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Spatial Analysis of Oil Spills from Marine Accidents in Greek Waters

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Abstract

Greek marine spatial area is located in the Mediterranean Sea with semi-enclosed characteristics. Thus the maritime traffic is undoubtfully significant for political and economic reasons, arousing particular interest unceasingly, because of its specific geographical location, the increasing improvements of freight services and port infrastructure and, the upcoming regional drillings. Marine incidents and accidents that often happen, vary from rather insignificant to serious ones, affecting both humans and environment. This research aims to examine the implementation of a framework analysis of shipping-based oil pollution (accidental and operational) by using spatial analysis and geographical information system. It makes use of data gathered from marine accidents that occurred from 2001 to 2011 in the Greek marine waters. The analysis of the thematic maps introduces firstly marine accidents' data as points in a dot map. Then, the implementation of spatial analysis approach to mapping these accidents, including the identification of hot spot areas, is elaborated, so that frequency and density might appear versus time over a limited geographical area. This study presents the oil-spills distribution in Greek marine waters through thematic maps and proposes both a methodological and analytical framework for marine accidents evolving into oil spills and combining GIS techniques and spatial analysis.

JEL Classification: R41; C19.
Keywords: Spatial analysis; GIS; Oil spills; Marine pollution; Marine incidents; Marine accidents.

1. Introduction

Marine pollution and degradation of coastal areas constitute severe problems, which become even more apparent especially in semi-enclosed seas, such as the Mediterranean Sea. Human health and prosperity is highly depended on the level of degrading or upgrading the marine environment. Developed societies should take all necessary measures to deal with pollution at sea, which- according to the Joint Group of Experts on the Scientific Aspects of Marine Pollution (GESAMP)- is defined *"as the introduction by man, directly or indirectly, of substances or energy into the marine environment which results* *in such harmful effects as harm to living resources, hazards to human health, hindrance to marine activities including fishing, impairment of quality for use of sea water and reduction of amenities".*

Marine pollution encompasses a wide range of threats, such as land-based sources, oil spills, untreated sewage, invasive species, persistent organic pollutants (POP's), acidification, radioactive substances, marine litter, overfishing and destruction of coastal and marine habitats (Nyström *et al*., 2000, Bellwood *et al*., 2004). Oil discharges and spills to the seas have been reduced by 63% compared to the mid-1980s, and tanker accidents have gone down by 75%, (partly as a result of the shift to the double-hulled tankers) from tanker operations by 90% and from industrial discharges by some 90%, (UNEP 2006; Brown *et al*., 2006).

2. Types of pollution and marine accidents

2.1 Pollution from ships

Although the shipping industry is filled with responsible and conscientious people, there is still sea pollution on deliberate basis. There are a number of reasons for that. Firstly, it is cheaper to dump waste at sea rather than collect it in the approved way and then deposit it on onshore facilities. Secondly, it is easier and quicker to dump than to spare the time and effort needed for disposal at approved processing sites. Thirdly, ship owners and operators often justifiably argue that shore based waste reception facilities are not readily available.

Marine oil pollution by vessels, known as "operational pollution", includes various types of oil and oil mixture discharge, as a result of the daily routine of ships (Ferraro *et al.*, 2008). There are mainly three types of routine ship operations, which pollute the sea, namely: ballast water, tanker washing and engine room effluent discharges. The first two are mainly linked with tankers, while the third one is related to all other types of ships. Because of these operations, large amounts of oil are deliberately discharged from ships every day along the Mediterranean coast line. Additionally, there is a growing awareness that smaller scale operational ship – source oily discharges (<1000 litres) contribute more to oil pollution in marine environments than larger scale often catastrophic oil spills (National Research Council, 2003). Furthermore, accidental oil spills attract more attention from the media, the politicians and the public in general, than all other types of marine pollution together. They seem to be more "fascinating" than other categories of marine oil pollution probably due to their very own nature that can be roughly described as "concentration", that is large quantities of oil release onto a limited sea surface in a relatively short period of time.

Prevention of operational and accidental pollution from ships is determined in the Annex 1 of MARPOL 73/78, which constitutes -in a nutshell- the response of the international community to the problem under discussion. In the aforementioned annex, the Mediterranean Sea is designated as a special area, where oil discharges from ships have been completely prohibited, with minor exceptions. A special area is defined as *"a sea area where for recognised technical reasons in relation to its oceanographical and ecological* *conditions and to the particular character of its traffic, the adoption of special mandatory methods for the prevention of the sea pollution by oil is required".*

Nations ensuring marine vessel compliance with MARPOL rely on three principal means of regulation: onboard inspections of ships while portside, at sea surveillance using aircrafts (Volckaert *et al*., 2000, Carpenter, 2007) and satellites (Ferraro *et al*., 2008). Onboard inspections involve reviews of official documents recording the buildup, transfer and disposal of oily waste. Inspectors also look for magic pipes and oily residue in exhaust flanges as direct evidence of illegal discharges of oily wastes at sea (Canessa *et al*., 2008). The use of aircraft to detect pollution in the sea is extremely expensive and may not cover spatially all the exclusive economic zone. Satellite images still have a number of constraints despite their extensive coverage, since they give a significant number of false alarms. Qualified staff assess the images, together with supporting meteorological information to determine the likelihood of the presence of oil spill on the sea surface and to assist in identifying the source of the pollution.

2.2 Marine accident and incident

The terms marine "accident" and "incident" denote undesirable events in connection with ship operations (IMO, 1997). An accident is an undesirable event that results in adverse consequences, for example injury, loss of life, economic loss, environmental damage and damage to or loss of property. Accidents are due to an unexpected combination of conditions or events. Although the resolution A. 849(20) of the International Maritime Organisation (IMO) defines a clear distinction between "accident" and "incident" in terms of the magnitude of consequence, the term "accident" is used in this paper to denote both meanings.

The type of vessel accident which is reported in this paper includes: collision, fire/explosion, foundering, grounding, machinery breakdown, illegal discharge and oil gas leak. A collision accident occurs when a vessel strikes or is struck by another vessel on the water surface. Fire can occur in whatever part of the vessel, usually in the engine room and can evoke an explosion accident. In a foundering accident, there is total loss of the vessel which is settled on the sea bottom. In a grounding accident, the vessel is in contact with the sea bottom or a bottom obstacle. A machinery breakdown typically involves equipment failure on the vessel. Illegal discharge of oil and oil gas leak constitute environmental accidents, which occur when the vessel causes pollution (Talley *et al*., 2012).

3. Spatial analysis of maritime accidents and oil spills

3.1 Maritime accident analysis

Maritime accident analysis is growing thanks to risk management, accident prevention and response planning. Since most decisions are location-sensitive, one important consideration in marine traffic analysis involves maritime risk analysis, including spatial analysis to identify hot spot areas. These areas are concentrations of accidents within a limited geographical area that appear over a time (Marven *et al*., 2007). Accidents could be analysed by type, severity, vessel type, activity, temporal period or by other portioning criteria specified by the analyst. Integrated with additional information (e.g. environmental, weather) cluster methods could generate questions and hypotheses about the relationships between accident locations and other contributing factors, attempting to reply to assumptions, such as why high concentrations of incidents happen in specific areas.

In order to identify "hot spot areas" there are several types of cluster techniques which can be applied to maritime accident and activity data sets. The case-study of Shahrabi, J. and Pelot, R. (2007) deals with the implementation of cluster analysis to maritime fishing traffic and accidents in the Canadian Atlantic waters. It is proved that hierarchical cluster analysis -statistical method for finding homogenous clusters of cases based on measured characteristics- is able to identify hot spot areas where fishing accidents and activities are concentrated. Another advantage of this method is that each order of cluster would be appropriate for different purposes of risk management, such as accident prevention, search and rescue operation centres allocation, strategic management and long term planning.

3.2 Using GIS in analysing oil spills

A Geographical Information System (GIS) is a facility for preparing, presenting and interpreting facts that pertain to the surface of the earth. In other words, it is an organised collection of computer hardware, software, geographic data to efficiently capture, store, update, manipulate, analyse and display all forms of geographical referenced information (Redlands, 1990). GIS is an efficient tool for the collection, visualisation and analysis of information on oil spills in the marine environment. One of the major advantages of GIS is the ability to extract oil parameters, such as location, liner size and spill areas. Spatial and temporal information (i.e. oil spill distribution at sea and its evolution in time) allows the users to establish the major source of oil spill and then outline the risk areas (A. Ivanov *et al.*, 2008). GIS techniques are now widely used for spill planning and response because they support integration and preparation of geospatial information on the location, nature and sensitivities of different resources with rapid access (APASA, 2003).

Taking into consideration the above-mentioned assumption, the Joint Research Centre (JRC) of the European Commission has focused its attention on the need to monitor the long term sea-based pollution. Its research aimed to map the oil spill, to identify the hot spots and to define the trends in the European seas (North sea, Baltic sea, Northeast Atlantic, Mediterranean Sea and Black Sea). Among the major results, it is proved that the operational pollution in the seas around Europe seems to be decreasing and the high concentration of marine oil spills occurs to the main maritime routes and in congested ports (G. Ferraro *et al*., 2008).

The use of exploratory spatial analysis with the assistance of aerial surveillance for identifying hotspots of shipping-based oil pollution in the Pacific Region of Exclusive Economic Zone of Canada, is presented extensively by R. Canessa *et al*. (2008). It is found that oil spill hotspots were more clearly defined using Kernel Density Estimation, which is a technique used to obtain a smooth estimate of the spatial variation in intensity from a set of observed occurrences (Bailey *et al*., 1995). After the standardisation of oil spill detection two remarkable results derived from this study: (a) Previous hotspot areas were reduced in intensity thanks to the relatively higher aerial surveillance effort. (b) Areas with lower relative surveillance effort showed either similar or exaggerated relative oil spill densities.

Implementation of the web-based GIS system for monitoring, predicting and visualising various marine environmental processes has been described in detail by M. Kulawiak *et al*. (2010). It should be noted that an oil spill model has been developed by the Hellenic Centre for Marine Research within the framework of Poseidon project. The oil spill simulation system consists of an oil spill model designed to use the results of three operational models (meteorological, waves and hydrodynamic) that on a daily basis provide 72-hour forecasts for the Aegean and Mediterranean Sea (Papadopoulos et al., 2002). The resulting system allows end users to view the simulation results in a geographical context which form thematic layers and the user is presented with interactive elements such as, animation of the oil spill spread, its volume and geographical coordinates.

4. Methodology

4.1 Typology of Greek maritime traffic

Shipping in the Greek seas represents a very complex activity nowadays. Over the last fifty years shipping has undergone a succession of drastic changes that have completely transformed all aspects of this industry. These changes have affected the size, shape and speed of ships, their propulsion, equipment on board, communications, ways in which the cargoes are carried, ports and other infrastructure, management of ships, and even the profiles and size of their crews. Shipping comprises the carriage of passengers, general cargoes both in traditional ways and in containers, livestock and cars, dry and liquid bulk cargoes, and many other goods, resulting in the coexistence of various types and sizes of vessels.

Maritime traffic in Greece is characterised by the dominance of the port of Piraeus, which in the last decade has established itself as one of the most strategic ports in the Mediterranean (National Port Strategy, 2013) along with the existence of a large number of smaller ports in the region (more than 200) but also by a significant volume of traffic which only passes through the Aegean sea, without calling at any of these ports. The area of the Aegean Sea is the natural continuation of the close geographical zone linking the Black Sea with the Mediterranean marine area and is also one of the most common marine corridors. Its geographical extent is classified as the third largest sea in the eastern Mediterranean -the first two being the Ionian Sea and Levantine Sea- and functions as a commercial channel of three continents namely Europe, Africa and Asia. The Aegean Sea is most frequently crossed by vessels leaving the Dardanelles and using either the narrow straits of Kithira towards Gibraltar, or the narrow straits of Karpathos towards Suez.

The Aegean Sea might represent an extreme example of a marine safety risk area where an undesirable event may occur. The risk of an accident occurrence is even more aggravated by the existence of several other conditions, such as high maritime traffic density, transportation of large quantities of crude oil and refined products through the region (high transport density of vessels from and to the Black Sea passing narrow straits that are formed by over 1600 islands dispersed all over the Aegean), narrow and congested straits through which ships enter and exit.

4.2 Geocoding and database

The structure of a geographical base requires a digital map and the procedure of digitisation accidents on it. This is accomplished through geocoding, which is the process of creating cartographic database taking into consideration the spatial information. The geocoding was conducted at Quantum GIS open source system, integrating the geographic coordinates (latitude, longitude) of the accident, the sea area where the accident had happened, making use of the Hellenic MET Office weather areas.

The current study is based upon accidents recorded by the Ministry of Shipping and Aegean covering the period from January 2001 to December 2011. The number of records amounts to 311. The database contains 288 accidents of vessels such as bulk carriers, container ships, general cargo vessels, tankers, passenger ships tugs, supply vessels and 23 accidents of coastal facilities that caused oil spills. There are not included any accidents caused by recreational boats.

4.3 Descriptive statistics

The statistical distribution of marine accidents at Greek seas is represented in Figure 1. Twenty six (26) accidents occur on average every month. The figure shows that there is a period with high frequency of accidents occurring from June to August while the lowest frequency is presented in September. The proportion of accidents occurring in July is 11% of the total and at the same time 27% higher than the month average. The proportion of accidents occurred in September is only 5% of the total and thus 34% lower than the month average. All these accidents cannot be possibly attributed to seasonality, seeing that only merchant vessels and no recreational boats are integrated in the data. Statistics by shiptype in Figure 2 indicate that the percentage of accidents of general cargo vessels is the largest one by far (approximately 41%), followed by oil tankers (20%) and passenger ships (18%).

The distribution of accidents under the registered flag and the white-grey-black list which is issued by Paris Mou flag list 2009-2011 (2012), are displayed in Figure 3. The main points which can be derived are as follows: (a) 74% of registered ships belong to white list (62% distributed to European flags and 38% to non-European flags). The majority of accidents occurred in vessels under Greek flag (37%) and Panama flag (10,4 %). (b) 11% of registered ships belong in black list, whilst 3% in grey list.

Figure 1. Number of accidents per month

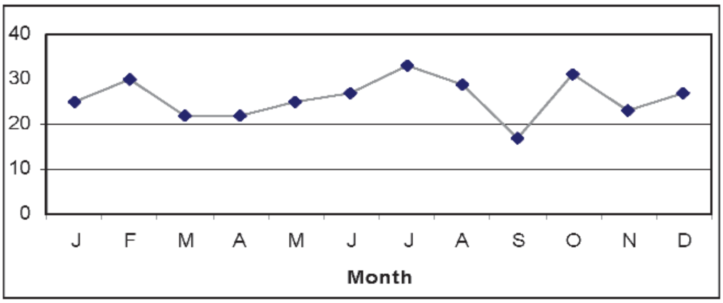


Figure 2. Accidental distribution by ship type

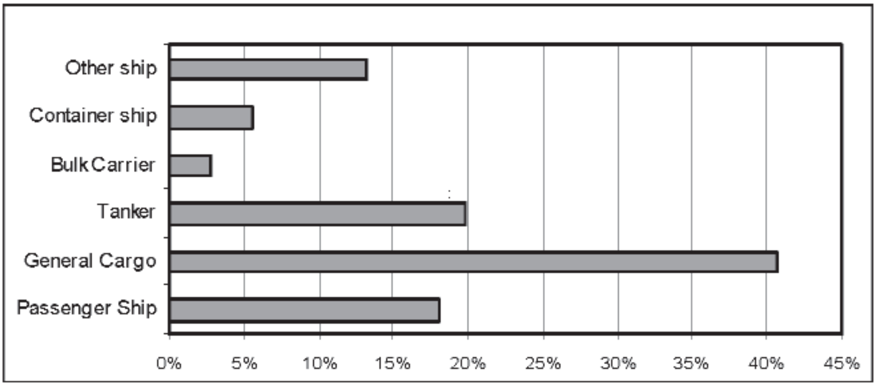
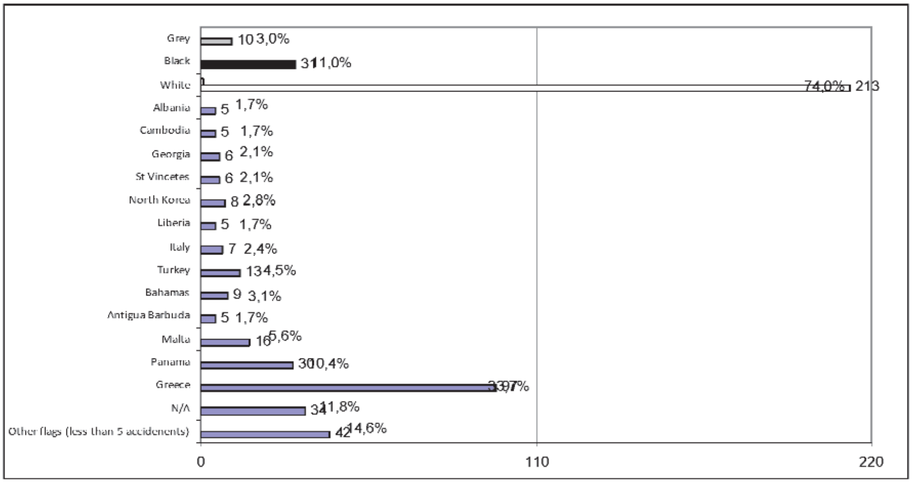


Figure 3. Distribution of accidents under flag registration



4.4 Spatial distribution analysis using cartography

The highest frequency of accidents is presented in Figure 4 and located in the Saronikos Gulf. This is the result of the increased maritime traffic of the port of Piraeus, through which both passenger and freight transportation is provided. Moreover, the regions with the second highest accident rate seem to be the northern and the southern Aegean Sea. This fact may be attributed to the increased marine traffic due to the transit ships to and from the Bosporus strait.

In Saronikos Gulf also, the total sizes of polluted areas are very small spots compared with the vast number of incidents. This significant result shows that operational pollution by vessels usually results in accidents with minor quantities of oil spill which create small spots in the sea area. Saronikos Gulf, therefore, is not only characterised by heave maritime traffic but is also affected by industrial activities along the shoreline.

Figure 4. Dot distribution of polluted and non-polluted marine accidents in Greek coastal areas

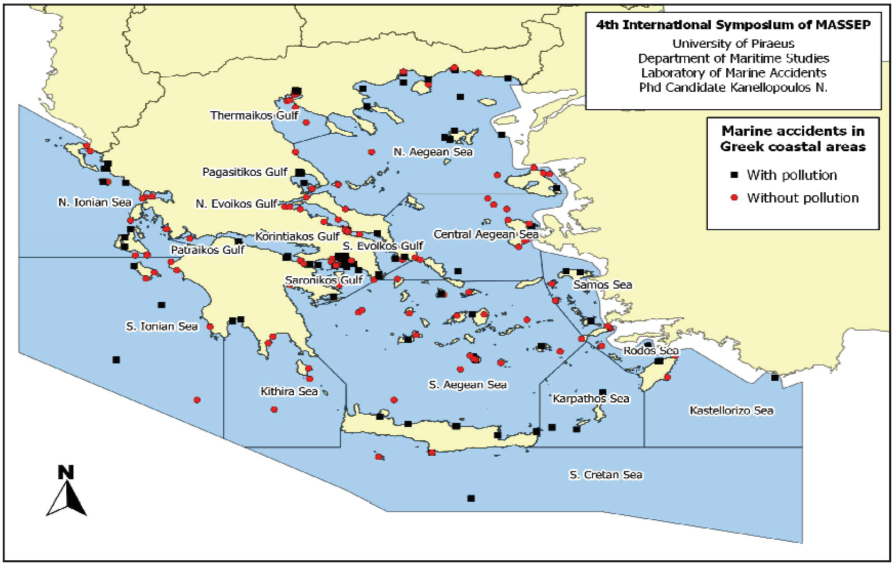
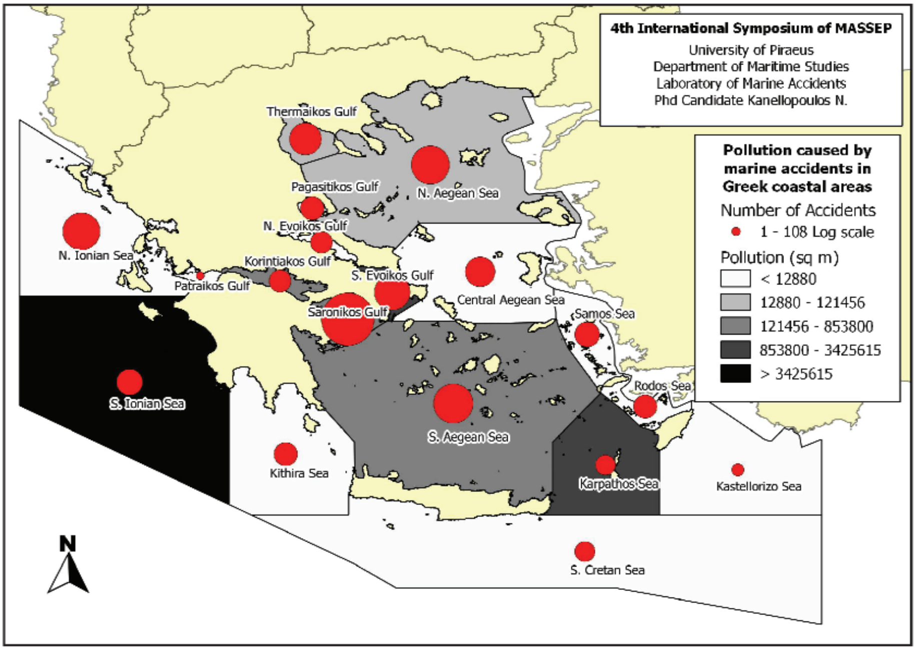


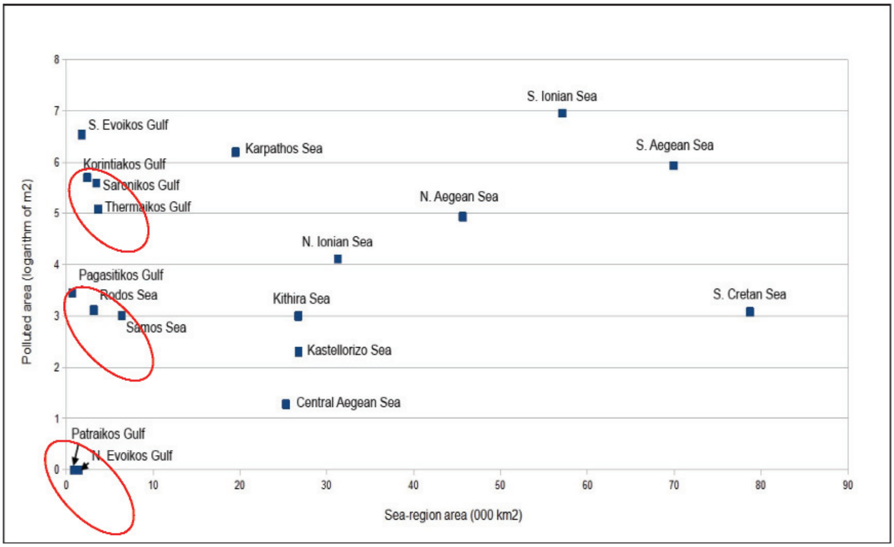
Figure 5 illustrates the spatial distribution of two variables: the quantity of accidents and the total size of oil spilled areas. The number of accidents per region is displayed with circular red marks using a logarithmic scale. This mode of presentation was adopted because of the large range of values (from 1 to 108). Otherwise a linear scale would result in maps almost impossible to read, since the smaller marks on the one hand would be too small to be seen and the larger ones, on the other hand would cover the entire map. The use of logarithms of values reduces this range and makes it easier to display them. In order to display pollution on the same figure, the 18 sea regions have been classified in 5 groups using the Jenks natural breaks classification method, an algorithm that is very commonly used in thematic mapping and is supported by most GIS software packages. This method minimises the variance within a class and maximises the variance between classes. In other words, it creates classes in such a way that the regions inside each class are as similar as possible to each other, yet the classes themselves are as different as possible to one another. Additionally, another remarkable result is demonstrated in Figure 6, namely the greatest marine accident occurring in the Southern Ionian, which resulted in an oil spill of 9 km^2 and was caused by the foundering of a general cargo ship.

Figure 5. Usage of the Jenks natural breaks classification method to display quantity of accidents and the total size of spilled areas



Due to the fact that the size of the oil spilled areas ranged from rather insignificant (1 m^2) to quite small (9 X10^6 m^2) and taking into consideration the variable sea area, a logarithmic procedure is applied in order to check where there are any clusters with common characteristics. In Figure 6, the formation of three groups is shown: (a) the first one consists of Saronikos, Korinthiakos and Thermaikos Gulf. While the similarity in this group consists in the almost proportional size of the polluted area, the difference lies in the fact that in areas with the less traffic few accidents have occurred which have yet caused significant oil spills. (b) the second one is comprised of small sea areas (Samos and Rodos Sea, Pagasitikos Gulf) where accidents rarely occurred, and (c) the third one is made up of sea regions where almost no accidents had taken place and there were not, thus, any spilled areas.

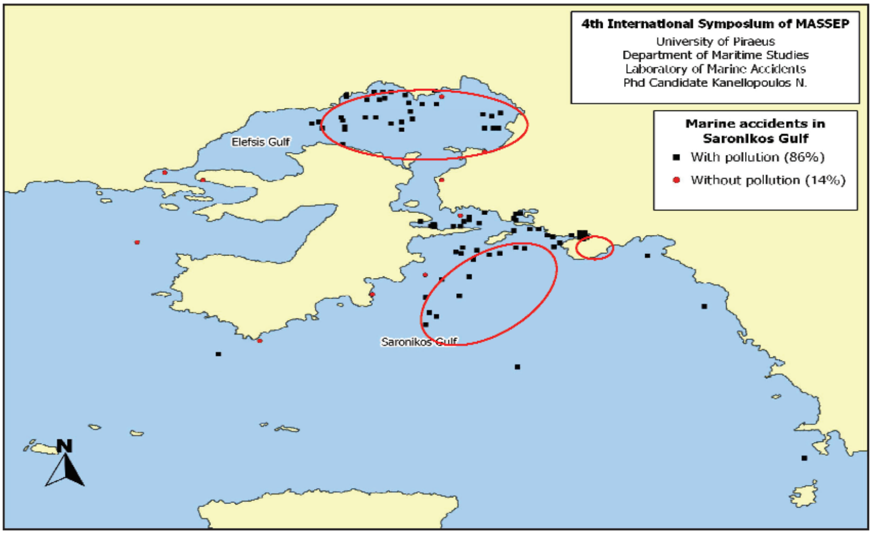
Figure 6. Illustration of pollution and sea –region area



4.5 Spatial analysis at Saronikos Gulf

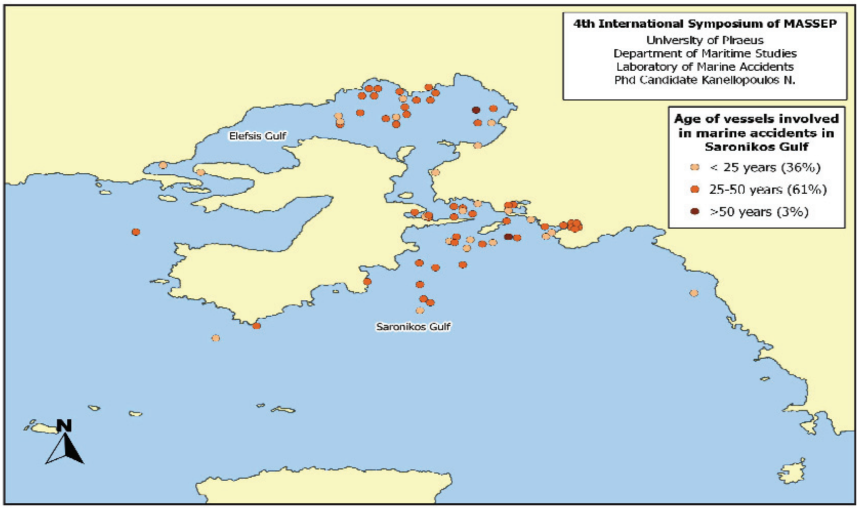
Figure 7 shows that majority of accidents in Saronikos Gulf have resulted in pollution. It is remarkable that there are three sub-sea regions of Saronikos Gulf where accidents mainly arise: (a) the first one is inside the passenger port of Piraeus, where accidents take place during the bunkering of passenger ships from small vessels, wherein leakage of fuel oil falls towards directly into the sea. (b) the second one is located in the anchorage area-approximately 2 or 3 miles away from the commercial terminals of Piraeus port, whilst vessels wait in queue. (c) the third one is at the commercial harbour of Elefsis Gulf, where although no passenger traffic is facilitated, there are daily arrivals of cargo vessels. Along the coast of the aforementioned gulf, oil facilities are located and there is a common traffic by medium sized oil tankers.

Figure 7. Dot distribution of polluted and non-polluted marine accidents in Saronikos Gulf



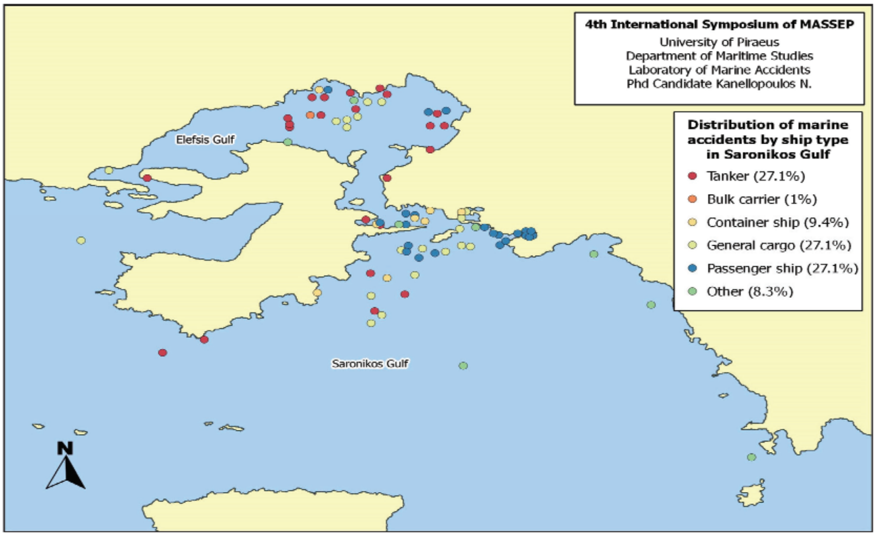
With regard to the age of vessels at the time of the accident, the following classification has been taken into account: (a) short age, less than 25 years. (b) intermediate age, between 25 and 50 years. (c) extensive age, more than 50 years. The majority of ships in this study fall within the middle age category whereas only 3% belongs to the third category. This is represented in Figure 8.

Figure 8. Age of vessels involved in marine accidents in Saronikos Gulf



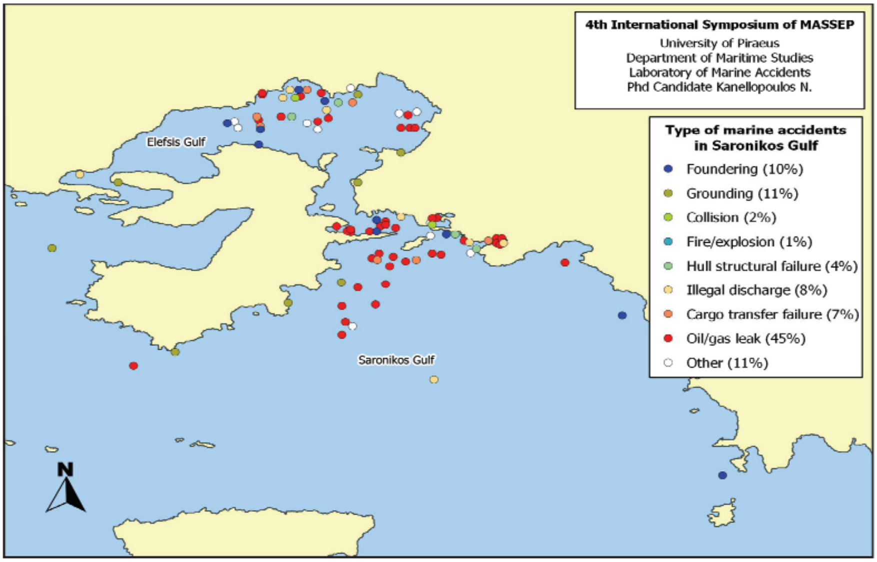
The spatial distribution of accidents by shiptype is displayed in Figure 9. The majority of spatially distributed accidents occur with passenger ships (27.1%) mainly in the port of Piraeus. This result is rather presumable, since Piraeus is the starting and ending point of several passenger sea routes connecting the Greek mainland with the plethora of Greek Islands. On the contrary, the majority of tanker accident frequency (27.1%) is observed in the Elefsis Gulf, as its north coast is cited as the largest industrial area of Greece, with activities such as shipyards, oil refineries and cement industries. More emphasis should be laid on the rational and management of shipping and the of safety navigation, seeing that vessels over 100.000 dwt carrying vast quantities of crude oil pass through the narrow straits of Saronikos islands

Figure 9. Spatial distribution of marine accidents by ship type in Saronikos Gulf



With reference to the classification of accident type (Figure 10), it is found that most of foundering accidents (10%) occur in the Gulf of Elefsis, usually due to long-term anchoring vessels that are not used anymore and are placed adjacently to each other, without proper surveillance measures. Last but not least a significant percentage of oil/gas leak accidents (45%) occur in vessel traffic sea area as well as in the inner part of the sea area of the passenger port.

Figure 10. Spatial distribution of marine accidents by type of accidents in Saronikos Gulf



5. Conclusions and Recommendations

As the risk management as well as the cluster analysis techniques evolve, the implementation of the maritime accident analysis will further be developed. GIS is an undisputable efficient tool for the analysis of information on oil spill in the marine environment. In this study the use of thematic maps in exploring the distribution of oil spills in the Greek coastal areas is presented. It is made clear that small sizes of oil spills are detected as the result of accidental and operational pollution caused by vessels the majority of which have been built between 25-50 years ago. In Saronikos Gulf, where there is a high density of maritime traffic, the total sizes of polluted areas are very small spots compared with the high number of incidents. Furthermore, an oil spilled area that is caused by a severe marine accident in a sea region could surpass in size small operational oil spilled accidents.

The fact that most vessels involved in the study are under the Greek flag is somewhat expected since the area under examination is characterised by many ships under the Greek flag. As most incidents seem to occur in the summer, it is recommended to strengthen surveillance measures, especially during summer months, as well as in areas where most oil pollution is reported, such as the Saronikos Gulf and the Gulf of Elefsis. More emphasis should be laid on vessels that most frequently cause these incidents, such as tankers, general cargo and passenger ships. Although new shipping regulations on eco-design, maintenance and operation are being adopted internationally, it is advisable to impose stricter penalties in order to prevent these incidents from happening.

Further research work needs to focus on the development of a set of measures and recommendations that will efficiently assist to the prevention oil pollution in the Greek waters.

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