AN INTEGRATED APPROACH TO MODEL OIL SLICK DISPERSION OFFSHORE SOUTHERN CRETE (GREECE)

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ABSTRACT

Technological disasters are emergencies characterized by a sudden threat to lives, property, public health, or the environment, arising from a failure of critical infrastructure systems. They can result in the release of oil, radioactive materials, or hazardous chemicals into the air, land, or water. These emergencies may occur from transportation accidents, events at facilities that use or manufacture chemicals, or as a result of natural or man-made hazard events.

Oil spills on oil and gas platforms or resulting from maritime accidents comprise a major environmental and financial threat, mobilizing thousands of specially trained emergency response personnel and challenging the best-laid contingency plans. Although many spills are contained and cleaned up by the party responsible for the spill, large-scale spills require assistance from local and state agencies.

The main scope of the present study is to combine bathymetry, geomorphological - geological data and oceanographic information to investigate the impact of oil spills in an accident scenario in South Crete. Near-coast morphological and structural data are combined with oceanographic information model oil dispersal in near shore areas. GIS techniques are in the mapping of topographic, geological and oceanographic features of the study area. High to very high susceptibility zones are possibly related to faulting showing orientation to specific directions. The combination of a susceptibility map and simulations of an oil slick dispersion in time is probably successful and it can be primarily used by emergency managers and urban planners to establish preparedness plans and alert systems.

INTRODUCTION

Oil spills derived from explosions on oil and gas production platforms (Piper Alpha, 1978; Montara, 2009 and the BP Deepwater Horizon spill, 2010) or sea accidents of tankers (http://www.lenntech.com/environmentaldisasters.htm#5._Major_oil_spills_of_the_20th_and_21st_century), comprise a major environmental and financial threat, mobilizing thousands of specially trained emergency response personnel. These larger oil spills usually challenge the best-laid contingency plans. The potential vulnerability of the shoreline to oil spills is a piece of information critical to emergency response planners during an emergency.

The island of Crete) is part of the outer-arc in the Aegean-African subduction system (Fig. 1). On the island is recorded N-S and NW-SE stretching, which generated a complex mosaic of fault blocks and associated Late Miocene-Holocene sedimentary basins (Meulenkamp et al., 1988; van Hinsbergen and Meulenkamp, 2006; Kokinou and Kamberis, 2009; Kokinou et al., 2012). Onshore, Crete is characterized by a highly mountainous landscape suggesting rather young and rapid uplift (Pirazzoli et al. 1982; 1996; Stiros 1996). Significant uplift of the island after the early Pliocene is indicated by marine Pliocene deposits up to several hundreds of meters above the present sea-level (Meulenkamp et al., 1988, 1994). Offshore, a series of E-NE trending depressions or troughs are observed south of Crete (e.g. Hellenic, Ptolemy, Pliny, Strabo). The Ptolemy, Pliny and Strabo trenches comprise NE-striking basins of the transitional zone between areas of extension and convergence within the forearc region, interpreted as transform faults (McKenzie, 1978) or strike-slip faults (Chaumillon and Mascle, 1997).

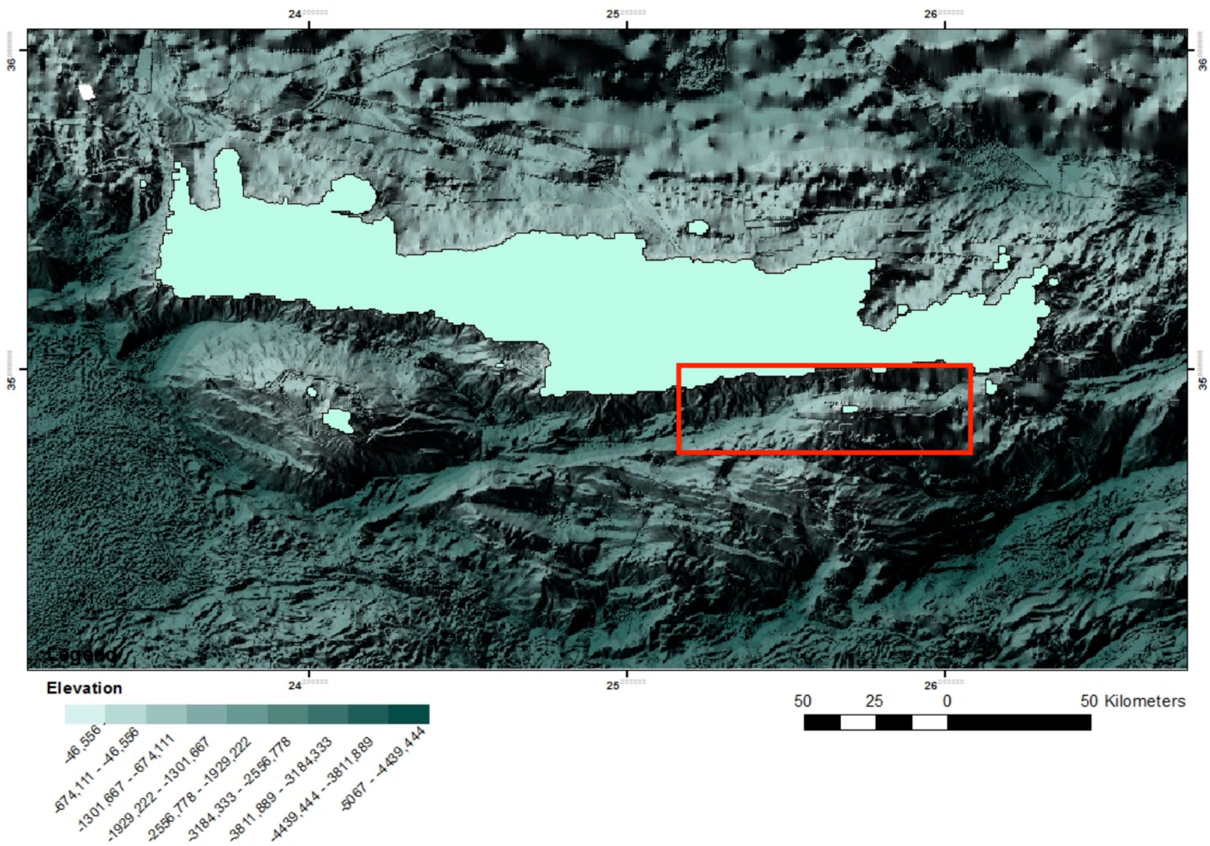

Figure 1: Map showing the bathymetry of the Cretan and Libyan Seas, surrounding Crete. Red polygon indicates the study area in this work.

In this study are presented the preliminary results of a multidisciplinary approach. In detail, a susceptibility map for a selected area located offshore SE Crete was produced to classify the offshore and near shore areas in terms of their susceptibility to oil spills. This task is important as during the last decades intense urbanization has occurred along the coast in the selected study area.

As a first step, bathymetry, geomorphological - geological and oceanographic factors influencing the dispersion of an oil slick near to the coast were evaluated. Additionally, we simulated oil dispersion in time (see also Lardner et al., 2006; De Dominicis et al., 2010), in order to check the reliability of the susceptibility map. GIS techniques were used to evaluate the various thematic layers of the factors used in the susceptibility assessment. Studies, carried out in the last years in onshore areas (Bathrellos et al., 2009; 2012; Papadopoulou-Vrynioti et al., 2013) were of special importance to our modelling to evaluate potential hazards.

METHODOLOGY

The study area is located in the Ptolemy trench (Fig. 1). Earthquake epicentre data in Becker et al. (2006) indicates the Ptolemy trench as a tectonically-active feature along entire length.

Bathymetric metadata and Digital Terrain Models have been derived from the EMODNet (European MArine Observatory and Data Network) Hydrography portal - http://www.emodnet-hydrography.eu. The EMODnet Hydrography data products comprise Digital Terrain Models (DTM) for selected maritime basins in Europe that have been produced from collated bathymetric data sets integrated into a central Digital Terrain Model (DTM). Our DTMs have been based, where possible and available, upon high-resolution data sets. For this study, DTMs for the Eastern Mediterranean region have grid sizes of 25 seconds (~77 metres). Each grid cell comprises the following information: x,y coordinates, minimum water depth in meters to LAT, average water depth in meters to LAT, maximum water depth in meters to LAT, standard deviation of water depth in meters, number of values used for interpolation over the grid cell, number of elementary surfaces used to compute the average grid cell depth, average water depth smoothed by means of a sp line function in meters to LAT, an indicator of the offsets between the average and smoothed water depth as a % of the water depth, reference to the prevailing source of data with metadata.

Digitization techniques and algorithms in GIS were applied to produce susceptibility maps. GIS systems can generate many useful derivative datasets from both raster imagery and topography. Two useful products susceptibility assessment are slope and aspect plots. A slope map (Fig. 2) assigns colours or grey levels to the slope angle of each pixel of the bathymetric raster. This type of image may illuminate tectonic activity not apparent otherwise, and can be used to isolate ranges of topographic slope angles for statistical treatment, predictive capabilities of slope stability, or outcrop exposure. Similarly, aspect plots assign colours or grey levels to the azimuth of the slope direction (Fig. 3). Both of these plots can be used for either topography or subsurface horizons to illuminate trends associated with deformation. The slope map (Fig. 2) was derived from the DEM and the slopes were grouped in six classes: (i) < 5^o (ii) 5 – 10^o, (iii) 11 – 20^o, (iv) 21 – 30^o, (v) 31 – 40^o (vi) > 40^o. The aspect map was also derived from the DEM and the azimuth of the slope direction was grouped in nine classes: 0-40^o, 40-80^o, 80-120^o, 120-160^o, 160-200^o, 200-240^o, 240-280^o, 280-319^o, 319-359^o.

Oceanographic information concerning dominant E-W to SE-NW current directions were taken into account in calculated susceptibility maps. Additionally the transport of a possible surface slick governed by both water currents and by direct wind was simulated by the user-friendly software package MEDSLIK (Lardner 2006; Lardner et al., 2006; De Dominicis et al., 2010; Zodiatis et al., 2012). MEDSLIK uses a Lagrangian representation of the oil slick, i.e., the oil slick is represented by a large number of particles. It requires as input data the type of oil and its characteristics, the wind field, the sea surface temperature and the three dimensional sea currents. The advective velocity of each oil parcel can be a sum of the mean and turbulent fluctuation components of the drift velocity. The mean advection of the slick is caused by the combined effects of surface currents and wind drag. MEDSLIK uses a drift factor approach, which is considered to be a most practical approach for adjusting the mean advection of oil slicks coming from rather low resolution circulation models. With this method the mean drift velocity of the surface oil is considered to be a weighted sum of the wind velocity and the surface Eulerian velocity field.

An Iso Cluster Unsupervised Classification (ArcGIS 10 Help) was applied for the preparation of the oil spill susceptibility map. Unsupervised classifications are similar to cluster analysis where observations (in this case, pixels) are assigned to the same class due to their similar values. Unsupervised classification is useful when there is no preexisting field data for the image area, and the user cannot accurately specify training areas. Additionally, this method is often used as an initial step prior to supervised classification.

Iso Cluster Unsupervised Classification performs unsupervised classifications on a series of input raster bands using the Iso Cluster and Maximum Likelihood Classification. Their main outputs are classified rasters. The minimum valid value for the number of classes is two. There is no maximum number of clusters. The value entered for the minimum class size should be approximately 10 times larger than the number of layers in the input raster bands. Generally, the more cells contained when intersecting input bands, the larger the values for minimum class size and sample interval should be specified. Values entered for the sample interval should be small enough that the smallest desirable categories existing in the input data will be appropriately sampled. The class ID values on the output signature file start at one and sequentially increase to the number of input classes. The assignment of the class numbers is arbitrary. Better results will be obtained if all input bands have the same data ranges. So according to the previous mentioned, the Unsupervised Classification:

- Requires minimal amount of input from user
- Based solely on numerical information in the data
- Matched by the analyst to information classes
- Pixels with similar digital numbers are grouped together into spectral classes using statistical procedures such as cluster analysis ISODATA
- Iterative Self-Organizing Data Analysis Technique - Automated spectral clustering
- User then identifies which class membership for each cluster

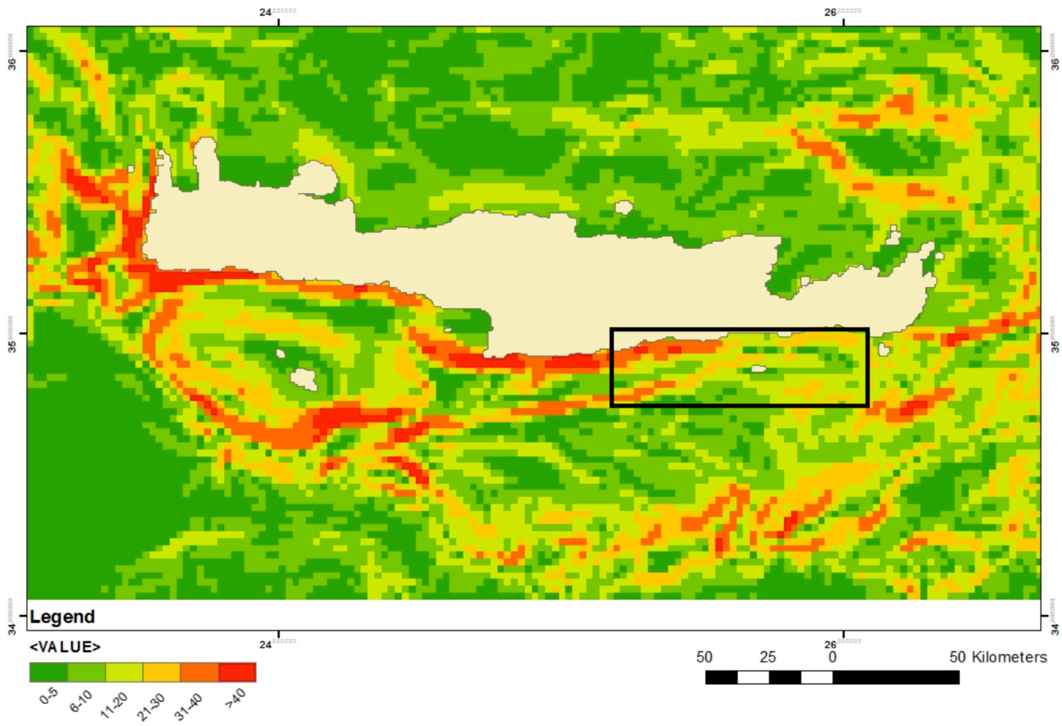

Figure 2: Slope map (°) of the study area. Black polygon indicates the study area.

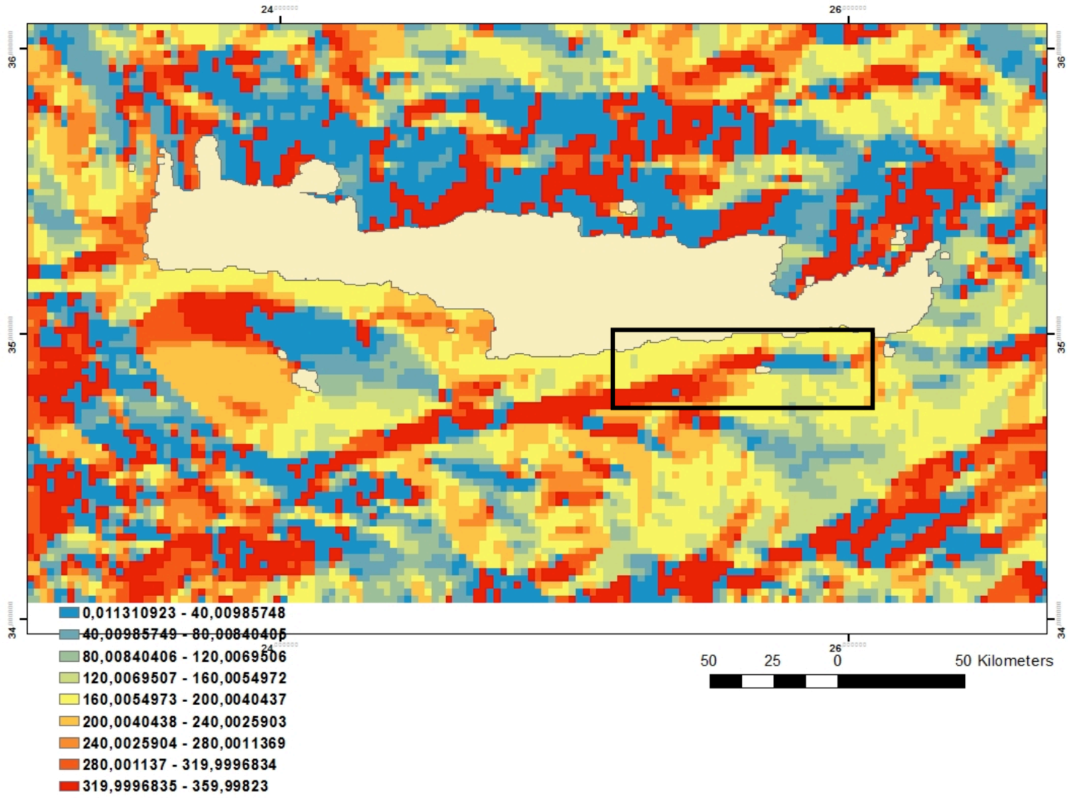

Figure 3: Aspect (°) map of the study area. Black polygon indicates the study area.

RESULTS AND DISCUSSION

The quality of the produced susceptibility maps depends on the data layers used. The digital elevation model (DEM) represents the basic data layer from which various topographic parameters can be digitally generated. In the present case high accuracy bathymetric data was used taking into account the difficulties to exactly determine the topography in marine environments.

Digital elevation models (DEMs) and DEM analysis methods are used for fault recognition as about 90% of faults can be defined quantitatively. Slope and aspects were used in the context of this work (Fig. 4) to confirm these geomorphologic structures, partly defined in previous work (Kokinou et al., 2012). Prevailing slopes in the study area are greater than 20°, while prevailing aspects are 0-40°, 160-200°, 280-320° and 320-359°. It is obvious that steep slopes are mainly related to N-S, E-W and WNW-ESE oriented faulting. Additionally, sudden changes corresponding to the azimuth of the slope direction are generally related to the pre-mentioned faulting.
The final outcome of the Iso Cluster Unsupervised Classification progress was a susceptibility map showing which marine and near coast areas will be affected in case of an oil spill accident (Fig. 4). This map was compiled taking into account geomorphologic factors (slope and aspect) and current direction orienting E-W to SE-NW. The division of a probability map into categories was performed for visualization purposes and does not imply a discrete zonation of the study area in safe and unsafe places (Begueria and Lorente, 2003; Lamelas et al., 2008). These values were categorized into four classes, corresponding to different susceptibility levels (low, moderate, high and very high).
Our results demonstrate that the high to very high susceptibility zones are possibly related to E-W and WNW-ESE oriented faulting and only in one case with N-S oriented faulting. The zone of low susceptibility is located in the SE and NW part of the study area. In order to confirm the reliability of the susceptibility map, the dispersion of an oil spill is presented in Figure 5, by assuming the following parameters:

- Position of accident (Lon): 25.9044
- Position of accident (Lat): 34.9208
- Initial Volume of oil: 10000
- Evacuation time (Hours): 5
- Duration of Integration (Hours): 96
- Output graphic every (Hours): 2

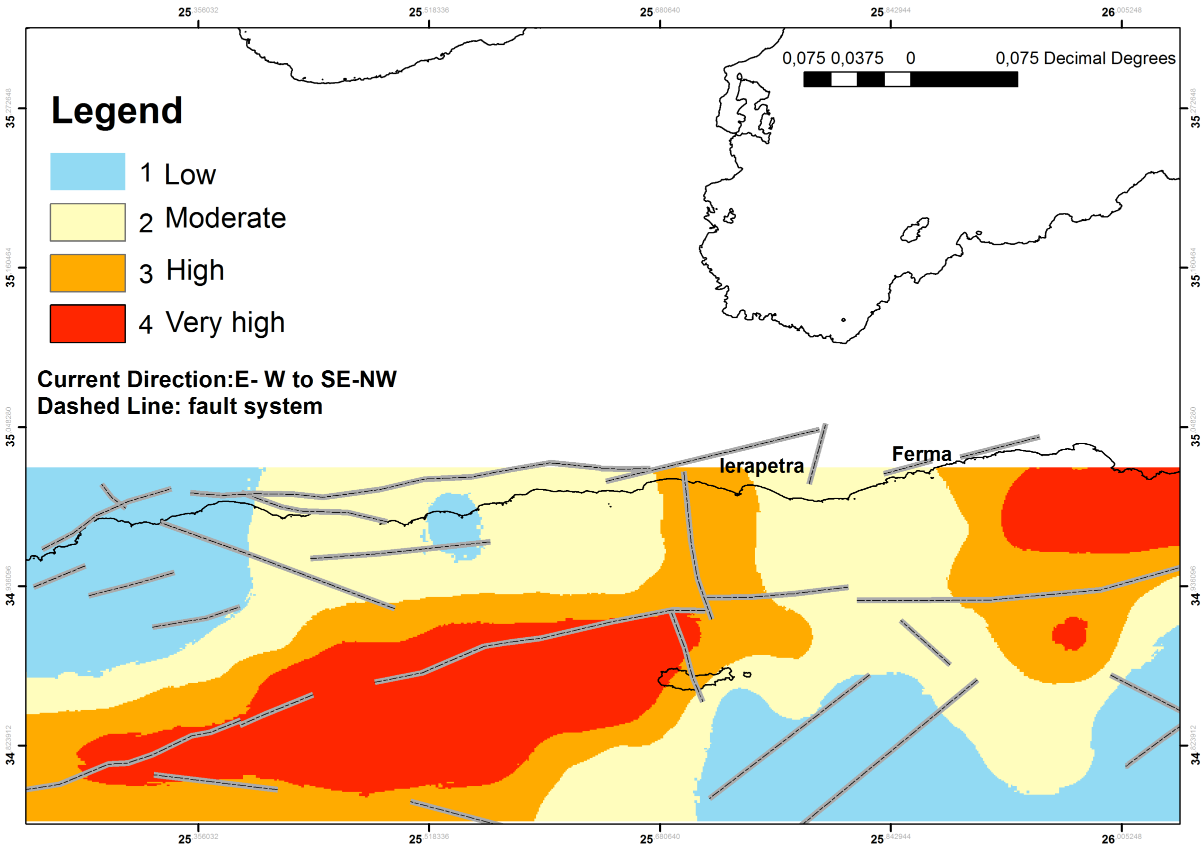

Figure 4: Susceptibility map of the study area considering predominant E-W to SE-NW currents as shown in Figure 5.

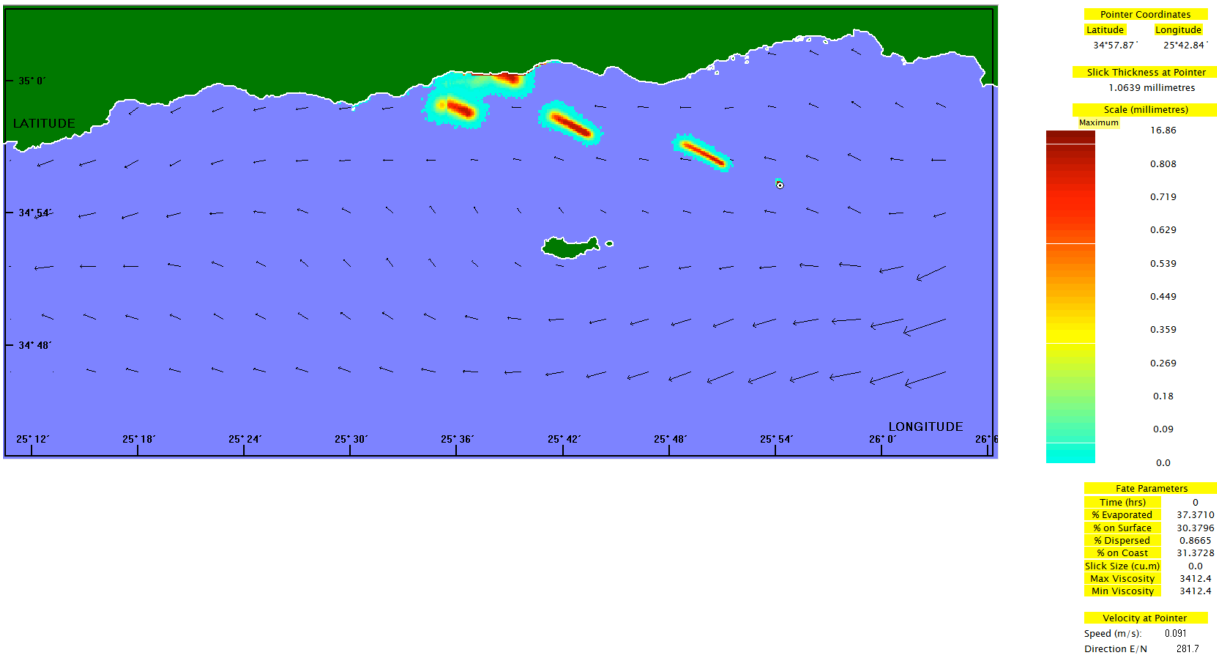

Figure 5: Superimposed oil spills dispersion using MEDSLIK model.

CONCLUSIONS

The main conclusions of this study are, as follows:

a) Oil spill susceptibility maps are crucial to early response in oil spill accidents. This is because intense urbanization in the study area requires an accurate management planning.

b) In offshore susceptibility studies, more than three factors should be taken into account to accomplish the susceptibility assessment. These should anyway include slope, aspect and sea current orientation.

c) Lack of information in more distal offshore areas makes more difficult the susceptibility evaluation. In the case of an oil spill in the deeper part of the study area, real-time oceanographic and meteorological data will be paramount to model the path and dispersion rates of future oil slicks.

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