TSUNAMI HAZARD ASSESSMENT IN THE NORTHERN AEGEAN SEA

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ABSTRACT

Emergency planning for the assessment of tsunami hazard inundation and of secondary effects of erosion and landslides, requires mapping that can help identify coastal areas that are potentially vulnerable. The present study reviews tsunami susceptibility mapping for coastal areas of Turkey and Greece in the Aegean Sea. Potential tsunami vulnerable locations were identified from LANDSAT ETM imageries, Shuttle Radar Topography Mission (SRTM, 2000) data and QuickBird imageries and from a GIS integrated spatial database. LANDSAT ETM and Digital Elevation Model (DEM) data derived by the SRTM-Mission were investigated to help detect traces of past flooding events. LANDSAT ETM imageries, merged with digitally processed and enhanced SRTM data, clearly indicate the areas that may be prone to flooding if catastrophic tsunami events or storm surges occur.

Key Words: Aegean Sea, tsunami hazard, remote sensing, GIS, morphometric terrain analysis

1. INTRODUCTION

The present study concentrates on tsunami susceptibility mapping for coastal areas in the Aegean Sea where the geomorphologic and lithologic characteristics are similar to areas struck by recent catastrophic tsunamis in the Island of Sumatra, where historic records of floods and tsunami events are available and reliable for purposes of comparison. Disaster emergency planning requires development of maps that delineate the hazard for coastal areas that are susceptible to future tsunami impact. There is a high potential for the generation of large tsunamis around the Aegean Sea, as well as for destructive local events in near-shore zones. The historic record shows that parts of both the Turkish and Greek coastlines were struck by destructive tsunamis (Yalciner et al., 2001, 2004). Most of the historic tsunamis have occurred along well known geologic fault zones and volcanoes. However, there are numerous other areas that can generate destructive tsunamis in the Mediterranean region in the future. Potential tsunamigenic source areas should include the normal fault zones and the subduction zone in the Tyrrhenian sea (Yolsal and Taymaz, 2003; 2004; 2005).

The impact and spatial destructiveness of a potential tsunami will depend on such factors as: a) Width of the continental shelf; b) Near-shore bathymetry (Wijetunge, 2006); c) Energy focusing effects; d) Coastal topography; e) Tsunami terminal velocity and runup height; f) Type of land use in the affected coast - including density of vegetation and buildings.

However, detailed studies are necessary to understand and determine the way by which the above factors could influence the spatial variations in the extent of inland flooding, maximum tsunami runup heights and the degree of damage along the affected coastline. Such information would help determine the degree of vulnerability of the coastal communities to future tsunami events, as well as to storm surges. Although storm surges are not potentially as destructive as major tsunamis, they occur more frequently. Therefore, for effective emergency planning and tsunami preparedness both near and far field effects of potential future tsunamis must be considered. Also, it is important to prepare maps that illustrate the extent by which a coastal area could be inundated by tsunamis and storm surges and to identify potentially vulnerable areas.

2. APPROACH

The present study explores a strategy adopted to generate maps that illustrate areas vulnerable to tsunamis and secondarily-induced effects such as landslides. The methodology is based on the support provided by a standardized, spatial GIS database for the delineation of potential hazard sites. To establish a cost effective method and a quick determination of factors that influence damage intensity in tsunami prone areas, one must analyze the preparatory or causal controlling factors using remote sensing and GIS methodology. For a better understanding of the complex processes and their interactions during tsunami inundations, emphasis is put on a spatially accurate, GIS integrated representation of those influencing parameters and determining factors - provided that such data is available. For example, such parameters as height, slope degree and/or curvature of slopes, can be derived from digital elevation models (DEM). On a regional scale, the areas of potential tsunami risk in the Aegean Sea are determined by an integration of remote sensing data, geologic, seismotectonic and topographic data, and reports of historical tsunamis.

LANDSAT ETM and DEM data were used as layers for generating a Tsunami Hazard GIS and combined with various geodata. For the purpose of the present study the following digital elevation data were evaluated: **S**huttle **R**adar **T**opography **M**ission -SRTM, 90 m resolution) data provided by the University of Maryland, Global Land Cover Facility (http://glcfapp.umiacs.umd.edu: 8080/esdi/). For a geomorphologic overview and for deriving the characteristic, geomorphologic features of tsunami prone areas, terrain parameters and morphometric maps were extracted from SRTM DEM data, such as shaded relief, aspect and slope degree, minimum and maximum curvature, or profile convexity maps, using ENVI 4.3 / CREASO and ArcGIS 9.2 / ESRI software. For enhancing the LANDSAT ETM data, digital image processing procedures were carried out. With digital image processing techniques, maps can be generated to meet specific requirements, considering the tsunami risk site mapping. As a complementary tool, Google Earth Pro Software was used in order to benefit from the high-resolution 3D imageries of the coastal areas (http://earth.google.com/). A systematic GIS approach is recommended for tsunami risk site detection based on SRTM data as described in Figs.1 and 2 extracting geomorphometric as part of a Tsunami / Hazard Information System. The digital topographic data were merged with LANDSAT ETM data (Band 8: 15 m resolution).

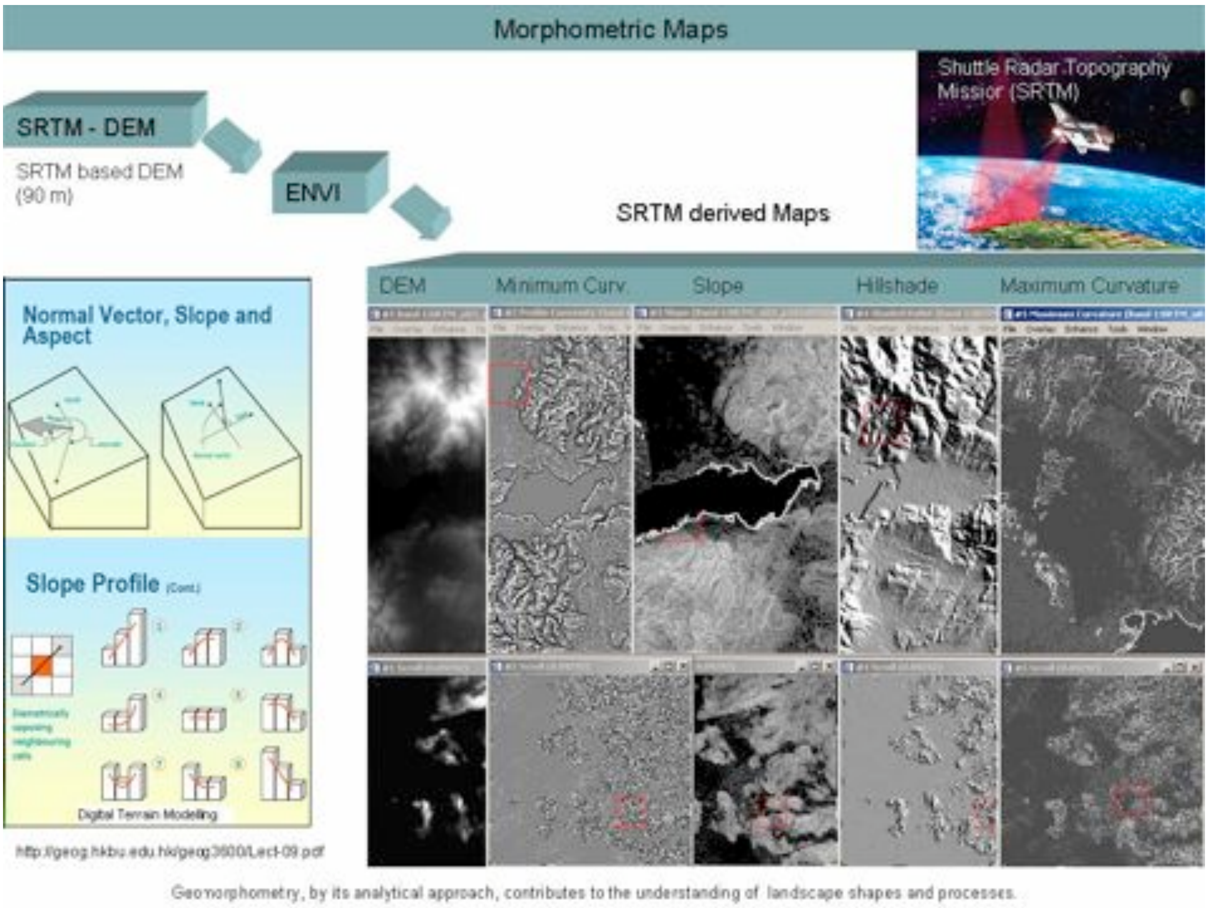

Figure 1. Deriving morphometric maps from SRTM DEM data and integration of these maps into a GIS as shown by the example of the Izmir area.

The evaluation of digital topographic data is of great importance as it contributes to the detection of the specific geomorphologic/ topographic settings of tsunami prone areas.

Evaluations of digitally processed and enhanced LANDSAT ETM imageries (merged with the pan-chromatic band for getting 15 m resolution) and high resolution imageries provided by Google Earth as QuickBird (up to 0,60 m resolution) from recently tsunami prone areas in Sumatra and Sri Lanka, have shown the existence of typical morphologic, hydrologic and lithologic properties as there are: ¾ linear, parallel, seawards oriented, erosional features related to marine abrasion, flux and reflux; ¾ remnants of tsunami floods are irregular swamps, ponds and lagoons near the coast; ¾ concentration of lagoons in a higher density; ¾ arc-shaped "walls" and "terraces" opened towards the sea, terraces and scarps parallel to the coast; ¾ fan-shape like or channel-like arranged drainage pattern; ¾ fan shaped, flat areas; ¾ broad river beds and estuary plains; ¾ seawards orientation of the slopes; ¾ sedimentary covers visible due to characteristic, spectral properties; ¾ abrasion areas visible due to characteristic morphologic and spectral properties (Theilen-Willige, 2006)

Hill shade maps for example help to identify marine abrasion platforms. A fan-shaped, flat morphology at the coasts is often related to flooding events. Aspect maps, minimum curvature and slope gradient maps contribute to the detection of arc-shaped walls and terraces oriented towards the sea.

The northern part of the Aegean Sea was chosen to investigate the potential of satellite data for the detection of traces of flood waves. The coastal areas of the Aegean Sea are investigated in order to detect typical geomorphologic and hydrologic features as described before and assumed to be related to past tsunamis. Merging morphometric maps as height, hill shade and profile convexity map from this region helps to visualize the areas being susceptible to flooding.

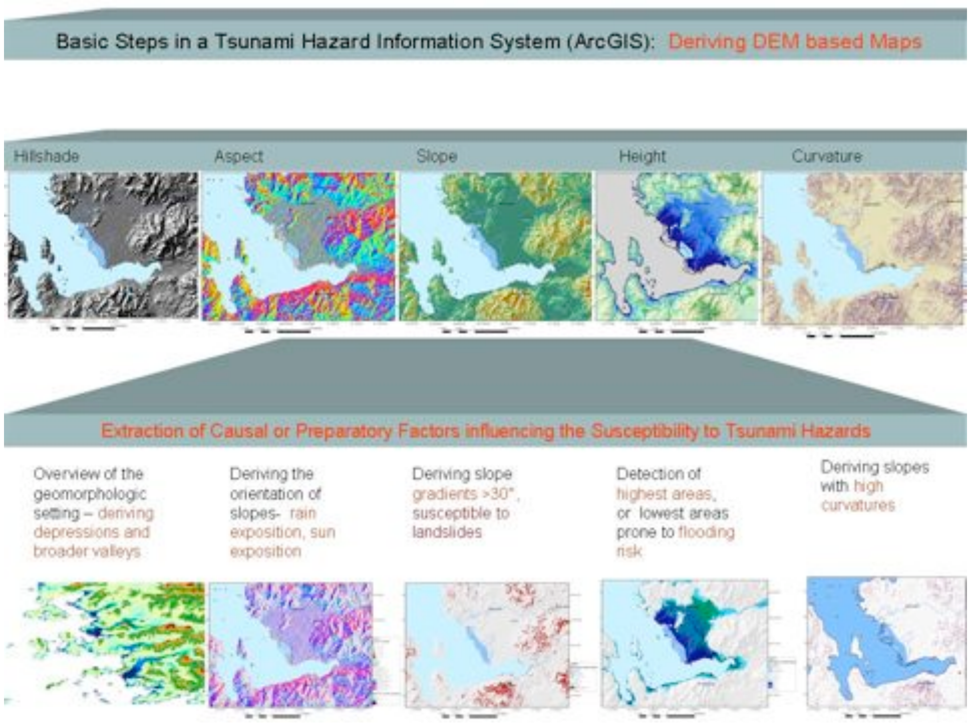

Figure 2. Deriving morphometric maps based on Digital Elevation Model (DEM) data provided by the Shuttle Radar Topography Mission (SRTM) in February 2000 in order to detect tsunami-related geomorphologic features demonstrated by the example of the Izmir area / West -Turkey

Potential risk sites for hazardous tsunami waves were identified by analyzing areas showing heights below 20 m above sea level (Fig.3). These regions below 20 m height were studied then more detailed evaluating LANDSAT ETM, QuickBird and SRTM DEM data. Investigations were focused on those areas where evaluations of SRTM , LANDSAT ETM and other geodata allow the assumption that catastrophic tsunami events might have occurred in the past and that these areas could be susceptible to flooding in future again.

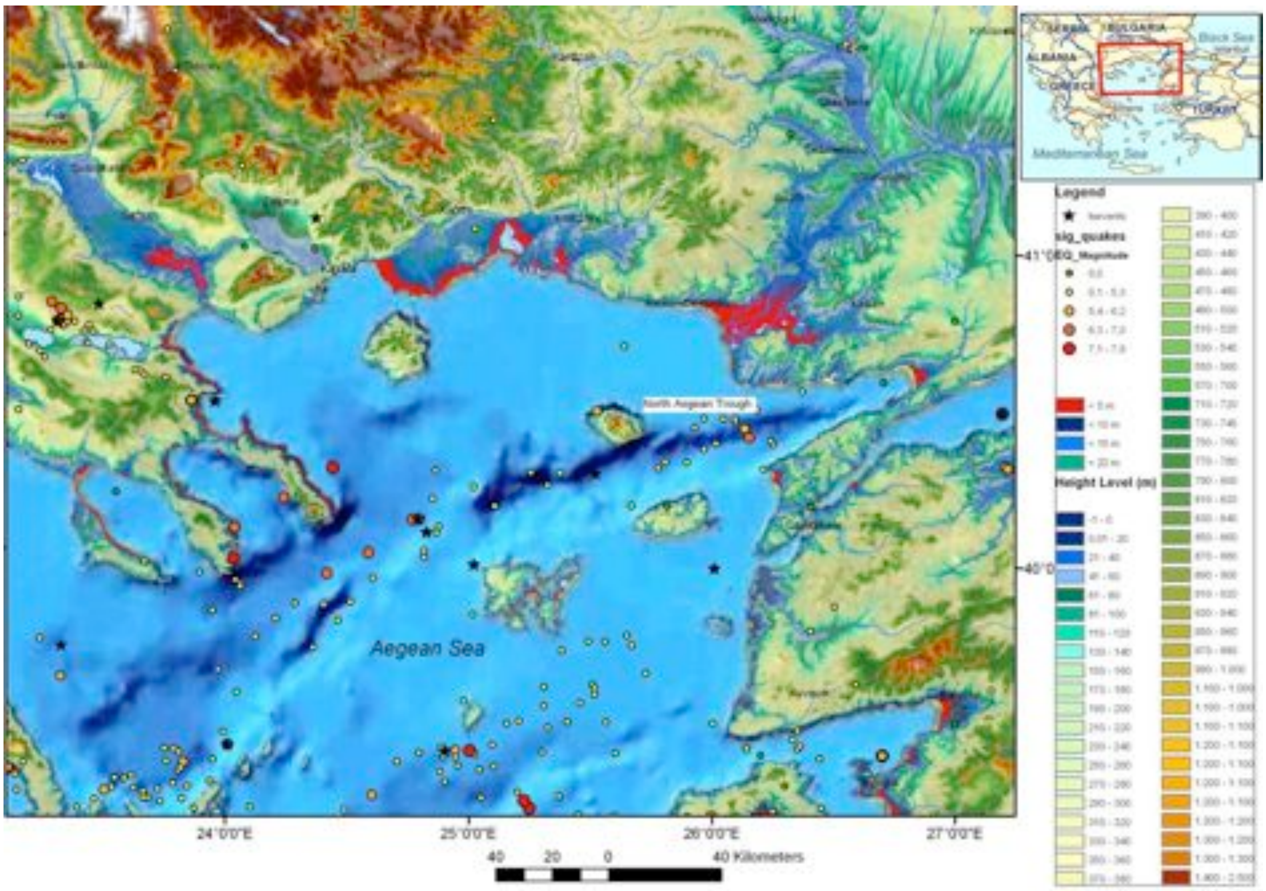

Figure 3. Earthquake and tsunami occurrence in the Aegean Sea

Tsunami data: http://map.ngdc.noaa.gov/website/seg/hazards/viewer.htm
Earthquake data: http://neic.usgs.gov/neis/eq_depot/2003/eq_030814/neic_xlaf_p.html
http://www.gein.noa.gr/services/infoen.html
Bathymetric map: http://worldwind.arc.nasa.gov/

3. GEOLOGIC AND TECTONIC SETTING

The most significant bathymetric feature of the north Aegean Sea is the North Aegean Trough (NAT), which consists of a series of deep fault-bounded basins. Those in the west have a NE trend, while those in the eastern part of the system trend ENE. The easternmost basin, the Saros trough, is also the narrowest: in its western part, south of Samothraki, the bathymetry and gravity suggest it is a half graben bounded by a large normal fault system along its northern margin (Taymaz et al., 2004). Fault plane solutions in the western part of the North Aegean Trough show mainly strike-slip faulting, consistent with right-lateral slip on NE-SW striking faults. The focal mechanisms give the impression that the north and central Aegean Sea is dominated by distributed strike-slip faulting: most of it right lateral with a NE to ENE strike. Several of the islands appear to be the uplifted footwall crests of such normal faults, and are adjacent to deep basins offshore. There is further evidence from paleomagnetism that this western region rotates clockwise relative to stable Europe. In the central and eastern Aegean, and in NW Turkey, distributed right-lateral strike-slip is more prevalent, on faults trending NE to ENE, and with slip vectors directed NE. The strike-slip faulting that enters the central Aegean from the east appears to end abruptly in the SW against the NW-trending normal faults of Greece. Tsunami hazards are well documented in the Aegean Sea. Some of the known tsunamis are presented in Fig. 3.

4. EVALUATIONS OF SATELLITE DATA FROM COASTAL AREAS OF THE AEGEAN SEA

4.1. Detection of potential hazard sites

As can be seen in Fig. 3 the susceptibility of coastal areas to flooding varies depending on their morphologic properties. This is visualized using satellite data by Fig. 4 summarizing some of the different coast types and their susceptibility to flooding – similarly to the study by Kumaraperumal et al. (2007).

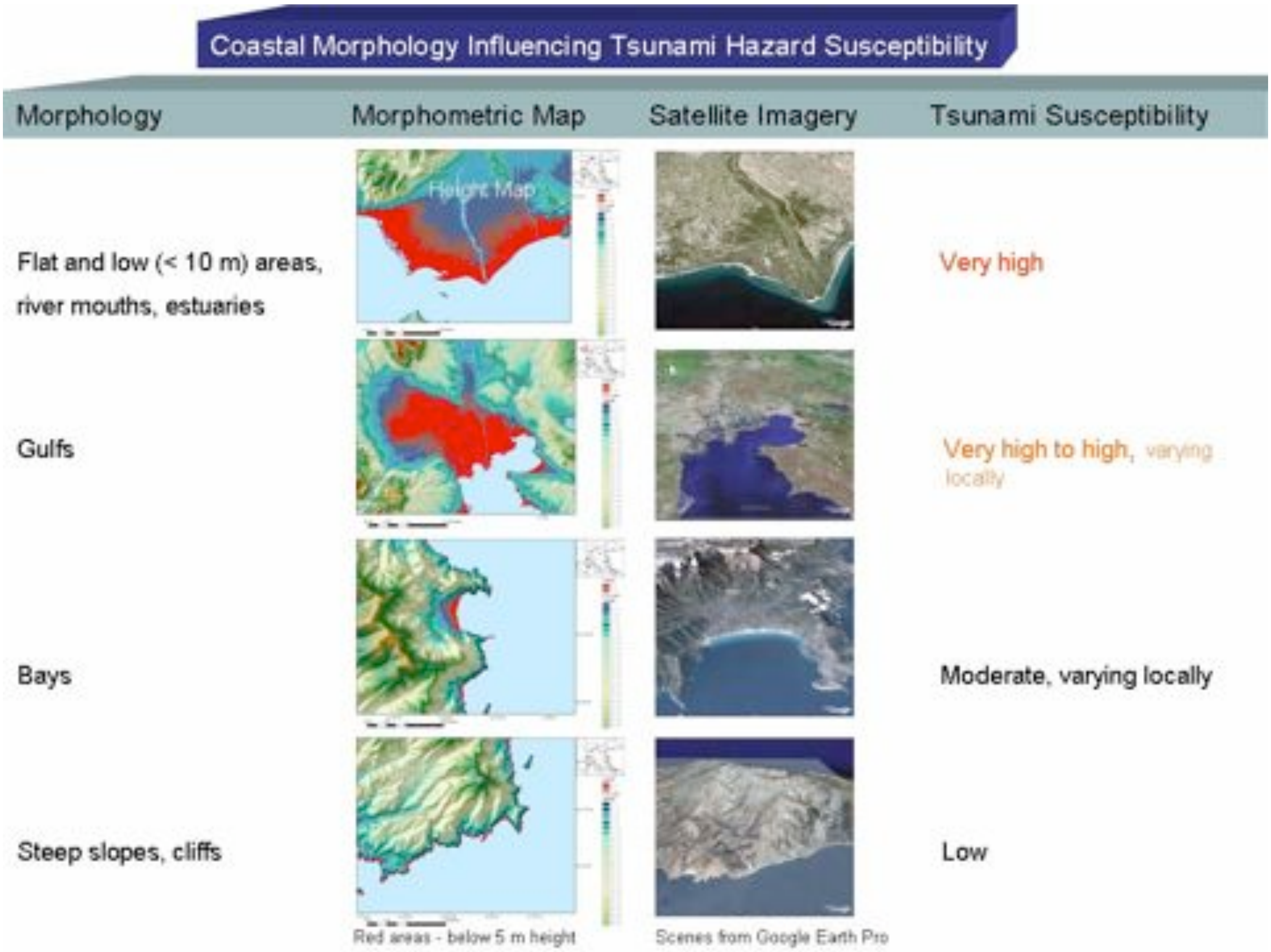

Figure 4. Coastal morphology influencing tsunami flooding susceptibility

A local increase of tsunami damage near the mouth of rivers, due to the refraction of tsunami waves with dependence on river orientation and direction of arrival of tsunami has to be considered. The extent of inundation is also be determined by the angle of incidence of the tsunami surge as well as its velocity. The fluctuating surges of water could cause infilling and draw down bays and send volume of water miles inland along large coastal rivers. As larger bays and gulfs in the Northern Aegean Sea are most probable to be affected by flooding in case of catastrophic tsunami events those areas are shown in Fig. 5.

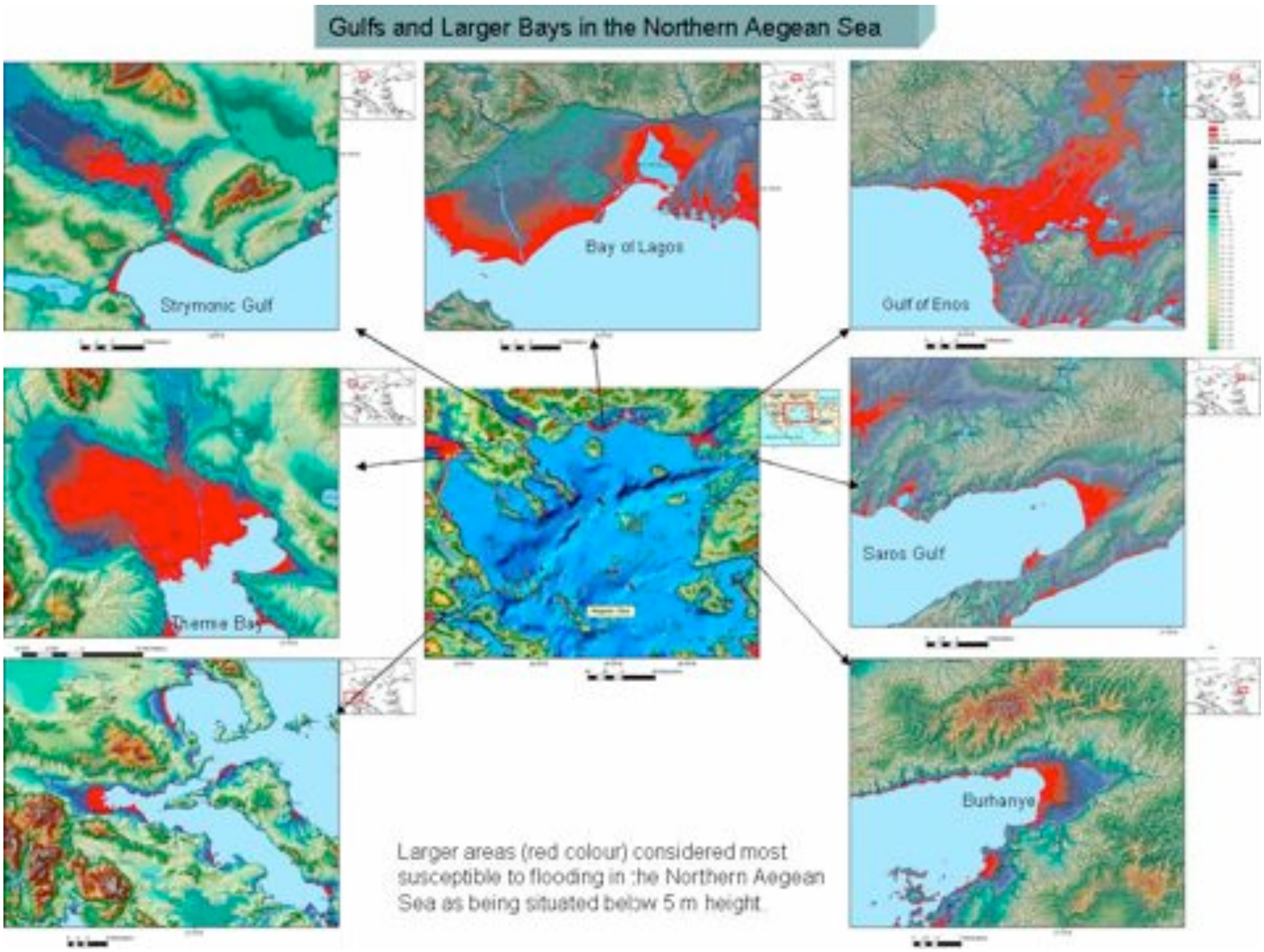

Figure 5. Extended areas with high flooding susceptibility in case of tsunami events

As example to demonstrate the potential of remote sensing and GIS methodology for the site detection of tsunami hazard prone areas is shown the area of the Bay of Lagos (Fig.6 a and b). An overlay of height levels and a profile convexity map derived from SRTM DEM data clearly shows flat and low areas forming terrace-like, morphologic features, opened towards the sea. The morphometric maps of this area (Fig.6 a) support the assumption that this area was hit by catastrophic tsunamis in the younger geologic past.

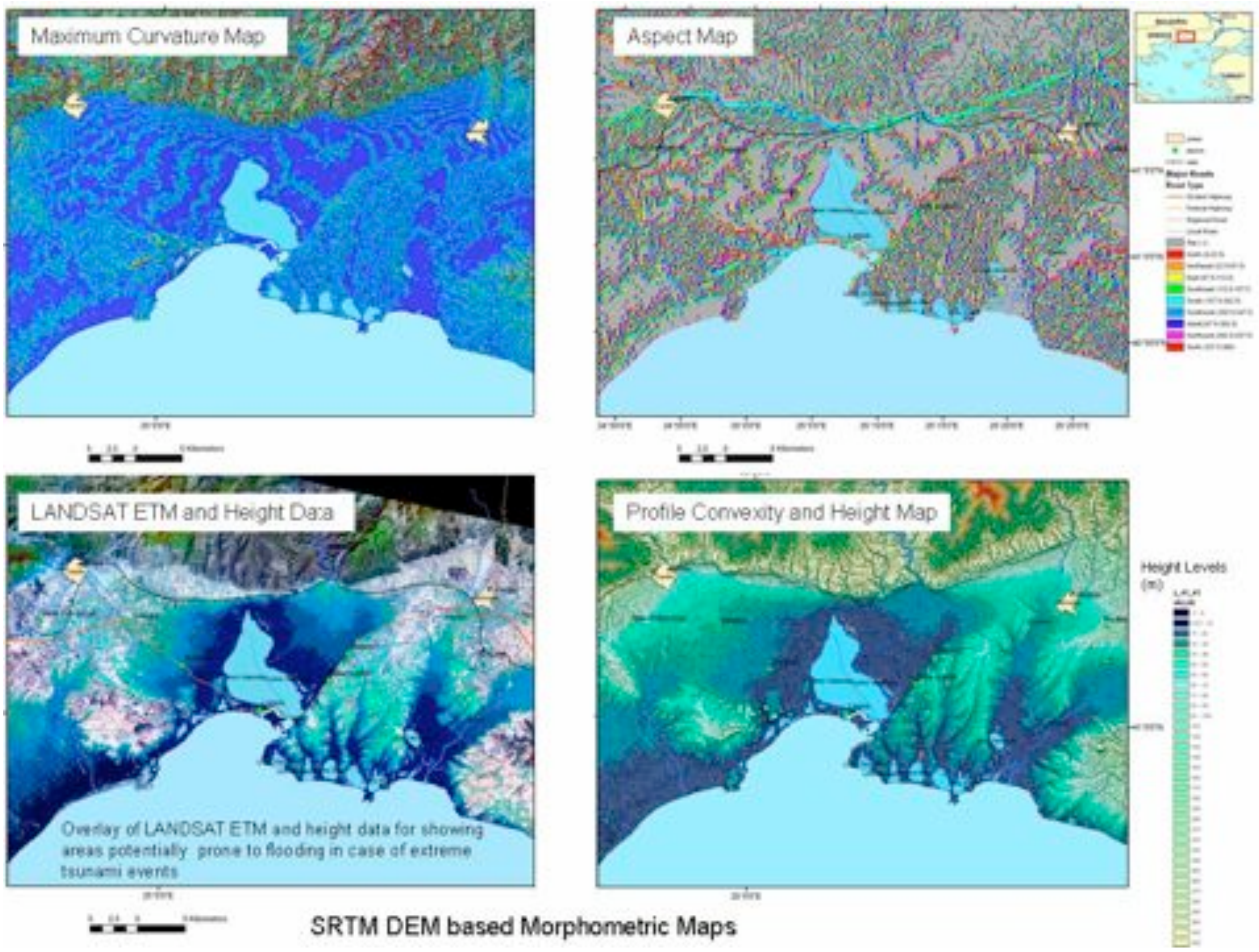

Figure 6 a. Morphometric maps of the northern coastal area of the Aegean Sea

Probable, ancient flooding waves seem to be traced by arc-shaped, terrace-like features at the coasts on the maximum curvature map, profile convexity map and aspect map. Merging the SRTM based height data with LANDSAT ETM imageries (sharpened to 15 m resolution) allows a more detailed analysis and mapping of potentially flooding prone areas. The LANDSAT ETM / height level data overlay (Fig.6 c) shows that fortunately no larger settlements, roads and railways are situated in areas below 10 m height. The minimum curvature map seems to trace marine waves.

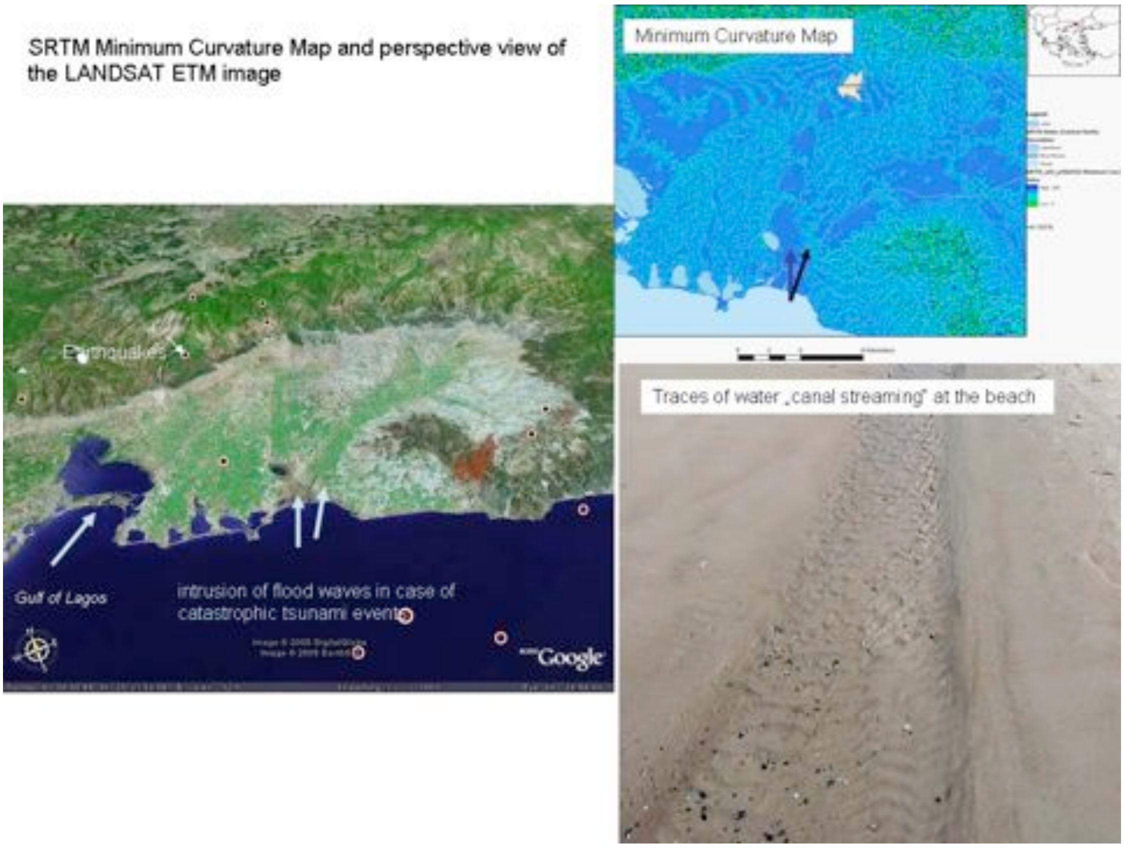

Figure 6 b. Lagos and Anadoli Bay

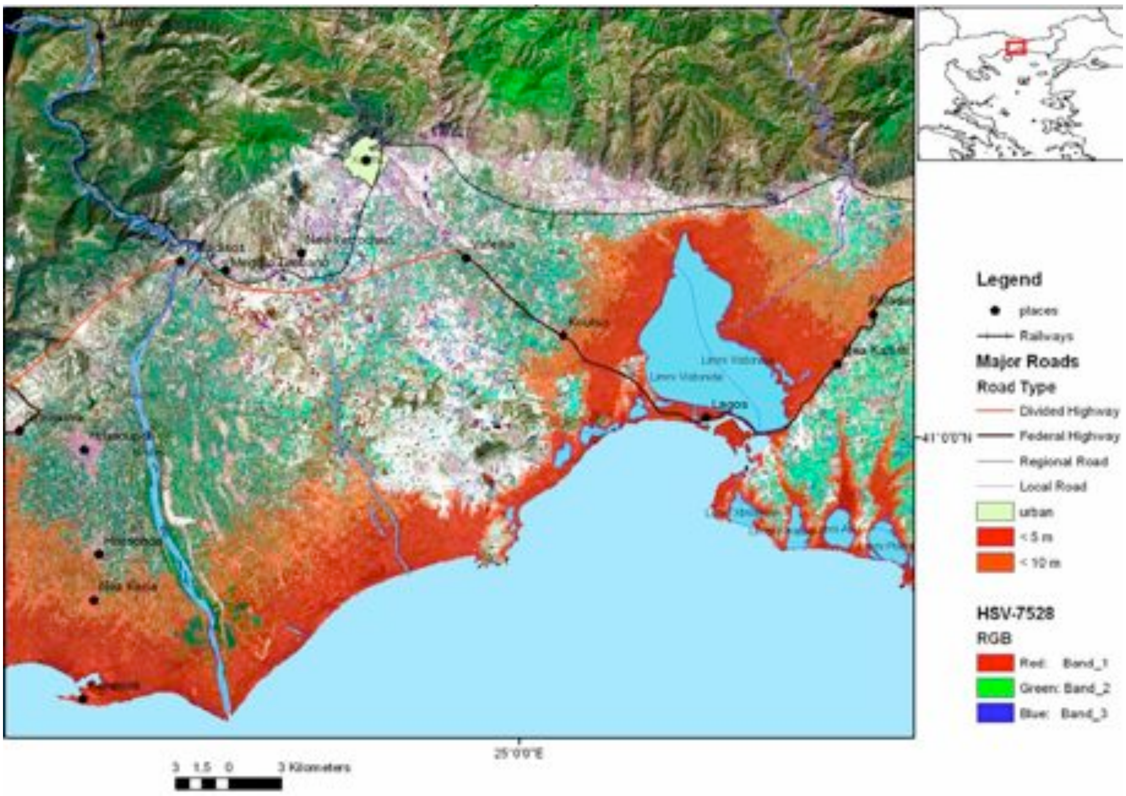

Figure 6 c. LANDSAT ETM scene merged with height data.

4.1. Evaluations of LANDAT and SRTM Data for the detection of surface-near sea water currents

An important contribution of digitally processed satellite imageries is the **visualization of surface water currents**. This might give information of those areas where flood wave energy might be focused due to the influence of coastal morphology. Evaluations of LANDSAT imageries for the detection of surface-near water currents have been carried out for the northern part of the Aegean Sea. The LANDSAT ETM image (Fig.7) visualizes the water currents and circulation in the northern part of the Aegean sea at the acquisition date (20.08.2001). The influence of the coastal morphology and of the islands on the streaming mechanisms is clearly visible. The height level information is derived from SRTM data. Areas below 5 m height are shown in red for enhancing those areas most susceptible to flooding in case of extreme tsunami events.

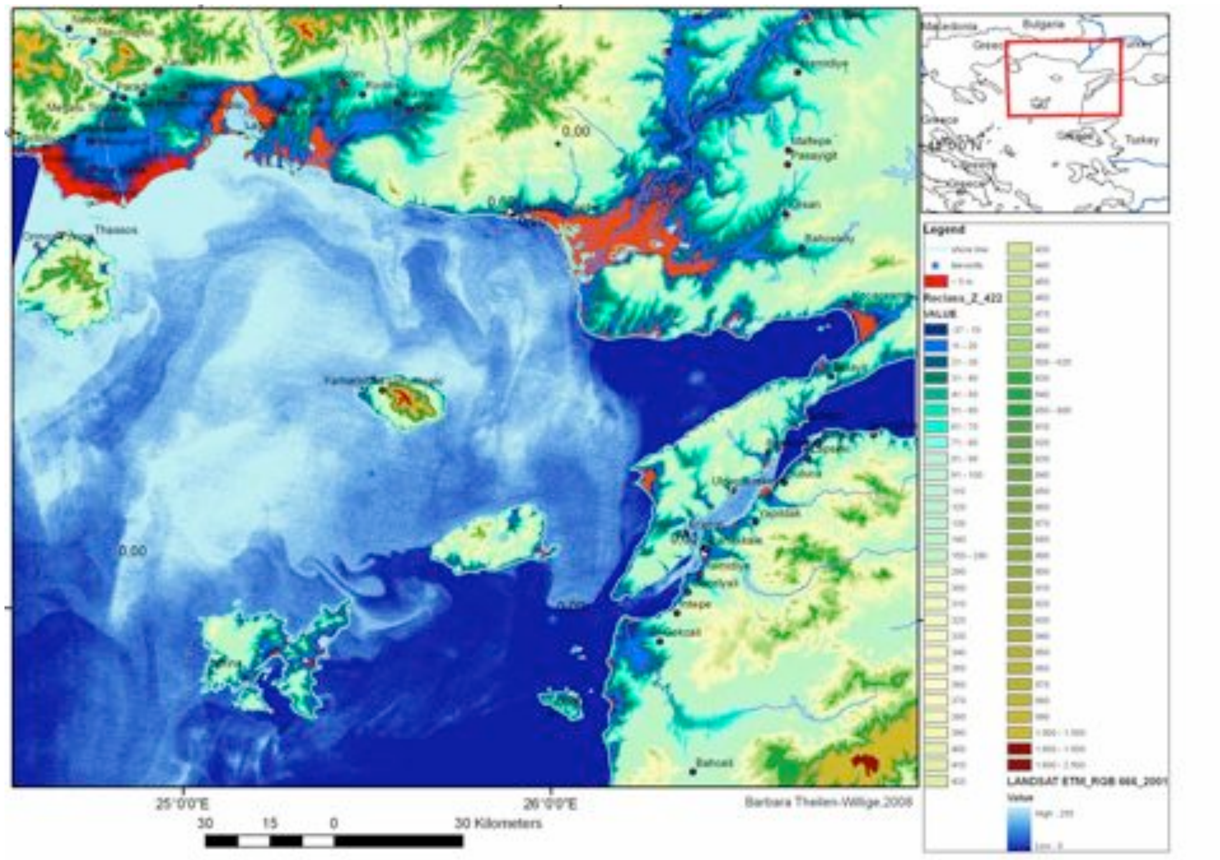

Figure 7. LANDSAT ETM image (thermal band) and height level overlay of Limnos (lower left) and Gškceada islands

Areas below 5 m are presented in red. These areas are most susceptible to flooding

How a small island can influence water streams coming from the Sea of Marmara is shown by the next figure (Fig.8) and the influence of coastal morphology in Fig. 9. As a small island is situated directly within the water streams coming from the Sea of Marmara, it divides the water streams. This can be observed on the color-coded LANDSAT image.

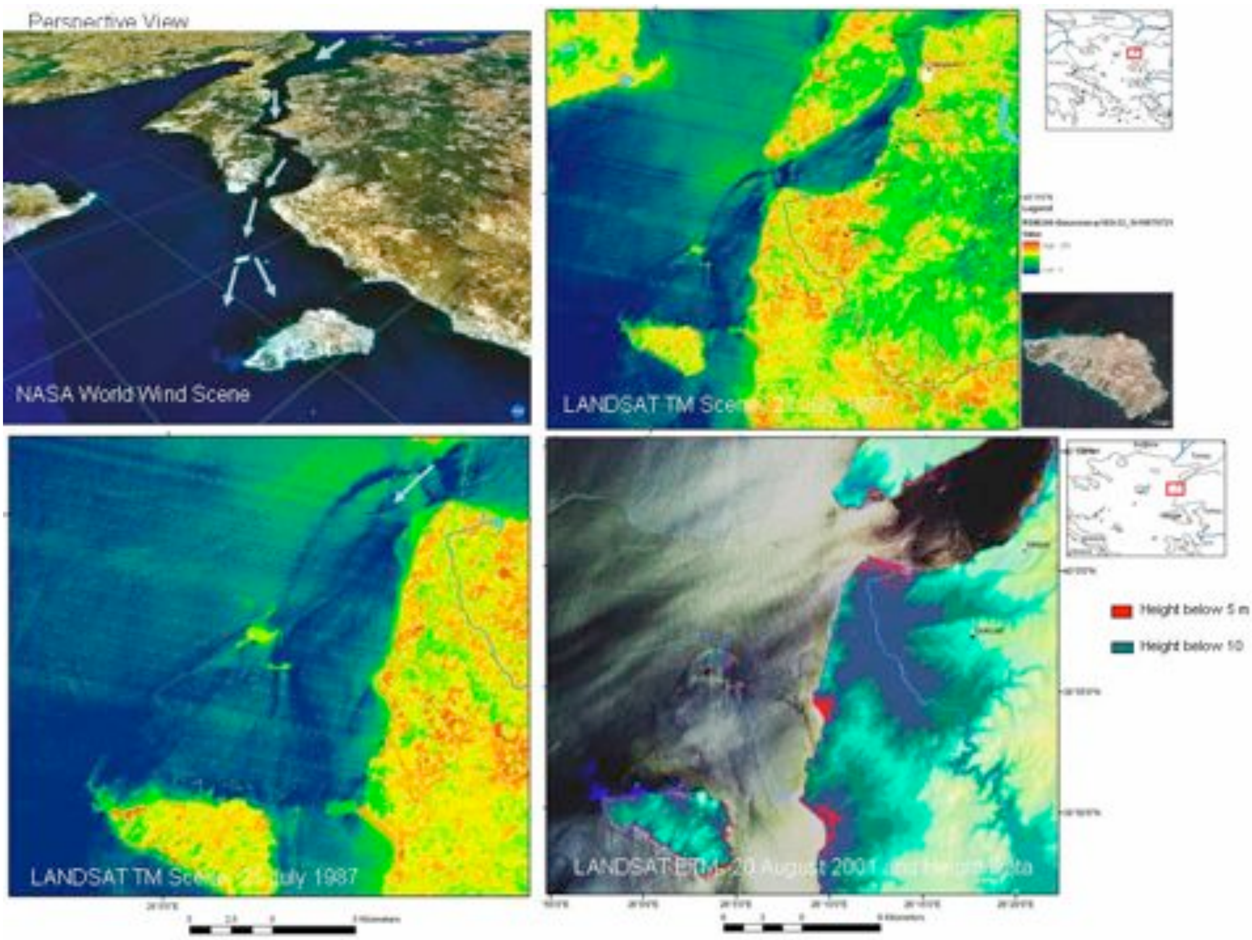

Figure 8. Influence of islands on water streaming mechanisms

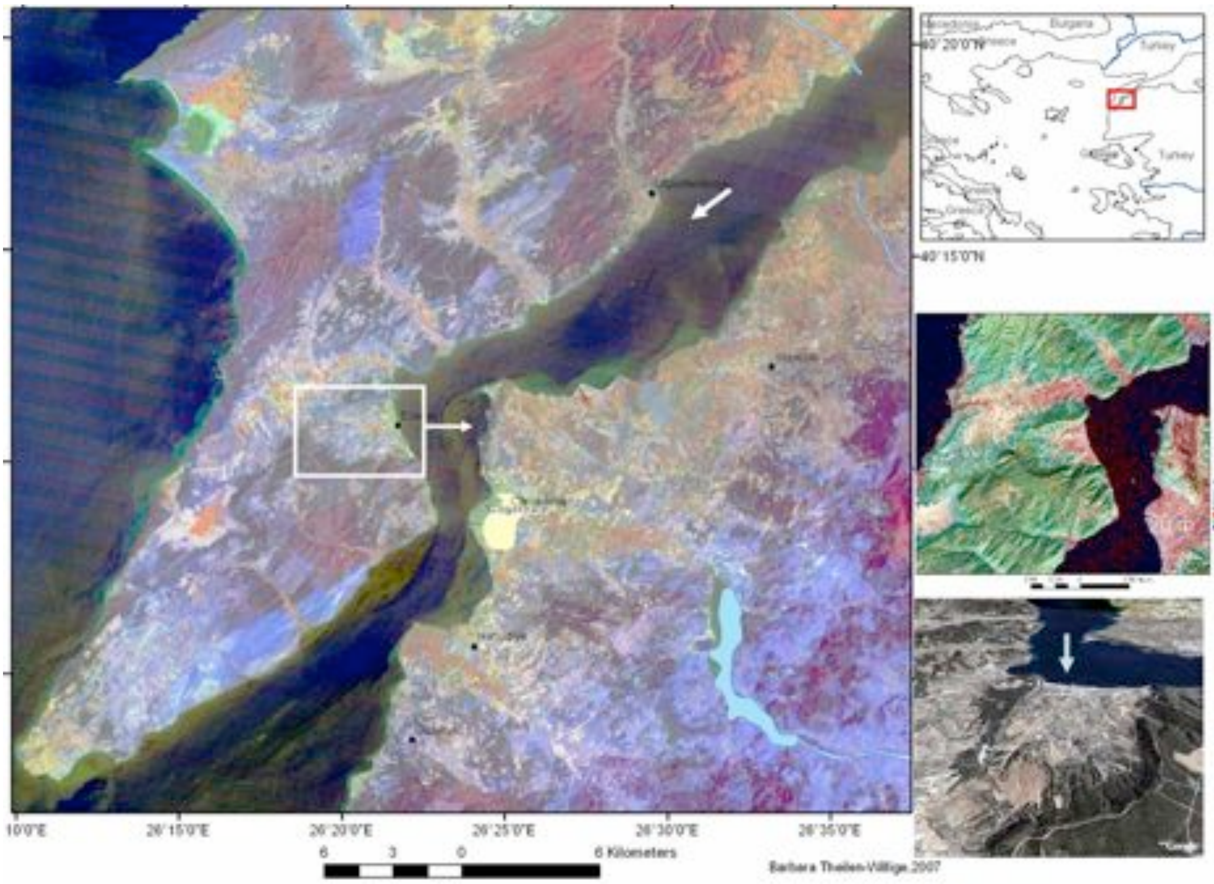

Fig.9: Areas most susceptible to flooding due to focusing effects

When calculating values below 0 m sea level based on SRTM data small sea surface height differences become visible as shown in Fig.10. Although these height differences most probably are related to wind conditions at the acquisition date such a sea surface height map contributes to a better understanding of the influence of coastal morphology on water

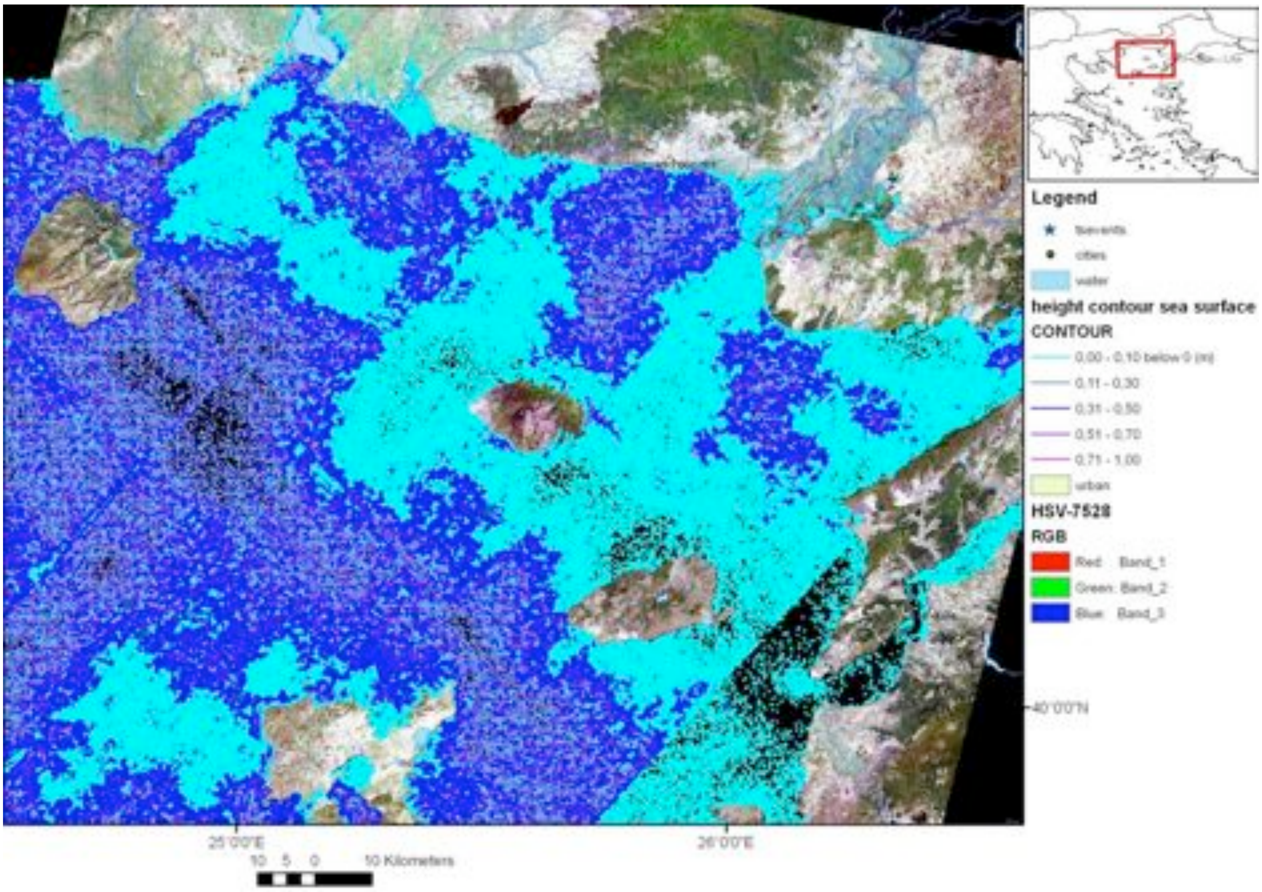

Figure 10. LANDSAT ETM and SRTM data for detecting water currents and sea surface height variations, mainly due to wind intensity and wind direction and temperature gradiation

5. CONCLUSIONS

The evaluations of different remote sensing data combined with other geodata in a GIS environment allow the delineation of areas susceptible to tsunami flooding and inundation in the coastal areas of the Aegean Sea. This might contribute to the detection of future potential flooding regions. The interpretation of remote sensing data from ancient tsunami prone areas will help to a better recognition of hazardous sites in future and, thus, being one basic layer for a tsunami alert system. The findings can be converted to recommendations for the local governments such as towns and villages in order to plan disaster-reducing activities.

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Satellite Data:
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http://worldwind.arc.nasa.gov/download.html

http://earth.google.com/

Shape files:

http://map.ngdc.noaa.gov/website/seg/hazards/viewer.htm
http://www.cipotato.org/diva/data/DataServer.asp?AREA=DZA&THEME=_adm