Summary report on the climate change driven main hydroclimatological risk at Vinica city, streamlining to urban planning and design helping to reduce urban flood risk.

Results of the project titled

Adaptation to climate change: planning and modelling tasks in a vulnerable city to support the prevention of damage caused by cloudburst

Created by the

MEGÉRTI Ltd.

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Content: summary of the main elements and results of the project

Content

1. Executive Summary

According to the 6th Assessment Report of the United Nation's Intergovernmental Panel on Climate Change on Impacts, Adaptation and Vulnerability, human health, lives, livelihoods, and also property and critical infrastructure such as water management systems are being increasingly adversely affected by hazards from heatwaves, storms, flooding and other extreme weather events (IPCC, 2022). **North Macedonia is also under different risks due to climate change.** Since a part of climate impacts are no longer avoidable, beside urgent mitigation of climate change it is crucial to adapt to unavoidable changes. This project titled ***Adaptation to climate change: planning and modelling tasks in a vulnerable city to support the prevention of damage caused by cloudburst*** focuses on Vinica municipality and Vinica town which are vulnerable to flood events because of their location, topography conditions and climate.

The aim of the project is to support local authorities to turn the region into a shaper of more resilient development for the benefit of the residents and to gather stakeholders, collect existing knowledge, needs and interests for improved resilience planning for the future.

The first step towards the study of climate vulnerability of a region is to indicate the climate exposure. To study the exposure to flood events which are the main focus of our project it is necessary to indicate changes in heavy rainfall events, called cloudbursts. **This document involves the details of our analysis indicating changes in cloudbursts focusing on North Macedonia and Vinica.** The methodology of climate vulnerability analyses and the critical climate indicators, the climatological data and climate model simulations and the implemented data post processing methods used are also introduced.

The results introduced in this document show the expected rate of change in climate indicators of cloudburst events which may lead to flash flood. Even though the occurrence of these events during the reference period is rare in the region of Vinica in comparison with e.g., the western part of the country, **the flood risk is projected to increase during the upcoming decades**.

As our cloudburst analysis show, the climate change is projected to increase flash flood risk, that means the adaptive capacity of Vinica must be strengthen. Therefore, it is highlighted in the document that **climate resilience can only be achieved through long-term, strategic urban planning and technical infrastructure designing**.

Climate adaptation can be typically dealt with at the regional or local level, as the effects can vary by different geographic regions. That is why we recommend, that strategic goals and policy considerations defining concrete responses should be approached from a territorial perspective. It can be achieved with integrating the results of climate model simulation-based calculations into urban planning and technical infrastructure designing.

Our situation exploring clearly points out that the tools of adaptive capacity are unfavourable in the region of Vinica: poorly developed infrastructure, vulnerable social groups, and the almost complete lack of available financial resources. All this underlines the need for measures to promote adaptability, which must be based on well-defined, short-, medium- and long-term goals, strategic approach, and integrated stormwater management.

Preparation for flash flood events also includes building an early-warning system (IPCC, 2022) and proper infrastructure for draining and retaining water. Although, the construction of green infrastructure would be beneficial against other climate affects, due to the high exposure and sensitivity, it is not sufficient. Considering our results, the best way to adapt to cloudbursts is drainage implementation concatenated with storage in reservoirs, **so the settlement can be prepared for the effects of droughts in addition to flash floods**.

Climate model simulation-based results must be integrated into current and future strategies for all sectors that are sensitive to the effects of climate change (agriculture, energy management, tourism, etc.). Since the presence of regional-level strategies is still extremely poor in Vinica, it is necessary to consider regional aspects of climate change in national-level strategies. Regardless**, it is recommended to develop regional strategies and display the topic of climate change**. The main priority is the revision of the Climate Change Strategy of Vinica based on the results, which is still being developed.

To implement climate adaptation goals, tools must be well defined. Partnership between different regional level and the involvement of the private sector could be with key importance in our expert's opinion. Although it is worth considering financial sources available in North Macedonia, in this case **it is probably necessary to find international funds** for the development (for example United Nations Development Program or European Union funds).

Note that, it is also important for infrastructure investments to consider the results, which is why it is recommended to include them in the local technical guidelines as well. The consideration of climate aspects for this kind of investments is already an expectation within the European Union, so showing these kinds of results can make the path to obtaining EU funds easier.

2. Introduction and aim of the document

This document is a product of the third milestone of the project titled *Adaptation to climate change: planning and modelling tasks in a vulnerable city to support the prevention of damage caused by cloudburst* supported by the West Balkans Green Center Nonprofit Llc. The project in North-Macedonia **provides an interdisciplinary overview and capacity building programme** for a pilot area and the local drainage system operators that help to facilitate investment projects for improved operational and design issues of the system. In the focus of this pilot project is the city of Vinica in North Macedonia facing the problem of flash flood events and the related damages in e.g., the infrastructure of the settlement.

Vinica, is significantly exposed to the effects of climate change. In addition to phenomena closely related to rising temperatures (e.g., heat waves, droughts), an increase in the **frequency of extreme precipitation events is also expected.**

Cloudburst events specifically endanger the region by increasing the risk of flash floods, which is the reason of the project's main objective and subject. In addition to the risk of climate effects, aspects essential to **adaptive capacity are also seriously lacking in the region**, such as technical preparedness, forecasting infrastructure, available experts, and financial background.

The main goal of the project is to **support the prevention of flash flood damages** which may be the result of heavy precipitation events, also called cloudbursts. These events which can cause **huge economic loss and human injuries**, are the result of combination of different factors like relief, valleys, geology, land use and land cover.

To address the possible solutions to adapt to the expected of climate change, this document assess knowledge on the process of how we used climatological datasets and climate model simulations in the cloudburst and **how to address climate change issues in urban development and planning**.

The potential impacts of climate change and **adaptability can typically be dealt with at the regional or local level**, as the effects can vary by different geographic regions. It follows, that strategic goals and policy considerations that define concrete responses, can only be effective if they are approached from a territorial perspective.

This project provides dissemination to **support the development and implementation of adaptation strategies** in two main areas:

- Applicability of climate model outputs on regional level in vulnerability assessment studies and climate strategies on climate resilient utility planning focusing on expected challenges caused by cloudburst
- Incorporation of climate change related challenges to urban development and planning

Since the formulated proposals are based on scientific results, they can form a relevant and integral part of the strategic guidelines, as well as form the basis of specific technical measures for stormwater management. To have results of the strategic objectives, the **tools for its implementation are also listed** including potential financial resources.

Projects of this kind are not new to the Western Balkan region and thus to North Macedonia, and some of them will be presented as applicable good practice for the future.

This document is the outcome of the third project milestone involves the dissemination of the completed tasks and a professional report of the project results. These were also briefly presented in a form of an online webinar about the climatological and urban planning related results achieved during the project.

3. Preliminary assessment on climate change in Vinica

To successfully execute a cloudburst analysis for the city of Vinica, preliminary survey was necessary to indicate the current level of knowledge of the Mayor's Office of Vinica and the municipality water utility operators. With the participation of stakeholders of Vinica and experts of the project from the field of climatology, hydrology, and geography an online workshop has been held. Based on a preliminary questionnaire and the real time knowledge exchange,

climate change has already negative effects on Vinica recognised by locals and causing damages mainly by flash flood events.

An additional estimation of the vulnerability of Vinica to climate change was possible as a part of a personal workshop held with the participation of local stakeholders of the municipality in Vinica. The vulnerability of infrastructure elements such as the cables of the power supply system or the sewage system was observable in the city (1. Figure).

1. Figure Vulnerable electric infrastructure and drainage system pieces in Vinica, North Macedonia.

Beside collecting the locally available knowledge and information related to climate change it was also important to synthesize the previous scientific results on the climate change processes in the region according to scientific publications and reports. According to the literature the most intense changes in extreme weather events in North Macedonia were observed in the duration and frequency of heat waves and droughts and increased risk of flooding.

To see how these processes are going to change in the country, **cloudburst analysis has been implemented**. This document is the outcome of the cloudburst analysis focusing on the city of Vinica which is especially vulnerable to the changes in heavy precipitations events.

This vulnerability appears in a form of flash flood risk caused by regional e.g., climatological or land cover conditions. **Generally flash floods are quite concentrated in space and time**. Their formation and duration only take a few hours with a spatial extent over an area of 10200 km^2. The phenomenon can be linked to heavy precipitation events which can be caused often by convective events, when several tens of millimetres of precipitations fall in a few hours and the surface is unable to handle, receive, and conduct the waterflow properly at such a fast rate. **The land use, the type and density of vegetation**, the type of soil and the water content of the soil have a **significant influence on flash floods**, as they play a decisive role in drainage.

Particularly vulnerable areas are mountainous and hilly regions like Vinica and its surrounding area, where there are small watercourses. Since the beds of the small streams are narrow, they may not be able to drain more than 10 mm of precipitation in a few hours, so flooding inevitably occurs in the area. Furthermore, **the relief factor also increases the severity** of flooding with the help of gravity. Intense precipitation can also cause problems in urban areas, since there are many waterproof layers (e.g., concrete) that prevent the infiltration.

Beside the conditions indicating flash flood risk caused by the location of Vinica, other problems such as the bad status of the drainage system, the missing early-warning system or proper disaster management and the lack of financial opportunities increases the flood exposure of the region.

According to the local experience and knowledge it is crucial to prepare for these effects based on carefully planned and implemented adaptation strategies. A key for operative and costeffective adaptation is the thorough assessment of climate exposure of the region (see chapter
4.1).

Policy documents concerning climate change are available in North Macedonia ensuring the horizontal embedding of the issue into planning at the national level. However, **there is a lack of regional or settlement-level programs, strategies or action plans** that reflect regional or local problems. Sectoral strategies are characterized by the appearance of climate change; however, concrete measures and interventions are usually lacking.

It is an important step forward that the municipality of Vinica is preparing a climate strategy, however the inclusion of the results in the document is extremely important for promoting climate policy goals as well as **climate-resilient planning of infrastructural investments**. It is important that the document must be prepared in English too, so that the results and development needs can be widely disseminated on the international scene.

4. Cloudburst analysis' methodological approach and data

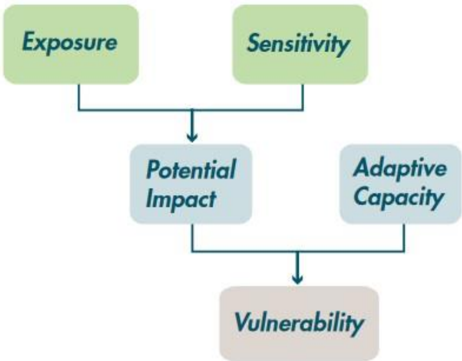
In this chapter, we summarize the climatological-theoretical background of our methodological approach (chapter 4.1.), as well as the climatological database and climate model simulation results applied for the examinations (chapter 4.2.). Furthermore, the postprocessing of data including the selection of the climate variables and the climate windows, geographical delimitation, the bias correction of the data as well as the calculation of the indices are also presented (chapter 4.2.3.).

4.1. Climate vulnerability analyses

Climate change vulnerability is defined by the IPCC as the susceptibility of a system to the negative effects of climate change, including climate variability and extremes (IPCC, 2007). In this meaning, vulnerability is described by three factors: **exposure to climate impacts, sensitivity, and adaptive capacity of the objects under assessment**. The main purpose of the climate change related vulnerability analyses are to explore how vulnerable a certain geographical area to the effects of climate change, and to define the relative territorial differences with comparing the different regions.

Climate Change Vulnerability Assessments (CCVAs) are methods that can be used as an initial, and essential step in the adaptation planning process. A CCVA focuses on systems of interest and helps identify the greatest risks to them from climate change impacts. A CCVA identifies factors that contribute to vulnerability, which can include both the direct and indirect effects of climate change, as well as non-climate factors.

The aim is to understand the potential impacts of climate change and associated dangers in related to cloudburst events in the city of Vinica. For this, the Climate Impact and Vulnerability Assessment Scheme (CIVAS) model has been chosen. The method has been developed as the part of the CLAVIER international climate research project (IPCC, 2007). The CIVAS model is applicable in the context of exposure → sensitivity → expected impact → adaptive capacity → vulnerability (2. Figure).



2. Figure Key components of vulnerability, illustrating the relationship among exposure, sensitivity, and adaptive capacity (Glick et al., 2011).

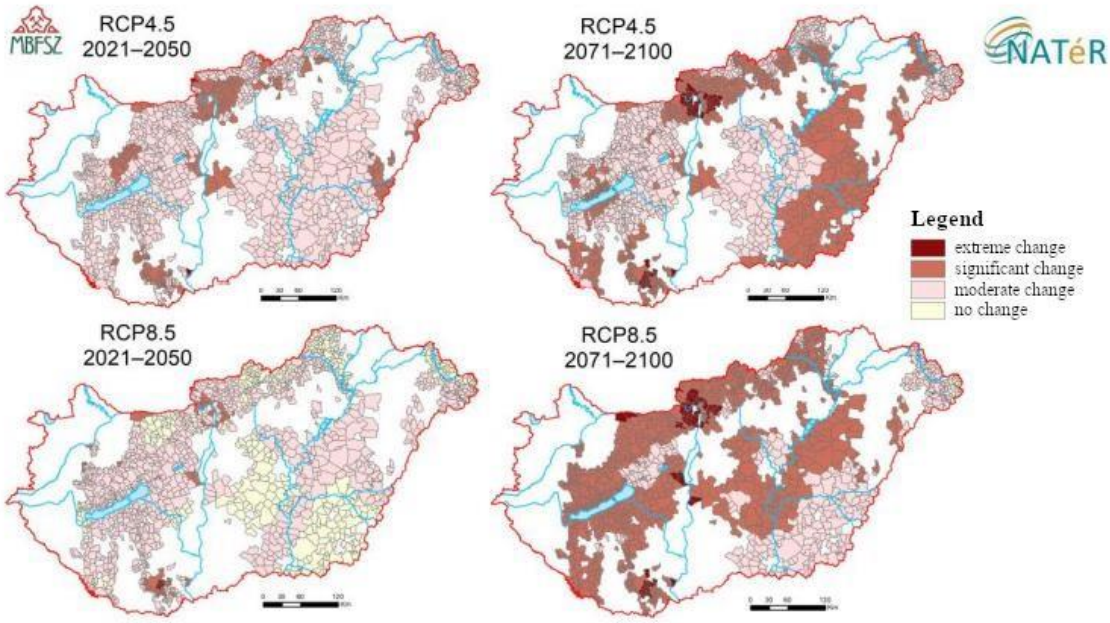
The elements of the CIVAS model are the following (Geological and Geophysical Institute of Hungary, 2016):

- **Exposure** shows amount and rate of change that a system experiences from the direct (e.g., temperature, precipitation changes) impacts of climate change,
- **Sensitivity** refers to characteristics of a system that are dependent on specific environmental conditions, and the degree to which it will likely be affected by climate change (e.g., temperature or hydrological requirements),
- **Potential impact** is a mathematic combination of sensitivity and exposure. It is also characterized by the geographic location and the examined system,
- **Adaptive capacity** is the ability of a system to cope and persist under changing conditions through local or regional conformation,
- **Vulnerability** is a complex indicator with combined potential impacts and the adaptive capacity, considering that the same expected impact in a given area with lower adaptive capacity may have more severe consequences than in a different territory with better adaptation capacity.

One of the **main objectives of our project was to examine Vinica's exposure to flash flood**. Before producing our exposure analysis, the steps of such study in explained using an example from Hungary (Rotárné et al., 2020): The main cause of the study was the fact that extreme weather conditions have caused difficulties in the Hungarian drinking water supplies many times. On one side there is a risk of excessive precipitation, flood and flash flood evolved over karstic areas, and several water supplies had to be excluded from operation to avoid the risk of infections. On the other side, the high demand for drinking water in dry summer periods and the accompanying reduction in water resources lead to insufficiency in the availability of number of water supplies. The future increase in extreme events and other climatic indices effecting drinking water availability made it necessary to analyse the vulnerability of drinking water resources to climate change. For this assessment, the CIVAS model was used. The examination includes the analysis of climatic parameters that mainly determine drinking water supplies. **Four indicators were selected** for the analysis of climate exposure:

- climatic water balance[1]
- ratio of the total precipitation of the two hydrological half-year[1]
- number of dry days[3]
- maximum length of consecutive dry days

A complex exposure indicator was formed from the above mentioned four indicators, which is the first step towards a vulnerability assessment to determine the impact of climate change on drinking water supplies, as important element of city infrastructure (3. Figure).



3. Figure An example to demonstrate the expected climate exposure for given water utility service area. Using the CNRM-CM5-RCA4 model simulation under RCP4.5 and RCP8.5 scenario for two period (2021–2050, 2071–2100; reference period: 1971-2000, Rotárné et al., 2020).

Following the concept of the CIVAS model, a *cloudburst analysis for the city of Vinica has been implemented to estimate the expected changes of different heavy rainfall events*.

A precipitation event is defined as extreme when it **exceeds a predefined amount of precipitation**. It is not possible to use the same indicator everywhere because of the high regional differences in variability of precipitation. To provide consistent general guidance in defining extreme precipitation, parameters, such as magnitude (intensity), duration, severity should be comprised. Based on the national (Djurdjevic, 2020) and international

[1] Hydrological summer half years (SH) from May to October and for hydrological winter half years (WH) from November to April.

3 Number of days with daily precipitation amount of less than 1 mm.

recommendations (Vuković and Vujadinović (2018); Djurdjevic et al., (2018)), we selected three indicators for our cloudburst analysis which involve both the short and long-duration extreme rainfall events:

1 The climatic water balance (WB) provides information for water availability, which is the difference between the annual precipitation (P) and the annual potential evapotranspiration (PET).

- Extreme precipitation events**: number of days with heavy precipitation (daily precipitation > 20mm and 40mm);** (For the short-duration extremes rainfall, which is linked to flash floods with limited spatial extent)
- Multi-day rainfall: **number of events when the 5-day precipitation accumulation was above 60 mm;** (A multi-day rainfall has a broader spatial distribution than a short-duration rainfall and, more extensive flooding can be explained with it.)

4.2. Climatological data

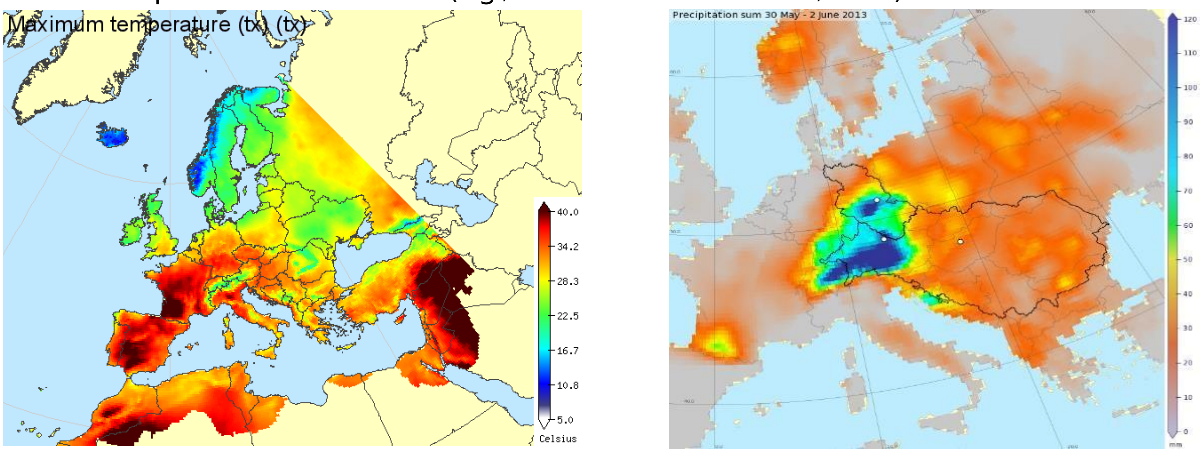
Our examination is based on climatological databases, which includes measurements and climate model data. The purpose of climatological analysis is to **quantify the changes expected in the future considering the past and the current climate trends**. To implement the cloudburst analysis, the E-OBS was chosen as a reference database, which is necessary for the validation of climate model simulations within the framework of exposure examination. The climate model simulations were selected from the EURO-CORDEX database. To produce indicators, it was also needed to perform a post-processing procedure on the data.

4.2.1. E-OBS

E-OBS is a gridded dataset, i.e. is a two-dimensional dataset representing meteorological parameters along an evenly spaced matrix [2 – copernicus.eu]. Datasets interpolated to a grid net are widely used for climate analyses. The interpolation is important to make regular grids from spatially irregular meteorological observations. For example, interpolated data eventuate the best estimates of climate variables at locations away from observation stations, thereby allowing studies in data-sparse regions. Note that the actual number of the observed data used to generate the E-OBS dataset can vary regionally, for instance in case of North Macedonia, data from three meteorological stations are involved in E-OBS. More measurements could increase the quality of the meteorological data provided by E-OBS. **Climate variability studies often seek regional patterns of coherent variability** that prefer regular observations the predominance of values in regions with a higher density of observation stations. In addition, surface observation-based dataset of gridded time series is used as reference in the climate model validation that is also important regarding the climate change. The direct comparison between interpolated data and models assumes the same spatial scale (Gadzhev et al., 2021). Therefore, a construction of gridded dataset is needed where each grid value is the best estimate average of the grid cell and is the most appropriate for validation of the models (Haylock et al., 2008).

In this regard, E-OBS dataset has been developed, that consists of high-spatial resolution daily gridded data, while it is required by many users (Cornes et al., 2018). The E-OBS covers the European region and is based on the station data collated by the European Climate Assessment & Dataset (ECA&D) project initiative. The datasets are directly supplied by the European National Meteorological and Hydrological Services (NMHSs) or other data providers across Europe. It provides gridded fields at a spacing of 0.1° x 0.1° and 0.25° x 0.25° in regular latitudelongitude coordinates. The density of stations progressively increases through collaborations with NMHSs within European research contracts. The full datasets cover the period 1 January 1950 to the present with daily temporal resolution, which are available in NetCDF-4 file format [1 – copernicus.eu].

It has originally been developed and updated as parts of the ENSEMBLES (EU-FP6), EURO4M (EU-FP7) and UERRA (EU-FP7) projects. Currently it is maintained and elaborated as part of the Copernicus Climate Change Services. It is updated frequently (new versions added every 6 months) – the latest version (v25.0e) was released in April 2022 [3 – ecad.eu]. **The sequential improvements ensure the continued usage of the dataset in the future**. The E-OBS originally included daily mean, minimum and maximum temperature (°C) values as well as daily precipitation amounts (mm) (4. Figure) [4 – ucar.edu]. In later work relative humidity (%), surface shortwave downwelling radiation (W m^{-2}), wind speed (m s^{-1}) and mean sea level pressure (hPa) were also implemented and added (e.g., van den Besselaar et al., 2011).



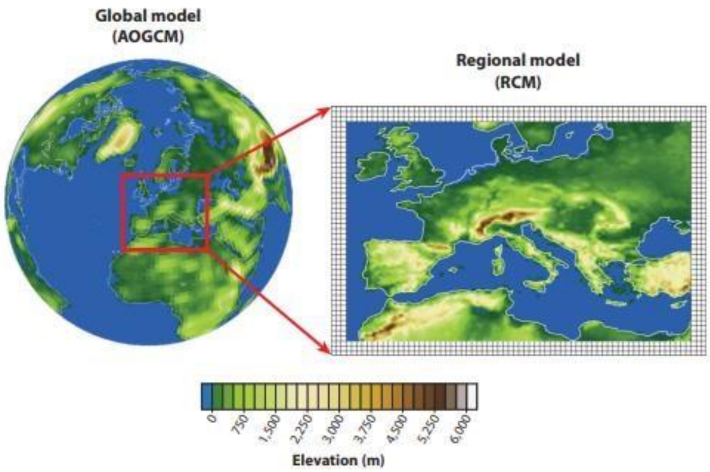
4. Figure E-OBS-based Daily Maximum Temperature (°C) for August 4 in 2003, which was one of the hottest days in Europe (left) and Accumulated Precipitation (mm) for May 30 - June 2 in 2013, which led to massive floods in central Europe (right). Source: [4 – ucar.edu].

As mentioned above, the E-OBS is widely used as reference in the model validation in many studies (e.g., Cornes et al., 2018; Gadzhev et al., 2021). These studies are generally based on the newest ensemble-based versions of the E-OBS that provide an improved estimation of interpolation uncertainty through the calculation of a 100 ensemble-members of realizations of each daily field. Users will notice differences between the original and the newest E-OBS versions, especially for precipitation, which arises from the different gridding method used. In the studies mentioned above the main goal was the comparison of the earlier and the newer E-OBS databases. Differences were revealed especially regarding precipitation, which arises from the different gridding method used.

It can be concluded that the E-OBS is unique in Europe due to the relatively high-spatial horizontal grid spacing, the daily resolution of the dataset and the provision of multiple variables. The main advantage of the database is that **the available data is provided free of charge with unrestricted access** [3 – ecad.eu]. Furthermore, it is also used for monitoring the magnitude and frequency of daily extremes, which is particularly crucial for the assessment of climate change. Therefore, the E-OBS is expected to remain one of the most important datasets for model validation, and it is recommended to use this database if there is no finer resolution data that covers the study area (Gadzhev et al., 2021).

4.2.2. EURO-CORDEX

We used the results of climate model simulations available in the EURO-CORDEX database to explore future climate conditions in North Macedonia. EURO-CORDEX initiative ensures an ensemble of regional climate projections for Europe [5 – euro-cordex.net]. The development and use of regional climate models (RCMs) originated in the late 1980s. The idea of downscaling coarse-resolution fields of global climate models (GCMs) to high-resolution climate models was first proposed through the use of large ensembles of short (3–5 days) simulations (Dickinson et al., 1989). The so-called nesting is one of the various downscaling techniques that are currently available. The basic strategy of the nesting approach (5. Figure) consists of first running GCMs to describe the effects of large-scale forcings and processes on the general circulation of the atmosphere, which determines the sequence of weather events characterizing the climate of a region (Giorgi and Gutowski, 2015).



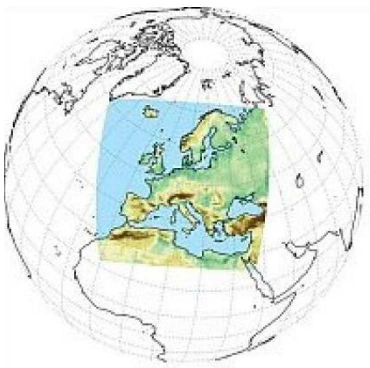
5. Figure Schematic depiction of the RCM nesting technique. The figure shows the refinement in topography and coastlines that can be obtained from the use of an RCM. The squared area surrounding the RCM interior domain represents the lateral buffer zone (Giorgi and Gutowski, 2015).

Nowadays, several RCMs are available, as many institutions worldwide develop and use them (e.g., Copppola et al., 2021; Vautard et al., 2021). In addition, within the RCM community, a number of regional intercomparison projects have occurred (e.g., Jacob et al., 2007; Mearns et al., 2012), which have led to considerable improvements of RCMs. However, differences in model setups and simulation protocols have made it difficult to transfer knowledge from one regional program to another. It has been recognized that multi-model ensembles of experiments are necessary to explore different dimensions of the uncertainty space in regional projections and that intercomparison of results is important for a better understanding of downscaling issues. Thus, the global coordination of such efforts can further advance RCM development, analysis, and application. Finally, the Coordinated Regional Downscaling Experiment (CORDEX) initiative was created within the World Climate Research Program (WCRP) to include the results of regional climate models in a framework, which coordinates the implementation of related regional climate simulations worldwide. The CORDEX is known as the first attempt at full worldwide coordination of regional downscaling work using a common experimental framework [6 – wcrp-cordex].

The freely available CORDEX database, which contains the results of regional climate simulations through international cooperation, represents a major evolution in research with regard to the climate exposure examination and has now become the main international reference framework for downscaling activities. The CORDEX main goals are the following according to [6 – wcrp-cordex]:

1. To better understand relevant regional climate phenomena and their variabilities through downscaling;
2. To evaluate and improve regional climate downscaling techniques;
3. To produce coordinated data sets of regional downscaled projections worldwide;
4. To exchange communication and knowledge with users of regional climate information.

The CORDEX database is divided into 14 regions and covers most of the Earth. Numerous experiments have occurred for most CORDEX domains, of which EURO-CORDEX is the European region of the CORDEX initiative and includes the territory of North Macedonia as well (6. Figure). Within EURO-CORDEX, model combinations can be created from 12 different GCMs and 10 different RCMs. The CNRM-CM5 global model and RCA4 regional model, as well as the EC-EARTH global model and RCA4 regional model combinations were selected. **The simulations are available over the European domain** at the standard 0.44° (EUR-44, ~50 km) grid spacing and also at a finer grid spacing of 0.11° (EUR-11, ~12 km). For the current analysis, the latter resolution (EUR-11) was chosen to use a resolution similar to the reference E-OBS database.



6. Figure The European CORDEX domain. Source: [5 – euro-cordex.net]

The EURO-CORDEX considers the lobal climate simulations up to the year 2100. These simulations can be separated into historical and future periods. The historical period is 1951–

2005 for most climate simulations. The future projections (for the period of 2006–2100) are based on greenhouse gas emission scenarios (Representative Concentration Pathways, RCPs) corresponding to stabilization of radiative forcing after the 21st century at 4.5 W/m² (RCP4.5 – moderately optimistic scenario), rising radiative forcing crossing 8.5 W/m² at the end of 21st century (RCP8.5 – pessimistic scenario) [5 – euro-cordex.net].

4.2.3. Post-processing of the data

Climate indicators defined in Chapter 4.1. have been selected to determine the climate exposure for the examined area. The production of the indices from observed climatological data and climate model simulations was preceded by several steps of processing the raw data:

1. Download and selection of climate variables
2. Selection of the reference period and the climate windows
3. Geographical delimitation for the examined territory
4. Regridding procedure of data
5. Bias correction of the data
6. Calculation of the indices

The processing was carried out using the Climate Data Operators [7 – CDO] and the Python Programming Languages [8 – Python].

Download and selection of climate variables

To implement a cloudburst analysis, we needed daily precipitation sum data. The data was downloaded in the selected spatial and temporal resolution. The object was to select databases with the highest spatial resolution to ensure a detailed representation of indicators (See in Chapter 4.2.1. and Chapter 4.2.2.). E-OBS has a spatial resolution of 0.10° and EURO-CORDEX has a grid resolution of 0.11°. The EURO-CORDEX data can only be downloaded in separated files (in 5-year periods from 1971 to 2100) so we merged the data before further postprocessing.

Selection of reference period and climate windows

To determine the indicators, we first had to select the reference period and the future climate windows which are used to study the changes over time. In climate change studies, averages of 20–30 years are created to investigate the changing on a climatological scale. In this analysis the period 1986–2005 was selected as the reference period. For the future, two climate periods were selected, one for mid-century 2031–2050 and one for the end of the century 2081–2100. The four selected extreme precipitation indicators were determined for these climate windows.

Geographical delimitation of the examined territory

As shown in Chapter 4.2.1. and Chapter 4.2.2., the E-OBS and CORDEX databases cover a larger area than the territory of North Macedonia. The geographical delimitation of the examined territory was implemented using Climate Data Operator (CDO) codes [7 – CDO].

Regridding procedure of data

Regridding is the process of interpolating from one grid resolution to a different grid resolution. EURO-CORDEX and E-OBS database have different grid spacing. Data taken from E-OBS (with higher spatial resolution) have been interpolated to the grid spacing of the EUR11 domain (with lower spatial resolution) with a bilinear interpolation. The method was necessary because databases with different grid points are not comparable. Thereby, to calculate indicators, we worked with databases at a grid resolution of 0.11°.

Bias correction of the data

Both Global and Regional Climate Models (GCM, RCM) have systematic errors (biases) in their output. These errors can be caused by a range of factors. Errors or biases are due to limited spatial resolution (large grid sizes), simplified thermodynamic processes and physics or incomplete understanding of the global climate system [2 – copernicus.eu]. Thus, the use of raw model outputs in impact models or climate impact assessments can often give unrealistic results. However, the **error can be well estimated with a database of observational data**. Several bias correction procedures have been developed to remove errors from a data series, but some methods can be more effective based on the focus of the research. In this case, the aim was to retain the predicted extreme values, not to smooth it. The quantile mapping method is proposed for the examined of extremes values (Themeßl et al., 2011). This method corrects the differences in the distribution of the variables, thus comparing not only the means of models and observations (such as the delta change method) but also their variances. The code of the quantile mapping bias correction is implemented in Python (7. Figure).

```
########### USED FUNCTION FOR CORRECTION ##########################
def quantile_correction(obs_data, mod_data, sce_data, modified=True):
    cdf = ECDF(mod_data)
    p = cdf(sce_data) * 100
    cor = np.subtract(*[np.nanpercentile(x, p) for x in [obs_data, mod_data]])
    if modified:
        mid = np.subtract(*[np.nanpercentile(x, 50) for x in [obs_data, mod_data]])
        g = np.true_divide(*[np.nanpercentile(x, 50) for x in [obs_data, mod_data]])

        iqr_obs_data = np.subtract(*np.nanpercentile(obs_data, [75, 25]))
        iqr_mod_data = np.subtract(*np.nanpercentile(mod_data, [75, 25]))

        f = np.true_divide(iqr_obs_data, iqr_mod_data)
        cor = g * mid + f * (cor - mid)
        return sce_data + cor
    else:
        return sce_data + cor
class BiasCorrection(object):
    def __init__(self, obs_data, mod_data, sce_data):
        self.obs_data = obs_data
        self.mod_data = mod_data
        self.sce_data = sce_data

    def correct(self, method="modified_quantile"):
        if method == "basic_quantile":
            corrected = quantile_correction(
                self.obs_data, self.mod_data, self.sce_data, modified=False
            )

        elif method == "modified_quantile":
            corrected = quantile_correction(
                self.obs_data, self.mod_data, self.sce_data, modified=True
            )

        else:
            raise Exception("Specify correct method for bias correction.")

        #self.corrected = pd.Series(corrected, index=self.sce_data)
        self.corrected = corrected
        return self.corrected
```

7. Figure Used functions for the quantile mapping method in the Python Programming Language

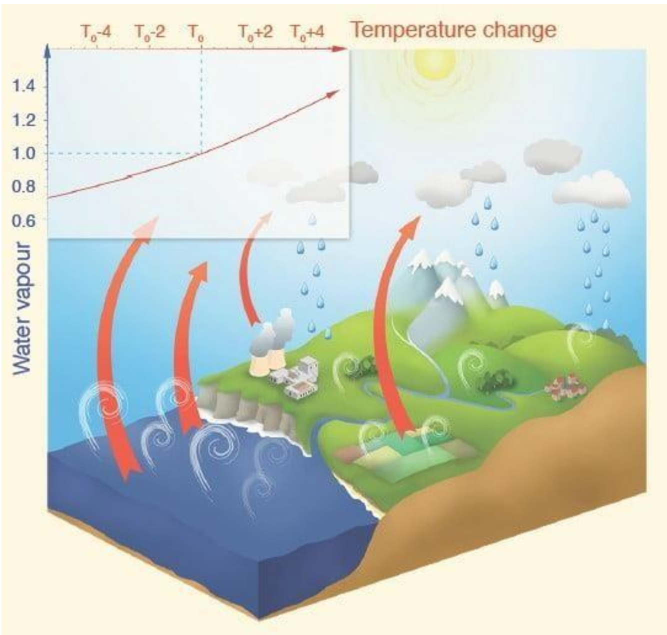
Calculation of indices

After generating the corrected data series, the indicators can be calculated. To calculate climate indices, we created our own functions, mainly using the *xarray*, which is an open-source project and Python package that makes working with labelled multi-dimensional arrays [9 – xarray]. The indices were visualized by the *basemap package* [10 – basemap]. This is an extension of the *matplotlib library* from Python, which offers a wide range of data visualization, geographic projections, country boundaries, and rivers. The country's municipalities were displayed using a shapefile [11 – GDM].

5. Cloudburst analysis based on climatological data (climatological analyses)

Global warming causes changes in all the parts of the Earth System including the atmospheric circulation and the water cycle. These changes effects the wind belts and influences the storm development and their routes which alter the temporal and quantitative distribution of precipitation. Beside that the warming atmosphere can hold more and more water vapor at a rate of 7% per 1°C increase, and this excess water, in addition to increasing warming, can fuel heavy rainfall events (8. Figure).

Thus, hydrological cycle intensifies with global warming, which likely increases the intensity of extreme precipitation events and the risk of flooding. Intense precipitation events or **cloudbursts may result in flash floods and/or landslides** which could cause not only huge economic loss in the form of damage to houses, industries, public utilities but human injuries and loss.



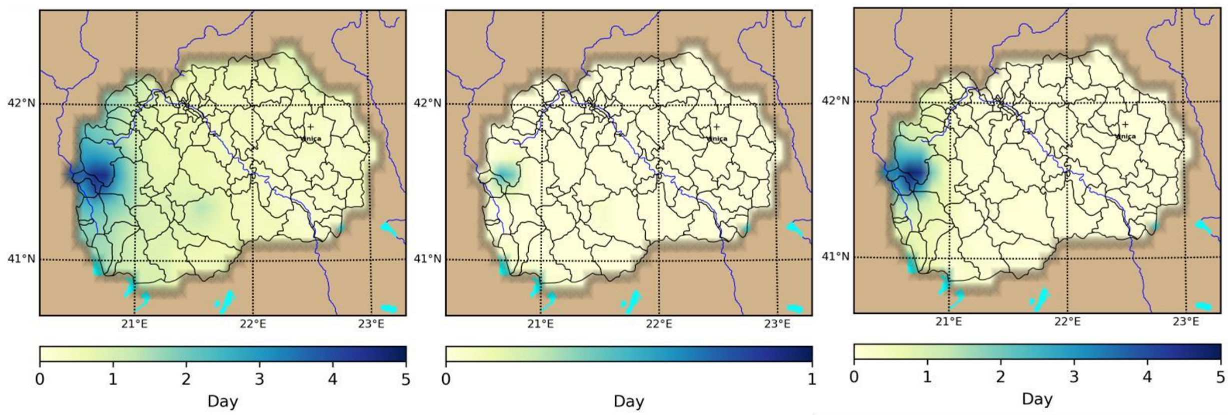
8. Figure Illustration of the water cycle and its interaction with the greenhouse effect. Source: [12metlink.org]

The cloudbursts are the result of combination of different non-climatic factors like geology, steepness or land use and land cover. The identification of areas potentially under risk of cloudbursts are the first step to build up an early-warning system for disaster management and form a climate resilient settlement by implementing adaptation strategies against cloudburst events. It is also crucial to **develop infrastructure prepared not only for the current risk level but for the increase in extreme rainfall events expected as the result of climate change**. For the preparation of a database with areas under increasing risk of cloudburst, landslides, floods, it is necessary to provide information about changes in critical climatic indicators.

5.1. Critical climatic indicators' changes in North Macedonia and Vinica

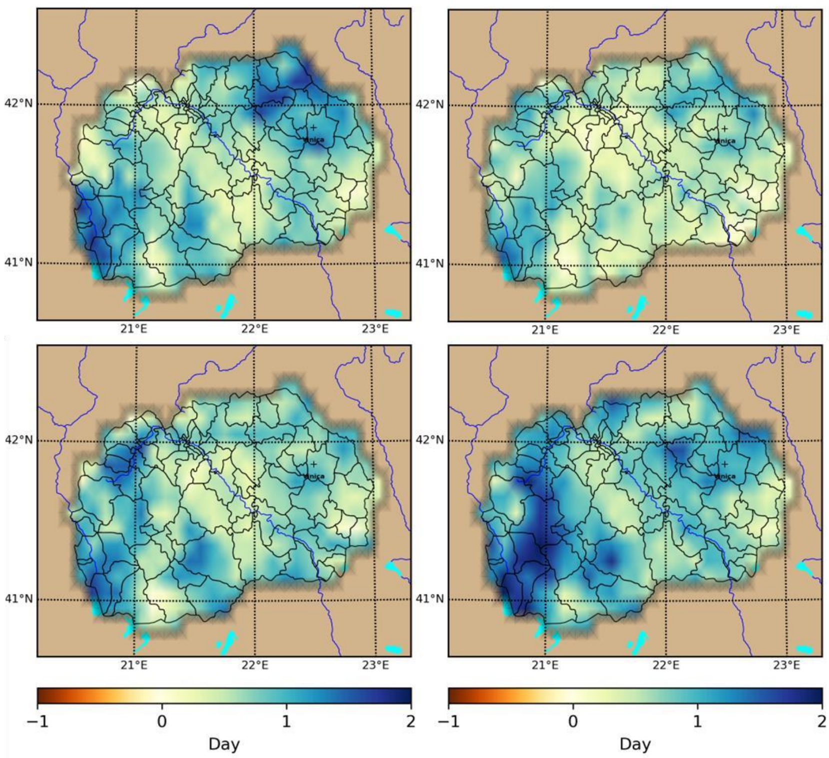
The expected change in extreme precipitation indicators in North Macedonia and Vinica by the middle (2031–2050) and the end of the century (2081–2100) has been analysed using data from the E-OBS climatological dataset and EURO-CORDEX climate model simulations (Chapter 4.2). The quantile-corrected simulated data with EUR-11 resolutions are following the RCP4.5 and RCP8.5 scenarios. Results obtained based on GCM-RCM model pair simulations of the ECEARTH and CNRM-CM5 global climate models and RCA4 regional climate model. The following climate indices has been calculated: number of days (9. Figure) and changes in number of days with daily precipitation amount > 20 mm hereinafter referred to as RR20 (10. Figure, 11. Figure) and > 40 mm referred to as RR40 (12. Figure, 13. Figure) and number of multi-day precipitation events with precipitation > 60 mm in 5 days referred to as RR5D60 (14. Figure, 15. Figure).

The RR20, RR40 and RR5D60 during the reference period (1986–2005) are shown on 9. Figure. In the western part of the country, there were an average 4-5 days with over 20 mm precipitation and with RR5D60 events, while only around half-day with RR40. However, in the eastern part where Vinica is located the number of RR20 is less than one day annually calculated for the 20-year average period. More extreme events such as RR40 or RR5D60 rarely or did not occur in Vinica.



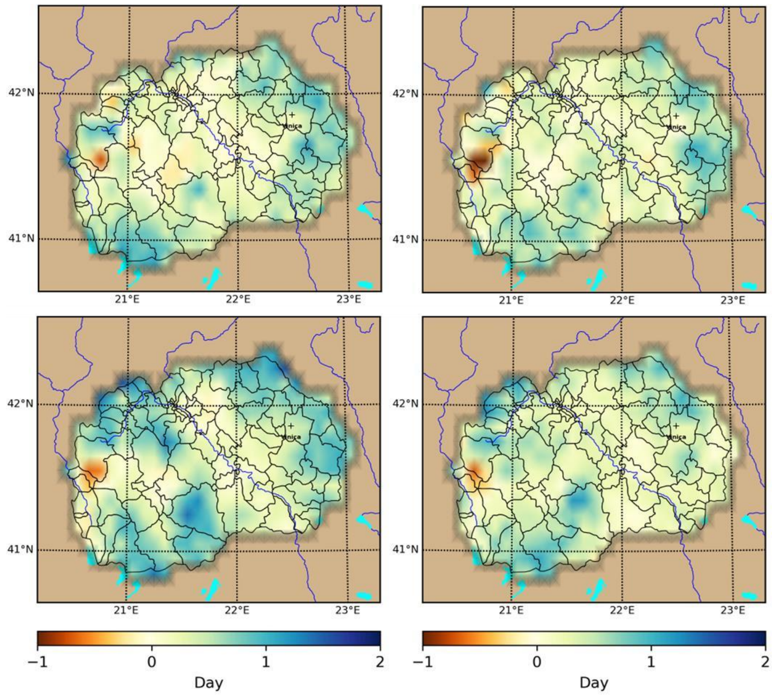
9. *Figure The number of days with precipitation amount > 20 mm (RR20, left), > 40 mm (RR40, middle) and number of multi-day precipitation events with precipitation > 60 mm in 5 days (RR5D60, right) during the reference period (1986–2005) based on the E-OBS data. Note that the scale is different for RR40. Source: own calculation*

The highest increase in extreme precipitation indices can be seen in case of RR20 according to the CNRM-CM5-RCA4 and the EC-EARTH-RCA4 model pairs (10. Figure and 11. Figure). In case of CNRM-CM5-RCA4 there is an overall increase in the country in RR20 in both periods and scenarios while in case of EC-EARTH-RCA4 there is a decrease in the number of these events in the region where the RR20 was the highest during the reference period. This indicates the overall drying and changing in precipitation pattern in the country.



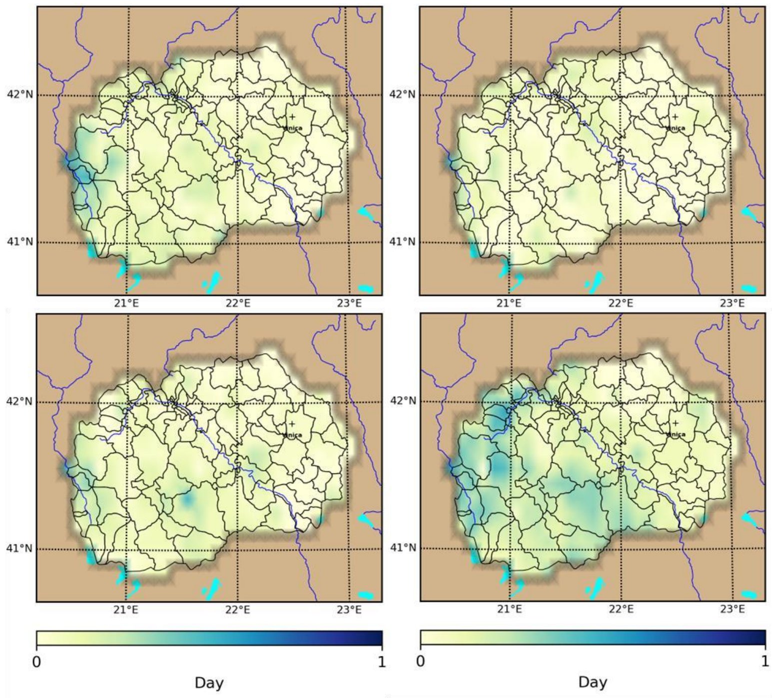
10. Figure Changes in number of days with precipitation amount > 20 mm (RR20) according to the CNRM-CM5-RCA4 model pair. Top maps are projections for the middle of the century (2031–2050) and bottom ones for the end of the century (2081–2100). Left maps are based on the RCP4.5 and the right ones on the RPC8.5 scenario. Source: own calculation

In Vinica, increase is expected in RR20 by the middle and end of the century according to both GCM-RCM model pairs and RCP scenarios. By the middle and end of the century, RR20 events are projected to occur more than four times more according to CNRM-CM5-RCA4 based on the RCP4.5 and RCP8.5 respectively. RR20 events are expected at least two times more often according to all the CNRM-CM5-RCA4 simulations.

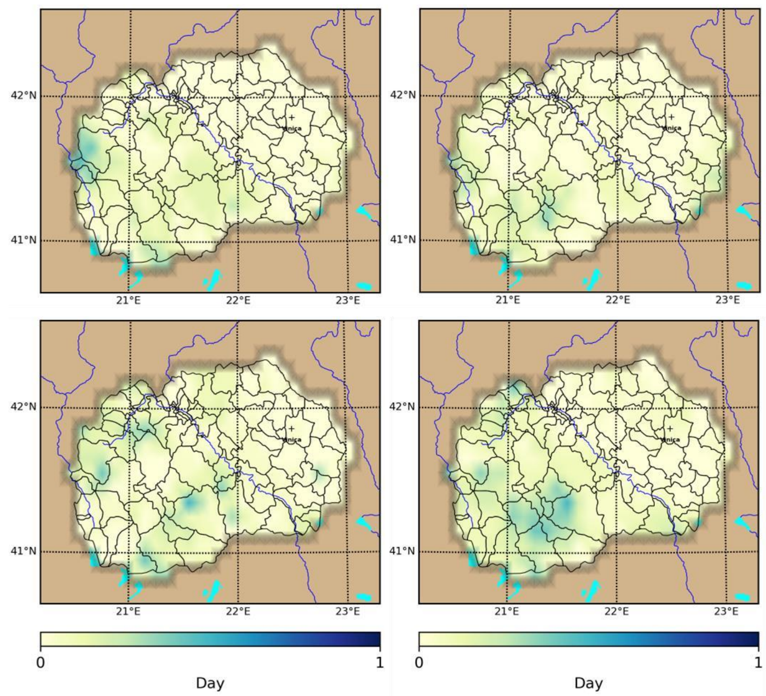


11. Figure Changes in number of days with precipitation amount > 20 mm (RR20) according to the EC-EARTH-RCA4 model pair. Top maps are projections for the middle of the century (2031–2050) and bottom ones for the end of the century (2081–2100). Left maps are based on the RCP4.5 and the right ones on the RPC8.5 scenario. Source: own calculation

RR40 events in North Macedonia almost never occur on a 20-year average during the reference period and there is no significant increase expected according to the simulations used in this study (12. Figure13. Figure). However, it is important to note that just because these events are expected to remain rare on an average, RR40 days are still possible to occur in the city of Vinica (and other parts of the country). **These precipitation events are great risks for settlements** especially when there is a lack of drainage system or the existing one is not maintained. Even one heavy precipitation event can cause damage with high recovery cost and other economic or social harm such as health-related dangers e.g., via contamination of drinking water base as an impact of flash flood.



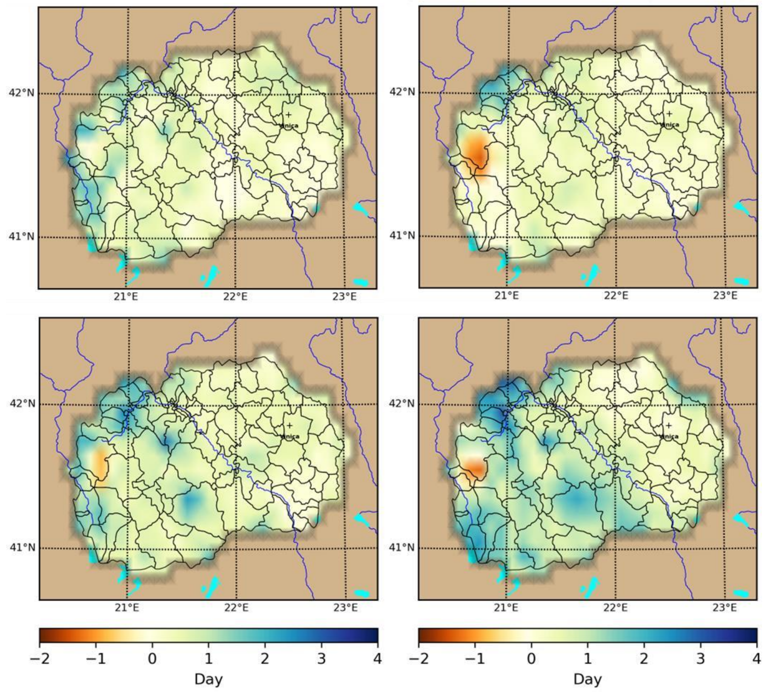
12. Figure Changes in number of days with precipitation amount > 40 mm (RR40) according to the CNRM-CM5-RCA4 model pair. Top maps are projections for the middle of the century (2031–2050) and bottom ones for the end of the century (2081–2100). Left maps are based on the RCP4.5 and the right ones on the RPC8.5 scenario. Source: own calculation



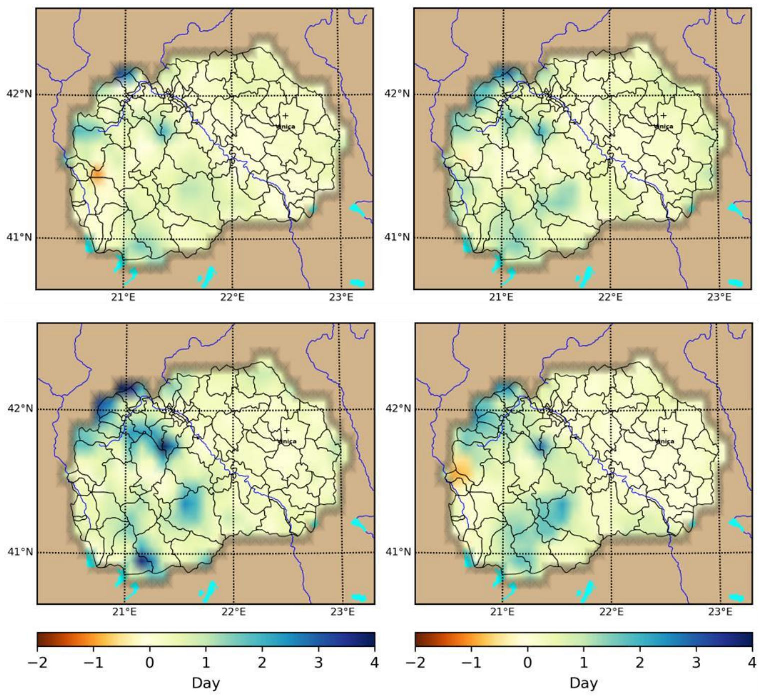
13. Figure Changes in number of days with precipitation amount > 40 mm (RR40) according to the EC-EARTH-RCA4 model pair. Top maps are projections for the middle of the century (2031–2050) and bottom ones for the end of the century (2081–2100). Left maps are based on the RCP4.5 and the right ones on the RPC8.5 scenario. Source: own calculation

The RR5D60 is also an important indicator in cloudburst analysis because these events usually mean heavy the occurrence of heavy precipitation not only within one day but consecutive days. These events can mean a higher risk to settlements than the single-day heavy precipitation indicators. The impacts of the consecutive single-day events of an RR5D60 event can add up and worsen the cost of the damage.

These events barely occur in the reference period (9. Figure) except the western part of the country. Vinica located in the eastern region is projected to experience these events in the future according to both GCM-RCM pairs and both scenarios (14. Figure, 15. Figure). These events are expected not only at the end of the century but also by the middle-of the century. The highest increase in the number of RR5D60 is expected according to the CNRM-CM5RCA4 simulation by the end of the century following the RCP4.5 scenario.



14. Figure Changes in number of multiday precipitation events with precipitation > 60 mm in 5 days (RR5D60) according to the CNRM-CM5-RCA4 model pair. Top maps are projections for the middle of the century (2031–2050) and bottom ones for the end of the century (2081–2100). Left maps are based on the RCP4.5 and the right ones on the RPC8.5 scenario. Source: own calculation



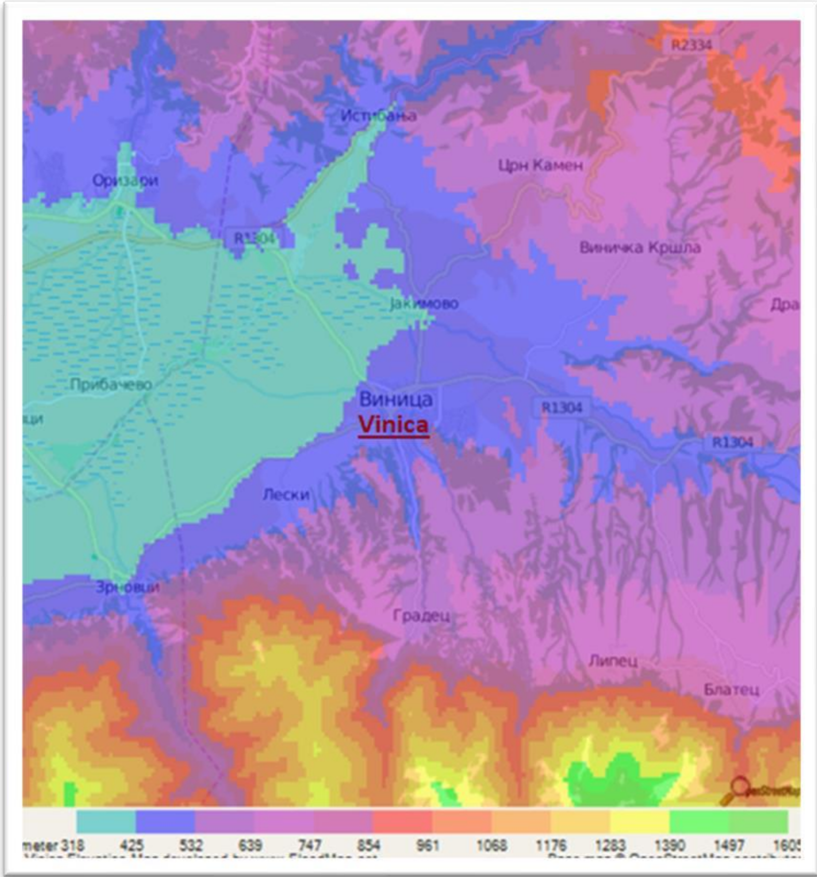
15. Figure Changes in number of multiday precipitation events with precipitation > 60 mm in 5 days (RR5D60) according to the EC-EARTH-RCA4 model pair. Top maps are projections for the middle of the century (2031–2050) and bottom ones for the end of the century (2081–2100). Left maps are based on the RCP4.5 and the right ones on the RPC8.5 scenario. Source: own calculation

6. Assessment of climate vulnerability of Vinica

This chapter involves an overview of the relevant **climate impacts** in Vinica. These impacts have already arisen as a risk even in the region, and their harmful effects may potentially increase in the future, endangering the population of the town and its surroundings. Due to the main goal of this project, **we focused on the analysis of cloudburst effects,** but other relevant effects were also considered (e.g., heat waves, drought). Besides that, some dimensions of **adaptive capacity were also included**, obtaining a more complete picture of the settlement's **climate vulnerability.**

6.1. Flash flood risk

For the region of Vinica, **sudden and heavy rainfalls are already a risk factor and expected to occur more frequently in the future** (see Chapter 5. Cloudburst analysis based on climatological data, hereinafter: *Cloudburst Analysis*). Heavy rainfalls sometimes **can be predicted only in a few hours before the precipitation event and may result in flash floods**. Beside intensive rainfalls, the possibility of appearance and intensity of **flash floods are influenced by topography, vegetation, condition and permeability of the drainage systems, and the structure and location of the settlements**. If extremely intensive precipitation is concentrated on a small area and its runoff cannot be discharged by a drainage infrastructure, it can easily cause flash flood as well as landslides and debris flow indirectly (J. Ritter et al., 2021). Vinica buil-in area is located in al small area under high mountains and steep slopes (16. Figure) where there are several torrents and rivers flow through the area making **local characteristics especially exposed to flash flood events**, and **significantly increasing the risk** the town is posed.



16. Figure: Elevation map in the municipality of Vinica (Vinica town is highlighted in red). [Source: 13-floodmap.net]

In urban areas the damage caused by flash floods can be large because of dense population and because the vital infrastructure concentrating here (R. A Falconer et al., 2011). Here where the settlement is a small city, but in generally true that the denisity is higher in the city center then outside of the build-in-area.

As long as the potential impact of flash flood events concerned it could be stated that,in general and also here the case is that **flash flooding is a major risk for cities.** On the one hand, **water absorption capacity of built-in surfaces is much lower** than green areas, which increases the likelihood of inland floods in the absence of a proper drainage system; on the other hand, **cities also have the highest population concentrations**, so not only material and financial damages but also social risks are the highest here. As a result, **towns surrounded by mountains such as Vinica are highly vulnerable to flash floods.** This will be explained in next chapter in details.

Disadvantaged groups (the poor, the elderly, the sick, the disabled, minorities) **are mostly affected** by the changes, as they have less capacity for adaptation. Unfavourable changes in housing conditions and damages caused by extreme weather situations, storm damage, floods, and ground movements make these groups extremely vulnerable. Vinica is characterized by an aging society due to the continuous emigration of younger residents in the recent past [14-stat.gov.mk], therefore, a **significant risk exists for a large part of the population** of the settlement.

The potentially caused **damage by flash floods can pose a danger to the town indirectly** as well. Due to floods and storm the **number of accidents can largely increase** which means increasing pressure **on the healthcare system** (in addition to potential infrastructure damage). As long as the impact concerned the infrastructure damage , mainly road system is the main result of not only series but could be even of a heavier cloudburst event. Possible flood risk in urban areas

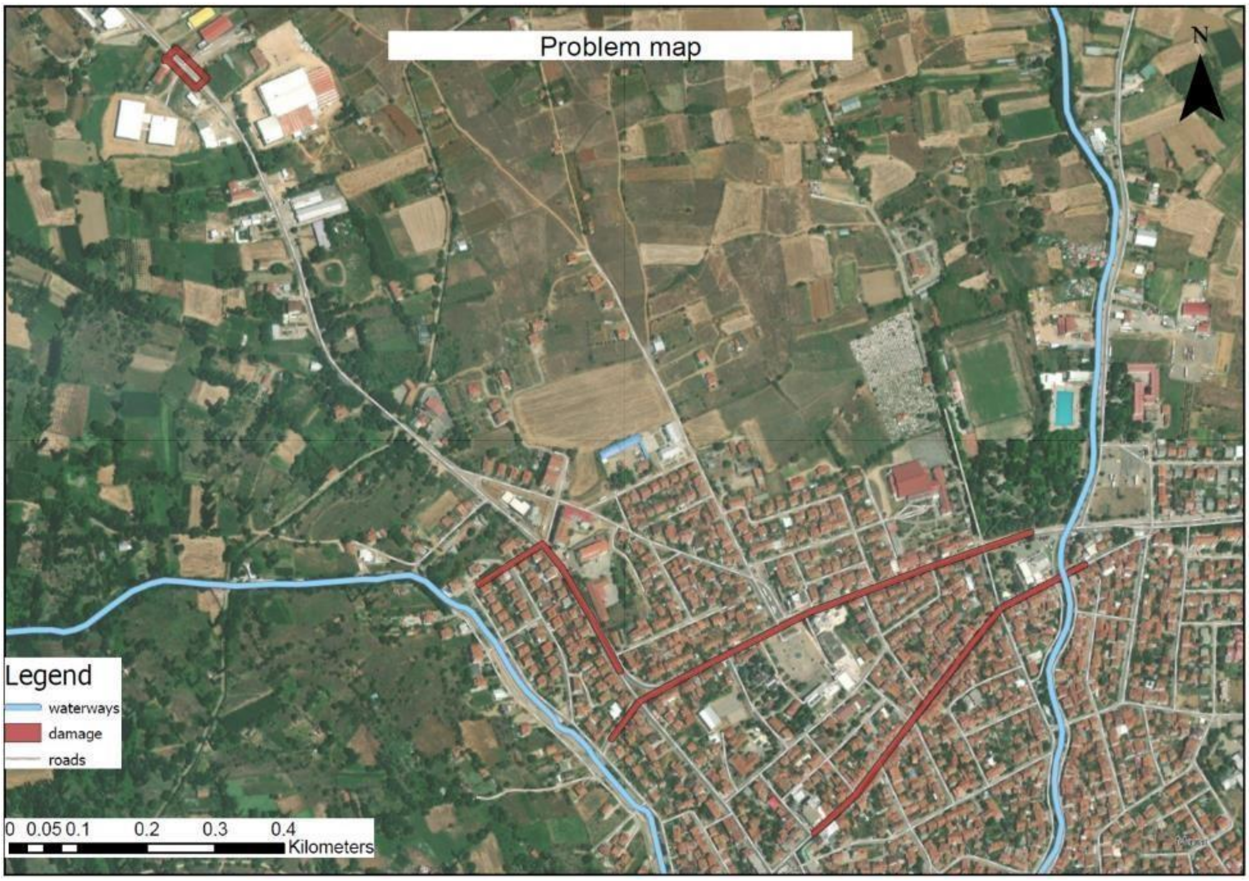
During intensive precipitation events, the drainage systems in an urban area may unable to handle the water volumes in case they fall beyond the range that the drainage systems were designed to handle. Or, as general as the main characteristics of the cloudburst events that there is no any infiltration, there is only simple runoff that flows where it finds it way. It behaves as an overland flow, ~~Instead, the water will start to free flow on any kind of paved surface (). Without the ability either to drain the water away in pipes and sewers, or to infiltrate it into the ground, the surface runoff will reach unsustainable volumes, causing, potentially, massive damage to key technical systems, or inhabitants in the cities~~.

Based on Oscar (2016), the types of damages that arise from an extreme cloudburst event can be grouped by two attributions:

- Direct and indirect
- Tangible and intangible

A *direct consequence* is defined as a direct implication of water coming in physical contact with an object, such as short circuiting an electrical cabinet and causing a power failure. Similarly, a tangible damage is a damage that can be connected to a direct consequence and thus can be measured in economic terms.

Due to its location, the settlement of Vinica was significantly exposed to flash floods. As it is known and registered from the past events, the settlement's drainage system was significantly damaged during previous rainfall events. Significant flooding occured on the storm water drainage network in the area of the R1304 main road and in the industrial area on the outskirts of the city. The rainwater accumulated in the industrial area is transported by a 100 m long 30 cm diameter pipe to the nearby creek. The slope of this pipe is low, that can affect backwater effect on the network. Flooding is regular in the area, and the water level can



17. Figure: Damaged drainage system elements

reach 30-50 cm depth.

The following pictures were taken during the field visit in 2022 summer, and it can be seen, that the rainwater drainage network of the area is in need of maintenance. Part of the trench is filled with sediment, so it can’t drain the rainwater efficiently. The parts, that are not burried, the drainage ditches were overgrown with plants, so the drainage of rainwater is not solved in the area. The water sinks are clogged with grass and garbage, and the culverts are also neglected.

18. Figure: Photo of the affected area

19. Figure: Clogged gully pot

20. Figure: Unusable drainage element

The other group are the *indirect consequences and intangible damages*. The key difference is that this type of effects is difficult to measure in economic terms and are not necessarily a direct consequence of a cloudburst. Such as, the feeling of stress and anxiety. These categories are defined in a matrix. An example of such a matrix is shown in 1. Table.

1. Table Types of loss from floods (Disaster loss assessment guidelines, 2002)

	Direct loss	**Indirect loss**
Tangible	Buildings and contents, vehicles, livestock, crops, infrastructure	Disruption to transport, loss of value added in commerce and business interruption, legal costs associated with lawsuits
Intangible	Lives and injuries, loss of memorabilia, damage to cultural or heritage sites, ecological damage	Stress and anxiety, disruption to living, loss of community, loss of cultural and environmental sites, ecosystem resource loss

Tangible - Direct

Flooding of urban areas can result in significant damage to private property, including homes and businesses. The free-flowing water will enter buildings and other areas in the city, causing serious damages. Losses occur due to damage to both the structure and contents of buildings. In this case, Vinica is of particular importance for its cultural value. In the territory of Vinica, there are several archaeological sites (several settlements from medieval and Roman times, fortress from late ancient times, necropolis from the Iron Age), which makes it particularly important to develop adaptation strategies and implement actions against extreme rainfall events.

Tangible - Indirect

As communication links and infrastructure such as power plants, roads and bridges are damaged and disrupted, some economic activities may come to a standstill, people are forced to leave their homes and normal life is disrupted. Disruption to industry can lead to loss of livelihoods. Reduction in purchasing power and loss of land value in the floodplains can leave communities economically vulnerable. In the case of Vinica, this category is a priority because one of the major activities in the town is agriculture. Farmers engage in the production of rice, which is typical in the basin where Vinica is located. Textile and wood furniture production industries are also important.

Intangible - Direct

In many natural systems, floods play an important role in maintaining key ecosystem functions and biodiversity. They link the river with the land surrounding it, recharge groundwater systems, fill wetlands, increase the connectivity between aquatic habitats. These natural systems are resilient to the effects of all **but the largest floods**. This is also an important factor in the area of Vinica because there are several rivers that flow through the territory, like the Vinička, the Gradečka and the Osojnica. Furthermore, flash floods are extremely difficult to predict, which makes them extremely dangerous to human life.

Intangible - Indirect

Floods can also traumatise victims and their families for long periods of time. The loss of loved ones has deep impacts, especially on children. Displacement from one's home, loss of property and disruption to business and social affairs can cause continuing stress. For some people the psychological impacts can be long lasting.

Overall, as minor cloudburst events become more frequent and extreme events more severe, cities will need to rapidly transform their stormwater drainage and interdependent systems, and the knowledge systems that guide their infrastructure decisions and policy to protect against these extreme rainfall events.

7. Cloudburst impact analysis (hydrological analyses)

The largest watercourse near the settlement is the Bregalnica river, which continues in a northerly direction. The total length of the Bregalnica River, which originates from the Malesev Mountains, is ~211 km. The river is one of the major sources of water in Eastern Macedonia. There are several reservoirs on the river, e.g. Kalimanci, Ratevo. The river carries the maximum water flow in April, while the smallest water flow is in September (http://www.bregalnicancp.mk/). Vinica stream runs along the center of the Vinica settlement in a northerly direction. The stream bed is in relatively good condition. The stream collects significant amount of water during rainy periods. In the western part of the settlement

Gradechka river can be found, which flows in northwest direction. Following the slopes of the Plačkovica mountain, the river passes through the village of Gradec and the town of Vinica. Gradechka flows into Bregalnica river north of the village of Vinica. The river is approximately 18 km long and its catchment area is 55 km2. The discharge of the river is quite varying.

7.1 Methodology applied for the hydrological analyses of cloudburst event

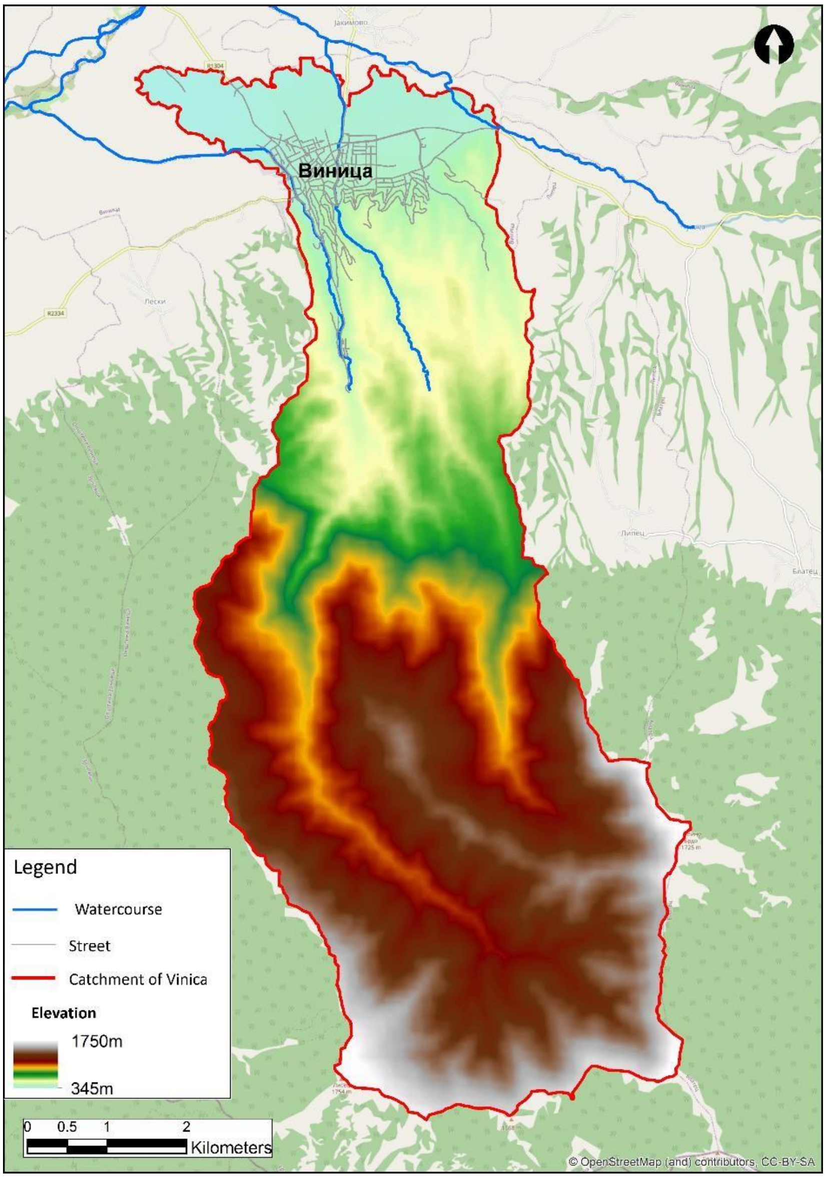
To understand the system main characteristic basic steps are down as described below. Such as catchment delineation to understand from where the water flows to the settlement and how big the contributing catchment, land cover and flow path to understand from where the water could move and how the movement could be slowed down by different land cover types.

Catchment delineation

The catchment area was delineated using SRTM DTM (Digital Terrain Model), the resolution of which is ~30m. The area of the watershed is 49.5 km2. The accuracy of the catchment area depends significantly on the resolution of the terrain model.

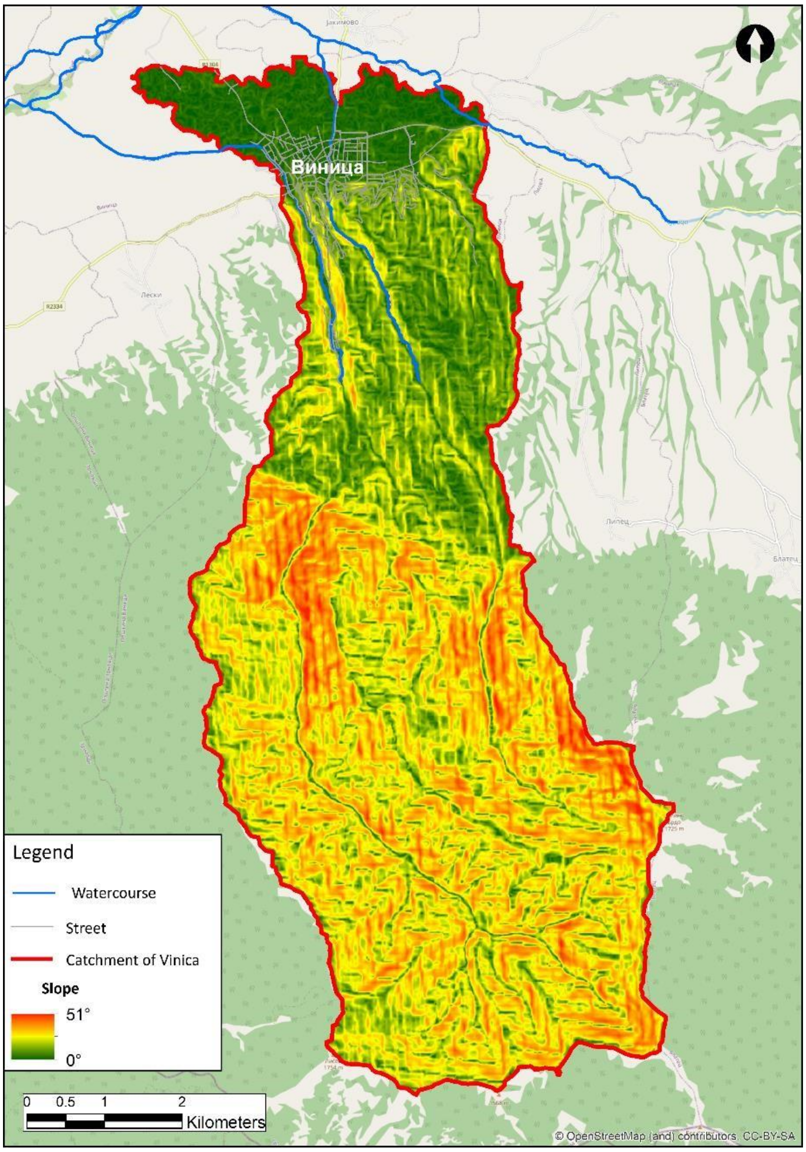
21. Figure: Catchment of Vinica

The highest point of the catchment is 1750m, and the lowest point is 345m above sea level. The high points are located in the area of Plačkovica mountain in the catchment area of the river basin, the village of Vinica is located in the lower area of the catchment. There are significant level differences in the area.



22. Figure: Terrain of the catchment

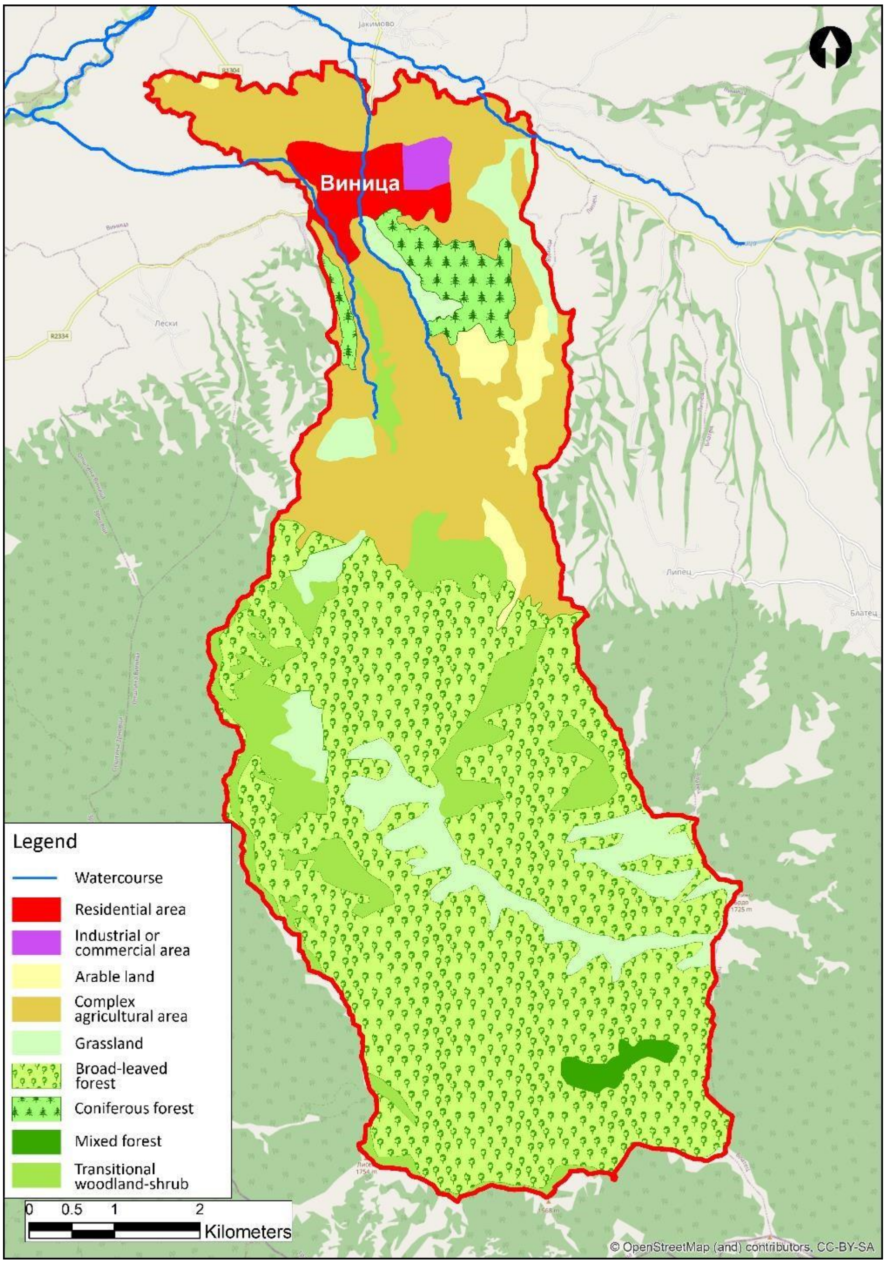
The following figure shows the slopes of the catchment. Steep slopes are mainly situated at the southern part of the catchment. Declivous slopes are located in and around the city of Vinica, pointing out on the serious relief of the terrain.



23. Figure: Slopes of the catchment

Land cover

Land cover is important to study in order to get better picture for runoff potentials from the upstream area. Land use is diverse in the study area. At the higher points of the catchment, there are typically forests, and in the areas close to the city, mainly agricultural lands and urban areas can be found.



24. Figure: Land use map

Flow Paths

Flow paths show how the rainwater moves towards the settlement Vinica from the mountain. Definition of flow paths are very important for the construction of the hydrodynamic model. The rainfall runoff routes were defined based on the terrain model.

25. Figure: Flow paths

Applied software for analyzes

Flood screener

Flood screener is a device developed by DHI, which can be used to define flow paths and areas exposed to inundations. Using the DTM (Digital Terrain Model), the program can simulate the flood depths of different areas. The program uses the features of the terrain to evaluate the effects of different precipitation events.

MIKE +

Mike+ is dedicated for urban systems, aimed at analyzing the stormwater drainage network. The software is developed for the integrated modelling of urban water processes.

The 'soul' of MIKE + 2022 modelling software is the so-called Pipe Flow Model, which is suitable for the simulation of unsteady flows in a pipe network, both for free surface and pressurized flows. The basis of the calculations is the implicit solution of the Saint-Venant system of equations (1-D, free surface) with finite differences. This algorithm is efficient and capable of sufficiently accurate calculations for the calculation of networks consisting of many connected sections.

The applied numerical algorithm is used to describe the flow of fluids that can be considered homogeneous in the vertical direction. This condition is fulfilled in a very wide range of pipe diameters, both at the free surface and in cases where it becomes under pressure due to backwater effect. Hydrodynamic calculations can also be performed on channels with prismatic beds. The same numerical scheme handles flowing and rushing states, automatically adapting to current local conditions. The downstream reactions and spills can also be accurately calculated in this way. The computability of pressurized flows is handled by the Preissmann slot. It is means a vertical extension of a closed tube with a very narrow gap. Since free surface and pressurized flow are calculated by the same algorithm, the calculation of transition processes will be numerically stable.

The entire system of non-linear equations can be handled either automatically or with user-specified boundary conditions. In addition, both the fully dynamic and the simplified description can be used.

By modelling physical systems, it becomes possible to analyze the operation of already existing or planned networks.

In the MIKE+ Pipe Flow Model, the calculation of unsteady flows in pipes is possible using the dynamic flood wave, for which we need to solve the 'Saint Venant' equations.

Where:

- The liquid is incompressible and homogeneous, i.e. its density does not change;

- The slope of the bottom is small, so the cosine of the angle with the vertical can be assumed to be 1.
- The wavelengths are large compared to the water depth. This ensures that the flow can be considered parallel to the bottom, i.e. the vertical acceleration and the vertical change of the hydrostatic pressure are negligible
- The flow is laminar.

The general form of the equations is as follows:

Continuity equation

$$\frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} = 0$$

Momentum equation

$$\frac{\partial Q}{\partial t} + \frac{\partial \left(\alpha \frac{Q^2}{A}\right)}{\partial x} + gA\frac{\partial y}{\partial x} + gAI_f = gAI_0$$

where:

Q = flow, [m3s-1]

THE = flow cross section, [m2]

y = water depth, [m]

g = gravity acceleration, [ms-2] *x* = distance in the flow direction, [m] *t* = time, [s] *a* = is the inequality factor of the velocity distribution

I0 = slope of bottom

If = the slope of the energy grade line

The derivation of the equations can be found in countless technical literature. General descriptive equations are non-linear, hyperbolic, partial differential equations. Their solution gives the flow characteristics (changes in water depth and water flow) in a pipe or ditch according to the specified perimeter and initial conditions.

Their analytical solution is only possible in special cases, which have just small practical importance, therefore, for wide applicability, we must choose numerical solutions.

7.2 Type of analyses executed

7.3 Flow simulation model

Used data, applied methodology

During the construction of the model, we processed data from various sources. The completed model is based on the digital terrain model, which is a NASA SRTM product.

With the help of the digital terrain model, we determined the different flow pathes, which are included in the model as a network. The higher the resolution of the terrain model, the more accurate the model provides. In this case, the resolution of the terrain model is ~30m. The precipitation data for the various analyzes were taken based on the results of Prof. Zivko and Blagoja Todorovski, that is described in the document "Intensive Rainfall in the Republic of Macedonia". The flooding of areas in the area of the city of Vinica can be determined by applying rains with different return periods.

For the construction of the "network", in addition to the drainage lines, we also took into account the roads and the already existing rainwater drainage network. This network has been heavily damaged in the past. Drawings and previous damage information provided by GTI – GEOTEHNICKI INZENERING Limited Liability Company.

Data on land use were derived from the CORINE Land Cover database. Incorporating land use into the model is important because different land uses have different infiltration rates, roughness and other characteristics that can modify the rate and amount of rainfall runoff.

The watercourses and streets in the settlement were downloaded from the OpenStreetMap interface.

In addition, we also used a field survey prepared by DHI Hungary Kft.

The process of model building

The aim of building a simulation model is to create a model depicting reality by applying different steps. MIKE+ enables the simulation of different flows and water levels in rainwater drainage networks and natural drainage routes. The model building process consists of the following steps:

Review and evaluation of available data and documents

Defining system simplification

Data collection (existing network, flow paths)

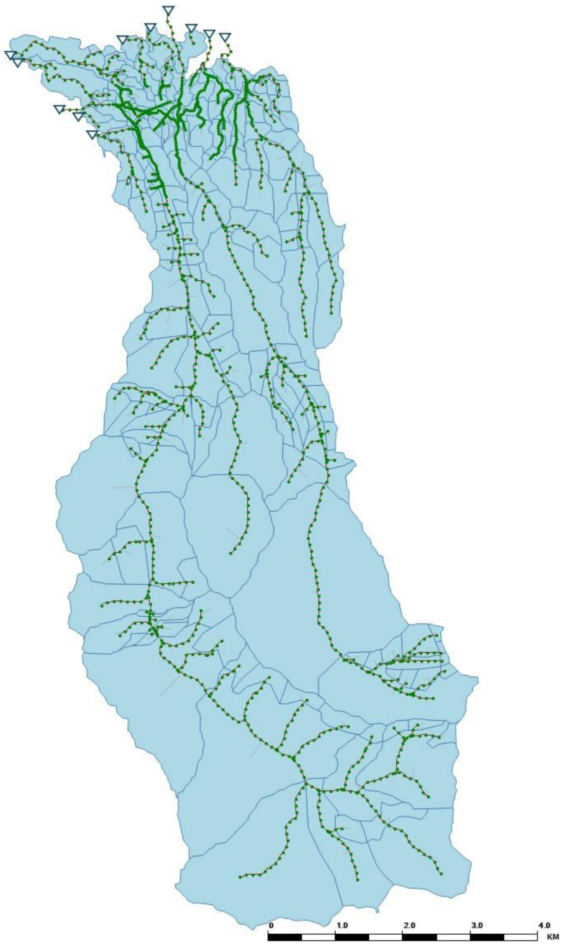
Model building

About the simulation model

During the construction of the model, the Rainfall Runoff of the water catchments and the Hydrodynamic module of the rainwater drainage network were used. The Rainfall Runoff module is suitable for simulating hydrological processes in the catchment area. The Hydrodynamic module is suitable for the simulation of flows in the collection network.

The MIKE + modelling software includes several different surface runoff models. The UHM (Unit Hydrograph Method) runoff type was used in the project. The UHM is a simple linear surface runoff model that is suitable for determining the runoff from rainfall events in the catchments. The UHM model is excellent in areas where no or only a small amount of data is available. The UHM model calculates rainfall runoff assuming that infiltration losses can be described as a fixed initial and permanent loss or proportional loss (rational method) or the US Soil Conservation Service (SCS) method, or the generalized SCS method. During the construction of the model, we needed the CN (Curve Number) numbers, which are empirical parameters for the calculation of hydrological flows.

The runoff in the field was mapped using the runoff paths, and the currently existing rainwater drainage network is also part of the model. The following figure shows the structure of the system:



26. Figure: Topology of Mike+ model, where the picture shows the subcatchments that are contributing to runoff and main flow path lines

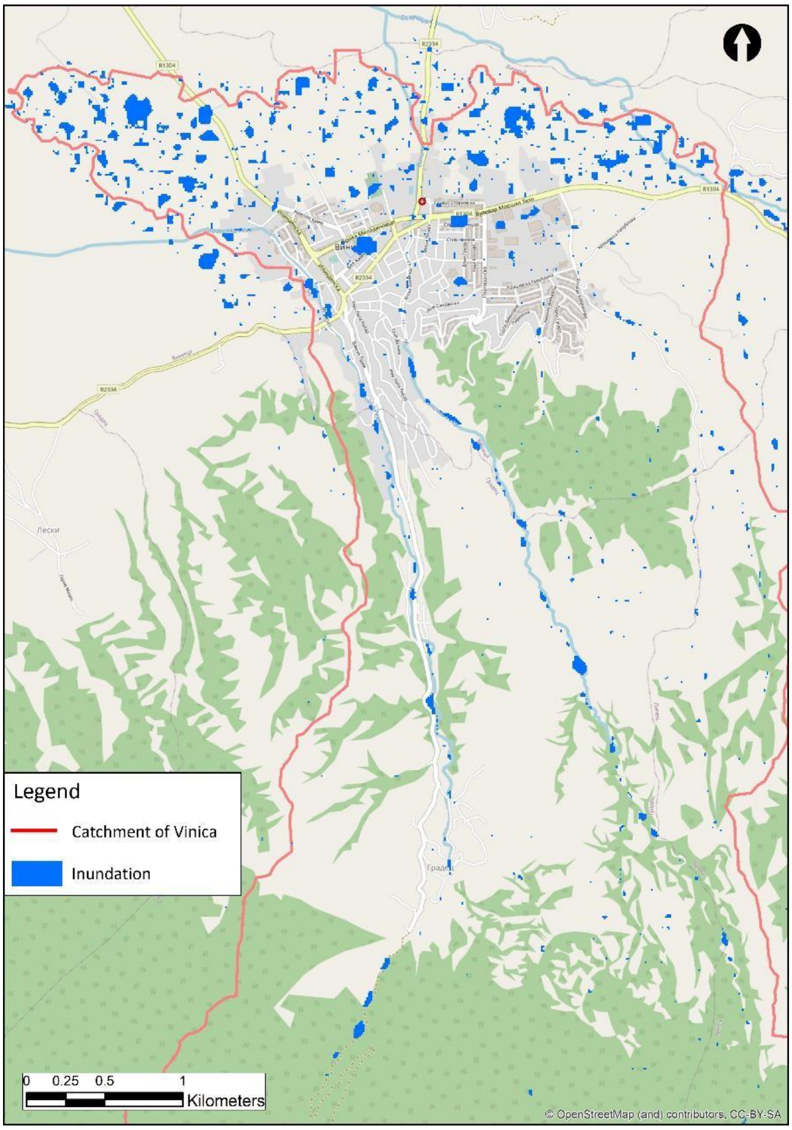
Results

Screening of impacts of (Inundations by) heavy rainfall events

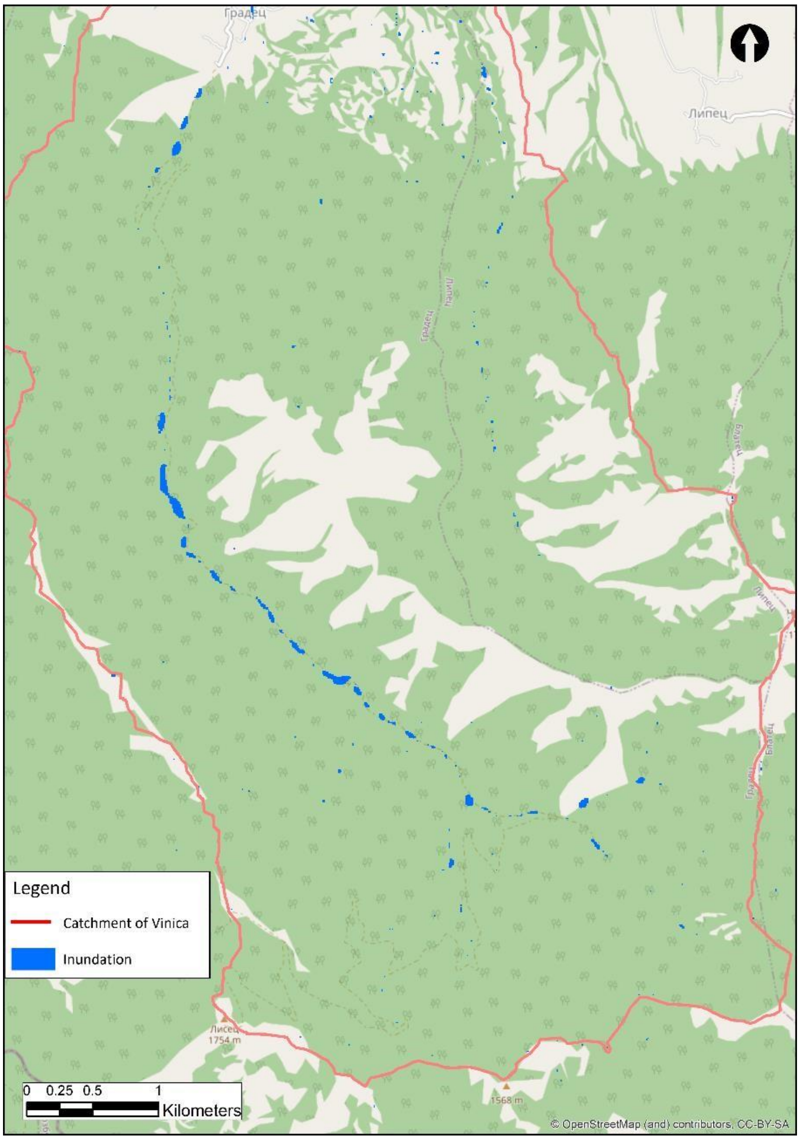
Resolution of the topography model used for the inundation study is defining the accuracy of the results of model simulation. The resolution of the starting DTM is 1 arc seconds (approx. 30m) in size, so the accuracy of the results can't be better. This level of detail is suitable for obtaining a comprehensive picture on a settlement scale about runoff conditions and potentially flooded areas. However, in reality, many other influencing factors can modify the runoff. For example, if there is a drainage trench or canal in the area, the resolution of 30m is not enough to include the object in the terrain model, but in reality this object drains water away from the area.

It is also important to mention that the analysis does not take into account infiltration. It is due to the fact that simulation is made for the kind of the rain which considered as cloudburst, where the rain event occurs after a dry period. The rain events most critical for the city do occur during summer. This is the period when there is no effective infiltration, simple the runoff that is to be considered. The aim of this analysis is to create a comprehensive picture of the flow conditions and the delineation of areas with a risk of flooding occurring in Vinica settlement.

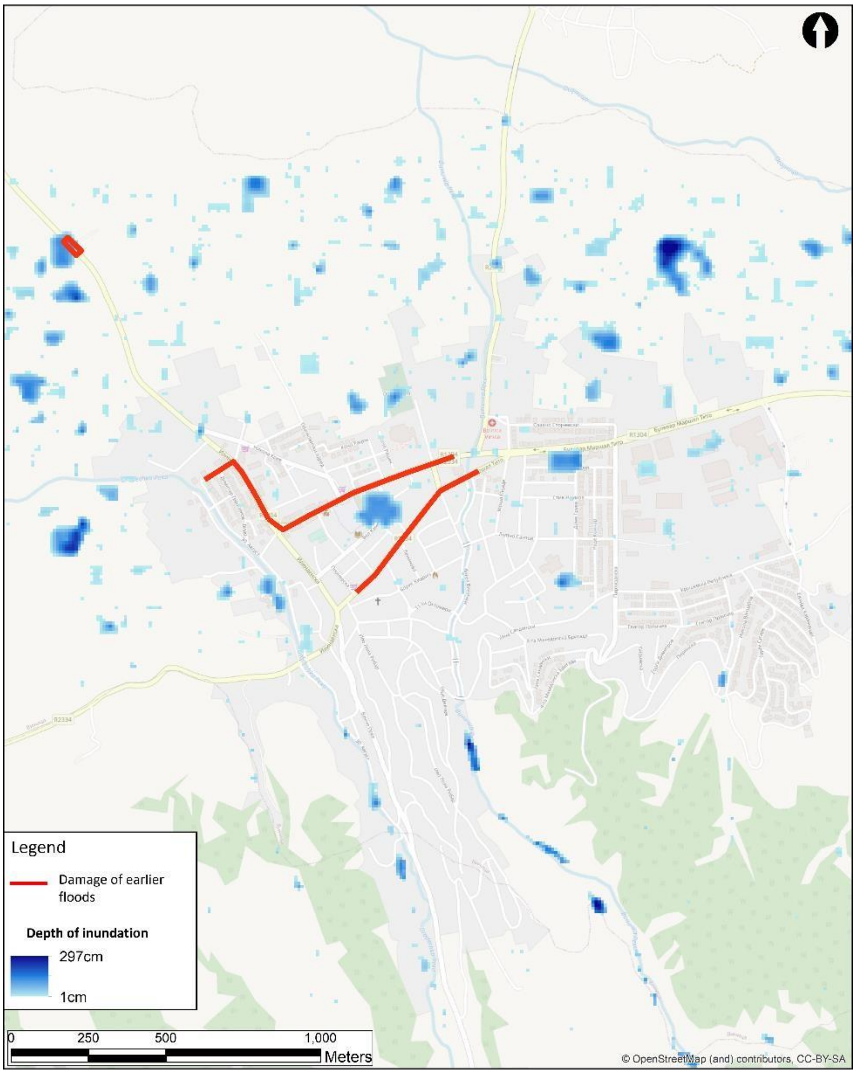
The following figures show where inundations can be expected based on the topography model. It can be seen, that larger-scale flooding is expected along the watercourses and in the area north of the city of Vinica. A significant part of the flooding affects industrial areas and residential areas.



27. Figure: Possible inundations on the northern part of the catchment (based on the terrain model)



28. Figure: Possible inundations on the southern part of the catchment (based on the terrain model)

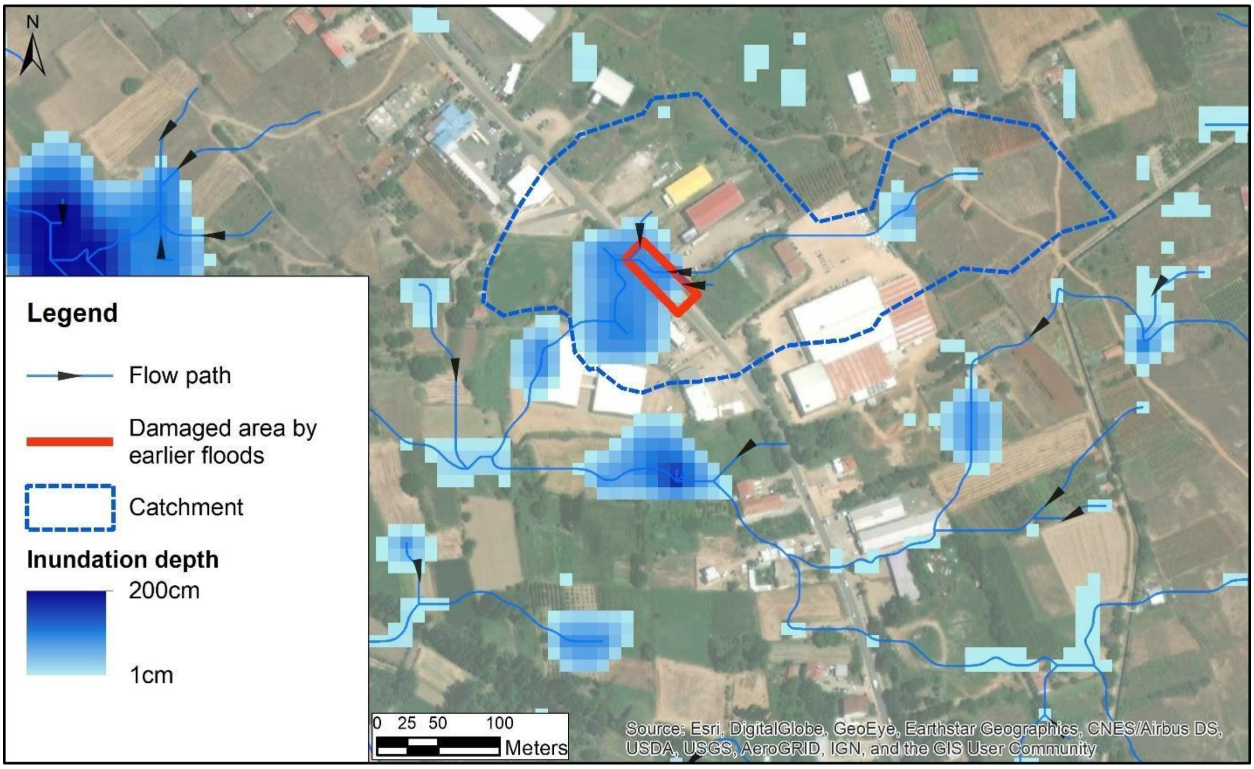


29. Figure: Water depths of the inundations

With the help of Flood Screener analyses**, we detected the areas (exact locations) that are exposed to flash floods.** These areas are mainly in residential and industrial/commercial areas. These areas lie at low points.

A particular focus area is located by the R1304 main road, as critical events happened in the past there. In recent years heavy rainfall events caused big problems there. Using the method presented here, we examined from where large amount of rain may accumulate on the site and how and how much water that could accumulate.

Based on the information provided by the local government the **problem is typically experienced in the summer, during very intense heavy rains.**



30. Figure: Possible inundations by R1304 main road

Result of flood screening analyses shows there are three large areas exposed to inundation and some smaller ones. The analyses also highlighted the previously affected area by R1304 main road. Special attention should be paid in designing that areas, but in the way and by using numbers for design that are presented in next chapters.

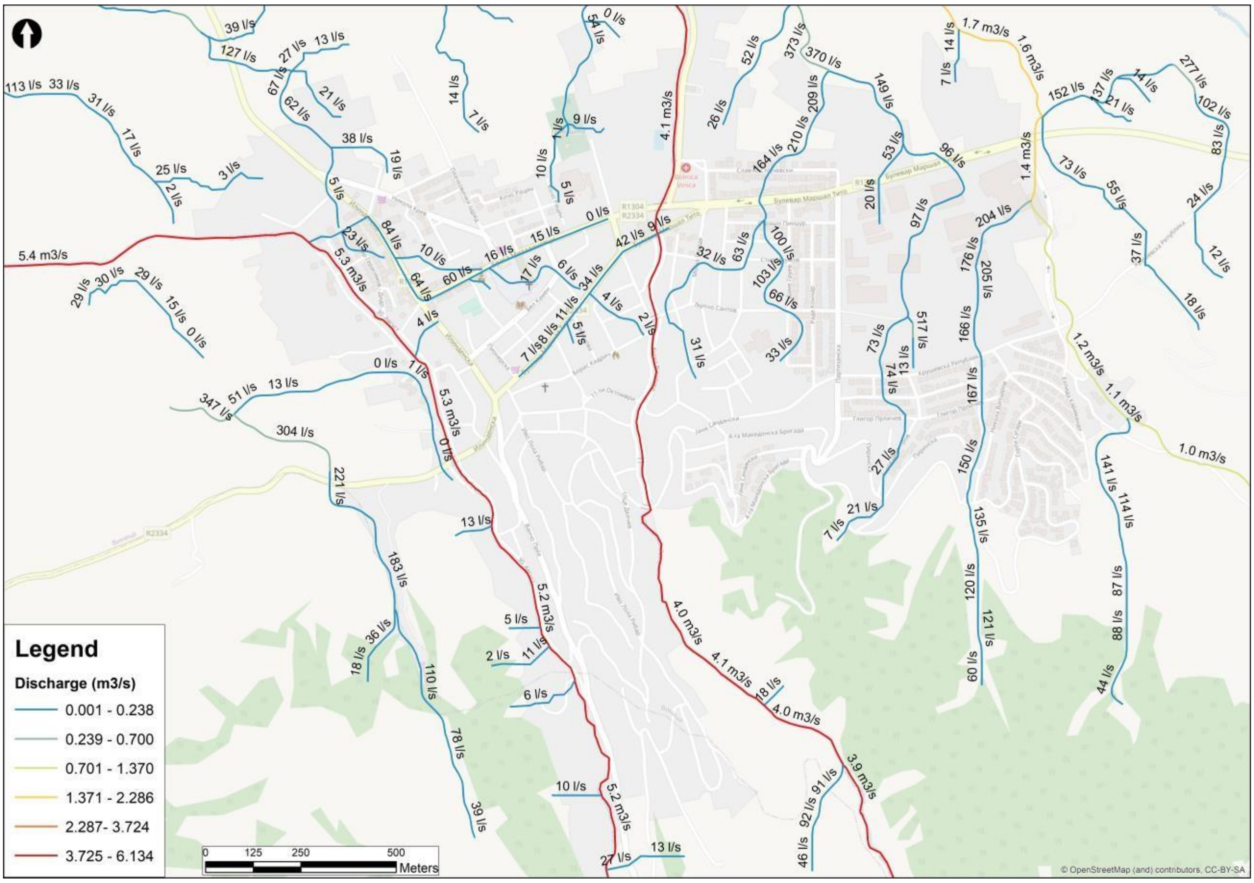
This preliminary calculation pointed out to the fact experienced, the location under water stress(urban flooding) is validated. Hereby we present here for comparison the evaluation of former rainfall events: the locations (marked with blue on the next two figures).

Critical point	Road to Kochani	Brakia Miladinovi	Ilindenska street

31. Figure identified location under urban flooding stress

7.4 Results of simulation model

Different rainfall events were defined (and used as so called boundary conditions in simulation model) in different scenarios to be able to analyse what happens after different type of rain events in the city built up areas. 12hour long and 24 hour long rainfalls were analysed with 10 and 20% probability. **The aim was to define the runoff discharges on the flow paths to have detailed information for the design of future stormwater management system**. As different rainfall events have different effects on the network it was essential to analyse them separately. Next image shows the results of 12 hour long rain event with 20 percent probability of occurrence.

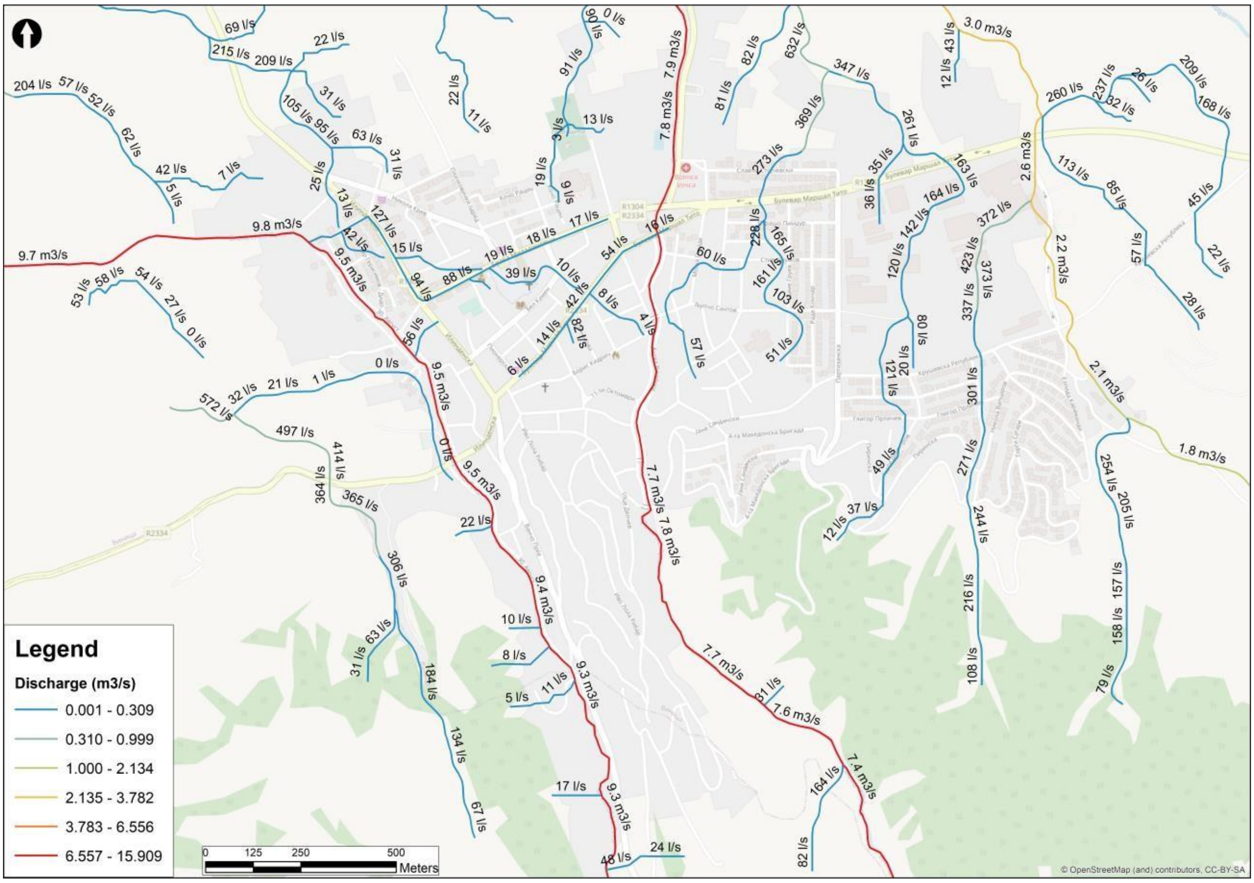


32. Figure: 12 hour long 20% probability rainfall event's maximum discharges

Maximum discharge in the settlement was about 5.3m3/s during the simulation. In fact this discharge was in Gradechka river. In Vinicka river max discharge was about 4.1m3/s. In the residential areas maximums were around 0.15m3/s.

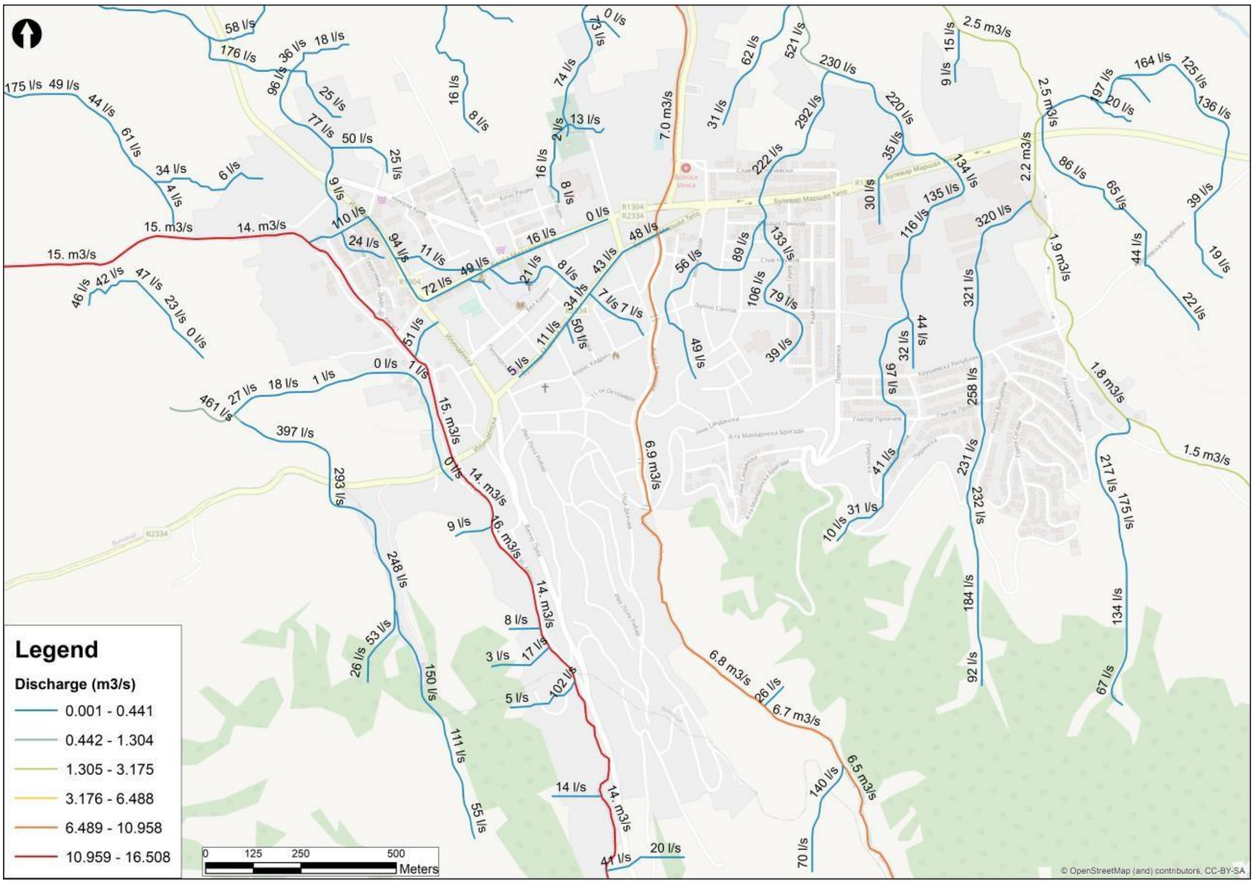
12 hour long rain event with 10% probability of occurrence effects higher discharges. In

Gradecka river values exceed 9m3/s, in Vinica the discharge is approximately 7.7m3/s. By the previously damaged drainage network there are parts where flow can reach 127l/s based on the model.



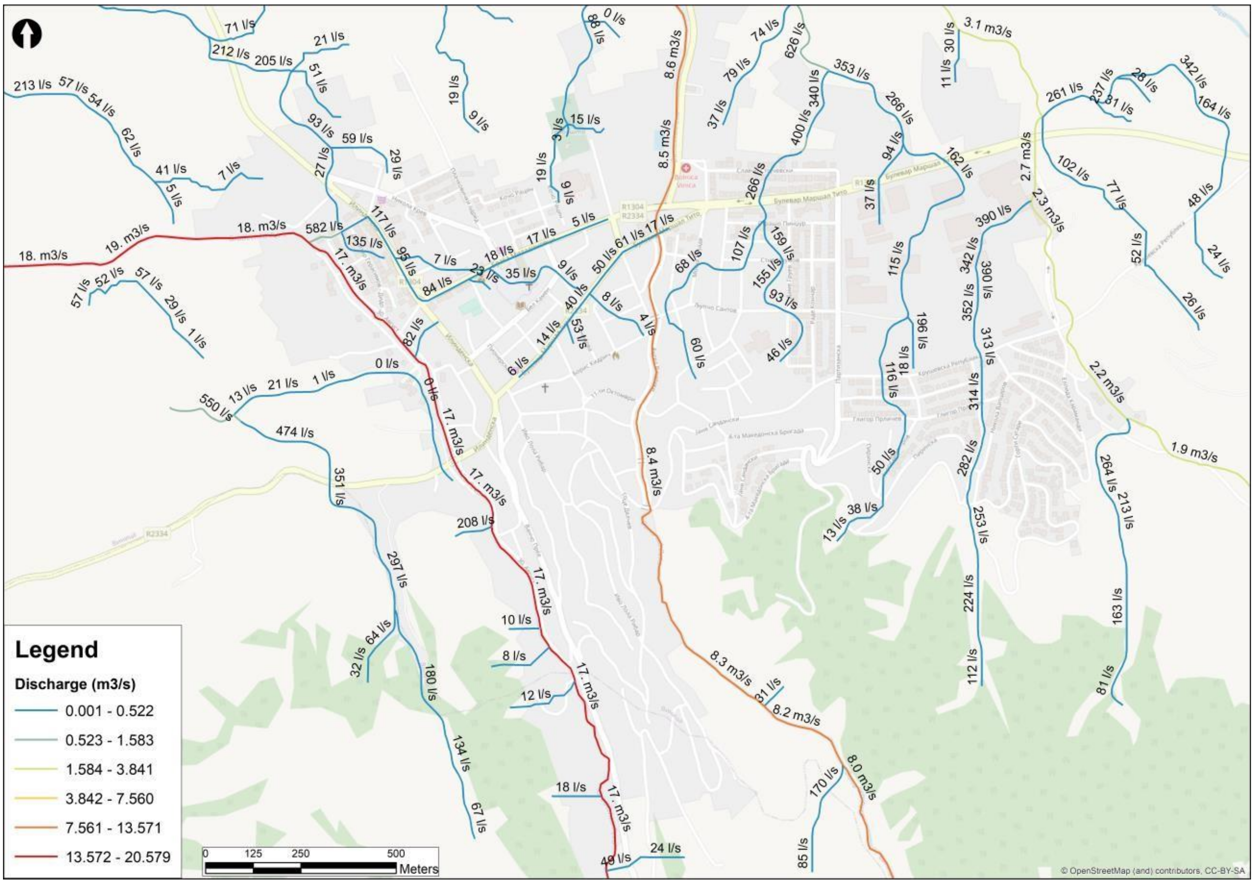
33. Figure: 12 hour long 10% probability rainfall event's maximum discharges

Longer rain events generates higher discharges mainly on flow paths having large subcatchments. Thus the two river and flow routes on the eastern part of the model area have significantly bigger discharge values. In the central part of the settlement discharges don't change significantly.



34. Figure: 24 hour long 20% probability rainfall event's maximum discharges

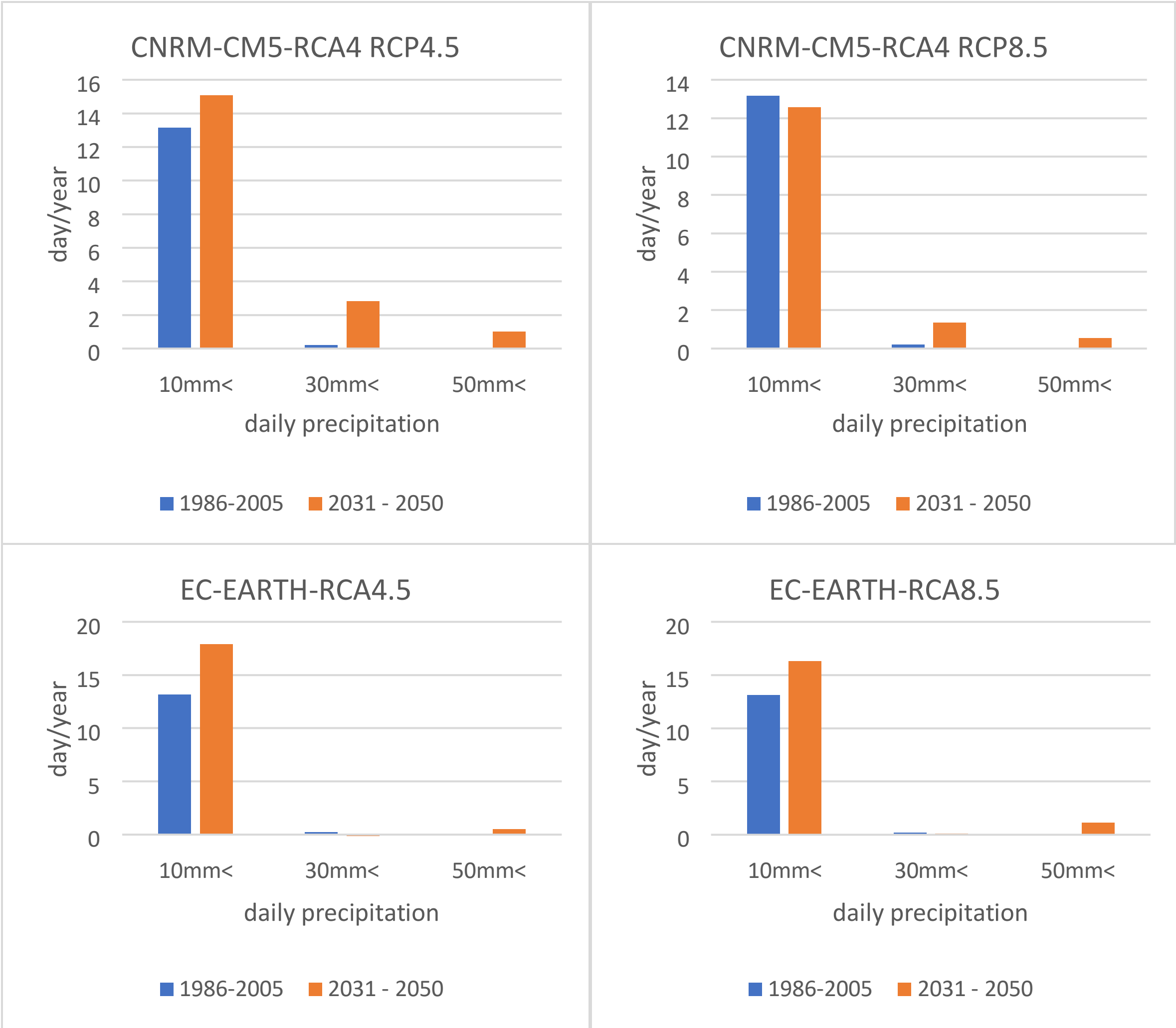
Simulation results show about 14m3/s maximum discharge in Gradechka river during 20% probability event and 17m3/s during 10% probability event. In Vinicka river the 20% return period can effect 7m3/s while the rarer event cause 8.5m3/s discharges



35. Figure: 24 hour long 10% probability rainfall event's maximum discharges

7.4 Predicted changes of different precipitation amounts (climate change impact)

In the framework of the project an analyses made analyses related to the expected changes of the climate. By using several climate change models forecast for expected rainfall sum is defined for the city that we show in below picture:



36. Figure Climate change model resulted daily rainfall calculated changes till 2050

The diagrams on Figure 19 show that almost all scenarios predict higher daily maximums. The occurrence of extreme daily precipitation will be more frequent in the future, so *the rainfall analyses results described in this study, are likely to be associated with a higher probability* in the future.

8. About the adaptation capacity

"Adaptation is adjustment in ecological, social, or economic systems in response to actual or expected climatic stimuli and their effects or impacts. This term refers to changes in processes, practices, or structures to moderate or offset potential damages or to take advantage of opportunities associated with changes in climate. It involves adjustments to reduce the vulnerability of communities, regions, or activities to climatic change and variability "Adaptation to climate change can be viewed as taking advantage of opportunities. The determinants of adaptive capacity include a variety of systems, sectors and location specific characteristics that are path dependent. "Adaptation also is considered an important response option or s t r a t e g y, along with mitigation (Fankhauser, 1996; Smith, 1996; Pielke, 1998; Kane and Shogren, 2000) " Creating the adaptation scenarios means preparation of a set of possible scenarios of consecutive adaptation actions regarding **control measures** and **adaptation measures**. *Control measures* consist of flood water transfer, flood proofing of buildings and technical infrastructure, drainage and pumping systems, flood water storage and channel conveyance and capacity. *Adaptation measures* include land use and river corridor management. Land use management consists of spatial planning, an infrastructure, and a categorization of land cover, while river corridor management includes the recognition of the interdependencies of river and streams and adjacent floodplain and wetland areas and of upstream and downstream areas (Doroszkiewicz and Romanowicz, 2017).

Considering the importance of the **geographical and social characteristics in relation to flash floods**, it can be concluded that **Vinica is a vulnerable area**. The harmful effects of flash floods are influenced by mainly the topography, vegetation, condition and functionality of the existing drainage and lack of water retention systems, and basically the location of the settlement. Vinica is spread over a relatively small area under relatively high mountains and steep slopes and several smaller rivers (with permanent or temporary discharge) flow through the area. It follows that the local features are especially favourable for flash flood events, significantly increasing the risk the town is posed. Besides, Vinica is an important industrial and agricultural centre and has considerable cultural value because of the archaeological sites.

8.1.1. Available capacities for flash flood protection in Vinica

The adaptive capacity of a given settlement to the effects of flash floods is a complex issue, but it can be described by the following aspects [15 – climate-adapt.eea]:

- The construction and condition of the **drainage infrastructure**;
- way of **land use** and the **covering**;
- existence of the **forecasting- and warning system**;
- **disaster management**;
- **financial opportunities**.

According to our personal experiences in Vinica, as well as through the confirmation of Macedonian experts, the **drainage infrastructure has severe shortages.** In most streets, even on main roads, the drainage of sudden downpours is unsolved (37. Figure).

37. *Figure: Shortages of the drainage infrastructure of Vinica experienced in the study visit. Source: Selfmade pictures*

The riverbeds, typically seen with extremely low water levels or dried up in the summer, and are not maintained (dredging, vegetation etc.) properly (38. Figure), which is clearly prevents safe drainage of suddenly rushing water.

38. *Figure: It can be seen that neither the existing drainage system, nor the riverbeds, nor the canals have been cleaned in drainage system of Vinica. Source: Self-made pictures*

In the future, **climate and climate change should be always considered in the process of physical design of rainwater drainage systems** based on climatological data and climate projections to calculate the **capacity of the systems**.

In terms of **land use**, Vinica has relatively little tool available, considering that the town is already built on an area that is exposed to a significant flood risk. By increasing the green areas, flooding waves can be offset by infiltration, however, according to contractor's hydrological experts, that could only moderate the runoff-speed in Vinica, so **green infrastructure is not a final solution.**

One of the biggest obstacles in preparing against flash floods is that due to their sudden onset, it is difficult to predict exactly when the flood waves arrive. In the latest report of the Intergovernmental Panel on Climate Change (2022, hereinafter: IPCC) it is highlighted that **early warning systems have key importance** in estimating the increasingly frequent extreme precipitation events. According to North-Macedonian experts, **there is no warning system in Vinica** that can accurately indicate and spread the information about the arrival of flash flood events, so it is not possible to alert the population in case of an emergency.

Disaster management could best be assessed by the arrival time of firefighters and ambulances, but there is no information on this available for Vinica. There is a fire station located in the town, which can be beneficial in case of damage control, but the number of people working in disaster control is low, and due to the many elderly residents (MAKSTAT, 2022), high rate of population cannot be involved in damage control. **Vinica does not have a risk management plan** either, so the disaster management can only be performed within an unstructured framework. Although adaptability also includes means of damage control, it should be noted that interventions aimed at **prevention are more favourable to achieve climate resilience.**

The lack of **financial resources** is typical throughout North Macedonia, and the municipality of Vinica is no exception. Joining the EU as soon as possible could be a breakthrough in terms of receiving financial resources, however, the accession negotiations have not yet advanced enough to be relevant to discuss about. Other international sources can emerge (e.g., the **United Nations** and its sub-organisations), but according to experience, little of these flows into the country either. Vinica's climate strategy is just being elaborated by Macedonian experts (Climate Change Strategy of Vinica Municipality, 2015-2025 – *draft version*), that was supported by the **United States Agency for International Development** (hereinafter: *USAID*) with the development of a methodology for North-Macedonian municipalities to create climate strategies. USAID could be another potential source but not for real investments, only for planning projects. Generally, the **financial background necessary for adaptive capacity to flash flood hazard is not available** for Vinica.

8.2. Other climate impacts and adaptive capacity

Although the main goal of the project is analysing the risk of flash floods caused by cloudbursts, to integrate the strategic recommendations, it is necessary to consider other emerging climate impacts as well. It is important because **integrating climate issues into policy planning**

cannot be narrowed down to one single climate effect, since they are closely related to each other, so the solution may be common as well. According to our results based on climate model simulations, Vinica is not only affected by extreme precipitation events but **increasing temperature** (and its indirect effects) and **decreasing amount of annual and seasonal precipitation** are also a relevant risk so **climate resilient planning must be introduced** as soon as possible.

8.2.1. Vulnerability of Vinica to heat waves

Prolonged summer heat and **heat waves** are already a relevant problem in Vinica, however, **climate simulation-based calculations for the region showed an expected increase in the duration and frequency of heat waves** (Vukovic et. al., 2018). The large proportion of builtup areas absorb the incoming radiation on a higher rate than green areas result in a higher temperature in the cities than it would be in case of more natural surface. This temperature difference can make the cities especially hot during heat waves.

High temperatures can have impact on people's productivity reducing efficiency in working hours and are **harmful to human health** especially to vulnerable social groups: young children, the elderly, population with cardiovascular disease and people working outdoors. Consequently, heat waves could potentially increase the number of ambulance alerts and those in need of hospital care, increasing the burden on the city's health care system in the region (OECD, 2014). Vinica has a significant agricultural activity, which means **a high proportion of people working outdoor**, as well as a **high number of elderly people** lives in the town and its municipality, making the population more sensitive to this aspect of climate change (MAKSTAT, 2022).

Adaptability to heat waves can be understood along several dimensions:

- social and infrastructural conditions;
- economic development;
- installation method and land use.

Social resilience to heat waves can best be described by the **state of the health care system**. The **number of general practitioners** and **hospital beds per capita** are suitable indicators for measuring adaptive capacity. While the **number of family doctors is low in Vinica**, the **number of hospital beds is relatively high for a settlement of this size** (MAKSTAT, 2022), so the town's adaptability shows a mixed picture regarding health care preparedness.

From an **economic point of view**, the financial resources of individuals, i.e., **the income per capita**, as well as the **financial resources available at the municipality** must be considered. In Vinica, capita per income is only slightly below the national average, but the lag is more outstanding in European scale. With low incomes, it is more difficult to implement individual solutions for dealing with the heat, such as installing air conditioning, modernizing dwellings and houses, etc. As already mentioned, the municipality of Vinica has few financial resources, so only **few incomes can be allocated for investments that can reduce the heat risk** (relocation of steam gates, building recreational spaces, development of a housing modernization program, etc.).

In terms of **land use**, the existence of green areas and the possibility of increasing them mean capacity for adaptation. It has already been mentioned that there are few green spaces in Vinica, and due to the lack of local government financial sources, there is a little chance of changing this. The **increase and correct design and ongoing maintenance of green areas would be particularly important**, since infiltration could also be increased this way, which is very important in case of heavy precipitation, promoting the need of a complex solution to the town's challenges against climate change.

8.2.2. Drought vulnerability of Vinica

Droughts are getting longer and more frequent in the Western Balkan Region and are also **typical for the region of Vinica** (Vukovic et. al., 2018). Persistent drought is not only affecting agricultural production negatively, but **urban water scarcity is also a risk**, so it is worth addressing the issue cumulatively regarding Vinica. This unfavourable phenomenon of cities is further exacerbated by the high proportion of paved surfaces, because this way most of the rainwater drains and less moisture enters the surface soil layer. (OECD, 2014).

There are many karsts water sources surrounding Vinica [16 – countryreports.org], which can be used for both drinking water and irrigation purposes. This means that under the current conditions the region can compensate for decrease in precipitation. However, according to our calculations, **the annual mean precipitation sum is expected to decrease** in the future by the end of the century. **This could affect water-bases negatively and may lead to a decrease in the currently existing water sources. It is important to approach the adaptation of water management strategy in an integrated way** with **building an infrastructure capable of drainage of stormwater, as well as storage of water** for drought periods. It is important to ensure that the provision of different local water needs does not cause conflicts in the future. To achieve this, a balance must be found between agricultural and urban water uses.

8.2.3. Forest fire risk of Vinica

Forest fires are common in the Western Balkans, including North Macedonia, especially during the summer drought (Vukovic et. al., 2018). Although, forest fires are not particularly frequent in the region of Vinica [17 – effis.jrc], but the risk may be intensifying as the frequency and length of drought periods increase. Vinica is surrounded by mountains with dense forests, which can further increase the spread when a wildfire develops. The infrastructural deficiencies and the difficult accessibility of the forests in the mountains reduce the possibilities of prevention and therefore the adaptive capacity to forest fires. Overall, forest fires are not considered as a major risk for Vinica currently, however, as drought increases in the region the risk is more relevant, which may be further increased by the weak ability to resilience, so it is worth addressing this issue as well.

9. Technical proposals for flash flood protection in Vinica

In this chapter, we make proposals for the development of a climate-resilient high-precipitation drainage system for Vinica. In addition to mentioning some specific technical solutions, we will also provide recommendations about how climate model simulation-based results can be incorporated into the strategic planning and implementation of climate resilient drainage system. Since the question of financing is crucial in such a resource-deficient region as Vinica, we also mention potential financial sources by analysing the possibility of obtaining funds.

9.1. Identification of drainage system to adapt

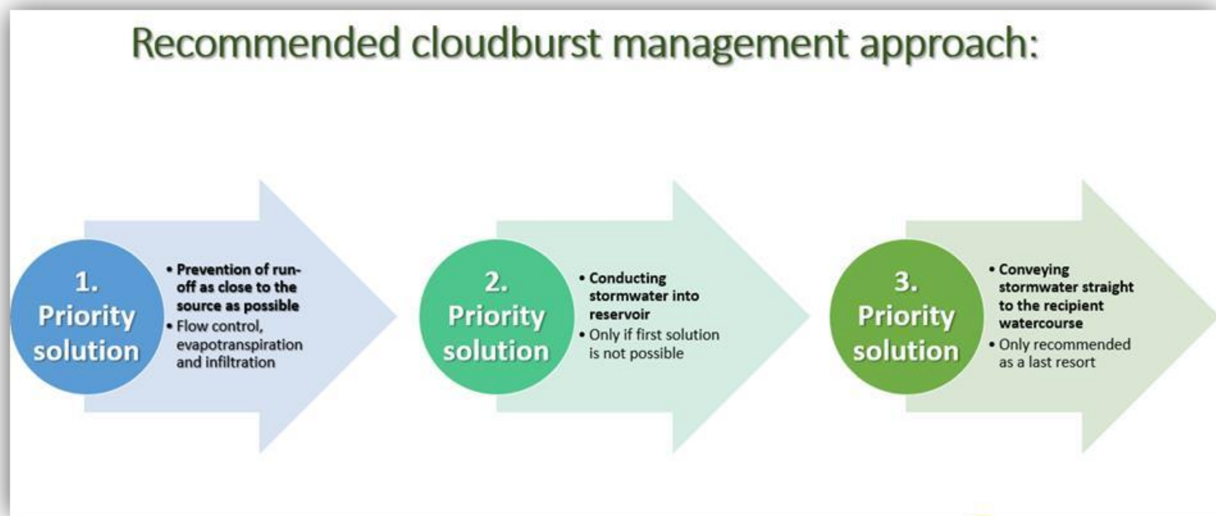
To decide which is the most efficient **technical solution for draining excess water** in an area, we need to know the **local conditions** about:

- water volume of heavy precipitation events;
- flow and conditions;
- slope conditions;
- settlement spatial structure and land use;
- financial capacities.

As the studies and our climate model analyses for the region indicate, the frequency of certain extreme precipitation events is increasing in the nearby Vinica, so it is not enough to base the design of the drainage system on existing experience, **excess water must be expected and calculated into designing.**

Due to the steep slopes surrounding Vinica, the velocity of the water flowing down is very high (see the results of in the hydrological analysis chapter). Since there is a low rate of green space in Vinica, the infiltration capacity of surface is very low, which means that floods may spread over a large area, causing more damage. Reducing surface runoff and increasing infiltration into the soil reduces the risk of erosion and flooding at certain rainfall events.

Although both the amount of water and the speed of the flow could be reduced by green areas, it is not possible to fully rely on green infrastructure [18 – epa.gov], so a complex solution is needed. To find the best solution the **prioritization of potential solutions is recommended** (39. Figure)



39. Figure: Prioritization of potential solutions for drainage of excess water. Source: Self-edited figure

Stopping the run-off water near the source is preferable, because in this way the amount of runoff water and the speed of runoff can be reduced. **Flow control** measurements are usually costly investments, and the geographical conditions of the region are not favourable either, so this solution **is less recommended** especially **due to the lack of financial sources. Preparing for the increasing risk of drought in the future, draining and keeping the water outside the territory of the settlement can be a favourable solution and is significantly more costeffective than the previous one.** Draining the water without utilization is only recommended if the available financial resources do not allow for the solutions that are more prioritized because **due to the expected increase in drought risk in the future, it is also necessary to think about retaining water.**

9.2. Recommendations on integrated stormwater management

Analysing the possible solutions, the following factors narrowed the concrete proposals:

- Green infrastructure is not feasible due to topographical conditions (steep hillsides) and the resulting high-speed runoff -> it could only reduce runoff speed;
- The capacity of reservoirs within the town is limited due to the lack of space -> storage of water is recommended in unincorporated areas (can be useful for agricultural activity);
- Due to lack of financial resources, low-cost and easy-to-implement solutions are needed.

Most likely solution regarding local conditions and financial situation is to construct drainage **ditch** (22. Figure) and storing excess water for periods of water scarcity in **rain reservoirs or wet pool** (23. Figure) in the periphery of Vinica.

40. *Figure: The most effective solution to drain excess water is covered ditch (above); The most costeffective solution is open ditch (below)*

41. *Figure: Storing excess water for droughts is feasible in wetlands (left) or in a pond (right)*

10. Integrating climate change issues into urban planning

Below are presented the strategic proposals that promote the inclusion of the issue of climate change in Vinica's policy and urban planning. In addition to concrete proposals, some theoretical approaches are also outlined.5.1 Strategic approach for stormwater management

One of the principles of effective flood protection is strategic approach for water management. For this to be realized, the method of the approach must be selected in terms of flash flood protection. According to the OECD (2014), the following four methods of flood protection are possible:

- **Prevention:** e.g., flood risk prevention through proper land use.
- **Preparation:** e.g., a real-time monitoring and forecasting- and warning system can be used to prepare for the expected danger in good time.
- **Protection:** e.g., coordinating the work of the authorities, including the protection of the population against floods and their consequences.
- **Reconstruction:** financial and material assistance to the inhabitants of the municipalities concerned

Protection and reconstruction are very important after a flood event has already occurred; however, these two approaches focus on damage control and preventive activities are favorable for achieving adequate adaptability. Since Vinica has already been built on an area that is exposed to significant risk, adaptation through land use is not possible, therefore **preparation is recommended for strategic approach of the town and municipality of Vinica.**

For preparation, a real-time monitoring and forecasting system is very useful to avoid as risk as possible before flash flood events, but for planning with a strategic approach, **it is necessary to know what can be expected in the medium- and long-term regarding climate change impacts** (in this case, heavy precipitation events). To integrate climate issues into planning, **climate model results must be integrated into planning** with preparing:

- **Calculations** for Vinica in short, medium- and long-term **based on climate model simulation** results,
- the *Cloudburst analysis* has been prepared during this project, which means that **our results can be incorporated into strategic documents** being prepared currently and in the future.
- regional **climate impact** assessments
- In addition to analysing expected changes in climate parameters, climate impact assessments also consider non-climatic factors and local conditions, so they also provide information on how sensitive the given area is to climatic factors, and on probability of occurrence of a given risk (for example: flash floods). Our analyses partly include considerations of sensitivity, but more detailed, preferably quantitativebased impact assessments should be elaborated which requires better data availability.
- and **vulnerability** assessments
- Vulnerability assessments are the most complex types of analysis related to climate change, as they include both climatic and non-climatic factors of the given area and socio-economic and technical factors too, providing information about adaptive

capacity. The present study mentions the main issues about climate adaptability of Vinica, but it is recommended to carry out detailed, quantitative analyses for vulnerability assessments and then involve them to strategic planning.

It is important to note that because of constantly renewed scientific results and methodologies, all kind of **climate-related assessments must be periodically overviewed** and based on the innovations, **climate protection goals and related strategic considerations are proposed to review.**

For horizontal climate-resilient planning, **climate change considerations must be integrated into strategies of all the relevant sectors** (e.g., agriculture, forestry, water management). With the support of North Macedonian experts and open-source information, we have identified the following relevant strategies that need to be reviewed and updated:

<u>Regional level:</u>

- Climate Change Strategy of Vinica (still *being prepared*) ○ As mentioned earlier, a climate strategy methodology was developed with the support of USAID, following which the development of the climate strategy for Vinica municipality began. For the strategy to be prepared based on up-to-date information, **it is recommended to include the results of the** *Cloudburst analysis* at the relevant points.
- Tourism Development Strategy for the Municipality of Vinica 2020-2024 [19 – eprints.ugd] ○ The **Strategy does not address climate change and its effects on the tourism sector** at all. Tourism is known to be **one of the most vulnerable sectors to climate change**, the increasing temperature, as well as more frequent extreme weather events (such as heavy precipitation) can change e.g., **the duration of the tourist season** and make **altered tourist seasons.** It is important for stakeholders to prepare for these impacts and adapt to the new seasonality trends, so **the Strategy should integrate climate considerations.** Climate change can affect local tourism (cloudbursts, temperature increase, drought), so our *Cloudburst analysis* **results can be included as relevant information.**

It has already been mentioned that there are only a few regional and settlement-level strategies available in the country, but there are some relevant ones. For example, Skopje's Urban Climate Strategy can provide a good example. It is a comprehensive document covering all relevant climate impacts and specific targets and measures for adaptation. For Vinica's regional climate strategy, it is worth reviewing this document in detail and considering using the relevant elements.

<u>Country level:</u>

Since the range of available regional and/or settlement-level strategies is extremely poor for Vinica, it is worth embedding local climate issues in policy documents at the national level:

❾ Horizontal strategies

- THIRD NATIONAL COMMUNICATION ON CLIMATE CHANGE, 2014 ○ North Macedonia has commitment to the UN to prepare **National Communication on Climate Change (NC)** documents at intervals. NC-s can be complied to a national climate strategy in the hierarchy of climate policy. The regional aspects are strongly lacking in the document, strengthening this, **the results for Vinica could be integrated as a good example.** Although **the latest communication document** will be adopted at the end of 2022, it **is worth considering its revision.**

-> Sectoral strategies

- STRATEGY FOR ENERGY DEVELOPMENT OF THE REPUBLIC OF NORTH MACEDONIA UP TO 2040 [20 – economy.gov.mk] ○ The energy sector faces many challenges because of climate change. In North Macedonia, both the increased demand for cooling due to rising temperatures and the effects of extreme weather events on infrastructure can also be a risk. As a result, it is essential to integrate strategic considerations into the preparation of the country's energy strategy. Since there is currently no energyrelated regional or settlement-level strategy, it is also necessary to present the different regional and local aspects here.
- NATIONAL FOOD SECURITY STRATEGY (STILL BEING DEVELOPED) [21 – fao.org] ○ Agriculture, and thus all segments of the food industry, is one of the most vulnerable sectors to climate change, so the topic of climate change is of prime importance in the strategies being prepared on the subject. Since there is currently no such strategy available for Vinica, it must be integrated into the national food safety strategy that is currently being prepared.
- DEFENCE STRATEGY OF THE REPUBLIC OF NORTH MACEDONIA, 2020 [22 – mod.gov.mk] ○ Defence policy has a key role in disaster management which is an important aspect of climate resilience especially regarding flash floods, therefore the integration of regional aspects is necessary to integrate into national policy.
- NATIONAL HEALTH STRATEGY IN NORTH MACEDONIA (still being developed) ○ The health effects of climate change are wide-ranging, especially relevant in the case of heat waves, but the infrastructure is also exposed to the effects of extreme weather events. In this regard, it is important to mention in the strategy most vulnerable regions to climate change and to promote their strategic preparation.
- NATIONAL EMPLOYMENT STRATEGY 2021-2027 (with Employment Action Plan 2021-2023) [23 – mtsp.gov.mk]

    ○ Climate change affects the labour market as well (see agricultural and tourism employees), so it is essential to consider climate aspects in the planning of labour market development.
- FISCAL STRATEGY OF THE REPUBLIC OF NORTH MACEDONIA (with prospects until 2026) [24 – finance.gov.mk] ○ In this case, the simulation results can assist the planning of the allocation of various financial resources for climate adaptation.

Although strategic documents at the regional level reflect much more on local problems and solutions, in the absence of these, embedding them in national strategies is also a good starting point. However, it is important to highlight that the regional aspects of national strategies can be effectively implemented if they stimulate the creation of regional strategies in the long term.

Technical guidelines available for Vinica should also be reviewed, and **climate model results must be incorporated into them**. In case of flash flood protection, it means that the **construction of drainage pipelines should be planned considering the expected increase in heavy rainfall** events for the future. It is important for introducing climate resilient planning and implementation for investments.

There are many ways of strategic integration, the most typical solutions can be found below (VÁTI Magyar Regionális Fejlesztési és Urbanisztikai Nonprofit Kft, 2011 – hereinafter: VÁTI, 2011):

- Integration implemented by partnership
    - accompanies each step of the planning process (situation analysis, setting goals, appointment of those responsible for implementation).
- Integration with horizontal objectives and tools
    - complementing climate-independent targets with climate-specific considerations as a horizontal principle.
- Integration with independent goals and tools o defining specifically adaptation (or mitigation) goals and tools.
- Planning accompanying procedures to ensure integration
    - procedures for examining the planning process; With suggestions, that can enrich the planning with climate change considerations before the plan is implemented.

10.1. Tools of implementation

The development of strategic aspects is the cornerstone of measures that pay off in the long term (e.g., the development of a drainage network based on climate model simulations), however, it is important that the goals are not only described "on paper" but are followed by actual interventions. For the reason, the **tools of achieving well-defined objectives must be clarified:**

- financial resources;
- responsibilities and tasks;
- principles to be followed.

Financing

USAID, and the **Western Balkans Green Centre** (supporter of this project) may provide support for the implementation of strategic planning and preparatory works (which have already been partially completed), and the **United Nations Development Program** (UNDP) could also be a potential source (see Skopje's Climate Strategy).

In the case of implementation, the UNDP may arise as a potential source, however, in case of a large-scale investment like Vinica needs, **EU funds would be the most reliable support.**

Although the accession negotiations have already begun between the EU and North Macedonia, the Western Balkan integration is still far from over and this will most likely not change soon. Regardless, there is a chance to receive EU funds as an external country, so **it is recommended for Vinica to build a partnership relationship** in this direction.

To stimulate the shift to and significantly scale up investments in climate-resilient urban infrastructure, a critical step for national governments is to engage the private sector and mobilise investment for urban green infrastructure projects: (OECD)

- Establishing market instruments and other policies to directly incentivise green urban investment such as energy-efficient buildings (e.g., through carbon pricing to make greener alternatives competitive with carbon-intensive options, and regulations such as performance standards).
- Establishing sound investment policies to protect property rights, stimulate international trade and ensure fair competition among local and international suppliers or investors.
- Strengthening financial market policies that can help to mitigate risk and improve returns National policies and enabling conditions by supplementing local capital markets with low-interest lending or loan guarantees, developing green bonds, or setting up green investment banks.
- Funding programmes and instituting policies to provide training and technical support to enhance access to private capital markets and build expertise needed for climate actions (e.g., in local financial and industrial sectors).

Passing legislation concerning municipal finance to expand cities' authorities to tax and to enable cities to establish and improve their creditworthiness; reforming rules governing the use of transfers from senior governments (especially where they limit the ability of cities to mix funds from different sources and thereby impede the adoption of integrated solutions cutting across policies); and ensuring that regulations governing cities' indebtedness, participation in PPPs, etc., encourage cities to make the best use of available financing mechanisms. National governments could play a key role in greening urban finance by redesigning sub-national taxes and grants, especially those with an impact on the built-in environment.

Responsibilities and tasks

Defining the tasks of a development is a good guideline and helps to designate the experts and stakeholders to be involved in the development, as well as to determine the persons responsible for the given tasks:

- Scientific **experts in climatological, hydrological,** or other water research fields for the scientific justification of the implementation.
- **strategic planners and technical designers** for the provision of preparatory work
- **policy experts** who can ensure the course of implementation in the municipality and governmental bodies (if necessary).

- **project managers** who are responsible for smooth progress of tasks, allocation of resources and coordination of workflow.
- **engineers and construction workers** who carry out the technical implementation.

The **involvement of stakeholders** in the development of urban climate policy is essential, as only initiatives adopted by the city's actors can result in a legitimate policy. In a favorable case, we already approach the starting point in a partnership - is climate policy needed? - so partnership is present when developing ideas (VÁTI).

Among the potential partners for urban climate policy, the following important groups can be highlighted:

- services (climate-friendly or air-conditioned service areas, climate-free cooperation);
- employers (climate comfort, climate cooperation);
- research and development, and educational institutions (urban climate research, forecasting; information);
- homeowning communities, condominiums (climate comfort);
- residents and their organizations who are elderly and in poor health;
- municipal institutions and those responsible for urban public services (water supply, electricity supply).

The aim of climate partnership is representation of urban communities, so local actors could also experience their responsibility. Involvement of different actors in neighbouring areas and settlements (multi-level governance) is very important too. To achieve multilevel governance means coordinating city-, urban area-, surrounding settlements-, micro-regional region-, and national level international policies, so **cooperation is needed** in:

- <u>Regional – county level</u>
    - Climate planning approaching the spatial level can harmonize the planning work in each city and provide a starting point for urban planning. Thus, for example, a climate-conscious regional disaster management plan harmonises the flood protection plans of some settlements in the region (e.g., the construction of one settlement does not increase the flood protection risk of the other).
- <u>Country – European level</u>
    - promotes the channelling of national and European policies into local climate protection initiatives, in addition to climate policy, such as transport, health, education and water management.
- <u>Climate-friendly city networks:</u>
    - Inter-settlement type management initiatives: In networks organized on a geographical basis, adaptation preparedness can also become more effective

due to the coordination of protection and the exchange of experiences (e.g., cities in a river valley can harmonize their flood protection strategies, large Mediterranean cities can exchange public shading experiences). Bottom-up and practice-oriented initiatives in urban networks could provide feedback to higher levels.

- Urban-rural relation: Lower territorial level, such as micro-regional, county level; In particular, the following aspects of climate protection should be addressed in a crossborder regional approach, such as:
    - A significant part of climate change adaptation interventions can typically be organized on a county scale, both in terms of planning and implementation. Thus, it requires cooperation between municipalities, for example in the field of water management and flood protection (OECD, 2009).
    - Common regional strategic planning and rethinking of the settlement structure, considering relevant urbanization (e.g., urban sprawl) and rural (e.g., depopulation) processes in the region.

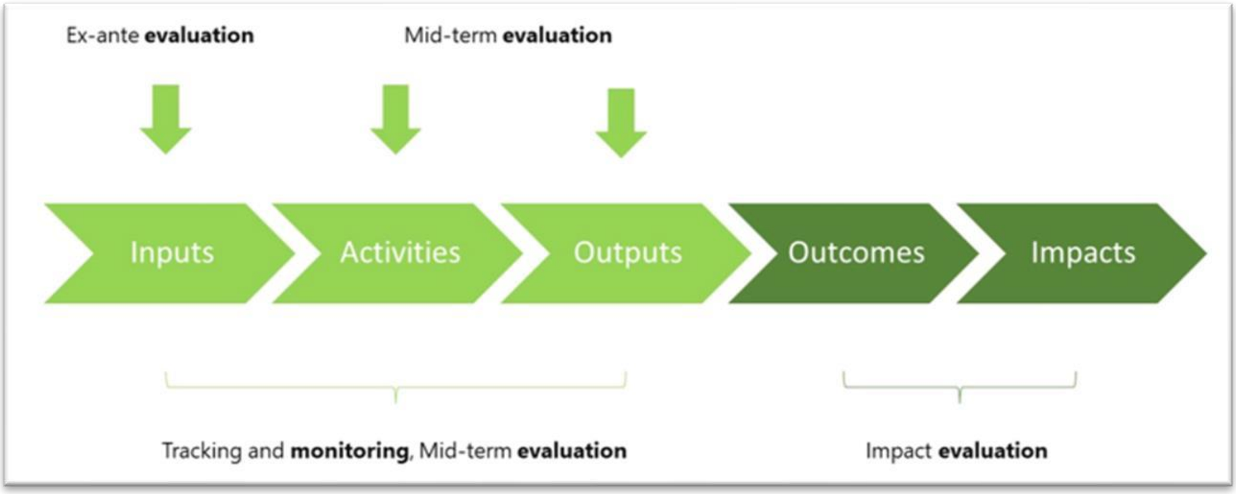
Principles to be followed

The basic principles can practically be the formulated ideas throughout this document:

- Conscious, strategic planning ○ well-defined objectives must be set, for which the steps to be implemented and the tools of implementation are also outlined, ensuring coherence between strategic ideas and actual developments.
- Long-term thinking ○ The possible consequences of climate change must be considered during planning. The calculations based on various climate model simulations supports climate impact analyses and vulnerability assessments with quantified results and provide an excellent reference point for integration of climate change issues into strategic and urban planning.
- Legal basis ○ The ideas must appear in all relevant policy documents and regulations, thus providing a legal basis for developments according to the climate-resilient approach.
- Employing a team of experts
    - In order to develop and implement climate adaptation measures with the appropriate scientific basis and taking into account all aspects, all relevant experts must be involved in the planning and implementation (see above at responsibilities and task).
- Cost effectiveness ○ Given the lack of financial sources in Vinica and its' region, in addition to the need to act according to strict professional compliance criteria, it is important to find the most cost-effective solution. Different types of cost-benefit analysis and option analysis can be appropriate methods for this.

Monitoring and evaluation

Meeting the set objectives is not a simple process, in addition to the already mentioned implementation frameworks, continuous monitoring of the tasks and periodic evaluation of the results is necessary. The following figure shows the framework of how monitoring and evaluation works in practice (42. Figure).



42. Figure: Framework of monitoring and evaluation. Source: Self-made edition

Ex-ante evaluations (evaluation before implementation) provide information about different risks including climate exposure and sensitivity, and the potential impacts of climate change for a given region or measure. Environmental impact assessments are good examples for such activities. Evaluation is very important during the implementation as well, since **mid-term evaluations** can support performance in many ways providing feedback on how the set goals met with the implementation so far. Regularly provided, quantified information on the results of a given project or development supports the **on-going monitoring** of the progress achieved. **Ex-post evaluations** can provide information on the existing objectives, results of the implementation of related projects thus giving feedback for further planning and measures.

9. Good practices for flash flood protection measures

Below is a brief presentation of two different projects concerning Western-Balkan Region, but both aimed at protection against flash floods.

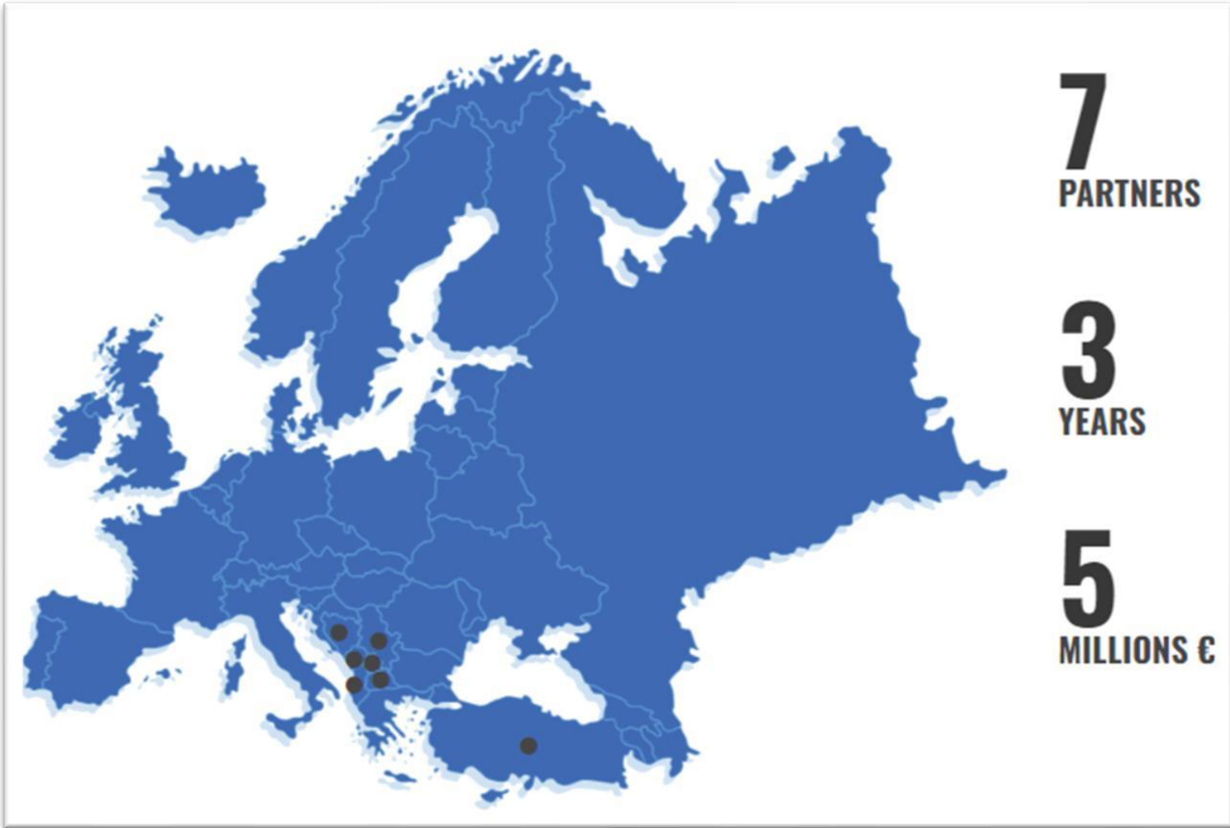
IPA - IPA Floods and Fires program [25 – ipaff.eu]

The 3-year EU-funded IPA Floods and Fires program aims at improving capacities for flood and forest fire risk management in Albania, Bosnia and Herzegovina, Kosovo, Montenegro, North Macedonia, Serbia, and Turkey (43. Figure).

The Program is structured into two components: **Component 1 – Floods** and **Component 2 – Forest-fires.**

By fostering regional cooperation and exchange of good practices, the IPA Floods and Fires Implementing Consortium collaborates with the **local authorities of civil protection** and **other relevant local agencies and institutions** to improve the legal and institutional framework related to the EU floods directive (EUFD), and institutional coordination among all the actors involved in the EUFD implementation, and to improve prevention, preparedness and capacity to respond to forest fires at central, regional and EU level.

Activities will include workshops, trainings, table-top and field exercises, exchange of experts, procurement of ground forest firefighting equipment and awareness raising campaigns.



43. Figure: Operation area of IPA. Source: [25 – ipaff.eu]

<u>Improving Resilience to Floods in the Polog Region</u> [26 – undp.org]

The **project's ambitious goal** is to instigate transformational change in managing flood risk in the region, accelerating the shift from purely reactive responses to floods to integrated systems to manage hazards, vulnerabilities and exposure of communities and assets to prevent/mitigate losses and alleviate the impact of future floods.

The project aims to substantively support achieving: a) an improved knowledge of region's flood risk, causes and appropriate responses among authorities and other stakeholders; b) an inclusive approach to flood risk management planning in line with EU legislation that is sensitive to the specific needs of different vulnerable social groups; c) a better preparedness for flood risks and strengthened recovery capacity thanks to improved governance; d) progress toward flood risk-based urban and economic development; e) a reduction in the adverse consequences of future floods in high-risk areas through the repair or construction, as demonstration projects, of flood control infrastructure in line with contemporary approaches and techniques; f) creation of a flash-flood early warning and public-alert system; and g) progress in the adoption of the objectives and principles of the EU Floods Directive and the Sendai Framework for Disaster Risk Reduction.

The **expected results of the project** are the following:

- Improved understanding of flood risks in the Polog region and the capacity to manage them in an informed manner;
- Enhanced disaster preparedness of institutions and communities in the Polog region for effective response, recovery, rehabilitation, and reconstruction;
- Implementation of priority flood risk mitigation measures informed by international best practices to effectively reduce future risks in the Polog region (44. Figure).

Improvement of the national legal and regulatory framework for disaster risk reduction in line with the Sendai Framework and the EU Floods Directive and conceptualization of risk financing and risk transfer mechanisms.

44. Figure: Development of pond for water drainage and retention outside Polog. Source: [26 – undp.org]

10. Summary and discussion

The aim of this document to introduce the result of our cloudburst analysis implemented for North Macedonia and Vinica and possible solutions to **adapt to the expected climate change via integrating the potential impacts into urban development and planning**.

Our preliminary assessment showed that heavy precipitation events are already a risk in the city of Vinica. We used the E-OBS gridded climatological dataset and the EURO-CORDEX climate model simulation database to indicate the expected change in critical climatic indicators of flash flood events. We used climate simulations based on two GCM-RCM model pair applying the RCP4.5 and RCP8.5 scenarios to project changes by the middle and end of the century.

The highest increase is projected in case of RR20 for all the simulations. RR40 events are projected to remain rare on a 20-year average but it does not mean that these events cannot occur in the future in the region. Beside singe heavy rainfall events, the occurrence of the RR5D60 indicator is expected in the city of Vinica by the middle and end of the century. These **multi-day rainfall events are especially risky for a settlement** because consecutive days with extreme precipitation may add up and worsen the rate of damage.

Note that data description the quality of the open-source data available for North Macedonia may limit the analyses. Hence it is highly recommended to implement a more detailed analyses in case of potential financial sources available for data acquisition. The better quality of the dataset and the more reliable information could be provided about the expected changes in the climatic indicators of the region which would be important for the most cost-effective adaptation steps. Also, a wider range of GCM-RCM pairs would allow to indicate the possibility and rate of the lowest and highest risks for the region which is necessary to develop a climate resilient infrastructure on a long term.

The **exposure of the of the region is caused by not only the occurrence of extreme rainfall but other risk factors** such as steep slopes and lack of green spaces/high rate of built-in areas worsening intensifying the risk of floods. Cloudbursts are high risk to the city's water and wastewater system and this problem can be addressed through implementation of further climate adaptation interventions.

To prepare for flash floods, it is essential to **include the triggering climatic events for designing a proper drainage infrastructure**. It means considering the potential impacts of cloudbursts until the end of the century. The results of climate model simulations enable to plan the capacities for a long-term solution in Vinica.

In addition to examining cloudburst analyses and other climate impacts, we also assessed the most important aspects of adaptation to climate change in Vinica: infrastructural development, policy background, population composition, financial capacities. The document containing the strategic proposal goes through all these factors, and our policy and planning proposals are formulated based on them.

Our results, and similar climate impact studies to be prepared in the future, must be integrated into strategic documents to provide a basis of urban planning. The results and strategic proposals need to be integrated into plans and programs at the regional level. Only a few regional or municipal-level strategies are available for the Vinica region, however, the Municipality's climate change strategy is being developed, in which it is highly recommended to integrate the existing results. In the absence of policy documents at the regional level, it is worth displaying the results in the national level documents of climate change and different sectors.

Our experience in the city of Vinica indicated that the drainage infrastructure has serious shortcomings regarding both existence of drainage-line and efficiency of available capacities. Therefore, for achieving the goals, the necessary tools must be determined in advance so that specific investments could follow. The most effective way of protection against flash floods is prevention, which requires a well-planned drainage infrastructure. Since the risk of drought in the region is also expected to increase, it is **worth striving for an integrated solution** that can simultaneously **drain excess water and store it** outside Vinica's built area.

In cases where flash floods cannot be avoided, it is necessary to build an early-warning system that can alert the population in time of coming disaster. Thus, the social risk can be significantly reduced.

Finally, the document discusses the most important question, which is the existence of available financial resources. Since the region of Vinica is to be particularly lacking in financial sources, this represents the most problematic area to be solved. Basically, the **lack of financial sources is typical** for the whole country, but it is worth attracting the existing national sources to the region. For this, good national and governmental relations must be built, and **the involvement of the private sector are essential**. However, a real breakthrough can only be achieved by bringing in international capital, for this it is necessary to build relationships outside North Macedonia and to attract various subsidies based on existing best practices.

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