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SPATIO-TEMPORAL PATTERNS OF FLOODED AREAS IN THE LOWER PART OF THE SANA RIVER BASIN (BOSNIA AND HERZEGOVINA)

Abstract: Floods are the most frequent and devastating natural hazard event in Bosnia and Herzegovina. The detected increase in extreme precipitation over the study area in the last period has altered flood event patterns due to climate changes. Higher frequency of flood events and lack of flood protection infrastructure has a severe impact on socio-economic sectors and natural ecosystems. This paper focuses on the identification of flooded areas for each single flooding event in the lower part of the Sana river basin during the period 2016-2020. For delineating flooded areas, both radar and optical satellite imagery were used. Data obtained after processing remote sensing images were overlaid with a detailed land cover map in order to get insight into flooded land cover types. From temporal aspects, floods are most common during the spring season. They are usually caused by rapid snowmelt and prolonged excessive precipitation. Considering spatial aspects, flooded areas vary from 110 to 522 hectares in the study area. Over 95% of the flooded areas are arable land, meadows and pastures. Most affected settlements by floods are urban and suburban area of Prijedor, Gomjenica, Hambarine, Rakovčani, Rizvanovići, Brezičani, Donja Dragotinja, Vitasavci, Svodna, Blagaj Rijeka and urban area of Novi Grad. The applied methodological approach represents a starting point for further investigation of flooded areas in the Sana basin and data obtained by this analysis can be used in water management, spatial planning and emergency planning.

Key words: flooded areas, remote sensing, climate change, Sana river

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Introduction

Changes in the climate system in recent years and decades have been confirmed whilst many studies show that air temperatures have increased on various spatial levels (Fei et al., 2014; IPCC, 2022; Milovanović et al., 2018; van der Schrier et al., 2013). Regional studies showed that the seasonal and annual air temperature in Slovenia, Croatia, Serbia and Montenegro has pronounced and mostly significant positive trends in the late 20th and the beginning of 21st century (Bajat et al., 2015; Burić et al., 2014; Cindrić Kalin et al., 2018; Ducić et al., 2009; Milošević et al., 2013). The positive trends in annual air temperatures are mainly implicated by prominent summer and winter trends. The highest air temperature trend values are identified in summer, and then for winter and spring. In Bosnia and Herzegovina, an increase in mean and extreme air temperatures was determined over the entire territory, especially in the northern areas of the country (Popov et al., 2018; Trbić et al., 2017). During the period 1961–2015, the annual temperature increase was in the range of 0.2–0.5°C per decade. Although warming is apparent in all seasons, the trend is most prominent in summer, and then in winter and spring. A slight increase has only been observed in autumn (Trbić et al., 2017).

As opposed to air temperature, relatively distinguished precipitation patterns of insignificant trends have been reported on a global scale (Adler et al., 2017; Gu & Adler, 2015). Global scale studies also indicate that changes in precipitation extremes are in general consistent with a wetter climate (Donat et al., 2013; IPCC, 2022). Furthermore, there are more regions in the world where heavy precipitation events increased than those where they decreased (IPCC, 2022). Similar results were also obtained for the European continent (Chen et al., 2015; Klein-Tank & Können, 2003). On the regional level, annual precipitation showed no uniform trend (Ćulafić et al., 2020; Gajić-Čapka et al., 2015; Unkašević & Tošić, 2011), while precipitation intensity had regionally increased (Alpert et al., 2002; Andjelković et al., 2018; Tošić et al., 2016). Non-significant positive values were detected on the majority of meteorological stations in Serbia, Bosnia and Herzegovina and Montenegro, except for some stations (in mountainous areas) with a significant precipitation increase from 2% to 8% per decade (Milošević et al., 2021).

Trends in extreme precipitation in Bosnia and Herzegovina have similar characteristics as trends in the region where an increase in either the frequency or intensity of heavy precipitation was detected (Popov et al., 2017). The aforementioned studies show that the highest annual daily precipitation has increased since the year 1960. In the last decade, intensive precipitation caused several severe floodings and the most catastrophic flood has been recorded in the year 2014 when several locations in the Bosna river catchment recorded a maximum discharge that exceeded the return period of 500 years (Hydro-Engineering Institute Sarajevo [HIES], 2015).

Recent climate change has already affected the global hydrological cycle and these effects have manifested in changing the seasonal river discharges and increasing the frequency and severity of floods and droughts in some regions (European Environment Agency [EEA], 2017; Madakumbura et al., 2019). Because of their repetitive behaviour patterns, most types of floods are 'known risks' (White, 1942). Floods are restricted to floodplains and knowing their spatio-temporal patterns is beneficial for many sectors including water management, emergency response, agriculture, housing, transportation, etc.

Several studies conducted in the Southeast Europe region have already determined that changes in river discharges occurred. Changes in river discharges will have impact on frequency and severity of floods in the countries of Southeast Europe (Blöschl et al., 2017). A negative trend in annual and seasonal discharges was detected in all seasons except autumn for major rivers in Serbia (Kovačević-Majkić & Urošev, 2014). Negative discharge trends are also detected in all seasons over the entire North Macedionia (Radevski et al., 2018). In Montenegro, Morača river had downward trend in mean annual discharge for the period 1951–2010, but in the period 1991–2010 increasing trend in mean annual discharge was detected as a consequence of the growth of annual precipitation in the Morača river basin (Burić et al., 2016). In Slovenia, decrease in mean daily discharges was found at majority of hydrological stations (Ulaga et. al., 2008), while in Croatia discharges are decreasing in summer season but upward tendency was detected in autumn and winter seasons (Čanjevac & Orešić, 2015).

Trends in river discharges in Bosnia and Herzegovina are similar to the trends in the southeastern part of Europe. Mean annual discharges for Bosna, Vrbas, Vrbanja and Sana rivers displayed downward trends (Gnjato, 2018; Gnjato et al., 2019; Gnjato et al., 2021; Hadžić & Drešković, 2014). The most prominent decrease in river discharges was determined during the summer season at Sana and Vrbanja rivers (Gnjato et al., 2021). Regarding the increase in extreme precipitation in the region, it is expected that flooding in smaller basins could increase (Blöschl et al., 2019). Moreover, it is noticed that shifts in the timing of flooding are present in the region. According to the study by Blöschl et al. (2017) larger part of Bosnia and Herzegovina faced altered temporal flood patterns which resulted in earlier floods. Monitoring flood events is critical for gaining insights into causes and flood damages (Ghofrani et al., 2019; Refice et al., 2018).

For the simulation and visualization of flood areas, traditional methods such as hydraulic and topographic modelling can be used. The shortcomings of these methods are reflected in lower accuracy, high costs and time consumption (Khalifeh et al., 2019). On the other side, the integration of Geographic Information System (GIS) and remote sensing products have a great potential for monitoring, identifying and assessment of flooded areas. Different platforms such as satellites, aircraft and UAV-s can be used for mounting numerous types of active or passive sensors that gather remotely sensed data.

Optical or multispectral imagery can be used for mapping flooded areas when the area is not covered by clouds (Manakos et al., 2020; Sivanpillai et al., 2021). Due to the advancement in technology over the years, there is an increase in the availability of optical and multispectral remote sensed data both in terms of quality and quantity (Anusha & Bharathi, 2020). The number of satellites gathering optical and multispectral remotely sensed data are relatively higher than those that collect radar data. In this regard, chances for obtaining more pre and post-flood imagery are enhanced. If a visible image of a flooded area is available, image classification is often easier and straightforward. When flood events happen during periods of extended cloudiness the exploitation of optical and multispectral data may become limited. Thus, remote sensed radar data may be the only resource for the identification and monitoring of flooded areas.

The Sentinel-1 constellation offers a good foundation for mapping flooded areas (Huang et al., 2018), due to the frequent revisit time and relatively high resolution. Although radar sensed data provide a number of advantages there are some factors that are influencing the accuracy. For example, local environmental conditions, such as submerged vegetation or roughening of water surfaces due to the wind can significantly affect the quality of flooded area detection (Manakos et al., 2020; Uddin et al., 2019).

Although floods are the most frequent and devastating natural hazard in Bosnia and Herzegovina, the data on flooded areas after every single flooding event actually doesn't exist. Also, the effects of the flooding events were poorly documented and there is a lack of comprehensive studies with quantitative data on floods. In order to overcome the existing gaps in knowledge, the main goal of this paper is to identify the extent of flooded areas in the lower part of the Sana river basin in the period 2016–2021. For identification of flooded areas, both radar and optical satellite imagery were analysed during the single pre and post-flooding events. In addition, spatial extents of flooded areas obtained after remote sensing data processing were overlaid with a detailed land cover map in order to get insight into flooded land cover types. Results from this paper can be a starting point for further investigation of flooded areas in the Sana River basin as well as a suitable background for water management planning, spatial planning and emergency planning.

Study area

The Sana river basin is located in the north-western part of Bosnia and Herzegovina and the Republic of Srpska respectively (Figure 1). The watercourse of Sana is 146 km long and represents the most important tributary of the Una River. The overall area of the basin is 3782 km2 and the mean altitude of the basin is 505 m (Gnjato, 2018). The geology and hydrogeology of the basin are complex. Aquifers with karst-fracture porosity prevail in the southern (upper) part of the basin, while aquifers of intergranular and/or fracture porosity, as well as terrains without aquifers alternate in the rest of the basin (Spahić et al., 2014). The climate is altering from the mountain climate in the south to the moderate continental and continental in the central and lower part of the basin. Sana river is characterized by the pluvialnival water regime where the highest water levels are detected in April and the lowest in August (Gnjato, 2018). The average annual river discharge at the hydrological station Prijedor in the period 1961–2020 is 79,6 m^3/s. The study area encompasses the lower part of the Sana basin, starting at Miljakovci and Čarakovo villages and ending at the Una river confluence in Novi Grad. The total length of the Sana river within the study area is 41,1 km. In the study area, the Sana river flows through a relatively flat landscape where the majority of flood zones are located.

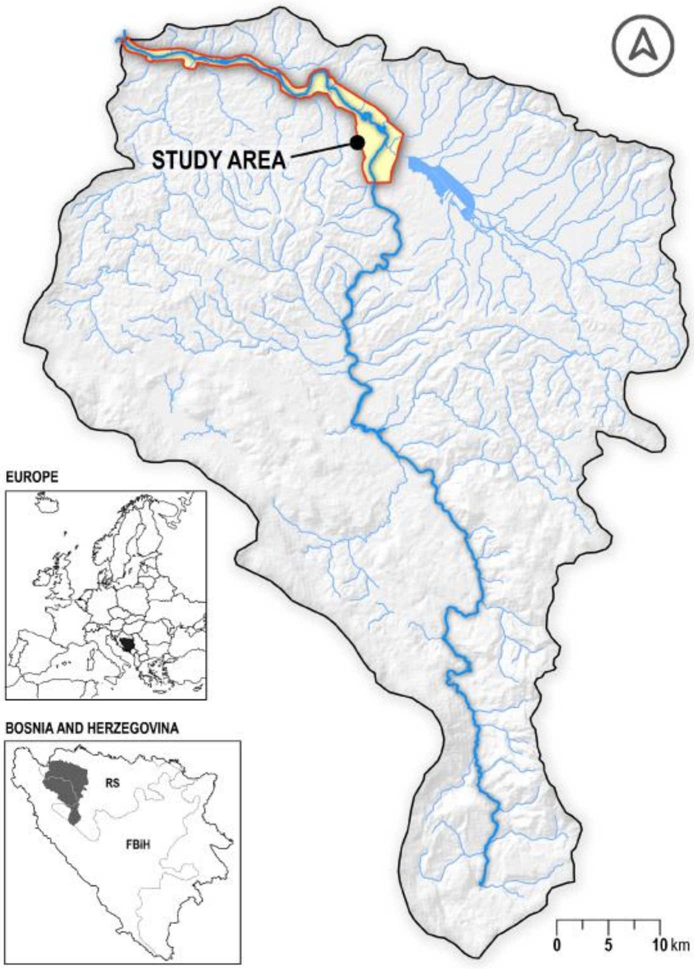

Fig. 1. Study area of the Sana river basin

Data and methods

River discharges and water level data

Daily data on river discharges and water levels (1961–2020) were collected for hydrological station Prijedor from the Hydrometeorological Service of the Republic of Srpska. The Prijedor hydrological station is the only station with continuous long-term measurements in the Sana river basin and is located in its lower part. Flood events were detected by observing the dates when the water level was higher than the elevation of regular/emergency flood defence and when the river discharge exceeds 500 m^3/s for three consecutive days. For the HS Prijedor, the elevation of regular flood defence is 420 cm and the elevation of emergency flood defence is 460 cm. Due to the limitations in the availability of both radar and optical satellite data, the time frame of detailed analysis was limited to the period 2016–2020. Also, trends in mean annual and seasonal river discharges were calculated by using nonparametric Mann-Kendall test and Sen's slope estimator, as a complement to this analysis.

Detailed land cover map

A detailed land cover map was prepared for the study area due to the lack of appropriate maps for analysis. As a mapping base layer, 24 tiles of digital orthophoto in scale 1:5000 was used. The main method of differentiation of land cover classes was imagery visual interpretation. Main classes were differentiated into built-up areas, infrastructure, agricultural land, vegetated areas and water bodies. All classes are further divided into subclasses (Table 1).

Tab. 1. Land cover classes and subclasses

Class	Subclass
Built-up areas	Housing
	Industry/commercial
	Special purpose buildings
	Non-productive land
Infrastructure	Roads
	Parking lots
	Railways
Agriculture land	Arable land
	Pastures and meadows
	Gardens around houses
	Orchards
Vegetated areas	Forest
	Shurb vegetation
	Urban green spaces
Water bodies	Watercourses
	Swamps, ponds and lakes

For some subclasses certain types are determined (e.g. roads - magistral, regional, local and uncategorized). During the process of land cover map creation, a total of 8191 polygons were digitalized in QGIS (version 3.16.3 Hannover) software.

Sentinel-1 radar satellite data and methodology for identification of flooded areas

Polar-orbiting imaging radar mission Sentinel-1, developed by European Space Agency, is characterized by high temporal and spatial resolution data, which allows a good foundation for flood mapping (Clement et al., 2017; Huang et al., 2018). Sentinel-1 Synthetic Aperture Radar (SAR) provides continuous day and night imagery in all weather conditions, at C-band with frequency within the microwave portion of the electromagnetic spectrum. The C-SAR instrument supports operation in dual (horizontal and vertical) polarization (HH+HV, VV+VH) implemented through one transmit chain (switchable to H or V) and two parallel receive chains for H and V polarization. (Jutz & Milagro-Pérez, 2018). A total of 3 Sentinel-1B Ground Range Detected products, between 4th and 27th March 2019 were downloaded from Copernicus Open Access Hub (Table 2). These products belong to the same orbit cycle as the Sentinel-1B satellite. The satellite image obtained by Sentinel-1B on 4th March 2019 is considered a pre-flood image. The image taken on 15th March 2019 is considered an image during the flood, while the image from 27th March 2019 represents a post flood image. All these images form input images for analysis (Tab. 2). Images were downloaded from Copernicus Open Access Hub (https://scihub.copernicus.eu/dhus/#/home).

Tab. 2. Specification of the SAR data

Satellite	Sentinel-1B	Sentinel-1B	Sentinel-1B
Stage	Before flood	During flood	After flood
Date	04.05.2019	15.05.2019	27.05.2019
Instrument	SAR-C	SAR-C	SAR-C
Mode/Beam	IW	IW	IW
Resolution	High	High	High
Polarisation	Single - VV	Single - VV	Single - VV
Product level	L1	L1	L1
Product type	GRD	GRD	GRD
Identifier	S1B_IW_GRDH_1SDV_20190504T164922_20190504T164947_016097_01E47B_BB92	S1B_IW_GRDH_1SDV_20190515T050156_20190515T050221_016250_01E955_B4BE	S1B_IW_GRDH_1SDV_20190527T050203_20190527T050228_016425_01EEB6_925F

The initial step in delineating flooded areas was pre-processing of downloaded satellite imagery. Pre-processing of imagery is used for rectification of radiometric and geometric distortions due to the characteristics of the imaging conditions and imaging system. The Science Toolbox Exploitation Platform (SNAP) open-source software, developed by ESA, was used for Sentinel-1 data pre-processing. During the pre-processing stage, Level-1 images were imported into SNAP software. The first operation was to remove thermal noise and apply the orbit file. Then, a tool for removing GRD border noise was used, as well as tool for imagery calibration. After imagery calibration, a speckle filter was applied along with terrain correction. After pre-processing step, the imagery was ready for further analysis. The second step for delineating flooded areas from non-flooded areas refers to the thresholding method. This method relies on the fact that the backscatter of water is lower than the surrounding area (Manakos et al., 2020). A threshold is determined on the first histogram valley that indicates low intensity area that corresponds to flooded areas. In this manner, preliminary flooded area maps are generated. Preliminary flooded areas were exported in GIS readable format for further analysis. To avoid misclassification and optimize results, a detailed land cover map was used to eliminate objects that are similar to potentially flooded areas. With the detailed land cover map, flooded areas can be excluded from permanent water bodies in the study area, enabling the generation of final maps of flooded areas. This is done with geoprocessing tools in QGIS.

PlanetScope optical satellite data and methodology for identification of flooded areas

The PlanetScope constellation provides high-resolution imagery (3-5 meters resolution) with daily revisiting time. The PlanetScope Analytic Ortho Scene Products (PSAOSP) were used for delineating flooded areas during cloud free conditions over the study area (Table

3). Orthorectified PSAOSP data consist of a 4-band multispectral image (blue, green, red and near-infrared) with applied radiometric corrections as well as atmospheric corrections (Frazier & Hemingway, 2021). Multi-temporal cloud free imagery from pre-flood, during a flood and post-flood events, were used for analysis. Because of the existence of cloud free imagery over the entire study area during the flood event in March 2018, flooded areas were successfully identified. On the other hand, imagery from the flood event that occurred in May 2019 did not meet the requirements for complete identification of flooded areas.

Tab. 3. The PlanetScope Analytic Ortho Scene Products reference data

Product	Date	Event	Area coverage
PSAOSP	09.03.2018	Pre-flood	Full
PSAOSP	11.03.2018	During flood	Full
PSAOSP	15.03.2018	During flood	Full
PSAOSP	25.03.2018	Post flood	Full
PSAOSP	11.05.2019	Pre-flood	Partial
PSAOSP	18.05.2019	During flood	Partial
PSAOSP	24.05.2019	Post-flood	Partial

There are several approaches that rely on band ratios obtained from spectral data and threshold values for identifying water bodies such as Normalized Difference Water Index (McFeeters, 1996), Modified Normalized Difference Water Index (Xu, 2006), New Water Index (Ding, 2009) and Automated Water Extraction Index (Feyisa et al., 2013). Considering multispectral properties of reference data, Normalized Difference Water Index (NDWI) was chosen for delineating of flooded areas. The NDWI uses a near-infrared and green band to enhance the presence of water bodies and is calculated as follows:

$$NDWI = (green - NIR) / (green + NIR) \quad (1)$$

The selection of these bands was used in order to maximize the reflectance of water by using green light wavelengths and to minimize the low reflectance of NIR by water bodies. Also, the selection of these bands takes advantage of the high reflectance of NIR by vegetation and soils (McFeeters, 1996). In other words, after the imagery processing, water bodies will have positive values, while vegetation and soils will have zero or negative values. All operations with imagery and NDWI calculations were done in QGIS software by raster calculator and geoprocessing tools. In addition, a detailed land cover map was used for the optimization of the results.

Results and Discussion

The mean annual and seasonal values of river discharges over the period 1961–2020 indicate that there are negative discharge trends, except autumn season were slight increase of river discharges were detected in period 1990–2020 (Table 4). The highest discharge values were registered in spring (119.3 m^3/s), and the lowest in summer (41.3 m^3/s).

Tab. 4. Average annual and seasonal discharges values in 1961–1990 and 1991–2020 (m^3/s) and annual trend values in the period 1961–2020

Period/season	Annual	Winter	Spring	Summer	Autumn
1961–1990	81.6	98.2	122.5	47,7	57.5
1991–2020	76.4	95.7	116.0	35.0	58.7
Trends in 1961–2020	-0.27	-0.3	-0.05	-0.38	-0.14

Following the upward trend of extreme precipitation events, it can be noticed that flooding events became more frequent over the study area (Figure 2). Flooding events registered in the period 1995–2020 have increased fourfold compared to the period 1961–1989. Observing seasonal distribution, the number of flood events in the period 1961–1987 was slightly higher during the summer than spring season. The seasonal distribution of flood events has changed significantly in the period 1995–2020 when spring floods were recorded in greater numbers than flood events in the summer season. Observed changes are directly related to climate changes, especially considering the changes in air temperatures and precipitation patterns on the annual and seasonal scale which ultimately have an impact on flood events.

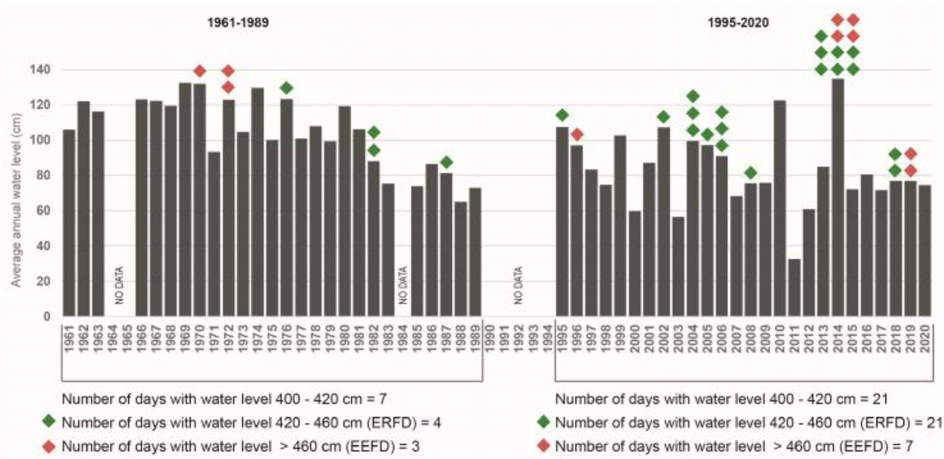

Fig. 2. Number of days with a water level that exceeds an elevation of regular and emergency flood defence over the period 1961–2020.

Detailed analysis of daily data on river discharges and water levels in the period 2016–2020 showed that flooding events could be detected only when water levels exceed the elevation of regular flood defence (420 cm) and elevation of emergency flood defence (460 cm). In this case, a total of two flood events in the period 2016–2020 were detected and spatially delineated using remote sensing products. The first flooding event was registered in march 2018 when the maximum water level was 428 cm at the HS Prijedor. Because of cloud free conditions in march 2018, high-resolution optical images were used for delineation of flooded areas. A total of 4 dates were analysed which include pre-flood, during a flood and post-flood events.

The first occurrences of small-scale flooding were recorded on march 9 when the water level reached 378 cm. Interpretation of high-resolution optical imagery revealed that water has covered smaller areas directly along the river, as well as smaller natural depressions located downstream from the city of Prijedor. The flooded area at this date was 110 ha. In the following days, the water level was constantly growing up to march 13, when the water level reached a maximum of 428 cm, respectively water discharge was 716 m^3/s. After interpretation of high-resolution optical imagery from March 11, it was identified that flooded areas covered 363 hectares. Imagery from March 15, indicate that flooded areas spanned to 518 hectares (Figure 3). At the end of the month, more precisely on the 25th of March, the water level dropped to 190 cm but 17 ha were still covered by a thin layer of water, mostly in smaller natural depressions which are adjacent to the Sana river. Arable land took the largest share in the flooded areas with 69.1% while pastures and meadows are present with 25.7% of the total flooded area. Even though the large areas of agricultural land were flooded, severe damages were not recorded because the majority of parcels were not sown and the flooding duration was short. Even though other land cover categories such as housing, industry, commercial, roads, and railroads were spatially less covered by floods, property damage was recorded. After the analysis, a total of 226 residential and commercial buildings, as well as a larger number of auxiliary buildings, were affected by the floods. It is important to stress that 30% of above-mentioned buildings were directly affected by floods with different proportions of material damage, while the rest of the objects were affected indirectly or suffered minimal material damage. From the location aspect, the largest number of affected objects were recorded in the urban and suburban areas of Prijedor, while a smaller number of affected objects were registered in rural settlements of Gomjenica, Hambarine, Rakovčani, Rizvanovići and Donja Dragotinja. In the municipality of Novi Grad, the largest number of the affected object were registered in the urban area of Novi Grad, and some affected objects were registered in Blagaj Japra, Blagaj Rijeka and Vitasavci. When it comes to the road infrastructure, it was recorded total of 134 locations where water was adjacent to the road or covering the road itself. Major roads were passable, while some streets in the urban area of Prijedor, as well as several sections of uncategorized roads in rural areas, were temporarily impassable.

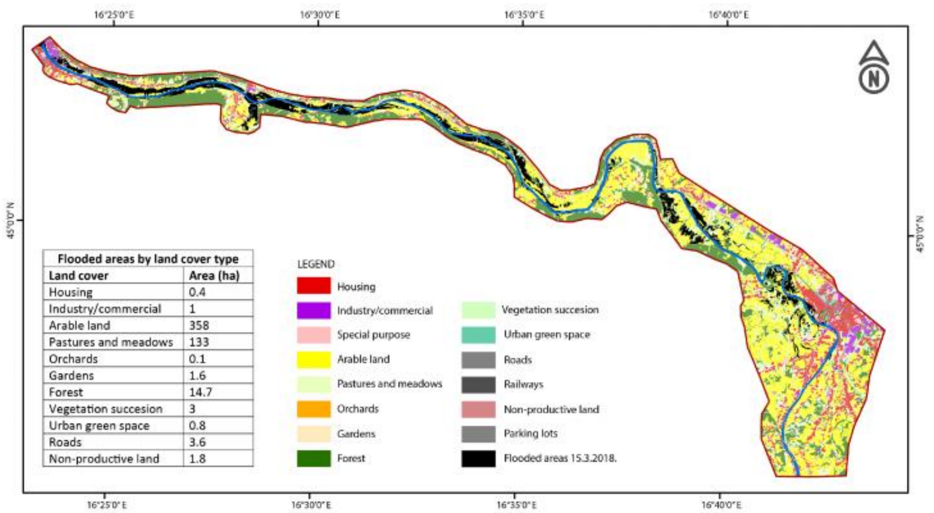

Fig. 3. Flooded areas during the March 2018

The flood event in May 2019 was slightly different compared to the flood event that occurred in March 2018 because there was a coincidence with the high-water level on the

Gomjenica river, the right tributary of the Sana river. The water level at HS Prijedor rose from 123 cm to 320 cm in the period from 12 to 13 May 2019. The next day (14.5.2019.) water level exceeded the elevation of emergency flood defence and reached the maximum value of 474 cm, respectively water discharge was 902 m^3/s. Due to the cloudy weather in May 2019, there were difficulties in optical imagery use. Only smaller parts of the scene were visible to optical instruments so radar products were used for delineation of flooded areas. A total of three dates were examined including the pre-flood event (04.05.2019), during flood event (15.5.2019) and post-flood event (27.05.2019). By interpretation of radar products, no flooded areas were detected on scenes from pre-flood and post-flood events. Image taken on March 15, 2019 revealed the extent of the flood (Figure 4). The total flooded area was 522.4 ha. Unlike the year before, arable land participated with 81.3% of total flooded areas. Pastures and meadows followed by 16% in total flooded areas while other land cover categories participated in a much smaller proportion. When it comes to material damage, the flooding event from 2019 was more serious than the flooding event from 2018. It is estimated that at least 341 residential and commercial buildings were affected by floods of which 25% were affected directly. The most affected areas were Gomjenica and the urban and suburban areas of Prijedor. Less affected areas refer to rural settlements of Hambarine, Rakovčani, Rizvanovići, Brezičani and Donja Dragotinja in the municipality of Prijedor. Also, floods affected Trgovište, Svodna, Vitasavci, Blagaj Rijeka, and the urban area of Novi Grad in the municipality of Novi Grad. After analysis of detailed land cover, it was detected a total of 121 locations where water was adjacent to the road or covering the road itself. Some sections of major roads in the study area were impassable for a short period of time because of the rapid rise of the water level. Also, several sections of uncategorized roads in rural areas were temporarily impassable during this flooding event which resulted in a disturbed local traffic regime.

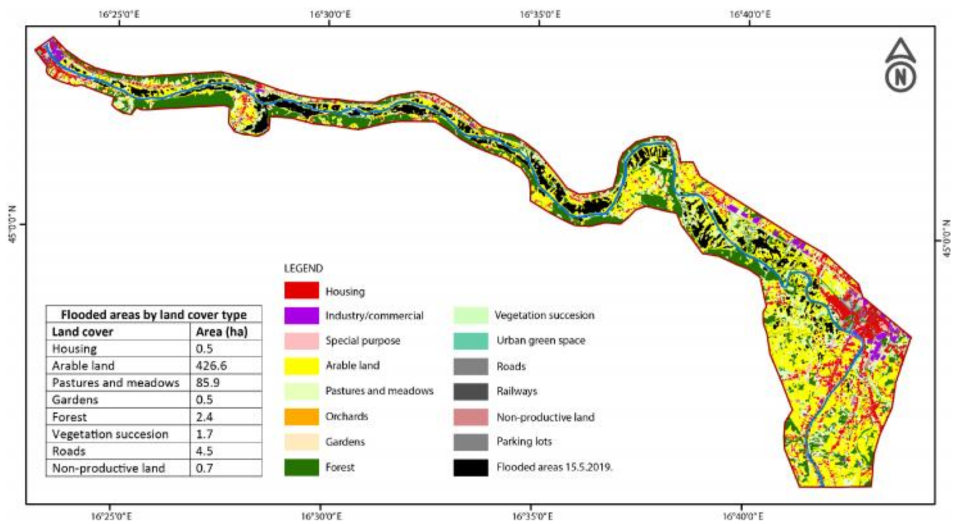

Fig. 4. Flooded areas during the May 2019

The obtained results indicate that some areas and locations are continuously affected by floods when water level exceed 420 cm at HS Prijedor (Figure 5). Flooded areas are evenly distributed both on the left (225.8 ha) and right (228 ha) side of the Sana river. These areas are adjacent to the Sana river and they are spread over the following settlements:

Gomjenica, Prijedor, Hambarine, Rakovčani, Rizvanovići, Donja Dragotinja, Blagaj Rijeka, Vitasavci and Novi Grad. Areas that are continuously flooded are mostly arable land (76.5%) and pastures and meadows (22%) while other land cover classes participate in a much smaller proportion. Even though the largest flooded areas are located in Vitasavci (34.9 ha), Blagaj Japra (32.9 ha) and Donja Dragotinja (29.4 ha) the major material damage was recorded in the urban and suburban areas of Prijedor, Gomjenica, and Novi Grad.

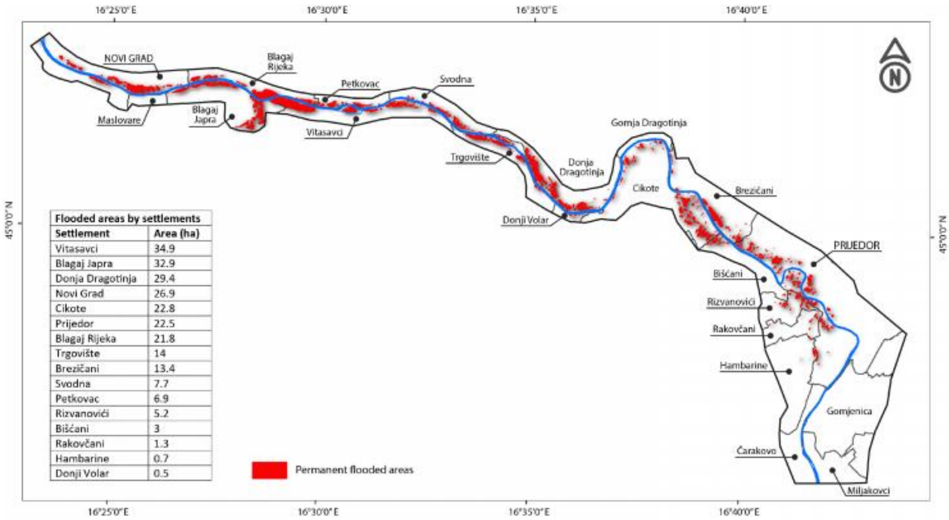

Fig. 5. Permanent flooded areas (flooding events 2018. and 2019.)

Material damage to residential and commercial buildings was caused mainly because of poor land use planning, lack of flood protection infrastructure and insufficiently developed sewage system. Endangered objects are mostly built during the 1990s and 2000s, more precisely when urban sprawl started without an adequate urban plan. In that period, objects in flood-prone zones were built mainly by refugees and other immigrants because of the lower land prices. That led to complex situations when it comes to flood defence. To date, local government did not identify flood-prone zone nor adopted special conditions for construction in these areas. Besides housing and the commercial sector, agricultural activities are also endangered by floods. The period of highest probability of flooding events coincides with a period of agricultural operations in the springtime like plowing and sowing. Thus, there can be disruption in agricultural operations in flooding zones which can lead to financial losses. For further activities related to flood protection, spatial data on flooding areas are crucial. The methodology used in this paper can be adequate for the delimitation of flooded areas. Remote sensed radar and optical imagery, combined together, may provide usable spatial data of flooded areas during different flooding events and different weather conditions especially when there is no official data on floods. Data on flooded areas should be incorporated into relevant strategies, spatial and urban plans as well as projects that directly and indirectly treat flood protection.

Conclusion

Over the study area, more than 400 ha of agricultural land is affected by floods. Forest areas, artificial surfaces and non-productive land are affected in a much smaller proportion but material damage in these areas caused by floods can be significant. The most affected residential and commercial areas are located in the vicinity of the Sana river namely in the urban and suburban areas of Prijedor, Gomjenica, Novi Grad and in parts of rural settlements of Hambarine, Rakovčani, Rizvanovići, Brezičani, Donja Dragotinja, Trgovište, Svodna, Vitasavci, and Blagaj Rijeka. Poor land use planning, absence of flood protection infrastructure and incomplete sewage system led to material damage caused by floods. The response to flood damage must be comprehensively planned and it has to cover all sectors including water management, housing, economy, infrastructure, energy and agriculture. One of the starting points for such activities is the existence of adequate data on flooded areas. This paper shows that remotely sensed products such as optical and radar imagery can be effectively used for the delineation of flooding areas during different flooding events. Certainly, additional research has to be done in order to establish optimal methodology and workflow for delineating flooded areas by remote sensing products. Data derived this way can be useful not just for water management and spatial planning but for emergency planning too.

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

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