AN ON-LINE FLOOD DATABASE FOR GREECE SUPPORTED BY EARTH OBSERVATION DATA AND GIS

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ABSTRACT

Flooding, a result of both natural and anthropogenic factors, poses serious risks for life, properties and infrastructure. On global scale, with respect to the direct or indirect impact of natural disasters on millions of people per year, floods are ranked as number one catastrophe. In Greece, despite the plethora of major and catastrophic events in the country during the past decades, floods had not been adequately studied. Furthermore, although Earth Observation (EO) data and Geographic Information Systems (GIS) provide a secure and economic way of delineating, monitoring and ultimately managing flood events, they have been hardly used in relevant studies in Greece. The main objectives of the present study were the production of an online flood database for Greece, the use of EO and GIS techniques for flood mapping and the provision of freely available geospatial data. EO data used mainly included Synthetic Aperture Radar (SAR) (e.g. ENVISAT/ASAR, ERS) and medium to high resolution optical satellite imagery (e.g. Landsat, SPOT) for delineating flooded areas and producing flood and flood-risk maps. The results of the investigation are publically available over the internet through the project's website, with potential for further updates and expansion. Overall, it is envisaged that the data provided through this project, shall serve as a basis for flood disaster management in the future, both during as well as in the pre- and post-crisis phases.

Keywords: Greece, floods, database, GIS, Earth observation, mapping

1. INTRODUCTION

Flooding, a result of both natural and anthropogenic factors, poses serious risks for life, properties and infrastructure. On global scale, with respect to the direct or indirect impact of natural disasters on millions of people per year, floods are ranked as number one catastrophe (Bell, 1999).

During the last decades, the escalating frequency of flood events around the world, together with the evidences and warnings about global climatic change, rendered this phenomenon a very serious issue. Efficient flood management is thereafter a fundamental necessity, in order to minimize the adverse consequences, in terms of human safety and damage to property.

To this end, European Union (EU) Member States are conducting a preliminary flood risk assessment and subsequently developing flood hazard (i.e. showing flood probability) and flood risk maps (i.e. related to the potential adverse consequences of a flood), whereas by 2015 flood risk management plans will be drawn for high risk zones (Directive 2007/60/EC). This three stage process applies to all kinds of floods (river, lakes, flash floods, urban floods, coastal floods, including storm surges and tsunamis) on all of the EU territory and will need to be reviewed every six years (European Union 2007).

According to the definitions given by the U.S. National Oceanic and Atmospheric Administration (NOAA), floods are overflows of water onto normally dry land that may last days or weeks. They are caused by rising water in an existing waterway, such as a river, stream, or drainage ditch, with the ponding of water occurring at or near the point where the rain fell. A flash flood is caused by heavy or excessive rainfall in a short period of time, generally less than six hours. Flash floods are usually characterized by raging torrents after heavy rains that rip through river beds, urban streets, or mountain canyons sweeping everything before them. They can occur within minutes or a few hours of excessive rainfall. They can also occur even if no rain has fallen, for instance after a levee or dam has failed, or after a sudden release of water by a debris or ice jam. Depending also on the geological and geomorphological regime, the water can remain in the affected area for several days or, more commonly, run off within just a few hours.

Earth Observation (EO) data, along with Remote Sensing and Geographical Information Systems (GIS) techniques, provide safe and cost-effective tools for monitoring, mapping and assessing the evolution and damages caused by flood events. Initiatives, dedicated centres, institutions and services, such as (i) the International Charter (http://www.disasterscharter.org), (ii) the Centre for Satellite Based Crisis Information (ZKI, http://www.zki.dlr.de/), (iii) Services and Applications For Emergency Response (Safer, http://safer.emergencyresponse.eu) and (iv) SERTIT (Service Régional de Traitement d'Image et de Télédétection, http://sertit.u-strasbg.fr/), use satellite images for Earth monitoring, offering substantial support to major flood events and natural disasters in general, around the world.

In Greece, despite the plethora of major and catastrophic events in the country during the past decades, floods have not been adequately studied. In particular, although EO data and GIS provide a secure and economic way of delineating, monitoring and ultimately managing flood events, they have been hardly used in relevant studies in Greece. This has been mainly attributed to the fact that most floods occurring on Greek territory are relatively (with respect to the global average) small scale flash-floods, meaning that EO data of high spatial and temporal resolution are required, in order to “capture” the disaster. Regrettably, this kind of data is generally not available and hence it is considered as highly unlikely for flash-floods to be recorded with appropriate satellite acquisitions. However, in early 2011, a project focusing on the creation of a flood database for Greece and its combined use with EO data and GIS was carried out (Mouratidis 2011, Mouratidis et al. 2011, Mouratidis et al. 2012). One year later, Diakakis et al. (2012) published another historical flood catalogue together with a statistical and spatial analysis of flood events, while the Ministry of Environment Energy & Climate Change of Greece published a detailed report on the assessment and management of flood risks in Greece, in accordance to the European Union Directive (YPEKA, 2012).

The main objectives of the present study were the production of an online flood database for Greece, the use of EO techniques and GIS for flood mapping and the provision of freely available geospatial data. EO data used mainly included: a) Synthetic Aperture Radar (SAR) satellite imagery (ERS , ENVISAT/ASAR, ALOS/PALSAR) for delineating flooded areas by change detection techniques and b) high resolution optical satellite images (e.g. Landsat, SPOT, IKONOS, Quickbird) are related classification techniques, mainly for the creation of flood risk maps and, where feasible, also for the delineation of flooded areas.

2. DATA AND METHODOLOGY

2.1 Gathering information on floods in Greece

The first step involved a thorough investigation of all available sources (scientific papers, reports, news, articles and other internet sources) for the identification of past flood occurrences in Greece. A few incidents covered by initiatives such as the International Charter and/or those which have been already addressed with remote sensing techniques were excluded from further study, but were taken into account for statistical reasons.

In 2011, based on the collected data, as well as on ancillary information obtained or produced in the course of the study (e.g. coordinates, internet links referring to each particular flood event, photos, maps, etc.), a flood database was created, including also reference/source of information for each entry. In 2013, the database was further updated, also using the report on the assessment and management of flood risks in Greece, published by the Ministry of Environment Energy & Climate Change of Greece (YPEKA, 2012). Overall, the database currently contains more than 1800 flood events.

Subsequently, the database was imported in a GIS and converted into a vector geospatial information layer in a shapefile format (*.shp). Additional vector data (prefectures, settlements, watersheds, lakes, rivers, etc.) were either obtained from the Greek open data repository (http://geodata.gov.gr) or were digitalized from the very beginning^. Data were also acquired from the Hellenic Military Geographical Service (GYS) topographical maps (scale 1:50.000), as well as from the Hellenic Institute of Geology and Mineral Exploration (IGME) geological maps (scales 1:50.000 and 1:500.000).

2.2 Creation of flood maps based on the created geodatabase

By recording and describing the most significant floods of the past, the most significant negative impacts of similar events in the future may be predicted (European Union, 2007). The conversion of the database information into a map can provide useful information to this end. In this context, the database created in a GIS offers the possibility of creating different thematic maps of Greece (e.g. concerning the number of floods, their seasonal or monthly distribution etc.), depending on the end-user needs (see e.g. Fig. 6-8).

2.3 Selection of case studies and data

Apart from the information collected for the whole country, particular case studies were selected for further investigation. These were mainly chosen on the basis of the availability of satellite data, but also the attributes of each area (geography, geomorphology etc.) and the characteristics of the reported flood events. Emphasis was given to the availability of Synthetic Aperture Radar (SAR) data with acquisition dates coinciding with those of the floods, due to the inherent advantages of SAR imaging (under any weather conditions, during day and night).

Some indicative examples of flood events selected for further study are given henceforth.

2.3.1 Case study 1 (Thessaloniki, 2006)

This case study concerns a severe flash-flood in the prefectures of Thessaloniki and Halkidiki, in October 2006 (Fig. 1). The first available SAR data were acquired about 48 hours after the peak of the flood, but the morphology of the terrain favoured the concentration of the remaining water in an extended area, making possible for some inundated areas in the Prefecture of Thessaloniki to be well delineated, using change detection techniques (Nikolaidou 2009, Nikolaidou et al. 2010).

For the needs of this case study, the following satellite data were acquired:

- Three SAR images (Envisat/ASAR, IMG mode), with spatial resolution of approximately 30m (source: ESA)
- One multispectral image (Landsat-7/ETM+), with 15m spatial resolution (source: Global Land Cover Facility, http://glcf.umiacs.umd.edu)

Figure 1. Indicative catastrophes caused by the flash-flood of October 8th, 2006, in the prefectures of Thessaloniki and Halkidiki (North Greece).

2.3.2 Case study 2 (Thessaloniki, 2011)

This case study concerns another flash-flood event that occurred in the same area as per the first case study. In particular, on September 21st, 2011, the area around Lake Volvi experienced severe floods causing numerous damages. Landsat-5/TM images acquired two days after the peak of the flood, as well as medium resolution Envisat/ASAR satellite images acquired four days after the event, were used to "capture" the water still present in the area (Fig. 2).

For the needs of this study, the following data were acquired:

- Two satellite radar images (Envisat/ASAR, wide swath mode/WSM) with 150m spatial resolution, (source: ESA).
- Two multispectral satellite images Landsat-5/TM, with 30m spatial resolution (source: NASA, ESA)

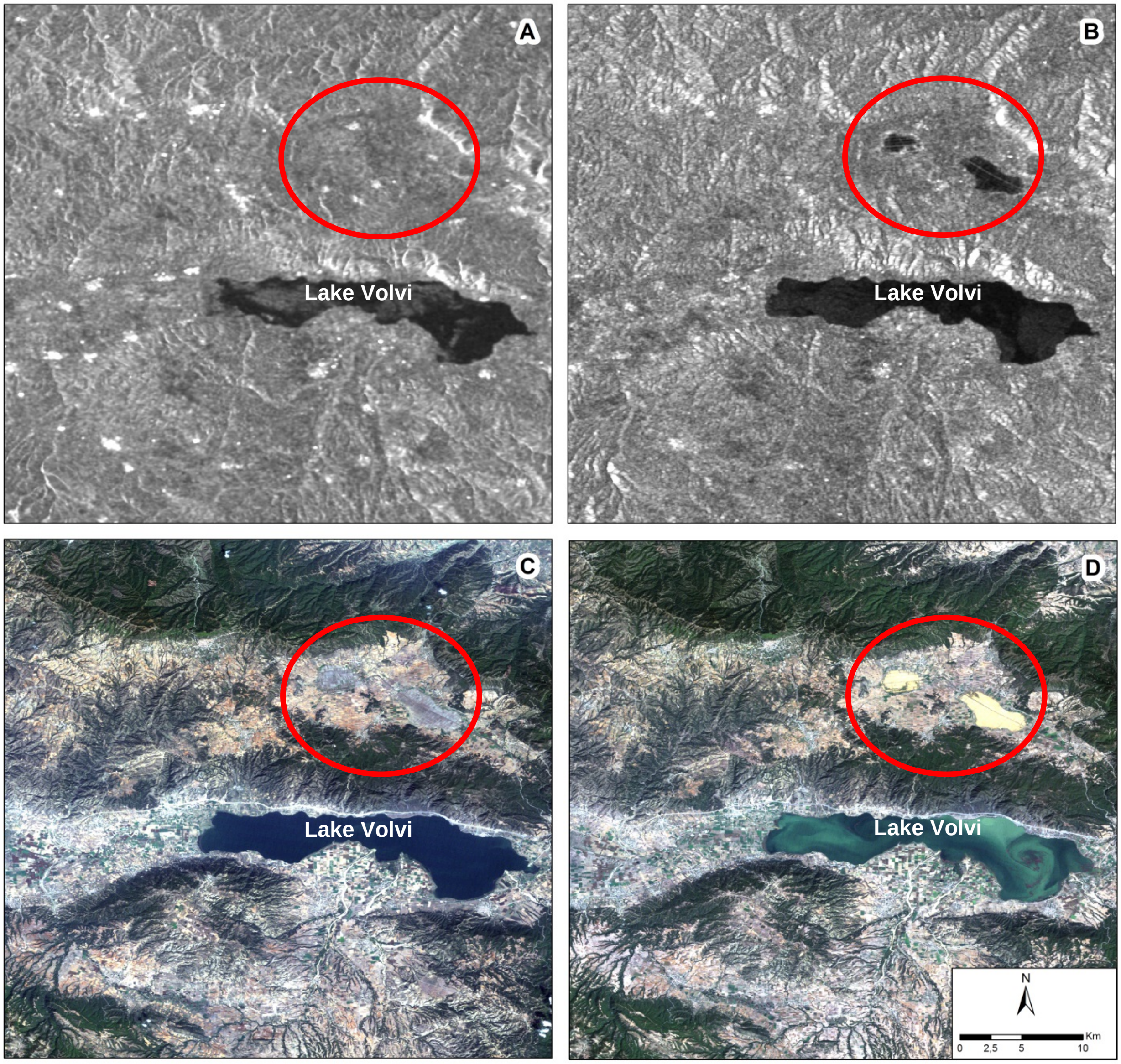

Figure 2. Characteristic example of imaging the effects of the September 2011 flash-flood near Lake Volvi, using multi-sensor Earth observation data. Top: Envisat/ASAR WSM image of the study area before (A) and after (B) the flood event. Bottom: Landsat-5/TM true colour composite image (R/G/B=3/2/1), before (C) and after (D) the flood. Notice the differences between A-B and C-D inside the red circles.

2.3.3 Case study 3 (Thrace, 2007)

The third case study concerns the major flood events occurred in the broader area of Lake Vistonida, in the Prefectures of Xanthi and Rodopi, Thrace (NE Greece), during November-December 2007 (Fig. 3).

For the needs of this study the following data were acquired:

- Eight satellite radar images (Envisat/ASAR, IMG mode) (source: ESA)
- Two multispectral (Landsat-7/ETM+) satellite images with 15m spatial resolution (source: Global Land Cover Facility, http://glcf.umiacs.umd.edu)
- Very high spatial resolution images (0.2m), derived from aerial photos (source: KTIMATOLOGIO A.E., http://gis.ktimanet.gr/wms/ktbasemap)
- ASTER-GDEM elevation data (http://www.gdem.aster.ersdac.or.jp)

- SRTM elevation data (http://srtm.csi.cgiar.org)
- Corine Land Cover (CLC) data (http://www.eea.europa.eu/data-and-maps/data/corine-land-cover-2006-raster-2)

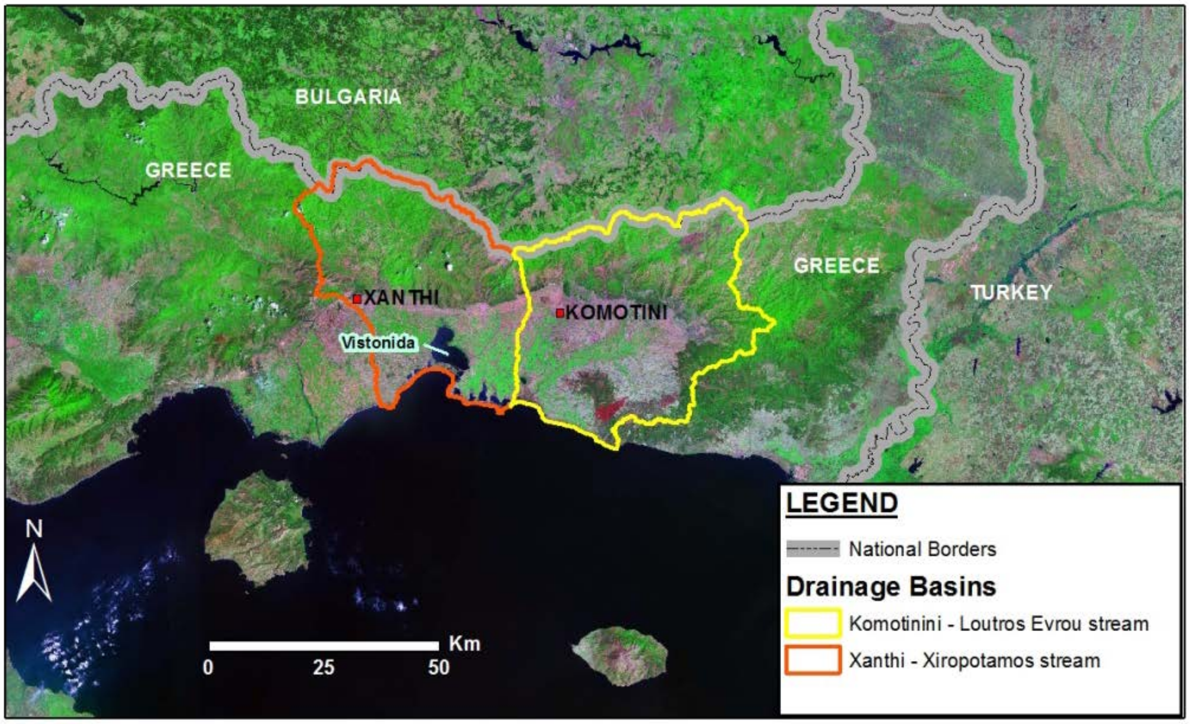

Figure 3. The study area around Lake Vistonida, is hydrologically defined by the watersheds of the Prefectures of Xanthi and Rodopi - the latter also including a small part of the Prefecture of Evros to the East).

2.3.4 Case study 4 (Thessaly, 2003)

In early 2003, the region of Thessaly in Central Greece experienced severe floods, which lasted for about 12 days (27 January - 7 February 2003). For the depiction of inundated areas a number of SAR images before, during and after the event were used.

In particular, for the needs of this study the following data were acquired:

- Five satellite radar images (ERS-2, IMG mode), of which three images under dry conditions and two images during the flood occurrence (source: ESA)
- Two satellite radar images (ENVISAT ASAR, IMG mode), of which one image under dry conditions and one image during the flood event (source: ESA)

2.4 Image processing

2.4.1 SAR image processing

Contrary to optical sensors, radar systems with their all-weather, day and night applicability make SAR data more appropriate for monitoring flood events (e.g. Badji and Dautrebande 1997; Yésou et al. 2000; Sarti 2004; Li et al. 2005), as the latter are normally associated with bad meteorological conditions and a high percentage of cloud coverage.

During the pre-processing of SAR images using NEST (Next ESA SAR Toolbox) and Envi™, the following steps took place:

1. Image calibration, by converting pixel values from digital number (DN) into backscattering coefficient (σ^0) following Rosich & Meadows (2004), so that the value of the same pixel in each image, as well as the different pixel values in the same image, would become comparable.
2. Co-registration of all SAR images in order to ensure geographical and geometrical overlap.
3. Optional orthorectification of the co-registered images using a Digital Elevation Model (DEM) (e.g. SRTM).

Subsequently, the main SAR image processing for the detection and mapping of flooded regions included:

1. The production of the average "dry" image, by calculating the mean values for each pixel using all the available "dry" images.
2. The implementation of a Change Detection Analysis (CDA) approach. CDA encompasses a broad range of methods used to identify, describe and quantify differences between images of the same scene at different times. In this study, the False Colour Composition (FCC) was adopted and applied. Typically, two images were used; one before (mean of the dry images-where more than one of them were available) and one during/after the flood. In each case study, the flood image was assigned to both the red (R) and the green (G) channels while the ''dry'' image was assigned to the blue (B) channel, in order to create an RGB false colour composite.

With respect to the interpretation of these RGB image products, unchanged or almost unchanged features appear in variations of grey, whereas any change in the scene (denoting change in backscattering) from one acquisition to the other appears in colour, so that:

1. Regions with significantly lower backscatter in the flood image appear in blue, indicating possible flooded areas.
2. Regions with significantly higher backscatter in the flood image appear in yellow (yellowish), indicating a possible increase in soil moisture.
3. Areas with little or no change are depicted as grey, the result thus being approximately equivalent with that of each image independently (Fig. 8-11).

2.4.2 Optical image processing

The first step of the optical imagery processing was the merging of the multispectral with the respective panchromatic image, in order to combine in one image the best spectral and the spatial features of the two images. In particular, the implementation of Principal Components Analysis on the multispectral and panchromatic ETM+ images resulted to a new image with the spatial resolution (15m) of the panchromatic and the spectral resolution (6 bands) of the multispectral image (Chavez et al. 1991; Phol and Van Genderen 1998; Tsakiri et al. 2002). A series of indices, i.e. NDVI, NDWI and NDBI, was then applied to the fused image and the output images with information concerning the vegetation, water and infrastructure respectively, improved considerably the classification result.

The false colour composites of the optical images were a very useful tool in order to detect the flooded areas by a visual inspection. By combining different bands of the multispectral images in a wide variety of combinations, different image visualizations can be obtained, highlighting each time the features of interest. For our case studies, the bands combination 7,4,3 was the most suitable to point out the water bodies (e.g. Fig. 12).

The land cover types of the study area were essential for the estimation of flood vulnerability (Fig. 13 and 14) as well as for the delineation of flood events, where optical images were available close to the peak of inundation (e.g. Fig. 12). The image classification was based on Object-Based Image Analysis (OBIA). In that case the analysis is done on groups of pixels (objects) with certain spectral, geometric and contextual attributes rather than on single pixels, facilitating in such a way the handling of remote sensing image information (Castilla and Hay, 2006). The OBIA classification was accomplished in two main steps: the image segmentation, i.e. pixels grouping into homogenous areas for the formation of objects, and fuzzy classification, i.e. objects classification based on the fuzzy logic.

For the image segmentation, the suitable scale and homogeneity parameters should be set, so that the resulted segments represent meaningful objects/land cover classes. The algorithm begins considering each pixel as one object and after several iterations it merges the small objects into larger ones. The size of the final objects formed is proportional to the scale parameter defined (Baatz and Schäpe, 2000). In our case study, the Corine land cover classes were the basis for the creation of the first segmentation level. For the second segmentation level, the weight for each spectral band was the same, due to the significant spectral variation of land cover types in all the bands. After a trial-and-error process, the optimal scale parameter value was defined as equal to 20. The second object level was the sublevel of the first (Corine level), meaning that the objects' boundaries were limited by the boundaries of Corine polygons. In this way, the detection of land cover changes and Corine's update were facilitated.

The updated Corine land cover classes were resulted from the integration of remote sensing images, aerial photos and ground truth validation. Therefore, the classification of the image was not possible to be done automatically according to Corine 2000 classes as they are described at its third level. Thus, the classes of interest in the Object-Based Analysis were mainly from the first and the second Corine's level. Each class was described based on defined rules relevant to the shape, spectral and geometric characteristics of the image objects.

The vegetation and water areas were firstly classified based on the information of the corresponding indices, i.e. NDVI and NDWI. The height information of the DEM assisted at the separation of the shadowed areas from water bodies. The Ratio Blue, the Brightness value and the NDBI were used for the classification of the built areas. The geometric feature Length/Width and NDBI were used for the delineation of the road network. The classified image combined with the visual interpretation of high resolution Google Earth™ images led to the detection of further/additional changes in the area. In particular, Corine's classes were the basis and the change polygons contributed to Corine's update (Figure 4).

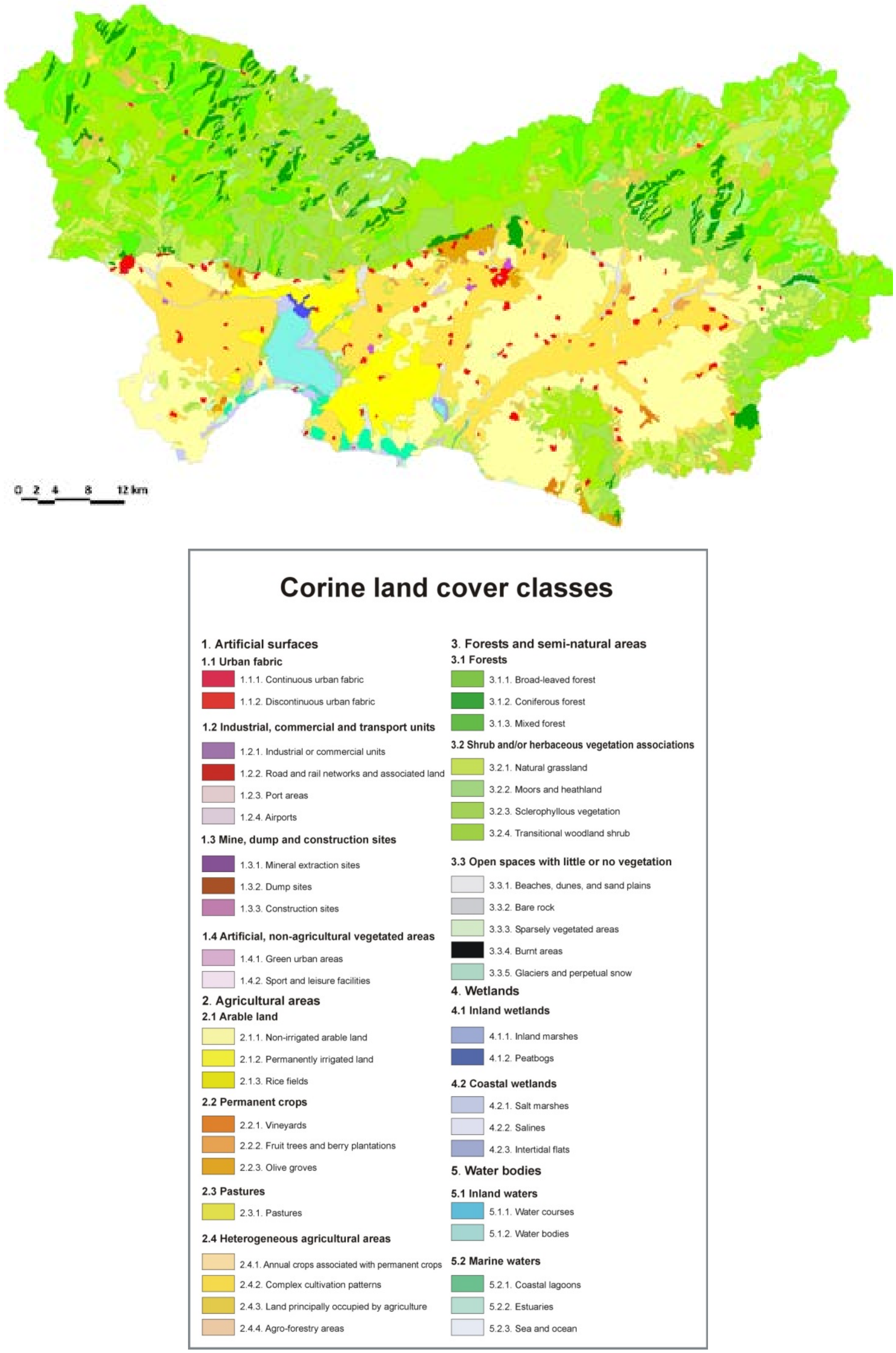

Figure 4. The land cover classes produced by using the OBIA analysis of Landsat/ETM+ image of July 2007 (case study 2). The terminology is in accordance to European Program Corine 2000.

2.5 Spatial data processing in a GIS environment

After the identification of the study areas and the collection of related data, critical ancillary and secondary information was produced for further process in a GIS (ArcGIS™). This information concerns mainly the geomorphological background and the hydrological attributes of the study areas and is based on the available DEM from SRTM data, as well as other information (geology, land cover, vegetation index etc.).

Thus, information such as slope, flow direction, flow accumulation, as well as other secondary information such as topographic wetness index, rock permeability, vegetation and surface roughness, were some of the important output of the GIS analysis. These products were further processed and used for the production of susceptibility and flood risk maps.

In the susceptibility map, the areas are classified according to the probability of flooding, based on their characteristics (geomorphological, geological etc.). The risk map on the other hand represents the potential negative impacts of floods that may occur in the area, mainly based on the population and the type of economic activity that is threatened.

More specifically, for the flood susceptibility map (e.g. Fig. 13), the following parameters were used: topographical wetness index, permeability of the rocks, surface roughness and vegetation. The Analytical Hierarchy Process (Saaty, 1980) was used for prioritising the importance of the parameters. Respectively, for the creation of the flood risk map (e.g. Fig. 14), the land cover classes as well as the population that may become influenced by a potential flood event, were taken into consideration. The methodology for the particular study was adapted from Nikolaidou (2009).

3. RESULTS

The results of the study can be categorized in four groups:

a. Flood maps over Greek territory based on the contents of the created database (Fig. 5-7).

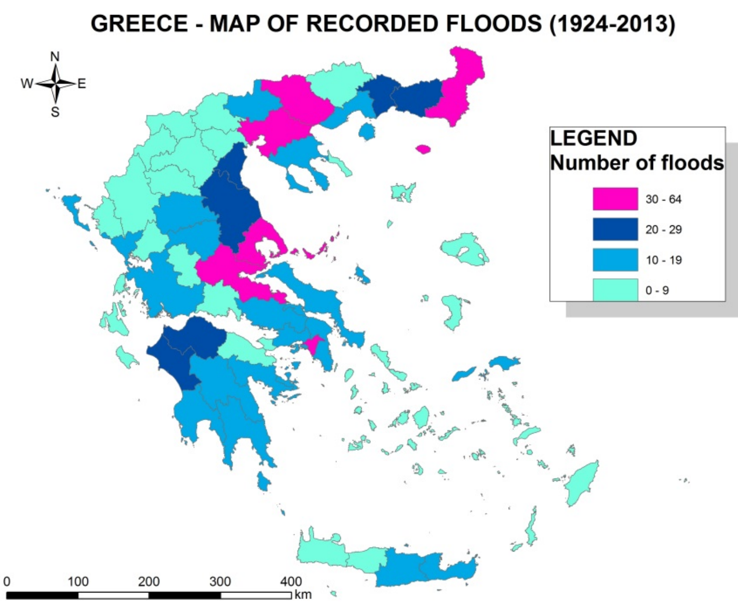

Figure 5. Flood map of Greece based on the collected information.

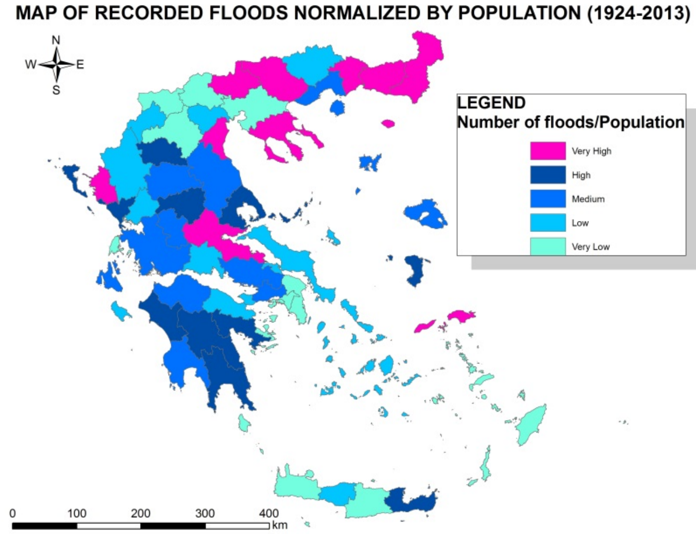

Figure 6. Flood map of Greece in proportion to the population.

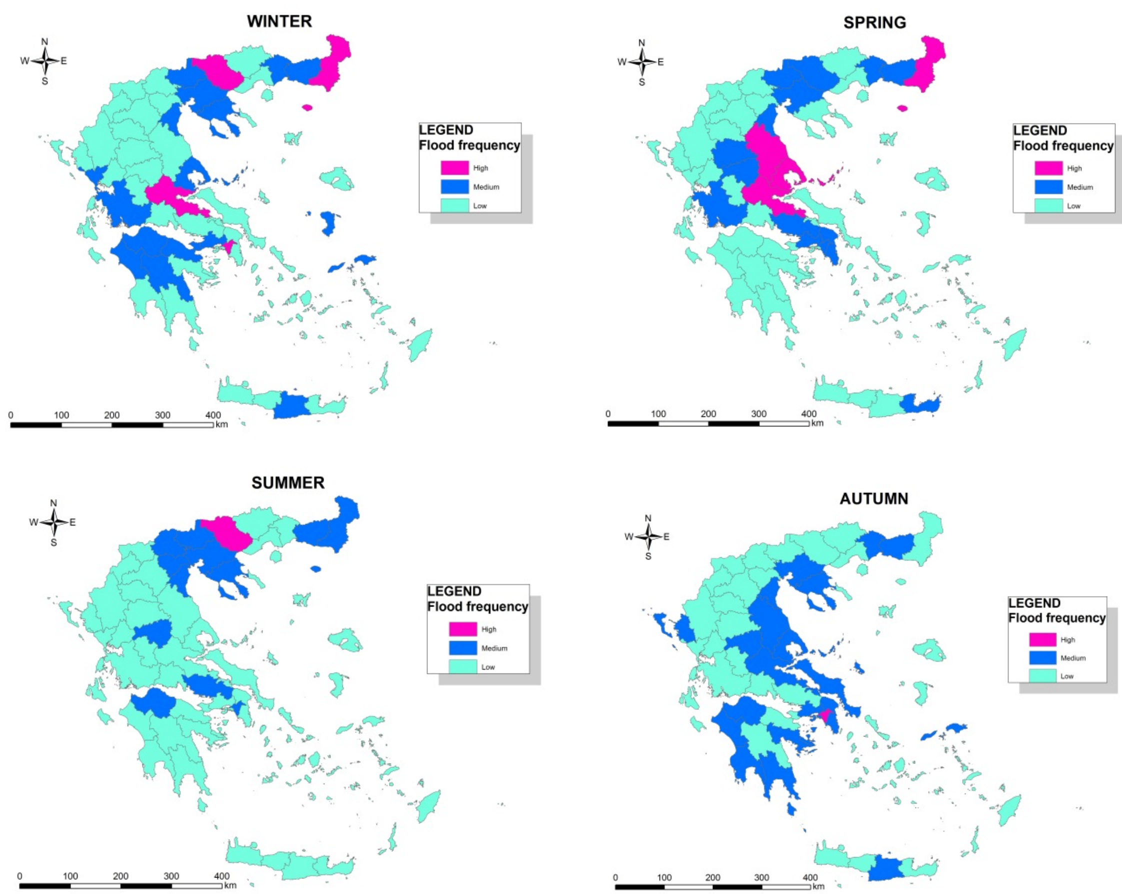

Figure 7. Seasonal flood frequency map of Greece (1924-2013).

b. Flood maps for selected case studies, with the aid of EO data and image processing techniques (Fig. 8-12).

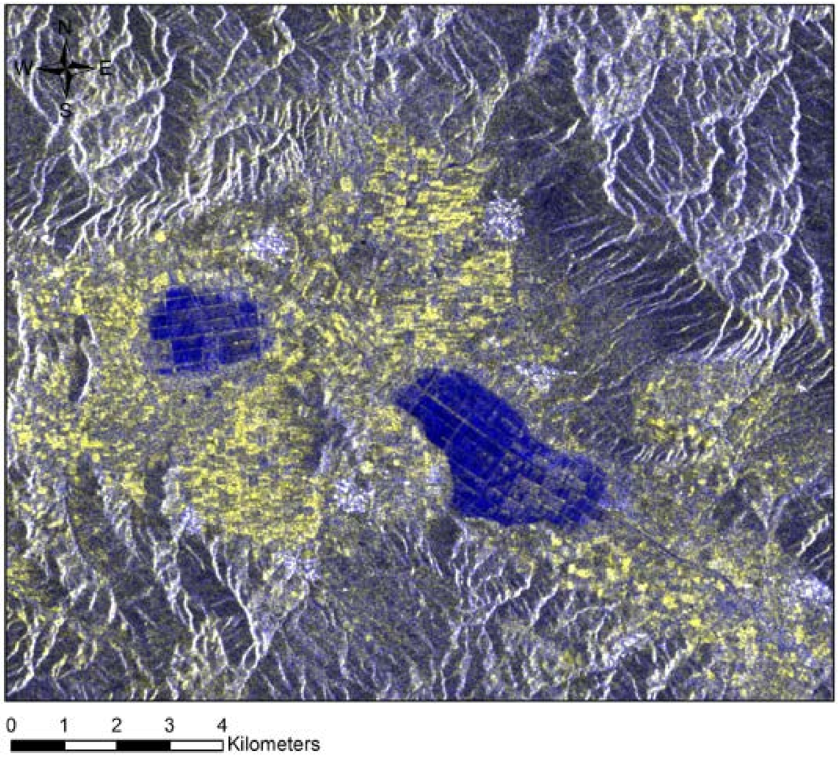

Figure 8. Delineation of flooded areas by change detection techniques, in the post-crisis period (two days after the flash-flood) in the prefecture of Thessaloniki (case study 1), using an ENVISAT/ASAR IMG mode false colour composite: R=G=10/10/2006 (flood image), B=(5/10/2004 + 25/10/2005)/2 (average of two images during the same season, but under dry conditions). Blue colour depicts flooded regions, while yellow colour depicts wet soil.

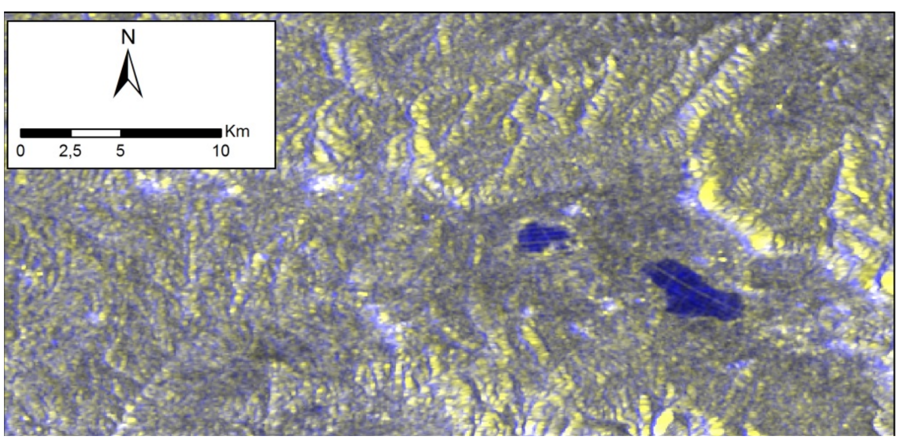

Figure 9. Delineation of flooded areas in the prefecture of Thessaloniki in 2011 (case study 2), during the post-crisis phase (four days after the flash-flood), using an RGB false colour composite of orthorectified medium spatial resolution (150m) ASAR Wide Swath Mode data. R=G=25/09/2011 (flood image), B=25/09/2011 (dry conditions). Blue colour depicts flooded regions, while yellow colour depicts wet soil.

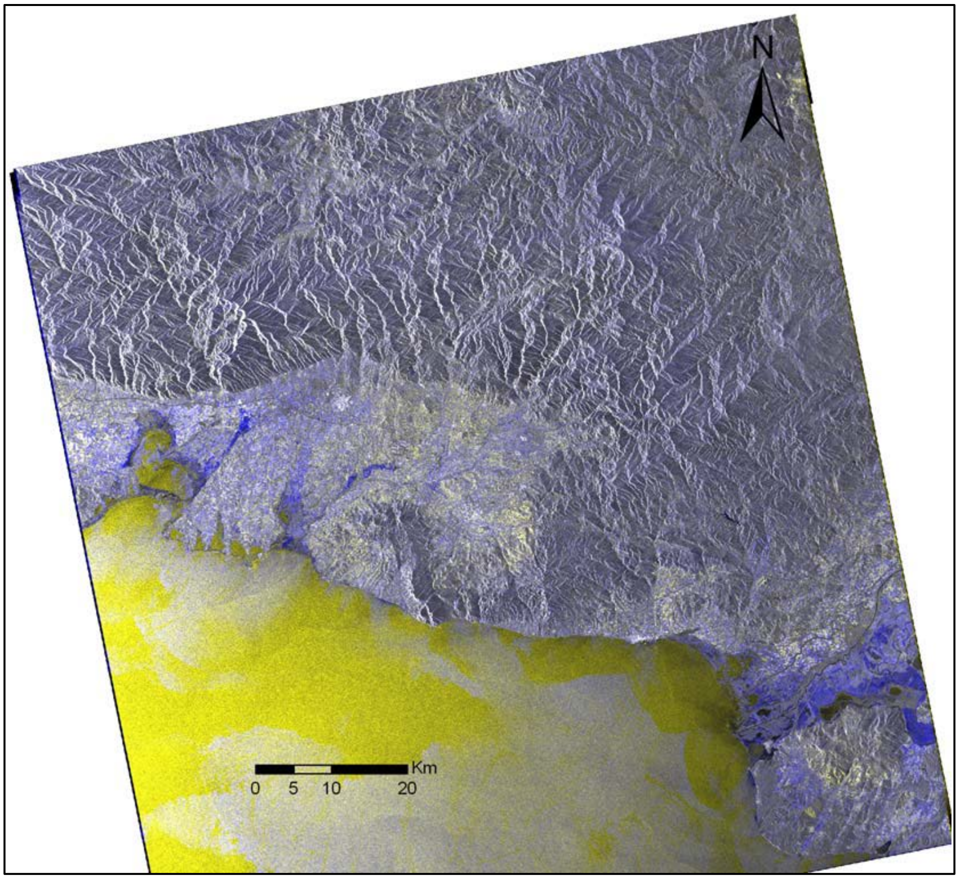

Figure 10: Overview of flooded areas in the prefecture of Thrace in 2007 (case study 3), during the crisis period, by change detection techniques, using an ENVISAT/ASAR false colour composite: R=G=18/11/2007 (flood image), B= average of seven images taken under dry conditions. Blue colour depicts flooded regions while yellow colour depicts wet soil.

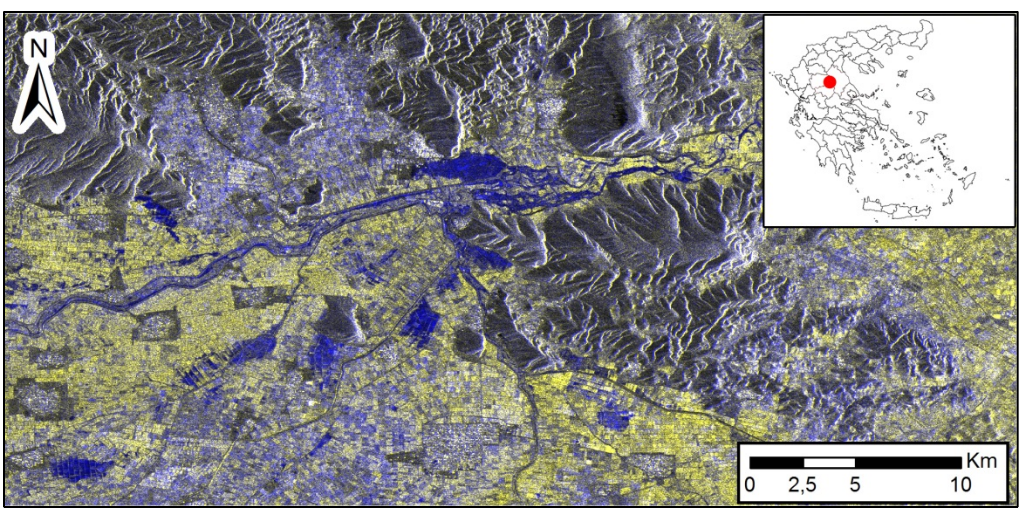

Figure 11: Floods along Pinios river, near Piniada, Farkadona and surrounding areas in Thessaly, in 2003 (case study 4), captured by ERS-2 during the crisis phase. SAR RGB false colour composite: R=G=02/02/2003 (flood image), B= 06/02/2005 (dry conditions). Blue colour depicts flooded regions while yellow colour depicts wet soil.

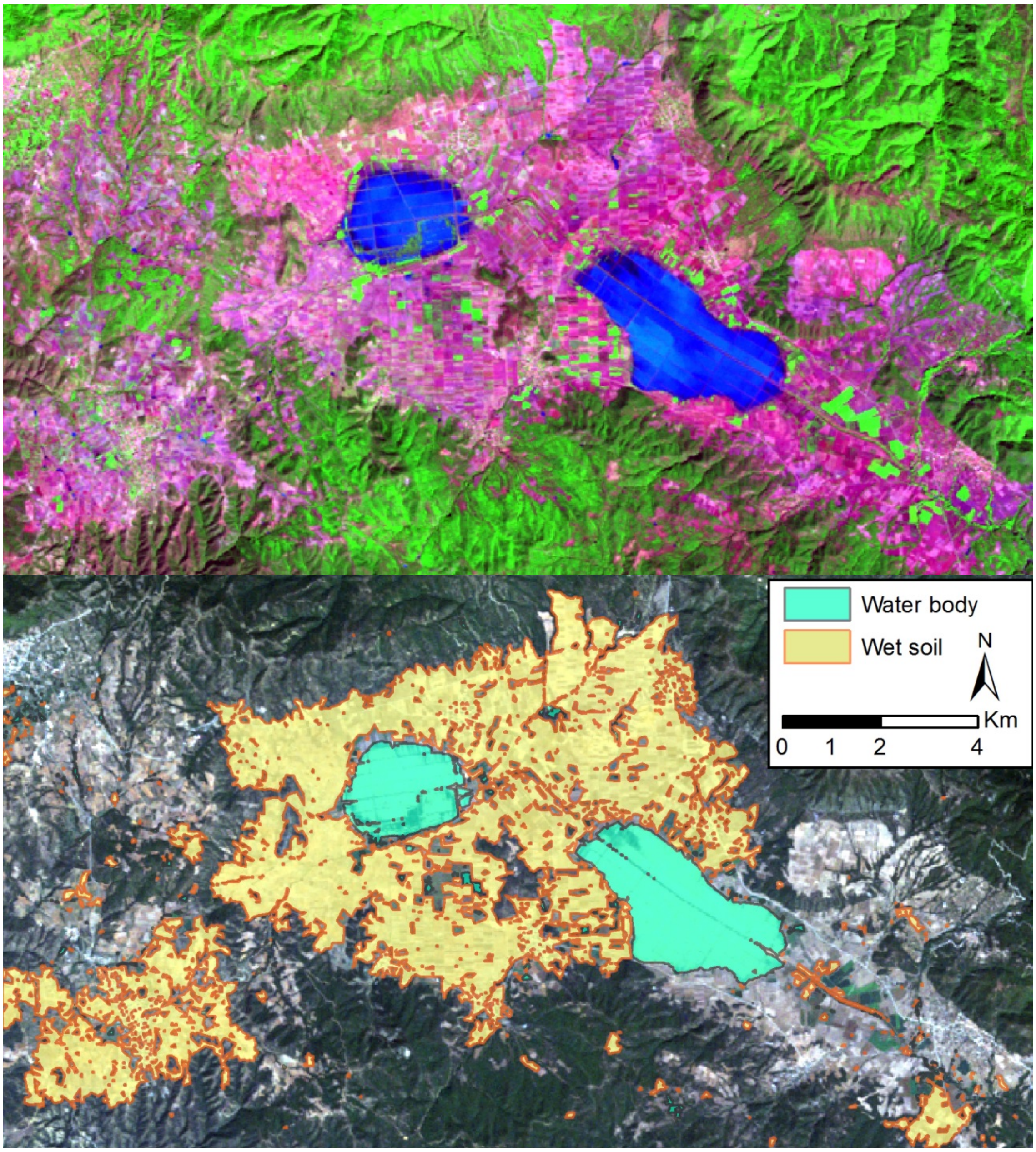

Figure 12: Results from the 2011 floods in Thessaloniki (case study 2); Above: Landsat-5/TM image, R/G/B: 7/4/3, depicting the flooded areas in light blue colours. Below: Classified Landsat-5/TM image depicting water and wet soil classes.

c. Susceptibility and flood risk maps for selected case studies:

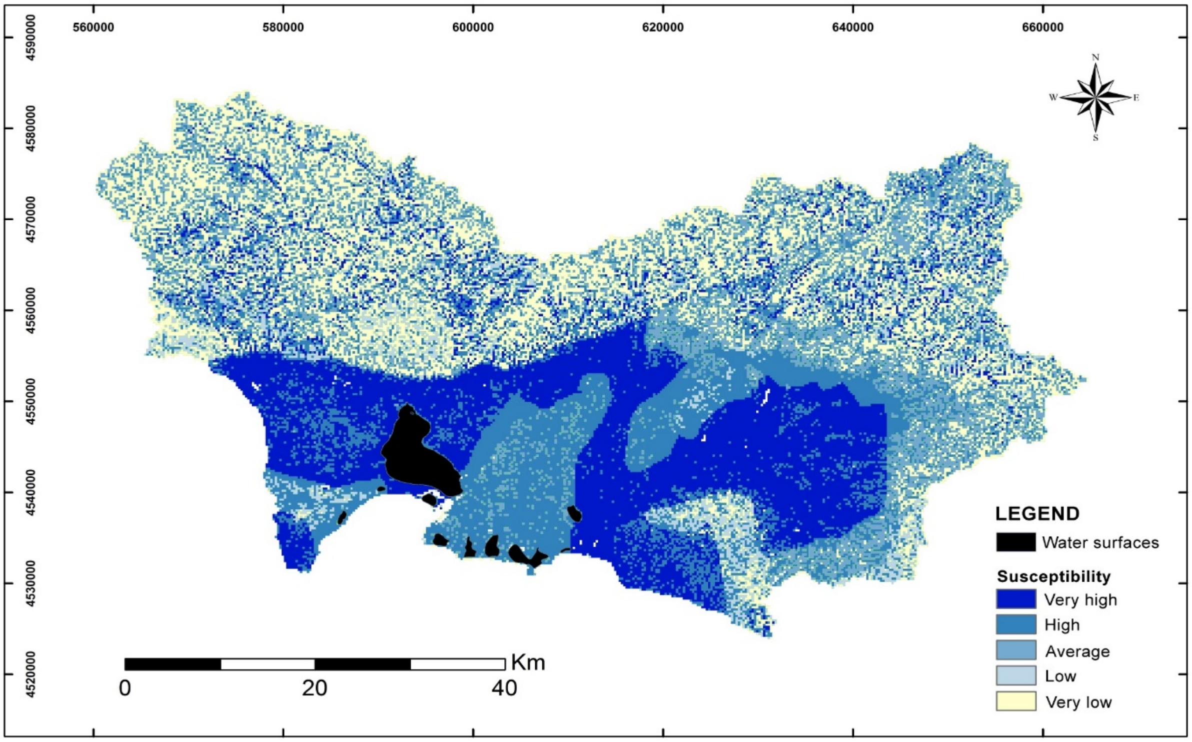

Figure 13. Flood susceptibility map from the area of Thrace, NE Greece (case study 3).

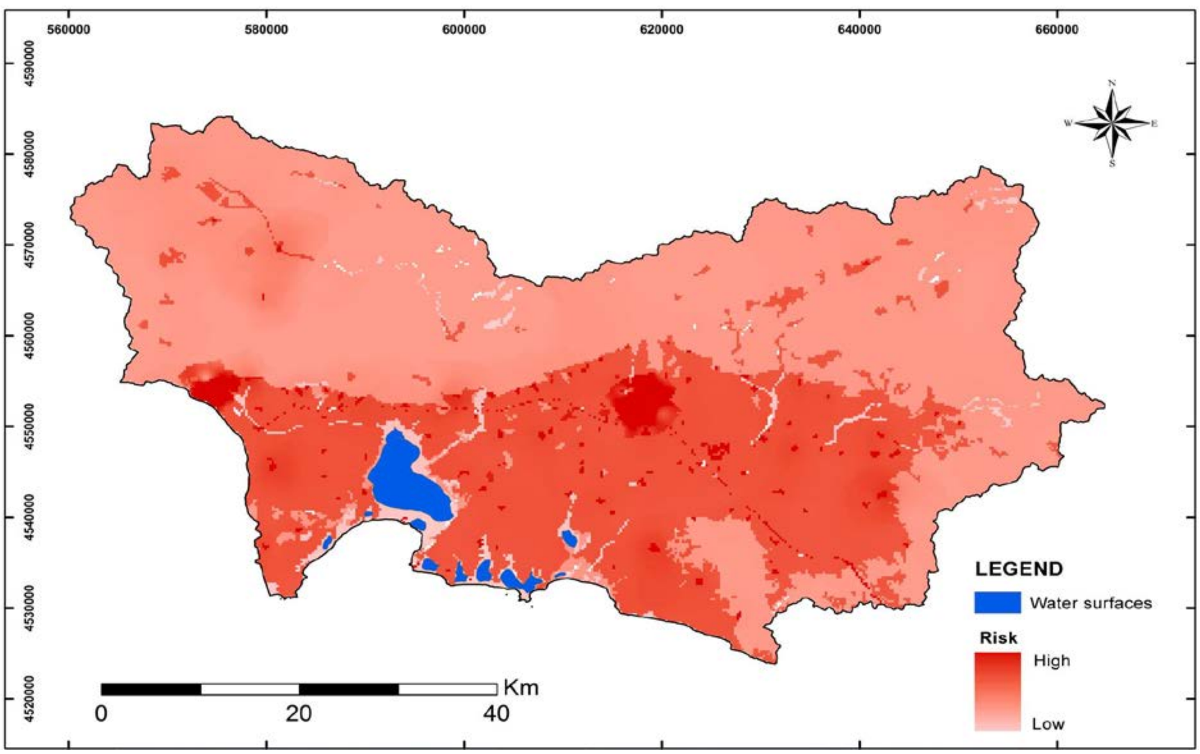

Figure 14. Flood risk map from the area of Thrace, NE Greece (case study 2).

d. Website dedicated to the project

The results of the investigation are publically available on the internet through the project's website (http://ceogis-floods.web.auth.gr), with potential for updating and expanding the collected information, thus contributing to the increase of available geospatial data and improvement of natural disaster management in Greece.

Users are able to retrieve statistical information from the database, produce different thematic maps over Greece with a GIS depending on their needs (e.g. concerning the number of floods, their seasonal or monthly distribution etc.) and access flood maps created with EO data, where available.

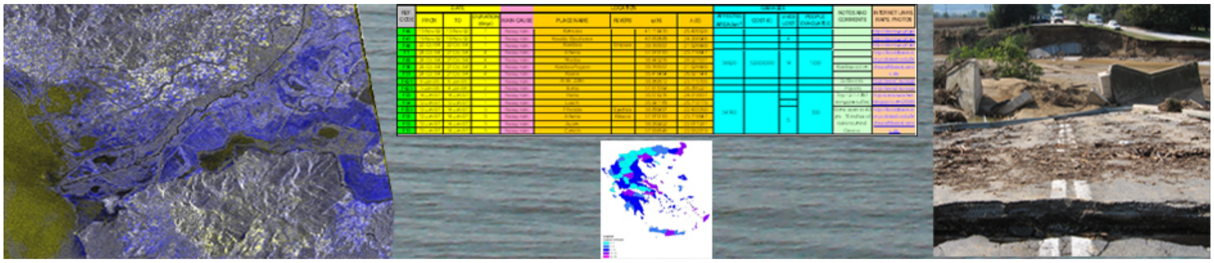

Figure 15. Snapshot from the flood database website (http://ceogis-floods.web.auth.gr)

4. CONCLUSIONS

Flood is a complicated phenomenon that is influenced by several different parameters (climate, topography, geology, geomorphology, hydrology, human interventions). A prerequisite for its efficient management is thus the presence of relevant geospatial information. The present study contributes towards this direction, with the creation of a GIS-compatible flood database for Greece, as well as flood case studies using Earth Observation (EO) data. All this information is readily available to anyone interested through a dedicated website.

This study has also initiated a deeper investigation on the performance of EO data, from which interesting conclusions have been drawn. The experience gained after 20 years of systematic EO with SAR data, has well demonstrated the efficiency of these active instruments in imaging and monitoring flood events at various scales. The main issue that has not yet been resolved is related to the increase of SAR observations to a frequency that would allow to record and ultimately to follow the evolution of random flash-flood phenomena (the majority of floods in Greece). Optical and infrared images are also very useful, usually for the estimation of flood-related catastrophes and more rarely, under favourable weather conditions, also for "capturing" the flood. Further details on the efficiency of EO data, in terms of temporal and spatial resolution, for managing flood events, as well as on the prospects of future EO missions are provided in Mouratidis & Sarti (2013).

Overall, it is envisaged that the data provided through this study and related website, including the database, the GIS layers and information derived from the exploitation of EO data, shall serve as a basis for flood disaster management in the future in Greece, both during as well as in the pre- and post-crisis phases.

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