollution: risk index is highest in areas with high vulnerability (usually close to coast) and high hazard of pollution (usually near offshore platforms and main shipping lanes). The whole methodology considers superposition of different influences: e. g. in an area with many shipping lines, the resulting hazard is higher, conversely, presence of more than one type of protected areas increases vulnerability. Due to the lack of specific data and information on the hazard and vulnerability outside the considered buffer sizes, for precautionary approach HarmoNIA methodology indicates that risk is not null close to hazard sites (e.g. around offshore platforms), even if, with the current knowledge, vulnerability is regarded low. To allow this precautionary approach, grid points outside any hazard buffer are assigned hazard index 1 (very low). With the same approach, grid points outside any vulnerability buffer have vulnerability index 1 (very low). In the case that hazard index is 1 and vulnerability index is 1, risk index becomes 1 (1*1=1), which represents the lowest risk.

HarmoNIA approach and the specific tool implemented have following advantages:

- Connection to hydrodynamic model
- Flexibility of updating or revising information to calculate Risk Index, either of adding more precise layers or revising weight factors
- Speed of processing - calculation of hazard, vulnerability and risk index for three case study areas and whole Adrion region took less then 5 minutes. With additional optimization potential user can change parameters with web interface and almost instantly see result.
- In connection with speed of processing is possibility that in some future upgrade, operational hydrodynamic model can be used, producing more realistic and accurate results.

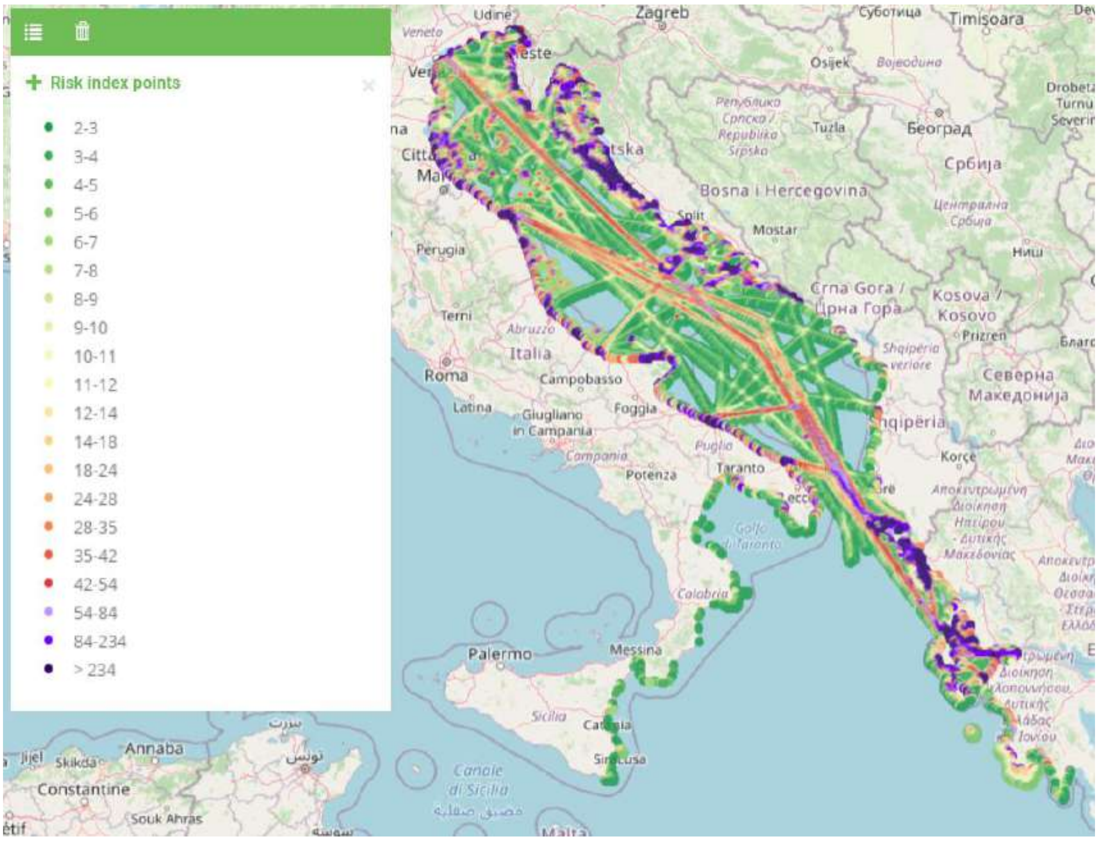


Figure 28 Risk Index map for the Adrion region

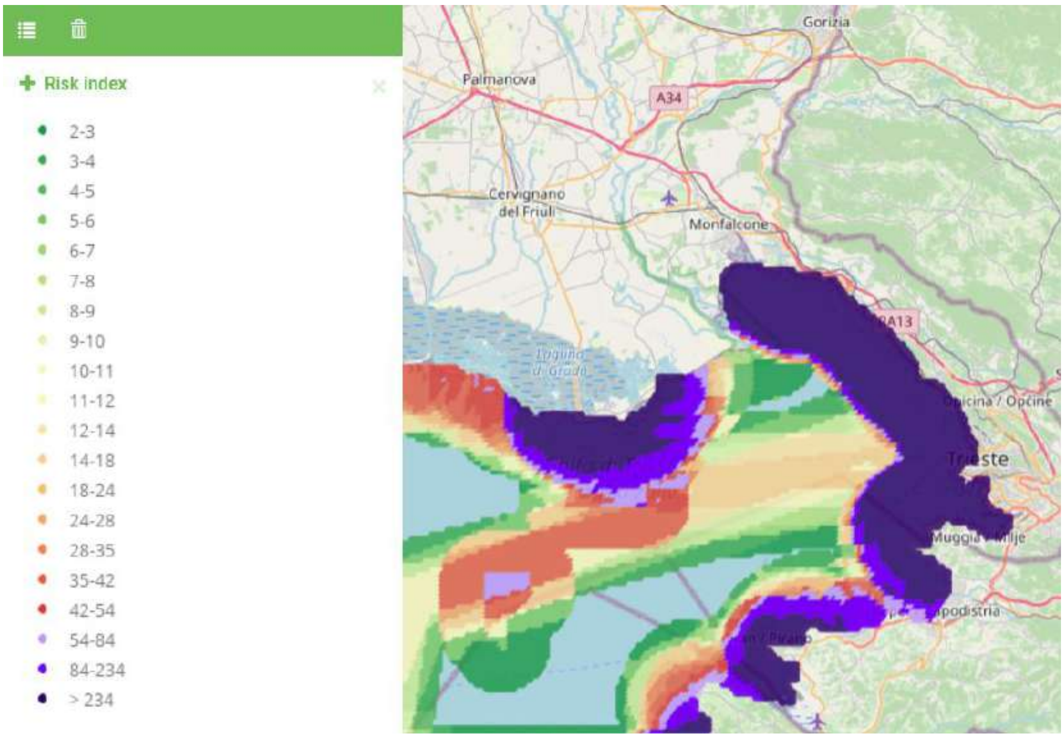


Figure 29 Risk Index map for the Gulf of Trieste

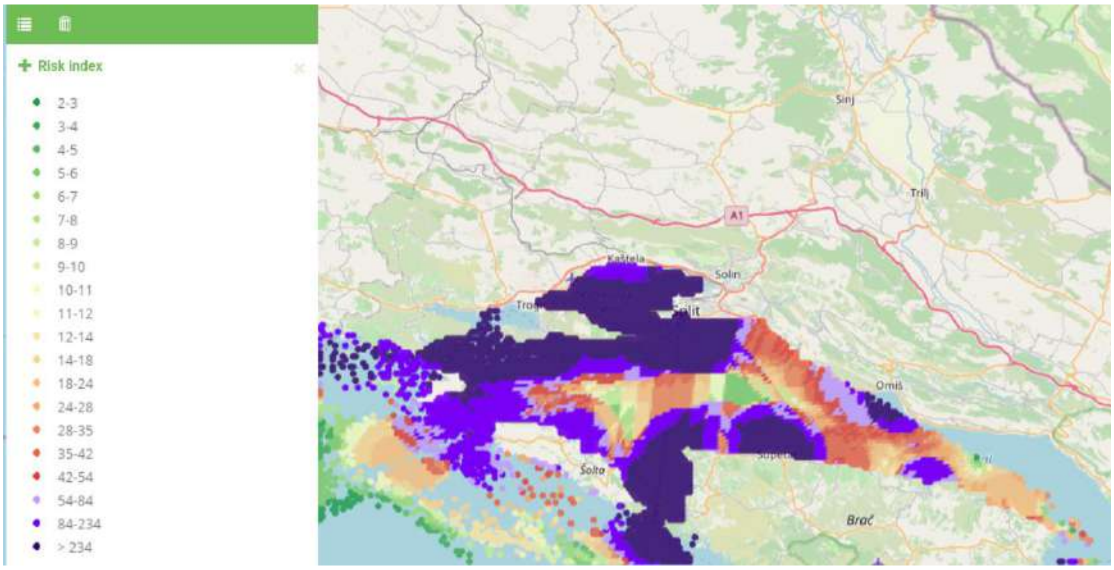


Figure 30 Risk Index map for the Bay of Split

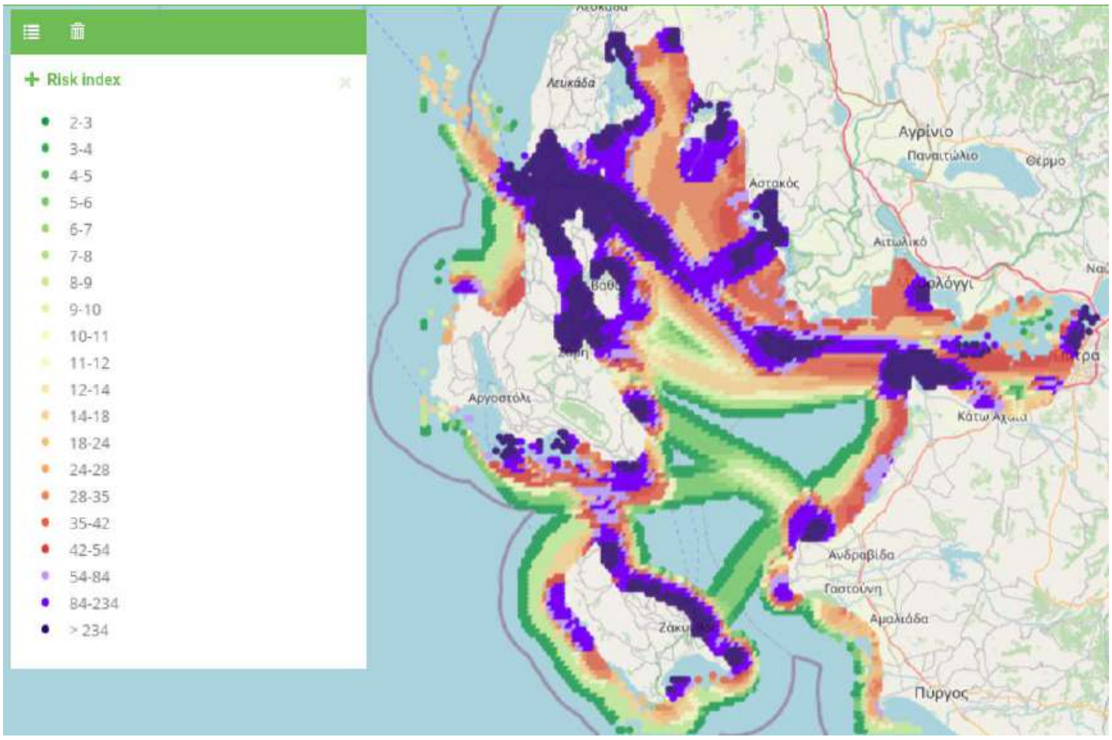


Figure 31 Risk Index map for the Gulf of Patras

6. Possible improvements

The proposed methodology can be improved in three major areas for better and more relevant results:

Improve quality of input layers

Input layers are essential to produce any result. The quality of input layers can be improved in more than one aspect:

- Updating of layers, showing present and existing features.
- Higher precision and resolution of the layers (i.e. layers are not merged: e.g. shipping lanes with each individual lane, not just coverage of all lanes).
- Distinction of layers specifically relevant for pollution risk assessment (eg. distinction of traffic routes of oil tankers or of HNS vessels from general maritime traffic)
- Layers with correct geometry (often layers don't have correct geometry definitions, which are not visible on the map, but this lack of information prevents correct spatial calculations)

Higher resolution for grid of spatial points and spatial contours

For more smooth and precise results, the grid of spatial points can be defined with higher resolution. Spatial contours can be calculated from grid of spatial points. Doing that we can produce polygons showing areas with some range of index values.

Use of hydrodynamics to transform grid of points to grid of lines

With the described methodology, it is possible to calculate the risk indexes for each individual point from the defined grid. Defined buffers are correlated with the movement of potential oil spills driven also by hydrodynamics of the sea. The extension of the buffers is isotrophic, that means equal in all directions, but, especially during strong weather events, surface currents can be strong and surface oil spill will be distorted by currents. To take this into account, we can replace grid of spatial points with grid of lines, replacing point with line having length and direction according surface current in that particular point. Calculating distance from line instead from point will distort buffer around according surface current. At **Figure 27** grid points are visible together with averaged surface currents. Imagine that buffer distance from each point is not depending only to spatial distance, but this distance is modified according direction and magnitude of arrow (surface current) from this point.

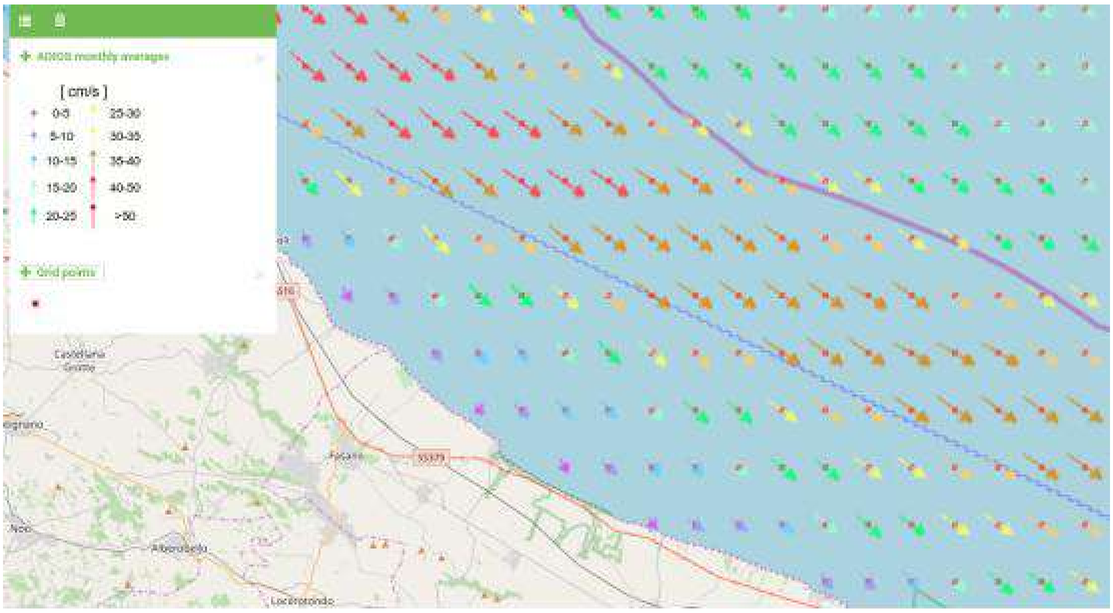


Figure 32 Grid of spatial points and surface currents

Use of quantitative approaches to assign weight factors

Availability of more objective information to assign weight factors to hazard and vulnerability layers is required to obtain more solid results. For example, approaches based on evaluation of ecosystem services may lead to a more transparent evaluation of coastal vulnerability.

7. References

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8. Annex I: The environmental risk index in the Guiding lines for the drafting of the Relevant risks document and for the risk evaluation in agreement with Italian national legislation Dlgs. 145 18/7/2015

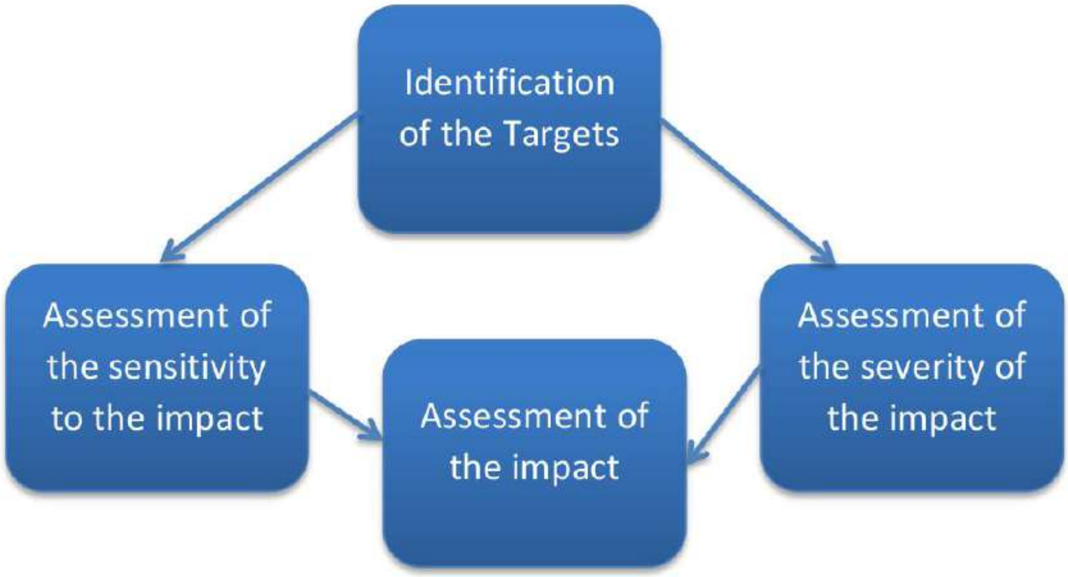

Figure 33 Steps in the italian Dlgs. 145 18/7/2015 environmental risk assessment process

In the first step all the receptors have to be identified. They should include at least those three targets:

1. Protected areas and habitats including species protected by the Italian and International legislation, Sites of Community Importance (SCI) as defined in the European Commission Habitats Directive (92/43/EEC), Natura 2000, and Bird Directive's (2009/147/CE) special protected areas (SPA's), Area hosting species included in the IUCN Red List of Threatened Species.

2. Marine and coastal environment including at least Habitats of interest defined in the EU 92/43 Directive (Annex 1).

3. Mrea of socio-economic and cultural interest (Blue flag beaches, bathing sites, aquaculture and fish harvesting sites, fish nursery and spawning areas, feeding grounds.

For each targets, the sensitivity level and the severity of the impact have to be defined. The combination of the two, gives the significativity of the impact, and to derive its environmental risk.

The environmental **sensitivity index** (ESI) is derived for target 1, and scaled between 1-10 (**Table 4**) Instructions and referencese are provided in the text for the classification and the.

Table 4 Classification of the environmental sensitivity index

ESI (from 1 to 10)		Simplified ESI	Mapping of simplified ESI
Index 1 and 2	→	1 (very low)	Not represented
Indexes 3, 4, 5 and 6	→	2 (low)	Not represented
Index 7	→	3 (medium)	Not represented
Index 8	→	4 (high)	**4 (high)**
Index 9 and 10	→	5 (very high)	**5 (very high)**

The **sensitivity** of the impacts on receptor 3 are computed taking into account the **recovering time** of the impacted socio-economic activity. A moderate sensitivity is assigned for a recovery time of 1-3 years, a severe sensitivity is assigned for a recovery time of 3-10 years.

The **severity** associated to all the Targets1 and 2 is done in terms of lenght of the impact interms of time, space and in terms of type of change of the targets (non detactable, detectable, evident, important) **Table 5**.

Table 5 Valuation matrix, severity of the impact for all the targets

	Valuation criteria			
Ranking	**Length of the impact**	**Extension of the impact**	**Alteration of the target**	**Severity of the impact**
1	Temporary	Local	Non detectable	**Scale from 3 to 12**
2	Short term	Regional	Detectable	
3	Long term	National	Evident	
4	Persistent	Transboundary	Important	
Score	**(1; 2; 3; 4)**	**(1; 2; 3; 4)**	**(1; 2; 3; 4)**	

The significativity of the impact, is therefore computed for each target using the **Table 6** by combining the two elements, the *Sensitivity of the target* and the *Severity of the impact*, and providing a value between 3 and 12, which can provide a significativity from Low to Very High.

Table 6 Matrix of determination of the significativity of the impact

		Sensitivity of the target		
		Low	Medium	High
Severity of the impact	3-4	Low	Low	Medium
	5-7	Low	Medium	High
	8-10	Medium	High	Very High
	11-12	High	Very High	Very High

The risk for the environment (acceptability of the impact or the environment) is then computed using the **Table 7**, which takes into account the frequecence of the impact and the number of environmental targets impacted.

The table discriminates between the green area , which provides an acceptable level of risk that does not prevent the oil offshore activity but requires a continuing monitoring and improvement, and the red zone which requires to revise the production process to reach a lower level of risk.

Table 7 Risk index classification

Consequences		Increasing frequency, events per year					
Index	Environment	0	A	B	C	D	E
		$< 10^{-6}$	10^{-6} -10^{-4}	10^{-4} -10^{-3}	10^{-3} -10^{-2}	10^{-2}-10^{-1}	$>10^{-1}$
1	Up to 3 elements of low significativity						
2	2 eleents of low or 1 of medium significativiy						
3	2 elements of medium or 1 level of high significativity						
4	2 elements of high or 1 element of very high significativity						
5	3 elements of high or 2 element of very high significativity						

9. Annex II: Hazard, vulnerability and risk index calculation: Technical details

Layers on vulnerability and hazard are prepared and loaded into Oracle database 19.3. Layers containing grid points are also in database, with point defined in geom column (proper spatial object, not just two numbers). For index calculation we are using Oracle spatial function:

SDO_WITHIN_DISTANCE(geom_point, geom_layer,distance)

"geom_point" is the spatial representation of individual points, "geom_layer" is the spatial representation of some features from vulnerability or hazard layers, and distance is a string defining distance and unit (e.g. 'distance=800 unit=meter'). Function returns 'TRUE' if input feature is within distance from grid point. Combining different input layers with different impact on index we can calculate vulnerability, hazard and risk index. The quality of the results strongly depends on the quality of input layers. Those depend on:

- Coverage of input layer for whole Adrion region or case study region.
- Individual layer features. E.g. if we have all particular active ferry routes for some area, each ferry route will increase hazard index on common route pathway. If we have just summarized coverage of all routes, hazard index will be same for area where is path of just one or ten ferry routes.
- Valid layer geometry. If some input layer have some invalid spatial geometry (wrong defined), then the behavior of the spatial function is not deterministic.