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Machine Learning Techniques in Agricultural Flood Assessment and Monitoring Using Earth Observation and Hydromorphological Analysis †

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Abstract: Climate change could exacerbate floods on agricultural plains by increasing the frequency of extreme and adverse meteorological events. Flood extent maps could be a valuable source of information for agricultural land decision makers, risk management and emergency planning. We propose a method that combines various types of data and processing techniques in order to achieve accurate flood extent maps. The application aims to find the percentage of agricultural land that is covered by the floods through an automatic map estimation methodology based on the freely available Sentinel-2 (S2) satellite images and machine learning techniques.

Keywords: flood assessment; remote sensing; data processing; machine learning

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1. Introduction

Floods constitute one of the greatest threats to the property and safety of human communities. Flash floods are events occurring on a small spatial scale within a short time, under conditions of rapid production of surface runoff [1]. Climate change could provoke more frequent, intense and adverse meteorological phenomena resulting in flash floods [2]. In this work, we used remote sensing (RS) data that offer a synoptic and repeated view over the areas of study [3]. More specifically, we exploited image data from the Sentinel-2 (S2) mission of the European Space Agency (ESA) that offers advanced spatial, spectral resolution and revisit frequencies.

Two major flood events occurred during summer 2020 in Greece, Evia floods and Ianos Cyclone floods. Thus, the objective of the study was to propose an efficient methodology to combine multitemporal/multisource data and processing techniques in order to extract information on flooded areas and produce more accurate maps.

1.1. Pilot Areas

Three sites were selected as pilot study areas: the Evia Politika area, Kefalonia and Thessalia plains in Greece (Figures S1, S2a, S2b and Table 1).

Table 1. Study site region, location and surface water conditions.

Region	Location	Surface Water Conditions	Extent (km^2)
Evia	Politika	Flooded areas due to severe rainfall event—3 fatalities	84
Kefalonia	Municipality Pilareon	Flooding event—natural hazards	59
Thessalia	Enipeas Pinios rivers	Flooded cotton fields	76

1.2. Data

The data used are Sentinel-2 [4] multi-temporal satellite data, orthophotos DEM (Digital Elevation Model) and ancillary land cover/use maps. The acquisition dates of satellite images for the respective areas are:

- Evia: 29 July 2020, 3 August 2020, 13 August 2020, 28 August 2020;
- Kefalonia: 05 September 2020, 20 September 2020;
- Thessalia: 31 August 2020, 20 September 2020.

2. Methodology

Multitemporal remotely sensed data along with ancillary data such as cartographic maps and ground truth data were processed and analysed using image processing and GIS techniques.

Two methodologies were used for the analysis of data as shown in Figures S3 and S4. The hydrological analysis was based on Reuter, H.I. et al. [5], who suggested a comprehensive approach for DEM preprocessing and hydrological analysis. Initially, administrative boundaries of Greece were downloaded from GEODATA [6] to select the pilot project areas. The DEM of 5 m resolution of the Greek Cadastre was also used. Various image processing and vector GIS techniques were used in order to define watersheds and streams of the pilot areas.

Concerning the methodology for identifying changes to land cover due to flood events in the three pilot areas, two machine learning techniques were applied, namely Self Organising Maps (SOM) [7,8] and isodata clustering [9].

For the Evia Politika area and the Thessalia plain, both the spectral index and the Image-Unsupervised Classification Self-Organizing Map were used on the S2 images in order to discriminate all inherent land/flood cover classes of the satellite images.

Classification results were further analysed in GIS along with various maps and information acquired from ortho-photos. Land cover changes were identified by comparing land cover classification results based on satellite data before and after the flood event.

For the Kefalonia pilot area, the isodata unsupervised classification technique [9] was applied on S2 images. The areas classified as flooded areas were converted from raster to vector and combined with agricultural data from the Greek Payment Authority of Common Agricultural Policy to identify the land cover types affected by floods.

An area of 10 km^2 of Evia Politika basin had been affected by the flood event. The analysis provides satellite evidence that the disaster was caused by a large mass of rock/sediment/mud/debris dislodged from the slopes of/higher altitude areas of the basin. It started as erosion, slope instabilities and even landslides and then transformed into a mud and debris flow, causing destruction along its path. Fatalities were due to severe stream flow discharge from Polititika village towards the plain (Figure S5). The analysis of satellite images acquired before and after the event can be used to quickly determine and quantify key measures of the event, e.g., elevation differences and travel distances of erosion products/water. This study clearly shows that satellite data could play a significant role in future high mountain hazard assessments, in particular for evaluating large and relatively inaccessible areas. It is suggested that due to climate change, such events might be happening more frequently, and that the full potential of satellite data and knowledge should be utilized to identify possibly dangerous regions (Figure S6).

For the Thessalia plain, the flooded area was about 35% of the total area, while 15% of summer cultivations were affected. Changes caused by the flood event were mapped even at the field level, and this can be useful during field inspections. Various summer cultivations and mainly the ready-for-harvesting cotton fields were affected. Figure S2 images provided precise data for tracking the spatial footprint of surface water changes/flood waters at regional and local scales, i.e., a field of 23.7 ha (Figures S7 and S8).

2.1. Processing Techniques

Various image processing and vector GIS techniques were used for the analysis of both the satellite imagery and the collected map data and field information, such as Georeferencing, Resampling, Water/Vegetation spectral features, Colour Composites, Intensity Hue Saturation (HIS) Images, Identification of Areas of Interest (AOI), Automatic combination of the classification result of multi-temporal imagery, Automatic conversion of raster to vector data, Collection/Input/Coding, Storage/Management, Retrieval of various data and Processing/Analysis.

2.2. Visualization and Mapping

In terms of Image Classification-Unsupervised Classification techniques using neural networks, Artificial Neural Networks (ANNs) are generally quite effective for the classification of remotely sensed data. For classification purposes, the Self Organized ANN method was used on the Sentinel 2 images in order to discriminate all inherent land/flood cover classes of the satellite images using automated conversion of raster to vector data: the raster output of the classification and/or interpretation process was converted to vector data and these data were analyzed with the corresponding map data and observations acquired in the ortho-photos. Further processing and analysis was performed to derive information concerning land cover changes due to flooding in the pilot study areas (Table 2).

Table 2. Total areas calculated.

Land Use (LU)	Sum Area of LU (m^2)	LU Flooded (m^2)	LU Remain (m^2)	LU Remain (%)	LU Affected (LC) (%)	Total Percentage (%)
Forest	3,043,611	210,799	2,832,812	93%	7%	100%
Vineyard	229,634	18,240	211,394	92%	8%	100%
Vineyard Mix	181,007	27,853	153,154	85%	15%	100%
Arable	905,322	144,450	760,872	84%	16%	100%
Arable Mix	3,397,804	475,221	2,922,583	86%	14%	100%
Olive Growing	9,266,342	412,194	8,854,148	96%	4%	100%
Olive Growing Mix	3,354,840	384,223	2,970,617	89%	11%	100%

3. Conclusions

In summary the following areas were identified during the aforementioned process: flooding, erosion, abrasion surfaces, areas of sediment transport due to flood events, areas of slope instability, landslides and land cover types affected by the flood events.

In this work, we evaluated a methodology to automatically map flooded areas from multispectral Figure S2 images. The methodology enables the identification, delineation, and monitoring of floods and estimates of changes in surface land cover/use. The techniques involved in the developed methodology could be applied for the monitoring of aspects of floods and, eventually, could be used for the mitigation of their environmental, social and economic footprints. The methodology targets regional and local agencies that are in charge of managing rescue operations and assessing damage effectively.

Supplementary Materials: The following are available online at: https://tinyurl.com/efita178, Figure S1: Pilot Project Areas, Figure S2a: Evia Politika area a, Figure S2b: Evia Politika area b, Figure S3: Hydrological analysis, Figure S4: Change detection due to flood disaster, Figure S5: Mapping changes due to the 9th August Evia flood event, Figure S6: Example of classification of flood surface waters of Thessaly using multitemporal Sentinel 2 images, Figure S7: River basins and Hydrological analysis of the Pilareon municipality, Figure S8: Land use classes due to flood disaster.

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Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available due to the reason that this is an ongoing study.

Conflicts of Interest: The authors declare no conflict of interest.

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