ESA STUDY – FINAL REPORT		
ESA Contract No: 4000130071/20/I-DT	**Subject:** Contextualization of EO data for a deeper understanding of river environment changes in Southeast Europe (EOcontext)	**Contractor**: ZRC SAZU, Ljubljana, Slovenia **Subcontractor:** Institute of Ethnic Studies
ESA CR( ) No.:	**No. of volumes:** 1 **This is Volume No.:** 1	**Contractor's Reference:** EOcontext /FR

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Contextualization of EO data for a deeper understanding of river environment changes in Southeast Europe (EOcontext)[1]

Final Report

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June, 2022

[1] This study is funded by the Government of Slovenia through an ESA contract under the EO science for society permanently open call. Contract Number 4000130071/20/I-DT. The view expressed herein can in no way be taken to reflect the official opinion of the European Space Agency.

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Contents

List of Abbreviations

AOI	Area of interest
EO	Earth observation
HPP	Hydroelectric power plant
HR	High-Resolution
EOcontext	Contextualization of EO data for a deeper understanding of river environment changes in Southeast Europe
GIS	Geographic Information System
JRC	Joint Research Centre
MR	Medium-Resolution
NGO	Non-governmental organisation
RF	Random Forest
SSMA	Spectral signal mixture analysis
SVM	Support Vector Machine
VHR	Very High-Resolution

1. Introduction

The aim of the “Contextualization of EO data for a deeper understanding of river environment changes in Southeast Europe” (EOcontext) project was to monitor and compare the river environment changes of Mura and Vjosa rivers. We made a comparison on these two rivers that initially share similar physical-geographical characteristics with the only difference being the intensive damming and regulation on Mura. We observed the impacts of anthropogenic influences on the river (such as hydropower plants (HPPs) and harsh regulation) on the Mura river environment and the natural changes that occurred on Vjosa river through the years. From this comparison we were able to assess how infrastructural interventions affected the river environment of the Mura river and how planned HPPs on Vjosa might further change its riverine environment.

Through synergistic use of EO data (Landsat and Sentinel-2), previously unavailable in-situ data and community-based knowledge this project focused on the changes of land use/land cover and gravel depositing sites (gravel bars) in the middle and lower part of these two comparable border rivers in the period of almost 40 years.

The main outcome of the project was the development of a StoryMap, a knowledge base that translates highly specific and expert-oriented analysis of satellite imagery into user-friendly, publicly accessible information that meets the needs of various non-governmental organisations (NGOs), initiatives and local communities in Slovenia and Albania. The StoryMap takes the form of an interactive web page where users can find all the information we have collected and analysed as part of this project.

This project that started at the end of August 2020, and was later prolonged until the end of April 2022, is organised in five work packages (WPs): WP1 deals with project management and reporting while WP2 deals with data, WP 3 and WP 4 are methodological, and WP 5 deals with synthesis of all the results. The purpose of planned WPs was to develop a common operational methodology for changes of riverine environments that was based mainly on RS and geographical analysis and considers theoretical foundation from anthropological research.

This report summarizes the main activities and progress that was done in the complete time of the project. It first describes study areas and data used as a scope of the work being done under the WP2: Data collection and preparation. Later we focus on the methodology and the analysis under the WP3: Time series and change detection. Once the results are obtained, we compare them with the data gathered in the fieldwork: WP4: Comparison and evaluation of the results and in the end, we combine and contextualise all the results in WP5: Implementation of a StoryMap. In the end we offer a short conclusion of all the experiences and propose future work related to this project.

2. Study areas

In this project we focused on the observation and comparison of changes in the two main areas: the Slovenian part of the Mura River (northeastern Slovenia) and the Albanian part of the Vjosa River (southern Albania). Since the area of the two rivers in both countries is quite large, we have divided each of them into subsections to allow a deeper and more detailed analysis. The exact definition of the two study areas is presented in detail in the report "Deliverable 1".

2.1. Mura, Slovenia

The Mura is a typical alpine river which has its origin in the central crystalline Alps of Austria, rising in the Hohe Tauern National Park in the province of Salzburg and flowing into the Drava River near Legrad (Koprivnica-Križevci County) in Croatia. The Mura River is 465 km long in its entirety but flows through Slovenia for a total length of 93 km, with the section of the Slovenian "inner" Mura about 33 km long and the rest forming the border with Austria and Croatia. The study area of Mura is presented in the Figure 1 below.

Figure 1. Overview of the Mura study areas. (Data sources: Google Satellite, 2020).

We defined three main study areas in Slovenia, encompassing almost all of the Mura river course in the country of Slovenia. We also included the riparian zone with the width of up to 4 km on either side of the river. All this area was considered in the remote sensing part of the study. For anthropological and social-geographical analysis, the following settlements along the Mura river have been taken into account: Ceršak, Sladki vrh, Konjišče, Črnci, Petanjci, Radenci, Bakovci, Hrastje-Mota, Dokležovje, Veržej, Ižakovci, Razkrižje, Hotiza, Petišovci, Benica.

2.2. Vjosa, Albania

The Vjosa river (anciently known as Vovousa) springs as river Aoos in the Pindos mountains in northern Greece and straddles the Greek-Albanian border after 80 km. It flows in a NW direction through the relatively mountainous terrain and forested slopes down to the Adriatic Sea. The Vjosa River basin is characterised by three main tributaries: Sarantaporo, Drinos and Shushica tributaries. As Vjosa river is considerably longer compared to the Mura, we have separated the Albanian case study in four parts, namely: 1.) the river spring, 2.) the border region between Greece and Albania, 3.) the region that will be most affected by the potential hydroelectric power plants, and 4.) the river delta. The latter, the river delta and its changes, was not analysed this time specifically and is described in more detail in our earlier works (see journal article: *Linking geomorphological and demographic movements: The case of Southern Albania* – Gregorič Bon, Kanjir and Josipovič, 2018). In this project, we focused more on changes occurring in the rivers source and middle reaches of rivers.

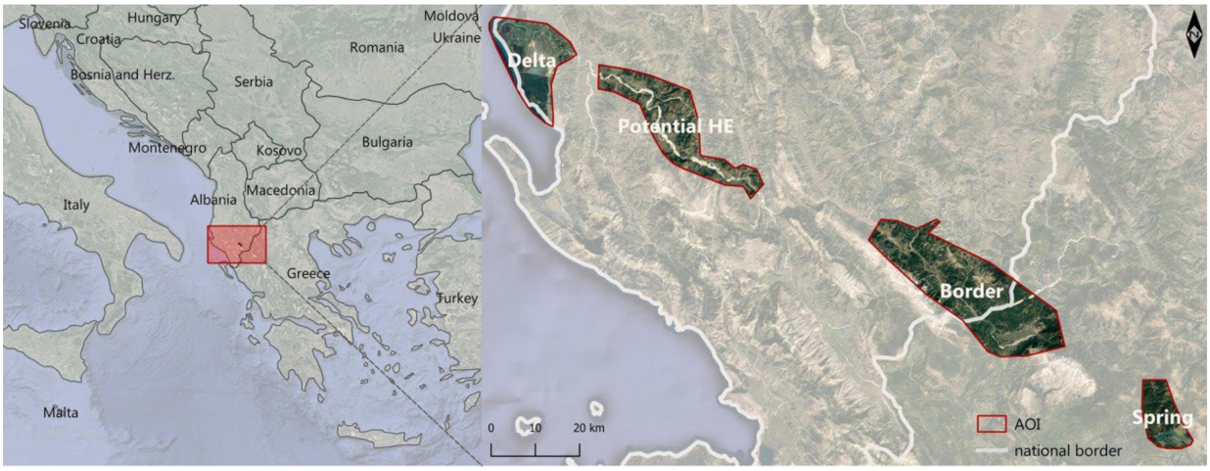

Figure 2. General demonstration of study areas in Albania around the river Vjosa.

Figure 3. Overview of the specific areas around river Vjosa in Albania. (Data sources: Google Satellite, 2020)

The anthropological component of the study focused on the middle part, which is most affected by the proposed HPPs. During fieldwork in Albania, stakeholders suggested redefining the locations of our first planned sites to include the villages of Selenica and Memaliaj. These locations are more populated, and the people have a closer relationship with the river than the people in the small town of Permet and the village of Pocem, as originally planned. Therefore, the team members adjusted the study area accordingly and conducted the fieldwork in the next towns or villages: Përmet, Qesarat and Iliras, Kutë and Selenicë.

3. Data used

The first part of the data collection were multi-band satellite images of different spatial resolution: medium resolution (MR) 30 m (Landsat), high resolution (HR) 10 m (Sentinel-2) and very high resolution (VHR) < 5 m (PlanetScope, Pléiades, and WorldView-2) data. The latter was used only as validation data or visual representation of the results and were not specifically used for the analysis. The services operated in a cloud-based environment.

In addition to satellite data, we have also acquired aerial photographs to provide insight into points much further back in time. In addition to the spatial data, we obtained hydrologic information on the discharges and water levels of the two rivers studied in order to determine their river regime. In addition, many more descriptive and in-situ data were collected for a better understanding of our study areas.

3.1. Satellite images

The main EO data used in this study were optical data from the Sentinel-2 and Landsat remote sensing systems. In addition, VHR data from the GeoEye-1, PlanetScope, Pléiades, and WorldView-2 systems and aerial orthophotography were used to validate and visualise the results. The main satellite sensors and their characteristics are described in detail in the Deliverable 1 report of this project.

During the project, it was also planned to include in the analysis satellite images from the first Slovenian Earth observation satellite called NEMO-HD, which was launched in early September 2020. Currently, the images are still in the commissioning phase (tested, calibrated and validated). The NEMO - HD (Nanosatellite for Earth Monitoring and Observation - High Definition) is expected to provide pan-sharpened imagery in four spectral bands with 2.8 m GSD and a high definition real time video at 1920 by 1080 pixels. The imagery, with three times better resolution than the Sentinel-2, will be used for either current situation overview or validation. Due to technical issues (satellite is still in commissioning phase), we were not able to use this data during this project, but our future work will focus on river observations with this national sensor and incorporate the experience gained during this project.

In this project, we used the cloud service CloudFerro (CREODIAS) to store and analyse larger amounts of satellite data. The service we used is an on-demand service with ICT requirements that ensure high performance and computing power per month (8 CPU, 32 RAM, 128 G). The list of required data that we accessed through the network includes Sentinel-2 and Landsat data.

3.2. Ethnographic data

In our cross-disciplinary research that combines remote sensing analysis and ethnographic research we consider the social and historical background of both rivers as crucial for the analysis and interpretation of our data.

MURA RIVER - Brief geographic, hydrographic and historical characteristics

The Mura is a typical alpine river, which has its origin in the central crystalline Alps of Austria. During its middle course it transports sand and other sediments across the plain of Graz (Austria) through Slovenia to its confluence with the Drava River at Legrad on the border with Croatian-Hungarian. Its natural course has been significantly altered by a chain of HPPs on the Austrian river course, with the majority (14) of the 26 HPPs in operation being built after 1974. The downstream course of the Mura River in Slovenia, Croatia and Hungary still has no HPP. However, there are plans to build several HPPs as far as Legrad. During the construction of HPPs in Austria, hydrologists noticed a reduced flow of sand and gravel through the low-lying HPP southward of Graz. With the strong damming of the upper and middle river in Austria, the Mura lost the stability of the water flow on its way through Slovenia. This has had a significant impact on the water level itself and the level of the groundwater, and the rapid deepening of the riverbed is particularly problematic. Measuring the discharge though, the Mura has maintained its century average from 1907-2016 at 168.2 m^3/s.

Historically, most of the Mura River that flows through present-day Slovenia was part of the Panonian principality; only the westernmost part near Ceršak belonged to Carantania, a Slavic principality. The border between the two was somewhere near the present-day village of Cmurek. Later, in 1919, the Mura River (between Ceršak and Gornja Radgona) became the border between the Kingdom of Serbs, Croats and Slovenes, and German Austria. Today it flows through Slovenia for a total length of 95 km, with the section of the Slovenian “inner” Mura being about 33 km long and the rest forming a border with Austria and Croatia.

The history of the territorial affiliation of **Prlekija** to the Austrian internal order, and **Prekmurje** and Medjimurje to Hungary, led to a drastic difference in the structure of land-parcel division and landownership (see Figure 4 below).

Prlekija, as part of the Styrian Duchy, was characterised by viticulture, rental farming, and landless agricultural producers. Land ownership remained the property of the feudal lords up until the end of WWI, when feudal ownership was finally abolished by agrarian reform in the Kingdom of Serbs, Croats and Slovenes. After the agrarian reform the feudal land was by and large divided among the peasants, the former serfs. The partial collectivisation of agricultural production in the form of Agricultural Combines (*Slovenian*: Kmetijski kombinat) resulted in a larger share of consolidated land.

On the other side of the river, Prekmurje was part of the historical Hungarian branch of the Twin Monarchy, where the old Roman law was re-established after the collapse of Ottoman rule in the late 1690s. The land was allocated to villagers to secure their economic welfare. In comparison with Prlekija, the Prekmurje peasants historically retained the right to own land and to keep it for their offspring. The consequences of modernisation in the mid-19th century enabled a doubling of the population in less than a half a century, resulting in a division of the land among many descendants. The process of fragmenting the land parcels was so pronounced that the major part of the land was scattered among tens of thousands of local owners, who became poorer as a result. This also contributed to the first modern migration waves that began in Prekmurje at the end of 19th century. Overall, land later remained predominantly privately owned with only the former feudal land being nationalised for state-owned agricultural production.

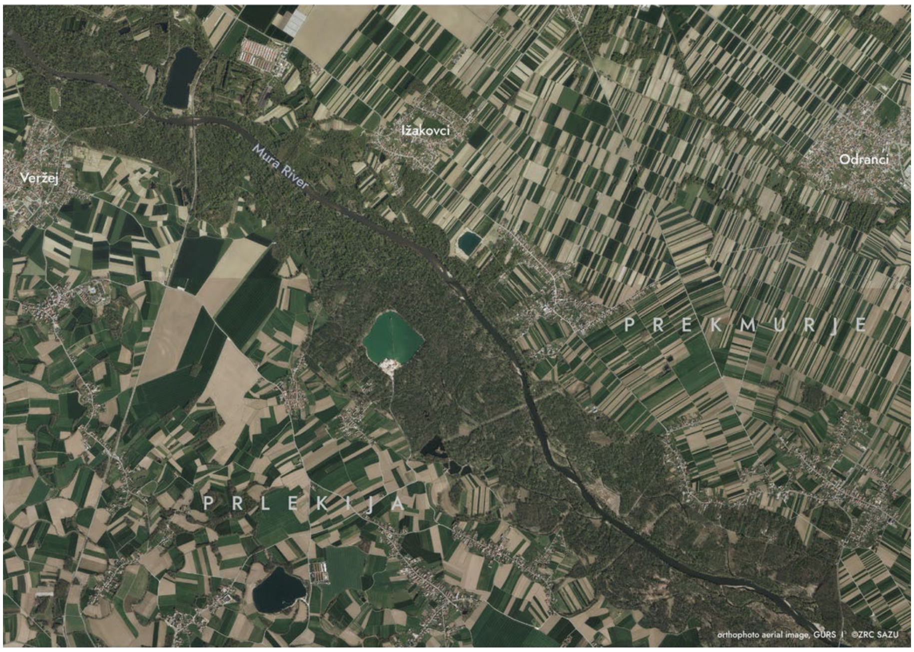

Figure 4. Differences in the land-parcel division between Prekmurje and Prlekija

VJOSA RIVER - Brief geographical and historical characteristics

The Vjosa rises as the river Aoos at an altitude of 1235 m on the Piges-Aoos plateau in northern Greece. It flows in a north-westerly direction through the relatively mountainous terrain and forested slopes of the northern Pindos Mountains. After 80 kilometres, it crosses the small town of Konica and the Greek-Albanian border and enters Albanian territory "as a formed river with relatively low gradient, a high width-to-depth ratio, and low sinuosity" (Daja et al., 2018). After a few kilometres, the river valley widens to form the gorges of Kalivaç and Poçem, and near the town of Tepelena the landscape is characterised by broad gravel banks, the widest in Europe, extending for a width of about 2 km near the village of Kuta. After Selenica, the valley becomes wider as the slope of the watershed decreases, and the Vjosa begins to meander. Here, the riverbed widens and gradually flows into the Adriatic Sea in the lagoon of Narta (Schiemer et al., 2020).

Vjosa has lost its water and transport capacities. The discharges confirm a significant change in its water regime, Vjosa lost a third of its discharge in less than 35 years (from around 1960 to 1990). The data first assumed the effects of a massive shift in the precipitation pattern and the drying up of the Pindos Mountains, but after the fieldwork in the area, locals told us this is the consequence of the water diversion of river stream for agricultural irrigation, located between the technical lake and the nearby village Hrysovitsa. This can negatively affect downstream streamflow by reducing it, which then results in changes in sediment transport, and in floodplain flooding.

Except for the HPP built in its spring in Greece, the Vjosa is considered one of the rare yet near to intact rivers in Europe with one of the widest gravel bars. Its three main tributaries Sarandoporous, Drinos and Sushica, significantly contribute to its hydro-morphological character. A high sediment transport is characteristic especially in its middle part - before and after the confluence with the Drinos - where the river forms a dynamic and erosion-prone landscape due to the wide gravel banks.

Before the signing of the Memorandum of Understanding between the Albanian Ministry of Tourism and Environment and the CEO of Patagonia **to declare Vjosa a National Park on June 13, 2022** (while this project already officially ended), at least 42 HPPs were planned on the Vjosa River (for locations see Figure 5). 34 of them were to be built on its tributaries and 8 on its main course. In recent years, environmental activists and NGOs (EcoAlbania, Euronatur, Balkan River Defence, etc.), together with scientists and locals, have conducted a major campaign to achieve this.

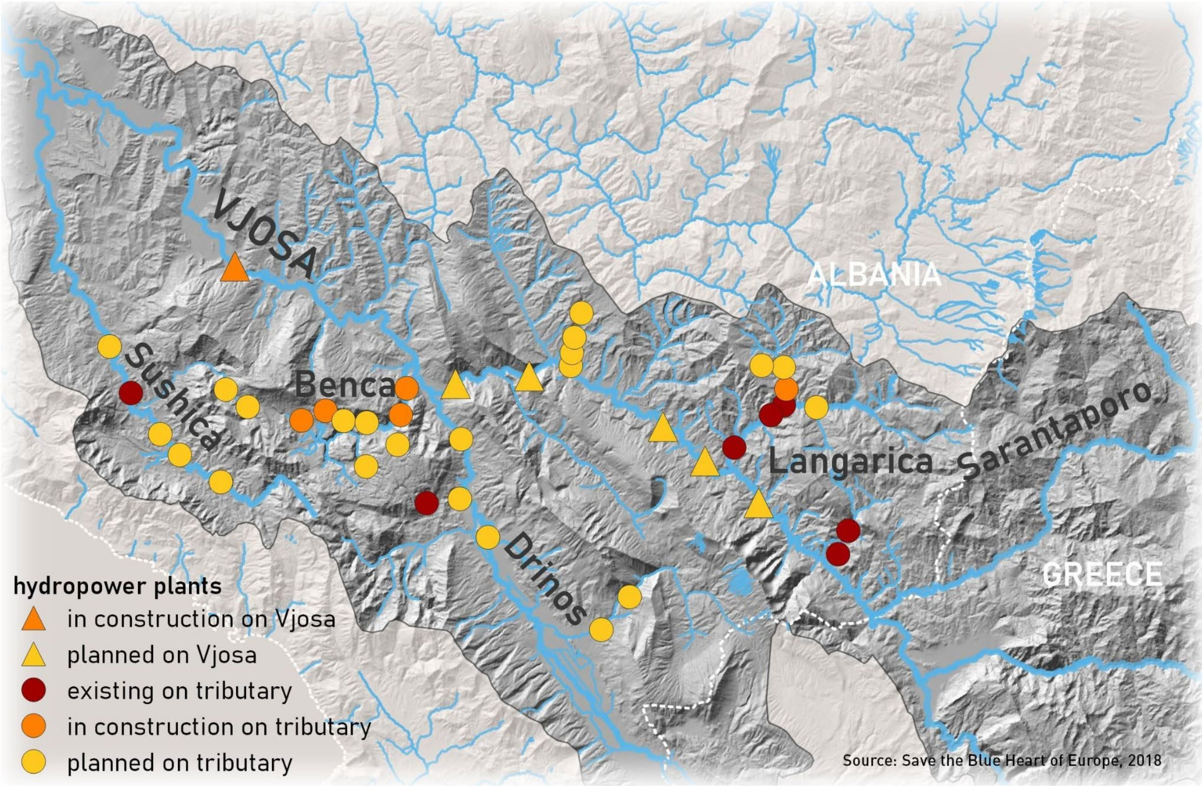

Figure 5. The map of planned HPPs on river Vjosa in Albania.

In the past the Vjosa Valley was culturally and geographically divided into two regional areas (Zojzi, 1950): **Labëria** (at the southern bank), a relatively mountainous area, dominated by limestone and pastoralist society, and **Toskëria** (at the northern bank), which is mainly lowland with dominant clay, and agricultural society (the areas are shown on the Figure 3). For many centuries the communities populating both banks of the river had little contact, which is still relevant today. Historically, both regions were subject to many in- and out-country migrations, with the highest rates occurring at the beginning of Ottoman rule in the 15th century; during the interwar period (Zojzi, 1950/2020); and after the collapse of the communist regime. The only exception was the communist regime when out-country migrations were strictly forbidden (due to the country's isolation) whereas in-country migrations were directed and controlled. During this period, agrarian reform took place in 1958. Work brigades (collective labour actions) expanded agricultural fields, built irrigation canals, cut back Mediterranean shrubs along the Vjosa River and transformed the riverine landscape into a productive area.

After the collapse of the communist regime in 1991, the agricultural cooperatives collapsed and the process of land de-collectivization began, this process is still ongoing. As a result, the once collective land has been fragmented into several smaller parcels, which means that the management and cultivation is in the hands of the family or the individual owner. The latter often sell the land to local or foreign real estate companies due to the current economic and political situation in Albania. Most locals return to their villages only during the summer holidays, or when they retired or died for there is still - especially in the rural areas - for the strong tradition of burying ancestors in their hometowns or so-called place of origin is still maintained.

As a result of general political, economic and social crises in the country that followed the fall of the regime, severe deforestation took place on the riverbanks - either for personal use or for the market. Other infrastructural interventions also took place during these years - gravel mining for construction purposes, which flourished after 1991.

After 2014, due to Albania's accession to the EU candidate process, the European, American and other investment funds began to invest in infrastructural development. This included, for example, the construction of roads and HPP in Kalivaç and (planned) in Poçem, which is stopped now due to the EU Council's ban and ensuing resolution of Memorandum of Understanding to declare Vjosa a National Park on June 13, 2022.

3.3. Hydrologic and other data

We used hydrologic data to verify the agreement between processes observed on EO data and the situation that was measured in-situ. The hydrologic data for the Mura was obtained from the archives of the Slovenian Environment Agency. Eight different gauging stations have been in operation on the Mura river in Slovenia. We selected the data from the Petanjci station, because it has the longest available archive, from 1956 until today. Additionally, it is in the centre of our study area and can thus be considered the most representative. We obtained daily average water levels and discharge information (Slovenian Environment Agency, 2021). The data is available openly and free of charge.

Hydrologic data for the Vjosa was more difficult to obtain. The relocation of data archives led to the loss of numerous records. Finally, through personal communication with a researcher from the University of Tirana we got access to the water levels at the Dorez gauging station near the Poçem settlement, published in Hauer et al. (2019). The data consisted of daily water levels from August 1958 until December 1990.

In addition to the hydrologic data, we have used the Global Surface Water dataset (made by JRC) for the water extent comparison.

For training and validation samples while performing land use/land cover classification we used the ground truth data (agricultural and forestry land use in Slovenia) provided free of charge by the Ministry of Agriculture, Forestry and Food. In the case of Albania these data were compiled manually from Planet data.

4. Temporal sections

Determination of the temporal cross sections or time points appropriate for selection of the EO data was done as part of WP3, Task 3 (Definition of temporal sections). The objective of the discharge analysis of both rivers was to define the main analytical windows for measurement and comparison with EO for the next steps of the analysis.

One of the assumed characteristics of the fluvial regimes of the two rivers to be compared, the Mura and the Vjosa, was the geographical comparability of their upper, middle and lower streams in terms of flow evolution from a small stream at higher elevations to a fast river and finally to a reduced velocity with increased discharge.

With heavy damming of the upper and mid-stream in Austria, Mura lost the stability of water discharge and the intra-annual distribution along the course through Slovenia. This made a significant impact on the water level itself and the level of underground water, and what is especially problematic, a deepening riverbed base. As already stated in the section 3.3. above, both rivers shared a comparable discharge (Mura: 164.6 m^3/s in 1946–1954, 155.5 m^3/s in 1985–1989, 140.0 m^3/s in 1990, and as much as 166.8 m^3/s in 2018 and Vjosa 165.7 m^3/s in 1958, 169.5 m^3/s in 1957–1961, 115.2 m^3/s in 1985–1989 to historically low 66.4 m^3/s in 1990). The Vjosa River had lost up to 30% of its former water discharge from the 1960s, due not only to rising temperatures that thinned the snow cover and the redistribution of precipitation, but also to the detour of water from the river for agricultural irrigation at the technical lake, close to its source.

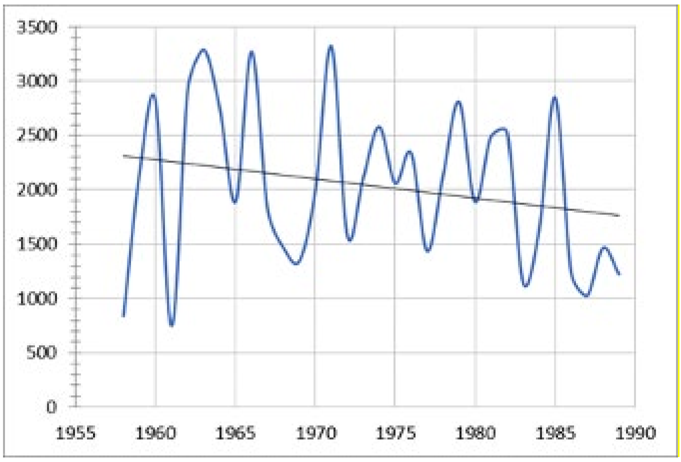

Figure 6. The lowering of annual maximum discharge at Poçem gauging station, Vjosa.

From the hydrographical data we were able to distinguish three extremes for both rivers in the testing period 1984–1990:

a) **Vjosa** exerted two maximums in autumn (from the end of November to the beginning of December; with the preferred dates for RS data extraction between 1st and 5th of December) and in late winter (from the end of February to the beginning of March; with the preferred dates between 1st and 5th of March); and late summer minimum (end of September; preferable dates around 20th of September).

b) **Mura** exerted two minimums in winter (from mid-January to first decade of February; preferably between 15th of January and 10th of February) and in late summer - early autumn (second decade of September to first decade of October; preferably between 10th of September and 10th of October); and a spring maximum (from the end of May to mid-June; preferably between 15th of May and 10th of June).

Figure 7. A case of low water of the late summer minimum on Mura near Veržej.

These results were than included for determining suitable time dates for annual land cover/land use classifications, described in the next section.

5. Time series and change detection

This section was part of the work under WP3, where we collected information on land use/land cover change on the Vjosa and Mura rivers with the use of time series analysis. The extent of land cover and gravel bar changes on both rivers is a key indicator and one of the principal drivers of hydrological changes in the river morphology and its extensive network.

5.1. Colour composites

First, we performed a simple visual methodology that showed us the main changes through the river basin between years. Using RGB-NDVI colour composites, we attempted to demonstrate a simple technique for visualising the changes that occur along the Mura and Vjosa rivers over an almost 40-year period. This input was crucial to give to the interlocutors while an anthropologist and a geographer conducted fieldwork. With a basic understanding of additive colour theory and knowledge of what NDVI data are coupled with primary colours, we have visualised and assimilated the spatial and temporal trends of river changes in a landscape.

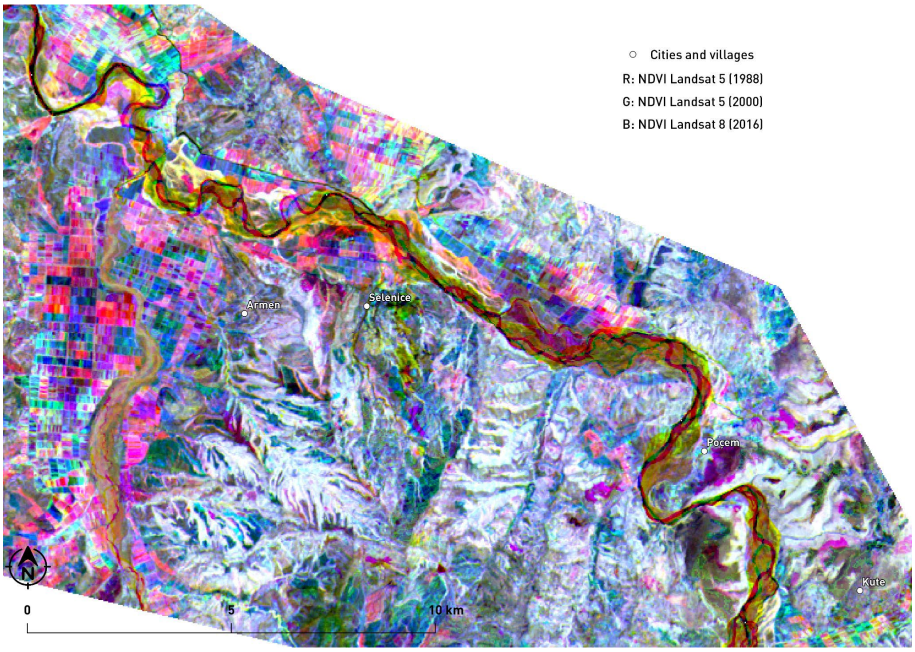

Figure 8. A section of an RGB-NDVI colour composite of a Vjosa River middle stream, where a great part of the fieldwork was also conducted.

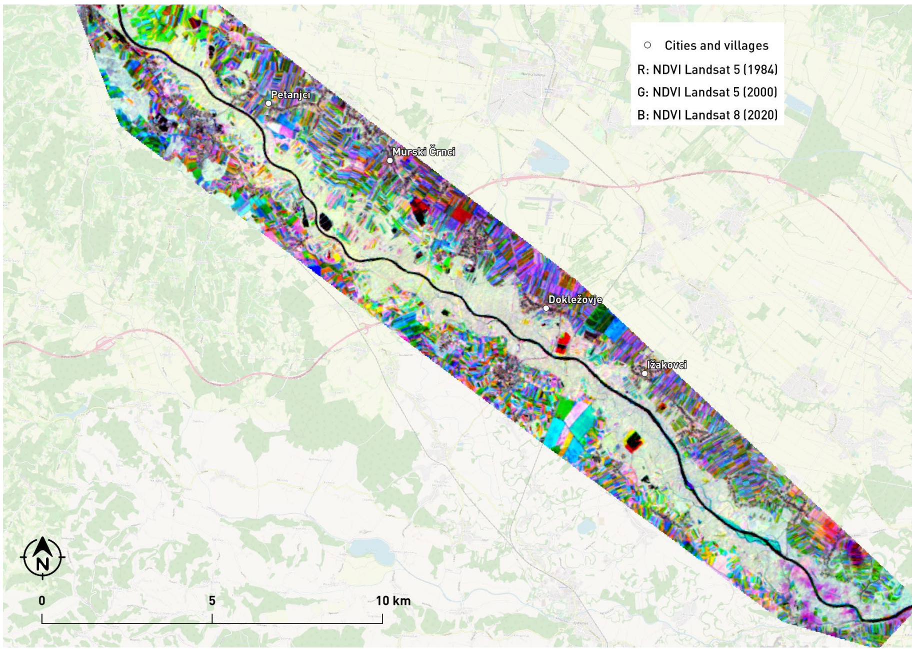

Figure 9. The detail of RGB-NDVI color composite over the lower area of Mura river (part that flows through Slovenia).

Looking at the changes in these images between the years 1984 and 2020, we can see how some meanders of the Vjosa River have evolved over time, changing their curvature and moving both transversely and longitudinally through and between all years (yellow, cyan, and magenta colours). In contrast, the curvature of the Mura River in this area has not changed significantly over time, due to heavy regulation prior to the first Landsat imagery. Only in the lower part of the image in cyan (south of the town of Ižakovci), where the Mura is no longer regulated and still has some natural meanders, few changes are visible.

5.2. Inter-annual land use change detection

First, we performed land use/land cover time series to detect intra-annual changes in surface water extent of the two different rivers. To do this, we used Landsat data (from 1984 to 2015) and Sentinel-2 imagery (from 2015 until present) of the rivers and wider riparian areas. The date of annual images used for each region have been following the time of high value of water amount in the rivers, calculated as described in the previous section. In this way, we gained a comprehensive overview of changes over the period of the last four decades. For both Landsat and Sentinel-2 data, we used relatively simple change detection algorithms (based on classifications using SVM and RF approaches) to identify the areas of the most extensive change in the course of both rivers. Comparing the accuracy performance of both approaches, SVM classification showed slightly better final results than the SVM classification for Landsat data, whereas RF approach gives better results on Sentinel-2 data, as it better deals with underrepresented classes. These procedures were then accordingly applied to produce maps for each year on the historical Landsat and current Sentinel-2 data for both areas. The RF classification results were later compared to determine the degree of change of each class through time in each studied area.

Mura

To identify long-term changes (1984 - 2020), we considered four land cover classes for the Mura region: river, agriculture, mixed forest, and urban. Gravel bars are not visible at the Landsat resolution of 30 m in this area and were therefore not included in the classification.

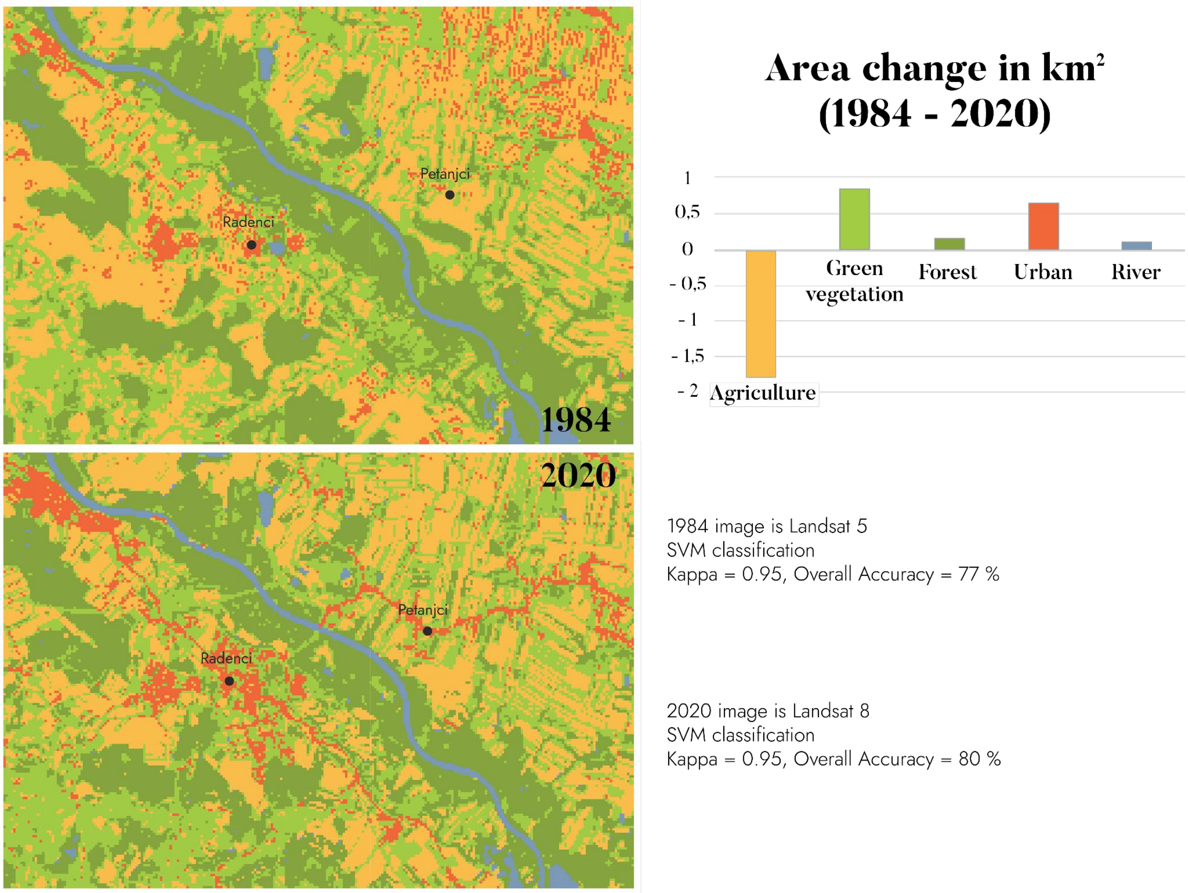

Figure 10. This image shows the classification results of two Landsat satellite images in the Petanjci region.

The graph on the right of the Figure 10 shows that the agricultural area has substantially decreased between 1984 and 2020, although there is still a lot of arable land in this area. Green vegetation (mainly meadows) and urban areas have increased, which is partly because of the usage of different sensors of satellite images (Landsat 5 and Landsat 8) were used in the classification, showing different levels of detail, so the classification results differ for the two images. The river and water areas have not changed drastically in this area over a period of almost 40 years, which is expected, as Mura was heavily regulated in this part of inner Slovenia even before the date of first Landsat image (1984).

Vjosa

For the Vjosa we considered five land cover classes, one more than in the case of Mura: river, agriculture, mixed forest, urban and gravel. Although Vjosa is considered having one of the widest gravel bars in Europe, the detection and classification of gravel bars from 30 m Landsat data is still problematic, mostly because gravel represented a very small part of the training data.

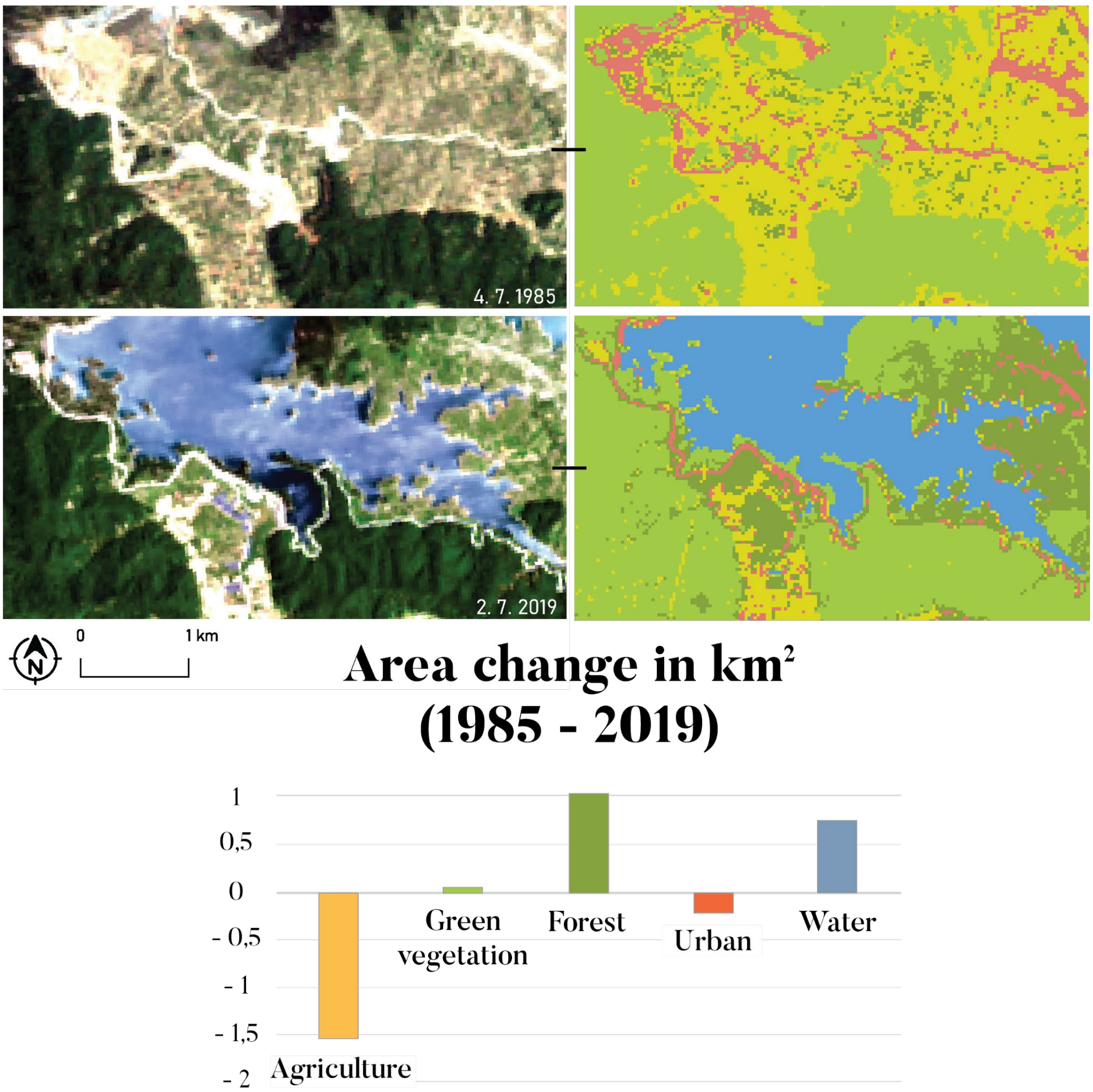

Figure 11. SVM classification of the Vjosa source study area. Satellite images and classification results show the detail of a processed area.

The river Vjosa is limited at its source in Greece by a HPP (with capacity electricity production of 210 MW) built between 1985 and 1990. As a result, a 9 km^2 technical lake was formed, which covers a large part of the Piges-Aoos plateau. However, despite this major intervention in the river at its source, electricity production reportedly covers about 0.25% of the country's total electricity production for the last four years (Katsulakos et al., 2019). The dam has gradually reduced the flow velocity of the river, increased the water temperature and impaired the aeration and oxygenation of the water.

The results of inter-annual classification have shown the great increase in water presence, as expected, and decrease in agricultural areas. Forest has also overgrown around the lake in this 40 years difference and the abandonment of agriculture in this area around technical lake.

5.3. Time series land use change detection

One dimension of the use of remote sensing is the interval over which change is detected. The difference between this time series analysis part and the part in the previous section is that more subtle changes in riverine landscapes are monitored in the context of land use dynamics. The result is a shift away from detecting change, usually based on two points in time, to monitoring or attempting to track change continuously.

For the detection of river intra-annual changes using time series Sentinel-2 satellite data we have used the method Time-Weighted Dynamic Time Warping (TWDTW) as implemented in the R package dtwSat (Maus et al., 2016). The TWDTW method for mapping land cover is based on comparing unclassified time series of satellite images with a set of known temporal patterns (e.g. phenological cycles associated with vegetation) (Maus et al., 2019).

First, we have prepared training and validation samples from ground truth data - official database of agricultural and forestry land use for Slovenia and manual collection from Planet data for Albania. From these ground truth data samples, we created temporal patterns of different land use/cover classes (similar as Figure 12 below). For this machine learning approach, a good training data set is of crucial importance.

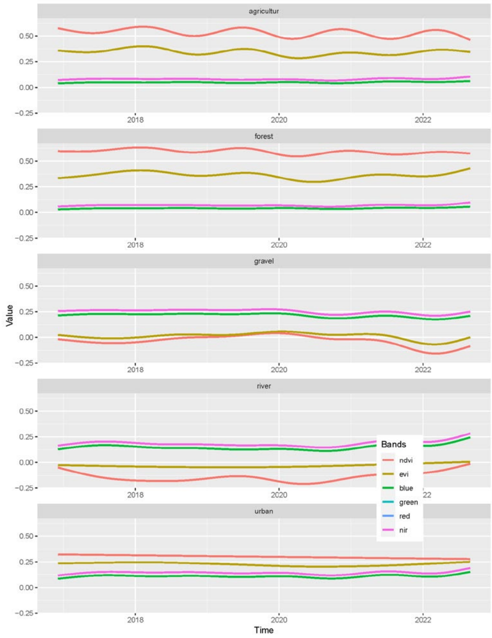

Figure 12. Temporal patterns of the selected classes based on different spectral bands and indices.

The procedure took much longer than the approach of SVM and RF, as it deals with much larger amount of data in the process. Apart from the long computation time, the final detection results for some classes (especially river and urban) are a bit too exaggerated compared to the actual representation of these classes in nature. Overall, however, the results seem promising; we achieved 83% overall accuracy in land use classification using this approach.

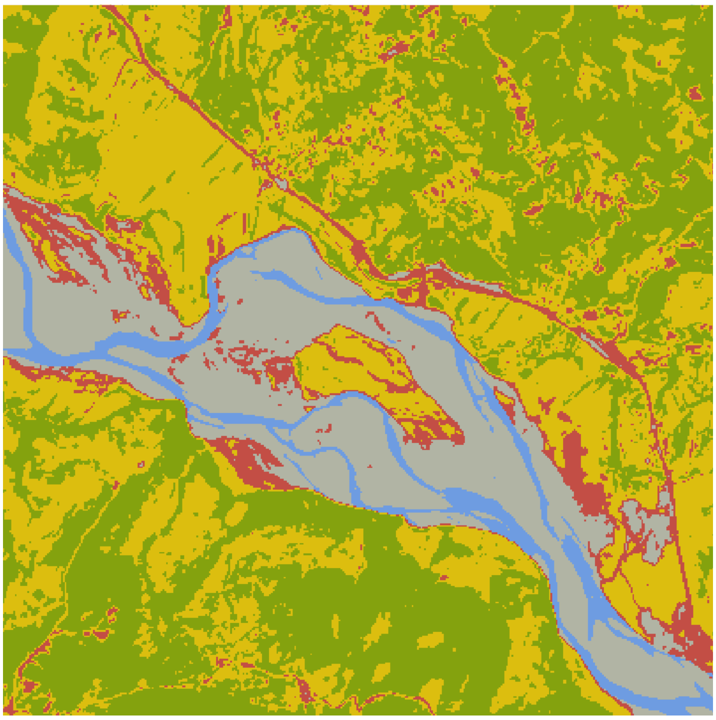

Figure 13. Classification results of the middle part of Vjosa (Quesarat) using TWDTW time series methodology and Sentinel-2 time series (2018 - 2019).

This approach is very useful for monitoring changes over time because it uses dense time series of satellite data and therefore considers the typical temporal variations in river dynamics as a more important factor than spatial variations. The method has demonstrated the benefit of creating a spatial vector dataset to support decision making in river management and to improve monitoring approaches for rivers and their environment.

5.4. Mapping of gravel bars

Next, we applied the spectral mixture analysis (SMA) to achieve subpixel mapping, for gravel bar detection and change. Using this approach, we considered three land cover classes only (gravel, vegetation, and surface water). Each land cover class of interest was represented with an endmember or spectral signature of a pure pixel containing only the selected land cover class. To increase the separability of the land cover classes, we calculated several spectral indices and used them along with the reflectance of the spectral bands for the SMA (MSAVI2, NDVI, NDWI, and MNDWI). The subpixel approach enabled a more accurate mapping of riverine landscapes and was especially key in gravel bar mapping. The extent of gravel bars was monitored as a sign of the natural dynamics of river processes. As a visible result of these processes, gravel bars can be considered reliable indicators of disturbance in the fluvial environment (Langhans and Tockner, 2014).

The SMA was performed on yearly cloud-free images for both the Mura and the Vjosa. The observation period was densified at selected study sections according to needs for further in-depth analysis. For example, all the available Landsat 5 images of the potential HPP study section between the years 1984 and 1990 were analysed to make comparisons with the in-situ hydrological data from the gauging station near the Poçem settlement.

The produced fraction maps were visually in line with the land covers observed. They provided a good source for quickly assessing the extent of changes and the dynamics on the river. We also performed simple differencing of fraction maps to observe changes in gravel bars. For example, on the Mura, clear changes in the deposition of bedload can be observed after the completion of the riverbanks regulations (Figure 14). It is possible to see that gravel bars started forming further downstream from the regulations where the river velocity and consequently its carrying capacity decreased.

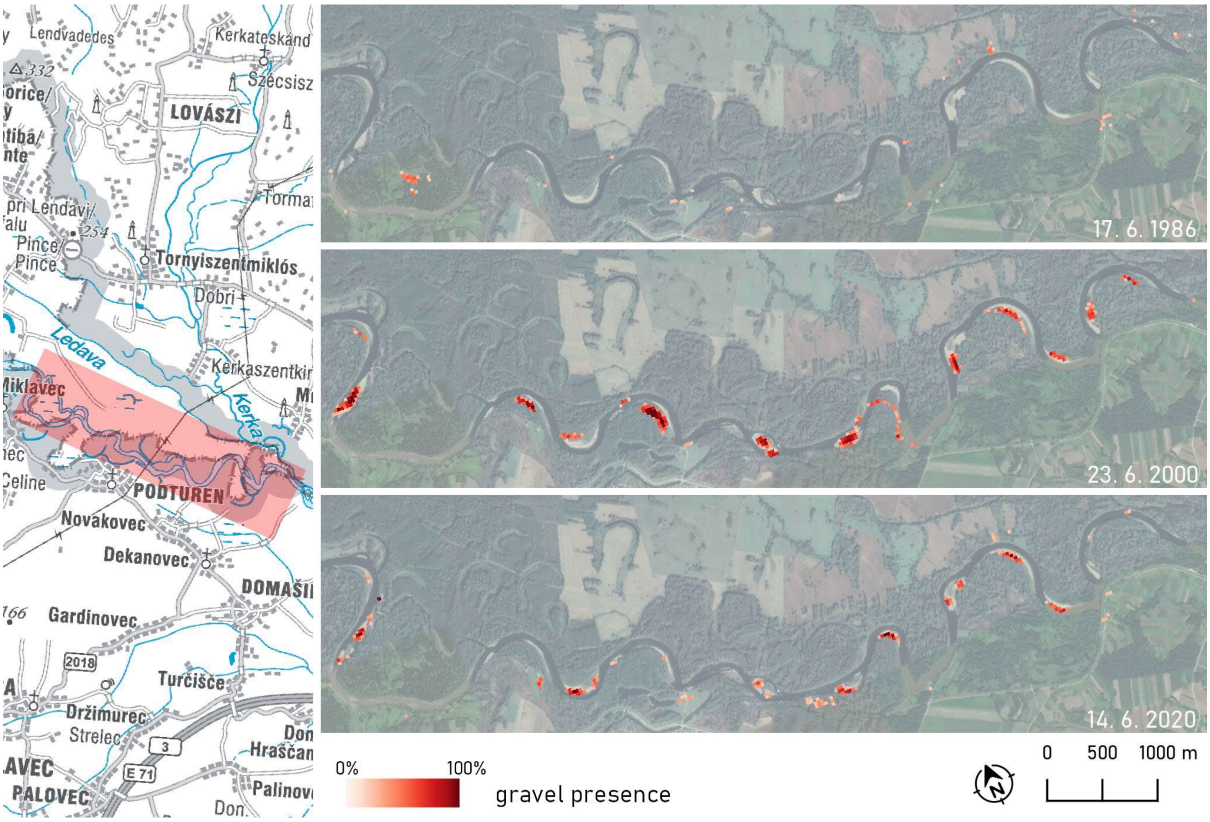

Figure 14. Gravel presence at three different time points on the Mura River on the border between Slovenia and Croatia. Based on spectral mixture analysis of Landsat images. (basemaps: Surveying and Mapping Authority of the Republic of Slovenia, 2021a; 2021b).

We performed an accuracy assessment of a fraction map of the Vjosa river. The fraction map to be assessed was selected as close as possible to the very high-resolution reference satellite image that was available to us. We acquired a WorldView-2 image from 12 June 2019 with a 2 m spatial resolution. Reference data was obtained by classifying this image into the three land cover classes of interest using a random forest classifier. We compared the reference data to a fraction map of the same extent based on a Landsat 8 image acquired on 7 June 2019. The comparison was done using a non-site-specific assessment to account for possible shifts in image geometry. We verified the agreement between the presence of the land cover classes of interest on the reference data to the presences on the fraction map. The results showed that gravel was mapped with the highest accuracy with the absolute difference in presence of 5%. Water was mapped slightly worse with an error of 6.5%. Vegetation was the most problematic with the absolute difference in presence of almost 12%. The high accuracy of gravel mapping is positive as this was the focus of our studies.

6. Fieldwork

In the preparatory phase prior to fieldwork, the most important parameter was the selection of sites where people perceived changes related to the river in each study area. In this phase, an anthropologist and a geographer defined questions for the inhabitants of Vjosa and Mura. Due to the anonymity of their personal data, their names will remain anonymous, while their year of birth, gender, and place of residence will be revealed. The main questions were:

1) Whether and (if so) where do you recognise the change in relation to the river in your village/town?

2) Can you reflect when you started noticing this change?

3) What has caused this change?

4) Can you evaluate it - what are its consequences and what impact will it have on your future?

5) What are these changes caused by / related to: physical environment, politics, economy, society, climate change, others?

6) How do you imagine the future in this place, region or country?

In the field, we have identified key informants (interviewees) at specific study sites to whom we asked the questions defined above. Since most of the interviewees did not feel like walking several kilometres along the river and taking photos of the changes they noticed in relation to the river, we had to change our methodology. Due to these circumstances, the latter no longer included Photovoice technique, but interviews that revolved around the places where they had noticed changes in recent years.

Fieldwork on the Mura and Vjosa rivers was conducted in parallel with quantitative remote sensing analysis (Landsat and Sentinel-2 data). We used a simple visual method (RGB NDVI colour composites) to visualise the geophysical changes along the Mura and Vjosa rivers over the last 40 years (see for example Figure 8). This visualisation helped the researchers to focus on the changes while interviewing the respondents in the fieldwork conducted.

In the case of Vjosa, a qualitative anthropological study was conducted using semi-structured interviews with selected inhabitants of the studied areas and participant observation. In answering the above questions, the interviewees were asked to mark the locations of possible changes on Google satellite maps showing their location and the river basin. After the fieldwork, the research team coded these changes on the map.

A series of interviews of people living around Mura were conducted, some of which are featured in the short films that can be viewed on the StoryMap website River Environments (see StoryMap section below). The fieldwork in Slovenia along the Mura River was conducted in two phases. The first phase lasted from late May to early July 2021, and as the fieldwork yielded more questions, additional interviews were conducted from fall 2021 to spring 2022. The series of locations along the Mura River was supplemented with additional locations up to the confluence of the Krka and Ledava Rivers. Due to the uninhabited area in the Murska šuma area in the south-eastern part, where the largest gravel deposits are located, no interviews were conducted there, although the nearest farmers were asked about their perception of the changes. Interviews were also conducted using the photovoice technique, slightly adapted to suit local conditions. Because the geographer is very familiar with the local physical environment, it was not necessary for the interviewees to physically show each location of the perceived change. Instead, a location was usually recognized simply by the interviewee describing the location in detail or showing it on the accurate map.

7. Contextualisation of the results and StoryMap

In this section we describe the changes detected, whether through analysis of the EO data or through a geographic and anthropological approach under the scope of the WP4. Thus, this section contains the results that we obtained in this project. With our results, we seek to increase user engagement by improving the usability of the vast EO data, not only for specialised and advanced users, but also for the general public. Most importantly, our goal is to contextualise EO-based products with local and national quantitative and qualitative (anthropological and geographic) results.

7.1. Comparison of detected changes

In this section, we expose the connection between the changes observed through EO data analysis and the people in the field. In both areas, we found a strong link between the qualitative ethnographic material and the quantitative results of the remote sensing analysis over a 40-year period. Fieldwork results and their interpretation in relation to the EO data is supported in the form of land use change maps and metrics on the extent of land use change and the extent of gravel bars. While doing the analysis we verified if the EO-based results can detect and monitor the hydrological processes on the ground, so we compared and tested the observations with in-situ data. Through analysis of hydromorphological data, we have noted the decline of water in both rivers, both consequences of human intervention in the structure and quantity of the water in the rivers. Finally, anthropological field research has allowed us to better understand how people living along rivers perceive or are affected by changes in their environment and how they, in turn, cause further changes through their activities (agriculture, logging, transhumance) and other infrastructural interventions (through national and transnational river management projects, plans to build hydropower plants, road construction, etc.).

In general, although there are many similarities between the two rivers (high mountains upstream of the alpine orogeny with high potential energy and gravel transport capacity, similar relief and length of the upper edge, etc.), the main difference in the case of the Mura is the impact of intensive damming and regulation measures, which are absent in the case of the Vjosa. Also, it is interesting how river carries an identity for local inhabitants. The major changes in the case of both rivers are described as entity wise – as few interlocutors said, Mura is “licking” its bedrock instead of carrying gravel and Vjosa is “eating” its banks. The main changes observed in each river basin from all perspectives are presented below.

Mura

On Mura, the presence of different land cover classes through time is relatively uniform and stable, as observed by analysing EO data through time. This is to be expected as the Mura is regulated, especially in the middle section, that flows through inner Slovenia. However, hydrological data show that the Mura has lost the stability of water flow on its way through Slovenia. Especially, the water level and the level of groundwater decreased due to the deepening of the riverbed, which is particularly problematic. **Deepening** is a product of both regulation, which has increased speed of the river flow, and the establishment of 31 hydropower plants on the upper and middle course in Austria, which have the amplified highs and lows of flows and thus increased extremes. The regulation itself not only increased horizontal surface drainage and denudation, which was anthropocentrically used to increase arable and cultivated areas, but also significantly changed the regime of groundwater fluctuations and thus changed the volume quality and flow of groundwater.

According to the measurements of an interlocutor in Črnci (a former member of the Hydrological Institute in Maribor), the riverbed of the Mura was lowered by more than one metre on average. Since these data are more than ten years old, he assumed that the process of deepening continues and should have already been more than two metres compared to the visible places on the bank. Nevertheless, these statements confirmed other visible results from in situ and EO data during the project that the subsurface water level has lowered due to accelerated erosion of the riverbed. This resulted in the death of meanders, reduced biotic diversity, and thus impacted agriculture and cropland. In addition to climate change, the Mura River basin suffers from additional droughts that cannot be restored if the river's water flow decreases further.

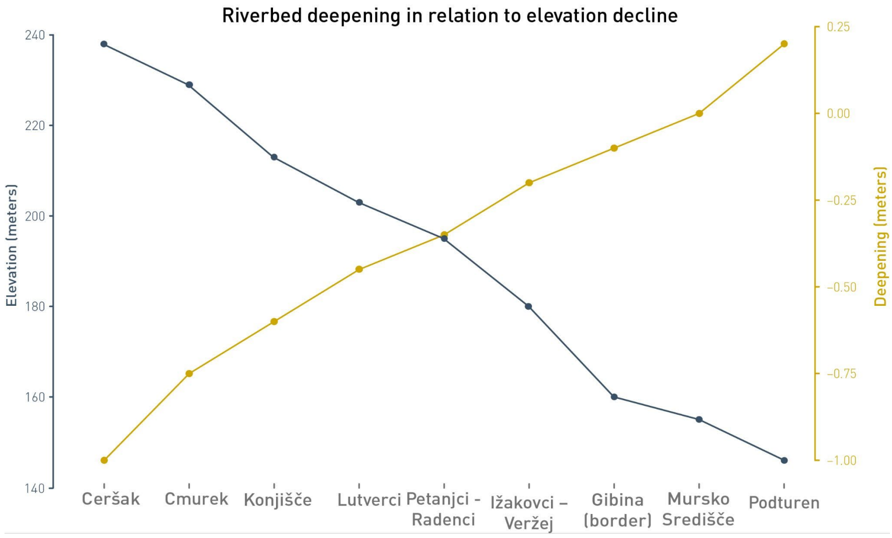

Figure 15. Riverbed deepening in relation to elevation decline.

The figure shows the effects of deepening the riverbed according to the acquired hydrological multipoint data along the course of the Mura. It shows an almost perfect correlation of the decreasing impact of deepening with the distance from the Austrian border. While deepening is most pronounced in the upper stream between Ceršak and Petanjci, it is less pronounced downstream. In the area between Gibina/Razkrižje and Mursko Središče the deepening has even disappeared, while further downstream the process of accumulation prevails over erosion. These results not only confirm the effects of deepening on the Lower Mura shown by the EO data, but they also clearly confirm the statements of local NGOs that the main reason is the unsuitable dam system in Austria. As some interlocutors said, the Mura "licking" its bedrock instead of carrying gravel.

Vjosa

In the case of the Vjosa, there is a much greater variability in the presence of the different land cover classes over the years, as the river is much wilder and more natural. The results also show a high correlation between the water surface area identified in the EO data and the water level measured in situ at the gauging station. We considered the agreement between the presence of water on fraction maps produced by SMA and the hydrologic data on the water level from a gauging station (Figure 16). The correlation between the two datasets was found to be high and statistically significant (Pearson's $r = 0.63$, $p < 0.001$). This indicates that the dynamics of riverine processes can be observed well with classifications of satellite images.

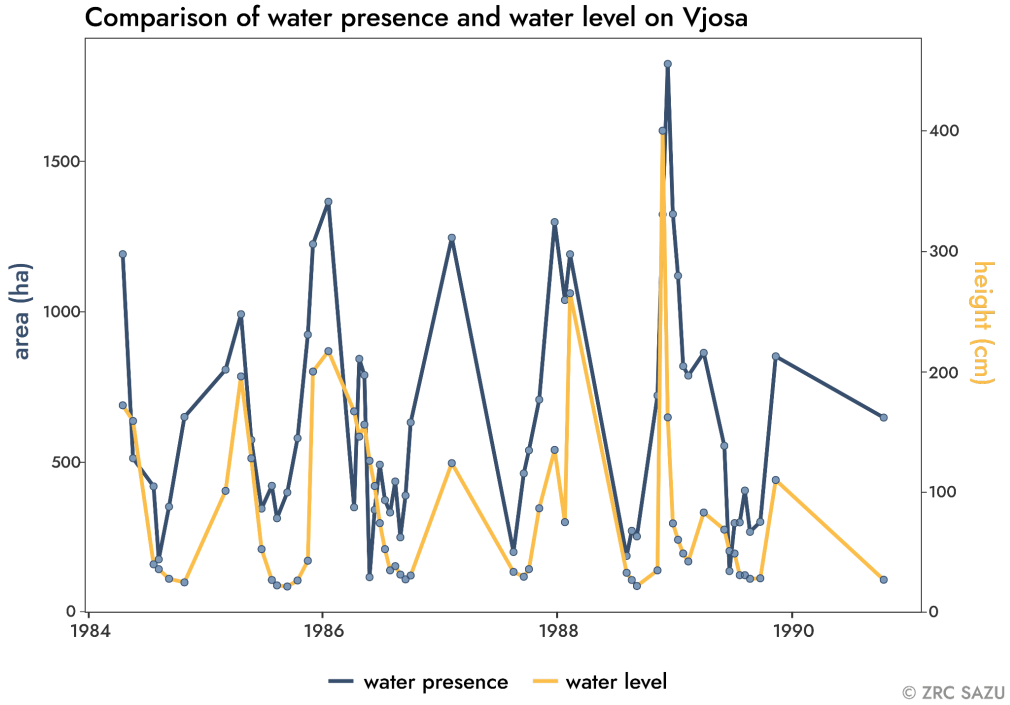

Figure 16. Presence of surface water from EO data in the potential HPP study section on the Vjosa and water level measured on the Dorez gauging station near the Poçem settlement from April 1984 to October 1990.

The fieldwork in Vjosa Valley was conducted in the upper and middle section of the Vjosa River. For exact locations of the places, see Figure 3. Results from the field show that people observe most of the changes in their environment that we detected using the EO data and can understand and explain them in the language of their respective socio-cultural environments.

I. In the upstream section of the Vjosa River

The town of Përmet

In the section around Përmet, the river has a relatively low meandering, a shallow but entrenched channel with low gradient with little or no floodplain. For this reason, analysis of EO data has not revealed significant changes over time in this area. Similar show the ethnographic data, as the inhabitants of Përmet do not perceive significant changes in the riverbed itself or in its surroundings.

Although the people of the upper and middle parts of the Vjosa seem to have an indirect relationship with the river, the latter is crucial to their lives. Through its irrigation channels and rich biohabitat, it provides water for their agricultural fields, their crops, their herds, and the people themselves.

II. The midstream section of Vjosa River

1) The villages of Iliras and Qesarat

This part has complex river flow patterns with predominantly branched and anastomosed streams. In particular, the area is characterised by very high sediment supply and consequent erosion of its river banks.

Likewise in the upstream of the river, peoples' relationship to the river have been built through terrestrial practices, such as pastoralism, agricultural activities and associated irrigation canals that link the river with the land. Many villagers of Qesarat and Iliras have their land plots located by the river on which they mainly grow corn, wheat, potatoes, beans, and other seasonal vegetables. During the interviews the villagers were showing their fields, which slope down to the wide gravel banks of the Vjosa River, and explained that because of gravel mining of the Albanian construction company that built a road, these fields are now more often flooded during the winter months than they were in last years.

The villagers of Qesarat and Iliras also explained that the construction company cut down poplars that spread along the course of the river and prevented the excessive river erosion. Since then, the river course has shifted tremendously, accelerating erosion of the farmland they own. Many of them have to pay taxes on the land which actually no longer exists. The visual representation of the river course through time shows precisely what the informants were talking about (see Figure 17 below).

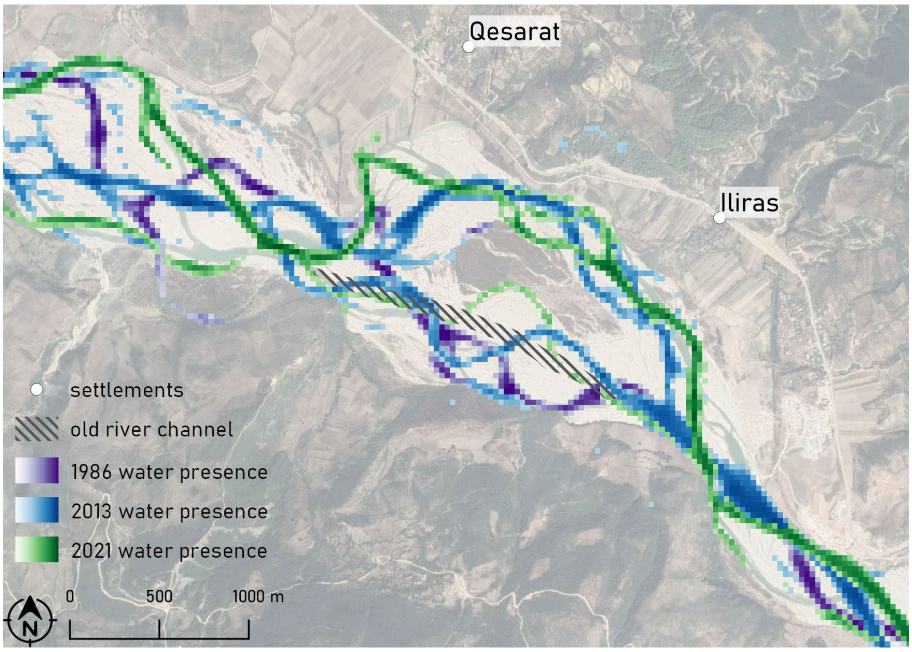

Figure 17. The analysis of the semi-open interviews conducted with some of the villagers of Qesarat and Iliras showed that people perceive changes similar to those observed through analysis of the EO data.

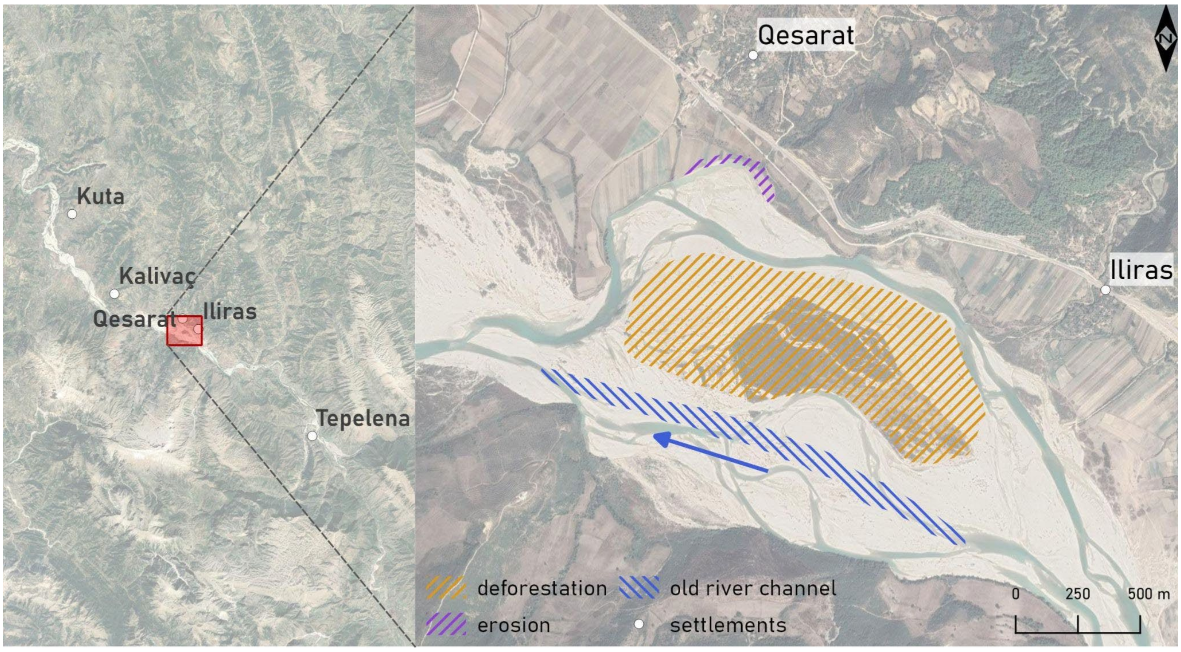

Figure 18. Changes observed by the key informants (interviewees) in the study areas of Qesarat and Iliras. Arrow marks the direction of flow.

Diversion of the stream more to the right bank of the river and increasing erosion of the river bank where the agricultural fields are located the villagers ascribed to the infrastructural interventions of the last decade are:

- gravel extraction for road construction between Kalivaç and the Greek border in 2016 and between Fier and Tepelene in 2010.

- heavy deforestation that took place after the collapse of the communist regime in 1991. In line with the economic and political crisis that followed many riverine inhabitants have cut down poplar and other trees for the firewood.

- the construction of the hydropower plant in Kalivaç since 1997. The construction was stopped at the initiative of the EU Commission and later by the Negative Environmental Statement of the Albanian Ministry of Tourism and Environment in 2021, and in 2022 banned due to the future recognition of Vjosa as a national park.

B) Kutë village

Downstream from Iliras and Qesarat, the river basin narrows and flows through the gorge near Kalivaç and Poçem village, where there was also planned (and recently banned) the construction of the HPPs. After Poçem, the Vjosa flows through the village of Kutë, which is known for its large gravel bars formed by the branching river. Wide and open gravel bars are home to many rare and/or endangered species.

The village of Kutë has a long tradition of agriculture and pastoralism. Along with the agricultural fields, the patrilines, who own particular plots of land, bear an important part of the social and cultural capital. In the period of the communist regime with collectivization, the patrilineal ownership of agricultural land was interrupted, especially with the establishment of an agricultural cooperative in 1958 (during the communist regime). Nowadays many elderly villagers often nostalgically recall the time when they worked in the fields with the pioneer brigades, building irrigation canals and transforming the riverine landscape into a productive area on the one hand and planting trees along its banks and gravel bars in order to mitigate erosion on the other. The village played an important role in agriculture until the fall of the communist regime in 1991. After that, when Albania was characterised by massive migration, the irrigation canals and the road leading to the village gradually deteriorated. Over time, the once central and prosperous village turned into a remote periphery.

Consequently, when asked about the river, people often talk about the agricultural fields and olive groves located along the irrigation canals where the river and the land meet and connect. They often describe the fields that provide food for their families and households, and the annual floods that inundate the fields. "But as the river takes, so it gives," they often emphasise. In winter, with its heavy rains, the Vjosa takes minerals from the soil, but in other seasons it brings water and irrigates the fields and orchards, bringing life and vitality.

In addition to the nostalgic memories of the communist period, the inhabitants of Kutë often talk about current problems related to the construction of the HPPs upstream, the construction and termination of which is still unsure. They cannot escape the fact that in 2016, when the Albanian government granted the concession for the construction of the HPP in Poçem, no public hearing was organised to inform them about the technical lake that will be formed in the location of their agricultural fields.

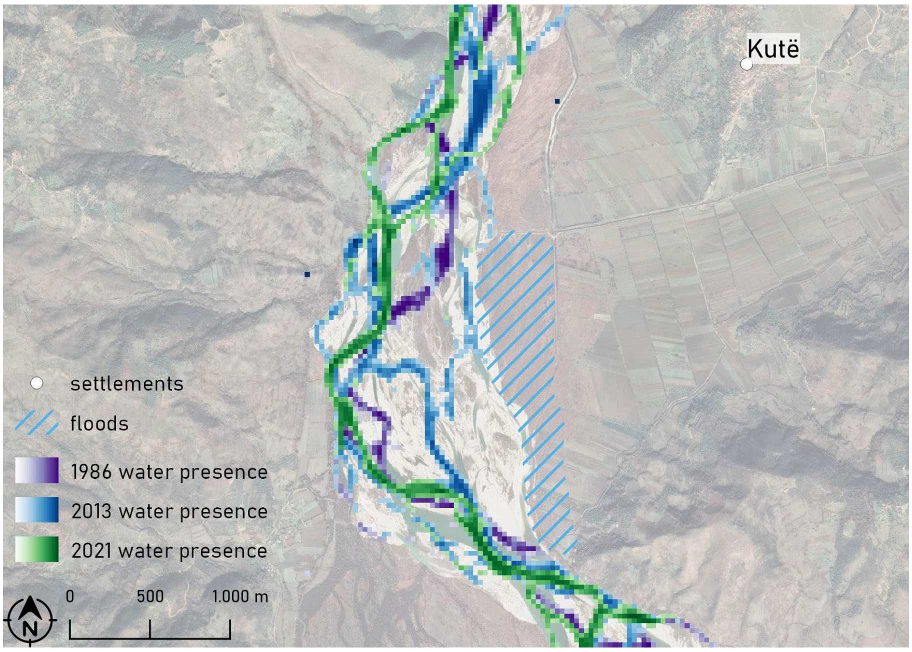

Figure 19. The flow of the Vjosa river and its water presence in three different datasets from Landsat data.

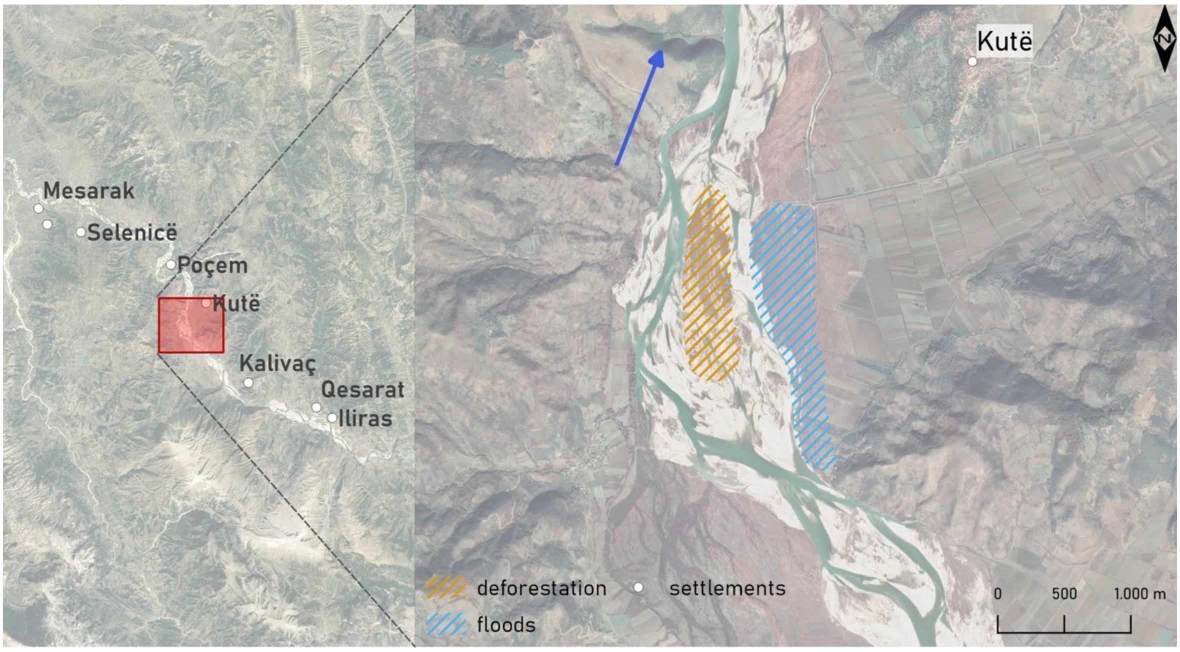

Figure 20. Due to wide gravel bars and dynamic hydromorphological processes, villagers observe slight erosion and seasonal diversion of the river to its right bank.

Most of the inhabitants of the village attribute these phenomena to continuous dynamics and constant changes that pertain to the landscape and people in the Vjosa Valley.

C) Selenicë village

Downstream from Kutë, the sinuosity of the Vjosa River increases and the gradient decreases. Near the small mining town of Selenicë and the villages of Armen and Mesarak, the river basin is characterised by a very high susceptibility to disturbance, a high sediment supply and a high potential for bank erosion.

Selenicë is famous for its natural bitumen deposit, known since ancient times. The deposit, located almost directly on the bank of the Vjosa River, gained its importance in 1871 under the management of French entrepreneurs. Later, in 1922, it came under the management of an Italian company. At that time Selenicë bitumen, unique in its category in Europe, was used for paving the streets and squares of Paris and Milan. During the communist regime the bitumen mine was owned by the state. The production grew together with the number of employees and inhabitants of the town. Because of the proximity to a bitumen mine and refinery, the communist leadership had ordered reforestation to mitigate erosion of the riverbanks. However, after the fall of the regime in 1991, due to the social, economic and political crisis in the country and the general poverty, many trees such as plane trees, poplars and acacias were cut down by locals for firewood or by small local companies selling wood on the Albanian market. Figures 20 and 21 again show the similarity between people's perception of change and the changes detected in the landscape using simple analysis EO.

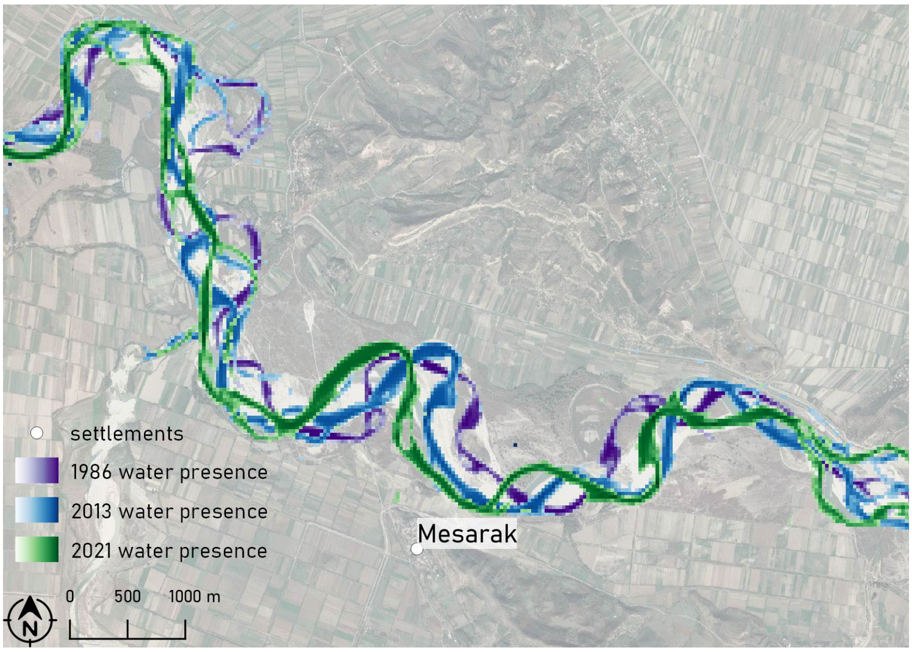

Figure 21. The water presence from Landsat data with the selected years.

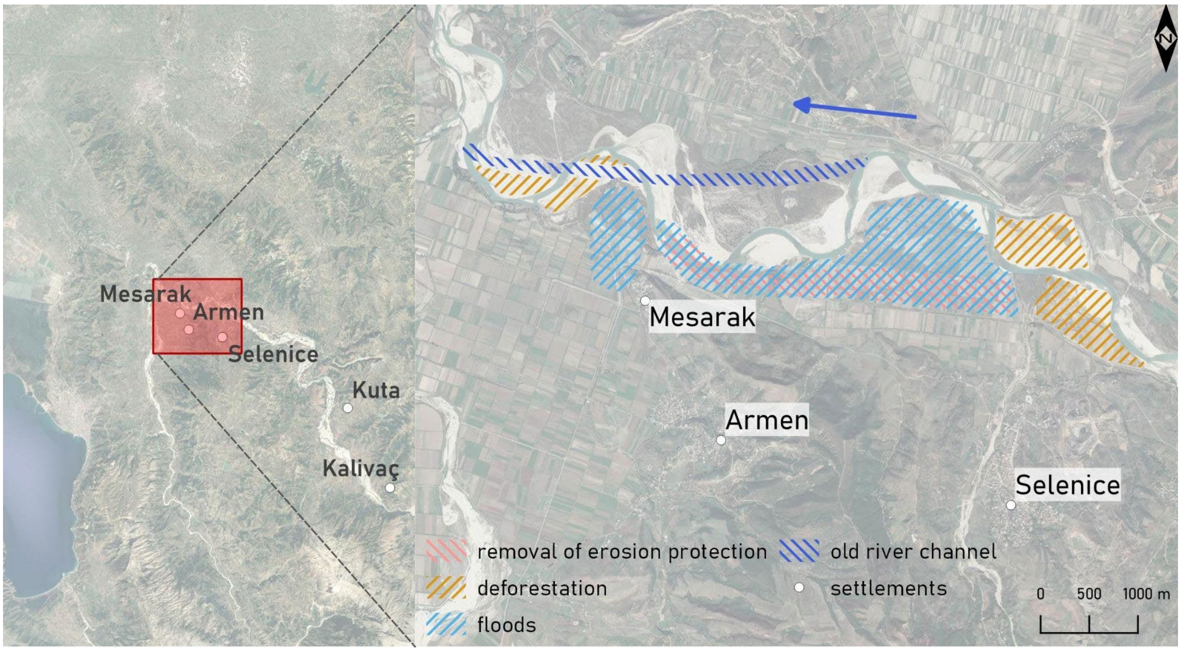

Figure 22. These changes are noticed by the locals, who have named almost exactly the places where the river environment has changed due to deforestation and the resulting bank erosion and detour of the river.

After Selenicë, Vjosa is joined by the tributary Shushica. In the lower catchment, the Vjosa riverbed widens and gradually flows into the Adriatic Sea north from the Narta lagoon.

7.2. StoryMap

In this project, StoryMap is a tool in the form of a webpage, that combines all of the results of the EOcontext project, accessible on **riverchange.zrc-sazu.si**. It combines text and photo material, interactive maps, graphic material and other multimedia content that we gathered throughout this project. The StoryMap entitled “**Riverine Environment**” is following Mura and Vjosa and it illustrates the myriad changes and continuities affecting both rivers over the course of four decades. It maps and explains how various minor and major infrastructural and other anthropogenic interventions as well as geophysical changes have altered the river and how these changes are experienced and lived by the people living in its river environment. With StoryMap we try to contribute to the empowerment and inclusion of the local population in decision-making processes, strengthen institutions and local initiatives to foster policy development.

StoryMap Riverine Environments is presented in a form that is easy to understand and follow. On the introduction page, one can click on one of the rivers to learn more about that particular location.

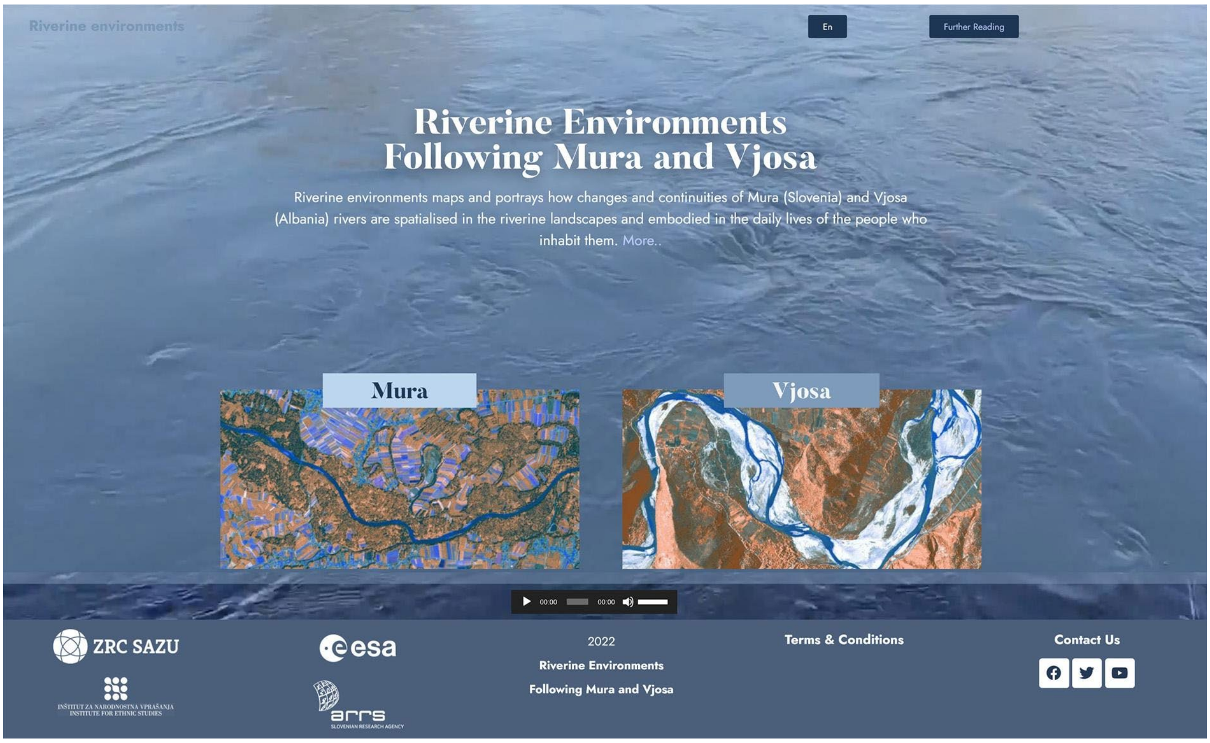

*Figure 23. Overview of the introductory web page of the StoryMap (**riverchange.zrc-sazu.si**).*

Once users select a specific river, one can select a more detailed location where our research was conducted. Users will find a description of each area (5 for each river) and additional informative content - history and hydrologic transformation - in a total of 7 sections, and can also click on the map of the section to a specific location.

In brief, on Mura the informative locations and additional context of the area are:

1. Austrian HPP (the information on the number of HPPs in Austria)
2. Ceršak
3. Petanjci
4. Ižakovci
5. Petišovci
6. History (the information on the historical aspect of the region)
7. Transformation (the information on the hydrological and ecological aspect of the region)

Similarly, for the Vjosa area, users can choose between 5 different locations and 2 additional informative content:

1. Source (the information at the spring of Vjosa river in Greece)
2. Përmet
3. Qesarat and Iliras
4. Kutë
5. Selenicë
6. History (the information on the historical aspect of the region)
7. Transformations (the information on the hydrological and ecological aspect of the region)

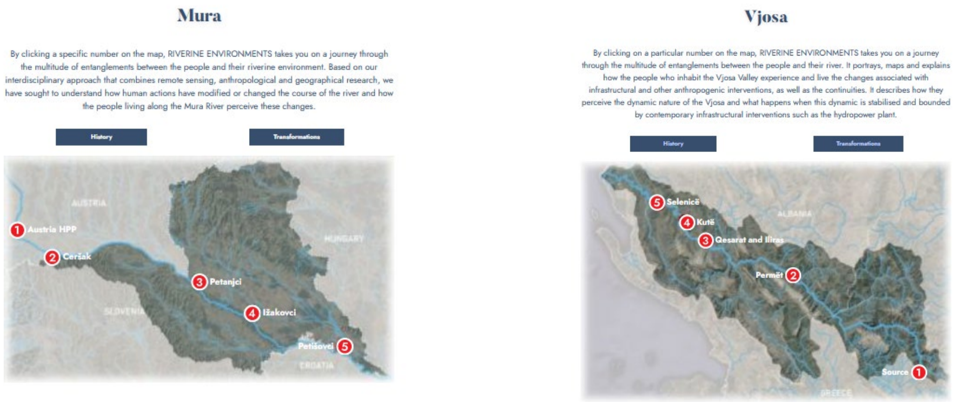

Figure 24. The introduction pages for Mura (left) and Vjosa (right) subpages, where more detailed content is further added with ethno songs traditional for both areas (below the map).

Each of the 7 "subpages" contain entries, or sections, that users simply scroll through. Each section in a StoryMap has an associated map, image, video or web page. StoryMap is supported on Internet Explorer 11 and above, Chrome, Firefox, Safari, and the most recent tablet and smartphone devices.

Figure 25. Couple of examples while scrolling through our StoryMap webage.

We will share the StoryMap "Riverine Environment" broadly with locals, NGOs as well as other international environmental organisations, policy makers, specific experts, etc. With it, we want to show how planned infrastructural interventions on the Vjosa could further change its riverine landscape, using the case study of the Mura River, where, as we have showed, the numerous HPPs on the Austrian side of this transboundary river have caused the loss of sediments and the resulting deepening of the river on the Slovenian side. The main objective of StoryMap is therefore to show how the consequences of infrastructure interventions on the upper reaches of the Mura River and the strict regulations will help users to predict and project the possible consequences of similar interventions on the tributaries of the Vjosa River. StoryMap also illustrates and explains how the lives of local people, an economic and political system around both rivers are interwoven with the river landscape and vice versa.

8. Conclusions

The use of time series analysis with medium resolution satellite imagery is becoming increasingly common for detecting landscape change, especially since the advent of freely available Landsat data. However, one of our goals in this project is to detect major changes in the main course of the Mura River due to infrastructural and anthropogenic interventions on the river, while present and real, have not been adequately captured by observing and analysing historical Landsat data, i.e., spatial data that view the land from above. However, these changes are leading to accelerated erosion of agricultural land, excessive flooding, and subsequently poor soils and lower field productivity. Following the narratives of local people, conducting field research in the area and observing field data, one can clearly see vertical changes that represent the deepening of the Mura River along its banks. Therefore, some of the spatial changes are not visible and could be overlooked if viewed only from a bird's eye perspective.

In this sense, it should be emphasised that the methodological design made valuable results possible in the first place. With the academic knowledge acquired, each individual member of the research team could only make assumptions based on their own patterns of thought and action. The project tried to overcome this "duality" through the cross-disciplinary approach already in the initial phase, without having a clear idea of possible contributions that started to occupy us at some point in the search for a methodological reproach. Crucial in this particular sense was the so-called "local experience and knowledge gained and collected through the fieldwork, with the method yielding such excellent results that the team had to reprogram parts of the originally defined fieldwork. The combination of two different methodological approaches and data sets allowed us to take different approaches and forced us to look beyond our own discipline, which helped us to reorient ourselves and find the real places of change. This insightful approach, which highlighted the whole chain of methodological arrangements, techniques used, and methods involved, confirmed us in the attitude that the whole research process is important: first the cross-disciplinary working group, then the collaboration with local stakeholders, the activation of local people through interlocutors and finally the synthesis through the StoryMap. The latter meant novelty not only for the stakeholders or interest groups, but also for each team member. Only a research design that is constantly rethought, that is open to change and adaptation, and that emphasises the need for cross-sector and cross-disciplinary collaboration can deliver an exceptional result.

This means that throughout the research project, we adjusted our intersectional and cross-disciplinary approach according to research findings at specific stages of our project. Although we had established key research questions at the beginning of our research, we allowed the data (EO data and ethnographic reports) to redefine our original research questions as well as the research methodology. Instead of relying on the original research questions, we allowed our study to proceed recursively, that is, we kept returning to the original research question and modifying it according to the research findings we obtained at a particular stage of the project.

Furthermore, the intersection of big, remote sensing data and thick, ethnographic data can be challenging in many ways. While anthropology deals with the thick data, focusing on the local peoples' experiences as well as their daily lives and other social, cultural, and historical dimensions, remote sensing examines the big data generated by analysing satellite imagery that "detects change" and maps it in space and time. These two different approaches also capture change in different ways. In reality, all things are constantly changing; it is the nature of life and time. Based on the history of the discipline, anthropology attempts to approach change (i.e., difference, transformation) from a bottom-up perspective, understanding it in the context of cultural patterns and social structure. In remote sensing, on the other hand, the nature of "change" tends to be defined depending on the needs and interests of a particular study. Satellite imagery also allows us to detect changes that are not relevant to our study (example: tidal differences in water levels). Whether this is useful information or simply a noise factor in an analysis depends on the context (Woodcock et al., 2019). Therefore, the importance of social, historical, political, and economic context in conducting remote sensing analysis is very great and often not considered. In parallel, the anthropological study of rivers often lacks knowledge of geographical and, in our case, hydromorphological processes, which are important to understand and trace the changes in the Mura and Vjosa rivers. The field visits and a deeper understanding of the place are of great importance when making the final remarks. Therefore, we believe that the proposed methodology can be used to increase quantitative knowledge of river forms and processes over time. We also believe that the combination of different social, historical, geographical, hydrological and ecological aspects adds more value to the understanding of remote sensing results. Therefore, we emphasise the importance of contextualising the spatial results obtained.

Further work

Among the future trends in river monitoring that we anticipate is the increased use of multiple sensors in monitoring activities, particularly focusing on data from the first Slovenian satellite NEMO-HD and incorporating lessons learned from that project. We also plan to focus on temporal accuracy of results, applications over larger areas, and operational use of time series analysis. This is because, although remote sensing data are recognized as very useful for the study of river forms and processes (Marcus and Fonstad, 2008), most EU countries currently do not fully exploit the potential of remote sensing technology for their hydromorphological surveys, even when EO data are already available at regional and/or national scales (Bizzi et al., 2016). Therefore, we plan to further improve the usability and applicability of the EO data with a cross-sectoral methodological interface to combine it with geographic and anthropological data, not only for these two selected rivers, but also for other Balkan rivers. Both cases, Mura and Vjosa, have raised a whole new set of interesting research questions that can be addressed in future projects.

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