sustainability

MDPI

Article

Detection of Seasonal Inundations by Satellite Data at Shkoder Urban Area, North Albania for Sustainable Management

Stefano Morelli [1,*], Matteo Del Soldato [1], Silvia Bianchini [1], Veronica Pazzi [1], Ervis Krymbi [2], Eriklida Shpori [2] and Nicola Casagli [2]

1 Department of Earth Sciences, University of Firenze, Firenze 50121, Italy
2 Department of Geography, University of Shkodër "Luigj Gurakuqi", Shkodër 4001, Albania
* Correspondence: stefano.morelli@unifi.it; Tel.: +39-055-275-5981

Received: 19 July 2019; Accepted: 14 August 2019; Published: 17 August 2019

Abstract: The European Space Agency satellites Sentinel-1 radar and Sentinel-2 optical data are widely used in water surface mapping and management. In this work, we exploit the potentials of both radar and optical images for satellite-based quick detection and extent mapping of inundations/water raising events over Shkodër area, which occurred in the two last years (2017–2018). For instance, in March 2018 the Shkodër district (North Albania) was affected twice by the overflow of the Drin and Buna (Bojana) Rivers and by the Shkodër lake plain inundation. Sentinel-1 radar data allowed a rapid mapping of seasonal fluctuations and provided flood extent maps by discriminating water surfaces (permanent water and flood areas) from land/non-flood areas over all the informal zones of Shkodër city. By means of Sentinel-2 data, two color composites maps were produced and the Normalized Difference Water Index was estimated, in order to further distinguish water/moisturized soil surfaces from built-up and vegetated areas. The obtained remote sensing-based maps were combined and discussed with the urban planning framework in order to support a sustainable urban and environmental management. The provided multi-temporal analysis could be easily exploited by the local authorities for flood prevention and management purposes in the inherited territorial context. The proposed approach outputs were validated by comparing them with official Copernicus EMS (Emergency Management Service) maps available for one of the chosen events. The comparison shows good accordance results. As for a further enhancement in the future perspective, it is worth to highlight that a more accurate result could be obtained by performing a post-processing edit to further refine the flooded areas, such as water mask application and supervised classification to filter out isolated flood elements, to remove possible water-lookalikes and weed out false positives.

Keywords: Western Balkans; radar applications; inundation mapping; Sentinel-1; Sentinel-2; spatial planning

---

1. Introduction

Detection and quick mapping of the extent and distribution of overflowed water surfaces during major flood events on urban areas can be significant for quantifying possible hazard maps within spatial and environmental planning strategies [1]. However, the wide lowland areas are characterized by very small gradients and subjected to pervasive minor inundations due to seasonal fluctuations of water levels. These water variations are equally important to be studied and to be spatially defined in comprehensive maps, since the related surface water circulation can adversely interfere with some of the waterside anthropic activities and, at the same time, can severely impact the ecosystem balance of wetlands, influencing the existing bioma. These effects can assume contours that are even more negative if occurring in those areas that suffer the foolish and disrespectful spread of a chaotic residential architecture carried out in an abusive way (settlements without authorizations or controls and with the application of unregulated construction techniques), which is universally named "informal architecture".

Therefore, the purpose of this paper is to identify, and consequently test, the best survey techniques that are nowadays able to detect the impact degree of various possible levels of inundations in a very short time. Throughout the quick detection of seasonal water fluctuations extent, useful and immediate information can be provided for the realization of a large scale mapping, the collection of local vulnerability related to the urban and natural arrangement, as well as for the criticality categorization to include in ordinary planning and management of extraordinary emergency situations. In such a perspective, the currently available remote sensing space-borne Earth Observation (EO) sensors are useful sources of information on inundation events over wide areas. Both of the two satellite imagery types, i.e., optical and radar data, can help with the rapid tracing of inundated areas by exploiting their time- and cost-efficiency as well as their wide area coverage, and thus, can successfully detect spatial and temporal water level variations and fluctuations extent maps [2,3].

On the one hand, optical satellite data are usually the best choice for such applications due to their simple readability. On the other hand, overflows often occur in cloudy and rainy periods, which are unfavorable weather conditions for optical images usability because cloud cover prevents good visibility. In this case, radar data acquired by SAR (synthetic aperture radar) satellite sensors offer a valid option for land surface water bodies monitoring and mapping [4]. Water bodies are a specular reflector of the radar signal, resulting in minimal backscattering returned to the satellite. The effectiveness of the radar return is dependent on a number of factors, notably surface roughness, dielectric properties, and local topography in relation to the radar look angle [2].

SAR sensors, in fact, are "active" devices that use microwave signals that can operate in all climatic conditions at large scale with good spatial resolution and indifferently during day and night. Easy-to-use and semi-automatic optical imagery- and SAR-based flood mapping approaches, such as texture analysis, change detection, histogram thresholding, have been tested and considerably used in literature in the last years (e.g., [2,5–8]). Moreover, disaster management authorities can activate satellite-based emergency response mechanisms such as the Copernicus Emergency Management Service (EMS) which are rapid mapping services performed on-demand in case of severe events [https://emergency.copernicus.eu/EMSR273 and https://emergency.copernicus.eu/mapping/ems/emergency-management-service-mapping].

Despite strengths of radar sensors compared to optical systems, there are challenges in identifying inundations and fluctuations of water levels. Roughening of the water body, created by heavy rainfall or wind can cause backscattering of the radar signal and prevent inundated areas to be possibly highlighted. Furthermore, SAR systems are side-looking along a radar beam's line of sight (LOS) which is inclined of a certain angle (off-nadir angle) with respect to the Nadir direction; thus, some geometrical distortions (i.e., radar shadowing, layover and foreshortening) arise from the combination of the satellite acquisition angles and the local morphological slopes. In particular, the radar shadowing can determine difficulties in mountainous areas since reliefs can create anomalous dark areas within the radar image which can be water-lookalikes pixels as false positive misclassified as water [2].

Finally, minimal variations of water levels cannot be detected due to the medium spatial resolution of the SAR images (i.e., the ground resolution in azimuth x range is about 20 m × 4 m for sensors that acquire in the microwave C-band). Optical data can reach higher spatial accuracy even if different resolutions are achieved in different spectral bands ranging from the visible spectrum through to shortwave infrared. Nevertheless, as already pointed out, optical sensors are based on "passive" remote sensing devices that capture the solar reflectance of the earth and thus are unable to penetrate cloud cover. Nowadays, the use of ESA (European Space Agency) satellites Sentinel-1 radar and Sentinel-2 optical data provide global, systematic scenes worldwide. Costless acquisitions have reduced technical limitations and time-consuming efforts in tasking and delivering satellite images for water surfaces and overflows mapping. Thus, free access and download, fine spatial resolution (i.e., 10 m and 14 × 5 m in Sentinel-2 and Sentinel-1 scenes, respectively) and reduced revisit time (up to 5 and 6 days, respectively) have significantly improved and enlarged the utility and efficiency of satellite EO data within the risk management applications.

On March 3, 2018 heavy rain and snow melting caused significant flooding and landslides in the northwestern part of the Albanian national territory and Copernicus EMS service was promptly requested to quickly understand the size of the event. The Shkodër district was the most affected area because of the Drin and Buna (Bojana) Rivers overflowing and the inundation of the Shkodër plain from the lake level raising. A total number of 25 delineation maps were produced by means of pre- and post-event images from Sentinel-1, RADARSAT-2 and COSMO-SkyMed satellites constellations to semi-automatically detect the inundated areas at 1:25,000 and 1:30,000 scales [see: https://emergency.copernicus.eu/EMSR273 and https://emergency.copernicus.eu/mapping/ems].

In this paper, we firstly provide an overview of the urbanistic framework of the Shkodër urban area (North Albania) and its hydrological hazards. In particular we focus on the main nucleus of the city facing the south-east shore of the Shkodër Lake where the main structures and infrastructures of the urban management are located (i.e., administrative, cultural, educational, healthcare competences and all the other social elements that are functional for the whole administrative unit and surrounding areas) that nowadays have an inextricable and seamless distribution from the old city center up to the most external informal areas (n. 1, 2, 3, 4, see Section 3 for details). Then, we exploit Sentinel-1 radar and Sentinel-2 optical data for detecting spatial and temporal water level variations of Shkodër lake occurred in 2017 and 2018 and we provide extent maps that are cross-compared with the considered built-up informal areas of the Shkodër urban area.

2. The Geo-Hydrological Framework of the Study Area

The Shkodër city and municipality are positioned in a karst depression of the southeastern Dinarides and developed along the shores of a large lake that takes its name from this city [9]. According to the current political geography, the lake is located between Albania and Montenegro state boundaries and approximatively two-third of its surface administratively belong to the latter [10]. In the south-west a mountain range, which reaches up to 1600 m a.s.l., physically separates the lake from the Adriatic Sea, just 12 km far (Figure 1).

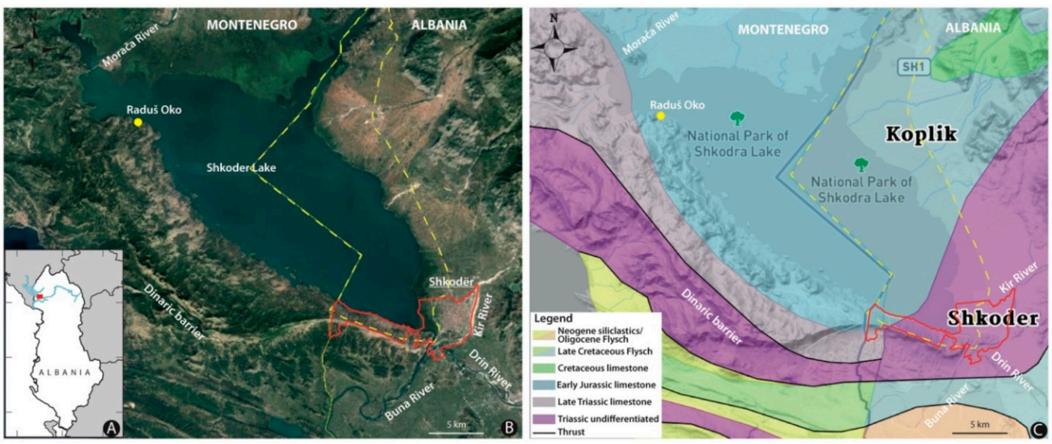

Figure 1. Location map of the study area. (**A**) Albanian Buna–Drin river system (in light blue) with the study area (in red). (**B**) Detailed view of the study area in relation to the Shkodër lake: The solid yellow line represents the border between Albania and Montenegro. (**C**) The geological map of the study area, modified from [11] (the Albanian and Montenegrin geological surveys are quite different, therefore formations not affected by thrust, i.e., late Cretaceous Flysch, are shown with different colour/names). In panel (**B**,**C**) the dashed yellow line is the Albanian Ramsar boundary, the solid red line delimits the Shkodër municipality, and the yellow dot is the sublacustrine spring.

The lake represents a crypto-depression in the Visoki Krš tectonic unit (mainly composed by Mesozoic carbonates, Figure 1C) with a Dinaric direction, being oriented northwest-southeast: 44 km in the longer axis and 14 km in width. The maximum depth is approximatively 60 m in an underwater Montenegrin doline which hosts a sublacustrine spring, called Raduš Oko, through which a carbonate aquifer discharges [9]. Excluding this confined peak of depth, the Shkodër lake is a shallow body of water with a mean depth of around 5 m with a maximum of 8.3 m [12]. The average altitude of the lake surface is 6.5 m a.s.l. and the water level can vary seasonally approximately from 4.7 up to 9.8 m a.s.l. in the late summer and during the spring, respectively [10]. Therefore, the depth of the lake extends below the sea level over an area that covers about 44% of the lake surface. Such fluctuations are due to the strict relation between the bathymetry, the lakebed morphology, and the seasonal cycles of the incoming waters (surface drainage and temporary or permanent karstic springs) which influence significantly the areal variation of the covered areas and their associated wetlands. The areal extension seasonally fluctuates between 370 and 600 km^2 [10,12] with extensive inundations during the spreading of the higher water levels in the northern and eastern flat shore areas, including most of the plot of lands surrounding Skhodër [12].

The most important tributary of the lake is the Morača River since it provides about 63% of the lake's water and most of the sediments and nutrients. The remaining percentage of flow contribution derives from a series of minor and short rivers. Because of heavy rain over several months, the lower parts of the inflowing rivers fall below the water level of the lake [12]. The Buna River is the only emissary river with an average outflow of 304 m^3/s. It starts from the southern coast and after a sharp curve, it passes through a narrow rocky passage about few hundred meters downstream the source. This morphological feature is also the main southern geographic doorway to enter the city of Shkodër, historically developed from here northwards. In fact, the oldest settlement that has been inhabited since the Bronze Age, is located on the top of the right slope in that area [13], strategically controlling the passage from north to south in a safe position from enemies and natural events. After the conjunction with the major channel of the lower Drin River (3500 m from its beginning at about 1300 m from the southern outskirts limits of the city) the waters, increased in quantity, flow directly to the Adriatic Sea.

The Shkodër lake catchment area covers 5631 km^2, and a percentage of about 81% belongs to the territory of Montenegro, while only the remaining 19% to Albania. Permeable limestone and dolomite occupy around 73% of the basin surface. They are also distributed below the other outcropping rocks, like the impermeable flysch and clastic sediments of the karst depressions with a total thickness over 3000 m [9]. Consequently, this area is characterized by alteration and erosion phenomena, spelogenetic processes, and landscape structures that are distinctive of holokarst areas and includes the most typical forms of karst relief. A karst aquifer is also well developed and is mainly recharged by diffuse infiltration of rainwater (autogenic recharge). The average annual precipitation on the area is relatively high (approximatively 2500 mm/year of which 80–85% of rainfall occurs between November and March [14]) due to its geographical position in relation to the Adriatic Sea and its terrain configuration. Despite that, there is no abundant surface water on this area neither a well-developed hydrographic network [15]. Almost all rainwater infiltrates rapidly into the permeable ground, percolating vertically until the water table, and the surface drainage network is poorly developed (limited to the abovementioned situations), with a small number of local watercourses that flow only in the rainiest period of the year [9].

The Kir River is the widest seasonal watercourse in the study area. It flows roughly from north to south by touching the easternmost neighbourhood of Shkodër and the suburban areas of all the crossed floodplain (just over 1/4 of the total length, which is 43 km). This watercourse has a catchment area of 264 km^2 [16] and a mean annual flow of 18.36 m^3/s based on data collected from 1948 until 2000 [17]. The annual distribution of flows is closer to the snow and rainfall regime with maximal amounts in winter and early spring and one minimum in late summer (August). At the highest water levels, the Kir River is characterized by a torrential regime, sometimes with turbulent flows that contribute to forming a braided channel with a lot of detrital material in bars of different elongated shapes and sizes. Its direction, partially fixed by local hydraulic interventions, is parallel to the shore of the lake up to its confluence with the Drin River, just upstream of the conjunction with the Buna River (hydrographic node). Therefore, the Shkodër city develops on the southern edge of a flat plain which is bordered on three sides by significant water elements: The lake (west), the mouth of the Buna Rive and the hydrographic node (south), and the Kir River (east).

Regarding the microclimate conditions of the entire basin, the temperatures in summer are high (hot and dry days), providing high evaporation, while in winter the temperature is low, rarely going down below freezing point (humid and cold days). Under the Köppen and Geiger classification [18] this particular summer state can be summarized with the *Cfa* subtype, while generically the Shkodër area is considered with a Mediterranean climate (*Csa* subtype). This aspect and the achieved degree of geo-hydrological development allow to grow an exceptional aquatic and wetland ecosystem within the Shkodër lake, that currently represents the basis for a series of lasting protection actions and sustainable management plans. In Montenegro, the Lake was classified as a "National Park" (IUCN—International Union for Conservation of Nature Management Category II) since 1983, with a surface area of 40,000 ha. In 2005 the Albanian government proclaimed, through a Ministers' Decision, the Albanian part of the Shkodër lake a "Managed Natural Reserve" (IUCN Category IV). At the international level, the lake is considered one of the largest European reserves of wading birds and a resting place of migratory birds; for this reason, it was designated an important bird area (IBA) in 1989 [19]. Moreover, since 1996, the Montenegrin portion of the lake was included in the Ramsar List of Wetlands of International Importance, whereas the remaining Albanian part (dashed yellow line in Figure 1B,C) was added later in 2006 comprising the whole lake [12,20]. Besides, in 2011 the lake was formally nominated for the UNESCO heritage status [12].

3. Urbanistic Framework and its Hydrological Hazards

Shkodër develops between 24 m a.s.l. in its northeast margin to 9.5 m a.s.l. in the lowland southwest areas (just below the maximum levels reached by the lake during the exceptional increase of water levels). The city covers an area of 23 km^2 and its suburbs, called Bahçalleku (informal area n° 5, Figure 2) in the south and Shiroka and Zogaj (informal area n° 6 and n° 7, respectively; Figure 2) in the west, extend up 1.8 km^2, overlooking the lake and the Drin River respectively [21]. The Shkodër city is the administrative, cultural, and financial centre of the region and it experienced significant demographical changes following the turbulent political and governmental transition of the early 1990s. After the collapse of the state-owned agricultural cooperative, it was difficult to continue to work profitably in the provinces and the abolition of the restriction to free mobility of people, emblematic of the communist regime, induced an important migration rate from other parts of the region [21–23]. Therefore, a huge mass of people concentrated in a short time in Shkodër and in its non-urbanized territories, causing crucial implications for the urban development. The population increased from 78,086 inhabitants in 1991 to 116,440 in 2014 despite high emigration rates. Such demographic growth was accompanied by a spontaneous and unplanned land occupation, exploitation, and the creation of new informal settlements of poor-quality housing around the original built-up nucleus due to the poor economic conditions and little government intervention. This rapid process of transformation from rural to urban use took place on collective farms, public land, and territories which had not given any specific use [21] with a total negligence of the environment [12] and its natural hazards [24].

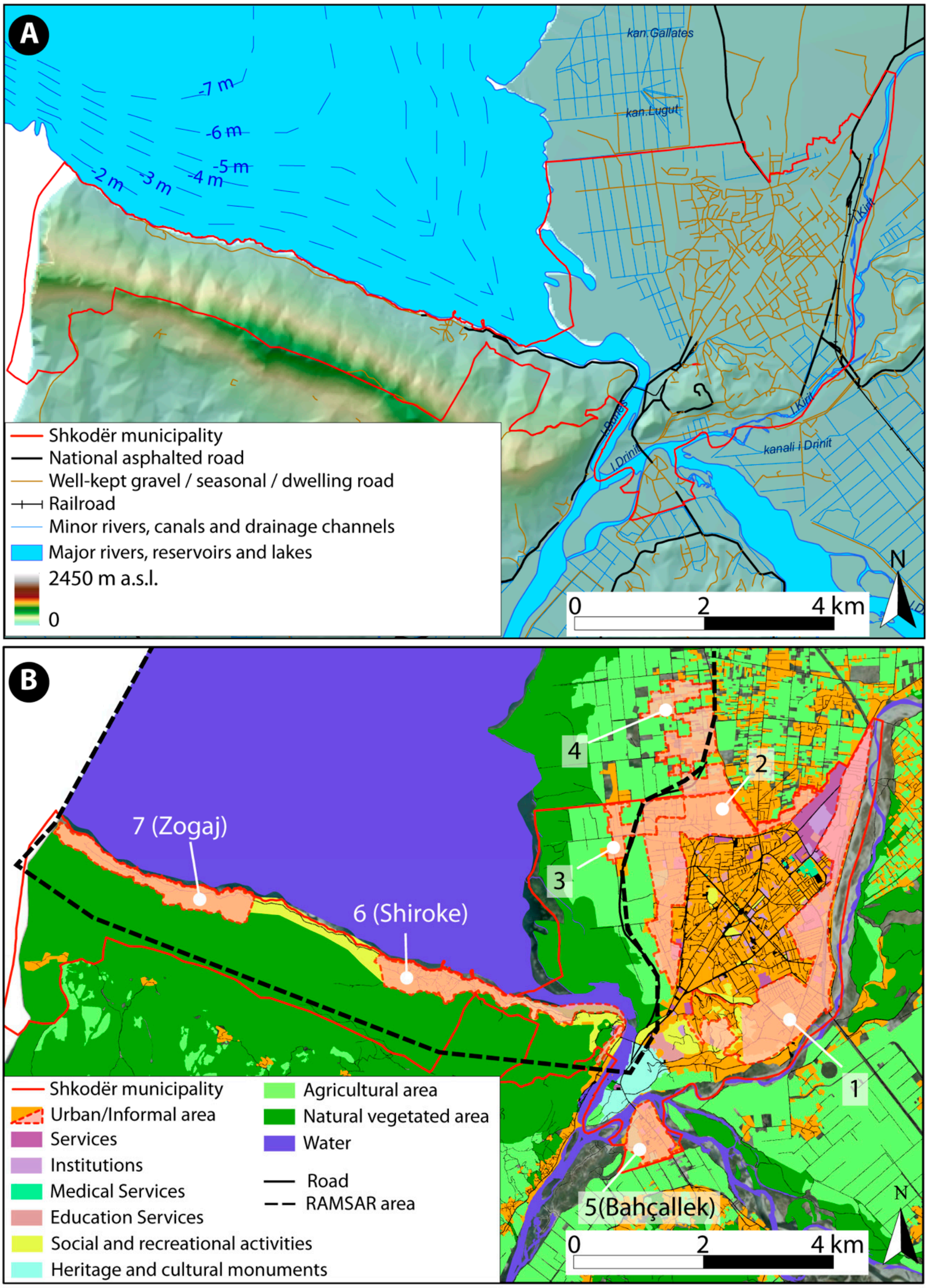

Figure 2. (**A**) The land relief base map and the bathymetric level of the lake. (**B**) The land use map and the seven informal urban areas of the Shkodër municipality (informal areas from 5 to 7, located outside the Shkodër city, are usually called with the name and not with the number, but for brevity here and in the following we will use numbers). The solid red line is the Shkodër municipality while the dashed black line is the Albanian Ramsar area limit designated for the lake.

Today, informal settlements in Shkodër city (Figure 2) represent the 40% of total housing area and they are composed by a mix of good-quality buildings and substandard products [21]. Moreover, informal settlements are irregular in their physical settings and illegal in the appropriation of lands and/or buildings rights. During the first intense construction phase, the existing urban plan was scarcely considered and the lack of a continuously updated plan, as a guide to the development, indirectly encouraged this uncontrolled phenomenon (the 1994 plan was used until the approval of the new one in 2005). At present, four informal areas can be recognized just around the original urban core of Shkodër and three areas are located in the immediate vicinity (those named at the beginning of this section and located at the foot of the southern mountains) but are outside of the Shkodër floodplain (Figure 2).

The local authorities are preparing targeted plans for these areas [21], based on a legalization process as expected by the current regulations [25]. The number of informal buildings is now estimated to be 7000 units, hosting over 22,000 inhabitants, with inadequate services access (e.g., waste management and pollution, transportation, education, and health services). The houses built in this speculative development are rarely slum dwellings as found in underdeveloped nations. The urbanization was driven by rural migrants and sometimes involved skilled workers. Approximately 7000 families (35% of the total Shkodër city population), spread over 150 ha, live in buildings with a recognized informal status. Most of the informal settlements occurred during the early 1990s and were already joined to the regular pre-existing city in early 1994.

All the informal areas, especially the urban portions that are nearby the formal one, seem to have been assimilated into it, reaching a similar level of density (approximately 40 houses per hectare). Sometimes here the real perceptible difference is only in the distribution of social and engineering infrastructures which are highly limited and based on illegal connections.

In relation to the main objectives of the present work, only four informal areas that enclose the long-established city and that are in direct contact with the original urban structures, are here considered in detail. Informal area n° 1 is the largest informal settlement of Shkodër and it is considered one of the biggest in the region. Throughout the last two decades, it grew up significantly, shaping the entire landscape of the eastern and southern peripheral areas of the city. Formerly agricultural land, the zone has a built surface of approximately 0.2 km^2 on a total of 3.0 km^2 [21]. This informal settlement, mainly based on well separated residential units on adjacent properties, has generally a good build quality. However, the properties of this area have been subdivided illegally and sold by its legal owner to people who built their houses without a regular building permit or following a regular design that should have considered the existing geo-hydrological risks. Another critical aspect of this land strip is linked to the abandonment or bad management (after 1990) of some pre-existing unused nationalized buildings that degraded and/or were not returned to their lawful owners. They were initially structured to accommodate new different public institutions or social houses, but they have not been well managed by the new public authorities and some groups, mostly composed by economically marginalized people, abusively occupied them. In addition, the areas of the industrial complexes (north-east) have been also colonized with new dwellings, and some parts of the industrial buildings were adapted to living purposes with several low-quality architectural adjustments. However, not all their volumes have suffered the same critical evolution and some previous storage facilities nowadays are preserved and still serve as warehouses or service units.

From the hydraulic hazard point of view, informal area n°1 developed all along the entire riverbank of Kir River (about 6.0 km from north to south). The high flow rates typical of late winter, when heavy and long-lasting rainfalls are combined with snowmelt, have historically caused damaging inundations in the eastern part of the city, which is basically its natural flooding terrain, up to the historical centre (e.g., in 1930 when the flow rate was about 1500 m^3/s). Only after the construction of a long levee section during the 1930–1935 (in the 1930s this section was 300 m long) in terrigenous material (fixing and rectifying the right bank of the river between the main two urban bridges), flood phenomena of such magnitude and extension no longer occurred in the city centre. Nevertheless, small and localized flood episodes (e.g., in 1960 when the flow rate was about 1300/1400 m^3/s) continued to happen regularly, but the adopted protection measures induced a high sense of security, leading to continuation of the exploitation of this suburb. Certainly, this residual problem of functionality did not discourage anyway from the rapid and uncontrolled urbanization of the 1990s that expands up to the most extreme limits of the Kir riverbanks: People massively occupied all the natural spaces originally pertaining to the river dynamics and mainly used in recent history for the food sustenance of the city (primarily agriculture). Such progressive operation of construction definitely fixed the morphologic evolution of the territory, influencing the socio-economic facet of the city and, at the same time, increasing the whole community's vulnerability to very exceptional flood events. Just for this reason, in 2015–2016 the old levee arrangement was extended southwards (nowadays the height of the levee varies between 13.0 m a.s.l and 16.0 m a.s.l.), enhancing the missing areas and reconsidering the hydraulic defence as a whole.

The informal area n° 2 encloses the old urban system on the western and northern side nearly constituting a continuous belt that joins the extreme limits of the informal area n° 1, except for a few pieces of land (i.e., narrow corridors that prevent the presence of an uninterrupted and closed informal ring around the center). In this case, the 4.6% of its total extension (1.94 km^2) is covered by urbanization [21] and characterized by hydraulic hazard that increases towards the outermost sectors in the direction of the lake shore, or towards the first stretch of the Buna River in the south. Both elements are here the main source of hydraulic problems.

The informal area n° 3 is a more recent T-shaped urban sprawl of the northernmost area, directly towards the shores of the lake. It developed from some neighbourhoods of the close informal area n° 2, but maintained an own urban and organisational identity. Its built-up surface is about 0.02 km^2 on a total extension of 0.48 km^2 [21]. Even in this case, as for the adjacent informal area n° 2, the hydraulic problems are connected to the water level oscillations of the lake in case of extraordinary growths and inundations.

A similar suburban enlargement is also present in the recent informal area n° 4, which roughly developed from the same portion of area n° 2 where area n° 3 also start to develop, with the difference that it arranges northwards approximately parallel to the coast with a meandering pattern (some land properties remain outside). In this case, the built-up surface is comparable to that of area n° 3 over a total extension of 1.1 km^2. In addition, in this case, the hydraulic problems derive from the exceptional variations of the lake level with worsening conditions (both in urban and social infrastructure) in the sectors closest to the lake.

As mentioned, these last three informal settlements are particularly exposed to Shkodër Lake dynamics because of their enlargement in topographically lower areas which are naturally prone to be submerged by excessive water flow rates (directly or indirectly). These events usually occur when the rainfalls are abundant, generally in January and February, and sometimes at the end of the coldest period due to the contribution of meltwater from the surrounding mountains. Providentially, the extent and the geographical distribution of the water catchment area of the Shkodër Lake is different from that of the Kir River, and therefore critical high levels of water do not always coincide temporally, usually avoiding simultaneous flooding phenomena both in the eastern and in the western parts of the city towards the historic center. In addition to these, a third aspect must be considered: The lake is drained by the Buna River, just southward the city, and after few kilometres it receives the Drin River along the hydrographic left. The Drin River is the longest river of Albania (average flow rate of 360 m^3/s, drainage basin of about 14,200 km^2, length of 285 km out of a total of 335 km; [26]) and its flow rate, besides inducing floods in the southern plains [27], can create a hydraulic barrier for the waters that move out from the lake [12,15] up to induce flow inversions. This is a real possible scenario in case of very high-water tables originated by the natural flooding of the Drin or as consequence of extraordinary opening of the upstream dams during the management of very high-water levels [24]. For example, in 2010, the water flowing through the dams was over four times greater than normal rates and caused management problems at the water containment facilities [28,29]. In both Drin dynamics possibilities, the slowed and blocked lake outflow can undergo a regurgitation that is able to put into crisis safety conditions of the emissary stretch, by causing first damaging inundations along the riverbed and, if the conditions persist, by raising the levels of the lake in front of the more proximal informal areas, with rapid effects on the coastal population.

In Table 1 the most damaging recent floods that submerged part of the city (impacting informal areas n° 2, n° 3 and n° 4) in the period immediately preceding that one considered in this study were summarized. The collected information has been functional for the research of a large-scale study methodology that can contribute to the overall understanding of the flood problem in the area.

Table 1. Description of the most injurious recent floods in the Shkodër city that show the persistence of the hydraulic problems before the observations with the Sentinel-1 satellite. Main and secondary causes are reported in relation to the complex hydrographic conformation and land conservation.

Dates	Main Causes	Additional Causes	Notes
3 December 2009	heavy rainfalls (constant intensity from 30 November till 3 December)	Change of land management and land use: • the transformation of agricultural land in construction land, • erosion problems from bad management of forests (regional deforestation), • constructions in forbidden areas, • the inappropriate exploitation of riverbeds, • construction in marshy lands, • inappropriate functioning of hydro systems and problems with their management	
11 January 2010	• Heavy, long-lasting rainfall and fast snowmelt at abnormally high temperatures in mountainous areas (from 25 December 2009 till 10 January 2010), • High flow rate also in the reservoir of Drin and Kir River (contributing to barrier effect upstream the hydrographic node), • Large volumes of water intentionally discharged into Drin River from one of the three dams along the Drin River (contributing to barrier effect upstream the hydrographic node).	Change of land management and land use: • the transformation of agricultural land in construction land, • erosion problems from bad management of forests (regional deforestation), • constructions in forbidden areas, • the inappropriate exploitation of riverbeds, • construction in marshy lands, • inappropriate functioning of hydro systems and problems with their management.	The flooding in the district of Shkodër was at the time considered the biggest emergency event. About 10,400 ha of land was inundated and about 2500 houses and 4800 people were evacuated.
6 December 2010	• Heavy, long-lasting rainfall from the second week in November until the middle of December (about 900 mm), • Unusual seasonal temperatures and snowmelt, • High flow rate also in the Drin and Kir River (contributing to barrier effect upstream the hydrographic node), • Sudden water release from the Drin dams without the due warning (contributing to barrier effect upstream the hydrographic node).	Change of land management and land use: • not properly working drainage system in the lowland, • the transformation of agricultural land in construction land, • erosion problems from bad management of forests (regional deforestation), • constructions in forbidden areas, • the inappropriate exploitation of river beds, • construction in marshy lands, • inappropriate functioning of hydro systems and problems with their management.	The water level of Lake Shkodër reached the maximum historic recorded level and the water load on Buna was higher than 4,000 m^3/s. the heaviest documented flood event of the last 50 years.
16 March 2013	• heavy rainfall, • melting of snow.	not properly working drainage system in the lowland	

4. Materials and Methods

In this work we exploit the potentials of both radar Sentinel-1 and optical Sentinel-2 images for a satellite-based quick detection and extent mapping of recent inundation/water raising events over Shkodër area.

The input data for analyzing the three major events occurred during the last two years (2017–2018) are listed in Table 2. Moreover, one date in the summer period was also considered for evaluating a dry scenario of the study area and validating the applied approach. By observing the situation on one summer day (e.g., 14 August 2017), it is possible to have an overview over Shkodër area in a time without rainfall and to check the usual water level of the lake without any inundation event.

Table 2. Satellite images from both Sentinel-1 and Sentinel-2 used for the extent analysis of the water raising events.

Date of Water Raising Events	**Satellite Image Acquisition Date**	
	Sentinel-1 Radar Data	**Sentinel-2 Optical Data**
14 August 2017	08/14/2017	08/15/2017
1 December 2017	12/05/2017	12/06/2017
3 March 2018	03/05/2018	03/08/2018
11 March 2018	03/11/2018	03/11/2018

The workflow of the satellite-based procedure carried out in this work follows two different methods for radar and optical ESA Sentinel data (Figure 3).

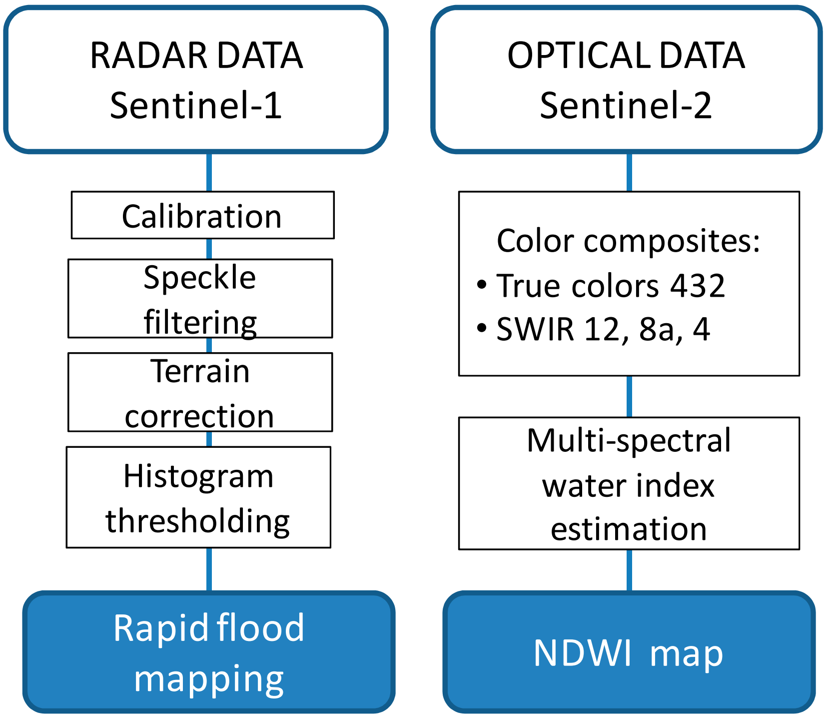

Figure 3. Workflow of the satellite-based procedure. In the optical data analysis, SWIR means short-wavelength infrared while NDWI is the Normalized Difference Water Index.

Sentinel-1 radar data, acquired in microwave C-band (wavelength 5.6 cm) and in interferometric wide (IW) mode, were available in the ESA Sentinel Hub (https://scihub.copernicus.eu) data open access Hub as Level-1 GRD (ground range detected) products, which consist of focused SAR data projected to ground range using an Earth ellipsoid model [30]. Automatic data ingestion in ESA Hub allows us to search and download SAR acquisitions that match specific user-defined criteria, i.e., date of flood event. On these SAR data, a rapid flood mapping approach was performed on the sentinel application platform (SNAP) free software. Firstly, Sentinel-1 SAR images in intensity band VV polarization, which is found in literature to be the best polarization to analyze flooding extent [2,31], are chosen and spatially subset. The cropped images are processed through radiometric calibration and speckle filtering, respectively for obtaining backscatter coefficient values and for reducing noise. A terrain correction is applied by using shuttle radar topographic mission (SRTM) 3 arcsecond data [32] to improve the geolocation accuracy of each scene by means of the compensation of the distortion caused by the LOS of the image acquisition. Then a semi-automatic thresholding procedure is used in order to determine flooded areas by means of threshold binning and unsupervised classification: The threshold is applied to the histogram of the filtered backscatter coefficient for generating water/land binarization and it is chosen to be the same for all the SAR images. The output is a flood extent map that discriminates surface water (permanent water and flood areas) from land/non-flood areas.

Sentinel-2 sensor is equipped with multispectral instruments (MSI) capable of acquiring 13 bands information at different spatial resolutions (10 m, 20 m and 60 m) and its optical data provide 10-day repeat coverage of land areas. The main visible and near-infrared Sentinel-2A bands (named bands 2, 3, 4 and 8) have a spatial resolution of 10 m, while red and near-infrared bands (5, 6, 7 and 8a) along with its two shortwave infrared bands (11 and 12) have a 20 m spatial resolution; the coastal/aerosol, water vapor, and cirrus bands (1, 9 and 10) have a 60 m spatial resolution. The optical dataset used in this work is the standard Sentinel-2 Level-1C product that can be downloaded from the ESA Sentinel Hub (https://scihub.copernicus.eu).

Firstly, two RGB (Red-Green-Blue) colour composites were provided to present visually informative images of the study area: "True Colours" composite based on bands 4, 3 and 2; and "SWIR (short-wavelength infrared) colours" composite based on bands 12, 8a and 4. The SWIR colour composite allows to easily identify the humid areas, thus water, and highly vegetated area [33].

Secondly, the multi-spectral water index, also called Normalized Difference Water Index (NDWI) proposed by [34], was estimated by means of the following Formula (1):

$$\mathrm{NDWI} = \frac{\text{band 3} - \text{band 8}}{\text{band 3} + \text{band 8}} \tag{1}$$

This index is intended to maximize the reflectance of the water body in the visible green band (band 3 for Sentinel-2) and to minimize the reflectance of water body in the near-infrared (NIR) band (band 8 for Sentinel-2). As a result, a NDWI map of the study area is produced to distinguish water/moisturized soil surfaces from built-up and vegetated areas.

Validation step of the maps is finally accomplished. In order to validate our results, the official delineation maps were downloaded from the Copernicus Emergency Management Service and were used to cross-compare products.

5. Results

For the four selected events, that refer to the three main recent floods in the last years (1 December 2017, 3 March 2018, 11 March 2018) and to one summer day (14 August 2017), we produced maps by means of the proposed satellite-based procedures, exploiting radar and optical Sentinel data (Figures 4–7).

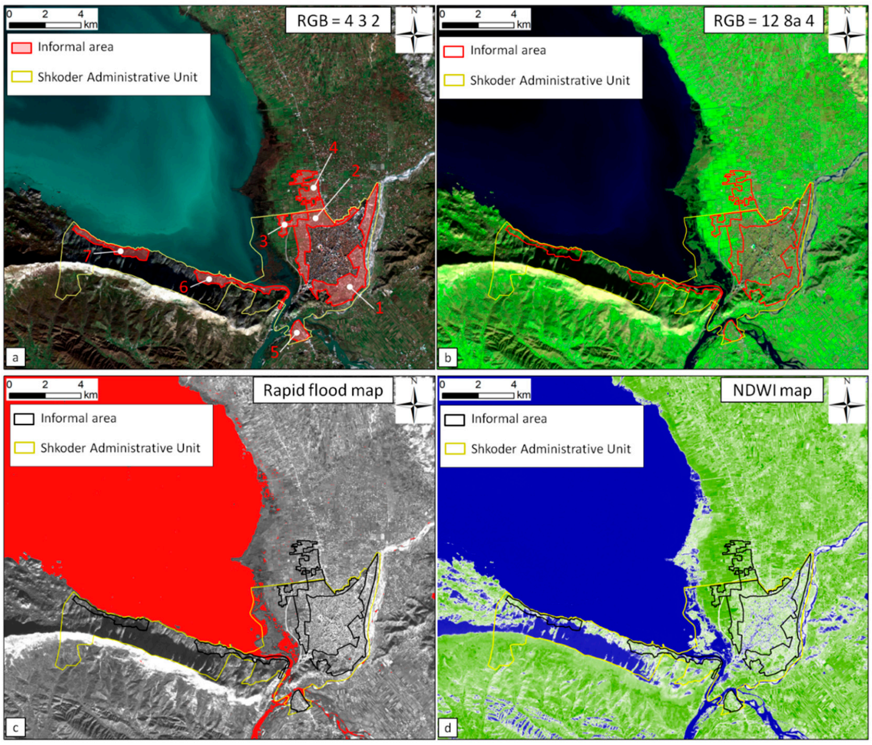

Figure 4. 1 December 2017 event: (**a**) Sentinel-2 optical image acquired on 6 December 2017: True colour composite 4/3/2; (**b**) Sentinel-2 optical image acquired on 6 December 2017: SWIR/near-infrared (NIR)/Red composite 12/8a/4; (**c**) rapid flood map through Sentinel-1 radar image acquired on 5 December 2017; (**d**) NDWI map through optical image.

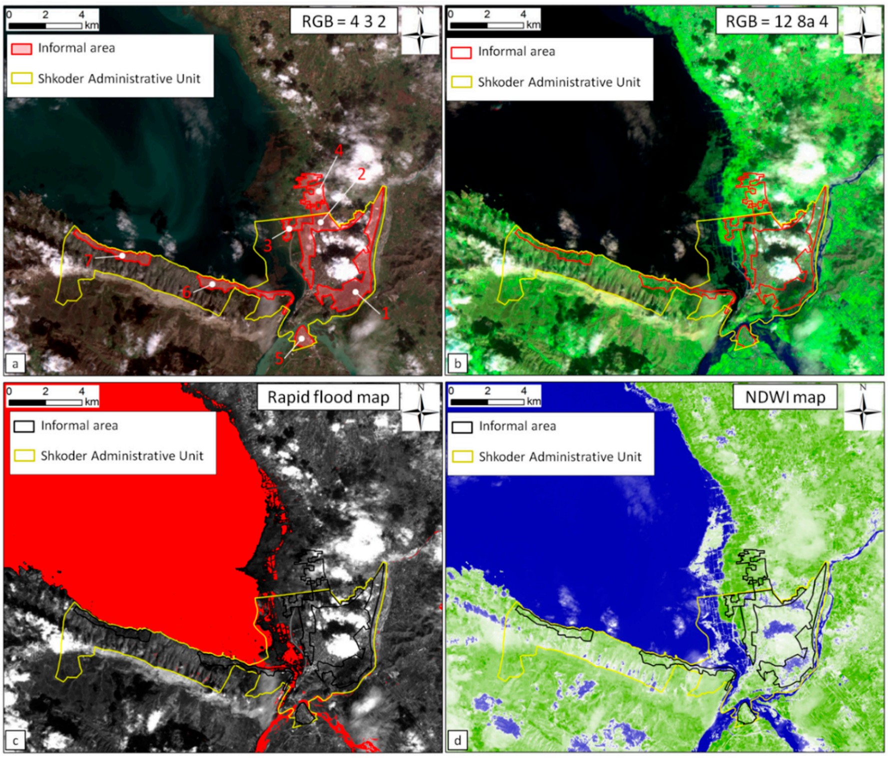

Figure 5. 5 March 2018 event: (**a**) Sentinel-2 optical image acquired on 8 March 2018: True colour composite 4/3/2; (**b**) Sentinel-2 optical image acquired on 8 March 2018: SWIR/NIR/Red composite 12/8a/4; (**c**) rapid flood map through Sentinel-1 radar image acquired on 5 March 2017; (**d**) NDWI map through optical image.

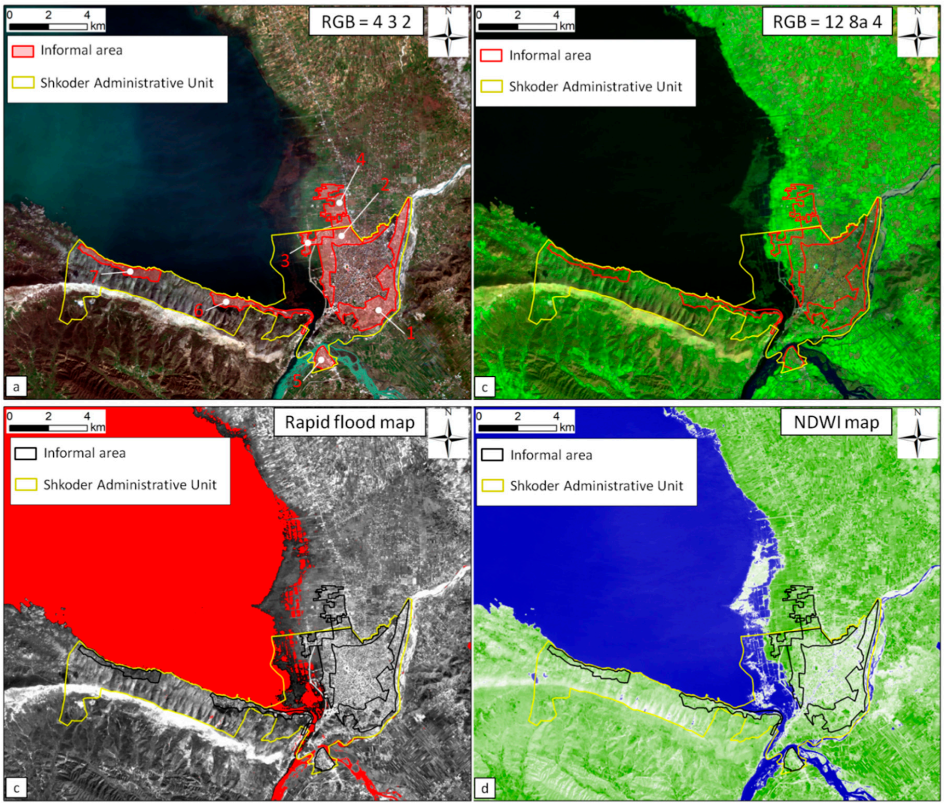

Figure 6. 11 March 2018 event: (**a**) True colour composite 432; (**b**) SWIR/NIR/Red composite 12 8a 4; (**c**) Rapid flood map through radar data; (**d**) NDWI map through optical data.

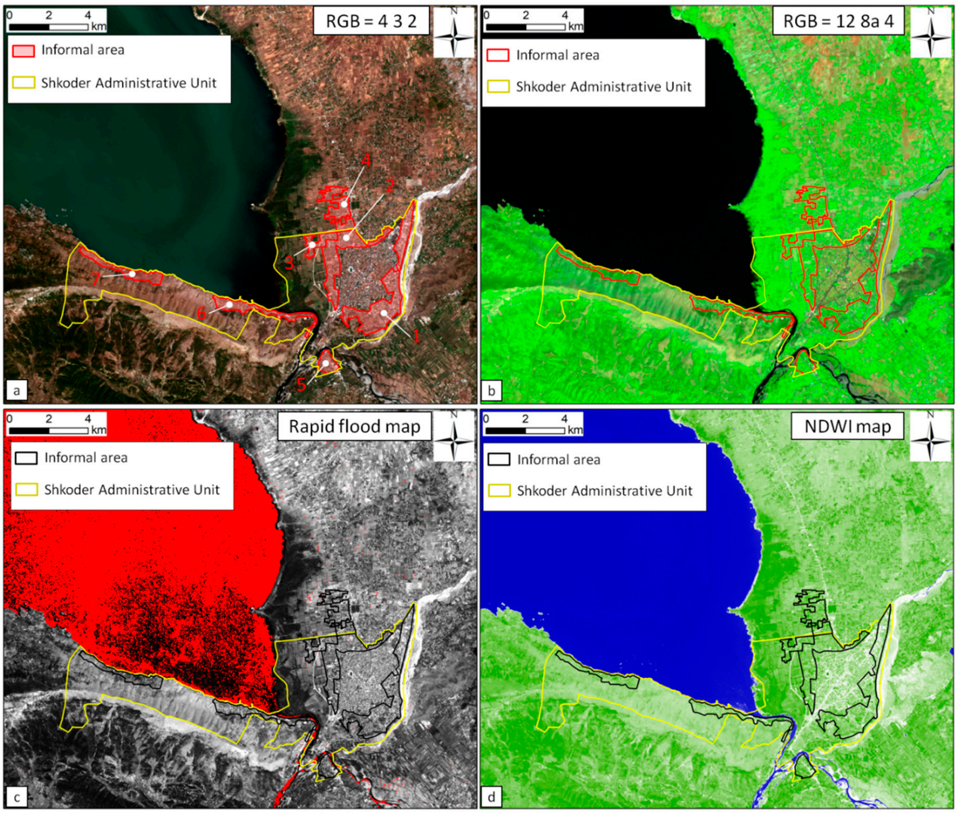

Figure 7. 14 August 2017 event: (**a**) True colour composite 432; (**b**) SWIR/NIR/Red composite 12 8a 4; (**c**) rapid flood map through radar data; (**d**) NDWI map through optical data.

Figure 4 includes images for the event occurred on 1 December 2017. The True Colours RGB composite (Figure 4a) and the SWIR composite were generated from Sentinel-2 optical image acquired on 6 December 2017 highlighting the flooded territory closest to the lake, while the informal areas were not inundated. The rapid flood map produced through the Sentinel-1 radar image acquired on 5 December 2017 allows evidencing water surfaces in red colour confirming the partially flooded areas on the lakefront towards Shkodër city that were detected by the optical image (Figure 4c). Isolated water elements are recognizable also in the inland area, potentially due to the presence of some more moisturized zones or even possible water-lookalikes false positive pixels. The NDWI (Figure 4d) enables to better detect the lake extent even if this index provides not perfect outcomes in the mountainous region located eastwards the informal area n° 1, since shaded north-facing slopes are characterized by high NDWI values and thus are somewhere confused with water surfaces.

Figure 5 shows the extracted map for the event occurred on 5 March 2018. The Sentinel-2 optical image was acquired on 8 March 2018, but it is very cloudy, so the two colors composites were not useful (Figure 5a,b). The derived NDWI map suffer from the cloud coverage and the composite shows it as water-lookalike zones areas displayed in blue color: They are false positive areas corresponding to cloud cover (Figure 5d) to be taken into consideration for avoiding misunderstandings.

Nevertheless, the high-water level of the Shkodër lake can be indifferently detected from the optical images due to the no presence in the lakefront area of clouds (Figure 5a,b). Better results were obtained by means of Sentinel-1 radar image acquired on 5 March 2018 that permitted to provide a good rapid flood map, highlighting a wide flooded area on the lakeshore and some more partially flooded inland territories up to the informal areas (Figure 5c).

Figure 6 shows images for the event occurred on 11 March 2018. The RGB colour composites true Colours and SWIR/NIR/Red derived from Sentinel-2 optical image acquired on 11 March 2018 (Figure 6a,b) reveal the high-water level of the Shkodër lake that inundated a large lakeside area. From the optical images it was almost difficult to precisely define the limit between the lake and the land. South-eastwards the water reached and inundated part of the informal areas.

The rapid flood map produced by means of Sentinel-1 radar image acquired on 11 March 2018 confirms this spatial extension, since the binary water mask shows many water surface pixels (coloured in red) detected inland the shoreline of the lake, identifying the flooded zones (Figure 6c). From the NDWI map we can also extract the current water surface area along the lake, which reveals alike results (Figure 6d).

Figure 7 shows images referred to 14 August 2017, chosen as date in summer period when no flood or critical lake fluctuation event occurred. The RGB colour composites true colors and SWIR/NIR/Red derived from Sentinel-2 optical imagery acquired on 15 August 2017 (Figure 7a,b) reveal dry pattern images and the water level of the lake appears extensively below the one detected in previous images acquired on flood event dates. In this case, the boundary between lake and land is well defined and easily recognizable. There was no influence of water on land, both over agricultural territories or over informal areas.

The rapid flood map produced by means of Sentinel-1 radar image acquired on 14 August 2017 as well as the NDWI map produced by means of Sentinel-2 optical image shows an identical reduced spatial extension of Shkodër lake, confirming the water level dropped down during the dry season (Figure 7c,d).

Finally, the validation step was performed by combining the obtained results based on satellite Sentinel-1 radar image acquired on 11 March 2018 (shown in Figure 5c) with the official delineation maps available through the Copernicus EMS (activation ID EMS273). The EMS maps were produced for the Shkodër area situation on 18 March 2018 by employing RADARSAT-2 scene acquired on 14 March 2018 and Sentinel-1 scene acquired on 18 March 2018. These official data were achieved by using ESRI World Imagery as background ortophoto and by rapid processing of satellite SAR imagery.

Results comparison (Figure 8) shows a successful spatial agreement between the EMS map and the rapid flood map produced throughout our Sentinel-1 radar-based procedure. Good spatial overlapping between the two maps is obtained over the flooded areas along Shkodër lake, while slightly dissimilar results are obtained along rivers, possibly due to the later date (18 March 2018) of the EMS delineation map.

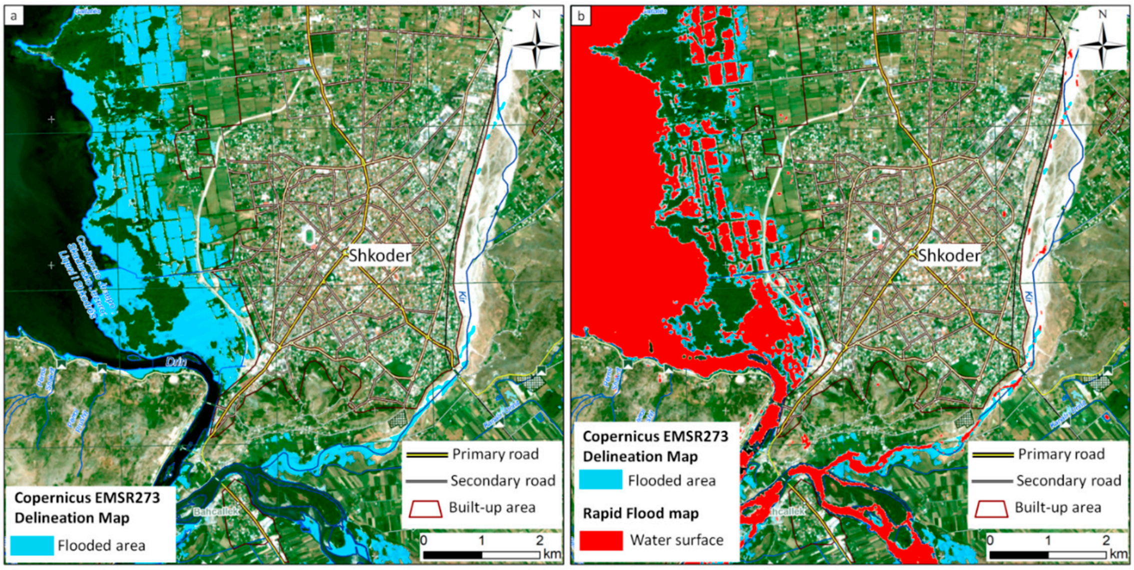

Figure 8. (**a**) COPERNICUS Emergency Management Service (EMS) delineation map: Situation as of 18 March 2018 (activation ID EMS273); **(b**) rapid flood map as binary water mask based on Sentinel-1 radar image acquired on 11 March 2018, overlapped on EMS Delineation map displayed in (1).

6. Discussion

The present availability and free access of Sentinel satellites data allow producing costless and rapid data with high spatial and temporal resolutions for surface water mapping on wide areas. The advances in managing such remotely-sensed satellite data have led to the development of various near real-time, semi-automated flood mapping algorithms [31,35]. As a result, Sentinel-1 and Sentinel-2 satellite imagery can easily support and provide useful information during an emergency or calibrate and validate hydrodynamic models during ordinary time, enhancing stakeholders understanding and accurate mapping of flood extents for environmental planning strategies [36–38]. The optical data are easily accessible and exploitable through the EO Browser platform (https://apps.sentinel-hub.com/eo-browser/) that allows basic processing. Nevertheless, the interpretation has to be carried out by expert users in order to consider the limitations of the data (e.g., cloudy scenes) and to avoid misunderstanding. Also, the radar data can be freely downloaded and quickly processed by user-friendly free software, but expert-knowledge and specific software is needed for an in-depth interpretation.

The validation of our outputs performed by comparing the satellite data with official Copernicus EMS map on the 11 March 2018 flood event shows good accordance results. It is worth to highlight that in our proposed methodology no refinement was applied to the SNAP processing as an overall overview was obtained at large scale. Conversely, a more accurate result could be obtained by performing post-processing edit to further refine the inundation areas at a more detailed scale such as supervised classification to filter out isolated flood elements, to remove possible water-lookalikes and to weed out false positives. Furthermore, in order to distinguish inundated areas from permanent water bodies related to the usual water level of the lake and the river, a reference "water mask" could be applied, for instance by using SWBD (SRTM water body data) source. Nevertheless, the results of this work show that the 1 December 2017 event has the minimum extension, as only scattered fields closest to the coastline, are submerged by a water sheet (with a spatial increase towards south) and none of the informal areas seems to be directly impacted by the event. On the contrary, the 5 March

2018 and 11 March 2018 events affected many natural vegetated areas and open spaces reserved for livestock farming (mainly cattle) covering most of the Ramsar protected area. Moreover, these last two events affected the informal area n° 6 in the topographically lower coastal areas and reached the south-west border of the informal area n° 2. In both cases, floods were due to the combination of the rapid rise of the lake level with the insufficient drainage capacity of the Buna river; the downstream hydrographic node was crucial in relation to the contingent hydraulic conditions, through which the lake waters have to be necessarily disposed of. However, in these occasions the more careful management of water flows passing through the upstream dams along the Drin river with respect to the past (e.g., contrary to the 2010 mismanagement) allowed to contain the water level, to limit the flooding expansion and to reduce the impact in the coastal urban areas. This improved management also produced positive effects on the informal area n° 5, which is normally exposed to high risk of flooding due to its geographical position related to the hydraulic dynamics of the bordering Drin river; the improvement makes this informal area to not suffer damaging inundations as in the recent past events. No one of the other informal areas were significantly affected by these events.

Furthermore, analysing the 2018 maps with regard to the distribution of the anthropic elements, some points of attention relevant for the local dynamics reconstruction were identified in the informal area n° 2 and in its adjacent natural areas. Such situations were subsequently verified and examined in detail with onsite visual surveys. In this case, the overflowed water distribution was not only the consequence of the artificial hydraulic regulation in response to the existing water flows, but rather also the effect of the structural interventions undertaken on the territory to secure the city from widespread floods. In particular, after the 2010 disastrous events, the local administration began to think of new urban planning and the World Bank financed the construction of an elevated earth embankment (up to 4 m above the plain elevation) working both as a ring road and, at the same time, as a protective levee against high floods. The design and the related construction work, now clearly visible in most of the satellite images, started in 2011/2012 in response to the increased need for security that emerged in the population after the consequences of the 2010 events, but it has not yet been concluded. Despite this effort, the already completed sections (especially close to the emissary river outflow) did not perform their protective function and large amounts of water filtered through the structure and locally through some open conduits currently with no protection. The road itself was not overflowed and therefore the size of the engineering work was well dimensioned: It did not suffer any structural damage, so the construction techniques were applied very well, whereas the materials assemblage was not able to contain all the spreading waters with a poor functionality of flow containment. Therefore, if on the one hand this structure is not able to stop a medium-sized inundation like the one analyzed, on the other hand it even creates stagnation zones with unnatural characteristics on the outside plain close to the urban landscape: (i) High water levels for long times, (ii) blockage of natural runout and surface outflows, (iii) fragmentation of the entrenched ecological continuity and creation of isolated spatial units, (iv) variation of the edaphic conditions. Despite these environmental consequences, the current Shkodër master plan (approved by the municipality in 2017) aims to finish and reinforce this road work since it is considered as a relevant boundary limit between the area which can be directly flooded by the normal fluctuations of the lake (outer side) and the area of urban interest to be preserved (inner side). In the vision of this territorial planning, the portion of land facing the lake is destined only for public green with a strict building ban, while the inland area towards the city center is considered of anthropic concern and possible urban enlargement. The proposed results can help to refine the definition of territorial characteristics in case of future targeted interventions or initiatives to tackle the aforementioned water/soils problems and to support the consequent political decisions.

7. Conclusions

Until today the environmental management of the city of Shkodër has not properly taken into account the water areas and their spatial variations across time although they have long been praised as a valuable area of development, as well as a natural wealth of high global significance for the existing ecological dynamics. With this awareness, Shkodër city is now at the beginning of a third phase of urbanization during which laws and regulations must be developed and enforced so that all real estate (existing or of new construction) will eventually become entirely formal in compliance with the undeniable environmental issues. Beyond upgrading, the informal settlements need to be spatially, functionally and socially integrated into the urban system. The assimilation of citizens of these areas into the city requires not only the improvement of services but also the spatial integration of the informal settlements through public transport access and the extension of road and pedestrian networks. Such measures can facilitate links of proximity and exchange between new districts and the established neighbourhoods of the core city. However, in approaching such development activities, we have to consider that the city of Shkodër is not still equipped with extensive, systematic, and quantitatively adequate hydraulic defence works able to control and regulate all the floods coming from the lake (its main hydraulic threat). Insufficiently designed and questionable existing interventions do not make the entire area enough safe.

The use of European Space Agency satellites Sentinel-1 radar data and Sentinel-2 optical data was successfully tested to evaluate the extension of the 2018 Drin and Buna Rivers overflow and of the Shkodër lake plain flooding. By means of Sentinel-2 data, two RGB colour composites maps and the NDWI map were produced, while using Sentinel-1 data a rapid flood mapping was generated. The proposed approach outputs were validated comparing them with official Copernicus EMS map available for one of the chosen events. This comparison shows good accordance results even if some refinement like post-processing edit can be applied (a) to filter out isolated flood elements, (b) to remove possible water-lookalikes, (c) to weed out false positives, and (d) to distinguish inundated areas from permanent water bodies related to the usual water level of the lake and river. Results show that natural vegetated area and agricultural ones located beside the lake are mainly affected by the water fluctuations. Summarizing: (a) The 1 December 2017 event has the minimum extension, and none of the informal areas seems to be directly touched by the event; (b) the 5 March 2018 and 11 March 2018 events, combined with the lake level rapid rise, the insufficient drainage capacity of the Buna river and of the downstream hydrographic node, affected many natural vegetated areas, the informal area n° 6, and reached the south-west border of the informal area n° 2; (c) the improved management of the upstream dams produced positive effects on the informal area n° 5, normally at high risk for its geographical position, as it did not suffer harmful inundations as in the recent past events; (d) no one of the other informal areas were significantly affected by these events.

Finally, as emerged from this work: (1) The results of this study show that Sentinel-1 and -2 data are complementary approaches to detect water level variations across time and hence to support a sustainable urban management and planning; (2) the use of other radar historical ESA archives (i.e., ERS and ENVISAT satellites) dated back to 1992 and of optical data available since the 1940s by exploiting satellite and aerial imagery allow researchers to perform a "back analysis" to improve the knowledge on the historically more prone to inundation areas; (3) the proposed satellite elaborations, if supported by a multidisciplinary territorial analysis, can help to understand flood/inundation hazard both from a broad point of view to a detailed point of view, given the high quality of the produced data; (4) we believe that the presented methodology could be easily applied by the local administrations to map the water surface and subsequent to prevent and manage flood in the inherited territorial context and to assess the flood vulnerability that has to be included in the city and regional master plan vulnerability assessments.

Author Contributions: Conceptualization, S.M.; methodology, S.M., M.D.S. and S.B.; software, M.D.S., S.B.; validation, E.K., E.S.; formal analysis, S.M.; investigation, S.M., M.D.S. and S.B.; resources, E.K., E.S. and N.C.; data curation, S.M., M.D.S., S.B. and V.P.; writing—original draft preparation, S.M., M.D.S., S.B., V.P. and E.K.; visualization, V.P.; supervision, S.M., N.C.; project administration, N.C.

Funding: This research received no external funding.

Acknowledgments: The authors would like to thank the local authorities and University of Shkodër for the provided support in data collection and in the technical suggestions about the real needs of the local community in relation to flood prevention.

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

References

1. Morelli, S.; Battistini, A.; Catani, F. Rapid assessment of flood susceptibility in urbanized rivers using digital terrain data: Application to the Arno river case study (Firenze, northern Italy). *Appl. Geogr.* **2014**, *54*, 35–53. [CrossRef]
2. Clement, M.A.; Kilsby, C.G.; Moore, P. Multi-temporal synthetic aperture radar flood mapping using change detection. *J. Flood Risk Manag.* **2018**, *11*, 152–168. [CrossRef]
3. Jung, H.C.; Hamski, J.; Durand, M.; Alsdorf, D.; Hossain, F.; Lee, H.; Hossain, A.; Hasan, K.; Khan, A.S.; Hoque, A. Characterization of complex fluvial systems using remote sensing of spatial and temporal water level variations in the Amazon, Congo, and Brahmaputra Rivers. *Earth Surf. Process. Landf.* **2010**, *35*, 294–304. [CrossRef]
4. Schlaffer, S.; Matgen, P.; Hollaus, M.; Wagner, W. Flood detection from multi-temporal SAR data using harmonic analysis and change detection. *Int. J. Appl. Earth Obs. Geoinf.* **2015**, *38*, 15–24. [CrossRef]
5. Bioresita, F.; Puissant, A.; Stumpf, A.; Malet, J.P. A method for automatic and rapid mapping of water surfaces from sentinel-1 imagery. *Remote Sens.* **2018**, *10*, 217. [CrossRef]
6. Chapman, B.; McDonald, K.; Shimada, M.; Rosenqvist, A.; Schroeder, R.; Hess, L. Mapping Regional Inundation with Spaceborne L-Band SAR. *Remote Sens.* **2015**, *7*, 5440–5470. [CrossRef]
7. Lu, J.; Giustarini, L.; Xiong, B.; Zhao, L.; Jiang, Y.; Kuang, G. Automated flood detection with improved robustness and efficiency using multi-temporal SAR data. *Remote Sens. Lett.* **2014**, *5*, 240–248. [CrossRef]
8. Pulvirenti, L.; Chini, M.; Pierdicca, N.; Boni, G. Use of SAR for detecting floodwater in urban and agricultural areas: The role of the interferometric coherence. *IEEE Trans. Geosci. Remote Sens.* **2016**, *54*, 1532–1544. [CrossRef]
9. Radulović, M.; Sekulic, G.; Blagojevic, M.; Krstajic, J.; Vako, E. An assessment of territory participation in transboundary karst aquifer recharge: A case study from the Skadar Lake catchment area. In *Karst without Boundaries*; Stevanovic, Z., Krešić, N., Kukuric, N., Eds.; CRC Press: Boca Raton, FL, USA, 2016; pp. 93–105.
10. Pešić, V.; Glöer, P. A new freshwater snail genus (Hydrobiidae, Gastropoda) from Montenegro, with a discussion on gastropod diversity and endemism in Skadar Lake. *ZooKeys* **2013**, *281*, 69–90.
11. Asch, K. The 1:5 Million International Geological Map of Europe and Adjacent Areas: Development and Implementation of a GIS-enabled Concept. In *Geologisches Jahrbuch, SA 3*; Hannover, B.G.R., Ed.; Schweitzerbart: Stuttgart, Germany, 2003; p. 172.
12. Pešić, V.; Karaman, G.; Kostianoy, A. The Skadar/Shkodra Lake Environment. In *The Handbook of Environmental Chemistry*; Springer: Cham, Switzerland, 2018; Volume 80.
13. Prendi, F. Epoka e bronzit dhe e hekurit në kërkimet shqiptare/Bronze and Iron Age in Albanian Researches. *Iliria* **1998**, *28*, 73–103. [CrossRef]
14. Bogdani, M.; Selenica, A. Risk assessment from floodings in the rivers of Albania. In *Variability in Time and Space of Extreme Rainfalls, Floods and Droughts, Proceedings of the 2nd International Workshop on Hydrological Extremes, Cosenza Italy, 6–8 June 2007*; Ferrari, E., Versace, P., Eds.; Nuova Editoriale Bios, S.N.C.: Castrolibero, Cosenza, 2008; pp. 155–162.
15. Radulović, M.; Radulovic, M.; Stevanovic, Z.; Sekulic, G.; Radulovic, V.; Buric, M.; Novakovic, D.; Vako, E.; Blagojevic, M.; Devic, N.; et al. Hydrogeology of the Skadar Lake basin (Southeast Dinarides) with an assessment of considerable subterranean inflow. *Environ. Earth Sci.* **2015**, *74*, 71–82. [CrossRef]
16. Meon, G.; Pätsch, M. Assessment Study for Gaps and Needs in Establishing a DEWS (Drin Early Warning System). Final Report for GIZ. 2013. Available online: balwois.com/wp-content/uploads/2015/02/2013-Drin_Final-Report-GIZ-with-annexes.pdf (accessed on 9 August 2019).

17. Fusto, F.; Niccoli, R. A prototype of flood alert system and the strengthening of hydrometeorological network of Shkoder area for civil emergencies. Some aspect of Italian Regional cooperation support program-RIVA project. In Proceedings of the BALWOIS 2012—Fifth International Scientific Conference on Water, Climate and Environment, Ohrid, Macedonia, 28 May–2 June 2012; Volume 2012-0118, pp. 1–10.
18. Peel, M.C.; Finlayson, B.L.; McMahon, T.A. Updated world map of the Köppen-Geiger climate classification. *Hydrol. Earth Syst. Sci. Discuss.* **2007**, *4*, 439–473. [CrossRef]
19. Grimmett, R.F.A.; Jones, T.A. *Important Bird Areas in Europe. ICBP Technical Publication No. 9*; International Council for Bird Preservation: Cambridge, UK, 1989; p. 889.
20. Kastratović, V.; Jaćimović, Ž.; Đurović, D.; Bigović, M.; Krivokapić, S. Lemna minor L.: As bioindicator of heavy metal pollution in Skadar lake: Montenegro. *Kragujev. J. Sci.* **2015**, *37*, 123–134. [CrossRef]
21. Krymbi, E.; Shpori, E. Spatial analysis of informal area: A case study of Shkoder city, Albania. *Balk. J. Interdiscip. Res.* **2018**, *4*, 21–33.
22. Tsenkova, S. Informal settlements in post-communist cities: Diversity factors and patterns. *Urbani izziv* **2010**, *21*, 73–84. [CrossRef]
23. Rustja, D. The Role of Geography in Managing Spatial Development Processes: The Case of the Peri-urban Area of Shkodër City, Albania. *Hrvat. Geogr. Glas.* **2011**, *73*, 81–92. [CrossRef]
24. Pazzi, V.; Morelli, S.; Fidolini, F.; Krymi, E.; Casagli, N.; Fanti, R. Testing cost-effective methodologies for flood and seismic vulnerability assessment in communities of developing countries (Dajç, northern Albania). *Geomat. Nat. Haz. Risk* **2016**, *7*, 971–999. [CrossRef]
25. Qirko, K. The steps followed for the implementation of formalization of informal buildings/zones by ALUIZNI in the Republic of Albania. In Proceedings of the Global Land Tool Network Expert Group Meeting, "Tools for Legal Integration and Provision of Environmental Improvements in Informal Settlements in Europe: Case Study: Albania, Greece", Athens, Greece, 27–28 November 2008.
26. Lushaj, B.; Hoxhaj, F.; Ndini, M.; Selenica, A.; Pambuku, A.; Dafa, I.; Hasimi, A.; Zaimi, K.; Marku, M.; Çomo, E.; et al. General Overview of the Transboundary Waters of Rivers, Lakes, Groundwater and Trend of them, in Albania. *Online Int. Interdiscip. Res. J.* **2016**, *6*, 418–446.
27. Pazzi, V.; Morelli, S.; Fidolini, F. A way forward to enhance the coping capacity of communities threatened by floods: The Dajc experience (Northern Albania). *Rend. Online Soc. Geol. Ital.* **2015**, *35*, 228–231. [CrossRef]
28. Pojani, E.; Tola, M. The effect of climate change on the water sector with a case study of Albania: An economic perspective. In Proceedings of the BALWOIS 2010—The Fourth International Scientific Conference on Water Observation and Information System for Decision Support, Ohrid, Macedonia, 25–29 May 2010; pp. 1–19.
29. Dione, D.P.R.; Dickinson, K.A.; St Pierre, S.; Weiss, T.M. Reducing Flood Risk in Shkodra Through Community Engagement. 2017. Available online: https://digitalcommons.wpi.edu/iqp-all/887 (accessed on 9 August 2019).
30. Geudtner, D.; Torres, R.; Snoeij, P.; Davidson, M.; Rommen, B. Sentinel-1 system capabilities and applications. In Proceedings of the 2014 IEEE Geoscience and Remote Sensing Symposium, Quebec City, QC, USA, 13–18 July 2014; pp. 1457–1460.
31. Twele, A.; Cao, W.; Plank, S.; Martinis, S. Sentinel-1-based flood mapping: A fully automated processing chain. *Int. J. Remote Sens.* **2016**, *37*, 2990–3004. [CrossRef]
32. Schreier, G. Geometrical properties of SAR images. In *SAR Geocoding: Data and Systems*; Schreier, G., Ed.; Wichmann: Karlsruhe, Germany, 1993; pp. 103–134.
33. Radoux, J.; Chomé, G.; Jacques, D.; Waldner, F.; Bellemans, N.; Matton, N.; Lamarche, C.; D'Andrimont, R.; Defourny, P. Sentinel-2's potential for sub-pixel landscape feature detection. *Remote Sens.* **2016**, *8*, 488. [CrossRef]
34. McFeeters, S.K. The use of the Normalized Difference Water Index (NDWI) in the delineation of open water features. *Int. J. Remote Sens.* **1996**, *17*, 1425–1432. [CrossRef]
35. Matgen, P.; Hostache, R.; Schumann, G.; Pfister, L.; Hoffmann, L.; Savenije, H.H.G. Towards an automated SAR-based flood monitoring system: Lessons learned from two case studies. *Phys. Chem. Earth* **2011**, *36*, 241–252. [CrossRef]
36. Schumann, G.; Bates, P.D.; Horritt, M.S.; Matgen, P.; Pappenberger, F. Progress in integration of remote sensing-derived flood extent and stage data and hydraulic models. *Rev. Geophys.* **2009**, *47*, 4001. [CrossRef]

37. Schumann, G.; Dibaldassarre, G.; Bates, P.D. The utility of space-borne radar to render flood inundation maps based on multi-algorithm ensembles. *IEEE Trans. Geosci. Remote Sens.* **2009**, *47*, 2801–2807. [CrossRef]
38. Grimaldi, S.; Li, Y.; Pauwels, V.R.N.; Walker, J.P. Remote sensing-derived water extent and level to constrain hydraulic flood forecasting models: Opportunities and challenges. *Surv. Geophys.* **2016**, *37*, 977–1034. [CrossRef]