CLIMAAX
climate ready regions

Deliverable Phase 2 – Climate risk assessment

CARE-ROPutna

Climate change floods risk assessment for enhanced preparedness and resilience of vulnerable Putna river basin local communities in Romania

Romania, Bucharest

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Abbreviations and acronyms

Abbreviation / acronym	Description
APSFR	Areas of Potential Significant Flood Risk
CRA	Climate Risk Assessment
EAD	Expected Annual Damage
IDF	Intensity Duration Frequency
JRC	Joint Research Centre
FD	Floods Directive 2007/60/EC
GD	Government Decision
GDP	Gross Domestic Product
ML	Machine Learning
NARW	National Administration Romanian Waters
NIHWM	National Institute of Hydrology and Water Management
NSMFR	National Strategy for the Management of Flood Risk in the Medium and Long Term
ROFFG	Romania Flash Flood Guidance System
RP	Return Period
TAU	Territorial Administrative Unit

Executive summary

This Deliverable (Phase 2) describes the refinement and improvement of the climate multi-risk assessment carried out in Phase 1 using local models and data of higher resolution and detail for the Putna river basin. Building on the results of Phase 1, this phase focuses on integrating local high-resolution data, locally developed methodologies, and advanced hydrological and hydraulic modelling to deliver a more accurate, detailed, and decision-relevant assessment of flood and heavy rainfall risks under present and future climate conditions.

The deliverable responds to the need for locally tailored climate risk information to support flood risk management, climate adaptation planning, and preparedness in vulnerable river basin communities. Putna river basin has experienced repeated severe flood events in recent decades, resulting in substantial social, economic, and infrastructural impacts. These impacts are amplified by high exposure, geographical constraints, and limited local adaptive capacity. Phase 2 directly addresses these challenges by improving the spatial resolution, methodological robustness, and local relevance of the CRA outputs.

During Phase 2, the CLIMAAX Handbook and Toolbox (European Commission Joint Research Centre (JRC): Handbook of Climate Risk Assessment – Concepts and Methods for Climate Change Adaptation, Publications Office of the European Union, Luxembourg, https://doi.org/10.2760/152339, 2020.

were applied in expert mode, enabling the customization of workflows and replacement of default datasets with locally sourced information. The assessment was enhanced through the integration of local exposure datasets (land use, transport infrastructure, buildings), locally derived vulnerability functions and damage curves, and high-resolution (1 m) digital terrain model. Advanced hydraulic modelling (HEC-RAS 6.6) was used to generate local flood hazard maps for selected Areas of Potential Significant Flood Risk (APSFRs) along Zabala and Naruja rivers, covering multiple return periods and both present-day and climate change scenarios.

A key methodological advancement in this phase is the transition from pan-European hazard layers used in Phase 1 to locally calibrated hydraulic modelling, allowing a realistic representation of flood extents, depths, and impacts at settlement scale. Climate change impacts were incorporated using discharge change percentages derived from multi-model GCM–RCM chains, with a focus on the late-century period under a medium-severity scenario. This approach ensures consistency with the CLIMAAX framework while maintaining strong relevance for local decision-making.

The refined assessment produced new and improved risk outputs, including: high-resolution flood hazard maps for present and future conditions; updated flood damage estimates for land use, buildings, and transport infrastructure; settlement-level indicators such as flooded area percentages, estimated economic losses, and exposed population; comparative analyses demonstrating the added value of local data and methodologies compared to Phase 1.

For the Heavy rainfall, the focus within Phase 2 was to extend the analysis by using regional high intensities local runoff, and flash floods risk assessment, for entire Putna river basin, based on the critical impact rainfall thresholds for 3h duration, derived from the configuration of ROFFG System and the experience of the NIHWM forecasters from using this system for real time flash flood warnings activities. For conducting the analyses we mainly used two new local precipitation datasets, one with gridded observational data and one bias corrected climate simulations.

Results confirm significant flood risks across the study area, with clear increases in hazard extent, damage magnitude, and exposed population under climate change scenarios. In several settlements, more than one quarter of the built-up area is projected to be affected during extreme flood events. Transport infrastructure—particularly bridges and national roads—emerges as a critical vulnerability, with high potential for cascading impacts such as community isolation and disruption of essential services. The use of local vulnerability data leads to substantial differences in both total and maximum damage estimates compared to Phase 1, clearly demonstrating the importance of localized assessments.

Stakeholder engagement was initiated during Phase 2 through an introductory workshop involving local and regional authorities. This process supported the incorporation of local knowledge, and increased awareness of climate-driven flood risks. Feedback collected through questionnaires indicates strong stakeholder interest, high perceived relevance of the results, and willingness to actively engage in the next project phases.

In conclusion, Phase 2 delivers a substantially enhanced and locally grounded climate risk assessment for the Putna River Basin. By combining the structured CLIMAAX methodology with high-resolution local data, expert modelling, and stakeholder input, the assessment provides a robust evidence base for prioritizing risks and informing adaptation planning. The findings confirm the urgency of flood risk management under climate change and directly support the transition to Phase 3, which will focus on the identification of targeted prevention, protection, and preparedness measures to strengthen local resilience.

1 Introduction

1.1 Background

Putna river basin extends over most of the territory of Vrancea, which has a population of 335,312 inhabitants 67% of whom live in rural areas and 33% in urban areas.

Within a varied landscape characterized by mountains, hills, and plains, the total length of permanent and torrential river bodies is approximately 2000 km, resulting to an average river network density of 1.24 km/km². Maximum flows are recorded in general from late spring (April-May), peaking in May-June often extending throughout the summer. Peak flows are caused by very high amounts of precipitation, generally with high intensity that often generate severe floods with significant damage.

During 2005, 2012, 2016, 2021 and 2022 significant heavy rainfall and floods events in Putna river basin caused major damage and even loss of life.

Local communities in Putna river basin have limited resources to increase climate or disaster resilience because, in general, they do not have sufficient resources to implement proper emergency response, recovery and adaptation measures, have high exposure to natural hazards due to the geographical position, have a large number of vulnerable people (children or elderly people) existing within the communities.

During phase 2, in order to validate and supplement the local data used in the risk analysis with field observations and local knowledge, the project team conducted a field trip in Putna basin, focusing on Naruja and Zabala basins, for which the detailed hazard analysis was performed. During this trip, some local exposure data was validated and the existing infrastructure elements and defense structures in the major riverbed were observed. Field images showing the observed exposure elements and relevant structures in the major riverbed can be found in Zenodo (Stakeholders_workshop)

1.2 Main objectives of the project

The main objectives of Phase 2 of the project, as mentioned in the flollow up plan are:

- improve the assessment of the flood hazard and risk maps under climate change impact, for the selected areas of potential significative flood risk in Putna river basin;

- involve stakeholders (e.g. local and regional administrative authorities) in preparing the ground for the new proposals for the program of measures which will include prevention, protection and preparedness measures for existing and future floods, taking into account the effects of climate change.

- increase the general knowledge and awareness of floods and flash floods risk at local and regional scale, as a result of the first introductory workshop;

By integrating local high resolution data sets using the Toolbox package as expert users, in order to create a fully customized regional risk assessment package, alternative methodologies and last generation hydraulic models were integrated during phase 2, resulting in new hazard and risk maps that can help improving the local knowledge of these risks in present scenario and under climate change.The improved and comprehensive risk analysis will support the proposal of better tailored mitigation and adaptation measures for increasing local community resilience to climate change impacts and risk awareness.

By understanding specific climate risks and their potential consequences, stakeholders can develop targeted strategies to address these challenges and build a more sustainable and resilient future for the region.

The main benefit of the use of CLIMAAX handbook is that it provides standardized, step-by-step methodology for assessing climate hazards, exposure, vulnerability, and risks. This ensures consistency, transparency, and scientific robustness in climate risk assessments across the RoPutna region. Applying the CLIMAAX Handbook ensures also coherence with EU climate adaptation frameworks and risk assessment standards. It also enhances stakeholder engagement and capacity building, enabling local authorities and practitioners to better understand and manage climate-driven flood risks.

1.3 Project team

In order to meet the objectives of phase 2 of the project, the team members working on specific tasks were mainly technical experts with Python skills who processed and prepared the neccesary files for customizing the workflows by integrating local datasets and hydrologist researchers with experience in climate risk assessment who had important roles in interpreting and validating the results obtained after each processing step. Also, team members specialized in hydraulic and hydrological modeling worked during phase 2 for developing the new high resolution flood hazard map.

In addition, members of the working team with experience in planning and organizing stakeholder engagement events were involved.

1.4 Outline of the document’s structure

This Deliverable 2 is structured to guide the reader through the objectives, methodology, results, and evaluation of Phase 2 of the CRA in a logical and transparent manner.

Section 1 introduces the context and scope of the deliverable, outlining its objectives, relevance within the CLIMAAX framework, and its position within the overall CARE-ROPutna project.

Section 2 presents the core technical content of Phase 2. It describes the applied methodologies, local datasets integrated and modelling approaches and presents the refined climate hazard, exposure, vulnerability, and risk analysis results. The chapter also includes monitoring and evaluation aspects, reflecting on lessons learned, stakeholder involvement, and remaining challenges.

It should be noted that, in this section, the page limit has been exceeded, as the customized CRA required additional analyses that resulted in additional workflows. These have been presented as concisely as possible, with most of the graphic materials being uploaded only to Zenodo.

Section 3 synthesizes the main findings of Phase 2, highlighting key results and conclusions derived from the refined climate risk assessment and their implications for the next phase.

Section 4 provides a progress evaluation, linking the outputs of this deliverable to the project’s planned activities, Key Performance Indicators, and milestones, and demonstrating alignment with the Individual Following Plan.

2 Climate risk assessment – phase 2

2.1 Scoping

2.1.1 Objectives

The main objective of the CRA developed in Phase 2 is to integrate local high resolution data sets (using the Toolbox package as expert users in order to create a fully customized regional risk assessment package) and valuable information from local knowledge of the exposed areas (obtained through consultation with local communities in the first workshop planned in the study area), alternative methodologies and last generation hydraulic models with the purpose of obtaining new hazard and risk maps that can help improving the local knowledge of these risks in current conditions and under climate change.

The main expected outcome of this phase is a customized refined and detailed CRA risk in present day conditions and under climate change in Putna river basin.

Another important outcome of this phase, following the first introductory workshop in the study area, is the stakeholders involvement process started and the ground for consulting them on the measures proposed for phase 3 prepared.

The main challenges encountered during phase 2 were related to data limitatios and technical issues in integrating large, high-resolution local datasets into the workflows.

Other technical limitations were related to workflow functionality after integrating local data with significant differences in resolution, when the resample function resulted in irrelevant data.

One challenge related to stakeholder involvement was presenting the technical results of the first phase in a way that was understandable to all event participants, given the diversity of their scientific backgrounds. Therefore, the presentations mainly used relevant graphics and images, as well as video representations of the processes.

2.1.2 Context

The current climate hazads, impacts and risks evaluation process in Romania, along with the national context and most impacted sectors in Putna river basin were described in detail in the Context section of Deliverable 1.

Based on the results of the climate risk assessment using CLIMAAX framework and toolbox, we aim to improve and complete the previous floods hazard and risk assessments, conducted within the implementation of Cycles I and II of FD (Floods Directive 2007/60/EC) in order to propose relevant measures for risk management in current conditions and under climate change (European Commission: Directive 2007/60/EC of the European Parliament and of the Council on the assessment and management of flood risks (Floods Directive), Official Journal of the European Union, L288, 27–34, 2007.

2.1.3 Participation and risk ownership

The involvement of stakeholders is an essential component in the development of the local adaptation strategy and the improvement of the flood risk management plan at the level of the Putna river basin. This process includes 3 stages, starting with phase 2: information, involvement, and consultation of stakeholders. The relevant representatives of known vulnerable groups and exposed areas are the main stakeholders that were involved starting with phase 2 of the project, according to the working plan.

The main stakeholders and beneficiaries of the CRA are the following: Ministry of Environment, Water and Forests, National Administration "Romanian Waters", Siret Water Basin Administration, local and regional authorities (mayors, County Councils), Civil Protection Authorities, community groups, agriculture/farmers, fisheries and aquaculture, NGOs, and nature protection. The organigram that maps the institutions and responsibilities and how they are interconnected is presented in Figure 2-1.

Representatives of the main stakeholders and beneficiaries of the project were invited to the 3 foreseen workshops in the study area (1 preparation meeting with stakeholders in the study area in September 2025, 2 stakeholder's consultation and project results dissemination workshops, in May and June 2026). During these workshops, they will be informed about the project and its implementation stage, directly involved in finalizing the new proposals for the program of measures which will include prevention, protection, and preparedness measures for existing and future floods, considering the effects of climate change. The results will be also communicated through dissemination posts in social media (3 posts on the FB page of INHGA and by preparing 2 notes for decision-makers) and an awareness-raising brochure (will be distributed electronically and on paper) targeting the local communities that will contribute to maximize the impact of the project results.

The institutions responsible for the assessment, management and mitigation of flood risk, the vulnerable groups and exposed areas and the acceptable level of risk are described in Deliverable phase 1.

The relevant representatives of the communities and vulnerable groups and exposed areas in the study area are operating as a part of and under the authority of the Mayors, as Social Assistance Department. Their official legal and institutional representatives are the mayors, that were invited and participated at the first stakeholders workshop held during phase 2 of the project.

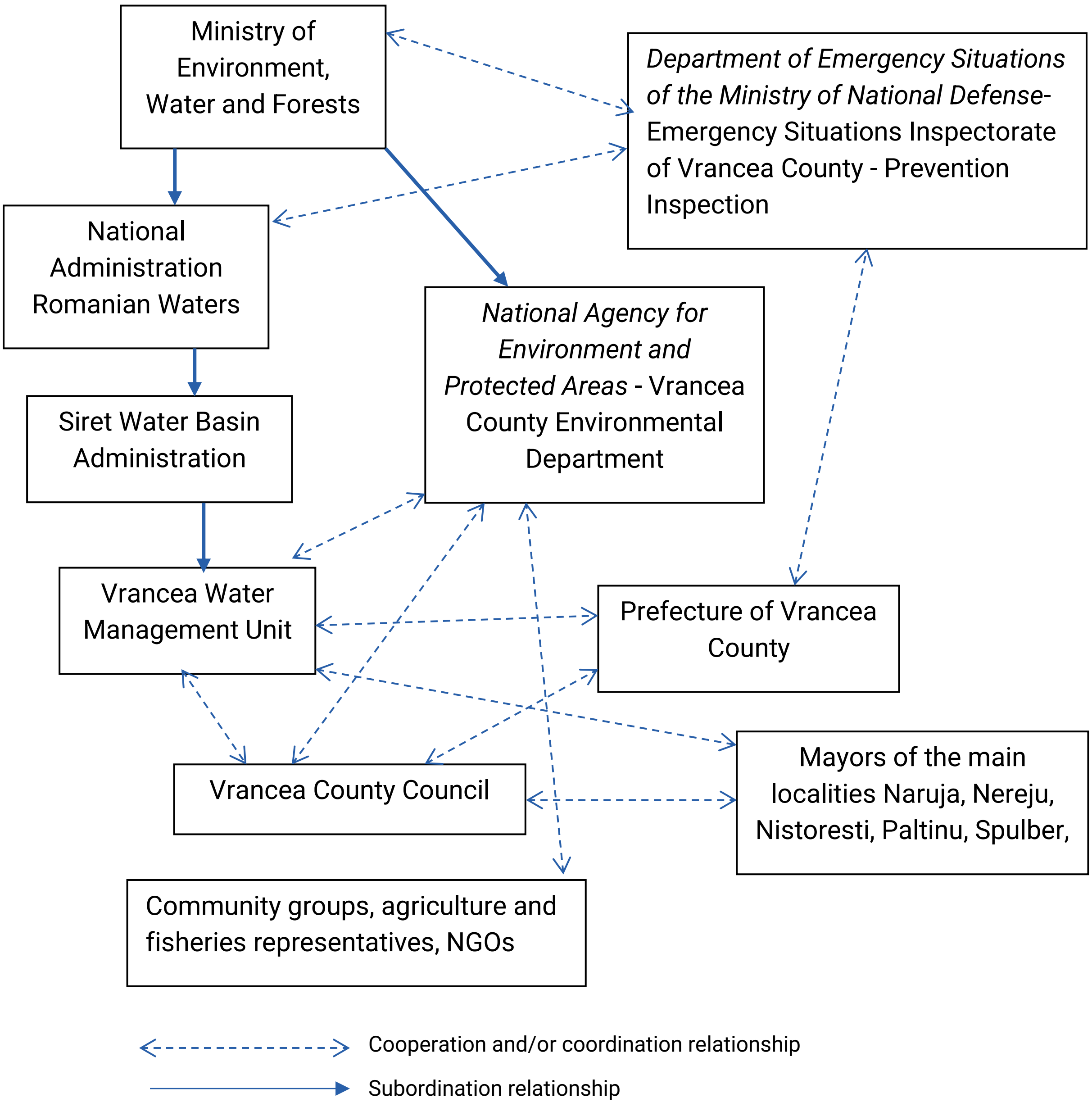

Figure 2-1 Stakeholders interconnection relationship diagram

2.1.4 Application of principles

Social justice, equity, and inclusivity were embedded throughout the assessment processes of the project. Stakeholder engagement was designed to ensure the representation of diverse social groups, including vulnerable populations such as elderly people, low-income households, and those living in flood-prone areas. The first workshop and consultations were held with local authorities and community representatives to take into account differential vulnerabilities and adaptive capacities. The analysis aimes to focus not only physical and environmental risks but also on the social dimensions of climate impacts, ensuring that adaptation measures proposed will benefit all segments of the community fairly.

The CRA for Putna river basin follows a systematic and transparent methodology consistent with the CLIMAAX Framework. All data sources, models, and assumptions were documented, and cross-validation was performed using available regional and national datasets. Quality control was maintained by using peer-reviewed data sources and validated methodologies (e.g., hydrological and climate models consistent with EU standards). Intermediate results and methodological choices were both debated among team senior researchers and experts and presented to stakeholders during the dedicated workshop., ensuring scientific rigour and transparency in the decision-making process.

All analytical outputs (maps, tables, plots,datasets) will be made available through the Zenodo open repository, ensuring that every result can be independently verified.

Given the inherent uncertainty of climate projections, as well as data limitations, the CRA analysis for Putna river basin applied a precautionary approach. Some datasets — particularly those related to exposure, socio-economic characteristics, and local infrastructure — were only partially available or had limited spatial and temporal resolution. These constraints and also some technical issues in the workflows were explicitly acknowledged and addressed by using approximations or generalizations, alternative methods and expert judgment where necessary.

Recognizing these uncertainties and limitations, the analysis will promote during the third phase adaptive and flexible approaches for the measures to be proposed, that will include no-regret and low-regret adaptation measures under a range of possible future conditions. This precautionary stance ensures that the measures to be proposed remain robust even when complete or high-resolution data are not available for all exposure or climate data.

2.1.5 Stakeholder engagement

In Phase 1 , according to Scoping Step from CRA Framework and step 1 from RAST Preparing the ground for adaptation, relevant stakeholders were indentified and their engagement process was planned.

In Phase 2, according to the working plan we started the stakeholder engagement process that ensures the development of adapted CRA's to local communities needs and uptake into strategic planning of adaptation mesures in the next phase of the project (phase 3).

In this regard, the first workshop dedicated to stakeholder involvement was organized in the study area, titled "The CARE-ROPutna Project – Introductory Workshop."The event took place on September 23, at the Vrancea Water Management Unit headquarters in Focșani city.

Over 20 representatives from relevant institutions from a diverse range of sectors responded to the invitation and actively participated in the discussions. Among them were members of the Vrancea County Council, the Vrancea Prefecture, local municipalities, as well as representatives from Siret River Basin Administration, Vrancea Water Management Unit, and Vrancea County Environmental Department (National Agency for Environment and Protected Areas).

During the meeting, after the presentation of the general CLIMAAX framework within which the project is implemented, the following topics were addressed:: the main objectives of the project; the results of the first phase and future activities planned, National and European context, Concrete ways for stakeholders and local communities to get involved, both in capitalizing on the project results and in developing proposals to reduce flood risk in the Putna River Basin.

The open discussions and debates between the presentations have aimed to engage relevant local stakeholders proactively, from gathering essential local knowledge on climate risks to preparing the ground for the next workshop dedicated to discussions on the proposal of adaptation measures suitable for the study area.

The overall discussions on local data and knowledge and mainly the debates aimed at raising awareness of climate-related risks and adaptation, were based also on information gathered during a field study visit by experts from the project working team to hot spot areas at high risk of flooding.

In addition to presentations and discussions, an effective method used in this phase of local stakeholder engagement was the completion of a detailed survey designed to gather both feedback from participants and key information about local knowledge and interest in involvement.

During the presentations and discussions held during the workshop a shared terminology for coherent messaging and effective communication was adopted, to establish a common understanding and language to be used in interactions with stakeholders and local communities.

After the workshop, media posts were made about the event, the topics discussed, and the conclusions through diverse channels, including national or local web portals in local language and English.

The summary of the feedback based on the questionnaires completed by participants at the workshop can be found in Zenodo (Stakeholders_workshop).

This introductory workshop is the first of a series of three scheduled throughout the project's implementation and represents an important step in the effective stakeholder engagement process, to the benefit of the communities in the region.

The second workshop, planned for April 2026 will be based on organising debates on the proposed measures based on the risk outputs of phase 2, and on gathering stakeholders feedback on these measures, in order to adjust them to the local context and their specific needs.

The final workshop, planned for June 2026 will present the outputs of phase 3 and overall results of the project and will gather stakeholders feedback on further implementation possibilities of the results in Putna river basin.

2.2 Risk Exploration

2.2.2 Screen risks (selection of main hazards)

Although in the Copernicul Climate Atlas (*https://atlas.climate.copernicus.eu/atlas*) , for most of the available climate variables relevant to floods there is an indication of lack of signal or conflicting signals in the study area, there are variables that indicate a general slight increase in precipitation intensity (for seasons), maximum precipitation accummulated in 1 and 5 days, and the number of days with heavy and very heavy precipitation.

As mentioned in Deliverable 1, the major climate-related hazards that local communities in Putna river basin are facing are flooding and heavy rainfall as a major risk factor for flash floods. These hazards were selected for analysis within the scope of the project. The risks derived from the selected hazards are loss of life, damage to properties, disruption of livelihoods and essential services.

In accordance to the local stakeholders that participated in the workshop and also to the annual damage reports issued for Vrancea County territory the most significant impact as values of damages was on key sectors like the transport infrastructure (national and county roads, bridges), hydro-technical works for bank consolidation, water supply and sewerage networks, households and annexes, treatment plants, agricultural land. The high impact of flooding and extreme precipitation on a major part of the traffic routes is of major importance for the local communities because the damage of roads leads to their isolation, also the flooded households, damages to water supply and sewerage networks and treatment plants have a major impact on the local community living.

As indicated by the main outputs of the CRA conducted in phase 1, the selected hazards and risks show high values for most of the selected return periods and generally increasing trends for future scenarios.

According to the work plan, during phase 2 of the project, local high resolution data sets, alternative methodologies and last generation hydraulic models for the selected areas are integrated in the CRA, using the Toolbox package as expert users, in order to create a fully customized regional risk assessment package.

2.2.3 Choose Scenario

To establish the relevant climate change scenario, the Discharges workflow was used, which was run for the analyzed sub-basin (Figure 2-2). Following the analysis of the results obtained (the percentages of change in flow for different time horizons and different climate scenarios), the value corresponding to the average value of gcm/rcm model chain for furthest time horizon (2070-2100) was selected for the medium severity scenario rcp 4.5 and a return probability of 2% (Figure 2-3)

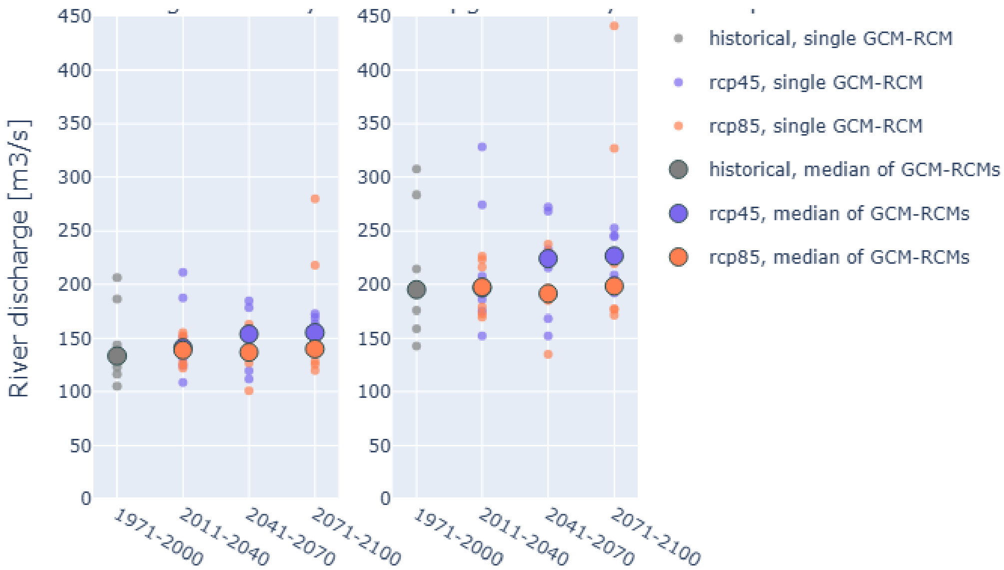

Figure 2-2 Estimated extreme river discharges for Zabala catchment for different GCM-RCM combinations, climate change scenarios and time horizons

time_period	scenario	rdisreturnmax10 _tmean	rdisreturnmax50 _tmean
2011-2040	rcp45	5,67	5,64
2041-2070	rcp45	11,90	14,93
2071-2100	rcp45	13,58	15,00
2011-2040	rcp85	(0,62)	(0,73)
2041-2070	rcp85	(3,28)	(4,39)
2071-2100	rcp85	20,68	24,41

Figure 2-3 Average values of relative change (%) in maximum discharges for Zabala catchment for different GCM-RCM combinations, climate change scenarios and time horizons

Since the River Flood Discharges workflow performs the analysis for return probabilities of 2% and 10%, we considered the average value of gcm/rcm model chain corresponding to 2% probablility of exceedance (50 years RP) to be relevant, given the current upward trend for all scenarios, between 10% and 2%.

This value was used to obtain the flood hazard map, based on the local hydraulic model, for the climate change scenario.

All the outputs of workflow Discharges can be found in Zenodo W4.

One of the limitations of this analysis was the lack of availability of high-resolution local data on future socio-economic development that could be integrated into the customized CRA alongside the 1m resolution hazard map in order to obtain relevant results.

2.3 Regionalized Risk Analysis

According to the work plan, in Phase 2, for the refinement and improvement of the multi-risk assessment carried out in Phase 1 using local data of higher resolution and detail, the full Toolbox packagewas downloaded, in order to create a fully customized regional risk assessment package allowing the inclusion of own local data on hazard, exposure, and/or vulnerability, and adjusted risk assessment methods.

The local high resolution exposure and vulnerability datasets integrated in the CRA are:

- Local landuse map
- Local damage curves for different landuse
- Local data on maximum damage values for landuse
- Local transport infrastructure map
- Local damage curves for different types of transport infrastructure
- Local data on maximum damage values for transport infrastructure
- Local detailed map on building footprint and type
- Local damage curves for buildings
- Local data on maximum damage values for buildings
- Local historical data with gridded 24 precipitation based on the observation
- Local bias-corrected climate model simulations.

Local exposure data was generated in the framework of the implementation of the Cycle 1 and 2 of Floods Directive (European Commission: Directive 2007/60/EC of the European Parliament and of the Council on the assessment and management of flood risks (Floods Directive), Official Journal of the European Union, L288, 27–34, 2007.

for the areas within Putna river basin, based on data collected from various local sources (from various relevant institutions in the form of digital files and maps). This data was prepared and analyzed to identify omissions and subsequently complete them, both in terms of vector elements and attributes. To complete these datasets, a hybrid approach was used to obtain the characteristics of all layers correlated with the necessary attributes, combining Machine Learning (ML) that uses orthophotomaps with manual methods. For example, for transport infrastructure data layers that could not be vectorized using ML (e.g., bridges), they were manually vectorized using orthophotomaps. In addition, attribute information for each layer, obtained through OSM, Google Street View photos, and orthophotomaps, was subsequently correlated with vector elements by merging attributes based on location (Spatial join). The final data was prepared by combining data from all available sources.

A key feature of the customized local CRA in phase 2 was the local high resolution flood hazard maps, developed based on local high resolution (1m) DTM model for Zabala and Naruja rivers for present day conditions and under climate change.Details on the methods and models used are described in the hazard assessment section below.

The technical workflows adjustments for integrating the local data are described in the following “Workflows - fine tuning to local context” sections.

Some of the most relevant new impact metrics in the customized CRA outputs of phase 2 are : percent of flooded area of the localities in present day conditions and under climate change for the event of 100 years RP, outputs of CRA for transport infrastructure, percent of change in discharges used to estimate the impact of climate change for different future scenarios, exposed population based on number of impacted buildings.

New metrics related to heavy rainfall in this phase are: new relevant spatially variable critical impact-based rainfall thresholds for 3h duration and computationof the associated projected changes in return periods for different severity events, future periods and climate projections.

The most relevant indirect impacts of flood risk in the study area (social, economic, environmental) will be considered in phase 3 of the project, as part of the proposed measures.

2.3.1 Hazard #1 River Flooding - fine-tuning to local context

According to the work plan of phase 2, at the beginning of this phase dedicated to refining the CRA obtained in phase 1, by integrating local data, in a first stage, local exposure and vulnerability data were integrated into the river floods workflow, together with the local methodology for estimating the value of damages, along with the JRC hazard map, for the entire territory of the Putna basin.Using the JRC hazard map as a common element.

For this first stage of phase 2, aimed at a comparative analysis with the results of the first phase, in order to estimate the influence of the use of local exposure and vulnerability data on CRA, the local landuse map and damage estimation data was integrated, alongside with JRC hazard map.

In the next stage of CRA refinement, according to the work plan, local exposure and vulnerability data was integrated into the workflow alongside the high-resolution local hazard map obtained through hydraulic modeling, in order to obtain a fully customized CRA for the selected areas.

Table 2-1 Data overview workflow #1 River flooding

Hazard data	*Vulnerability data*	*Exposure data*	*Impact metrics/Risk output*
JRC flood hazard maps	Local damage curves for different landuse Local data on maximum damage values	Local landuse map	River flooding risk maps related to landuse Comparative charts
Local high resolution flood hazard maps *Present and CC*	Local damage curves for different landuse Local data on maximum damage values	Local landuse map	River flooding risk maps related to landuse Plots (for current scenario and under climate change)
Local high resolution flood hazard maps *Present and CC*	…Local damage curves for different types of transport infrastructure Local data on maximum damage values	Local transport infrastructure map	River flooding risk maps related to infrastructure Plots (for current scenario and under climate change)

2.3.1.1 Hazard assessment

The development of high-resolution local flood hazard map

In accordance with the work plan, in order to integrate hazard local data in the customized CRA, a high resolution local hazard map was developed for the APSFR areas corresponding to the Zăbala and Năruja rivers, for the occurrence of maximum flows with probabilities of exceedance of 10%, 1%, 1% CC and 0.1%. The development of flood hazard maps was carried out on the basis of updating the basic data required for their creation to the level of 2025, respectively the updated hydraulic models.

Figure 2-4 comparatively shows the two flood hazard maps (JRC and local hazard map) for a section of the Naruja River.

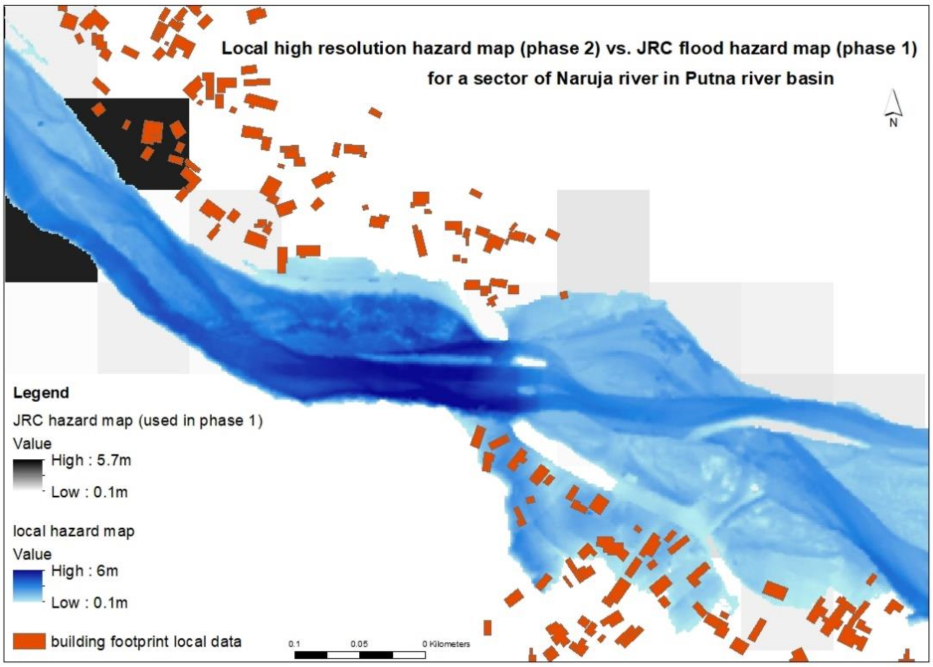

Figure 2-4 Local high resolution flood hazard map (phase2) vs. JRC flood hazard map (phase 1) for a relevant sector of Naruja river in Putna river basin

Local model input data

The following types of data were used to create the updated hydraulic models:

- Topographic data consisting of the high resolution digital terrain model (1m) for the area of interest (Figure 2-5);
- Hydrological data on maximum flow values with exceedance probabilities of 10%, 1%, 1% CC, and 0.1% on Zăbala and Năruja rivers (Zenodo/Local_flood_hazard)
- Other data and information (landcover data, satellite data from Google Earth, data from the Flood Risk Management Plan Cycle I and II, data from specialized literature)

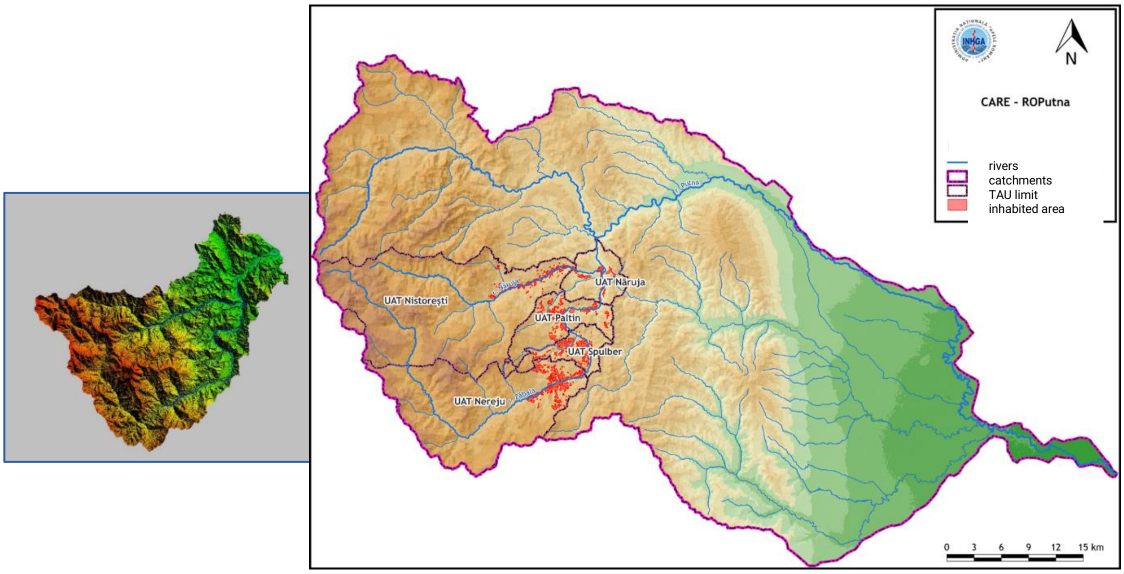

Figure 2-5 High resolution digital terrain model (1m) of Zăbala and Năruja river basins (Stereo 70 system, S-42 Romania datum) updated to 2025

Hydraulic modelling

The hydraulic models were developed using HEC-RAS 6.6 software, developed by the Hydrologic Engineering Center (HEC), which reproduces the propagation of flood waves under existing conditions, highlighting the hydraulic characteristics of riverbeds and the effects of any existing hydrotechnical works (U.S. Army Corps of Engineers (USACE): HEC-RAS River Analysis System, Version 6.6, Hydrologic Engineering Center, Davis, CA, https://www.hec.usace.army.mil/software/hec-ras/, 2023.. The mathematical modeling of specific hydraulic phenomena consisted mainly of rendering as accurately as possible the flow of water on the geometry of the riverbeds based on topobathymetric data collected in the project area of interest, both in the minor riverbed and in the major riverbeds (left bank – right bank), with the calibration of the models being performed based on historical floods recorded at the hydrometric monitoring stations (S.H. Nereju and S.H. Herăstrău).

Outputs

The main data provided by the model can be presented are:

- hydraulic characteristics regarding maximum flows, levels corresponding to maximum flows, widths at the water surface and average velocities in the riverbed, partial/cumulative distances, etc.;
- flood hydrographs calculated at the entrance points to the localities (Figure 2-6);
- the extension of flood-prone areas resulting from the intersection of the water level corresponding to maximum flows with probabilities of exceedance of 10%, 1%, 1%CC, and 0.1% with those of the terrain, the maximum water depths associated with flood-prone areas, by sectors of the rivers analyzed (Figure 2-7)

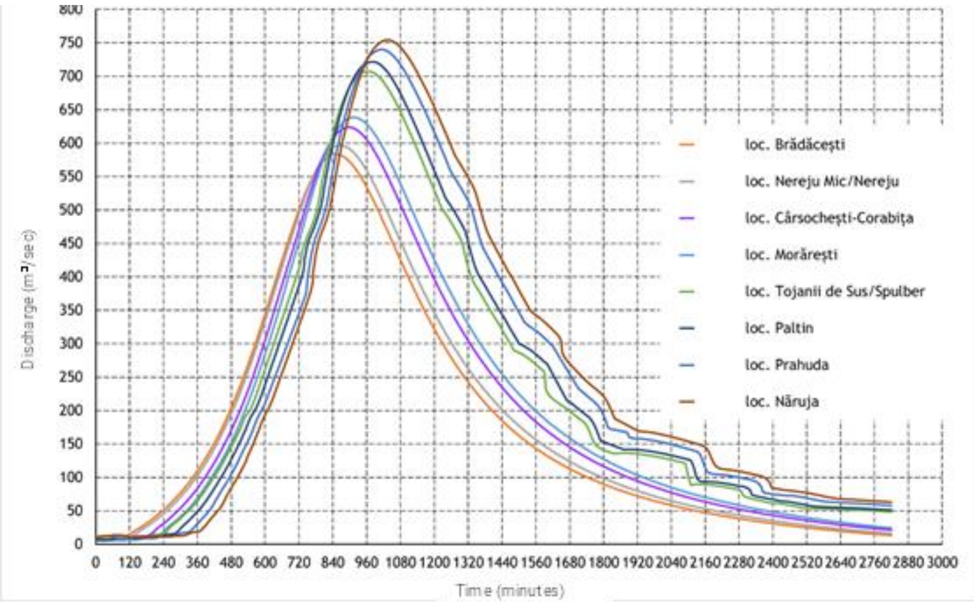

Figure 2-6 1% probability of exceedance flood hydrographs calculated at the entrance points to the localities located on the Zabala river for present day conditions

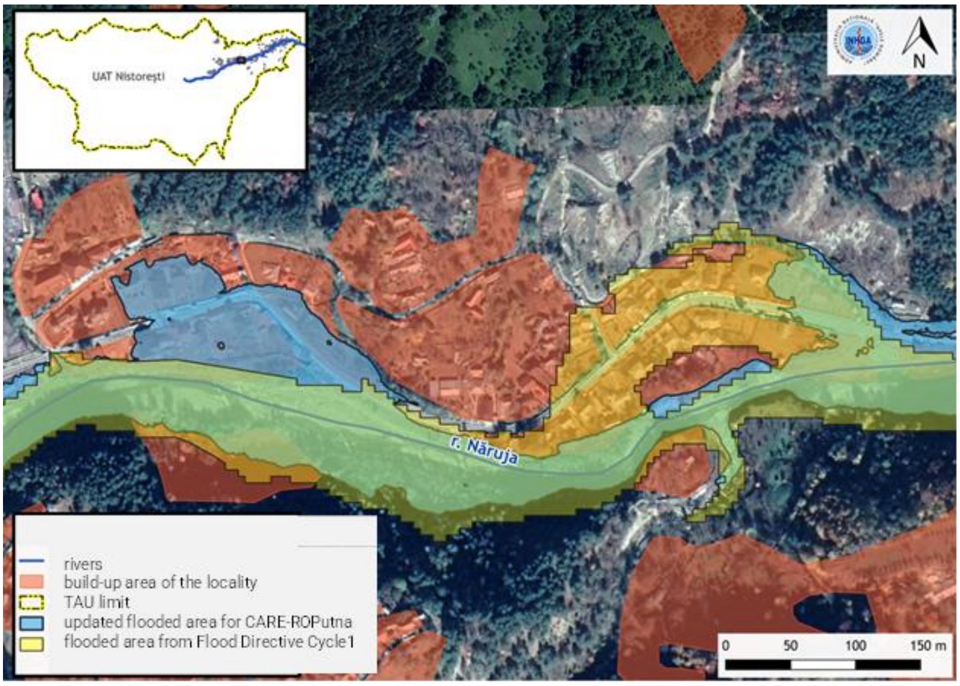

Figure 2-7 Example of updated flooded area for 1% probability of exceedance discharge (Vetresti-Herastrau localty) on Naruja River

The flood hazard under the impact of climate change was obtained by applying the percentage of change in flow resulted from gcm/rcm model chain for furthest time horizon (2070-2100) for the medium severity scenario rcp 4.5 (from River Flood Discharges workflow), to the present day discharge value with 1% exceedance probability and use the resulted value as input to the local flood hazard model (HecRas) for the analyzed area.

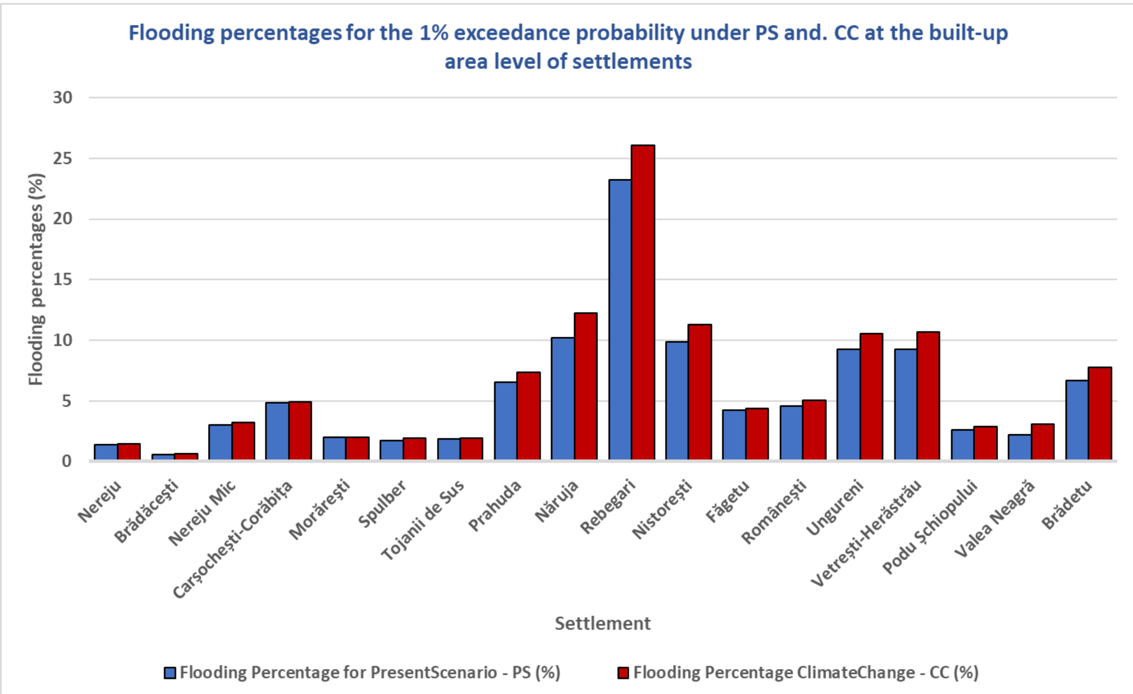

Figure 2-8 . Flooding percentages of the settlements on Zabala and Naruja rivers for 1% exceedance probability for present day conditions and under climate change

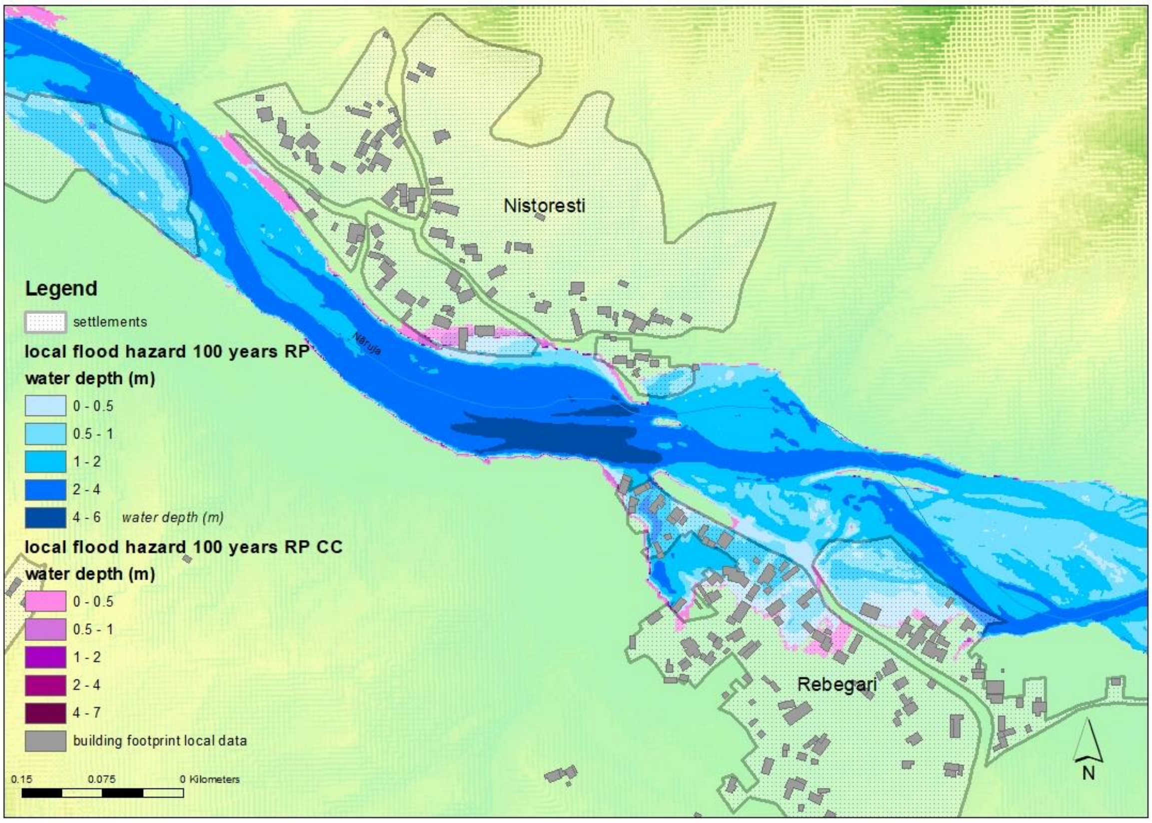

Figure 2-9. Flooding area for the 100 years RP event in present day conditions and under climate change scenariofor Rebegari and Nistoresti settlements on Naruja river

The chart presenting the flooding percentages (Figure 2-8) of each settlement on Zabala and Naruja rivers indicates a clear upward trend for the climate change scenario, reaching maximum values of over 25% (Rebegari localty, Figure 2-9).

The local data used to develop the high resolution hazard map and all relevant outputs for the study area can be found in Zenodo (Local_flood_hazard)

2.3.1.2 Risk assessment

Risk assessment based on JRC hazard map and local landuse and vulnerability data

The first stage of river flood risk estimation based on local exposure and vulnerability data and JRC hazard data was based on the integration of the following local data sets:

- Local landuse map (Zenodo: W1)
- Local damage curves for different landuse (Zenodo: W1 Local_vulnerability_data)
- Local data on maximum damage values for landuse types (Zenodo: W1 Local_vulnerability_data)

The local landuse layer (Figure 2-10)was obtained based on the Corine Land Cover (CLC2006) layer, substantially improved by NIHWM within Cycle 1 of the implementation of the Flood Directive, by updating and detailing the main classes for risk determination (types of agricultural use, built-up areas, roads and railways, waste disposal sites, lakes and reservoirs).

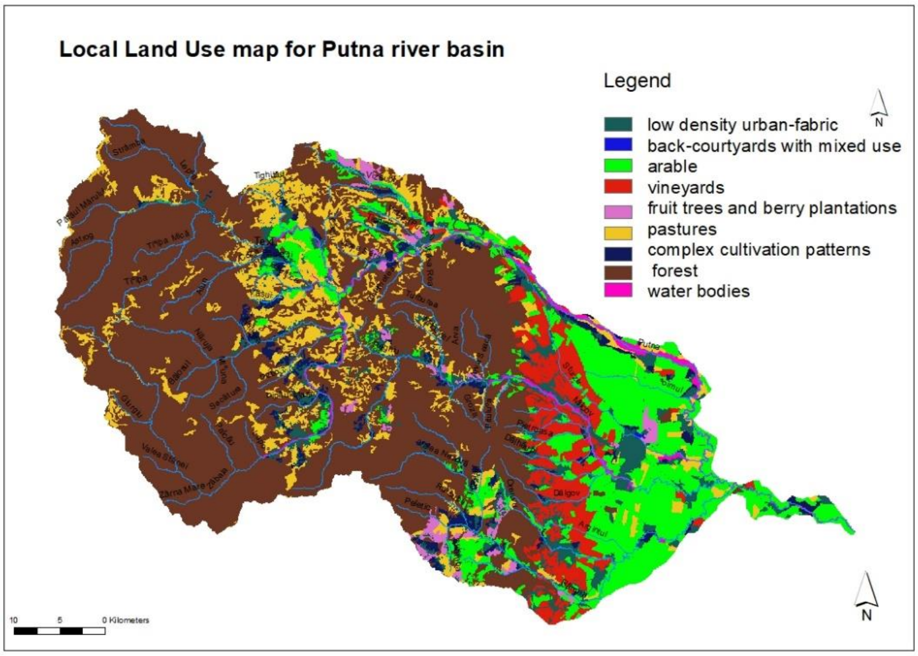

Figure 2-10. Local landuse map for Putna river basin

The local metholology for damage and loss assessment

The local damage curves for different landuse types and local data on maximum damage values are based on the local methodology for flood damage and loss assessment developed during the process of implementation of the Floods Directive in Romania. This damage and loss assessment methodology aims at determining the estimated aggregated national potential economic losses caused by large scale Romanian flooding. In this methodology, two approaches are distinguished: Damage and Loss assessment and Impact assessment, determining the adverse effects of flooding on the society in general (human health, cultural heritage, the environment and economic activities). The local methodology operates by assessing maximum damage values for each typology and by applying a percentage susceptibility to damage (%) at each potential flood depth at the property, resulting in a depth/damage curve.

For estimating the maximum damage values the following data was used:

- Estimated construction costs of the Order of Romanian Architects (2019).
- Maximum damage values from international literature. The primary sources are MCM (Multi-Colored Manual for Flood Risk Assessment, UK), HAZUS (USA) and SSM (Flood Damage Modell from the Netherlands) corrected based on GDP/PP to match the Romanian setting (Environment Agency: The Multi-Coloured *Manual: Flood Risk and Coastal Defence Appraisal*, UK Department for Environment, Food & Rural Affairs (Defra) and Environment Agency, London, United Kingdom, 2013. The susceptibility data is based on international literature plus local expertise and judgements (building and flooding specialists, etc.). This methodology (with its maximum damage values and depth damage curves) offers a hybrid solution for damage modelling at different levels of detail based on use land use and an object-based model, the latter having a higher level of detail and more typologies.

The local vulnerability data was integrated into the workflow based on the following steps:

- Remapping land use codes from local sourced to CLIMAAX ones;
- Using the national GDP per capita values;

For land-use code 1122 *Low density urban fabric*:

- Using local values of maximum structural damages (€/m²) for each building type (residential, commercial and industrial);
- Using local values of content importance factors for each building type (residential, commercial and industrial);
- Preserving the calculation formula provided by Climaax in the Excel file *LUISA_damage_info_curves* as detailed below:
    - Maximum structural damage (€/m²) = MaxStructure = sum(local max structure damage residential * CLIMAAX residential fraction from total buildings + local max structure damage commercial * CLIMAAX commercial fraction from total buildings + local max structure damage industrial * CLIMAAX industrial fraction from total buildings);
    - Maximum content damage (€/m²) = MaxContent = MaxStructure * sum(local content importance factor residential * CLIMAAX residential fraction from total buildings + local content importance factor commercial * CLIMAAX commercial fraction from total buildings + local content importance factor industrial * CLIMAAX industrial fraction from total buildings);
    - Structural damage (€/m²) = Structure = MaxStructure * CLIMAAX density factor;
    - Content damage (€/m²) = Content = MaxContent * CLIMAAX density factor;
    - Total damage €/m² = Total = Structure + Content;
- Using internal damage curves to determine, for each land-use category in the study area, the fraction of economic value at risk (damage factor) for a given flood depth.

For all other land-use codes assigned to the agriulture, the damage assessment was based on values provided in the “agricultural €/m²” column of the *LUISA_damage_info_curves* Excel file, derived from local sources. These agricultural values were considered the Total damage (€/m²) values;

- Local agricultural damage curves were used to determine the fraction of economic value at risk for a given flood depth.

To integrate local vulnerability data related to land use, the corresponding files from the initial workflow were used, into which the local data was loaded, preserving the structure, location, and format of the files so that no significant code changes were necessary.

The files corresponding to the local vulnerability data can be found in Zenodo (W1 Local_vulnerability_data)

Similar to the situation in phase 1, due to the resolution of the data used and the size of the Putna basin, the resulted overview damage maps for the entire basin (Zenodo W1) do not allow for a relevant visualization of the results, so a zonal statistics analysis was performed for each UAT, on total damages and maximum damages.

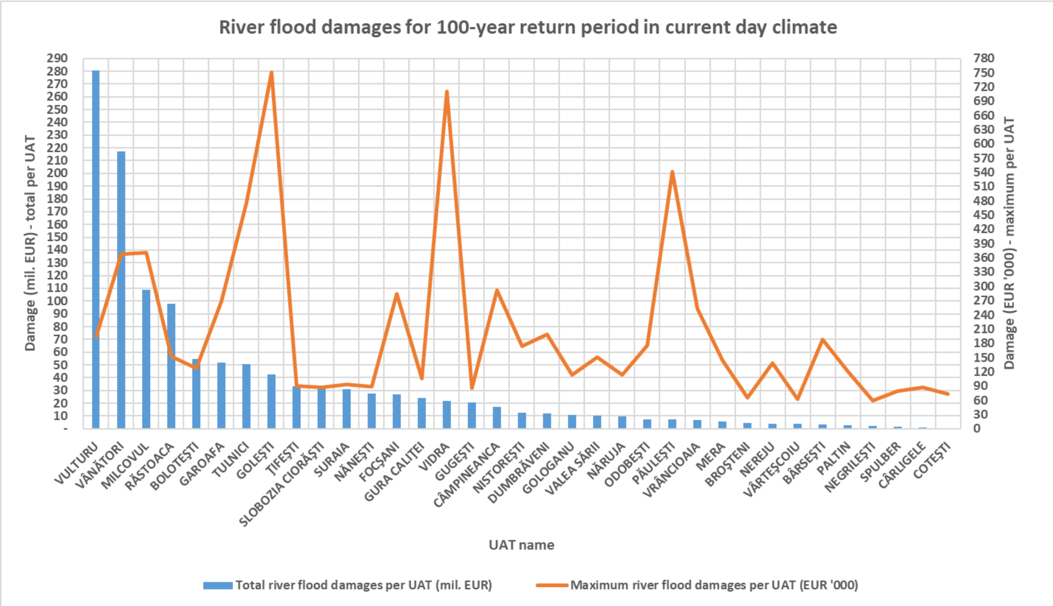

Figure 2-11. Landuse related river flood damages in UATs of Putna river basin, results from Phase 1 (Luisa landuse map and vulnerability curves, JRC flood hazard map)

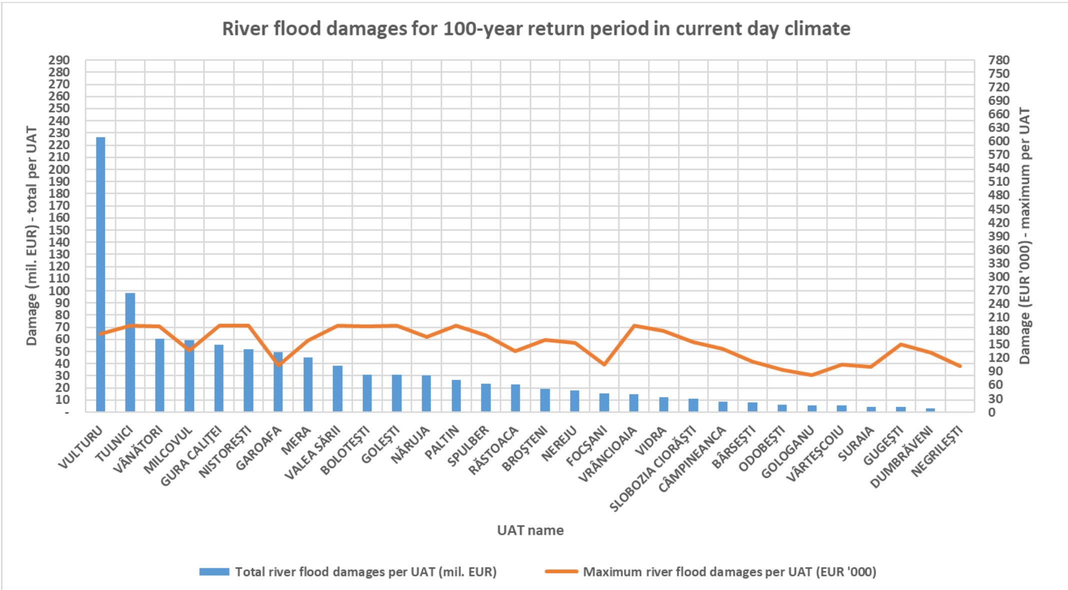

Figure 2-12. Landuse related river flood damages in UATs of Putna river basin, results from Phase 2 (local landuse map and vulnerability curves, JRC flood hazard map)

Comparative analysis of landuse related flood damages per TAUs resulted from phase2 vs results of phase1

Comparative analysis of the charts with river flood damages for the administrative units in the Putna basin resulting from phase 2 compared to those from phase 1 (Figure 2-11, Figure 2-12)indicates significant differences both for total damages and for the maximum damage value for each administrative unit. These differences are induced both by the use of local land use maps and, especially, by the use of local damage curves and local damage values.

There are differences between different UATs: for example, for UATs like Tulnici, Garoafa, Vrancioaia, the charts indicate higher total damage values in the phase 2 result (caused mostly by the differences between the local land use map and Luisa land use), but lower maximum damage values for the UAT (caused mostly by the different cost values between the local ones and those used in the Luisa methodology). However, for UATs such as Vulturu, Vanatori, or Milcovul, the total damage values are lower and the maximum damage values are similar or lower. There are also cases of UATs, such as Mera, where both the total and maximum damage values are higher as a result of the analysis with local data from phase 2.

The tables with data and maps behind the charts can be found in Zenodo W1.

Risk assessment based on local hazard map and local landuse map and vulnerability data for present day and climate change scenarios

According to the workplan, in order to obtain a fully customized CRA, local exposure (landuse map) and vulnerability data was integrated into the workflow alongside the high-resolution local hazard map obtained through hydraulic modeling, for the selected areas (Zabala and Naruja watersheds).

The technical risk workflow adjustments for integrating the local hazard map involved removing the code cells from the "download and explore the data" section and modifying the "combining datasets with different resolution" section, where the path to the local hazard rasters for the present and under climate change in tif format is entered in the section loop.

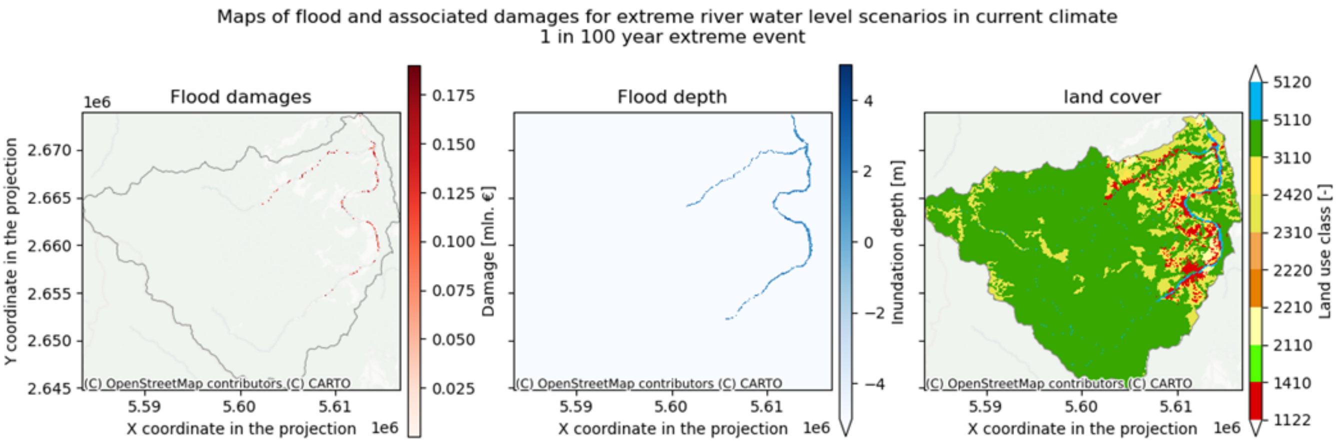

Figure 2-13. Flood damages, local hazard map and landuse for the 100 year RP event

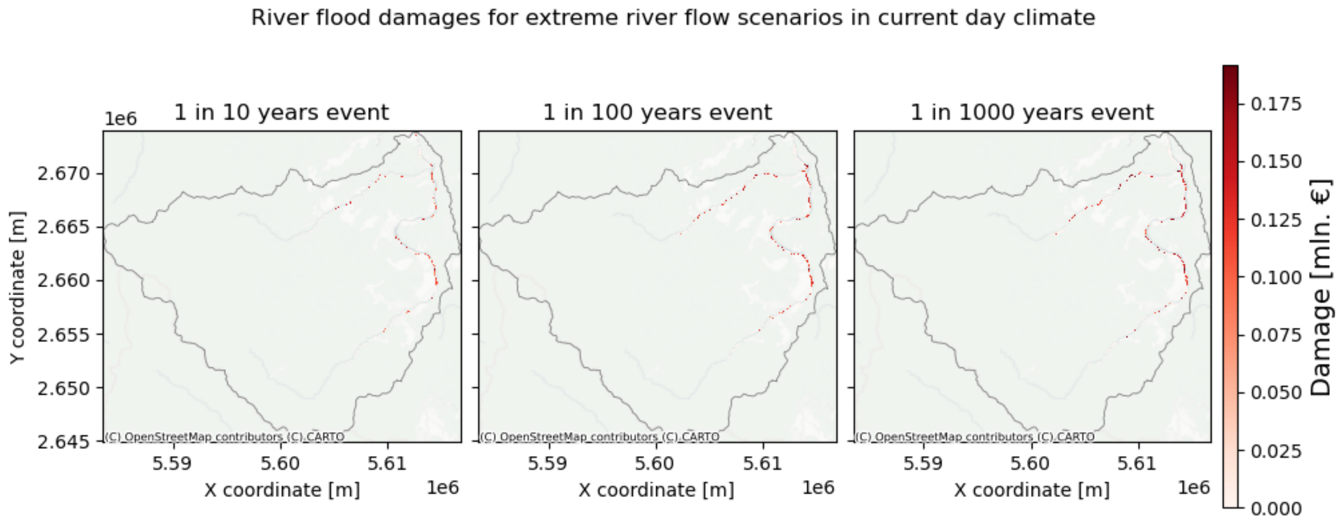

Figure 2-14. Flood damages for different RP events

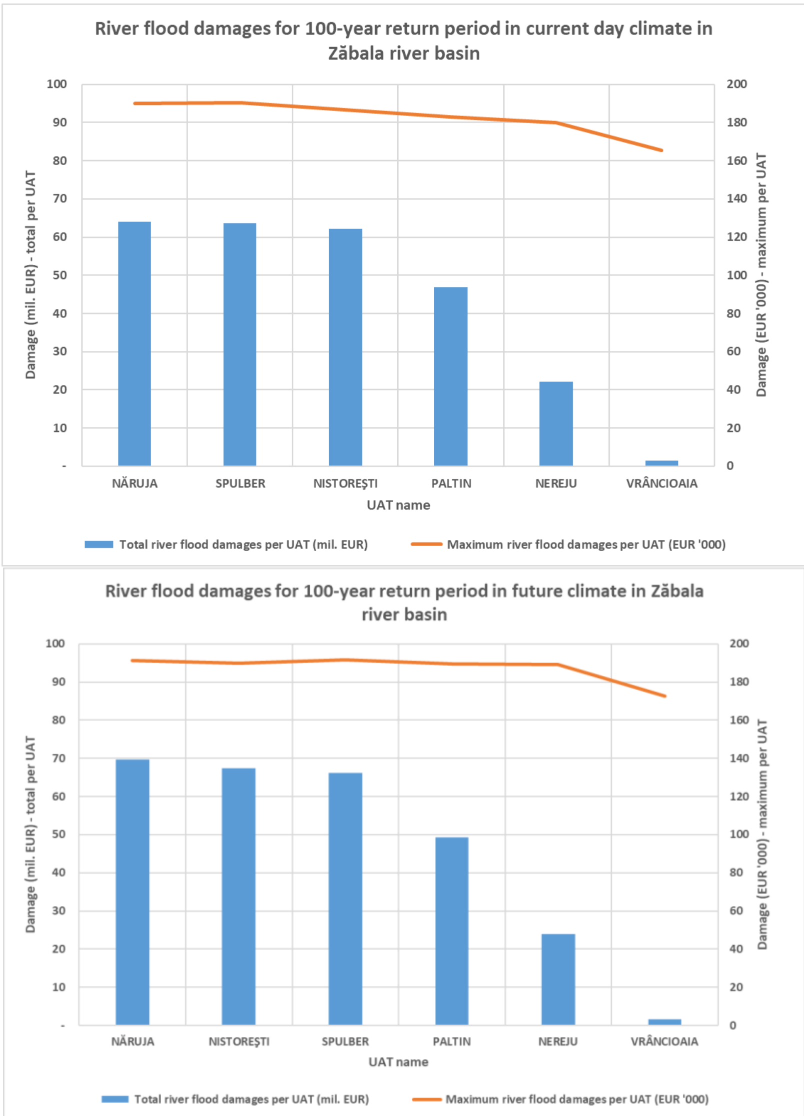

Figure 2-15. Estimated River flood damages for 100 year RP event in present day conditions and *climate change scenario for localities in Zabala river basin*

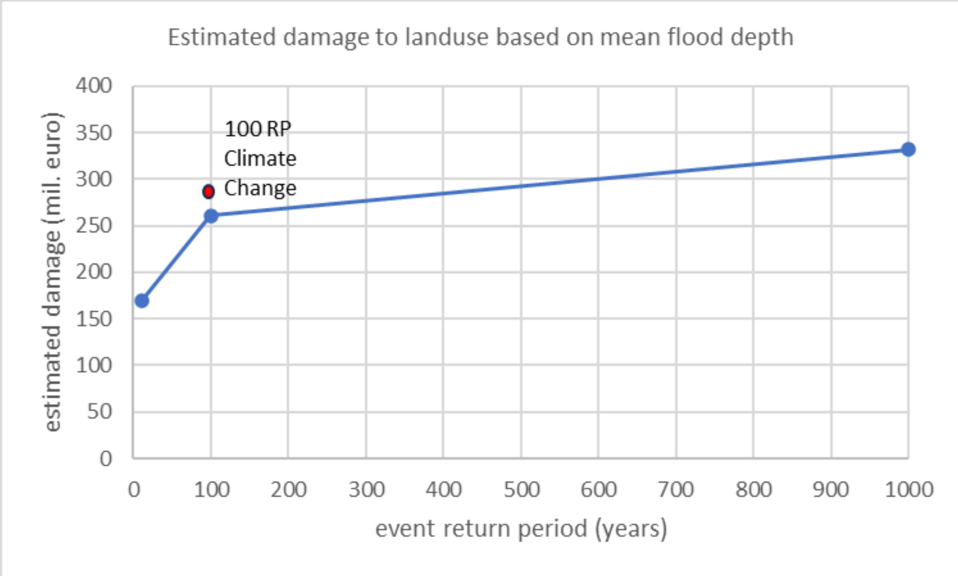

Figure 2-16. Total estimated landuse damage for the flooding event with different RP in present day conditions and for 100 year RP under climate change

Both the plot outputs directly resulting from running the customized workflow (Figure 2-13, Figure 2-14) and the charts obtained by separately processing the resulting data (Figure 2-15, Figure 2-16) indicate significant damage values for TAUs in the study area for all RPs analyzed, as well as an upward trend for estimated damage for the future climate change scenario.

All outputs and input data can be found in Zenodo W1

Risk assessment based on local hazard map and local transport infrastructure map and vulnerability data for present day and climate change scenarios

For this analysis, the high-resolution (1m) local hazard map and high-resolution (1 m) local data for road transport infrastructure (Figure 2-17) were integrated into the River Floods workflow, along with local road related vulnerability data.

Local road infrastructure data was processed within the implementation of FD Cycle 2, based on orthophotomaps. Road attributes such as length, width, type were completed using orthophotomaps, Google Street View images, and information available in OSM data.

The main data sources for bridges and footbridges were data received from the National Road Administration Company, NARW, county councils, Google Earth data, orthophotomaps, and OSM data. The locations of bridges and footbridges were validated using Google Street View images. Each bridge was digitized as a line on orthophotomaps and aligned with the corresponding road data.

For road infrastructure, the damage produced by fluvial floods represents structural damage, assessed for the following four categories: National Road, Cityroad / Unclassified paved road, Agricultural and unpaved road and Bridge.

The high resolution local road infrastructure rasters can be found in Zenodo W1

The damage values are adjusted using local damage curves specific to each infrustructure category.

Since the integration of these high-resolution local data with large file sizes encountered difficulties in running the flow (crash errors), the solution was adopted to run the script separately for the most representative TAUs in the study area.

Technical modifications of the workflow were related to the Resample section, the rest of the local data being integrated based on the existing initial files, preserving the structure and format.

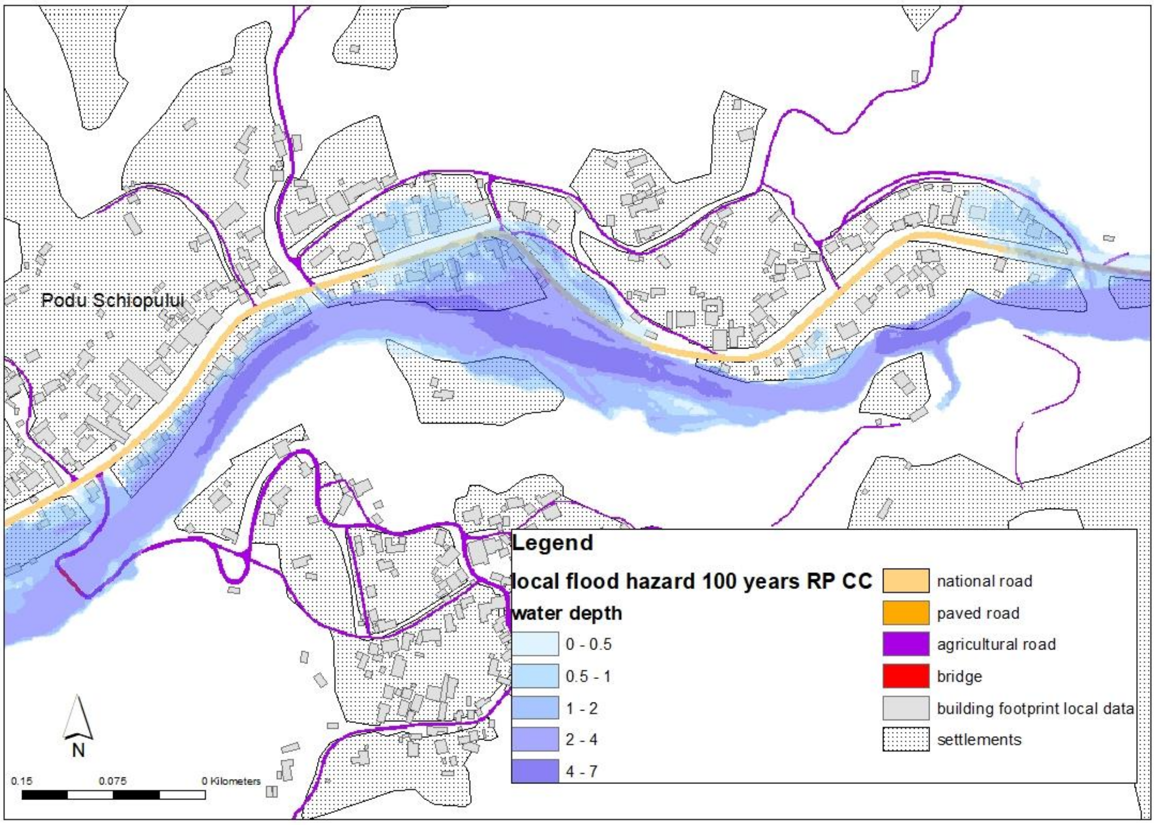

Figure 2-17. Caption of local road infrastructure map and local flood hazard for 100 year RP event under climate change scenario

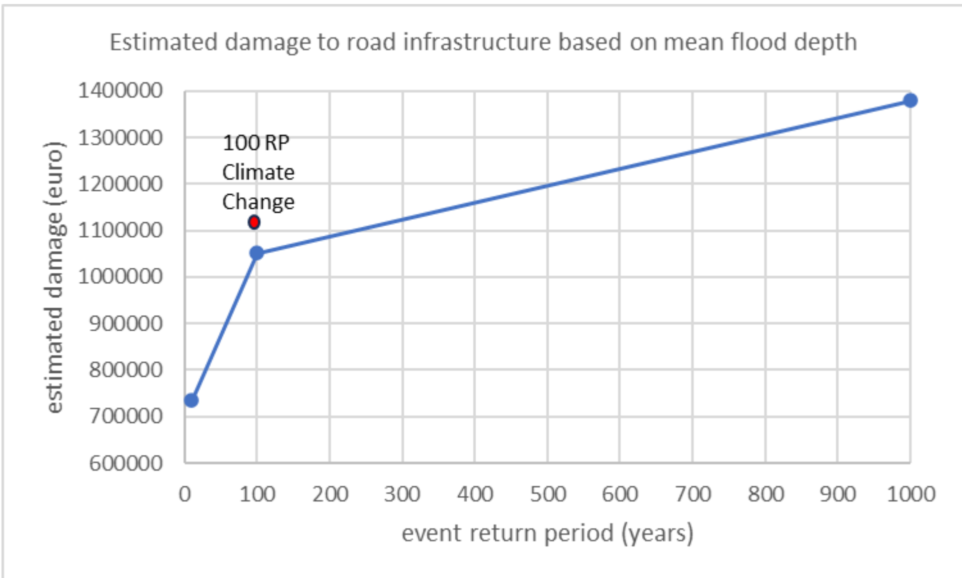

Figure 2-18. Total estimated road infrastructure damage for the flooding event with different RP in present day conditions

and for 100 year RP under climate change

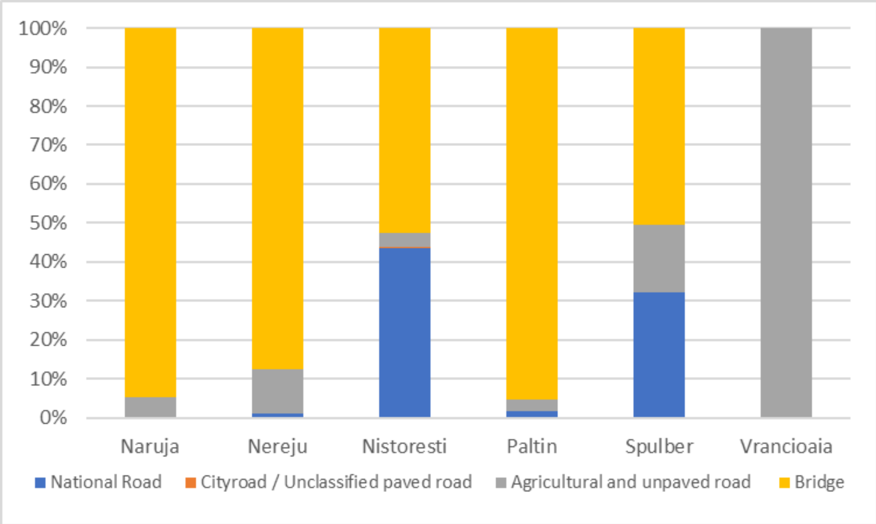

Figure 2-19. The damage corresponding to different elements of road infrastructure for the TAUs in Zabala river basin for the flooding event with 100 year RP

Due to the detailed resolution of the input data (1m), the plots resulting directly from the workflow are not relevant for visualization, so additional charts were generated based on the resulting data. Figure 2-18 indicates significant estimated total damage values for road infrastructure in the study area for all RPs analyzed, as well as an upward trend for road estimated damage for the future climate change scenario.
Figure 2-19 indicates that most of the damage is caused by the impact on bridges and sections of national roads, although there are TAUs where the value of the damage is mainly due to the impact on agricultural roads (TAU Vrancioaia).
All outputs, the files behind them and input data can be found in Zenodo W1.

2.3.2 Hazard #2 – Flood damage on buildings and population exposure

Table 2-2. Data overview workflow #2 Flood damage on buildings and population exposure

Hazard data	*Vulnerability data*	*Exposure data*	*Impact metrics/Risk output*
Local high resolution flood hazard maps *Present and CC*	Local data on maximum damage values for building types JRC damage curves for buildings	Local detailed map on building footprint	Buildings damage maps for present day scenario for different RPs and under climate change Plots
Local high resolution flood hazard maps *Present and CC*	Local thresholds for population exposure	Estimated based on local sources	Plot of river flooding exposed population for present day scenario for different RPs and under climate change

2.3.2.1 Hazard assessment

For this analysis, the same high-resolution local flood hazard map obtained through HEC-RAS modeling (presented in the previous section) was integrated in the workflow (Figure 2-20).

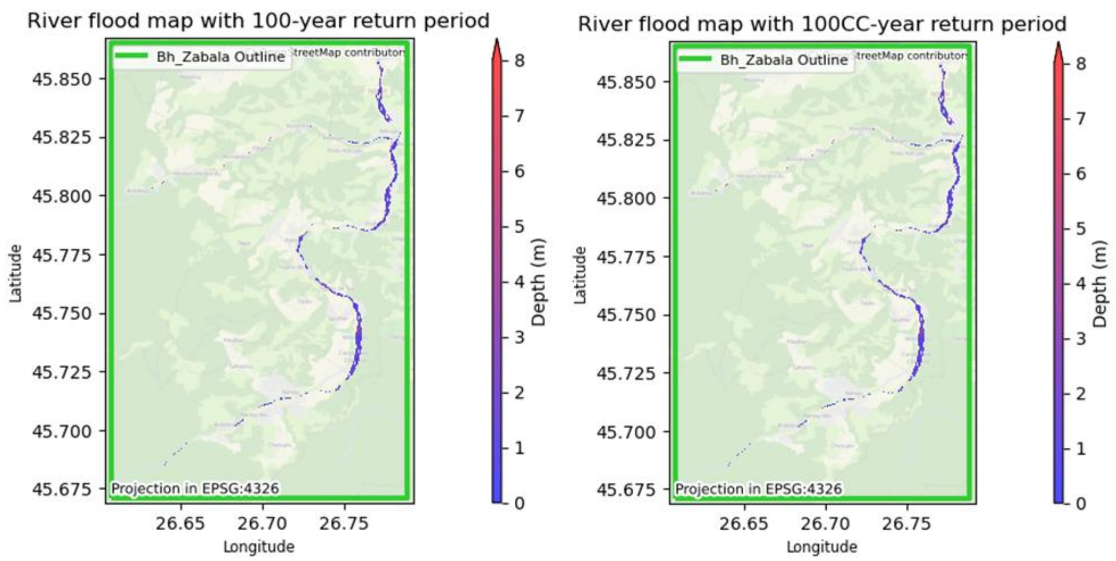

Figure 2-20. The local river flood hazard map for the event with 100 years RP in present day and under climate change

2.3.2.2 Risk assessment

The risk assessment was based on local hazard map, local buildings map and local vulnerability data for present day and climate change scenarios.

Local data for building footprints and types were obtained during Cycle II of the implementation of FD, by completing the available data (OSM) based on orthophotomaps, after extracting vector elements using the ML model.

The local methodology for estimating the value of the damage took into account the unit replacement cost and the value of the contents. Data for the unit replacement cost was obtained from various relevant institutions.

The workflow analyses the damages produced by fluvial flood hazards to built-up areas through building-level economic damage (footprint based), using the local vulnerability data, that was integrated in the workflow by following these steps:

- Remapping local building types to CLIMAAX building classifications;
- Using local values of Maximum structural damages (€/m²) for each building type (residential, commercial, industrial, and agricultural);
- Using local values of Content importance factor for each building type (residential, commercial, industrial, and agricultural);
- Preserving the calculation structure provided by CLIMAAX in the workflow (the step about Define depth-damage functions):

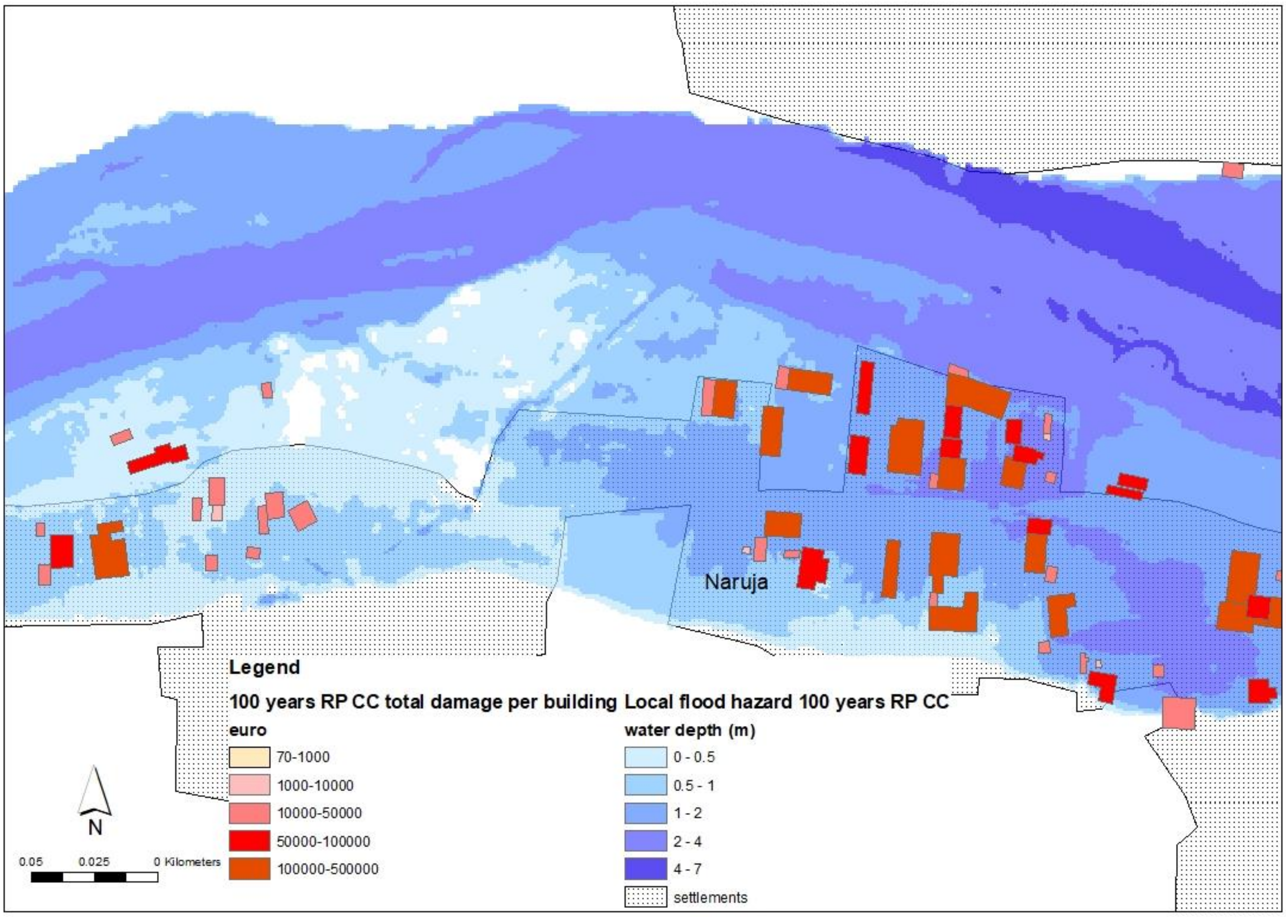

Figure 2-21. Estimated total damage per building for 100 year RP flood event under climate change scenario for Naruja localty

A detailed capture of the damage map resulted for Naruja localty showing significant estimated damages for buildings for the 100 year RP event under climate change scenario is presented in Figure 2-21.

The plot generated in the workflow (Figure 2-22) indicates significant estimated total damage values for buildings in the study area for all RPs analyzed, as well as an upward trend for buildings estimated damage for the future climate change scenario.

The input data and the complete output maps in .shp format can be found in Zenodo W2.

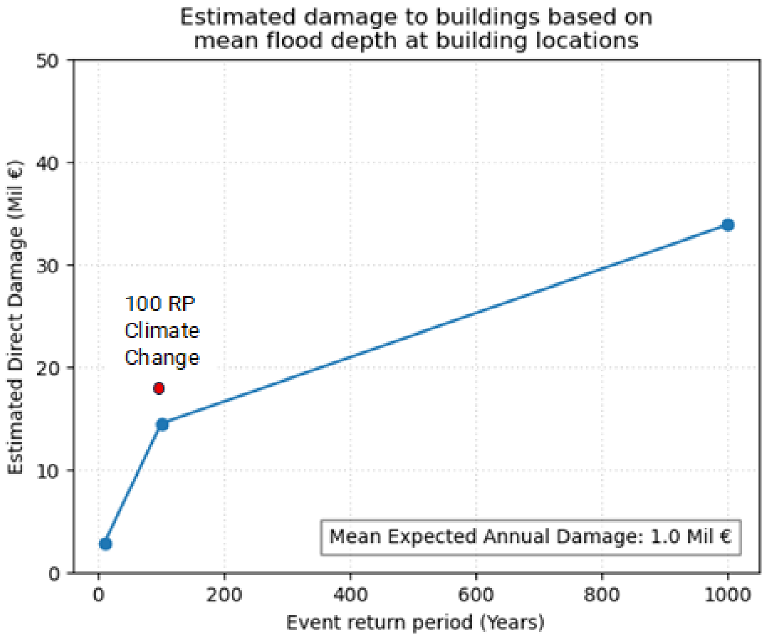

Figure 2-22. Estimated total damage to buildings for the flooding event with different RP in present day conditions and for 100 year RP under climate change

Estimation of exposed population to flood hazard

One of the limitations of the available local datasets is the lack of a high-resolution raster with population density. Due to the large differences in resolution between local hazard data and available regional data, and the lack of additional data to facilitate the application of a population density spatialization procedure required to run the Resample section of the workflow, the analysis to estimate the population exposed to local flood hazard was performed outside the workflow, based on the output with the number of impacted buildings.

Based on this value and taking into account the average number of inhabitants per residential building in the study area (according to local sources - National Institute of Statistics and the results of the Population and Housing Census, https://insse.ro/cms/), the number of inhabitants exposed to flood hazard with different return periods and under the impact of climate change was estimated.

The results of the analysis are shown in Figure 2-23, that indicates significant estimated number of people exposed to flood risk in the study area for all RPs analyzed, as well as an upward for the future climate change scenario. (Zenodo W2)

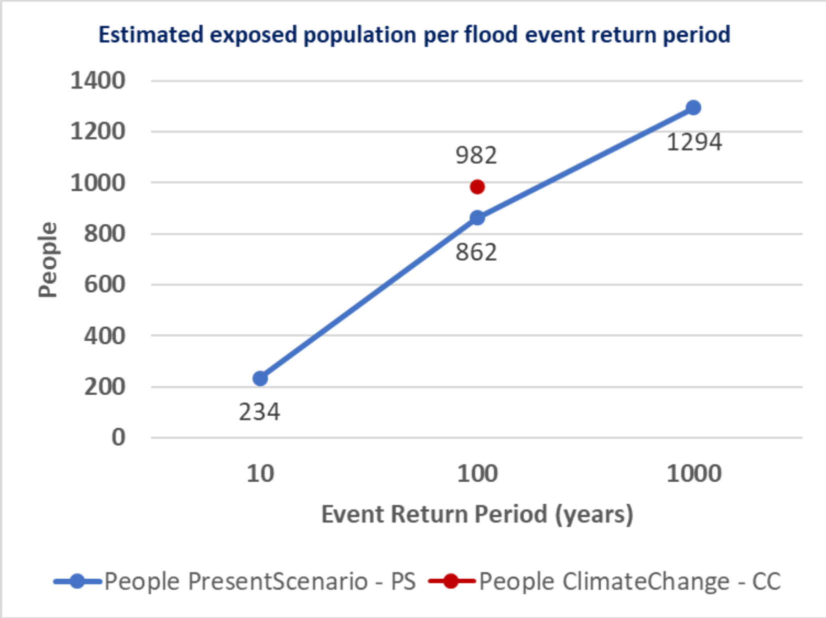

Figure 2-23. Estimated total population exposed for the flooding event with different RP in present day conditions and for 100 year RP under climate change

2.3.3 Hazard #3 – River discharge analysis

The River floods (discharges) workflow assesses the projected changes in river discharges due to climate change, modelled using a European-wide hydrological model forced with climate models. It is based on E-HYPEcatch hydrological model and climate projections produced by six GCM-RCM model combinations (EC-Earth, HadGEM2-ES, MPI-ESM-LR combined with RACMO22E, CCLM4-8-17, RCA4, REMO2009) to capture uncertainty. The resolution of the catchment-level data is approx. 0.11 degrees (5-10 km). (Lindström, G., Pers, C., Rosberg, J., Strömqvist, J., and Arheimer, B.: Development and testing of the HYPE (Hydrological Predictions for the Environment) model – A water quality model for different spatial scales, Hydrology Research, 41(3–4), 295–319, https://doi.org/10.2166/nh.2010.007, 2010.

The main datasets integrated in this workflow are:

- Daily river discharges (1991–2005) – used for flow duration curves and comparison with observations;
- Monthly mean river discharges – for historical (1971–2000) and future periods (2011–2040, 2041–2070, 2071–2100);
- Extreme discharges: absolute values – 10-year and 50-year return intervals;
- Extreme discharges: relative change – future change vs. reference (1971–2000).

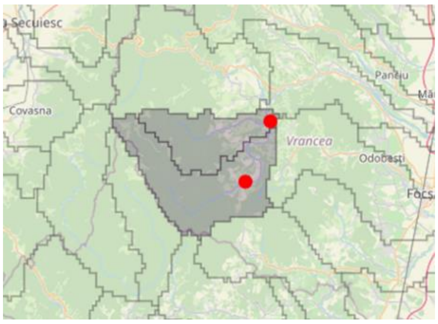

Figure 2-24. The E-HYPE catchments correponding to Zabala and Naruja watersheds

In order to run the workflow for the area of interest within Putna river basin, the corresponding catchment ID from the E-HYPE catchment grid was identified (9601694 – Zabala and Naruja watersheds (Figure 2-24).

For the daily discharge statistics (1991–2005), plots were generated for each GCM–RCM model combination. Each plot includes results from the eight hydrological models (Figure 2-25), as well as an additional plot showing the average across the multiple E-HYPE hydrological model realisations. Among the results, the climate model combination ICHEC-EC-EARTH_KNMI-RACMO22E shows an atypical evolution of the historical simulated discharges (overestimation) in the analysed sub-basins, indicating an error (Figure 2-25).

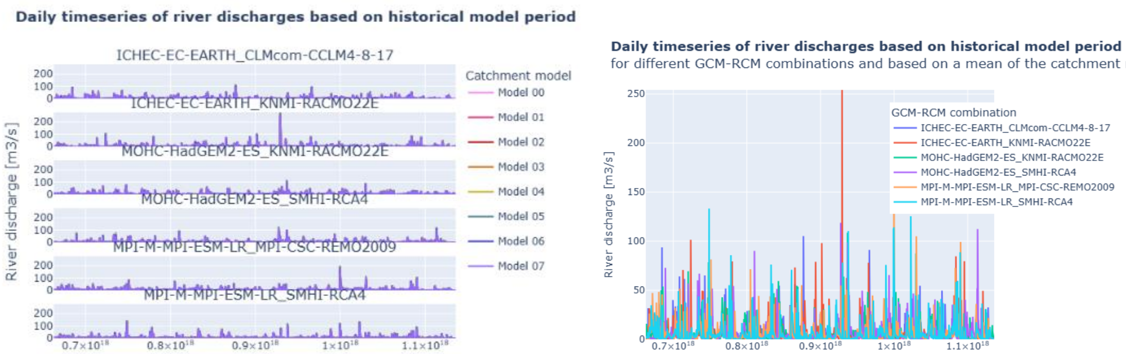

Figure 2-25. Daily timeseries of river discharges based on historical model period for Zabala watershed

Moreover the flow-duration curves (FDCs) in Figure 2-26, underline clear characteristics such as the magnitude of high flows, the low-flow conditions and the consistency with known hydrological behaviour. They are recommended to indicate whether some GCM–RCM combinations behave unrealistically or not, allowing such combinations to be excluded from the plots with the analysis.

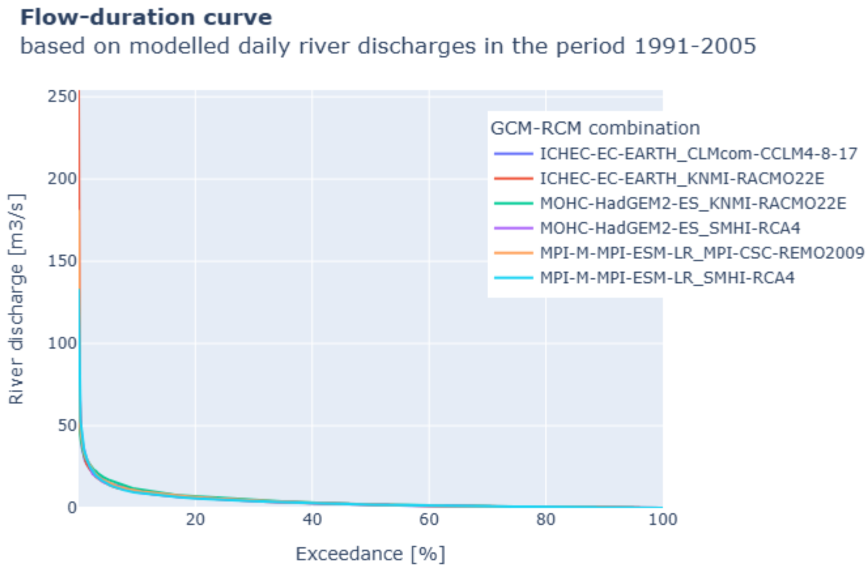

Figure 2-26. Flow duration curves based on modelled daily river discharges (1991-2005) for Zabala watershed

The seasonal river discharge behaviour (Figure 2-27) was analysed for the historical period (1971–2000) and for the future periods: 2011–2040, 2041–2070, 2071–2100, under RCP4.5 and RCP8.5 climate scenarios, showing whether future climates will encounter wetter or drier conditions, which months will have increasing or decreasing discharges or whether the peak discharge timing will shift due to changes in snowmelt. For the selected sub-basin the timing of peak discharges driven by snowmelt will occur earlier than in the historical period, with the tendency being more visible for the late future period (2071-2100).

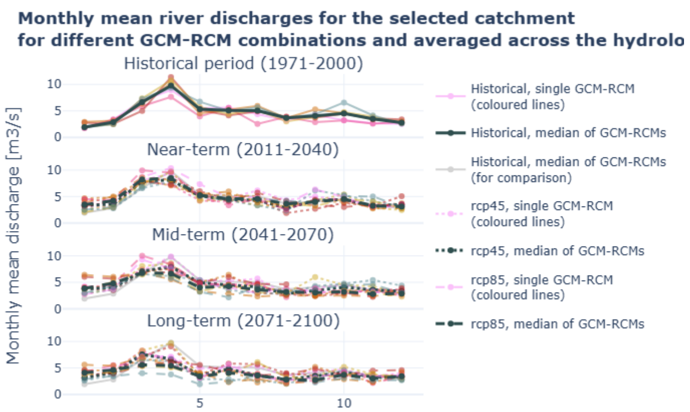

Figure 2-27. Monthly mean river discharges for Zabala catchment for different GCM-RCM combinations and time horizons

The absolute and relative values for the extreme river discharges (Figure 2-28) were calculated for historical and future periods for the 10-year and 50-year return periods, the resulting plots being presented for each GCM–RCM combination and also for the models median. The relative values are often more informative than absolute values, because model biases are canceled.

When evaluating the relative changes, the Naruja and Zabala sub-basins are projected to experience decreases in maximum flows for both the 10-year and 50-year return periods during the two near-future periods (2011-2040 and 2041-2070) under the RCP8.5 scenario. Thus the estimated changes are generally negative under this scenario. These values are around 0-10% (increase) under RCP4.5 scenario. In contrast, the late future period (2071-2100) is projected to show increases of up to 30% in maximum flows for both climate scenarios.

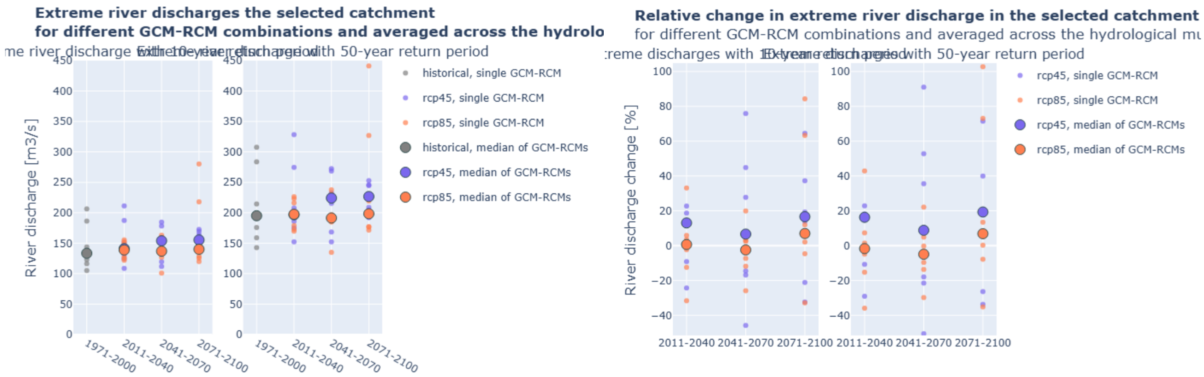

Figure 2-28. The absolute and relative values for the extreme river discharges for historical and future periods for Zabala catchment for different GCM-RCM combinations and time horizons

To assess how well the simulated discharge represents reality at the selected location before interpreting climate-change impacts, the validaton with observation can be done (Figure 2-29). In this analysis, local observational data were used for the historical period (1971–2000) for the selected subcatchments.

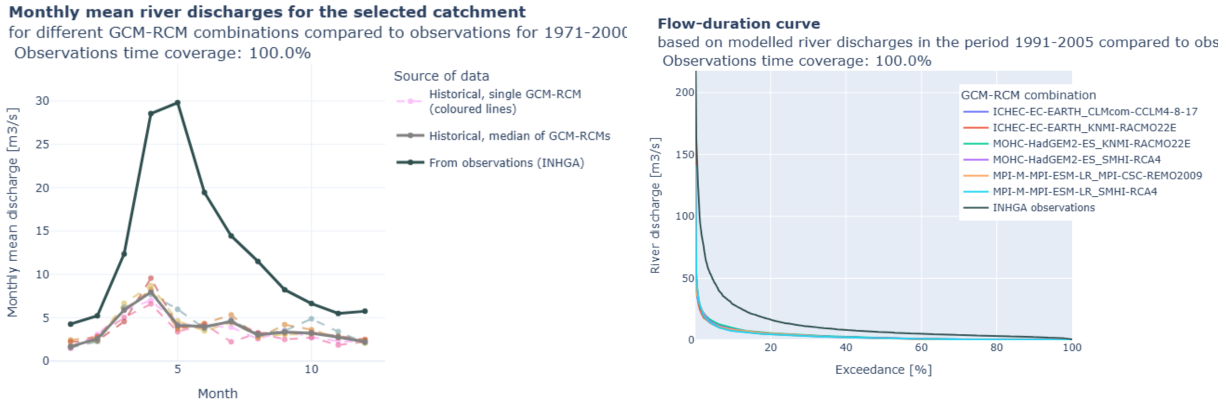

Figure 2-29. Monthly mean river discharges and flow duration curve based on modelled river discharges compared to the observations for Zabala watershed

Differences between simulated and observed (in situ) data are further underlined by the fact that the location of the hydrometric station is not the same with the sub-basin outlet. More specifically, for the upstream Putna River sub-basin, the Colacu hydrometric station is located downstream of the sub-basin outlet, which leads to higher observed discharge values.

To establish the relevant climate change scenario for the study area, the value corresponding to the average value of gcm/rcm model chain for furthest time horizon (2070-2100) was selected for the medium severity scenario rcp 4.5 and a return probability of 2% This value was used to obtain the flood hazard map, based on the local hydraulic model, for the climate change scenario.

All outputs and data related to this workflow can be found in Zenodo W3.

2.3.4 Hazard #4 – Heavy Rainfall

Table 2-3. Data overview workflow #4 Heavy rainfall

Hazard data	*Vulnerability data*	*Exposure data*	*Risk output*
Annual maximum precipitation	Critical impact-based rainfall thresholds for 3h, derived form the configuration of ROFFG System and the experience of the NIHWM forecasters from using this system for real time flash flood warnings.	Threshold Return Period map	Return period shift maps
Idf (Intensity Duration Frequency) maps			Precipitation shift maps

As indicated in the Phase 1 report, flash floods due to extreme precipitation could be considered as the main hazard risk in the Putna River basin, and due to climate change impact we could expect that such events will become more frequent and more severe in the future.
According to the planned activities, the focus within Phase 2 was to extend the analysis from the heavy rainfall toolbox, by using regional high intensities local runoff, and flash floods risk assessment, for entire Putna river basin, based on the critical impact rainfall thresholds for 3h duration, derived form the configuration of ROFFG System and the experience of the NIHWM forecasters from using this system for real time flash flood warnings activities.
For conducting the analyses we mainly used two new local precipitation datasets:

- Daily gridded precipitation dataset for Romania, derived from the observations within the National Netowrk of Meteorological stations, dataset produced by the Romanian Administration of Meteorology (https://data.gov.ro/dataset/date-meteorologice-zilnice-gridate).

RoCliB - Bias corrected CORDEX RCM dataset over Romania (Dumitrescu, A., Amihaesei, V-A & Cheval, S. (2023) RoCliB– biascorrected CORDEX RCMdataset over Romania. Geoscience Data Journal, 10, 262–275. Available from: https://doi.org/10.1002/gdj3.161

Table 2-4. Types of input data used in workflow #4 Heavy rainfall

Attribute	*Bias corrected datasets*
Global and Regional Climate Model Chains	ichec-ec-earth/knmi-racmo22e mpi-m-mpi-esm-lr/smhi-rca4
Representative Concentration Pathway (RCP)	RCP 4.5 RCP 8.5
Historical Time-frames	1976-2005

Attribute	*Bias corrected datasets*
Future Time-frames	2011-2040 2041-2070 2071-2100
Durations	24h

2.3.4.1 Hazard assessment

While in the first Phase our focus was to identify and present the most severe potential changes of the extreme precipitation regime for the entire Putna River basin area, based on all the climate models and different scenarious, in this Phase we focus on selecting and using for the new analyses the climate simulation model available from the new local datasets, and which is the closest to the observed data, for the reference historical period.
The first step in the analysis was to process the gridded observed precipitation datasets, by adapting the workflow scripts, to derive the spatial distribution of the extreme 24 precipitation, for different return periods (Figure 2-30).

The RoCliB - Bias corrected CORDEX RCM dataset over Romania contains a set of four climate variables from 10 General Circulation Models (GCMs), dynamically downscaled in the EURO-CORDEX initiative by several Regional Climate Models (RCMs) and adjusted (bias-corrected) over Romania for the period 1971–2100. The climate models data were obtained from the EURO-CORDEX archive, and two climate change scenarios were selected, namely the moderate (RCP4.5) and business-as-usual scenario (RCP8.5).

From this dataset we selected the bias corrected data for two climate models, that were also used and analysed within Phase 1: ichec-ec-earth/knmi-racmo22e and mpi-m-mpi-esm-lr/smhi-rca4.

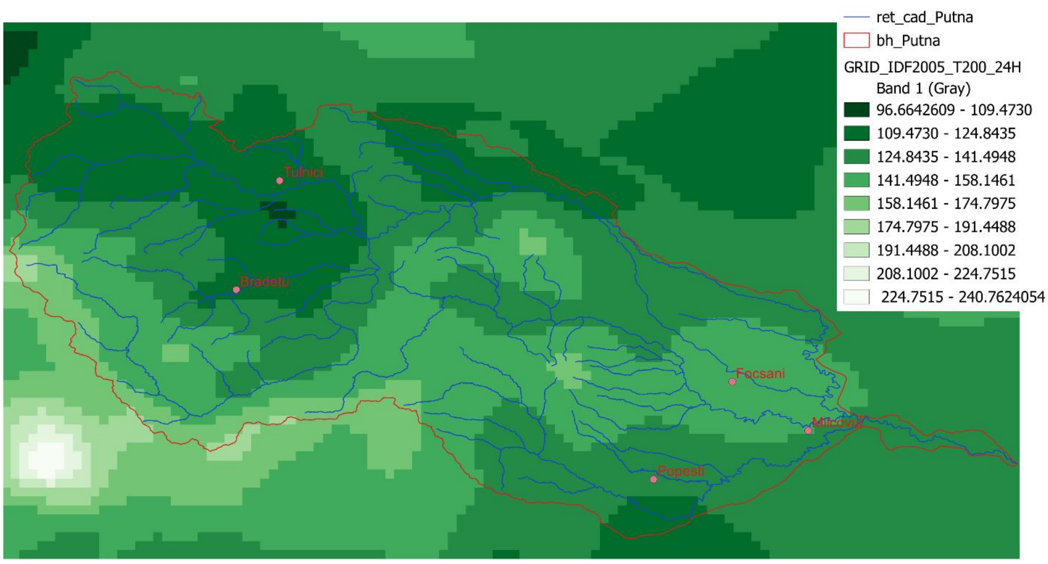

Figure 2-30. Map with the gridded 24 hour extreme precipitation, for a mean return period of 200 years, derived form the new gridded precipitation dataset, for the area of Putna River basin

For selecting the best climate model from these two models, we analysed the IDF curves for representative selected points within the Putna River Basin area, an example of the generated IDF curves is presented in Figure 2-31.

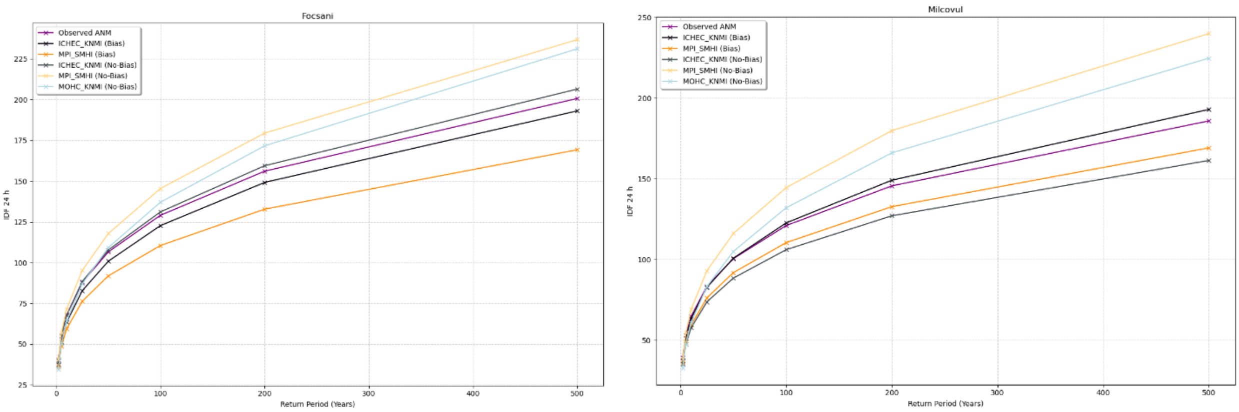

Figure 2-31. Analysis of different IDF curves for selected representative locations within the Putna River basin.

Based on these analysis we selected the ichec-ec-earth/knmi-racmo22e model, who provided the best match of the simulated extreme 24 hours precipitation, with the gridded observed precipitation dataset, for the historical reference period 1976 – 2005.

The next step in the analysis of the hazard of extreme precipitation, was to investigate the change in the magnitude of the extreme precipitation, for different future periods and the two climate projections, compared with the baseline, the historical period 1976-2005 (Figure 2-32).

All the analysed periods and scenarious, highlighed a general tendency of increase of the magnitude of the extreme precipitation, with a higher amplitude for the 2011 – 2040 and 2071 - 2100 future periods.

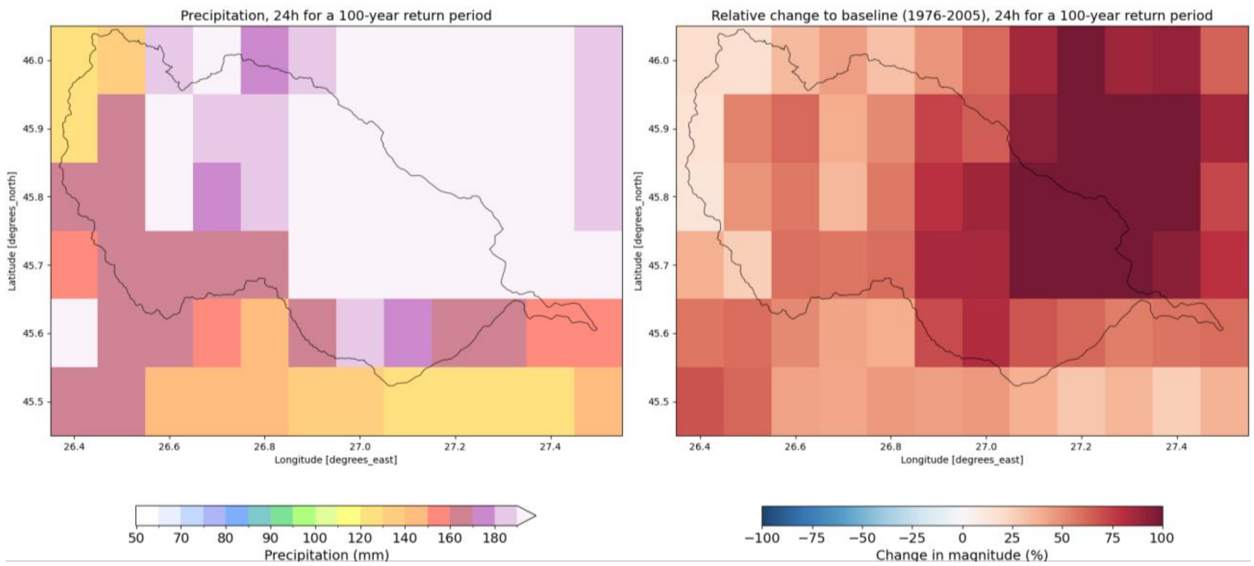

Figure 2-32. Relative change in magnitude for extreme precipitation in the future period 2011 – 2040, compared with the baseline (1976-2005), under the rcp85 climate projections

2.3.4.2 Risk assessment

The updated risk assessment started with estimation of new relevant spatially variable critical impact-based rainfall thresholds for 3h duration, which were derived mainly from the configuration of ROFFG System, as well as the experience of the NIHWM forecasters from using this system for real time flash flood warnings.

The Romanian Flash Flood Guidance system (ROFFG) is an adaptation of the San Diego Hydrologic Research Center's (http://www.hrc-lab.org) Flash Flood Guidance System used in various regions of the world to help forecasters cope effectively with flash flood warnings (GEORGAKAKOS , K.P. (2006): Analytical Results for Operational Flash Flood Guidance, Journal of Hydrology, 317, 81–103.

The ROFFG system utilizes the soil-moisture deficits estimated in a continuous way by a conceptual hydrological model (SAC-SMA model) for every small basin (mean area of approximately 30 km 2). The soil moisture deficits are used together with the up-to-date (1 hr, 3 hr and 6 hr) precipitation data to estimate the amount of additional precipitation needed for streams to reach the bankfull conditions. The ROFFG is designed to provide flash flood guidance products on a small basin scale across entire Romania (8851 small basins).

From the configuration of the ROFFG system, the following two main parameters were used:

- Threshold runoff for a 3 hour duration, for each of the small basin configured in the system, within the Putna River basin. Threshold runoff represent the amount of excess rainfall accumulated during a given time period over a basin that is just enough to cause flooding at the outlet of the draining stream (T.M. Carpenter, J.A. Sperfslage, K.P. Georgakakos, T. Sweeney, D.L. Fread, National threshold runoff estimation utilizing GIS in support of operational flash flood warning systems, Journal of Hydrology, Volume 224, Issues 1–2, 1999, Pages 21-44, ISSN 0022-1694.
- Threshold runoff estimates are indicators of maximal sustainable surface runoff for a given catchment.
- UZTWM - upper zone tension water maximum capacity, is one of the SAC-SMA model parameter. Within SAC-SMA, the soil is represented in two layers, or soil zones, to capture soil moisture processes near the surface as well as groundwater processes deeper within the soil column. Generally, the soil moisture within the upper soil layer (soil zone) is influenced by fast-response processes, and the soil moisture within the lower soil layer (soil zone) is influenced by the slow-response processes. Tension water may be removed only by evaporation or evapotranspiration, and it may exist in both the upper and lower soil zones.

By combining these 2 parameters from the ROFFG configration, as well as based on more than 15 years of using this system for real time operation, we derived for each small basin within the Putna River basin, three rainfall thresholds for 3h duration precipitation event, corrsponding to a Low, Medium and High risk of Falsh Floods.

Next step for the risk analysis was to adapt the workflow script to compute the projected changes in return periods for different severity events, future periods and climate projections. In order to estimate the 3 hour duration extreme precipitation data we used a regional robust statistical transformation factor, from the 24 hour precipitation data.

In the following figures (Figure 2-33 – 2-35), we present the results for the medium severity thresholds, and all the future period for the RCP8.5 projection. Based on these results, we could conclude that the medium severity flash flood events, for most of the small river basins configured in the ROFFG system, will become more frequent, for all the future period, under the RCP8.5 climate projection.

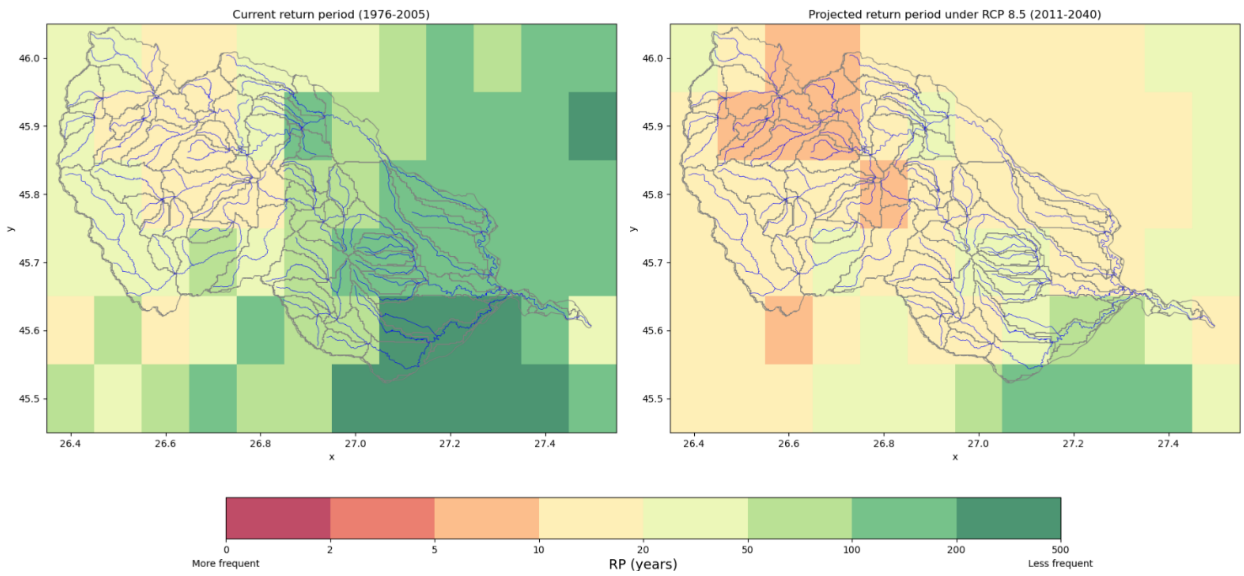

Figure 2-33. Projected changes in return periods in the future period 2011 – 2040, compared with the current return period, for the medium severity thresholds, under the rcp85 climate projections

During this Phase, we also investigated two other potential indicators, that could be used to support the assessment of Flash Floods severity:

Use of the simulated maximum discharge normalized by the cell's upstream drainage area (referred to as maximum unit discharge; $m^3\ s^{-1}\ km^{-2}$), a product from the Ensemble Framework For Flash Flood Forecasting (EF5), which was implemented for Romania using apriori estimated parameters in the last years by the NIHWM experts. EF5 it is used by the US National Weather Service for operational monitoring and short-term forecasting of flash floods, especially in the Flooded Locations And Simulated Hydrographs Project (FLASH) - (https://www.nssl.noaa.gov/projects/flash/). The normalization of discharge by basin area helps to focus the products on those specific locations that are most likely experiencing potential dangerous phenomena. In general, a peak unit discharge of 1.5 $m^3\ s^{-1}\ km^{-2}$ is typically used as one of the flash flood quick reference guides by NWS forecasters (Duarte, J., et al., Large Language Model-Based Classification of Flash Flood Impacts Across the United States. Intelligence for the Earth Systems, 104th Annual AMS Meeting 2024, held in Baltimore, MD and online, 28 January-1 February 2024, paper id. 430897

This simulated parameter was analysed within the Putna River basin, using as input extreme precipitation scenarios for a 100 year return period, for historical period and for the 2071 – 2100 future period, under RCP8.5.

- The other analysis was done only for the Naruja River basin, using a new specific local implemented 2D Hec-RAS model, using the same extreme precipitation scenarios as input data. In this case the focus was the simulated water depth.

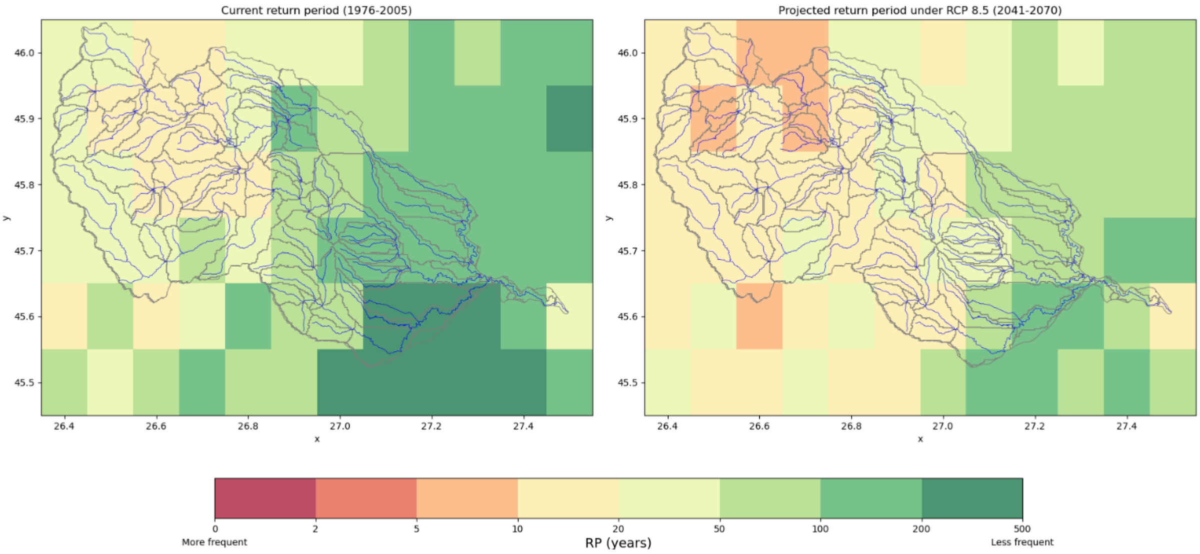

Figure 2-34. Projected changes in return periods in the future period 2041 – 2070, compared with the current return period, for the medium severity thresholds, under the rcp85 climate projections

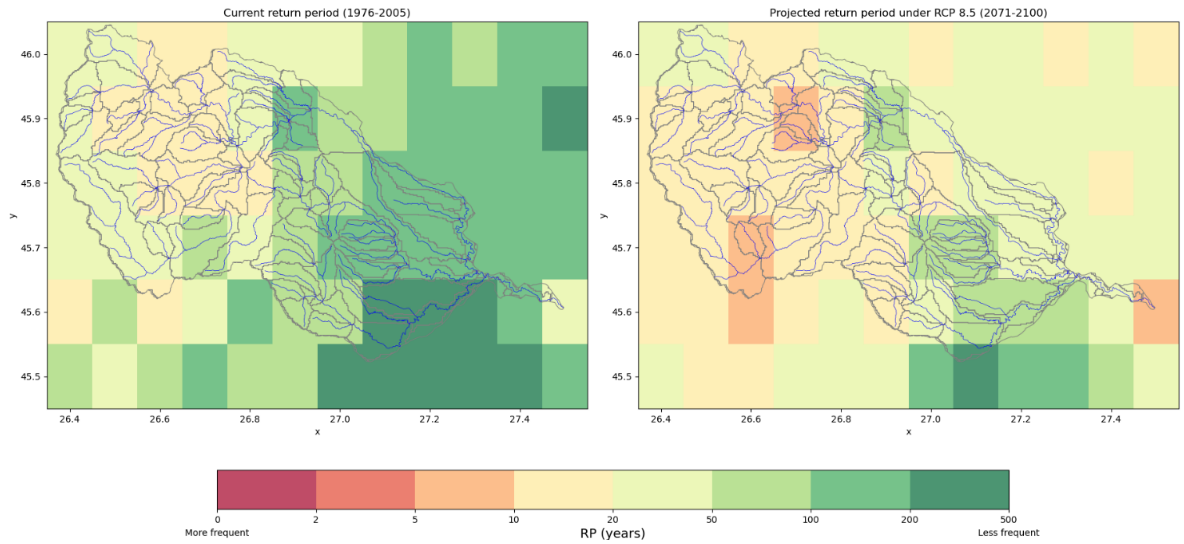

Figure 2-35. Projected changes in return periods in the future period 2071 – 2100, compared with the current return period, for the medium severity thresholds, under the rcp85 climate projections

Both of these supplemental investigations are considered for the moment as experimental, and they will be further considered in the future, to assess if they could bring more detailed support information for dealing with the flash flood risk change, due to climate change impact on extreme precipiation.

The update of hazard and risk map for Naruja river initially planned as part of this workflow, was included and presented within River Floods Worflow (Workflow 1), considering that Naruja is a tributary of Zabala river.

2.3.5 Additional assessments based on local models and data

All aditional analysis performed with local models and datasets are described in the previous sections, as they are part of the CRA customization corresponding to each workflow.

2.4 Key Risk Assessment Findings

2.4.1 Mode of engagement for participation

The engagement process has already been described previously in section 2.1.5.

In addition to the discussions and debates held at the workshop with stakeholders, feedback from participants was collected in the form of a questionnaire with nine questions with complex answer options, designed to provide comprehensive information on the level of awareness, involvement, and interest of stakeholders in the subject of flood risk in the study area. Charts based on the centralization of stakeholder responses are available in Zenodo Stakeholders_workshop.

Based on the centralized responses, it appears that the majority of stakeholders participating in the workshop have a high level of information and knowledge on the subject and indicate that the main causes of flood risk are climate change and construction in flood-prone areas. In addition, most respondents gave the workshop in which they participated the maximum score, stating that they clearly understood the objectives of the CARE-ROPutna project and believe that its results will have a positive impact on the adaptation of local communities to climate change.

Most participants expressed interest in participating in the next planned workshops and in actively engaging in identifying new measures to reduce flood risk.

Following the first workshop, stakeholders were contacted to fill in the key risks evaluation matrix through which (present and future) severity, urgency as well as resilience capacity is being assessed in terms of qualitative judgement by the process participants.

2.4.2 Gather output from Risk Analysis step

Based on the outputs of Risk Analysis step from phase 1 (flood hazard and risk maps, heavy rainfall analysis results) and some patial outputs from phase 2 (local high resolution flood hazard map) , adequate presentations and contextualization for stakeholders were prepared and used at the first workshop. Based on these presentations, together with their existing knowledge of flood risk in Putna river basin, stakeholders expressed their opinions on severity, urgency and capacity to respond to flood risk in Putna river basin.

2.4.3 Assess Severity

The severity of flood risk, in a historical context, has been outlined during 2005, 2012, 2016, 2021 and 2022, when significant heavy rainfall and floods events in Putna river basin caused major damage and even loss of life. In 2005, local communities in Putna river basin experienced the largest flood ever recorded, with a peak flow value of 1,500 m3/s, being considered the first in the chronological series of maximum flows with an exceedance probability of 2.5% (calculated for the period 1951-2022).
According to the damage reports for Vrancea County (described in detail in Deliverable 1), the most significant impact as values of damages was on key sectors like the transport infrastructure (national and county roads, bridges), hydro-technical works for bank consolidation, water supply and sewerage networks and other damages (banks erosion and damage to supporting structures, households and annexes, treatment plants, economic units, agricultural land). Given the characteristics of the relief and location of human settlements in Putna river basin, the high impact of flooding and extreme precipitation on a major part of the traffic routes is of major importance for

the local communities because the damage of roads leads to their isolation, having limited ability to recover by themselves.
According to the results of the survey conducted at the workshop the majority of stakeholders participating in the workshop have a high level of information and knowledge on the subject (Figure 2-36), giving their responses relevance and significant weight in the key risk assessment matrix.

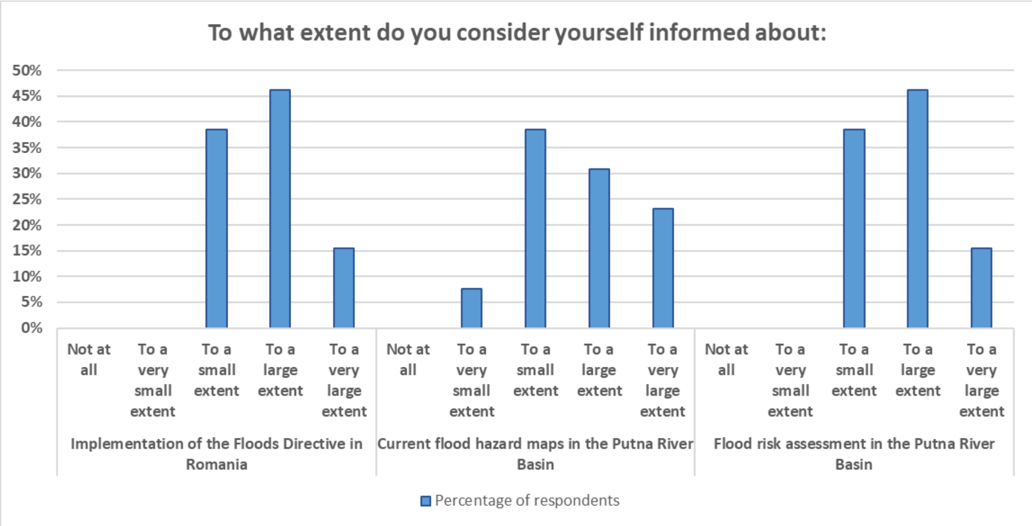

Figure 2-36. The level of stakeholder knowledge on the subject of flood risk in the study area

Stakeholders were asked to fill in the "Severity "column in the key risks evaluation matrix, according to the guiding questions provided under Key Risk Assessment on the CLIMAAX Handbook. Most of the stakeholders assessed severity as Substantial (High frequency and/or substantial impacts for the region or community with potentially intolerable, systemic effects; the functioning of communities, ecosystems, assets and infrastructure, the economy or the life and well-being of citizens is threatened.

2.4.4 Assess Urgency

Flooding and flash flooding risk can be considered as being based an a sudden hazard, for the upper Putna river basin, on small tributaries and for torrential runoff on slopes and a slower one on the middle and lower basin.
Most of the outputs from the analyses in phases 1 and 2 indicate significant damages associated with flood events of all RPs analysed and an upward trend in flood risk in the Putna basin for future climate change scenarios.
Stakeholders were asked to fill in the "Urgency "column in the key risks evaluation matrix, according to the guiding questions provided under Key Risk Assessment on the CLIMAAX Handbook and most of them assessed urgency as More action needed(Climate hazard and processes conditions are observed or projected to change significantly. They are anticipated to persist or happen during critical timing. If a future trend of hazard increase will be observed, the region/community is limited in taking action quickly. Adapting to the respective climate risk may take years to a decade).

2.4.5 Understand Resilience Capacity

Local communities in Putna river basin have limited resources to increase climate or disaster resilience because, in general, they do not have sufficient resources to implement proper emergency

response, recovery and adaptation measures, have high exposure to natural hazards due to the geographical position, have a large number of vulnerable people (children or elderly people) existing within the communities.
Within the implementation process of FD, flood prevention measures were identified for the Flood Risk Management Plan for River Basin Administration Siret (that includes Putna river basin) , of which a series of works are in various stages of execution (bank defenses, embankments, gabion consolidations, dam elevations, land extension, bank regularizations). These works are part of the category of flood protection measures and have the effect of reducing the risk of floods.

Also, a series of defense plans (basin, local committees, etc.) are drawn up that present actions to be carried out in a timely manner by specialized structures in order to prevent the worsening of the emergency situation, limit or eliminate, as appropriate, its consequences and identify, record and evaluate the types of risk and their determining factors, notify interested parties, warn the population, limit, eliminate or counteract risk factors, as well as the negative effects and impact produced by the respective exceptional events.

Stakeholders were asked to fill in the resilience column in the key risks evaluation matrix, according to the guiding questions provided under Key Risk Assessment on the CLIMAAX Handbook and most of them assessed it as Medium (Medium resilience capacity or some CRM measures in place).

2.4.6 Decide on Risk Priority

The final step of assessing key risks integrates the three sub-evaluation processes Severity, Urgency and Resilience Capacity. After contextualizing the risk outputs of the selected hazards in the provided excel template, Risk Priority was assigned manually in the final column. The individual risk context of the region or community requires a final, qualitative evaluation where high Severity, high Urgency, and low Resilience Capacity positively contribute to risk prioritization (very high risk prioritization); low Severity, low Urgency, and high Resilience Capacity negatively contribute to risk prioritization (low risk prioritization).

The final key risks evaluation matrix for Putna river basin resulted by averaging the responses gathered from the respondent stakeholders and from the internal evaluation based on the CRA outputs.

Climate risk in Putna river basin	Severity		Urgency	Capacity	Risk Priority
	C	F		Resilience/ CRM	
River flooding	3	3	3	2	High
Heavy rainfall/flash floods	3	3	3	2	High

Severity	Urgency	Resilience Capacity	Risk Ranking
Critical	Immediate action needed	High	Very high
Substantial	More action needed	Substantial	High
Moderate	Watching brief	Medium	Moderate
Limited	No action needed	Low	Low

Figure 2-37. The key risks evaluation matrics for Putna river basin

The results show that both river flooding and heavy rainfall/flash flood risks have substantial severity, high urgency (more action needed) and medium resilience capacity, indicating a final high risk priority estimation (Figure 2-37).

2.5 Monitoring and Evaluation

The second phase of the climate risk assessment provided important insights into both the magnitude of flood risk in Putna river basin and the practical implementation of a locally customized CRA within the CLIMAAX framework. The integration of high-resolution local datasets and advanced hydraulic modelling substantially improved the spatial accuracy of the results compared to Phase 1, particularly at settlement scale. Phase 2 confirmed that river flooding remains the dominant climate risk, with climate change expected to increase hazard extent, damages, and population exposure. The main difficulties encountered were related to data availability, heterogeneity, and scale, especially the integration of large, high-resolution datasets and the limited availability of spatially explicit socio-economic and population data.

Stakeholders play a key role in Monitoring and Evaluation process by validating relevance and contextualizing risks. Engagement through an introductory workshop and feedback questionnaires allowed local and regional authorities to confirm the relevance of the identified risks and to assess their severity and urgency. Stakeholders recognized climate change as a major driver of increasing flood risk and expressed strong interest in using the CRA outputs to inform flood risk management and adaptation planning, reinforcing the relevance of the assessment.

Learning is ensured through an iterative and participatory process. Internally, continuous interaction among technical experts supported methodological refinement and quality control. Externally, learning is promoted through stakeholder engagement, transparent documentation of assumptions and limitations, and open access to datasets and results via the Zenodo repository. This approach supports both institutional learning and long-term capacity building.

New local data was integrated in workflows during Phase 2, including high-resolution digital terrain models, updated local exposure datasets, and refined hydraulic models. However, the assessment also identified remaining gaps, particularly in high-resolution socio-economic and population data and information on future land-use and development trends. Additional resources, data integration capacities, and research on vulnerability would further improve future assessments.

CRA outcomes are communicated through deliverables, stakeholder workshops, open-access publications, ensuring accessibility for both technical and non-technical audiences.

Most of the activities in phase 2 worked well, including the use of local data, advanced hydraulic modelling and early stakeholder involvement. Resources were used efficiently, with staff time and analytical effort focused on high-impact tasks. Although technical complexity slightly constrained the scope of some analyses, efficiency gains enabled the delivery of robust results within the project timeframe.

The impact of the CRA on improved risk understanding is considered high, contributing to increased stakeholder awareness and an enhanced evidence base for identifying new adaptation measures.

2.6 Work plan Phase 3

According to the work plan, phase 3 of the project is dedicated to the exploration of potential adaptation options and relevant actions at local scale to address the risk and vulnerabilities identified from the multi-risk analysis carried out in Phases 1 and 2 and from the stakeholder's consultation workshops.

The first activity in plan is to review the previous proposed measures in the Flood Risk Management Plan, in Floods Directive Cycle II, taking into consideration the results from previous Phases, for the selected areas in Putna river basin.

A key activity is dedicated to the process of stakeholders involvement and it will consist in 2 local workshops for consulting stakeholders and selecting based on their feedback the most suitable proposals for the local context of Putna river basin, taking into cosideration the results of the local customized CRA conducted in phase 2.

Based on the improved local CRA results and on the active participation of stakeholders in dedicated workshops, new proposals for the program of measures which will include prevention, protection, and preparedness measures for existing and future floods, considering the effects of climate change.

3 Conclusions Phase 2- Climate risk assessment

Phase 2 of CARE-ROPutna project represents a substantial advancement in the application of the CLIMAAX framework to the Putna River Basin by transforming an initial screening-level assessment into a locally grounded and relevant climate risk assessment. The main objective of this phase—to refine and deepen the understanding of flood risk through the integration of local data, advanced modelling, and stakeholder input has been achieved.

A key conclusion of Phase 2 is that the customization of the CLIMAAX Toolbox in expert mode significantly improves the accuracy and usefulness of the CRA results at local scale. The integration of high-resolution digital terrain model, local land-use and infrastructure datasets, and locally derived vulnerability functions allowed the assessment to move beyond generalized European-scale assumptions. This addressed one of the main challenges identified in Phase 1: the limited ability of pan-European datasets to capture local flood dynamics and impacts in complex river basin settings.

The development of high resolution flood hazard maps for selected APSFRs along Zabala and Naruja rivers represents a major achievement of this phase. These maps provide a realistic representation of flood extent and depth for multiple return periods and climate change conditions and form the backbone of the refined risk analysis. Their use enabled more accurate estimation of flood impacts on land use, buildings, transport infrastructure, and population at settlement scale.

The refined risk assessment confirms that river flooding is the dominant climate risk in the Putna River Basin, both under current conditions and in future climate scenarios. Key findings indicate that climate change is likely to increase flood hazard extent, economic damages, and the number of people exposed, particularly during extreme events. In several settlements, a significant proportion of the built-up area is projected to be affected during extreme future events. Transport infrastructure, especially bridges and national roads, was identified as a critical vulnerability, with a high potential for cascading effects such as community isolation and disruption of emergency response and essential services.

A further important finding is the added value of local vulnerability and exposure data. Comparative analyses between Phase 1 and Phase 2 results show that damage estimates and risk rankings can change substantially when locally calibrated damage curves and detailed exposure datasets are applied. This demonstrates that localized assessments are essential for sound risk prioritization and for avoiding both underestimation and overestimation of climate risks.

Phase 2 also addressed the challenge of incorporating future climate change impacts by linking large-scale climate projections to local hydraulic modelling through discharge-based scenario analysis. While uncertainties remain, particularly regarding future socio-economic development and land-use change, the adopted approach provides a robust and precautionary basis for identifying new measures for adaptation planning.

An innovative estimation approach of new relevant spatially variable critical impact-based rainfall thresholds for 3h duration, for different level of severity, was succesfully applied within the extreme precipitation workflow, using the configuration of ROFFG System, as well as the experience of the NIHWM forecasters. The medium severity flash flood events, for most of the small river basins configured in the ROFFG system within Putna River basin, will become more frequent, for all the future period, under the RCP8.5 climate projection.

Some challenges were not fully addressed in this phase: data gaps remain, particularly regarding high-resolution socio-economic and population data and information on future evolution of exposure data. Technical constraints related to data volume and resolution required selective analysis for representative areas rather than full basin coverage at high resolution. These limitations have been transparently documented and will inform further refinement in future work.

Stakeholder engagement initiated in Phase 2 played an important role in validating the assessment results and enhancing their relevance. Feedback from local and regional stakeholders confirmed the perceived severity and urgency of flood risk and highlighted strong interest in using the CRA outputs to support adaptation planning. This engagement strengthened the relevance of the assessment and laid the groundwork for participatory measures identification in Phase 3.

In conclusion, Phase 2 delivers a robust, transparent, and locally relevant climate risk assessment that significantly improves understanding of flood risks in Putna river basin. The main challenges related to local data integration and hazard representation have been successfully addressed, while remaining gaps and uncertainties have been clearly identified. The key findings provide a strong evidence base for prioritizing risks and identifying targeted adaptation measures. Phase 2 thus serves as a bridge between initial risk screening and the co-development of prevention, protection, and preparedness measures that will be the focus of Phase 3.

4 Progress evaluation

This deliverable represents a key milestone in the CARE-ROPutna project, marking the completion of Phase 2 – Refinement of the Climate Risk Assessment. It provides the analytical foundation required to transition from risk identification and quantification to risk prioritization and the identification of adaptation measures in the subsequent project phase. The outputs generated in this deliverable are directly linked to the planned activities of Phase 3 and ensure continuity across the project work plan.

The refined CRA developed in Phase 2 delivers high-resolution, locally grounded hazard, exposure, vulnerability, and risk outputs that will be used as primary inputs for the following phase. In Phase 3, these outputs will support the prioritization of climate risks through stakeholder-supported evaluation of severity, urgency, and adaptive capacity, using the CLIMAAX Key Risk Assessment framework. The outputs of this phase will also inform the identification and spatial targeting of prevention, protection, and preparedness measures, ensuring that are evidence-based and tailored to local conditions.

Progress achieved in this phase aligns closely with the Individual Following Plan, as summarized in the tables below. Key Performance Indicators related to methodological refinement, data integration, and stakeholder engagement were met. The customization of the CLIMAAX Toolbox in expert mode, the integration of high-resolution local datasets, and the development of hydraulic flood models for selected areas demonstrate the achievement of the planned technical milestones. These actions resulted in significantly improved spatial resolution and reliability of the risk assessment outputs compared to Phase 1.

Stakeholder-related milestones were also achieved during Phase 2. The organization of an introductory stakeholder workshop and the collection of structured feedback through questionnaires contributed to validating the CRA results relevance and increasing awareness of climate-driven flood risks. These activities directly support the KPIs related to stakeholder involvement and they establish the basis for deeper stakeholder participation in the next project phase.

From an implementation perspective, the actions conducted during Phase 2 were completed within the planned timeframe and with efficient use of resources. Efforts were focused on high-impact analytical tasks, including data harmonization, hydraulic modelling, and new methodology integration. While technical complexity and data heterogeneity required additional effort, these challenges were managed without delaying project progress and resulted in higher-quality outputs.

Overall, Phase 2 delivered the expected outputs and achieved the planned milestones and KPIs as defined in the Individual Following Plan. The deliverable provides a robust and relevant evidence base that enables a smooth transition to Phase 3 activities, including risk prioritization and co-development of tailored adaptation measures.

Table 4-1 Overview key performance indicators

Key performance indicators	*Progress*
4 workflows (2 workflows for the refinement of the fluvial floods risk assessment and 2 workflows for the refinement of the heavy rainfall risk assessment) successfully applied on Deliverable 2	All 4 workflows (Fluvial floods and Heavy rainfall) were customized and applied, additional analysis were conducted.
1 preparation action with stakeholders	The first workshop dedicated to stakeholder involvement was organized in the study area on September 23rd, at Vrancea Water Management Unit headquarters in Focșani city. Over 20 representatives from relevant institutions from a diverse range of sectors responded to the invitation and actively participated in the discussions.

Table 4-2 Overview milestones

Milestones	*Progress*
Attend the CLIMAAX workshop held in Barcelona	Participation in the CLIMAAX Barcelona Workshop with poster on the first phase results and presentation within the CLIMAAX Success Stories.
First stakeholders meeting done	First stakeholders meeting done
Workflow for the refinement and improvement of the risk assessment carried out in Phase1 for fluvial floods successfully applied	The workflow for fluvial floods was improved and customized by integrating local data. Additional analysis were conducted.
Workflow for the refinement and improvement of the risk assessment carried out in Phase1 for heavy rainfall successfully applied	The workflow for heavy rainfall was improved by integrating local data, and by deriving and use of spatially variable critical impact-based rainfall thresholds for 3h duration.

5 Supporting documentation

Zenodo structure

- Main Report
- Local_flood_hazard
    - local_hazard_maps_hdr_shp
    - local_hazard_maps_png
    - impacted_settlements
    - model_hydrological_data_1%
    - model_input_hydrological_data
    - w1_Flooding_percentages_for_the_1%_exceedance_probability
- Stakeholders_workshop_and_media_posts
    - field_pictures
    - Workshop_CARE_ROPutna_Survey
    - Workshop_CARE_ROPutna_Survey_q1_3
    - Workshop_CARE_ROPutna_Survey_q4_9
    - Media_posts
- W1
    - 1_local_landuse_JRChazard
        - damage_maps_png
        - damage_maps_tif
        - local_landuse_map_raster
        - local_landuse_map
        - ZonalStatisticsDamageMap_analysis
    - 2_local_landuse_and_hazard
        - local_damages_maps_png
        - local_damages_maps_tif
        - local_landuse_maps_tif
        - local_damage_info_curves_landuse
        - local_landuse_damage_curves
        - ZonalStatisticsDamageMap_analysis
    - 3_local_infrastructure_and_hazard
        - roads_damage_maps_tif
        - roads_map_png
        - local_damage_curves_roads
        - local_damage_info_curves_roads
    - Local_vulnerability_data
- W2
    - local_building_damage_maps_plots
    - local_vulnerability_data_buildings
    - estimated_exposed_population_per_flood_event_return_period
- W3
    - extreme_discharges_outputs
    - plots_9601694_Zabala_Putna_Romania
    - w4_local_observation_data_Colacu_HS
- W4
    - hazard_assessment

    - IDF_curves_analysis_Putna
    - plots_Putna
    - results_Putna
    - updated_scripts
- risk_assessment
    - ef5_experiment_analysis_Putna
    - plots_Putna
    - results_Putna
    - thresholds_Putna
    - updated scripts

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