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# Hazardous and Noxious Substances (HNS) Risk Assessment along the Italian Coastline

Davide Astiaso Garcia[a,]*, Fabrizio Cumo[b], Franco Gugliermetti[a], Flavio Rosa[b]

[a]DIAEE (Dept. of Astronautical, Electrical and Energy Engineering) Sapienza University of Rome, Via Eudossiana, 18 - 00184 Rome, Italy
[b]CITERA (Interdisciplinary Centre for Housing, Heritage and Environment), Sapienza University of Rome, Via Antonio Gramsci 53, 00197 Rome, Italy
davide.astiasogarcia@uniroma1.it

The main purpose of this paper is to assess the risks associated with a potential HNS spill along the Italian coastline. The methodology adopted for this report included the elaboration of a comparative index, called RHNS (Risk Hazardous Noxious Substances), based on the application of the general principles of risk management and the development of new relevant equations for calculating the three main factors involved in any risk assessment: hazard, probability and consequences. The final equation was applied to the entire Italian coastline, dividing the total 8,375,000 m into 335 coastal stretches, each measuring 25,000 m in length on which an RHNS value was calculated. All the results obtained, including the RHNS index values and the collected data regarding the amount and typology of HNS substances in transit along Italian waters or landed in individual ports, were implemented in a national GIS database. This database produced thematic maps pinpointing areas where the potential risk of HNS disaster is higher.

## 1. Introduction

This paper briefly describes the activities and results obtained from research carried out by Sapienza University of Rome and supported by the Italian Ministry for the Environment, Land and Sea, the national department responsible for issues dealing with marine pollution involving HNS (Hazardous and Noxious Substances). According to the IMO Protocol on preparedness, response and co-ordination to pollution incidents by hazardous and noxious substances, HNS include “any substance other than oil which, if introduced into the marine environment, is likely to create hazards to human health, to harm living resources and marine life, to damage amenities or to interfere with other legitimate uses of the sea.” This report was based on the research group’s expertise in oil spill risk assessment (De Santoli et al., 2011) with the aim of adapting elaborated equations and matrices for the evaluation of the risk (Gugliermetti et al., 2007) and vulnerability (Cumo et al., 2008) of coastal and marine habitats to oil contamination to HNS risk assessment . The study began with an analysis of the leading international publications concerning HNS marine pollution and the relative regulatory framework to ensure that the results obtained by the research met current standards on international maritime agreements concerning the prevention of marine pollution and the environmental conservation of the seas. HNS maritime traffic includes the transportation of substances, materials and articles in packaged form, in bulk, and in tankers, regulated in two international conventions developed by the International Maritime Organisation (IMO): the International Convention for the Safety of Life at Sea – SOLAS, and the International Convention for the Prevention of Pollution from Ships (MARPOL). To supplement the SOLAS and MARPOL Convention provisions, IMO developed the International Maritime Dangerous Goods Code (IMDG Code) that contains technical specifications for the safe transportation of dangerous goods or hazardous material. Moreover, in consideration of local policies, the Mediterranean traffic of dangerous goods is also regulated by the regional agreement signed at the Barcelona Convention for the Protection of the Mediterranean Sea against Pollution. In light of this brief introduction to the HNS international pollution regulatory framework, and in addition to the substantial environmental value of Italian seas and coastline in terms of biodiversity

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richness as well as the number of endemic and protected species and habitats, an HNS risk assessment of Italian waters seemed essential for the protection of its marine environments. It should also be noted that, according to the European Maritime Safety Agency (EMSA, 2008), the overall capacity for HNS incident response in Italy is low. In fact, Italy has not ratified the OPRC-HNS Protocol 2000 (Protocol on Preparedness, Response And Co-Operation to Pollution Incidents by Hazardous And Noxious Substances) adopted by the IMO and it has not carried out any risk assessments specifically aimed at HNS marine transport. In this context, the main aim of our research was to provide useful tools and practical guidelines for planning preparedness and response actions required to prevent and mitigate potential HNS marine pollution.

Bearing this in mind, the specific goals of this research are: 1) to elaborate a comparative index to assess the risks of HNS contamination along the Italian coastline in the event of accidents by quantifying the potential environmental impact; 2) the implementation of a marine impact assessment (MIA) analysing the prevailing impact factors of HNS pollution along the typical marine and coastal Mediterranean ecosystems; 3) to elaborate a national GIS (Geographic Information System) database and thematic maps in order to highlight the most vulnerable national shorelines where the potential risk of HNS disaster is higher.

## 2. Materials and methods

The elaboration of the equation for HNS risk assessment was based on the application of the general principles of risk management and in particular on the Eq(1) (EMSA, 2007).

$$R = H \cdot P \cdot C \qquad (1)$$

Where: R: Risk; H: Hazard; P: Probability; C: Consequences. This equation has been used as a starting point for the elaboration of a new risk index for HNS maritime traffic, identified as RHNS. In particular, the three factors (H, P and C) have been quantified as described in the following paragraphs.

### 2.1 Hazard factor calculation

According to EMSA (2007), HNS hazard factor (H) is correlated to the hazardous nature and the quantity of each substance (French McCay et al., 2006). Considering the hazardous nature, the H factor depends on two different parameters: the first one is related to physical and chemical properties of any substance (Neuparth et al., 2011), while the second parameter is the containment system typology of any considered substance. Regarding the second parameter, the H factor includes two different hazard factor sub-indices: the first related to HNS transported in bulk ($H_B$), while the second one considers substances transported in packaged form ($H_P$). With regard to physical and chemical properties of HNS, in order to create an HNS risk index based on a standard classification of the numerous HNS typologies, it was decided to assess the hazard factors considering the HNS classification adopted by the last IMDG Code (Federchimica, 2010). IMDG Code provides an international standard for the safe carriage by sea of dangerous goods, considering 2,280 different substances. In particular, dangerous goods are classified into 9 classes according to their chemical properties and hazard characteristics: 1) Explosives; 2) Gases (Compressed, Liquefied or Dissolved under Pressure); 3) Flammable liquids; 4) Flammable solids or substances; 5) Oxidizing substances and organic peroxides; 6) Toxic and infectious substances; 7) Radioactive materials; 8) Corrosive substances; 9) Miscellaneous dangerous substances and articles.

158 out of these 2,280 substances (6.9 %) are identified as "marine pollutants" by IMO. Consequentially, an hazard coefficient (α) for each of the nine IMDG classes has been calculated taking into consideration the percentages reported as a standardized value of 100 of marine pollutants within each IMDG class (Table 1).

*Table 1: Evaluation of the hazard coefficients α related to the nine IMDG classes*

| IMDG Class (j) | Total substances | "Marine pollutant" substances | Percentages of marine pollutants | Hazard coefficient α |
|---|---|---|---|---|
| 1 | 372 | 3 | 0.81 | 1.73 |
| 2 | 208 | 3 | 1.44 | 3.09 |
| 3 | 409 | 8 | 1.96 | 4.20 |
| 4 | 285 | 8 | 2.81 | 6.02 |
| 5 | 151 | 4 | 2.65 | 5.68 |
| 6 | 507 | 124 | 24.46 | 52.46 |
| 7 | 25 | 0 | 0 | 0 |
| 8 | 287 | 4 | 1.39 | 2.99 |
| 9 | 36 | 4 | 11.11 | 23.83 |

$H_B$ indices are obtained from the sum of two sub-indices: $H_{Bp}$ (HNS in bulk handled at ports) and $H_{Bt}$ (HNS in bulk in transit in sea waters along the coastal stretches under examination). Moreover, in order to compare these values on a national scale, they have been standardized to range from zero to one hundred, where the value 100 has been assigned to the Italian coastline with a maximum $H_B$ value: Eq(2).

$$H_{\mathbf{B}} = 100 \cdot \frac{H_{Bp} + H_{Bt}}{\left(H_{Bp} + H_{Bt}\right)_{\max}} \qquad (2)$$

$H_{Bp}$ sub-indices, standardized to range from zero to one hundred, are obtained from the summation of the tons of HNS in bulk handled at each port (Tb) multiplied by the hazard coefficient (α) related to the relevant IMDG class and divided by the sea distance (d) between the port and the midpoint of the coastal stretches: Eq(3).

$$H_{Bp} = 100 \cdot \frac{\sum_{i=1}^{i=n} \frac{\sum_{j=1}^{j=9} \alpha_j \cdot \mathrm{Tb_j}}{\mathrm{d_i}}}{\left(\frac{\sum_{j=1}^{j=9} \alpha_j \cdot \mathrm{Tb_j}}{\mathrm{d_i}}\right)_{\max}} \qquad (3)$$

Where: $\alpha_j$: hazard coefficient related to the j-th IMDG class; $Tb_j$: tons of HNS in bulk of the j-th IMDG class loaded or discharged in the i-th port; $d_i$: sea distance between the i-th port and the midpoint of the examined coastal stretches. $H_{Bp}$ indices have been calculated only where the sea distance between the i-th port and the midpoint of the examined coastal stretch was shorter than 25,000 m; furthermore, the tons of HNS in bulk loaded or discharged in ports further than 25,000 m from the midpoint of the examined coastal stretches were examined in the $H_{Bt}$ index as HNS in transit. In order to elaborate a statistically significant risk index for HNS maritime traffic, statistical distribution of the data was considered. Unusual observations (outlier values) were highlighted by means of boxplot analysis and assigned the maximum $H_{Bp}$ value of one hundred.

HBt indices assessment is related to the amount of HNS in transit in bulk on the seas along the coastal stretches under examination, dividing the waters of the Italian continental shelf into the eight principal Italian Seas: Ligurian, Northern Tyrrhenian, Southern Tyrrhenian, Ionian, Sardinian, Sicilian, Southern Adriatic and Northern Adriatic Sea. The standardized $H_{Bt}$ values were calculated for each of the eight Italian Seas taking into consideration the reported summation as a standardized score of 100 for the tons of HNS in transit in bulk along the sea ($Tb_t$) multiplied by the hazard coefficient (α) related to the relevant IMDG class and divided by the sea surface (S) of the sea under examination: Eq (4).

$$H_{Bt} = 100 \cdot \frac{\frac{\sum_{j=1}^{j=9} \alpha_j \cdot \mathrm{Tbt_j}}{\mathrm{S}}}{\left(\frac{\sum_{j=1}^{j=9} \alpha_j \cdot \mathrm{Tbt_j}}{\mathrm{S}}\right)_{\max}} \qquad (4)$$

Where: $\alpha_j$: hazard coefficient related to the j-th IMDG class; $Tb_{tj}$: tons of HNS in bulk of the j-th IMDG class in transit along the examined sea; $S_i$: surface of the examined sea expressed in $m^2$ (Table 2).

*Table 2: $H_{Bt}$ values of the eight Italian Seas (Outlier value for the Ligurian Sea – boxplot methods).*

| Sea | $\sum_{j=1}^{j=9} \alpha_j \cdot \mathrm{Tbt_j}$ | S ($m^2$) | $\frac{\sum_{j=1}^{j=9} \alpha_j \cdot \mathrm{Tbt_j}}{\mathrm{S}}$ | $H_{Bt}$ |
|---|---|---|---|---|
| Sicilian Sea | 55,461 | 43,131,000,000 | 1 | 0.04 |
| Southern Tyrrhenian | 3,664,311 | 82,708,000,000 | 44 | 1.42 |
| Sardinian sea | 9,439,493 | 112,687,000,000 | 84 | 2.68 |
| Northern Tyrrhenian | 22,352,068 | 99,334,000,000 | 225 | 7.21 |
| Ionian Sea | 146,006,935 | 126,944,000,000 | 1,150 | 36.85 |
| Southern Adriatic | 94,990,793 | 42,530,000,000 | 2,234 | 71.55 |
| Northern Adriatic | 55,026,859 | 17,628,000,000 | 3,122 | 100.00 |
| Ligurian Sea | 408,926,344 | 13,718,000,000 | 29,809 | 100.00 |

HP indices are obtained following the same procedures and equations described in the preceding paragraph for $H_B$ calculation, but it considers HNS substances in packaged form instead of HNS in bulk.

$H_P$ indices are therefore calculated from the reported calculation as a standardized score of 100 for the two indices $H_{Pp}$ (HNS in packaged form loaded or discharged at ports) and $H_{Pt}$ (HNS in packaged form in transit in the sea waters along the coastal stretches under examination): Eq(5).

$$H_P = 100 \cdot \frac{H_{Pp} + H_{Pt}}{\left(H_{Pp} + H_{Pt}\right)_{max}} \tag{5}$$

Furthermore, $H_{Pp}$ and $H_{Pt}$ were calculated following, respectively, the same equations for $H_{Bp}$ and $H_{Bt}$, but taking into consideration HNS data transported in packaged form: Eq(6).

$$H_{Pp} = 100 \cdot \frac{\sum_{i=1}^{i=n} \frac{\sum_{j=1}^{j=9} \alpha_j \cdot \mathrm{Tp_j}}{\mathrm{d_i}}}{\left(\frac{\sum_{j=1}^{j=9} \alpha_j \cdot \mathrm{Tp_j}}{\mathrm{d_i}}\right)_{max}} \tag{6}$$

Where: $\alpha_j$: hazard coefficient relative to the j-th IMDG class; $T_{pj}$: tons of packaged HNS of the j-th IMDG class loaded or discharged in at the i-th port; $d_i$: sea distance between the i-th port and the midpoint of the coastal stretches under examination. Finally, $H_{Pt}$ indices assessment, relative to the amount of packaged HNS in transit in the sea along the coastal stretches under examination, were calculated for each of the eight Italian Seas using the following equation: Eq(7).

$$H_{Pt} = 100 \cdot \frac{\frac{\sum_{j=1}^{j=9} \alpha_j \cdot \mathrm{Tpt_j}}{\mathrm{S}}}{\left(\frac{\sum_{j=1}^{j=9} \alpha_j \cdot \mathrm{Tpt_j}}{\mathrm{S}}\right)_{max}} \tag{7}$$

Where: $\alpha_j$: hazard coefficient related to the j-th IMDG class; $T_{ptj}$: tons of packaged form HNS of the j-th IMDG class in transit along the examined sea; $S_i$: surface of the examined sea expressed in $m^2$;

**2.2 Probability factor calculation**

Probability factors (P) derive from statistics/incident reports which show the frequency of incidents (Mamaca et al., 2009). Analysing approximately one hundred incidents in European waters identified from 1987 to 2006, the EMSA report (2007) disclosed that the majority of incidents which resulted in an HNS discharge involved bulk materials: 61 % compared to 33 % of incidents involving HNS in packaged form, while the type of HNS cargo was unknown for the remaining 6 % of the incidents. Based on the aforementioned official data, it was possible to assign a correlated probability coefficient factor to the variables of incidents involving HNS in bulk ($P_B$) or in packaged form ($P_P$): Eq(8).

$$P = P_B + P_P = 100 \tag{8}$$

Based on this factor, according to the above mentioned percentages and excluding the 6 % of incidents with unknown type of HNS cargo we obtained: $P_B$=64.89 and $P_P$=35.11.

**2.3 Consequence factor calculation**

In an HNS risk assessment it is essential to assign a consequence factor (C) to each examined coastal stretch proportional to the environmental damage that would occur in said area. The amount of environmental damage caused by a spilled or discharged HNS depends on the typologies and the conservation status of the polluted coastal and marine ecosystems (CEFAS, 2009). Therefore, the C factor is correlated to the presence of priority habitats or protected species in the individual coastal stretches under examination, included in the Natura 2000 sites.

In fact, the Natura 2000 ecological network of protected areas (SPAs, Special Protection Areas, and SACs, Special Areas of Conservation), covers all European areas containing priority habitats or protected species listed in the EU Habitats Directive (92/43/EEC).

Therefore, the C factor was calculated by examining the percentage of surface included in the Natura 2000 sites for each coastal stretch: Eq(9).

$$C = 100 \cdot \frac{S_t}{S_n} \tag{9}$$

Where: C: consequence factor (between 1 and 100); St: total surface of the examined coastal stretch; Sn: surface of the examined coastal stretch designated as Natura 2000 sites.

### 2.4 RHNS risk index calculation

According to the EMSA equation, Eq(1), and taking into consideration all the other aforementioned equations, Eq(10) allows the evaluation of the RHNS index, reported as a standardized score of 100.

$$RHNS = 100 \cdot \frac{(H_B \cdot P_B) + (H_P \cdot P_P) + C}{[(H_B \cdot P_B) + (H_P \cdot P_P) + C]\max} \quad (10)$$

where: RHNS= risk indices for HNS maritime traffic; $H_B$= hazard factor related to HNS transported in bulk; $H_P$= hazard factor related to HNS transported in packaged form; $P_B$= probability factor related to HNS transported in bulk;$P_P$= probability factor related to HNS transported in packaged form; C = Consequence factor.

## 3. Results

The RHNS index was consequently applied to all the Italian shorelines in order to achieve a critical scale of HNS risk along Italian waters and shores.

The overall 8,375,000 m of Italian coastlines were divided into 335 coastal stretches of 25,000 m in length on which an RHNS value was calculated, assuming that the risk is considered homogeneous along a coastal stretch measuring 25,000 m.

The HNS Italian maritime traffic data necessary for the calculation of the RHNS indices have kindly been provided by the Coast Guard General Headquarters (Ministry of Infrastructure and Transport) and are in accordance with the 2009 annual HNS traffic records.

The results obtained are summarised in Figure 1 which shows the comparison between the RHNS mean values of each Italian Region and Sea. The results mark the fact that the Northern Adriatic is the Italian sea with the highest HNS spill risk.

Moreover, all the RHNS index values from the 335 coastal stretches have been implemented in a GIS (Geographic Information System) database making it possible to develop cartographic and digital RHNS index maps representing useful tools for decision-makers to evaluate a comparative spatial analysis of the risk values (Mattia et al., 2012). Lastly, Figure 2 shows two examples of GIS cartographic outputs with RHNS values related to the Ligurian Sea and the Northern Adriatic Sea.

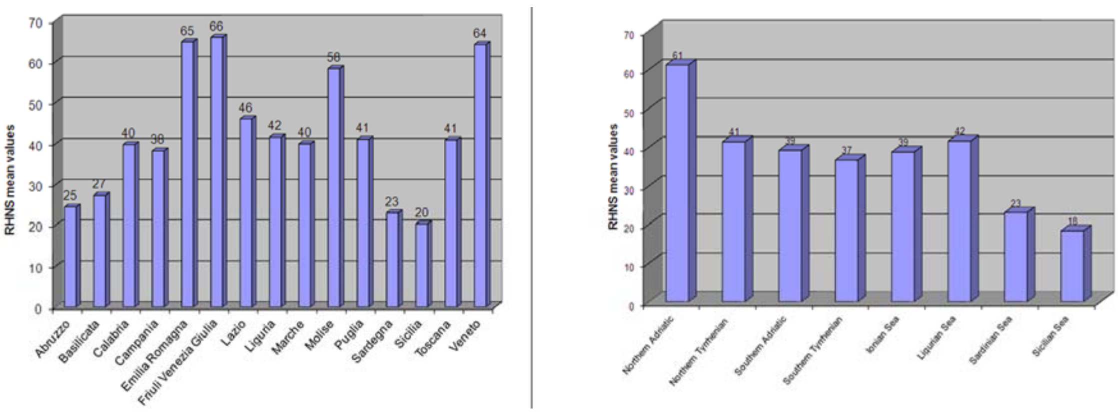


*Figure 1: Left: RHNS mean values related to the 15 Italian coastal Regions. Right: RHNS mean values related to the eight Italian seas*

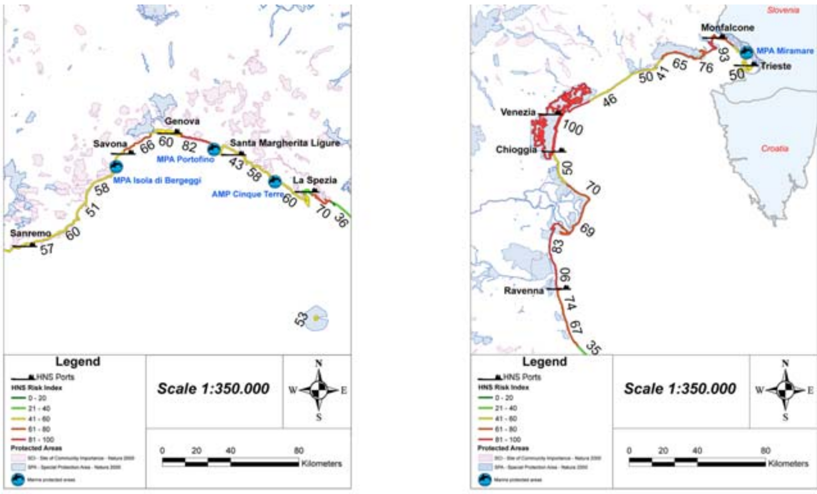


*Figure 2: HNS index map related to Ligurian Sea (left) and Northern Adriatic Sea (right)*

## 4. Conclusions

The methodology, together with subsequent GIS software data processing, has made it possible to pinpoint individual national coastal stretches characterized by high HNS risk providing a clear system for locating environmental priorities for the protection of those areas that result most vulnerable. These results offer a useful contribution for the planning of preparedness and prevention actions for prompt coordination in the event of consequences deriving from potential HNS spills along the Italian coastline.

Lastly, this GIS database, containing queried digital maps with collected data and their subsequent elaboration, is a valuable instrument for the application of the principles of Integrated Coastal Zone Management by decision makers, local stakeholders and public administrations.

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