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Development of flood risk maps using Remote Sensing Techniques in Cyprus

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Abstract: Floods are the most devastating natural disasters and are likely to become more frequent, dominant, and severe due to climate change, population growth, urbanization, and other factors related to watersheds and human activities. A flood can be defined as a body of water that causes runoff to land that is not normally covered by water. Ecosystems and floods are closely related. Urbanization across watersheds can lead to many causes of flooding. However, earth observation technologies such as satellite remote sensing can contribute to more efficient flood risk mapping by the European Directive 2007/60/EC on Flood Risk Assessment and Management. An interdisciplinary, integrated approach is used to present current and historical regimes of the selected watershed in Paphos region of Cyprus, combining Earth Observation (EO), Geographic Information Systems (GIS), hydraulics, surveying techniques (such as laser scanning), and crowdsourcing. This article presents a comprehensive examination of the utilization of satellite-based remote sensing techniques for flood detection, monitoring, and integration with flood models, highlighting recent advancements in the field.

Keywords: Flood, Risk assessment, Modelling, Earth Observation, GIS

1. Introduction

Floods are destructive disasters caused by factors like heavy rainfall, urbanization, deforestation, and poor drainage systems [1]. They have global consequences, affecting millions of people and causing significant economic losses [2]. Relief operations face challenges due to the widespread impact of floods [3]. Strategies to minimize flood damage are crucial given uncontrolled urbanization, socioeconomic growth, and climate change [4]. GIS technology and models play a vital role in flood analysis and prediction [5], [6]. Remote sensing, including satellite observations, provides accurate and timely flood information[7]. Thus, it is essential to employ advanced technologies like remote sensing, GIS, and hydrologic models to accurately map and manage floods event, as well as assess flooding risks [8]. Flood mitigation aims to reduce the adverse effects of floods through structural and non-structural measures [9]. The government of Cyprus is actively identifying vulnerable areas and proposing suitable mitigation and adaptation measures. Flood maps play a crucial role in managing flood risk by assessing the level of risk, informing land use decisions, and supporting emergency planning and infrastructure design. This article will outline commonly used Earth Observation (EO) data and techniques for flood monitoring and mapping. It will also evaluate approaches to integrate EO data with flood models.

2. Flood and Remote sensing techniques

Remote sensing is crucial for flood analysis and management, providing accurate and timely flood information. Satellite and airborne sensors are effective tools for monitoring and studying floods. They enable the analysis of large-scale surface changes caused by flooding, offering valuable insights for flood risk management, emergency response planning, and post-flood recovery [10]. Integrating remote sensing data with other spatial information improves the accuracy of flood risk maps and enables high-resolution flood inundation modeling. This approach has been successfully used to develop real-time flood risk maps in various regions [11]. Extensive research utilizing GIS and remote sensing techniques has been conducted to analyze and assess flood risk, underscoring the significant role of remote sensing in flood management and disaster risk reduction[12].

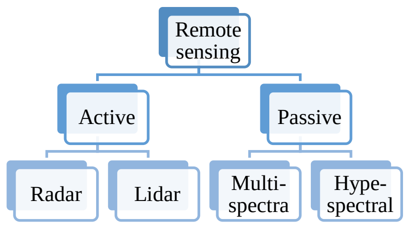

Figure 1: Classification of remote sensing methods

Remote sensing technologies can be classified into two types: active and passive. Active sensors use their own light sources, such as radar and LIDAR, to collect data from Earth's surface. Passive methods, on the other hand, rely on natural or sunlight for data collection[13]. Satellite-based remote sensing, which captures Earth imagery, is a form of passive remote sensing. Within passive remote sensing, there are two types: multispectral and hyperspectral. The classification framework of remote sensing technologies is shown in Figure 1. Most remote sensing technologies, including satellite-based methods, fall under the multispectral category. The subsequent sections of this study focus on flood prediction models using multispectral, LIDAR, and radar-based remote sensing techniques [14].

2.1 Multispectral

Multispectral remote sensing captures energy emitted or reflected by objects on Earth's surface using sensors that detect specific spectral bands. Satellites like Worldview 4,3,2, GeoEye-1, Pleiades, Sentinel l-2, Landsat 7, Landsat 8, MODIS and AVHRR utilize these sensors for data collection [15]. Several studies have utilized multispectral data for flood prediction. Massari et al. [16] combined satellite data, soil moisture readings, and rainfall to develop a flood forecasting model for Mediterranean catchment locations. Meng et al. [17] integrated the weather research and forecasting model with the Tianshan Snowmelt Runoff Model, using MODIS imagery and DEM data to predict floods in China's Juntanghu watershed. Cenci et al. [18] assessed the effectiveness of Sentinel-1 satellite data in gathering soil moisture information for flood forecasting in the Mediterranean Sea region.

2.2 LIDAR

LIDAR is an active remote sensing technology that uses laser pulses to create precise 3D models of the Earth's surface. It is used for generating Digital Elevation Models (DEMs), facilitating emergency response, and monitoring water levels for flood forecasting. Recent research proposes LIDAR-based methods for flood risk assessment and prediction. Mihu-pintilie et al. [19] combined high-density LIDAR data with hydraulic modelling to enhance urban flood hazard maps. Priestnall, Jaafar, and Duncan [20] focused on extracting surface features from airborne LIDAR data for flood inundation modeling. Webster et al. [21] used airborne LIDAR to map flood risks and assess climate change impacts on coastal regions in Charlottetown, Canada. LIDAR proves valuable in assessing flood hazards and studying climate change effects.

2.3 RADAR

Radar, or Radio Detection and Ranging, uses radio waves to detect and analyze object characteristics. Synthetic Aperture Radar (SAR) technology, a type of radar, is particularly useful for detecting flooded areas as it can penetrate through adverse weather conditions [22]. SAR, combined with GIS and satellite data, allows for flood damage estimation and supports flood mitigation efforts. However, SAR has limitations in measuring real-time water levels at fixed points and is more suitable for large water bodies [10]. When integrated with flood prediction models and data assimilation techniques, SAR-derived water level observations can contribute to flood forecasting. Garcia-Pintado [23] developed a flood prediction model using SAR-derived water level data in the UK, showcasing the potential of Earth Observations (EO) for independent flood forecasting.

2.4 Hyperspectral

Hyperspectral remote sensing captures detailed environmental information using specialized sensors, enabling the identification of unique spectral signatures in the visible and non-visible spectrum [24]. Niculescu [25] proposed a flood risk management method using radar and hyperspectral data in the Danube delta, employing the Support Vector Machine (SVM) algorithm for classification. Zhang [26] utilized multiple satellite datasets, including Gaofen and Zhuhai-1 hyperspectral, for flood detection. Their coarse-to-fine framework addressed land cover changes, producing reliable water mapping results using deep neural networks. Gambardella [27] introduced a methodology for mapping flood and landslide-affected areas, emphasizing accurate representation and interpretation of the landscape. The methodology involved flight planning, sensor selection, and data processing, identifying debris deposits through spectral analysis with use hyperspectral data .

3. Advanced Technologies for Flood Analysis, Management, and Risk Assessment

Flooding can have catastrophic impacts on local communities, highlighting the need to utilize advanced technologies such as remote sensing, GIS,, and hydrologic models for analysis, management, and flood risk assessment [8].

Table 1:Remote technology and sensors used for water resources, hydrological fluxes flood mapping.[8]

Application Fields	Specific Contents	Examples of Sensors or Satellites
Water resources	Glaciers	Landsat, ASTER, SPOT, ICESat, SRTM, etc.
	Soil moisture	SSM/I, AMSR-E, SMAP, SMOS, etc.
	Groundwater	GRACE
	Lakes, reservoirs, rivers, and wetlands	MODIS, Landsat, SPOT, ICESat, GRACE, SRTM etc
Hydrological fluxes	Precipitation	NEXRAD, TRMM, GPM, etc.
	Evapotranspiration	MODIS, Landsat, GRACE, etc.
	River, reservoir or lake discharge	MODIS, ENVISAT, Landsat, SRTM, IC
Flooding	Flooding	MODIS, Landsat, GRACE, UAV, AMSR-E, SMAP,SMOS, ENVISAT, ASAR, Sentinel-1A/2A, etc.

Remote sensing provides important data for analysing floods also can quantitatively measure hydrological parameters, such as precipitation, evapotranspiration, river stages and discharges (**Σφάλμα! Το αρχείο προέλευσης της αναφοράς δεν βρέθηκε.**). Precipitation products enhance hydrological simulation and flood prediction by offering extensive coverage and high spatial resolution [28]. Remote sensing techniques are becoming increasingly crucial in flood monitoring and emergency response (Remote technology and sensors used for water resources, hydrological fluxes flood mapping.[8]Table 1). Emerging Unmanned Aerial Vehicles (UAVs) offer a flexible low-altitude platform for monitoring vegetation growth, soil moisture conditions, flood inundation mapping, and damage assessment. Utilizing flood mapping data from diverse sources can significantly enhance disaster response [29].

Hydrologic models utilize remote sensing and GIS data to conduct physical experiments and scenario analyses. They offer comprehensive insights into past events and future projections. These models also provide a robust estimation of low-probability events that may not be captured by ground observations. By integrating various tools such as GIS, statistics, and numerical techniques, hydrologic models contribute to better understanding and management of flooding disasters within communities[30].

The following summarizes the 10 papers published in this special issue (Table 2), which explores the sum of state-of-the-art technologies, applications of remote sensing, Geographic Information Systems (GIS), and hydrological models in various aspects of water resources mapping and management. It covers topics such as satellite rainfall measurements, simulation of runoff and flooding, mapping flood and risk management strategies. By leveraging these tools and techniques, we can improve rainfall monitoring, assess flood risks, and develop effective strategies for flood management and mitigation. These articles were selected because focus on the modeling, mapping, and mitigation of floods using both active and passive satellite data.

Table 2. Remote sensing technologies and hydrologic models applied in the 10 papers published

Reference	Specific Contents	Methods	Data
[31]	Flood mapping and runoff modeling	SCS-CN, Coherence	SAR (Sentinel 1), Rainfall
[32]	Flood modeling	GAR , GSSHA model	GP, IMERG
[33]	Flood vulnerability mapping	HEC RAS under HEC-geoRAS interface Case	ASTER image, River Discharge data, ALOS ACNIR2, Thematic GIS Layers
[34]	Flood Risk Assessment	Comparison IPCC-A1B model PDHM (river runoff model)	Field data,Station based rainfall data MRI-AGCM
[35]	Flood inundation mapping	Supervised classification, Change detection	ENVISAT ASAR GM Mode Images, Land Cover Map, Rainfall, Surface Water Record (SWD
[36]	Flood Early Warning System	HEC-GeoRAS , HEC-RAS	SRTM, ASTER DEM, Historical flood records, River discharge data
[37]	Flash flood detection	Multi Satellite Precipitation Analysis (TMPA), constant threshold (CT), cumulative distribution functions (CDFs) and Jeddah flood index (JFI)	TRMM, Real time T3B2RT
[7]	Hydrological modeling	HEC-HMS	STRM DEM, CPC Data, (IRS) -1D Wide Field Sensor (WiFS) satellite data, LULC, Soil texture, Rainfall
[38]	Early Warning, vulnerability and flood mapping	Gumbel's Methods (for flood frequency analysis), HEC-GeoRAS, HEC-RAS	Aerial Photographs, Field data Rainfall and Temperature data
[39]	Flood Early Warning System	GeoSFM model Curve Number	Topographic data, Soil and Land cover data, Precipitation data Evapotranspiration data and spatial distribution of rainfall (RFE)

Conclusions

The combination of hydrologic and hydraulic models, as well as remote sensing techniques, can greatly enhance flood risk management and promote resilience in the face of climate change and other environmental challenges. These models and techniques allow for accurate and detailed predictions of flood events, enabling the development of effective flood management strategies and emergency response plans. They also provide insights into the contributing factors of flood risk, guiding the implementation of appropriate mitigation measures. Additionally, high-resolution flood risk maps generated through these methods facilitate easy understanding and communication with stakeholders, empowering them to make informed decisions. spatial analysis, and result map generation in relevant studies

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