Coastal geomorphology and the risk from tsunami waves in Imvros island (Gökçeada) using remote sensing data and Geographical Information Systems (GIS)

Niki Panagopoulou
Harokopio University, Dep. of Geography, El. Venizelou 70, 17672, Athens, Greece, nikipgeo@gmail.com

Abstract

The purpose of this paper is to combine two levels of analysis. Firstly, it focuses on the coastal geomorphology of Imvros island (Gökçeada) and how it would be affected by a possible tsunami wave in the area. In addition to this, advanced technology is used such as remote sensing data and Geographical Information Systems in order to lead to conclusions concerning the possible risks the area would face should such a phenomenon occur.

It is common ground that the Eastern Mediterranean, in which the island of Imvros is also included, belongs to that category of regions where tsunami waves do not happen very often. However, it is not groundless to talk about such a thing, due to the several observations of earthquakes and landslides followed by such a phenomenon as well as due to the seismicity of the region. Therefore, the seismicity of the area signifies a high risk of tsunami.

Imvros is an island situated really close to the North Anatolian Fault (NAF). Its position makes it vulnerable to earthquakes and to tsunami waves as a consequence. Furthermore, we should bear in mind that it is surrounded by areas with high seismic activity and several cases of tsunami in the past.

Regarding land cover, remote sensing, together with the variety of cases it can be applied to, plays a vital role. As a consequence, it offers a new perspective to the procedure of describing the land cover. This happens due to the fact that it provides a range of multispectral data which can give really useful output for further analysis after having been appropriately processed. As a result, in order for the vulnerable parts of the island to be detected, software like ENVI and ArcGIS was used. Through these programmes, it was possible to edit pictures and create maps respectively.

To be more specific, a satellite picture taken from LANDSAT 8 was used in order to study the land cover of the island. What is more, the ArcGIS software was used to create maps depicting the slope, the aspect as well as the buffer zones per altitude of the island. Finally, all these features were studied carefully, together with the data provided by the satellite picture concerning the land cover in order for conclusions to be drawn.

Keywords: Imvros island (Gökçeada), North Aegean, remote sensing data (LANDSAT 8), Geographical Information Systems (GIS), tsunami hazard, risk assessment

Introduction

Imvros (Gökçeada) is an island in the northern Aegean Sea and it is located at the entrance of Hellespontos. Other islands nearby Imvros are Lemnos, Samothraki, and Tenedos. It is a part of the administrative district of Çanakkale of Turkey. Imvros is the biggest island of Turkey and the fourth in the world as far as it concerns the natural water resources (Bektaş et al., 2004). The size of the island is 289,5 km^2 and it has got a climate of Mediterranean type. Regarding the geomorphology, it has low mountains, hills and two fields. Some more characteristics are the waterfalls, springs and valleys (Koral et al., 2008). In Fig. 1, the Digital Elevation Model (DEM) of the island is presented with some of the names of its highest mountains.

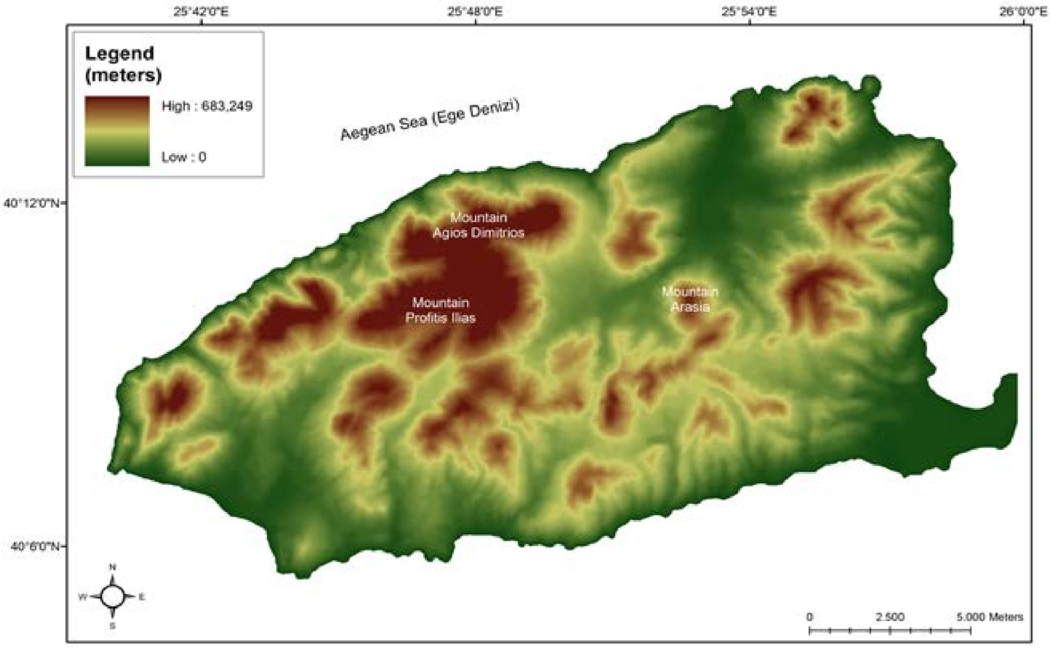

Figure 1: Digital Elevation Model (DEM) of Imvros

Concerning the coastal geomorphology, which is of high importance while studying tsunami waves, it has been affected by the North part of the Anatolian Fault (NAF). There are also other faults on the island which are almost parallel to the NAF and they have a northeast to southwest aspect (Parcharidis et al., 2009). The height in the north coast is about 673 m, whereas in the south it is 150 m. That explains the sharp geomorphology in the north, which is milder in the south.

In addition, the human geography of Imvros should be taken under consideration. The total number of the island's inhabitants is 8.288. Most of them (about 5.943) are living in Panagia (Merkez) the capital of Imvros and the rest of them in the villages (TÜİK, 2012 data).

Nowadays Imvros consists of the capital and nine villages, four of which where added more recently. Regarding the economy of the island, it is quite based on tourism, which explains the existence of hotels and other similar structures in the area. The regional economy is also based on agriculture. Both economic fields are of high importance as they are affected by the possibility of a tsunami happening in the island.

Image and maps' data, methods and techniques

The data used for this study cover two parts the combination of which can provide useful results concerning disaster management planning (Papathoma et al., 2003). At first place, a LANDSAT 8 image (11 bands: nine spectral and two thermal ones; 1 to 7 and 9 bands have a 30 m spatial resolution; 8 which is the panchromatic one, has a 15 m resolution; 10 and 11 bands have 100 m spatial resolution) acquired on 13/8/2013 was used in order to find out the land cover in Imvros (USGS). Secondly, the DEM information (the creation of which was based on a topographic map, in the framework of a research program of Harokopio University of Athens) was used and after proper methodology, a series of maps was created in order to reach the final one.

In the procedure of describing the land cover of a place, the remote sensing sector together with its different applications is playing a vital role (Parcharidis et al., 2009). That is the reason why a satellite image was used. More specifically, the date that was chosen is the most appropriate because there are no clouds and there are mild waves. Working on ENVI 4.7 program and using the 5, 4 and 3 bands (near infrared/NIR, red, green) a false colour image was created. After having made five groups of information (Regions Of Interest - ROI) which include 1) constructed areas, 2) bare rocks, 3) dense vegetation, 4) light vegetation and 5) aqua masses, the procedure of supervised classification with minimum distance follows. Then, in order to have a better result, Corine 2000 was used so that the land cover map (Fig. 2) would have more natural colours (geodata.gov.gr, European Environment Agency).

Fig. 2 shows the land cover of Imvros together with the capital of the island and the three largest villages according to their inhabitants. The Alyki can also be seen, which is a salt land and some mountains. What is more, it should be explained that the fifth category includes not only constructed areas but also bare rocks. This happens because of the reflection which is quite similar in these two categories and field research is needed in order to distinguish them. As a result, this category comprises villages, seaside resorts as well as bare rocks. Concerning the airport, it is located in the north, north-east part of the island (shown on the map as a red line).

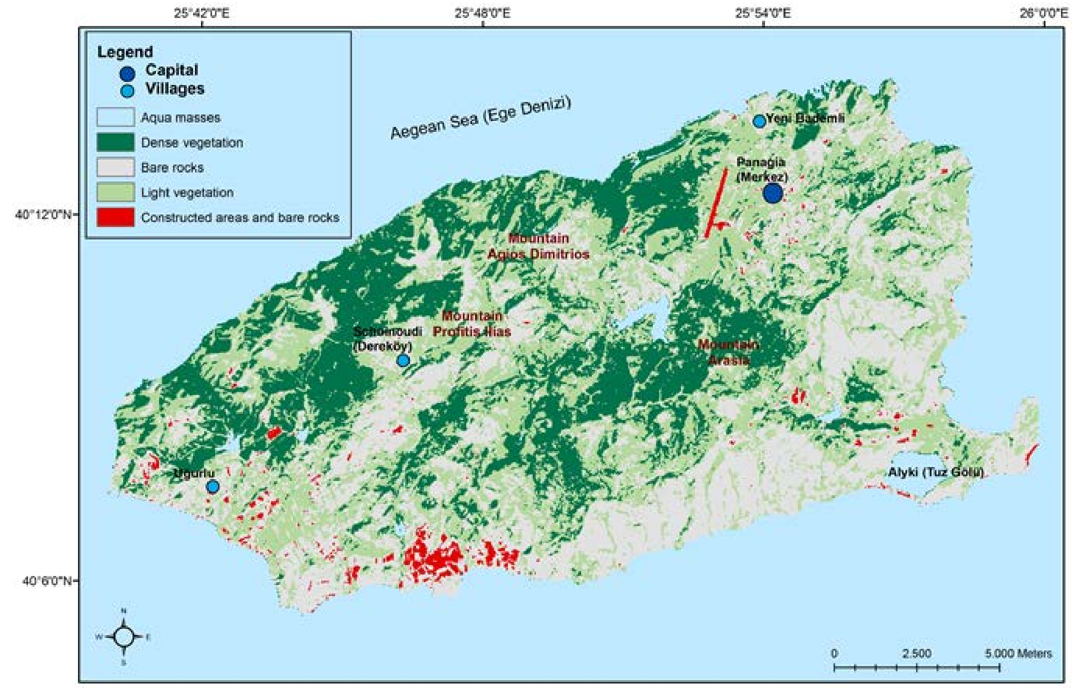

Figure 2: Land cover of Imvros according to the five ROI and Corine 2000

Furthermore, in order to get a map that shows the risk areas as a result, three more factors are needed. These factors are the slope, the altitude and the distance from the coastline. Each of them is depicted on a separate map, which has been created using the DEM file. The projected coordinate system used in all thematic maps is WGS_1984_UTM_Zone_35N. Also, the GIS software which was used is ArcMap 9.3 by ESRI and it has to be mentioned that there were no data for the southeast edge of Imvros, so the maps show the rest of the island which is the biggest part of it.

In Fig. 3, the slope of Imvros in degrees is presented. There has been a classification in five categories and it can be understood that the north and northwest part has a slope between 27 and 74 degrees, while a large part of the island has a small slope, between 0 and 11 degrees.

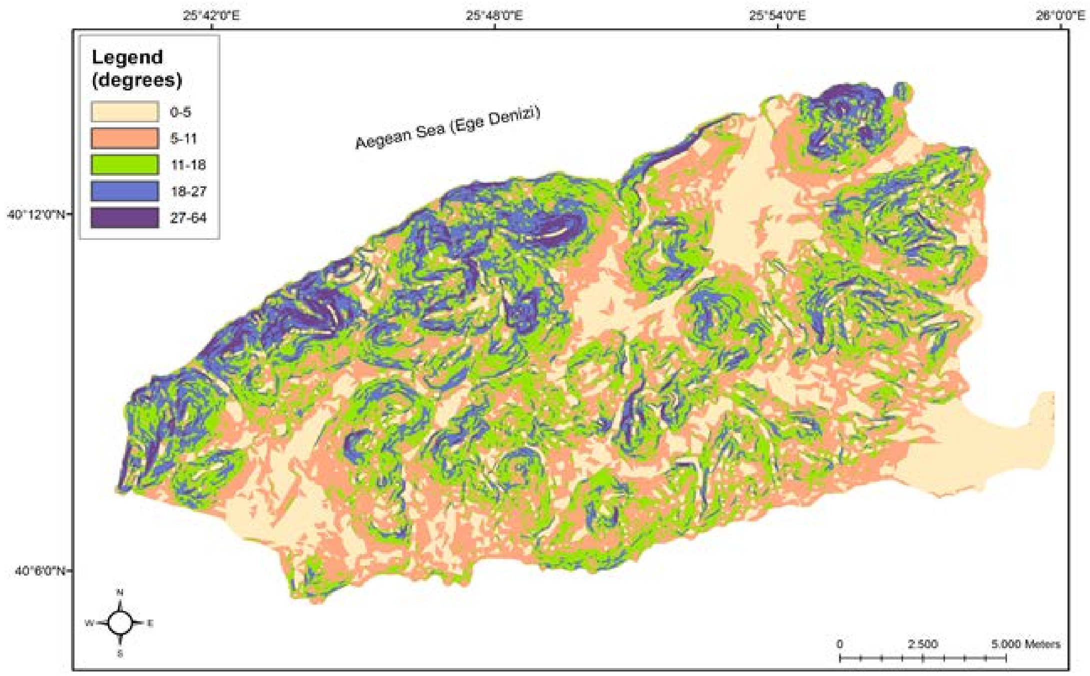

Figure 3: Slopes of Imvros (degrees)

Regarding the factor of altitude, four classes where created, up to 10, 20 and 30 meters respectively, and the fourth one includes the rest of the altitudes (Fig. 4). In that way, buffer zones per altitude were created. The reason why these sizes were chosen is based on bibliography where it is mentioned that the highest altitude tsunami waves have reached is 30 meters (Bryant, 2001).

The third factor, as already mentioned, is the distance from coastline which was measured in a straight line from the coast. Fig. 5 shows the three classes from 0 to 1200 meters that a tsunami can reach and the information for these sizes was also based on bibliography (Bryant, 2001).

Finally, one last parameter was taken under consideration in order to have a more clarified result. This parameter is the bathymetry of Imvros and it is of high importance because the consequences that a tsunami wave may have depend on how deep and steep the bottom of the sea is (Bell, 1998). For example, when a tsunami reaches the coastline, its wave length and speed may decrease, whereas its height may increase over 20 meters (Bell, 1998). Remote sensing data were used once again. More specifically, the first spectral band (coastal/aerosol) of LANDSAT 8, which has a small wave length (0,43 – 0,45 μm) giving a more detailed view of the bottom of the sea and this explains its use, which is for coastline intensive observation. The bathymetry of Imvros was digitalized according to the colour scale based on the depth of the seabed. The line that was created represents approximately 15 meters depth and exists only in the parts where the sea is shallow. Otherwise no line can be shown and that means the seabed at those parts is deeper than 15 meters.

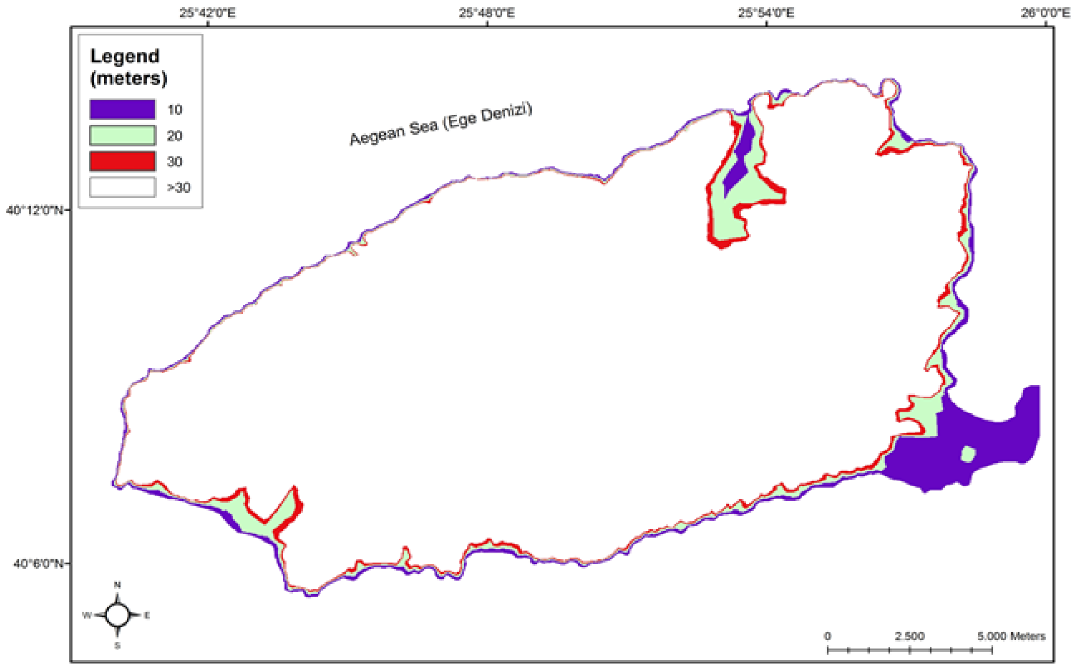

Figure 4: Buffer zones per altitude of the Imvros island (10 m., 20 m. and 30 m)

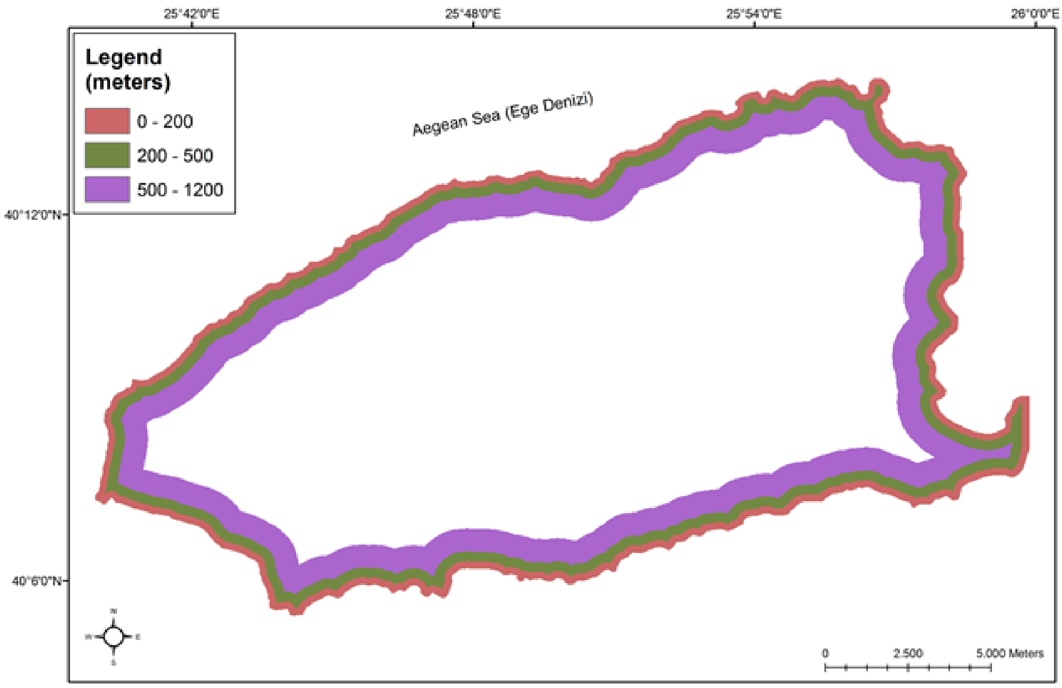

Figure 5: Distance 200 m. – 1200 m. from the coastline of Imvros

Results and Discussion

All the previous factors, which were shown in separate maps, are now combined in order to create the final map with the risk areas in case of tsunami waves in Imvros. Firstly, a classification of these parameters was made according to the percentage of impact of each of them. The result was a tsunami hazard scale which helped in the creation of the final map. For example, concerning slope, the first class which refers to 0 – 5 degrees was marked as the most hazardous. The next class was marked as less hazardous and in this way the last class was the least hazardous. The same motive was used for each of the factors and then these four scales were added.

Fig. 6 shows the result, where the risk areas can be recognised. There is a classification of these areas in three categories, which represent the high risk areas (with red colour), the medium (with green colour) and the low ones (with violet colour). In the same figure the bathymetry of Imvros can also be seen, which matches with the risk areas of the island according to their previous classification.

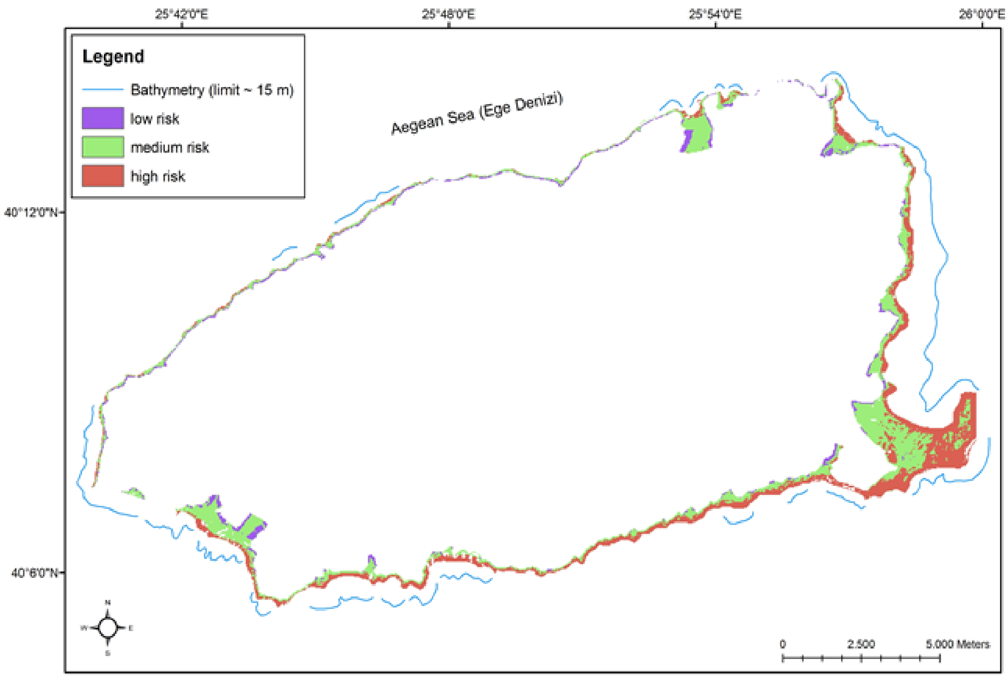

Figure 6: Risk areas of Imvros combined with bathymetry

Combining all this information, it seems that the high risk regions in case of a tsunami wave phenomenon are those at the south and specifically the south-east part of the island. This happens due to the fact that they both have small slopes and low altitudes. Furthermore, north-east, north, south-east and southwest parts of the island belong to medium risk regions.

Concerning the low risk regions, they are those at the southwest and the northeast part of Imvros. This can be explained by the north part of the Anatolian fault, which creates large slopes and high altitudes.

To sum up, Fig. 7 is the final map, which presents the tsunami risk assessment on Imvros island. Moreover, the areas according to their classification, the bathymetry and the villages of Imvros are depicted. As it is shown, most of the inhabited areas will not be affected in case of a tsunami wave. However, Kastro (Kaleköy) and Yeni Bademli situated in the northeastern part of the island seem to be at high risk and medium risk respectively. Uğurlu and Şirinköy both situated in the south-west part of the island as well as for Eşelek, which is located in the south-east part of Imvros, are close to high or medium risk areas. Despite the fact that they are not exposed to risk, they should draw equal attention due to their location.

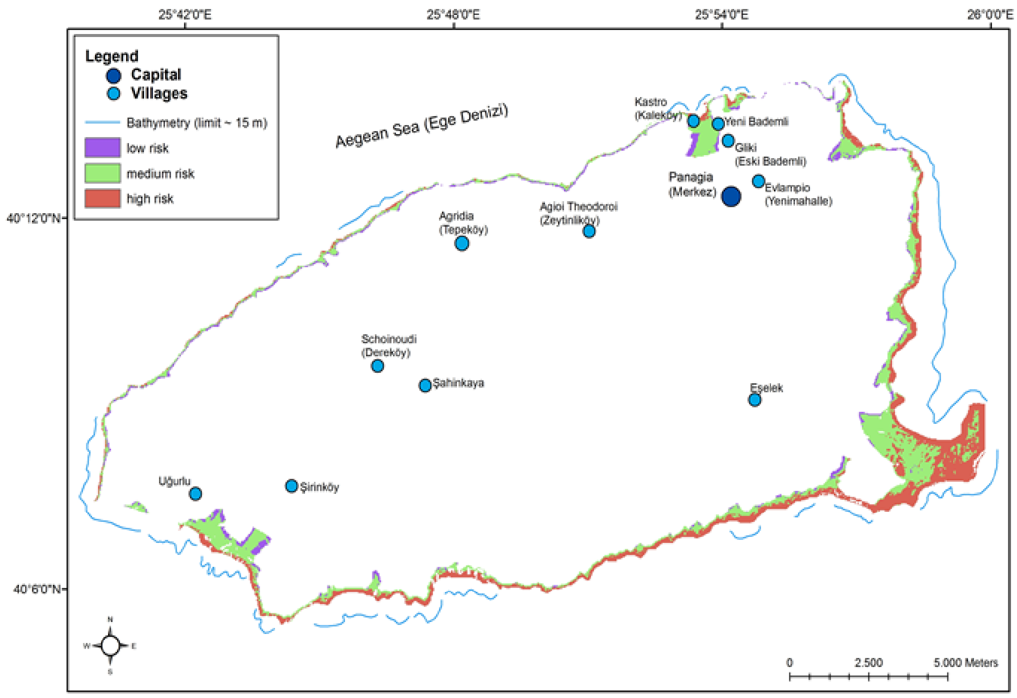

Figure 7: Final map of Imvros' areas and villages at risk of tsunami waves

Conclusions

In conclusion, after combining the remote sensing data and the DEM information, the final map was created presenting the areas of Imvros which are at risk caused by tsunami waves. In that way, it was proved that the combination of both techniques provides more clarified results, especially when it concerns issues of risk assessment. Locating the areas at risk can be used to make an effective disaster management plan to confront emergency situations.

The vulnerability of a place to a disaster depends on its exposure, resistance and resilience. Thus, the appropriate measures should be taken so that these factors are treated accordingly; exposure should be decreased while resistance and resilience should be increased.

Finally, raising awareness of the inhabitants about the possible risks as well as training them on how to cope with such emergency situations is of vital importance.

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